MILLETS: THE ANCIENT GRAIN FOR THE FUTURE

Badal Verma, Dr. N. R. N. V. Gowripathi Rao, Vishal Omprakash Kohire Patil, Soumya Hiregoudar, Ankit Saini, Bharat Bhushan Rana

Kripa Drishti Publications, Pune.

MILLETS:
THE ANCIENT GRAIN FOR THE FUTURE

Editors

Badal Verma
ICAR SRF Ph.D. Scholar,
Department of Agronomy,
JNKVV, Jabalpur.

Dr. N. R. N. V. Gowripathi Rao
Assistant Professor,
Research at Karnavati School of Research,
Karnavati University, Gandhinagar.

Vishal Omprakash Kohire Patil
Assistant Professor (Agronomy),
MGM Nanasaheb Kadam College of Agriculture,
Gandheli, Aurangabad.

Soumya Hiregoudar
Ph.D. Scholar, Food Science and Nutrition,
University of Agricultural Sciences,
GKVK, Bengaluru.

Ankit Saini
Project Associate in CSIR-IHBT Palampur.

Bharat Bhushan Rana
Ph.D. at Department of Agronomy,
CSKHPKV, Palampur, Himachal Pradesh.

Kripa-Drishti Publications, Pune.

Book Title: **Millets: The Ancient Grain for the Future**

Edited By: **Badal Verma, Dr. N. R. N. V. Gowripathi Rao, Vishal Omprakash Kohire Patil, Soumya Hiregoudar, Ankit Saini, Bharat Bhushan Rana**

Price: ₹500

1st Edition

ISBN: **978-81-19149-19-3**

9 788119 149193

Published: **May 2023**

Publisher:

Kripa-Drishti Publications
A/ 503, Poorva Height, SNO 148/1A/1/1A,
Sus Road, Pashan- 411021, Pune, Maharashtra, India.
Mob: +91-8007068686
Email: editor@kdpublications.in
Web: https://www.kdpublications.in

CONTENT

1. History and Domestications of Millets - *Dr. Arvind S. Totre, Dr. Amruta S. Jangale, Dr. Charudatta S. Chaudhari, Dr. Swati D. Shinde* **.......... 1**

2. Millet Based Industrial Products - *Akshay Kumar Kurdekar, Vishwanath S. Naik, Vinay Kumar M. I., T. Gangadhar, Kavyashree C., Dileep* **..16**

3. Millets in Era of Climate Change - *Swati Dash, Dr. Atheekur Rehman, H. M.* **..26**

4. Climate Resilience of Millets in Times of Global Warming - *Mr. Badal Verma* **..33**

5. Millets in Food and Nutrition Security - *Ms. Chinmayee Pattnayak, Ms. Rashmi Misra* **...49**

6. History and Domestication of Millet Crops - *Dr. Santosh Bhadkariyaa, Mr. Arif Khanal* **...62**

7. Field Cultivation Practices for Different Types of Millets - *Abhishek Sharma, Shani Gulaiya, Priya Kochale, Parikha P. Singh* **..72**

8. Agronomic Practices for Enhancing Millet Productivity - *Varsha Pandey* **..91**

9. Millets in Crop Diversification - *Sarilla Jeannie, B. Sriram Kumar, Sanapala Swetha* **...106**

10. Crop Breeding Strategies to Enhance Inherent Adaptability and Productivity of Millets - *Jyoti, Gopal Katna, Om Prakash Raigar, Nitesh Kushwaha* **...119**

11. Biotic Stresses in Millets and Their Management - *Ippa Vinay, Singarapu Snigda Srilaasya, Patel Supriya, Thalari Vasanthrao* **.......................141**

12. Post-Harvest Management in Millets - *Palli Susan Grace, Kobagapu Maniratnam, Buriga Teja Swaroop, Lakshmi Sowmya* **.......................................151**

13. Mitigating Biotic and Abiotic Stresses: Biotechnological Strategies for Improving Millet Productivity - *Ipsita Samal, Tanmaya Kumar Bhoi, Deepak Kumar Mahanta, J. Komal, Prasanta Kumar Majhi* **.............................168**

14. Ready to Serve Meals Based on Millets - *Desai N. B., Ganvit K. J.* **...........194**

15. Emerging Trends and Current Scenario in Millet Processing - *Yagini Tekam, Deepak Singh, Muskan Porwal, Gaurav Singh Rathore* **.................................... 203**

16. Global Status and Constraints in Millet Production - *Nikhil, Suraj Kumar, Abid Sultan, Kusumakar Gautam* **.. 218**

17. Bio Fortification of Millets - *Doppalapudi Vijaya Rani, Kaila Tara Meghana, Pemula Priyanka, Sushmita Moi, Himanshu Thakur* **.. 228**

18. Post Harvest Processing and Management of Millets - *Ashish Kumar Nagar, Kalpna Shrivastava, Badal Verma, Siddharth Namdeo* **..................................... 241**

ISBN: 978-81-19149-19-3

1. History and Domestications of Millets

Dr. Arvind S. Totre

Senior Research Fellow,
Pulses Improvement Project,
MPKV Rahuri (MS).

Dr. Amruta S. Jangale

Assit. Professor,
Chhatrapati Shivaji College of Agriculture Kirlos-Orous (MS).

Dr. Charudatta S. Chaudhari

Associate Professor,
Punyasholk Ahilyabai Holkar College of Agriculture Halgaon
MPKV Rahuri (MS).

Dr. Swati D. Shinde

Asst. Professor,
Post Graduate Institute
MPKV Rahuri (MS).

Abstract:

Climate change and biodiversity loss will push us to revolutionise and transform our existing food systems to feed the global population and provide sustainable nutrition. Alternative crops such as millet present a viable option to diversify our diet and contribute to food security. Over the years, millets have enjoyed the tag of "poor man's food grain" because of their sheer affordability. Millets have been classified into two groups on the basis of their grain size major millets and minor millets. Major classification includes sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), foxtail (Setaria italica), proso (Panicum milliaceum), and finger (Elusine coracana) millets whereas the minor ones being the kodo millet (Paspalum scrobiculatum), little millet (Panicum sumatrense), barnyard millet (Echinochloa frumentacea) millets that belong to the family Poaceae and kingdom Plantae. This year is declared as International year of Millets and theme for the International Year of Millets 2023 (IYM) is "Harnessing the untapped potential of millets for food security, nutrition, and sustainable agriculture". The theme reflects the goals of the initiative to raise awareness about the nutritional, ecological, and cultural value of millets, promote sustainable farming practices, and encourage their consumption as a healthy and sustainable alternative to other grains. The theme also highlights the potential of millets to contribute to food security and nutrition, particularly in regions where they are culturally relevant and deeply rooted in Indigenous Peoples' culture and traditions. Thus to know the history and domestication millets is very important for study. Plant domestication is associated with major morphological modifications to fit human needs. The theme emphasizes the need to harness the untapped potential of millets to achieve *sustainable agriculture, empower smallholder farmers, promote biodiversity, and transform agrifood systems.*

Keywords:

Millets, History, Domestication, Conservation, Germplasm.

1.1 Introduction:

In today's scenario, climate change, malnutrition and food security are burning issues around the world. As the population increases day by day, it becomes very important to address these issues to maintain the food balance among all. Millet represent a diverse group of versatile cereals that have long been a part of many agricultural ecologies in Africa and Eurasia. 'Millets' refers to a diverse group of annual cereal crops that produce small seeds. They include several foods, fodder, and biofuel grasses, such as sorghum (Sorghum bicolor), pearl millet (Pennisetum glaucum), foxtail millet (Setaria italica), proso millet (Panicum miliaceum), kodo millet (Paspalum scorbiculatum), finger millet (Elucine coracana), barnyard millet (Echinocloa sp.), etc. (Dwivedi et al. 2012).

The major distinctive character of the millets is their adaptability to cope with adverse agro-ecological conditions such as a semi-dry environment and nutritionally poor soil, the requirement of minimal inputs, and highly nutritious seed content (Lata et al. 2013). Millets, despite their therapeutic properties and agro-economic potential, they are denominated as "underutilized," "forgotten," or "orphan" crops due to their coarse character and minimum usage in convenience foods along with poor research and novel techniques for the development of food products (Dey et al. 2022).

This is primarily because of the lack of awareness of their nutritious qualities among most people and the non-availability of customer friendly and ready-made millet-based products. In the past few years, global attention and efforts have been applied to millets to acquire expedient and value-added processed products in consumer markets (Singh et al 2017).

Millet grains are also called "famine reserves" as they could be stored up to two years or more. They are considered among the sixth most important cereals. The world's highest production of millets is in India. Millets are sown and produced in countries of warm and tropical regions such as Africa, Asia, Eastern and Southern Europe, and some parts of America. The total area for the production of all types of millets is nearly equal in both Africa and Asia. Among the many of its properties, one characteristic is being gluten-free, which helps patients in curing celiac disease and gluten allergy. They are nutricereals, highly nutritious on the basis of protein, dietary fiber, vitamins, and minerals.

The plant domestication process is associated with considerable modifications of plant phenotype. The identification of the genetic basis of this adaptation is of great interest for evolutionary biology. One of the methods used to identify such genes is the detection of signatures of selection. However, domestication is generally associated with major demographic effects. It is therefore crucial to disentangle the effects of demography and selection on diversity.

The domestication of wild plant species to produce cultivated species is thought to begin with gathering seeds from the wild species, wild relatives, land races before progressing to deliberate planting and gathering. Gradual genetic changes in the wild plant lead to domestication-related characteristics that are desirable for human cultivation, such as suppression of seed shattering and selection of appropriate flowering time. There is also other methods available to make it under human cultivation like pre-breeding, bridge crossing techniques. The majority of millet grown worldwide, or 65% of all millets, is sorghum. Sorghum production between 60.18 and 58.70 million metric tonnes in 2010 and 2020, respectively. In India nearly 21 States grow millets. Rajasthan, Maharashtra, Karnataka, Andhra Pradesh, Tamil Nadu, Kerala, Uttarakhand, Jharkhand, Madhya Pradesh, Haryana and Gujarat are all seeing significant momentum. Millets are grown on 12.45 million hectares in India, yielding 15.53 million tonnes. More than 50% of the nation's territory is planted with millets. In 2020-21, India exported millets worth USD 26.97 million against USD 28.5 million in 2019-20. The FAO estimates that 89.17 million metric tonnes of millets will be produced globally from an area of 74.00 million hectares in 2020 (Kumar et al. 2023)

1.2 Sorghum (*Sorghum Bicolor*):

Plant domestication is a process not an event. It comes about through inter-action of man with the plants he uses. Man also influences the evolution of species he does not use. These evolve as weeds adapted to all habitats being disturbed by man. Domesticated species resemble weeds in habitat adaptation, and the ecological boundaries of wild, weed, and crop plants are often poorly defined. As with most cereals, a major step in the process of sorghum domestication was the loss of the shattering habit. Vavilov considered the old Abyssinian (Ethiopian) area as the center of origin, but Harlan suggests that sorghum arose across a large area, where it was likely domesticated a number of times over a period of years. Snowden thought that sorghum arose in several separate centers and from different species: races durra and bicolor from S. aethiopicum, guinea from S. arundinaceum, and kafrr from S. verticilliflorum. De Wet questions whether race virgatum, a desert grass, and arundinaceum, a forest grass, were involved with the direct origins of sorghum, since they grow outside the major habitat of the crop. He suggests that S. verticilliflorum was the first to be domesticated some 3,000 to 5,000 years ago (de Wet, 1986).

It is difficult to determine when and where domestication occurred. But Murdock (1959) has suggested that the mande people around the headwaters of Niger River may have domesticated sorghum. The archaeological evidences suggest that the practice of cereal domestication was introduced from Egypt to ethopia about 3000 B.C. It is possible that domestication of sorghum began about that time (Dogget 1995).

The sorghum had a diverse origin and probably arose from S. verticilliforum, S. arundinaceum, is a grass of the tropical forest and S. aethiopicum and S. virgatum are found in desert regions. These habitats are outside the major sorghum areas and probably contributed less to its domestication. S. verticilliforum is usually found in areas where sorghum is cultivated. There is tremendous variation in S. verticilliforum and it as well as the other wild species readily crosses with cultivated sorghum. It yields well and was probably collected and used before the advent of agriculture.

The races durra, guinea and kafir are closely allied and may have arisen from aethiopicum, arundinaceum and verticilliflorum respectively Snowden 1936 and Porteres 1951). Morphological differences between races may have arisen because of the ethnic isolation. Kafir is widely grown in Africa, while durra is not found. Caudatums are most common in central Sudan and Guinea found primarily in West Africa. Distribution indicates that the races kafir and caudatum were derived from verticilliflorum and that durra possibly could have come from arundinaceum. and not found where sorghum is extensively cultivated. Introgression studies indicate that cultivated sorghums probably developed through disruptive selection (Doggett 1955). Crossing easily occur between wild and cultivated types however they form distinct populations. It is speculated that, as man began to select there ws substantial gene flow between improved and umimproved types. This gene flow would decrease as field size become larger. The selection by man nature would provide a forces have been continuously active through time influencing cultivated and wild populations. The process of domestication involved a change in several characteristics of the plant. A tough rachis and persistence of the sessile spiklet were probably introduced early in the process. It is likely that the transformation of loose and open inflorescence into a compact type involved several changes. An increase in the number branches per node, increase in number branches per primary inflorescence branch and third a decrease internode length on the primary axis (rachis). An increase in seed size also was probably a product of domestication the seed becoming large enough to protrude from the glumes.

1.3 Pearl Millet (*Pennisetum glaucum*):

There are few substantiated early archaeological records of Pennisetum. Studies of the genus, including wild and cultivated types, have considered geographic distribution, morphological similarities, and genetic differences including isozymes and restriction fragment length polymorphism analysis. Domestication probably occurred 5,000 or more years ago in Africa in the savanna south of the Sahara and west of the Nile (Andrews and Kumar, 1992). Domestication may have occurred among different isolated populations over time going back 7,500 to 7,000 years with indication of close coexistence with wild millet 3,000 years ago; however, introgression continues at the present time. Genetic differences have been identified between wild and cultivated types, but domestication is considered to have involved relatively few genes (Andrews and Kumar, 1992). Its introduction into India is uncertain, but is likely some 3,000 years ago. It was cultivated in the United States by 1873, while its introduction into Central and South America likely came from southern Europe and France. Its cultivation there more or less terminated toward the end of the 19th century. It has been grown some in Europe, but its use was more in the 19th than in the 20th century. Pearl millet is known by a number of names: bulrush, cattail, and spiked millet in English; bajra in Hindi; dukhn in Arabic; and mil it chandelles in much of West and North Africa.

Some studies support the hypothesis that the very strong morphological differentiation we observe today was progressively selected over hundreds to thousands of years (Fuller 2007) and surprisingly that the speed of selection by humans was similar to that of natural selection (Purugganan and Fuller 2011). One important pathway for crop domestication, adaptation, and improvement that has been sufficiently well studied from a functional point of view is the pathway governing flowering time.

The current hypothesis concerning its domestication suggests it original. The current hypothesis concerning its domestication suggests it originated in the northern–central Sahel in West Africa.The oldest archaeobotanical evidence of pearl millet cultivation was found in Mali and dated at around 4,500 BP (Manning et al. 2011).The domestication process of pearl millet is associated with common morphological changes among cereals: suppression of spikelet shedding, reduction in the size of bristles and bracts, increase in seed size, increase in spikelet pedicel length, loss of dormancy, reduction in the number of basal tillers, and an increase in spike length. Interestingly, although the origin of cultivation is hypothesized to have occurred in the dry areas of the Sahel, pearl millet is also cultivated further south in more humid areas. Consequently, in West Africa, pearl millet displays a wide range of flowering times.

The wild progenitor of the cultivated pearl millet species has been identified as Pennisetum violaceum (Lam.) Rich. [syn. P. americanum subsp. Monodii (Maire) Brunken] (Brunken et al. 1977). The natural distribution of this species is restricted to the Sahelian zone, from Senegal to northern Sudan (Harlan 1992). However, it is often inferred that domestication occurred in the western part of this range, between Niger and Mauritania (Clotault et al. 2012**;** Dupuy 2014; Fuller 2003). The modeling of modern genomic data fits with the hypothesis of a southwestern Saharan origin for the domesticated form, whence pearl millet spread westward to Mauritania and southward into the savanna south of the Niger River bend (Burgarella et al. 2018). Here, we report new evidence for wild pearl millet, dating back to the middle Holocene (~5000 BC), from northeast Mali within the western Saharan zone, and the subsequent appearance of domesticated traits by midthird millennium BC. These data derive from the conventional study of impressions on sherd surfaces (Fuller et al. 2007) and microCT-scanning of sherds' interior content (following the recently developed methods by Barron and Denham 2018; Barron et al. 2017, 2020a, 2020b). We then combine these data with the available long-term archaeological evidence in western Africa to identify the evolutionary trends of pearl millet's domestication and diversification.

A native of the old world tropics, it reaches its greatest importance in the dry sahel zone which stretches across sub-Saharan Africa and in the semiarid regions of northwestern India. Throughout its distribution, pearl mil- let serves a multitude of traditional societies which would otherwise be hard pressed for their sustenance. In describing the region of Abyssinia (the Upper Nile), he mentions that two types of millet, durra and dokhn, are commonly cultivated. The first name refers to cultivated sorghum and the second to pearl millet. Both of these crops are grown under these same names in the Upper Nile today. The earliest mention of pearl millet in west- ern literature is attributed to Leo Africanus, a 16th century Moorish slave in the service of Pope Leo X for whom he wrote an account of Africa north of the forest zone (Pory, 1600). In his classic work on the origins of crops, Vavilov (1949/1950) placed pearl millet in the Ethiopian center of domestication. The high- lands of Ethiopia are today an agriculturally diverse region in which crops from many parts of the world are grown. The wild progenitor is adapted to the sandy, semiarid conditions of the sahel and very likely would have been absent from the high rainfall and high altitude environment of the Ethiopian highlands. Today pearl millet is a minor crop in Ethiopia and is probably the product of post-domestication introduction. A second theory as to the origin of pearl millet was proposed by Murdock (1959). Using primarily linguistic evidence, he postu- lated that pearl millet was one of several West African crops domesticated by the Mande people near the headwaters of the Niger River between 4000 and 5000 B.C.

Murdock's general hypothesis has been the center of considerable controversy since its publication. During the period suggested by Murdock, the headwaters of the Niger probably exhib- ited a climax, tropical rain forest type of vegetation. It is highly unlikely, therefore, that a dryland crop such as pearl millet would have been domesticated there. The greatest morphological diversity in pearl millet occurs today in West Africa south of the Sahara Desert and north of the forest zone. The wild progenitor also occurs in the drier, northern portion of this zone. Taking these facts into consideration, Harlan (1971) suggested a third center of origin for the crop in a diffuse belt stretching from western Sudan to Senegal. On the basis of present-day distributions, the sahel zone of West Africa does appear to be the original home of pearl millet.

Pearl millet was domesticated along the southern margins of the Saharan central highlands at the onset of the present dry phase some 4000-5000 years ago. Soon after domestication it was distributed widely across the semi-arid tropical areas of Africa and Asia [I). The primary centers of diversity for pearl millet arc in Africa, where cross fertile wild species exist. In West Africa, the wild species *P. glaucum* spp. *monodii* (Maire) Brunken (*Pennisetum violaceums* is distributed along the margins of southern Sahara and crosses freely with the cultivated pearl millet, leading to the formation of the adapted hybrid swarms of the weedy species *Pennisetum glaucum* spp. *stenostachyum*. Pearl millet is the fourth most important crop in India. after rice. wheat. And sorghum. It is important in the stales of Rajasthan. Gujurat, and Haryana. In India the annual rainfall of the millet growing regions varies from 150-750 mm, most of which occurs from June through September.

1.4 Finger Millet (*Eleusine coracana*):

Finger millet is the second most important millet in Africa after pearl millet. It was domesticated in Africa, with archeological records going back some 3,000 years. In approximately the same period it was introduced into India. Five races are recognized and likely all arose in Africa; there has been little diversification in India (de Wet, 1978). Finger millet was firstly documented by Linnaeus in *Systema Naturae*, where he identified it as *Cynosurus coracan* hence, the name *Cynosurus coracanus* L. The genus *Eleusine* was later described in detail by Gaertner (1788) in *De Fructibus et Seminibus Plantarum* and hence the appellation, *Eleusine coracana* (L.) Gaertn. Kingdom: Plantae Subkingdom:

Tracheobionta Superdivision: Spermatophyta Division: Magnoliophyta Class: Liliopsida Subclass: Commelinidae Order: Cyperales Family: Poaceae Subfamily: Chloridoideae Genus: *Eleusine* Gaertner Species: *Eleusine coracana* (L.) Gaertn. The genus *Eleusine* includes nine annual and perennial species as recognized by Phillips (1972), with eight African species and one New World species (*E. tristachya* Lam.) native to Argentina and Uruguay (Lovisolo and Galati 2007). The range of the genus has been extended by wide spread introduction of the crop (*E. coracana*) throughout the tropics, and the common weed often associated with cultivation, *E. indica* (L.) Gaertn. East Africa is considered the center of diversity of the genus and eight species (*E. africana, E. coracana, E. kigeziensis, E. indica, E. floccifolia, E. intermedia, E. multiflora and E. jaegeri*). The species of *Eleusine* Gaertn. are distributed in the tropical and subtropical areas of India, Myanmar, Sri Lanka, Nepal, China and Japan in Asia; while in Africa, it is grown in Uganda, Kenya, Tanzania, Ethiopia, Eritrea, Rwanda, Zaire and Somalia (Upadhyaya et al. 2010).

1.5 Foxtail Millet (*Setaria italica*):

The genus Setaria has approximately 125 species widely distributed in warm and temperate parts of the world, and this includes S. italica (foxtail millet). This genus belongs to the subfamily Panicoideae and the tribe Paniceae. It contains grain, wild, and weed species with different breeding systems, life cycles, and ploidy levels (Lata et al. 2013).

Evidence suggests that domestication likely occurred from central Asia to Europe. Movement westward into Europe and eastward into east and south east Asia and the Pacific Islands was gradual and accompanied by plant differentiation. Differentiation may have occurred in East Asia but not domestication. Findings from Neolithic Yang-shao suggest the possibility of a Chinese center of origin (Sakamoto, 1987).

In the eighteenth-century, Linnaeus (1753) classified green foxtail and foxtail millet into the genus *Panicum*, but named them as two different species, *Panicum viride* and *Panicum italica*, respectively. Later they were transferred to the genus *Setaria*, and their botanical names were changed to *S. viridis* and *S. italica*, respectively, remaining as two independent species (Austin 2006).

The classification of foxtail millet (*Setaria italica*) is as follows: Kingdom: Plantae Subkingdom: Tracheobionta Superdivision: Spermatophyta Division: Magnoliophyta Class: Liliopsida Subclass: Commelinidae Group: Monocots Order: Poales Family: Poaceae Subfamily: Panicoideae Genus: *Setaria* Species: *italica.* Botanical name: *Setaria italica* L.

Setaria italica is among the oldest crops who's farming possibly began about 5900 BC in the Gansu Province of Northwestern China. Geographically, the region ranging from Afghanistan to India is believed to be the crop's origin for domestication. Afterwards, the crop spread is thought to have been both eastward and westward (Sakamoto 1987). According to Vavilov (1926), the principal center of diversity for foxtail millet is East Asia, including China and Japan. Several hypotheses concerning the origin and domestication of foxtail millet have been proposed (De Wet et al. 1979; Kawase and Sakamoto 1987; Vavilov 1926) but the multiple domestication hypotheses are widely accepted based on three centers of origin: China, Europe and Afghanistan.

Foxtail millet is one of the oldest cultivated crops in the world, the earliest archaeo-botanical macro remains indicating its origin in Cishan and Peiligang ruins in Yellow River Valley in the northern province of China, approximately 7,400–7,900 years before present (BP) (Doust et al. 2009). Green foxtail (S. viridis) is the wild ancestral form of modern cultivated foxtail millet (S. italica). It has been proposed by Vavilov (1926) that the prime center of evolution and diversification of foxtail millet was East Asia, specifically China and Japan. Currently, foxtail millet is distributed in most of China, some parts of India, USA, Canada, the Korean Peninsula, Japan, Indonesia, Australia, and the northern part of Africa (Doust et al. 2009; Li and Brutnell 2011). In the United States, foxtail millet is primarily produced in the northern and western Great Plains, midwest, Colorado. Foxtail millet can be found grown mainly for feed purposes in some part of southern Europe. In India, it is cultivated primarily in Karnataka, Andhra Pradesh, Rajasthan, Madhya Pradesh and Chhattisgarh, and Tamil Nadu.

The first phase of foxtail millet domestication occurred from approximately 23,000 YBP to around 9000 YBP. No intact foxtail millet grains corresponding to this phase have been found, but there is ample evidence of plant starches and stone tools for processing green foxtail and/or foxtail millet and specific evidence of foxtail millet starch (Liu et al. 2013; Yang et al. 2012). The second phase of foxtail millet domestication took place between 9000 and 6000 YBP, in the middle phase of the Chinese Neolithic Age. The oldest foxtail millet grains found to date were retrieved from the Donghulin site in Beijing, and dated back to 11,000 to 9000 YBP (Zhao 2014). The third phase of foxtail millet development was its expansion after domestication, from approximately 6000 YBP. Carbonized foxtail millet remains have been recovered from hundreds of archaeological sites in China, with large quantities found at many sites. Typical sites of this phase are the mid- and late Yangshao Culture sites (6000–5000 YBP) located in the middle of the Yellow River region in Henan Province. Foxtail millet remains were found at the Chengtoushan site (6000 YBP) in the middle region of the Yangtze River in Hunan Province, south of the Yellow River region where foxtail millet was first domesticated.

A second hypothesis (Li et al. 1995) suggested that the landraces from Afghanistan and Lebanon had been domesticated independently and relatively recently, because they had primitive morphological characters. This idea was supported by ribosomal DNA data (Fukunaga et al. 2006). Furthermore) reported that foxtail millet landraces in central Asia, Afghanistan, Pakistan, and Northwest India not only had primitive morphological traits, but also showed relatively high cross-compatibility with foxtail millet from other regions (Kawase and Sakamoto 1987). Based on those results, they suggested that the original center of foxtail millet domestication was located somewhere in those regions, and China may be the secondary center of diversification. This is the only hypothesis that places China as the secondary center of foxtail millet domestication.

1.6 Proso Millet (Panicum Miliaceum):

Proso millet is one of the oldest cereal crops, the agricultural origin of which dates back to 10,000 BC in the semiarid parts of China (Hunt et al. 2014). It is known by different names depending on the geographic location. Proso, the Pan-Slavic name for millet, is known as common millet and hog millet in the USA, broomcorn millet in China, common millet in Japan, Korea and other counties in the Asia Pacific, hersey millet in Germany and French white in France (Rajput et al.)

The wild ancestor of proso has not yet been satisfactorily identified, but domestication is likely to have occurred in Manchuria. Weedy forms are spread from the Aralo Caspian basin to Sinkiang and Mongolia. More recently, these wild types have spread into Europe and North America. The earliest remains of proso have been dated to the fifth millennium B.C. in eastern and central Europe (Zohary and Hopf, 1988). Sites were found in the Ukraine, Czechoslovakia, and Germany. Other finds dating to the same period have occurred in Georgia. Finds in the fourth millennium B.C. include Yugoslavia, and in the Neolithic Yang Shao villages of north China. Proso was probably introduced into Europe at least 3,000 years ago; remains of spikelet and florets have been found in early farming sites dated around 1600 B.C. (de Wet, 1986). It appeared after this period in the Near East and India (Zohary and Hopf, 1988).

The agricultural origins of the millets are primarily in Africa and Asia. Phylogenetic studies suggest a monophyletic origin of domesticated pearl millet in Western Africa (Dussert et al. 2015; Oumar et al. 2008). Northern China is considered as the agricultural origin for proso millet with the record of cultivation dating back to 10,000 B.C. (Hunt et al. 2014). Finger millet is believed to be of African origin (Fuller 2014).

There is no substantial evidence for the center of origin for foxtail millet cultivation. Proso millet, belonging to the Panicoideae subfamily of the Poaceae family, is considered to be one of the earliest domesticated cereals in human history (Lu et al. 2009).

There are different theories about the origin of proso millet. Investigations of the charred seed remains recovered in Dadiwan in Northwestern China suggested the possible period of proso domestication to be approximately 5900 BC (Miller et al. 2016). In order to estimate the time of the domestication of proso millet, Lu et al. (2009) studied phytoliths discovered in ancient storage pits at the archeological site of Cishan situated near the boundary between the Loess Plateau and the North China Plain. They opined that the earliest proso millet farming began in the semiarid regions of China by 10,000 years BC based on the carbon-dating results of the 47 archeological samples investigated in the study. Relatively drier environments during the early Holocene probably encouraged the domestication of proso millet over other cereals. Lu and coworkers also suggested that proso was domesticated independently as a staple food in Northern China approximately 10,000 years go, and later spread to other neighboring areas in Russia, India, the Middle East and Europe (Lu et al. 2009). Zhao (2011), however, claimed that the actual age of the samples recovered from an excavation in Cishan is ca. 7600 to 8100 years old. He expressed doubts over the estimations by Lu et al. (2009) as the samples were already in a decayed state.

The samples used for dating were possibly a mixture of different grains, instead of actual millet grains (Zhao 2011). Miller et al. (2016) also questioned the estimate of proso millet origin as it was based on the analysis of *problematic* phytolith identification. Nevertheless, all the evidence indicates that the domestication of proso millet occurred in the semiarid region of the Northeast China. Miller et al. (2016) suggested that proso millet spread to Europe and West Asia towards the end of the first millennium BC because of the changes in agricultural practices in those areas (Miller et al. 2016).

The exact centre of millet domestication in China is still disputed. The presence of early millet sites in Dadiwan in the Loess Plateau and Xinle and Xinglonggou in northeast China, far from the Yellow River valley, does not seem to support the view of a north Chinese agricultural origin for proso millet and foxtail millet that is centered around the central Yellow River valley. However, it can also mean that a different location is the focus of proso millet domestication or there are multiple foci within China. Based on comparisons of landrace genetic diversity between regions in China, inferred a centre of proso millet domestication in the Loess Plateau.

The level of landrace genetic diversity from the Loess Plateau was not significantly higher than those from other regions of China. Sufficient precise geographical information is needed to enable analyses of phylogeography or genetic diversity of many accessions from China.

1.7 Kodo Millet (Paspalum Scrobiculatum):

Kodo millet was domesticated in India almost 3,000 years ago. The species is found across the Old World in damp habitats of the tropics and subtropics. Crossing readily occurs between cultivated and weedy races, and seed from hybrids is harvested along with those of the sown crop; hence, racial differentiation is not distinct despite the years of cultivation in India (de Wet, 1986).

Kodo millets are the coarsest and digestion-friendly millets. It is an ancient millet grain that originated in tropical Africa and was domesticated in India some 3000 years ago (D wet et al. 1983). Indian Crown Grass, Native Paspalum, Ditch Millet, or Rice Grass are a few names by which kodo millet is known. In India, it is also known as Kodra and Varagu. India, Pakistan, the Philippines, Indonesia, Vietnam, Thailand, and West Africa are among the countries that cultivate millets. It serves as the major source of food in the Deccan Plateau of Gujarat, India. Kodo millet is mainly grown in various parts of India such as Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Uttar Pradesh, Bihar, Maharashtra, Gujarat, and Orissa. Madhya Pradesh accounts for 33.4 percent of India's land area and 26.6 percent of the country's small millet production. In Madhya Pradesh, kodo (70%) and little (24%), together, contribute to 94% of the total area under small millets (Chouhan et. al. 2019). In Madhya Pradesh, there are two districts that have the highest area under the state: Dindori and Mandla for the production of kodo and Chhindwara and Dindori for the production of little millets.

1.8 Barnyard Millet (Echinochloa frumentacea):

Echinochloa crus-galli, commonly known as Japanese millet, according to archaeological records was domesticated in Japan about 5,000 years ago and is found in the temperate regions of Eurasia (de Wet, 1986). E. colona, domesticated in India, spread through the tropics and sUbtropics of the Old World. It was harvested as a wild cereal in predynastic Egypt. While the two species are morphologically similar, hybrids between them are sterile; however, crosses of both species with their respective wild relatives are fertile (de Wet, 1986).

Echinochloa frumentacea showed parallel line of evolution both in India and Africa. It is an annual cultivated in India, Central African Republic, Tanzania and Malawi (Doggett 1989). Its wild progenitor is the tropical grass E. colona (L.) Link, popularly known as Jungle rice, but the exact date of domestication is uncertain. Echinochloa esculenta is annual in habit and is cultivated mostly in the temperate regions (De Wet et al. 1983) of Japan, Korea, China, Russia and Germany. Its wild ancestor is barnyard grass (E. crus-galli (L.) Beauv.) from which it was directly domesticated some 4000 years ago in Japan (Doggett 1989). Archaeological evidence suggests that it was grown in Japan as early as Yayoi period, dating back some 4–5 millennia. Another study puts the earliest records of domestication from Jomon period of Japan in 2000 B.C. Nozawa et al. (2004) showed that E. esculenta was domesticated from a limited part of the E. crus-galli population. They used 13 SSR markers to study the genetic diversity of 170 Echinochloa accessions and grouped E. esculenta accessions into two classes, while ancestral species E. crusgalli was grouped into 11 classes. The domestication syndrome, which refers to all modifications occurring in a crop plant during the course of evolution when it becomes cultivated from the wild form and is dependent on selection pressure (Hammer 2003), is not well studied in barnyard millet although both E. frumentacea and E. esculenta showed marked difference from their respective wild ancestors E. colona and E. crus-galli with respect to reduced vegetative branching, more compact growth habit, larger inflorescence, reduced shattering and larger seed size. Yabuno (1975) considered low seed shattering, lack of seed dormancy, thick culms, wide leaves and round spikelets in E. esculenta were the main characters selected by man during the process of domestication. This suite of traits that constitutes 'domestication syndrome' for closely related foxtail millet (Defelice 2002, Doust et al. 2005 and pearl millet (Poncet et al., 2000) is likely for barnyard millet as well. Increase in seed size in Japanese barnyard millet during domestication is suggested by archaeological data. The mean size of Echinochloa caryopses from the Middle Jomon period (3470 B.C.E.–2420 B.C.E.) was about 20% larger than specimens from Early Jomon period (5000 B.C.E–3470 B.C.E), indicating that selection for larger seed size was taking place over several millennia in Northern Japan. The cross-compatibility between domesticated barnyard millet and their ancestral forms and the existence of naturally occurring intergrades between the two forms provide avenues to understand the mechanisms driving domestication and elucidate the genetics of domestication traits in this crop.

1.9 Little Millet (Panicum sumatrense Roth. ex Roem. & Schult.):

The subspecies psilopodium includes the wild progenitor of P. sumatrense (sarna). The two subspecies cross to produce fertile hybrids, which often are found as weeds in saran fields. Meiotic behavior in crosses suggests that the genomes of the two species are similar. Sarna is cultivated in much of India, in Nepal, and western Bunna. It is of particular importance in the Eastern Ghats of India. Race robusta is grown in northwestern Andhra Pradesh and part of Orissa where it crosses with race nana. Subspecies psilopodium is distributed from Sri Lanka to Pakistan and eastward to Indonesia.

Little millet was domesticated ~5000 yr ago in India (de Wet et al., 1983). It has historically been grown mainly in India, Mayanmar, Nepal, and Sri Lanka (Prasada Rao et al., 1993). Little millet accessions have been classified into two races based on panicle morphology, nana and robusta, with two subraces per race (laxa and erecta for nana and laxaand compacta for robusta) (de Wet et al., 1983; Prasada Rao et al., 1993). Little millet is tetraploid ($2n = 4x = 36$) (Saha et al., 2016). Like kodo millet, little millet can give consistent yields on marginal lands in drought-prone arid and semiarid regions, and it is an important crop for regional food stability (Dwivedi et al., 2012). Little millet is arguably the least studied of these three millets, and we are unaware of any molecular markers developed for it outside of specific single genes (Goron and Raizada 2015) and a small set of RAPD markers whose details were not described (M.S. Swaminathan Research Foundation, 2000).

1.10 Literature Cited:

1. Austin D 2006 Fox-tail millets (Setaria: Poaceae) abandoned food in two hemispheres. *Econ. Bot.* 60:143–158.
2. Andrews, D.J. and Kumar, K.A. 1992. Pear millet for food, feed, and forage. Adv. *Agron*. 48:89-139.

3. Barron, A., Turner, M., Beeching, L., Bellwood, P., Piper, P., Grono, E., Jones, R., Oxenham, M., Kien, N. K. T., Senden, T., & Denham, T. P. 2017. Micro CT reveals domesticated rice (Oryza sativa) within pottery sherds from early Neolithic sites (4150–3265 cal BP) in *Southeast Asia. Scientific Reports*, 7(1), 7410. https://doi.org/10.1038 /s41598-017-04338-9.
4. Barron, A., & Denham, T. P. 2018. A micro CT protocol for the visualisation and identification of domesticated plant remains within pottery sherds. *J. of Archaeo. Sci.* Reports, 21, 350-358. https://doi.org/10.1016/j. jasrep.2018.07.024.
5. Barron, A., Datan, I., Bellwood, P., Wood, R., Fuller, D. Q., & Denham, T. 2020[a]. Sherds as archaeobotanical assemblages: Gua Sireh reconsidered. *Antiquity*, 94(377), 1325-1336.
6. Barron, A., Fuller, D. Q., Stevens, C., Champion, L., Winchell, F., & Denham, T. 2020[b]. Snapshots in time: Micro CT scanning of pottery sherds determines early domestication of sorghum (Sorghum bicolor) in East Africa. *J. of Archaeo. Sci.*, 123-105259.
7. Burgarella, C., Cubry, P., Kane, N. A., Varshney, R. K., Mariac, C., Liu, X., Shi, C., Thudi, M., Couderc, M., Xu, X., Chitikineni, A., Scarcelli, N., Barnaud, A., Rhoné, B., Dupuy, C., François, O., Berthouly-Salazar, C., & Vigouroux, Y. 2018. A Western Sahara centre of domestication inferred from pearl millet genomes. *Nature Ecology & Evolution*, 2, 1377–1380. https://doi.org/10.1038/s41559- 018-0643-y.
8. Chouhan, R. S., H. K. Niranjan, and H. O. Sharma, 2019. "Economics of value added products of kodo and kutki," *Indian Journal of Economics and Development*, vol. 15, no. 3, pp. 465-469.
9. Clotault, J., Thuillet, A. C., Buiron, M., De Mita, S., Couderc, M., Haussmann, B. I., Mariac, C., & Vigouroux, Y. (2012. Evolutionary history of pearl millet (*Pennisetum glaucum* [L.] R. Br.) and selection on flowering genes since its domestication. Molecular Biology and Evolution, 29(4), 1199– 1212.
10. De Wet, J.M.J., D.E. Brink, K.E.P. Rao, and M.H. Mengesha. 1983. Diversity in Kodo millet, *Paspalum scrobiculatum.* Econ. Bot. 37:159–163.
11. De Wet. J.M., D. E. Brink, K. P. Rao, and M. H. Mengesha, 1983. "Diversity in kodo millet, *Paspalum scrobiculatum*," *Economic Botany*, vol. 37, no. 2, pp. 159-163.
12. De Wet, J. M. J. 1986. Origin, evolution and systematics of minor cereals. Pages 19·30 in: Small Millets in Global Agriculture. A. Seethararna, K. W. Riley, and G. Harinarayana, eds. Proc. Int. Small Millets Workshop, 1st, Bangalore, India. Oxford and ffiH Pub. Co., New Delhi, India.
13. Defelice, M. S., 2002: Green foxtail, Setaria viridis (L.) P. Beauv. Weed Technol. 16, 253-257.
14. Dey, S., Sexena, A., Kumar, Y., Maity, T. and Tarafdar A. 2022. Understanding the Antinutritional Factors and Bioactive Compounds of Kodo Millet (*Paspalum scrobiculatum*) and Little Millet (*Panicum sumatrense*). *J. of. Food quality* Volume-2022 pp-1-19.
15. Dupuy, C. 2014. Des céréales et du lait au Sahara et au Sahel de l'Épipaléolithique à l'âge des métaux. Revue Afriques, débats, méthodes et terrains d'histoire, 5-1376.
16. Doust, A.N., Kellogg, E.A., Devos. K.M, Bennetzen, J.L. 2009. Foxtail millet: a sequence-driven grass model system. *Plant Physiol*. 149:137–141.
17. Dussert Y, Snirc A, Robert T. 2015. Inference of domestication history and differentiation between early- and late-flowering varieties in pearl millet. *Mol Ecol* 24:1387–1402.
18. Doggett, H., 1989: Small millets-a selective overview. In: pp-245-253.

19. Doust, A. N., K. M. Devos, M. D. Gadberry, M. D. Gale, and E. A. Kellogg, 2005: The genetic basis of inflorescence variation between foxtail and green millet (Poaceae). Genetics 169, 1659-1672.
20. Dwivedi, S., H. Upadhyaya, S. Senthilvel, C. Hash, K. Fukunaga, X. Diao, et al. 2012. Millets: Genetic and genomic resources. Plant Breed. Rev. 35:247–375. doi: 10.1002/9781118100509.ch5 doi:10.1007/BF02858779.
21. Dwivedi, S, Upadhyaya, H, Senthilvel, S, Hash, C, Fukunaga, K, Diao, X, Santra D, Baltensperge, r D, Prasad M 2012. Millets: genetic and genomic resources. In: Janick J (ed) *Plant breed reviews*, Vol 35. *Wiley*, USA, pp 247-375.
22. Fuller, D. Q. 2003. African crops in prehistoric South Asia: A critical review. In K. Neumann, A. Butler, & S. Kahlheber (Eds.), Food, fuel, and fields: *Progress in African archaeobotany* (pp. 239– 271). Cologne: Heinrich–Barth Institut.
23. Fuller, D. Q. 2007. Contrasting patterns in crop domestication and domestication rates: Recent archaeobotanical insights from the Old World. *Annals of Botany*, 100, 903–924.
24. Fuller D.Q. 2014. Finger millet: origins and development. In: Encyclopedia of global archaeology. Springer, New York, pp 2783–2785.
25. Fukunaga K, Ichitani K, Kawase M. 2006. Phylogenetic analysis of the rDNA intergenic spacer subrepeats and its implication for the domestication history of foxtail millet, Setaria italica. *Theor Appl Genet.* 113 (2):261-9.
26. Gaertner J (1788) *Eleusine Indica* (L.) Gaertn. Wire-grass. Crab-grass. Yard-grass. De Fructibuset Seminibus Plantarum 1:8.
27. Goron, T.L., and M.N. Raizada. 2015. Genetic diversity and genomic resources available for the small millet crops to accelerate a New Green Revolution. *Front. Plant Sci.* 6. doi:10.3389/fpls.2015.00157.
28. Hammer, K., 2003: Evolution of cultivated plants and biodiversity. Nova *Acta Leopoldina NF* 87, 133-146.
29. Harlan, J. R. 1971. Agricultural origins: Centers and non-centers. *Science* 14:468-474.
30. Harlan, J. (1992). Indigenous African agriculture. In C. Cowan & P. J. Watson (Eds.), The origins of agriculture: *An International perspective* (pp. 59–70). Washington: Smithsonian Press.
31. Hunt HV, Badakshi F, Romanova O et al (2014) Reticulate evolution in *Panicum* (Poaceae): the origin of tetraploid broomcorn millet, *P. miliaceum*. *J. Exp. Bot.* 65:3165–3175.
32. Kawase M, Sakamoto S. 1987. Geographical distribution of landrace groups classified by hybrid pollen sterility in foxtail millet, Setaria italica (L.) *P. Beauv. Jpn J Breed.* 37(1):1-9.
33. Kumar, A., Kumar P., Mishra P.K. Aman, A.S and Bajpeyi, M.M. 2023. International Year of Millets. *Just Agriculture* pp-59-65.
34. Lata C, Gupta S, Prasad M. 2013. Foxtail millet: a model crop for genetic and genomic studies in bioenergy grasses. Crit. Rev. Biotechnol. 33:328–343.
35. Lu, H., Zhang, J., Liu, K.B., Wu, N., Li, Y and Zhou, K. 2009. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 yearsago. *Proc. Natl. Acad. Sci. U.S.A.* 106, 7367-7372. doi: 10.1073/ pnas.0900158106.
36. Li P, Brutnell, T.P. 2011. Setaria viridis and Setaria italica, model genetic systems for Panicoid grasses. *J. Exp. Bot.* 62:3031-3037
37. Liu, L., Bestel, S., Shi J. 2013. Paleolithic human exploitation of plant foods during the last glacial maximum in North China. *Proc Natl Acad Sci.* 110(14):5380-5.

38. Lovisolo, M.R. and Galati, B.G. 2007. Ultrastructure and development of the megagametophyte in *Eleusine tristachya* (Lam.) Lam. (Poaceae). *Flora* 202:293-301.
39. Li, P.H. and Brutnell, T.P. 2011. *Setaria viridis* and *Setaria italica*, model genetic systems for the Panicoid grasses. *J. Exp. Bot.* 62:3031-3037.
40. Li Y, Wu S, Cao Y. 1995. Cluster analysis of an international collection of foxtail millet (*Setaria italica* (L.) P. Beauv.). *Euphytica*. 83(1):79-85.
41. Manning, K., Pelling, R., Higham, T. F. G., Schwenniger, J.-L., & Fuller, D. Q. 2011. 4500-Year old domesticated pearl millet (Pennisetum glaucum) from the Tilemsi Valley, Mali: New insights into an alternative cereal domestication pathway. *J. of Archaeo. Sci.*, 38(2), 312-322. https://doi.org/10.1016/j.jas.2010.09.007.
42. Murdock, G. P. 1959. Africa-Its people and their cul- tural history. McGraw-Hill, N.Y.
43. Miller NF, Spengler RN, Frachetti M (2016) Millet cultivation across Eurasia: origins, spread, and the influence of seasonal climate. The Holocene 26:1566–1575.
44. Nozawa, S., H. Nakai, and Y. I. Sato, 2004: Characterization of microsatellite and ISSR polymorphisms among Echinochloa (L.) Beauv. spp. in *Japan. Breed. Res.* 6, 87-93.
45. Oumar, I, Mariac, C, Pham. J. L, Vigouroux, Y. 2008. Phylogeny and origin of pearl millet (*Pennisetum glaucum* [L.] R. Br) as revealed by microsatellite loci. *Theor Appl Genet* 117:489-497.
46. Pory, J. 1600. The history and description of Africa- written by Leo Africanus. R. Brown (ed.), Hakluyt Society Publ. No. 92.
47. Purugganan, M. D., & Fuller, D. Q. 2011. Archaeological data reveal slow rates of evolution during plant domestication. Evolution, 65(1), 171–183.
48. Phillips SM (1972) A survey of the genus *Eleusine* Gaertn. (Gramineae) in Africa. Kew Bull 27:251–270
49. Poncet, V., F. Lamy, K. M. Devos, M. G. Gale, A. Sarr, and T. Robert, 2000. Genetic control of domestication traits in pearl millet (Pennisetum glaucum L., Poaceae). Theor. Appl. Genet. 100, 149-159.
50. Prasada Rao, K., J. De Wet, V. Gopal Reddy, and M. Mengesha. 1993. Diversity in the small millets collection at ICRISAT. In: K.W. Riley, S.C. Gupta, A. Seetharam, and J.N. Mushonga, editors, Advances in small millets. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, India.
51. Riley, K. W. and Harinarayana, G. (eds), Small Millets in Global Agriculture, 3-18. *Oxford & IBH*, New Delhi.
52. Sakamoto S. 1987 Origin and dispersal of common millet and foxtail millet. *Jpn. Agr. Res*. Q. ;21 (22):84–9.
53. Saha, D., M.V.C. Gowda, L. Arya, M. Verma, and K.C. Bansal. 2016. Genetic and genomic resources of small millets. Crit. Rev. Plant Sci. 35:56–79. doi:10.1080/07352689.2016.1147907.
54. Singh, R. K. Muthamilarasan, M and Prasad M. 2017. Foxtail Millet: An Introduction, *Springer* International Publishing pp:1-7.
55. Upadhyaya, H.D, Sarma, N.D.R.K. and Ravishankar. C.R. 2010. Developing a mini-core collection in finger millet using multi-location data. Crop Sci 50(5):1924–1931.
56. Vavilov, N. I.1926. Studies on the origin of cultivated plants. *Inst. Bot. Appl. Amel. Plant*., Leningrad.
57. Vavilov, N.I. (1926) Studies on the origin of cultivated plants. *Inst Appl Bot Plant Breed* 16:1–248.

58. Vavilov, N.I. 1926. The origin of the cultivation of “primary” crops, in particular cultivated hemp. In: Vavilov N, editor. Studies on the origin of cultivated plants. Leningrad: *Inst. of Appl. Bot. and Plant. Breed.*; p. 221–33.
59. Vavilov, N. I. 1949/1950. The origin, variation, im- munity and breeding of cultivated plants. *Chronica Botanica* 13:1-366.
60. Yabuno, T., 1975: The classification and geographical distribution of the genus Echinochloa. *Weed Res.* 20, 97-104.
61. Yang X, Wan Z, Perry L, Lu H, Wang Q, Zhao C, Li J, Xie F, Yu J, Cui T, Wang T, Li M and Ge Q 2012. Early millet uses in northern China. *Proc. Natl. Acad. Sci*. USA 109:3726-3730.
62. Zhao, Z. 2011. New archaeobotanic data for the study of the origins of agriculture in China. *Curr Anthropol* 52: S295-S306.
63. Zhao, Z. 2014. The process of origin of agriculture in China: archaeological evidence from flotation. *Quat Sci.* 2014; 34: 73-84.

ISBN: 978-81-19149-19-3

2. Millet Based Industrial Products

Akshay Kumar Kurdekar, Vishwanath S. Naik,

Vinay Kumar M. I.

Department of Agronomy,
University of Agricultural Sciences,
Raichur, Karnataka, India.

T. Gangadhar

University of Agricultural Sciences,
Dharwad, Karnataka
City, Satate, Country.

Kavyashree C., Dileep

Department of Soil Science and Agricultural Chemistry,
UAS, Raichur, Karnataka, India.

Abstract:

Millets are a group of small-seeded grasses that are primarily cultivated in semi-arid regions of the world. These grains have been used for centuries as a staple food source in many countries, particularly in Africa and Asia. However, in recent years, millets have gained attention for their potential as a source of industrial products due to their unique nutritional and physical properties. In this chapter, we will explore some of the industrial products that can be made from millets. Advances in post-harvest processing and value addition technologies have made it possible to process and prepare value added products acceptable to both rural and urban consumers. Millets and sorghum have huge potential for wider use. With finger millet this potential is much harnessed. The other millets particularly minor millets remain un-researched and their potential untapped in diversified ways. Processing and utilization of millets in product development have promising prospects with regard to nutrition, quality and health benefits and can be an alternative to cereals but its full scope and utilization is yet to be established.

Keywords:

Millets, processing, puffing, fermentation and millet bioplastic.

2.1 Introduction:

Little grains that are heterogeneously grouped under the umbrella word "millet" are referred to as "coarse cereals" together with maize and sorghum. Although millets are not very important in the west, they are a staple in the diets of people in Asia and Africa. Their hardiness, tolerance of adverse weather, and ability to be cultivated with few inputs in low-rainfall areas give them agricultural relevance. Bajra or pearl millet (*Pennisetum americanum*), ragi or finger millets (*Eleusine coracana*), navane or foxtail millet (*Setaria sitalica*), samai or little millet (*Panicum miliare*), sharaka or kodo millet (*Paspalum scrobiculatum*), spanivaragu or proso millet (*Panicum miliaceum*), banti sor barnyard millet (*Echinochloa frumentacea*) are the important millets cultivated largely in the Asian and African countries.

Millet-based industrial products are goods that are manufactured using millet as the primary ingredient or raw material. Millet is a type of cereal grain that is commonly grown and consumed in many parts of the world, particularly in Africa and Asia. Millet can be processed and transformed into a wide range of industrial products, including food products, animal feed, biofuels, and other industrial materials.

Examples of millet-based industrial products include millet flour, which can be used to make various baked goods such as bread, biscuits, and cakes; millet-based snack foods such as puffed millet, millet-based breakfast cereals, millet-based baby food, and millet-based animal feed. Millet can also be used to produce biofuels such as ethanol and other industrial materials like insulation and paper.

2.2 Historical Background of Millet as A Source of Industrial Products:

Millet has been used as a source of food for thousands of years, particularly in Africa and Asia. However, its use as an industrial crop is a more recent development.

During the 19th century, millet was first used in Europe and North America for the production of birdseed, due to its high protein content and small size. In the early 20th century, millet began to be used for other industrial applications, such as the production of starch, alcohol, and paper.

During World War II, millet was used as a substitute for wheat and other grains that were in short supply. It was also used to produce fuel, due to its high cellulose content. In the years following the war, research continued on the use of millet as an industrial crop, and new applications were discovered. For example, millet straw was found to be a useful source of fiber for the production of paper and other products.

Today, millet is used for a variety of industrial applications, including the production of ethanol, bioplastics, and animal feed. Its use as an industrial crop is expected to continue to grow, as researchers discover new applications for this versatile grain.

2.3 Millet-Based Industrial Products:

Millet based industrial products include:

A. Millet Flour Millet flour is a versatile ingredient that can be used in a variety of products, such as bread, pasta, and baked goods. It is also gluten-free, making it a suitable alternative for people with celiac disease or gluten sensitivity.

B. Millet Starch Millet starch is a fine white powder that can be used as a thickening agent in soups, sauces, and gravies. It is also used in the production of noodles, puddings, and other food products.
C. Millet Protein Millet protein is a high-quality protein that contains all the essential amino acids needed by the human body. It can be used in the production of protein powders, protein bars, and other nutritional supplements.
D. Millet Syrup Millet syrup is a natural sweetener that can be used as a healthier alternative to sugar. It has a low glycemic index and is rich in minerals and antioxidants.
E. Millet Fiber Millet fiber is a dietary fiber that can be used as a functional ingredient in food products. It has been shown to have prebiotic effects, helping to promote the growth of beneficial gut bacteria.

Millet Bioplastics Millet bioplastics are biodegradable plastics that can be made from millet starch. They have the potential to replace traditional plastics in many applications, reducing the environmental impact of plastic waste.

2.3.1 Bread (Ragi & Bajra):

Normal white bread is made of wheat flour, which is deficient in many nutrients. Nutrient supplementation can be done by incorporating millets such as Ragi/Bajara to increase the nutritional value of the bread. This finely ground ragi/bajara flour is blended with wheat flour and the dough is prepared. Further, the dough is fermented, divided, proved, baked, sliced, and packed. The technology can be utilized in the rural sector at the cottage/family scale units to make composite bread containing millets such as Ragi/Bajara, which are rich in many macro and micro nutrients.

Whole-grain bread, Ezekiel bread, and rye bread are among the most healthful options for bread. Bread made from whole or sprouted grains contains essential nutrients, including protein, vitamins, minerals, and fiber. Others, such as processed white bread, contain very few nutrients. Composite flour has been used commercially in bread in several countries, but it is usually accepted only when there is a shortage of wheat flour.

However, newer trends in diversification of bakery products have created great scope for composite bread containing millets such as Ragi/Bajara. White bread has approximately the same carbohydrate and protein content as whole meal bread, contains soluble and insoluble dietary fiber, and a good percentage of nutrients4.

2.3.2 Millet Cookies:

Cookie is a small flat, baked product, commonly called biscuit. Cookie usually prepared from wheat flour, eggs, sugar and fat, sometimes toppings with raisins, oats or chocolate chips. Generally, wheat is one of the cereals used extensively throughout the world for the preparation of cookie. But cookie from non-wheat cereals like rice, jowar, maize or millet is uncommon. Recently, millets are gaining importance because they can offer several nutraceuticals, and also being rich in protein, minerals and vitamins. Its protein has a beneficial influence on the metabolism of cholesterol. Cereal or millet cookie is made from a fine flour of millet with leavening and shortenings.

2.3.3 Millet Snack:

Snacks are made from ragi flour to develop ready-to-eat snack products. Products are suitable as a low-fat snack which provides a good shelf-life without sacrificing the attractive texture and taste of a crispy snack. Product can be consumed as any time snack. Products are cost-effective and can also be considered as a health food (low fat-high fiber). In addition, fried chips also can be manufactured in same process lines.

A. Flaked Jowar RTE Low Fat Sweet & Savoury Snacks:

The jowar or sorghum snack is a ready-to-eat (RTE) product with either sweet or salt spicy in taste. It is suitable as a low-fat snack because the step of frying in oil fat has been omitted to provide a good shelf-life without sacrificing the attractive taste and texture of eating a crispy snack. The unit operation involved in the process is grading, roasting, flavoring, coating, drying and packing.

Figure 2.1: Flaked Jowar RTE Low Fat Sweet & Savoury Snacks

2.3.4 Millet Vermicelli:

Noodles or vermicelli are popular ready-to-cook products, normally prepared from wheat worldwide. There is growing interest on noodles from millets due to their nutraceutical content and the health benefits. Hence, noodles based on ragi (finger millet) and pulse flour was prepared. The product will be of low in cost and can be considered as health food (low fat and high fibre).

The noodles/vermicelli prepared exhibit good cooking and textural properties and may be used in any type of pasta dish--soups, stews etc. The noodles prepared can be used to make a variety of food and snack products like chaw-chaw, fried noodles. The noodles can be deep fat fried to a crispy snack, cooked in water and seasoned to soft snack, or boiled in milk and sugar to make a sweet dish.

Since, both ragi and soy are good source of minerals (rich in Ca, K and Zn) and nutraceutical (polyphenols, dietary fibre) the protein rich ragi vermicelli will offer several health benefits to the consumer.

2.3.5 Multigrain Pasta:

Pasta is known as one of the most ancient nourishment and as a very versatile dish, both from nutritive and gastronomic points of view. Nutritionist considers pasta as highly digestible. It also provides significant quantities of complex carbohydrates, protein, B-vitamins and iron and is low in sodium, amino acids and total fat. Recent developments in pasta products include attempts to improve the nutritional properties of pasta by the addition of supplements from various natural sources. The use of pasta products is more wide spread in the world because pasta products are simpler to make and quick to serve, if dried can be conveniently stored for a relatively long period of time without deterioration. The developed multigrain pasta formulation (based on millets, durum semolina and permitted additives) could be used to supplement the nutritional requirements of growing children and adults. The multigrain pasta has increased fiber and mineral content by 4-5% compared to normal pasta. It can be consumed along with tastemaker as a breakfast cereal/snack.

2.3.6 Multi Grain Sweet Mix (Halva):

Ragi/Sorghum/wheat, and rice, pulse and nuts based ready to cook mix for preparation of halva. Process involves grain size reduction, hydrothermal and thermal treatment and blending with ingredients.

2.3.7 Muffins (Ragi & Bajra):

A nutritious millet with 344 mg of calcium, 288 mg of phosphorus, 3.9 mg iron and 11.5 g dietary fiber. The Phytates, polyphenols and tannins contribute to antioxidant activity & important for health, aging and metabolic diseases. Gluten free muffins for normal people and celiac disease patients 1.5 times more dietary fiber, double the amount of phosphorus, 17 times higher calcium than wheat flour muffins.

Figure 2.2: Muffins (Ragi & Bajra)

2.3.8 Nutritious Millet Flour:

The prominent small millets are foxtail, finger, little, proso, barnyard and kodo millet. All these grains, except for finger millet, contain a non-edible husk as a distinct part, which needs dehusking, similar to paddy, before consumption. Unlike the major cereals, the milling machineries for dehusking and polishing of small millets are not fully developed. In this connection, preparation of husk free flour from small millets using roller mill was developed. In this process, the husked millet grains are directly milled using roller milling technology. In addition, the same mill is used to produce the semolina (sooji & rava) from the different dehusked millets and multi-millet semolina prepared. This semolina can be used as alternative to wheat semolina for the preparation of upma, halva and other traditional food products.

2.3.9 Ragi Flakes:

Finger millet or ragi (Eleusine coracana) is one of the important minor cereals. It is a nutritious grain and contains about 7% protein, 1.5% fat, and is a good source of calcium, dietary fiber and other protective nutrients. The health benefits of the millets are being recognized globally and non-traditional millet consumers are also looking for ready-to-use foods from the millet. Finger millet flakes are ready-to-use convenience products similar to rice, wheat and sorghum flakes. The flakes could be wetted with water and seasoned with spicy condiments, or sweetened for consumption as snacks. The thicker grade flakes may be deep fat fried or toasted to crispy textured products, and ready-to-eat snacks. The broken and pulverized flakes can be mixed with legumes and other ingredients to prepare traditional foods like bisibele bhath, idli and such other products. These flakes can also be used after toasting or blistering similar to corn flakes.

2.3.10 Millet Murukku Mix:

It is a ready mix for preparation of murukku, made from cereal flour either alone or blending with pulse flours. The blend after mixing with salt and spices is made into dough and deep fat fried to an attractive crispy snack. Even though the product is all time snack, it is commonly used as an evening snack along with tea/ coffee. Since, the product is an energy rich snack; it is an ideal snack for school children. The shelf-life of the mix is nearly 6 months with FFA content less than 10% when stored at ambient conditions.

Figure 2.3: Millet Murukku Mix

2.3.11 Millet Pappad:

It is a ready-to-fry crisp snack food adjunct. It is made from cooked dough containing cereal flour like ragi, rice, maize, sorghum, wheat flour or sago either alone or as blends with other pulse flours along with salt, khar and spices. It is deep fat fried to a attractive crispy wafer like product that is commonly used as an adjunct to a full meal.

2.3.12 Ragi Rusk:

A rusk is a hard, dry biscuit or twice-baked bread. It is sometimes used as a baby teething food. It is a popular baked product liked by all, especially children and working class, both in rural and urban sector. It is also a tea time snack which is yeast leavened containing 50% of 95% extraction ragi flour along with wheat flour. The crumb is pinkish brown color, pleasant flavor and crisp texture with a moisture content of about 4%.

2.4 Instant Beverage from Millet:

Beverages are a class of convenient foods, which are either in ready-to-drink form or in powder form, and can easily be reconstituted with milk or water before consumption. Beverages can be classified as specialty foods that provide energy and some of the essential nutrients like proteins, minerals and vitamins. These foods offer energy and nutrition to the consumers and help them to overcome fatigue and convalescence in the form of liquid food supplement.

2.4.1 Market Potential of Millet-Based Industrial Products:

- Millet is essential for creating a nutritious diet, hence the government and organisations in India encourage millet production. Millets are designated as Nutri-Cereals by the Government of India due to their nutritious content. To increase the area, output, and productivity of millets, the Department of Agriculture and Farmers Welfare (DA&FW) is also carrying out a sub-mission on nutri-cereals under the National Food Security Mission.
- The Food and Agricultural Organization (FAO) estimates that the production of millet on a global scale was 28.33 million metric tonnes in 2019 and 30.08 million metric tonnes in 2021. With a market share of 43.0% in 2021, India will continue to be the world's largest producer of sorghum (jowar), pearl millet (bajra), finger millet (ragi), and other minor millets. India's millet production climbed from 14.52 million tonnes in 2015–16 to 17.96 million metric tonnes in 2020–21, according to the Ministry of Agriculture and Farmers Welfare.
- The export of millet has increased as a result of the rising domestic production. A rise in millet exports from India to 159,332.16 metric tonnes in 2021–2022 from 147,501.08 metric tonnes in 2020–2021, as reported by the Director General for Commercial Intelligence & Statistics (DGCI & S), is expected to increase local millet output. In addition, the Indian government is encouraging the export of millet because of the growing demand on the international market.
- For instance, Agriculture and Processed Products Export Development Authority (APEDA) has planned 16 programs for the promotion of millets and millet products in

countries such as UAE, Indonesia, the United States, Japan, the United Kingdom, Germany, South Africa, Australia, Saudi Arabia, etc. to increase the millet exports of the country. Thus, the rising demand for millets in the global market and increased domestic production in India are anticipated to drive the market in the coming years.

2.4.2 Technology for Millet Value Addition:

Decortication/Dehulling: By virtue of a very hard seed coat, the first and foremost step in millet processing is dehusking or decortication. Traditionally, millets are decorticated through manual pounding. Traditional millstones) utilized for dehusking and grinding of millets grain are usually comprised of a small stone that is held in the hand and a larger flat stone that is placed on the ground.

The friction between these grinding stones results in Dehulling and grinding of millet grains. In general, 4–5 passes are required through this method to get the completely dehusked seeds. The traditional method of Dehulling is laborious and time-consuming with low Dehulling yield (50%).

Milling: The major limiting factors for the utilization of millets as ready-to-use value-added products are the coarse grains, hard seed coat, pigmented seeds, acidic or bitter taste, and poor shelf life of the processed products. Therefore, proper milling technologies are required for the value addition and commercialization of millet-based products. Various processing techniques like pearling, debranning, and chemical treatment of millets are reported to overcome some of these limitations to improve consumer acceptability.

Composite Flour: Blending of millet grains with widely utilized cereals like wheat and maize and some nutritious pulses is one possible way to enhance their widespread utilization. Many functional food products of wheat like cakes, pasta, macaroni, vermicelli, noodles, spaghetti, and flakes are widely consumed in developed and developing countries. In general, the major ingredient of these products is refined wheat flour or semolina.

Flaked Millets: Various processing treatments mainly the thermal treatment of grains induces the physicochemical and structural changes in starch–protein matrix which ultimately leads to the expansion of the grains to produce a puffed product. High treatment short time (HTST) is a common and convenient method to make expanded flakes and other popped products.

2.4.3 Pasta, Noodles, and Other Products Making Machines:

Noodles and pasta are the widely consumed food products among all the age groups in both developed and developing countries. Compared to other products noodles and pasta have a longer shelf life and economic significance. A variety of noodles and pasta are prepared from millets. It includes noodles solely made from finger millet flour, noodles made from finger millet and wheat flour in a ratio of 1:1 and finger millet mixed with wheat and soy flour in the ratio of 5:4:1. Fortified small millets noodles are prepared by supplementing with lysine to overcome the deficiency of amino acid on heat treatment.

2.4.4 Extruded Products:

Cooking procedure which is utilized for the post-harvest processing of starchy and protein-rich materials at high temperature for short timing is known as extrusion cooking. Extrusion cooking enhances the protein digestibility, quality, and versatility of the processed food items It is performed by direct application of heat through a steam injection or indirectly through a jacket by the dissipation of mechanical energy through shearing occurring within the blend. The ready-to-cook extruded products of millets by mixing pearl millet and finger millet flour are reported to have nutrient content, color, texture, and cooking quality and sensory properties in the acceptable range.

2.4.5 Fermented Products:

In general, millets are a good source of protein but the protein quality in terms of essential amino acid profile is low (Jaybhaye et al. 2014). Interestingly, probiotic fermentation and germination of millets are known to enhance the protein digestibility and content of lysine, thiamine, niacin, sugars, protein fractions, soluble fibers, and in vitro availability of micronutrients.

2.5 Conclusion:

Millet-based industrial products have great potential in the market due to their high nutritional value and health benefits. Millets are rich sources of various nutrients, including B vitamins, calcium, iron, potassium, magnesium, and zinc, and are gluten-free with a low glycemic index, making them suitable for people with allergies/intolerance to wheat, diabetic, or trying to lose weight. Millet-based industrial products include activated carbon, biscuits, amylase, proteases, and lignolytic enzymes, bioethanol, and animal feed. Millets are also used to produce flour, flakes, cookies, and other food products. The market potential of millet-based industrial products is increasing, given the growing awareness among the population regarding the health benefits of millets. Millets-based products such as flour, flakes, cookies, etc. are increasingly visible in the consumer market. The promotion of millet-based products is aimed at enhancing their visibility and total acceptance in both rural and urban populations, creating a sustainable ecosystem for growers and processors.

2.6 Reference:

1. Abdelrahman AA, Hoseney RC (1984) Basis for the hardness in pearl millet, grain sorghum, and corn. *Cereal Chem* 61(3):232–235
2. Arora S, Jood S, Khetarpaul N (2011) Effect of germination and probiotic fermentation on nutrient profile of pearl millet based food blends. *Br. Food J.*, 113(4):470–481
3. Badi S, Pedersen B, Monowar L and Eggum BO (1990). The nutritive value of new and traditional sorghum and millet foods from Sudan. *Plant Foods Hum. Nutr.*, 40(1): 5-19.
4. CFTRI: Millet products
5. Chandrasekara A and Shahidi F (2011). Determination of antioxidant activity in free and hydrolyzed fractions of millet grains and characterization of their phenolic profiles by HPLC-DAD-ESI-MSn. *J. Funct. Foods*, 3: 144-58

6. Chandrasekara A, Naczk M and Shahidi F (2012). Effect of processing on the antioxidant activity of millet grains. Food Chem., 133: 1-9.
7. Dahlin K, Lorenz K (1992) Protein digestibility of extruded cereal grains. *Food Chem* 48:13–18
8. Desikachar HSR (1975) Processing of maize, sorghum and millets for food uses. *J Sci Ind Res* 43:231–237 Devi MP,
9. FAO (1991) Food and Agriculture Organization. Amino acid scoring pattern. In: Protein quality evaluation. FAO/WHO Food and Nutrition Paper, Italy. pp 12–24
10. Hadimani NA and Malleshi NG (1993). Studies on milling, physico-chemical properties, nutrient composition and dietary fiber content of millets *J. Food Sci. Technol*., 30: 17-20.
11. Hadimani NA, Ali SZ and Malleshi NG (1995). Physicochemical composition and processing characteristics of pearl millet varieties. *J. Food Sci. Technol*., 32: 193-198.
12. Narayanasamy S (2013) Extraction and dehydration of millet milk powder for formulation of extruded product. *J Environ Sci Toxicol Food Technol* 7:63–70.

ISBN: 978-81-19149-19-3

3. Millets in Era of Climate Change

Swati Dash

PhD Scholar,
Department of Agronomy,
UAS, GKVK, Bengaluru Karnataka.

Dr. Atheekur Rehman, H. M.

Scientist,
UAS, GKVK, Bengaluru, Karnataka.

Abstract:

An increasing population means an ever-increasing demand for food. This builds pressure on agriculture to increase productivity with limited resources. Climate change have now adversely affected agriculture system as it mostly weathers dependant. Irregular rainfalls, soil erosion, decreasing land productivity have now put question mark on food security. Most of the conventionally grown crops like rice, wheat, maize is affected by changing climate. To find a solution to it millets comes as a very good alternative as a climate-smart crop. Most of the major cereal crops have a higher global warming potential than millets, so they should be considered in mitigating global food insecurity. In this chapter, we are going to discuss how millets can mitigate the effects of climate change and ensure food security as well as sustainable agriculture along with financial security to farmers.

Keywords:

Climate-smart; Food security; Millets

3.1 Introduction:

As we inch towards 2030 we look forward to meet the deadline of Paris agreement to reduce the global temperature below 2˚C and continue our efforts to maintain it upto 1.5˚C, which is necessary to reduce the impact of climate change. The changing climate is now the burning scenario of the globe which can be felt by erratic rainfalls, increasing instances of natural calamities and alarming rate of temperature rise. This is affecting everyone around the planet and all sectors of life as well. But agriculture is one such area which is getting directly affected by the climatic irregularities. Increasing soil erosion, vagaries of monsoon, heat waves, increasing inundation of agricultural lands by sea etc., are some of the instances where agriculture is affected by climate change.

Increasing population and declining arable lands has put us in a difficult situation where by 2030 we need to ensure zero hunger under sustainable development goals (SDG). Moreover, we need to eradicate malnutrition and reduce poverty as well, in developing countries. As major developing countries' economy depends upon agriculture and allied sector, we need to find solution to it.

We need to search for climate resilient agricultural practices and crops to meet or needs. And the answer comes is "Millets". At this point the United Nation's General Assemble agreed on India's proposal and accepted the year of 2023 as International year of millets. We can take this scope as a chance to exploit the climate-resilience of millets.

In the present scenario where rising temperature due to global warming and irregularities in rainfall due to climate change is affecting the global food production, millets can act as a beacon of hope. Moreover, the sustainable development goals which are targeted to achieve by the year of 2030, four of them can managed by growing millets, those are No Poverty, Zero Hunger, Good Health and Well Being, and Climate Action. In this chapter we can see how these '*Sri Anna'* is a climate smart crop. Millets come as solution of increasing the income of marginal farmers of our country. As climate change affects the agriculture sector and small and marginal farmers are majority of our farmers, growing millets can avail them profit.

3.2 What Are Millets?

Millets are collective group of small seeded annual grasses that are grown as grain crops (FAO), which belongs to the family poaceae. Those are pearl millet (bajra), sorghum, finger millet (ragi), foxtail millet, barnyard millet, kodo millet, proso millet and little millet. Among these major millets are sorghum, pearl millet and finger millet while remaining are minor millets. These are also called as nutra-ceutical crops as they are rich in macronutrients and micronutrients, with higher levels of calcium, iron, zinc, potassium, protein and essential amino acids. These also have a low glycemic index (GI) property which can be helpful in reducing type 2 diabetes. In addition, their nutrients can help avert cardiovascular diseases, lower blood pressure and cholesterol and improve gut health. Because of these nutritional values they are being included in public distribution systems in many parts of the country.

Presently rice, wheat and maize are the major cereals grown around the world which is reducing the crop diversity. This will affect food production if there is a pest breakout or unfavorable climatic condition prolongs. In such scenario "miracle Grains-Millets" offer an exciting opportunity to enhance agrobiodiversity around the world as it can be grown in varied climatic and soil conditions. Most importantly millets are domesticated majorly in African and Indian subcontinent, it can tolerate extreme and erratic environments, and cultivation of these cereals can improve productivity of arid landscapes and establish food security under a changing climate.

3.3 Millets - Climate Smart Crop:

As we discussed above that millets are acting as miracle crop under changing climate, here we are going to see what makes this coarse cereal a climate smart crop under the following headings:

A. Can be cultivated in marginal lands
B. Low GHG emission and carbon foot print
C. C4 mechanism

D. stress management mechanism
E. High water use efficiency
F. Low external input
G. Nutritional security

3.3.1 Cultivation in Marginal Lands:

The increasing population is leading to per capita reduction in arable land availability. It is projected that by 2050 the world is going to hit 9 billion populations [1]. Along with that climate change is affecting arable land productivity. Increasing soil erosion and intensive use of chemical fertilizers is the reason for that. This is leading to reduction in yield of conventional crops. In this scenario millets come as miracle crop which can be grown in wasteland and provide nutritional security. Low nutrient and water requirement of millet crops makes them one of the most preferable crops for degraded land.

For example, finger millet is one such crop which can be grown in saline soils, alkali soils and in drought condition as well. Millets are the best choice as they can be grown on shallow, low fertile soils with a varied (ranging from 4.5 to 8.0) pH [2]. Millets can be an easy replacement for conventional crops like wheat and rice. Further, millets like pearl and finger millet can grow up to a soil salinity of 11–12 dS/m, while rice has poor growth and productivity on a soil having salinity higher than 3 dS/m [2]. Millets are adapted to wide range of ecological conditions often growing on skeletal soil that are less than 15cm deep. They are considered as a poor man's crop due to their significant contributions to a resource-limited population diet offering several opportunities for their cultivation in developing countries.

3.3.2 Low GHG Emission and Carbon Foot Print:

As we work to reduce greenhouse gas emission to reduce global temperature we need to reduce GHG emission from agriculture sector as well. Agriculture is the second largest emitter after energy sector. It emits about 14% from that 17.49% is from rice cultivation, followed by 15.88% from agriculture soil by N_2O emissions. Thus, reducing the greenhouse gas is necessary to ensure sustainable agriculture. Release of CO_2 by the fertilizer industry is also another major source. Intensive agriculture practices and declining soil health demands higher inputs leading to higher production causing higher GHG emissions. But millets with lower fertilizer demands and their ability to produce good yield even in marginal lands can provide solution to it leading to reduction in emission directly or indirectly.

If we look at global warming potential which refers to total contribution to global warming resulting from the emission of one unit of any gas relative to one unit of carbon dioxide [3], among all the major cereal crops, wheat has the highest global warming potential of around 4 tons CO_2 eq/ha followed by rice and maize (around 3.4 tons CO_2 eq/ha) whereas millets have 3.2 tons CO_2 eq/ha. These crops also have a high carbon equivalent emission of 1000, 956 and 935 kg C/ha for wheat, rice and maize, respectively. However, the carbon footprints of millets are comparatively lower [3]. Thus millet cultivation can play the role of an alleviator that could reduce carbon footprint in the world.

Moreover, for chemical nitrogen fertilizer production, CO_2 is generated and as per an estimate to fulfill the present requirement of chemical nitrogen fertilizers in the world, annually 300 tera-gram (Tg = 1012g) of CO_2 is released into the atmosphere [4]. Millets are less nutrient demanding crops and if grown in dryland, it doesn't even require any fertilizer. As millets have more tillers or branches than corn and sorghum, they provide better fodder too. Millet crops also have a good ability to sequester carbon and so help climate adaptation, considering the water needs and methane emission of rice fields [5].

3.3.3 C4 Mechanism:

All millets are C4 crops which use C4 pathway of photosynthesis, which has negligible photorespiration and high water use efficiency. In the C4 system, carbon dioxide (CO_2) is concentrated around ribulose-1,5- bisphosphate carboxylase/oxygenase (RuBisCO), which in turn suppresses ribulose 1,5-bisphosphate (RuBP) oxygenation and photorespiration (Aubry et al., 2011). Thus, C4 mechanism enhances the concentration of CO_2 in bundle sheath, which suppresses photorespiration (around 80%) depending on the temperature and increases the catalytic activity of RuBisCO [6] leading to higher photosynthesis. Additionaly, RuBisCO of C4 plants works at elevated CO_2 levels upto 360 ppm, and temperature upto 35-40˚C, so millets have enhanced photosynthetic rates at warm conditions. Thus in case of climate change with increasing CO_2 and temperature millets will ensure food security. This leads to higher water use efficiency (WUE) and nitrogen use efficiency (NUE) which are 1.5 to 4- fold higher than C3 photosynthesis [7]. For instance, foxtail millet requires just 257 g of water to produce a dry biomass of 1 g, whereas maize and wheat require 470 and 510 g, respectively [8].

3.3.4 Stress Management Mechanism:

Certain morphological features are there which provide stress tolerance to millets. They have unique dumbbell-shaped guard cells with two subsidiary cells. This modification allows for faster and more refined stomatal responses, resulting in higher water use efficiency [9,10,11]. Most grasses are amphistomatic, with stomata on both sides of their leaves. These isobilateral leaves held parallel to the axis of irradiance allow for more efficient CO_2 diffusion with low evapotranspiration rates [12]. Paired with their C4 physiology, deep and fibrous root systems establish quickly to enhance water availability and maintain stability during environmental changes. Overall, a high specific leaf area, net assimilation rate, and root to shoot ratio increase the relative growth rate of C4 millets [13, 14]. Pearl millet is an ephemeral crop with short life-cycle of 12–14 weeks, which enables it to escape drought and to complete its life-cycle (seed to seed) whereas rice and wheat requires a maximum of 20–24 weeks. But in case of Sorghum, it tolerates the drought being a camel crop. They several traits such as short stature, small leaf area, thickened cell walls, and the capability to form dense root system [8]. Compared to maize, pearl millet can modulate their membrane dynamics better for water permeability to attain better water status during osmotic stress [15]. An increase in leaf tensile strength and root length was reported in teff and little millet under drought [16]. Several biochemical events, e.g., reactive oxygen species (ROS) regulation, enhances ROS scavenging enzymes (catalase and superoxide), and other stress-related proteins are accumulated in response to abiotic stresses in millets [17].

3.3.5 High Water Use Efficiency:

As climate change is leading to worldwide water scarcity due to erratic rainfall, it is affecting water use in agriculture. In case of India agriculture sector accounts for about 80% of water use, target has been made to bring it down upto 60%. This has a major problem as rising temperature demands for more irrigation. But millets with C4 mechanism have high water use efficiency. Millets have evolved a unique set of adaptations to avoid, survive, tolerate, or recover from water deficit stress. Sorghum, finger millet, and teff have water use efficiencies (WUE) of 4.2-13.4 kg yield/hectare mm rain; several times higher than comparable C3 cereals and other grain crops [18]. Cultivated millets have generally low rainfall requirements of 200-500 mm, compared to 500-900 mm for winter wheat and maize, and high WUE helps preserve soil moisture content [19]. One rice plant requires nearly 2-5 times the amount of water required by a single millet plant of most varieties, according to the Crops Research Institute for Semi-Arid Tropics (ICRISAT). Some millets avoid drought altogether like fonio and barnyard millet, which can reach maturity within 8 weeks [20].

This short season enables millets to escape unpredictable late summer droughts, or serve as a rescue crop if another grain crop fails. Drought tolerance itself is linked to the evolutionary history of millets, and C4 grasses express a set of unique, likely ancestral dehydration pathways under severe drought stress that are typically specific to seed desiccation [21]. When combined with anatomic and physiological adaptations, these dehydration responses allow millets to survive low critical leaf water potential until conditions improve.

3.3.6 Low External Input and Income Security:

As we spoke in previous parts how millets can be cultivated with minimal external input. It makes them most suited crops for LEISA- low external input sustainable agriculture crop. Moreover, they can be easily incorporated in natural farming (ZBNF-Zero-budget natural farming) and organic agriculture as well. As they also provide fodder, we feed cattle as well. Millets are basically low input crops which can provide higher income to farmers. Presently government is providing MSP for some millets like jowar, ragi and bajra, so this will ensure farmer's income. As 2023 is declared as international year of millets and India being the largest producer of millets aims to popularize them round the globe. For that government have intiated to produce large number of processed products from them like- biscuits, chips, flour and ready to eat products. The products add value which can lead to provide higher income to millet growers and processors. In case of drought situations millets also work as contingent crops, can be used as mixed crops also can ensure farmer's income.

3.3.7 Nutritional Security:

We aim to achieve SDG by 2030, therefore we need to ensure no one goes to bed hungry based on SDG 2 – Zero Hunger. In the context of climate change with sustainable agriculture in limited arable land, millets can provide necessary nutrients to all with less price. They are called nutri-cereals for a reason. They are loaded with minerals like calcium, iron, zinc, magnesium, phosphorus and potassium. They can also solve the major health issue of the globe i.e, obesity and diabetes. With lower glycemic index it can reduce blood sugar levels of diabetic patients if it is replaced in place of white rice.

Finger millet is very rich in calcium, it is thirty times more than rice, while every other millet has at least twice the amount of calcium compared to rice. In iron content, little millet and Pearl millet are so rich that rice is nowhere in the race. They also contain appreciable amounts of dietary fibre, Vitamins, folic acid and high amounts of lecithin which are useful for strengthening of the nervous system.

3.4 Conclusion:

All good being said about the millets, it also has certain de-merits. Like high shattering, anti-nutritional properties and allelopathic effect. If these factors are managed by breeding and cropping practices, it can be widely adapted by the farmers.

The stress tolerance ability of this miracle crop has no comparison with other crops. With its nutri-rich grains it makes the crop climate smart. It requires significantly fewer input costs for cultivation and very less pest and disease attacks. These features accentuate millets as crops of choice for the world population amid growing concerns about climate change. With advantages loaded in its favour such as low-maintenance, disease and pest resistance, nutritional benefits, market demand, fodder value and ecological benefits, millet is being considered as a smart crop.

3.5 References:

1. Godfray, H.C.J., Beddington, J.R., Crute, I.R., Haddad, L., Lawrence, D., Muir, J.F., Pretty, J., Robinson, S., Thomas, S.M., Toulmin, C. Food security: The challenge of feeding 9 billion people. Science, 2010; **327**:812–818.
2. Rathinapriya P, Pandian S, Rakkammal K, Balasangeetha M, Alexpandi R, Satish L. The protective effects of polyamines on salinity stress tolerance in foxtail millet (Setaria italica L.), an important C4 model crop, Physiol Mol Biol Plants. 2020;**26**(9):1815-29.
3. https://www.epa.gov>ghgemissions/understanding-global-warming-potentials Jain, N.; Arora, P.; Tomer, R.; Mishra, S.V.; Bhatia, A.; Pathak, H.; Chakraborty, D.; Kumar, V.; Dubey, D.; Harit, R.; Greenhouse gases emission from soils under major crops in northwest India. Sci. Total Environ.**2016**, **542**:551–561.
4. Jensen ES, Peoples MB, Boddey RM, Gresshoff PM, Hauggaard-Nielsen H, J.R. Alves B. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agron Sustain Dev. 2012;**32**(2): 329-64.
5. https://www.icrisat.org/farmers-turn-to-millets-as-a-climate-smart-crop
6. Sage, R. F., Christin, P. A., and Edwards, E. A. The lineages of C4 photosynthesis on planet. Earth. J. Exp. Bot. 2011; **62** :3155–3169.doi: 10.1093/jxb/err048.
7. Sage, R. F., and Zhu, X.-G. Exploiting the engine of C4 photosynthesis. J.Exp. Bot. 2011; **62**; 2989–3000. doi: 10.1093/jxb/err179.
8. Li, P., and Brutnell, T. P. Setaria viridis and Setaria italica, model genetic systems for the panicoid grasses. J. Exp. Bot. 2011; **62** :3031–3037.doi: 10.1093/jxb/err096.
9. Lawson T, Vialet-Chabrand S. Speedy stomata, photosynthesis and plant water use efficiency. New Phytol 2019; **221:93**–8.
10. McAusland L, Vialet-Chabrand S, Davey P, Baker NR, Brendel O, Lawson T. Effects of kinetics of light-induced stomatal responses on photosynthesis and water-use efficiency. New Phytol 278 2016; **211:1209**–20.

11. Stebbins GL, Shah SS. Developmental studies of cell differentiation in the epidermis of monocotyledons: II. Cytological features of stomatal development in the Gramineae. Dev Biol 1960; **2:477**–500.
12. Drake PL, de Boer HJ, Schymanski SJ, Veneklaas EJ. Two sides to every leaf: water and CO2 transport in hypostomatous and amphistomatous leaves. New Phytol 2019; **222:1179–** 87.
13. Atkinson RRL, Mockford EJ, Bennett C, Christin P-A, Spriggs EL, Freckleton RP, et al. C4 photosynthesis boosts growth by altering physiology, allocation and size. Nat Plants 2016; **2:16038**.
14. Simpson KJ, Bennett C, Atkinson RRL, Mockford EJ, McKenzie S, Freckleton RP, et al. C 4 photosynthesis and the economic spectra of leaf and root traits independently influence growth rates in grasses. J Ecol 2020; **108:1899**–909.
15. Bandyopadhyay T, Muthamilarasan M, Prasad M. Millets for next generation climate-smart agriculture. Front Plant Sci. 2017; **8:1266**.
16. Balsamo RA, VanderWilligen CV, Bauer AM, Farrant J. Drought tolerance of selected Eragrostis species correlates with leaf tensile properties. Ann Bot. 2006;**97**(6):985-91.
17. Ajithkumar IP, Panneerselvam R. ROS scavenging system, osmotic maintenance, pigment and growth status of panicum sumatrense roth. Under Drought Stress. Cell Biochem Biophys. 2014;**68**(3): 587-95.
18. Hadebe ST, Modi AT, Mabhaudhi T. Drought tolerance and water use of cereal crops: A focus on sorghum as a food security crop in sub-Saharan Africa. J Agron Crop Sci 2017; **203:177**–91.
19. An P, Ren W, Liu X, Song M, Li X. Adjustment and Optimization of the Cropping Systems under Water Constraint. Sustain Sci Pract Policy 2016; **8:1207**.
20. Kumar A, Tomer V, Kaur A, Kumar V, Gupta K. Millets: a solution to agrarian and nutritional challenges. Agriculture & Food Security 2018; **7:1**–15.
21. Pardo J, Man Wai C, Chay H, Madden CF, Hilhorst HWM, Farrant JM, et al. Intertwined signatures of desiccation and drought tolerance in grasses. Proc Natl Acad Sci U S A 2020; **117:10079**–88.

ISBN: 978-81-19149-19-3

4. Climate Resilience of Millets in Times of Global Warming

Mr. Badal Verma

Ph.D. Scholar,
Department of Agronomy,
College of Agriculture, Jawaharlal Nehru Krishi Vishwa Vidyalaya,
Jabalpur, Madhya Pradesh.

Abstract:

Millets are climate resilient small seeded grain crops cultivated worldwide in arid and semiarid regions. These are the crops which outperform all the other most dominating cereals crops of the world. Climate change has induced many biotic and abiotic stresses, which has posed a serious threat to agriculture production. The most promising cause of climate change is global warming, i.e., the increase in the overall temperature of the earth due to the absorption of heat by greenhouse gases such as CO2, CH4, N2O etc. This global warming has caused serious implications in the climate of the surroundings, witnessed as the change in precipitation pattern (prolonged drought in some areas and waterlogging stress in others), increased temperature stress and lodging, increased pest attack etc. These widespread issues have been successfully resolved by the cultivation of millets. This chapter discusses the serious implications of climate change, how millets are the best alternative in this era of climate change, the climate-resilient features of millets, along with their nutritional benefits and the mechanism of climate resilience of millets. The millets are inherently resilient to changing climatic conditions owing to their special morphological features and easy adaptation. The climate resilience of millet crops can further be enhanced by various newly merging techniques, such as the application of PGPRs and Cas9 technology. The climate resilience of millets is one property of millets that has made them the most reliant crops in this modern era of development. Sustainable agriculture production thus needs the cultivation of these crops to meet global food security.

Keywords:

Cas9 technology, Climate resilience, Global warming, Millets, PGPR, Sustainable agriculture.

4.1 Introduction:

One of the most pressing issues confronting the modern world is feeding everyone on the planet. The risk of global warming as well as a changing climate scenario persists even while some of these causes of hunger can really be tackled, leading to a slight drop in the total number of people that are suffering from malnutrition and starvation from approximately 1.0 billion during 1990–1992 to 850 million in 2010–2012 [1]. Estimates indicate that between 2-3 billion individuals may face hunger and food insecurity in 2050 as just a consequence of diminishing agricultural rate of production and further stress of sustaining a population approaching 9 billion [2,3]. Global warming presents agricultural experts with a new worldwide issue, impacting practically all climatic factors, such as air temperature, rainfall intensity and dispersion. Throughout the previous 65 years, there have been substantial changes in the world, including global warming as well as the anticipated and witnessed climate changes for such twenty-first decade. Climate change is a complex intergovernmental issue that affects a number of biological, environmental, socio-political, and socioeconomic fields on a global scale [4,5].

Recent years have seen the changing climate and also its unpredictability as significant obstacles to Indian agriculture. The worldwide climate change projections involve rising average temperatures, rainfall, and an increase in extreme weather events like flooding and heat waves, as well as increased levels of carbon dioxide in the atmosphere and ground-level ozone concentrations and rising sea level that will cause coastal areas to become submerged. It has become more evident recently as different regions of the nation have experienced climate disasterslike droughts, excessive rain, floods, cyclones, frost andheat waves Etc.

The expected implications of climate change on agriculture production, natural ecosystems, water resources and food security were detailed in the IPCC's fourth and fifth reports [6]. Climate change including rising worldwide mean temperaturesare thought to have a direct effect on agricultural productivity, yields, and the food system's sustainability. Whereas climate change may assist certain places by increasing production and output, this is unlikely to be sufficient to feed the world's rising population [7]. Moreover, the majority of academics predict that present levels of global warming and emissions of greenhouse gases would drastically diminish crop output. As a result, sustaining food security is heavily dependent on decreasing emissions of greenhouse gases in order to regulate global temperatures. Nevertheless, the agricultural sector is a significant generator of greenhouse gases, most importantly methane in the environment.

Increment of greenhouse gases, like carbon dioxide, methane, nitrous oxide, etc., are merely a result of inefficient agricultural practices, such as intensive tilling and burning of crop residues, which also negatively influence the productivity of both land and water. According to one prediction, worldwide surface air temperatures may rise by 4.0–5.8 °C in the future decades, counteracting the expected advantages of rising atmospheric carbon dioxide concentrations on crop plants. New environmental circumstances developed across time and space, which may be to blame for periodic droughts, rising temperatures, flooding, salinity, rising carbon dioxide levels, rising sea levels, and unpredictable rainfall patterns [8].

Global climate change has a large impact on agricultural production all around the world. Additionally, it directly affects biophysical elements like animal and plant growth as well as many aspects of food processing and distribution. To maximize agricultural production and satisfy the rising population's food needs, it is essential to assess the impacts of worldwide climate change and apply new tools and strategies to decrease their influence.

In this context, millets are the most valuable crop since they are nutritionally climate change-tolerant and have a very high potential for marginal areas to produce more significant economic returns than other millet, even in climate change with extreme temperature conditions. However, it has higher grain yield ceiling temperatures and serves as a crop with enormous nutritional quality that must be fully realized [9].

Since millet crops are more resistant to extreme climatic occurrences like drought and water scarcity, they can be extremely important in providing food and nutritional security in situations when the climatic environment is changing at an alarming rate. Millets are mostly grown on marginal lands in a rainfed environment.

They may continue to grow and yield sufficient grains even in drought-affected regions with an average precipitation of around 250 mm. Because of its distinctive qualities, which include the C4 plant's high photosynthetic efficiency, greater capacity for producing dry matter, and ability to survive in challenging agro-climatic situations with fewer number of inputs and greater economic returns, it outperforms as compare to all other cereals, including rice [10], wheat [11], maize, barley and sorghum [12].

Resilience is an emergent feature, and stress tolerance requires the coordinated deployment of dozens to hundreds of molecular or phenotypic modifications [13]. While cultivated and wild grasses share some resilience characteristics, others are unique to millets and their stress-tolerant cousins.

All millets and many types of grass use the enhanced C4 photosynthesis pathway, which lowers photorespiration and increases water use effectiveness, allowing millets to flourish in hot and arid regions.

Because C4 plants have "Kranz" anatomy in their leaves, they can fix inorganic CO_2 better and use water more effectively than C3 plants. It also has several benefits, including fast maturation, resilience to drought, low input requirements, and a general lack of biotic and abiotic stressors.

4.2 Different Climate-Resilient Millets and Their Benefits:

Millets are round, small-seeded whole grains that are commonly farmed as cereal crops or grains for livestock feed and human use. They are non-glutinous and easy to digest, making them non-allergenic, and they have a great nutritional profile. Compared to other grains, millets are a rich source of nutrients, particularly phosphorus, potassium, calcium, and magnesium.

Although all millet types are members of the *Poaceae* family, they vary in terms of colour, species, and other distinctive qualities. Major and minor millets are two classifications that have been created based on the crop's popularity and level of cultivation.

They fall into two broad categories; sorghum and bajra are the main millets, whereas barnyard, foxtail, kodo, proso, little and finger millet are minor millets (**Figure 4.1**).

Figure 4.1: Different Kinds of Climate Resilient Millets

4.2.1 Sorghum:

In India and Africa, sorghum is a typical ancient cereal grain. It is considered the most incredible alternative for celiac disease. Over 16 million ha of sorghum were grown in India in 1981, but that number gradually dropped to 7.8 million ha in 2007–2008, still accounting for 20% of the world's production in recent years. Sorghum works even better when used in place of wheat to make products like bread, pasta, biscuits, Etc. Ajono is a beverage that East Africans have traditionally prepared from sorghum millet. Sorghum crop can withstand drought conditions because of their deep root system, waxy leaves, and stem that contain mortar cells. It is more suited to dryland conditions compared to all cereal crops because it can survive greater temperatures at any stage of growth [14].

Benefits:

- Iron, calcium fibre, protein, and wax policosanols, all of which are found in sorghum, can help in lower cholesterol levels and provide other health advantages.
- For people with celiac disease or others who cannot tolerate items made from wheat, sorghum provides gluten-free grain.
- Most sorghum protein is prolamin (kafirin), with the unique trait of diminishing digestibility while cooking, so it can be advantageous in some dietary groups.
- Protein, fibre, thiamine, riboflavin, folic acid, and carotene are all abundant in them. With adequate levels of iron, zinc, and sodium, it is rich in potassium, phosphorus, and calcium [15].

4.2.2 Pearl Millet:

Pearl millet (*Pennisetum glaucum* L.), often called as Bajra. Throughout the last three years, India has been the most significant producer of pearl millet in Asia, producing 8.3 million tonnes with an average productivity of 930 kg/ha. Pearl millet has high protein content (12–16%) as well as low-fat content (4-6%). The amount of dietary fibre in it is 11.5%.

Pearl millet has the highest niacin level of any cereal. Foliate, magnesium, iron, copper, zinc and vitamins E and B complex are also present. Compared to other millets, it contains a lot of energy. Moreover, it contains a lot of healthy unsaturated fats and calcium. It is high in fat, magnesium, and insoluble fibre.

Its flour has poor storage quality, an unpleasant flavour, and a nutty taste due to the lipase enzyme [17]. It is ideally suited for arid areas due to its capacity to use water more efficiently than sorghum or maize. Nevertheless, unlike sorghum, it cannot withstand drought or water stress, but it can abbreviate its life cycle and flower earlier under such conditions.

This is referred to as the drought escape mechanism. Pearl millets were commonly cultivated in areas with poor soils and low average rainfall of 200–500 mm [18].

Benefits:

- Pearl millet has insoluble fibre, which aids in the decrease of excess bile, which leads to gallstones.
- It aids in the treatment of respiratory diseases and migraines.
- Food moves through the gut more slowly as a result. Hence, lessen the risk of inflammatory bowel illness.

4.2.3 Finger Millet:

Finger millet (*Eleusine coracana* L.), commonly called as Ragi, was previously considered a minor millet, but its increased adaptability has made it considerably more prevalent among cereals. It is one of the most valuable nutritional cereals. It contains the amino acid (methionine) as well as iron, calcium, fibre, protein (6–8%), and other nutrients which have been missing from the diet of poor people who have survived on starchy staples for a hundred years.

The most abundant source of calcium is finger millet (300–350 mg/100 g). Finger millet is utilized in Nepal to produce the fermented beverage known as a bear. It is the cereal with the highest tolerance to salinity.

Benefits:

- Constipation, anaemia, high blood pressure, asthma, and heart issues can all be avoided with its aid [16].
- Cakes, custard, and porridge are just a few of the delicious and healthy foods that can be made with finger millet.
- It is nutrient-rich and aids in fighting malnutrition and degenerative diseases and raising haemoglobin levels.
- The grains of finger millets are fully recognized for their extreme usage as weaning feeds and have good malting qualities.
- It has strong antioxidant properties.

4.2.4 Proso Millet:

Proso millet (*Panicum miliaceum* L.) has the most excellent protein content (12.5%). It contains a lot of carbohydrates and fatty acids. It is a less expensive source of manganese than other traditional sources such as spices and nuts. The specific features of proso millet contribute to its health benefits. It is a rapid or emergency irrigated crop with minimal moisture needs. It is a low-demanding crop without any recognized illnesses. Proso millet grows well in a variety of soil types and climates.

Benefits:

- Proso millet contains a high concentration of niacin (Vitamin B3), which aids in the prevention of pellagra. Pellagra is a skin disease.
- It also contains protein, calcium for bone strength, and fluoride for dental health.
- It is high in calcium, which is necessary for bone formation and maintenance.
- It lowers cholesterol levels while also lowering the risk of heart disease.

4.2.5 Kodo Millet:

The coarsest cereal in the world is kodo millet (*Paspalum scorbiculatum* L.). Almost 3,000 years ago, in India, kodo millet was domesticated. It can be found in humid tropics and subtropical regions. Kodo millet contains a high concentration of B vitamins, particularly niacin, pyridoxine, and folic acid, as well as minerals such as calcium, iron, potassium, magnesium, and zinc. It is high in protein (11%), low in fat (4.2%), and high in fibre (14.3%). It is a minor grain crop that has exceptionally high levels of fiber, antioxidants, and phytochemicals [19].

It is thought to have the best drought resistance of such minor millet and also to yield well with a growing time of 80-135 days. It can survive in both deep as well as shallow soil.

Benefits:

- It is a traditional cuisine that resembles rice and is easily digestible.
- It also aids in preventing women's menstruation and joint and knee pain.
- It includes a lot of lecithin and is great for strengthening nervous system.

4.2.6 Foxtail Millet:

German and Italian millet are other names of foxtail millet (*Setaria italica* L.). Under low precipitation, it is growing in both the tropics and the temperate zones. It contains minerals like copper, iron and a lot of carbohydrates. It has twice the protein content as compared to rice. It has a quick ripening process and high photosynthetic efficiency, making it ideal for use as a catch crop. It can provide a high yield with a single pre-sowing rain [20]. According to [21], this crop uses less water than maize and sorghum.

Benefits:

- It is full of nutrients, has a sweet, nutty taste, and is one of the most easily digestible and non-allergenic cereals.
- Because of its magnesium concentration, foxtail millet aids in the prevention of diabetes by lowering blood glucose levels.

4.2.7 Little Millet:

Little millet (*Panicum sumatrense*) is a species of millet in the *Poaceae* family. It is referred to as a little but not less than its nutritional worth because it contains vitamins, minerals, and vital fatty acids for the body. Because of its high fiber content, little millet is an excellent substitute for rice in pongal or kheer. It grows quickly and is drought and water-logging resistant [22]. The grains are comparable to rice grains. Because of its high fiber content makes it a healthier alternative to rice. B vitamins and minerals such as calcium, iron, zinc, and potassium are abundant.

- It has high iron content.
- It aids in the prevention of obesity.
- It has a high level of antioxidant activity.
- It contains approximately 38% dietary fiber.

4.2.8 Barnyard Millet (Sanwa):

Barnyard millet (*Echinochloa frumentacea* L.) is a kind of millet that is commonly produced in India, China, Japan, Pakistan, Africa, and Nepal. It is the most abundant source of crude fiber and iron. Its grains contain various beneficial ingredients, such as gamma amino butyric acid (GABA) and beta-glucan, which are utilized as antioxidants and lower blood lipid levels. It is a drought-tolerant crop that can be produced in marginal soils, matures quickly, and has excellent nutritional value [23].

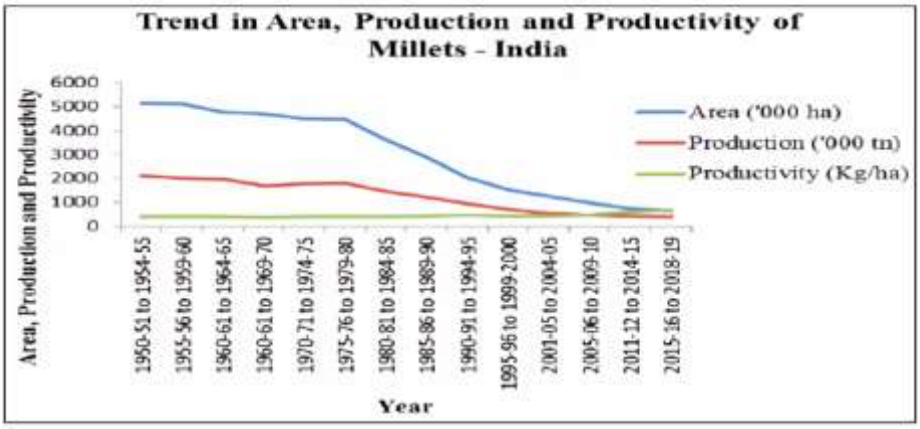


Figure 4.2: Area, Production and Productivity of Millets in India

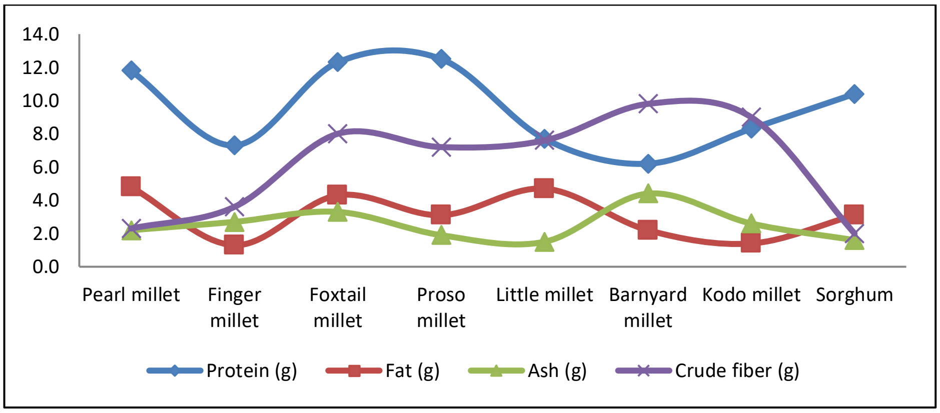


Figure 4.3: Comparison table of nutrient content in different millets per 100 grams of consumption

4.3 Traits Contributing to Climate-Resilience in Millet:

- **Tolerating Climatic Vagaries:** Climate change is generating a rise in the global mean temperature that is lowering agricultural productivity. Furthermore, it has a direct impact on biophysical properties such as animal and plant growth, as well as numerous aspects of food processing and distribution. Regarding present climate change, abiotic stressors offer a considerable risk for plant growth and development, resulting in a yield drop of more than 50% for a popular cereal crop [24].
- **Marginal Cultivation:** Millets are typically grown on marginal lands because of their natural ability to live in such environments and their resistance to abiotic stresses like drought, salinity, and heat. These fields also experience unpredictable and erratic rainfall patterns.
- **Food Security:** Millets offer food, nourishment, fodder, and livelihood security. They also have enormous promise in the fight against poverty and climate change.
- **Low Carbon Footprint:** Millets have a lower carbon footprint over wheat and rice crop, which have carbon dioxide equivalents of 3.9t and 3.4t per hectare, respectively. This contributes to mitigating the effects of climate change.
- **Ephemeral in Nature:** Millets short or limited life-cycle helps them avoid stress because it takes them 6-10 weeks to finish their life-cycle, but rice [25] and wheat [26] take up to 20-24 weeks.
- **Physiological Characteristics:** Because of RUBISCO's strong affinity for CO_2, the C4 mechanism increases CO_2 concentration surrounding the bundle sheath, suppressing photorespiration (about 80%) depending on temperature.
- **C4 Crop:** Millets are a C4 crop that have enhanced photosynthetic rates in warm climates and rapid water and nitrogen use efficiencies that are 1.5 to 4 times higher than those of C3 plants [27].
- **Additional Benefit:** Millets receive additional benefits from C4 photosynthesis in addition to WUE and NUE, such as greater ecological adaptation to hotter temperatures, more variable biomass allocation patterns, and lower hydraulic conductivity per unit of leaf area.

These characteristics of millets make these next-generation cereals with the potential for study into the qualities of climate-resilient plants and for using the knowledge gained to improve major grains.

4.3.1 Resilience of Millets to Various Climate Induced Stresses:

A. Resilience of Millets to Drought Stress Under Changing Climate:

Water shortage is an issue in the majority of semiarid and arid territories of developing nations, which has an impact on the kind and productivity of crops cultivated there. Research including *Panicum miliaceum*, *Setaria glauca*, *Panicum sumatrense*, and *Setaria italic* found substantial productivity loss when exposed to drought stress before flowering [28]. Two landraces of finger millet that had been subjected to drought showed 100% yield loss four weeks after sowing [29]. Due to terminal drought, which is occurred throughout blooming until maturity, a yield loss of almost 60% was noted. For pearl millet, the drought-related yield loss was around 51% [30].

In areas prone to drought, plants use a variety of abiotic stress tolerance mechanisms. A study of four fundamental millet adaptation mechanisms in places suffering from drought was published recently. These defence strategies include (i) **drought avoidance**, that is plant's capacity to maintain water balance amid stress preventing tissues water deficiency, (ii) **drought tolerance**, referring to a plant's capacity to yield biomass despite having less water available, (iii) **drought escape**, is a circumstance in which plants reach maturity prior to experiencing drought stress and (iv) **drought recovery**, which describes that the plant produces a less amount of yield while recovering from the impacts of intermediate drought once the water is available.

Millets' drought adaptations include changes in osmotic adjustment, stomatal opening, and cell membrane stability. One of these is an osmotic adjustment, which allows foliage to regulate leaf turgor pressure sometimes during severe drought by recapturing or absorbing moisture from even dry soils. The metabolic foundation of osmotic adjustment involves both inorganic and organic components, with proline build-up in moisture stress associated with improved drought tolerance.

Stomatal conductance is a measurement of how quickly CO_2 diffuses into the leaf or how quickly water vapour diffuses from the spaces behind the stomata. Under severe drought conditions, the plant closes the stomata to reduce transpiration, which also reduces stomatal conductance. Another way of coping with drought stress is increased root elongation. For instance, when subjected to drought, legumes like *Vigna unguiculata*, *Glycine max*, and *Arachis hypogaea* expand the length of their roots, allowing them to absorb water at a deeper level of the soil.

In reaction to drought stress, this crop will enable its foliage to roll and fold to reduce transpiration and the area covered by the leaves. Drought-induced at 21 days after germination caused leaf folding in a pearl millet genotype (IP 8210) recognized because of its drought resilience. However, it recovered by re-watering 12 days later [31].

Early flowering is an essential drought-escape strategy in crops, and rapid blooming following a short vegetative phase in wheat is a reaction to imminent terminal stress conditions [32, 33]. The presence of a waxy cuticle and asynchronous tiller development (found in pearl millet) are some other drought-resistant mechanisms.

B. Resilience of Millets to Heat Stress Under Changing Climate:

Even though the majority of millet species are heat-tolerant, heat causes several physiological and biochemical changes. The most vulnerable biological functions to heat stress are photosynthesis and respiration, which have a significant impact on crop yield. Up to a certain threshold (32 °C for cotton, 30 °C for soybeans, and 29 °C for maize), crop output rises with rising temperatures; but, beyond that threshold, even a small rise in temperature does indeed have a major negative influence on plant development and, ultimately, yield.

High-temperature stress hinders photosystem II activity, decreases electron transport, and increases ROS build-up. Moreover, it also desiccates the reproductive parts, which may cause plant infertility, seed abortion, a decrease in the number of seeds, and a shorter grain filling duration. Incompletely reduced oxygen species, such as the extensively researched singlet oxygen ($^1O_2$), superoxide anions (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH), are collectively referred to as "ROS". ROS have a quick half-life and significant chemical activity.

They have the capacity to cause protein denaturation and lipid peroxidation, ultimately resulting in cell death. Also, they play a major role in the induction of programmed cell death by acting as signaling molecules that change the characteristics of proteins by creating covalent bonds.

Resistant plants generate antioxidants such as copper-zinc superoxide dismutase’s (SOD), ascorbate peroxidases (APX), catalases (CAT), thylakoidal ascorbate peroxidase (tAPX), and glutathione peroxidase (GPX), to detoxify oxidative stress either by scavenging ROS superoxide or by activating a variety of detoxifying and protective proteins, preventing oxidative damage in plants under stress. Transcription factors, signaling molecules, heat-shock proteins, ion transporters, and the accumulation of osmoprotectants are some of the other mechanisms of tolerance [34].

C. Resilience of Millets to Water Logging Stress Under Changing Climate:

In high-precipitation regions, water logging stress is the primary cause of poor production [35]. Under conditions of water logging, water seeps into the soil pores, causing toxic chemicals to build up and preventing gas diffusion.

This ultimately has an impact on photosynthesis, stomatal conductance, and roots. Water logging primarily affects crops such as wheat and maize due to the high water-holding capacity of black clay soil [36]. Water logging treatment that has been applied from 2 weeks after planting to harvesting time resulted in corn production losses of approximately 18% for wild millet and 16% for proso millet [37].

Plants have a variety of defences against the stress of water logging, which is brought on by hypoxia (low oxygen levels) or anoxia (total absence of oxygen). It has been shown that finger millet (*Eleusine coracana*) also engages in anaerobic respiration as a response to low oxygen levels [38].

Although anaerobic metabolism is less effective than aerobic metabolism, ATP generated during fermentation temporarily sustains the cell. Water logging tolerant plants such as finger millet and rice demonstrate alterations in carbohydrate metabolism because this method demands higher sugar than aerobic metabolism.

Tolerant plants develop spongy tissue with air holes, called aerenchyma, during water logging stress, allowing gases to flow from stems to roots. These spaces can form either with or without cell death (schizogenous or lysigenous).

According to studies, aerenchyma (lysigenous) develops in the stressed sunflower (*Helianthus annuus*) within two days of the start of the stress. The growth of adventitious roots is another tactic used by plants resistant to water logging. In sorghum (*Sorghum bicolor*) and finger millet, adventitious roots have been seen to develop [39]. Certain crops, such as mung beans (*Vigna radiata*), have been observed to avoid logging due to their quick growth. While water logging tolerant crops, such as tef, react to water logging stress via raising the efficiency of nitrogen reductase inside the shoots, water logging tolerant plants also have enough solubilised sugar.

D. Resilience of Millets to Lodging Stress Under Changing Climate:

A typical issue with millet crops is lodging, which is the persistent bending of the stem from an upright posture. Many investigations have shown that lodging stress reduces tef and foxtail millet yield of crops. Compared to other cereal crops, millets are highly resilient to abiotic stresses, such as lodging.

However, new practices must be introduced, or existing ones must be modified in order for millets to benefit from application of suitable fertilizer to maximize crop yields. Simply limiting plant height through genetic alteration or exogenous chemical methods is a common approach for managing lodging stress [40]. Changes in the date of seeding, tilling techniques, and increasing intra-row space or lowering the number of plants in a row are further crop management techniques that might lessen lodging.

Also, it has been demonstrated that adding silicon amendments increases the output [41, 42]. According to reports, rice with a silica treatment had stronger stems due to increased silica deposition in the shoot, thicker or stronger culm walls, and improved stem stability [43, 44]. Several strategies have been used in millet crops to lessen or eliminate lodging stress and increase production. For instance, it has been demonstrated that applying Paclobutrazol to tef and finger millet reduces the height of the plants and lodging stress [45]. According to [46], gamma radiation or ethyl methane sulfonate (EMS) might induce nonlodging mutants in the kodo millet CO3 variety. Also, they created mutants (known as second mutants or M2) that had increased lodging tolerance due to culm thickness and photosynthetic efficiency (PhE).

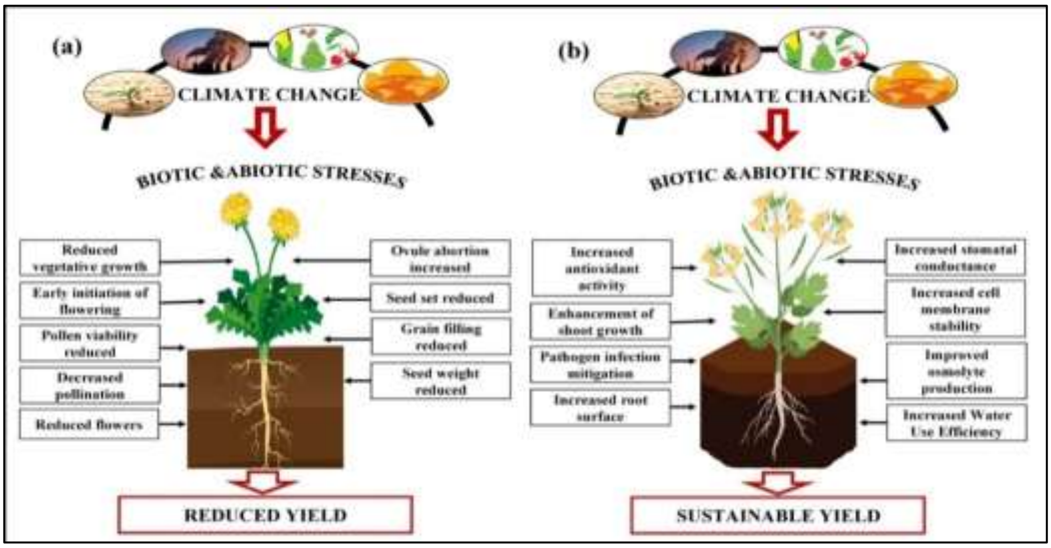


Figure 4.4: (a) Negative impact of various stresses due to climate change on the physiological processes of plant leading to reduce yield (b) Positive impact of millets that mitigate the negative impact of various stresses of global warming and climate change on plants physiological processes contributing to sustainable yield

4.4 Ways to Improve the Climate Resilience in Millet Crops:

A. Application of Plant Growth Promoting Rhizobacteria for Inducing Stress Tolerance in Millets:

These are the bacteria living in the rhizosphere of the soil, which can also be used to alleviate the biotic and abiotic stresses in crops due to climate change by enhancing the plant's performance. These organisms improve plant growth through the biosynthesis of plant growth regulators such as indole acetic acids (IAA) and gibberellic acid (GA3). The IAA synthesizing rhizobacteria results in enhanced root growth through the formation of lateral roots and root hairs. The ability of bacteria to produce hormones and to stimulate the production of endogenous hormones both considerably improve resistance. Moreover, PGPRs were reported to activate plant defence mechanisms and manufacture other growth regulators, including salicylic acid and jasmonic acid. It was also shown to assist plants with nutrient uptake from the soil under stressful circumstances. The presence of PGPRs improves the integrity of plant cell membranes by activating the antioxidant defence mechanism, increasing plants' drought-resistant ability.

B. Application of CRISPR/Cas9 to Improve Stress Tolerance in Millets:

The use of Genome-editing techniques has grown in recent times. One such technique is the utilization of the CRISPR/Cas9 genome-editing technique, which involves the identification of a candidate gene from a selected crop. A guide RNA is thereafter created with this gene of interest and inserted in a binary vector.

A binary vector also contains a Cas9 protein, an enzyme from bacteria. The next step is Agrobacterium-mediated transformation for trait enhancement using these gRNAs and Cas9 expression cassettes. The first millet crop sequenced was the foxtail millet plant [47].

C. Application of Seed Priming to Improve Stress Tolerance in Millets:

Seed priming is the process of treating seeds with natural and synthetic substances prior to germination in order to induce a certain physiological condition in plants. Without significantly reducing crop growth, it shields plants from infections and abiotic stressors. Seed priming has been reported to increase plant resilience to biotic stresses such as weeds, insects, pests, and diseases [48]. When compared to unprimed seeds, *Agropyron elongatum* seeds primed with gibberellin (GA) and abscisic acid (ABA) showed enhanced CAT and SOD activity which are known to impart drought resistance [49].

4.5 Biofortification of Millets Under Changing Climate:

Increasing the micronutrient content of staple crops by biological methods like plant breeding and genetic engineering is known as "biofortification." The biofortification of millets is an essential aspect of the changing climate. Climate change and global warming have caused serious ill effects on humans. The loss of nutrients from the soil and the accumulation of a harmful substance in the crop grains are visible through various deadly diseases in humans and animals. Thus, biofortification of millets for improvement of nutrient content in millets can increase the nutrient content of millet crops, which could alleviate malnutrition in people. Some of the biofortified varieties recently developed are:

Pearl millet- ICMH 1202, HHB 299, ICMH 1301, RHB 233, RHB 234

Sorghum ICSR- 14001 (Prabhani Shakti)

Finger millet- CFMV 1 (Indravathi), CFMV 2, Vegavathi

Little millet- CLMV-1, Sreeneelima

4.6 Conclusion:

The evergreen millet crops are the most promising crops under global warming and climate change. This was witnessed worldwide by the recognition of the year 2023 as the international year of millets. Their various morphological and physiological features, along with nutritional characteristics, are the characteristics that confer their climate resilience. These climate-resilient features enable them to flourish and overcome multiple biotic and abiotic stresses. However, despite having these enormous features, the ever-increasing climatic vagaries remain a threat to millet production. Thus, by applying newly emerging technologies such as PGPRs, CRISPR, and biofortified varieties, the climate resilience of millets could be further improved.

4.7 References:

1. Food and Agriculture Organization of the United Nations. Technical Note: FAO Methodology to Estimate the Prevalence of Undernourishment; FAO: Rome, Italy, 2012.
2. Wheeler T, Von Braun J. Climate change impacts on global food security. Science 2013; 341: 508–513.
3. Godfray HCJ, Beddington JR, Crute IR, Haddad L, Lawrence D, Muir JF, Pretty J, Robinson S, Thomas SM, Toulmin C. Food security: The challenge of feeding 9 billion people. Science. 2010; 327: 812–818.
4. Leal Filho W, Azeiteiro UM, Balogun AL, Setti AFF, Mucova SA, Ayal D, Oguge NO. The influence of ecosystems services depletion to climate change adaptation efforts in Africa. Sci Total Environ. 2021; 146414.
5. Feliciano D, Recha J, Ambaw G, MacSween K, Solomon D, Wollenberg E. Assessment of agricultural emissions, climate change mitigation and adaptation practices in Ethiopia. Clim Policy. 2022; 1–18.
6. PrasannaJakku, Mirza IAB, Pandagale AD. Millets as Climate Resilient Crops. Agriculture & food: e-newsletter. 2020; 2(9): 595-596.
7. Kang Y, Khan S, Ma X. Climate change impacts on crop yield, crop water productivity and food security—A review. Prog. Nat. Sci. 2009; 19: 1665–1674.
8. SainiJhanvi, BhattRajan. Global Warming - Causes, Impacts and Mitigation Strategies in Agriculture. Current Journal of Applied Science and Technology. 2020; 39(7): 93-107.
9. Krishnan R, Meera, MS. Pearl millet minerals: effect of processing on bioaccessibility. J. Food Sci. Technol. 2018; 55, 3362–3372.
10. Verma B, Bhan M, Jha AK, Singh V, Patel R, Sahu MP and Kumar V. Weed management in direct-seeded rice through herbicidal mixtures under diverse agroecosystems. AMA, Agricultural Mechanization in Asia, Africa and Latin America. 2022; 53(4): 7299-7306.
11. NiralaTanisha, Jha AK, VermaBadal, YadavPushpendra Singh, AnjnaMahendra, BhalseLakhan. Bio efficacy of Pinoxaden on Weed Flora and Yield of Wheat (*Triticumaestivum* L.). Biological Forum – An International Journal. 2022;14(4):558-561.
12. Nambiar VS, Dhaduk JJ, Sareen N, Shahu T, Desai R. Potential functional implications of pearl millet (*Pennisetumglaucum*) in health and disease. J. Appl. Pharm. Sci. 2011; 1: 62–67.
13. Bray EA. Plant responses to water deficit. Trends Plant Sci. 1997; 2:48–54.
14. Chaturvedi P, Govindaraj M, Govindan V, Weckwerth W. Sorghum and pearl millet as climate resilient crops for food and nutrition security. Frontiers in Plant Science. 2022; 13: 503.
15. Xiong Y, Zhang P, Warner RD, Fang Z. Sorghum grain: From genotype, nutrition, and phenolic profile to its health benefits and food applications. Comprehensive Reviews in Food Science and Food Safety. 2019; 18(6): 2025-2046.
16. Gull A, Jan R, Nayik GA, Prasad K, Kumar P. Significance of finger millet in nutrition, health and value-added products: a review. Magnesium (mg). 2014; 130(32): 120.
17. Malik S. Pearl millet-nutritional value and medicinal uses. International Journal of Advance Research and Innovative Ideas in Education. 2015; 1(3): 414-418.

18. Satyavathi CT, Ambawat S, Khandelwal V, Srivastava RK. Pearl millet: a climate-resilient nutricereal for mitigating hidden hunger and provide nutritional security. Frontiers in Plant Science. 2021; 12: 659938.
19. Deshpande, SS, Mohapatra D, Tripathi MK, Sadvatha RH. Kodo millet-nutritional value and utilization in Indian foods. Journal of grain processing and storage. 2015; 2(2): 16-23.
20. Liu T, Yang X, Batchelor WD, Liu Z, Zhang Z, Wan N, Zhao J. A case study of climate-smart management in foxtail millet (*Setariaitalica*) production under future climate change in Lishu county of Jilin, China. Agricultural and Forest Meteorology. 2020; 292: 108131.
21. Zhang S, Tang C, Zhao Q, Li J, Yang L, QieL, Liu X. Development of highly polymorphic simple sequence repeat markers using genome-wide microsatellite variant analysis in Foxtail millet [*Setariaitalica* (L.) P. Beauv.]. BMC genomics. 2014; 15(1): 78.
22. Wilson ML, VanBuren R. Leveraging millets for developing climate resilient agriculture. Current Opinion in Biotechnology. 2022; 75: 102683.
23. Maithani D, Sharma A, Gangola S, Bhatt P, Bhandari G, Dasila H. Barnyard millet (*Echinochloa* spp.): a climate resilient multipurpose crop. Vegetos. 2022; 1-15.
24. Pramitha L, Choudhary P, Das P, Sharma S, Karthi V, Vemuri H, Muthamilarasan, M. Integrating Genomics and Phenomics Tools to Dissect Climate Resilience Traits in Small Millets. In Omics of Climate Resilient Small Millets. Singapore: Springer Nature Singapore. 2022; 275-298.
25. Verma B, Bhan M, Jha AK, Khatoon S, Raghuwanshi M, Bhayal L, Sahu MP, Patel Rajendra, Singh Vikash. Weeds of direct- seeded rice influenced by herbicide mixture. Pharma Innovation. 2022;11(2):1080-1082.
26. Sahu V, Kewat ML, Verma B, Singh R, et al. Effect of carfentrazone-ethyl on weed flora, growth and productivity in wheat. Pharma Innovation. 2023;12(3):3621-3624.
27. Satyavathi CT, Solanki RK, Kakani RK, Bharadwaj C, Singhal T, Padaria J, Iqubal MA. Genomics assisted breeding for abiotic stress tolerance in millets. Genomics Assisted Breeding of Crops for Abiotic Stress Tolerance, 2019; 2: 241-255.
28. Tadele, Z. Drought Adaptation in Millets; InTech: London, UK, 2016.
29. Maqsood M, Ali SA, Effects of drought on growth, development, radiation use efficiency and yield of finger millet (*Eleucinecoracana*). Pak. J. Bot. 2007; 39: 123.
30. Ashok S, Senthil A, Sritharan N, Punitha S, Divya K, Ravikesavan R. Yield Potential of Small Millets under Drought Condition. Madras Agric. J. 2018; 105.
31. Kusaka M, Lalusin AG, Fujimura T. The maintenance of growth and turgor in pearl millet (*Pennisetumglaucum* [L.] leeke) cultivars with different root structures and osmo-regulation under drought stress. Plant Sci. 2005; 168, 1–14.
32. Shavrukov Y, Kurishbayev A, Jatayev S, Shvidchenko V, Zotova L, Koekemoer F. et al. Early flowering as a drought escape mechanism in plants: How can it aid wheat production? Front. Plant Sci. 2017; 8: 1950.
33. SisodiyaJitendra, Sharma PB, VermaBadal, PorwalMuskan, AnjnaMahendra, Yadav Rahul. Influence of irrigation scheduling on productivity of wheat + mustard intercropping system. Biological Forum – An International Journal. 2022;14(4):244-247.

34. Hatfield JL, Prueger JH. Temperature extremes: Effect on plant growth and development. Weather Clim. Extrem. 2015; 10: 4–10.
35. Ashraf M, HafeezM, Thermotolerance of pearl millet and maize at early growth stages: Growth and nutrient relations. Biol. Plant. 2004; 48: 81–86.
36. Patel Raghav, Jha AK, VermaBadal, Kumbhare Rahul, Singh Richa. Bio- efficacy of pinoxaden as post-emergence herbicide against weeds in wheat crop. Pollution research. 2023;42(1):115-117.
37. Linkemer G, Board JE, Musgrave ME. Waterlogging effects on growth and yield components in late-planted soybean. Crop Sci. 1998; 38: 1576–1584.
38. Hussain MA, Uddin SN. Mechanisms of waterlogging tolerance in wheat: Morphological and metabolic adaptations under hypoxia or anoxia. Aust. J. Crop Sci. 2011; 5: 1094.
39. Kulkarn S, Chavan P. Study of effect of waterlogging on root anatomy of ragi and rice. Am. J. Plant Physiol. 2014: 9: 46–51.
40. Yadav, P. K., Sikarwar, R. S., Verma, B., Tiwari, S., &Shrivastava, D. K. (2023). Genetic Divergence for Grain Yield and Its Components in Bread Wheat (Triticumaestivum L.): Experimental Investigation. International Journal of Environment and Climate Change, 13(5), 340–348. https://doi.org/10.9734/ijecc/2023/v13i51776.
41. Würschum T, Langer SM, Longin CFH, Tucker MR, Leiser WL. A modern Green Revolution gene for reduced height in wheat. Plant J. 2017; 92: 892–903.
42. Pardo J, Wai CM, Chay H, Madden CF, Hilhorst HW, Farrant JM, VanBurenR. Intertwined signatures of desiccation and drought tolerance in grasses. Proc. Natl. Acad. Sci. USA. 2020; 117, 10079–10088.
43. Ligaba-Osena A, Guo W, Choi SC, Limmer MA, Seyfferth AL, Hankoua BB. Silicon enhances biomass and grain yield in an ancient crop tef [*Eragrostistef* (Zucc.) Trotter]. Front. Plant Sci. 2020; 11: 608503.
44. Shukla S, Agrawal SB, Verma B, Anjna M, Ansari T. Evaluation of different doses and modes of application of ferrous ammonium sulfate for maximizing rice production. International Journal of Plant & Soil Science. 2022;34(23):1012-1018.
45. BizuayehuD, Getachew A. Paclobutrazol as a plant growth regulator. Chem. Biol. Technol. Agric. 2021; 8.
46. Jency JP, Rajasekaran R, Singh RK, Muthurajan R, PrabhakaranJ, Mehanathan M, Prasad M, Ganesan J. Induced mutagenesis enhances lodging resistance and photosynthetic efficiency of kodomillet (*Paspalumscrobiculatum*). Agronomy. 2020;10: 227.
47. Peng R, Zhang B. Foxtail Millet: A New Model for C4 Plants. Trends Plant Sci. 2020; 26: 199–201.
48. Jisha KC, Vijayakumari K, Puthur JT. Seed priming for abiotic stress tolerance: an overview. ActaPhysiologiaePlantarum. 2013; 35: 1381-1396.
49. Eisvand HR, Tavakkol-Afshari R, Sharifzadeh F, MaddahArefi H, HesamzadehHejazi SM. Effects of hormonal priming and drought stress on activity and isozyme profiles of antioxidant enzymes in deteriorated seed of tall wheatgrass (*Agropyronelongatum* Host). Seed Sci Technol. 2010; 38:280–297.

ISBN: 978-81-19149-19-3

5. Millets in Food and Nutrition Security

Ms. Chinmayee Pattnayak, Ms. Rashmi Misra

Assistant Professor,
Dept. Of Food, Nutrition and Dietetics (FND),
Faculty of Agriculture (FOAG), Sri Sri University,
Cuttack, Odisha.

Abstract:

Millets have a big part in the diets of people across the nation today. They have gained popularity due to qualities including drought resilience, strong yielding in dry places, and good nutritional properties. Pesticides and fumigants are not necessary for millets. More than one-third of people on Earth have been found to consume millets. Millet have been grown traditionally for many years and are consumed all over the world; the majority of the millet crop grown commercially worldwide is produced in China, India, Greece, Egypt, and Africa. India is currently the fifth-largest exporter of millets worldwide, with a CAGR of 4.49% during an eight-year period, from 2021 to 2029. The market for millet is projected to grow from $ 9 billion in 2019 to $ 14.14 billion in 2028. Except for teff and fonio, India is home to many other leading millet crops.

The current markets for drought-tolerant millet are in the urban, nutritional, and functional sectors (APEDA, 2020). The majority of millets grown for human consumption in rural areas, such as finger millet, sorghum, etc., are utilized as animal feed. Amazing nutritional and health-promoting qualities may be found in millet. Millets are also well known for offering numerous security benefits, including food, nutrition, livelihood, animal feed, and other things, making them an agricultural security crop. Millets contain a large number of micronutrients, such as vitamins and beta carotene, which are employed in the nutraceutical industry. Millet is rich with phytochemical, having therapeutic and health-promoting effects, specifically in terms of life style disorders like diabetes, obesity and cardiovascular diseases etc.

Keywords:

Millet, Millet Anatomy, Nutritional Security, Health Benefits, Millet Production, Millet based Foods.

5.1 Introduction:

Throughout the beginning of time, Asia, Africa, and Europe have all ingested millets as a staple food grain. These might have been one among the earliest crops grown during the "Hoe Age" and "Plow Age."Before, "Food security" was the primary concern in poor nations, and the Green Revolution's primary motivation was to end world hunger (Behera, 2017). The issue of hidden hunger then gained attention, and "nutrition security" was addressed.

The objective of the UN and other organisations is to define the targets for moving towards "sustainable diets," also known as "diets with low environmental impacts that contribute to food and nutrition security."

By meeting the requirements for becoming a smart food, many millet products are now referred to as Nutricereals in an effort to create "smart food" solutions for people, the environment, and farmers. They help the farmer and the environment by bringing diversity to the farm, are better crops for a variety of nutrient-rich grains, and can be grown on marginal soils with a minimal number of pesticides and fertilizer. All of these millets may be harvested more quickly and are easily adaptable to the challenging environmental circumstances. In agriculture, millets are also known as famine crops. These crops make a significant contribution to the nation's food security.

Because they contain the majority of the nutrients needed for the body to operate normally, millet crops are also referred to as "nutri-cereals" in popular culture. These underutilized crops are significant because they help the impoverished in different regions of the world have access to food, nourishment, and a means of subsistence. They also help to diversify our food supply.

5.2 Types of Millets:

Millets are traditional grains usually grown and being consumed in the Indian subcontinent since more than 5000 years. These grass family cereals with small grains are suitable for warm climates. These are extremely drought tolerant crops and need less rainfall to grow. Sorghum, pearl millet, and finger millet are examples of major millets. Lesser millets include foxtail millet, kodo millet, small millet, proso millet, and barnyard millet.

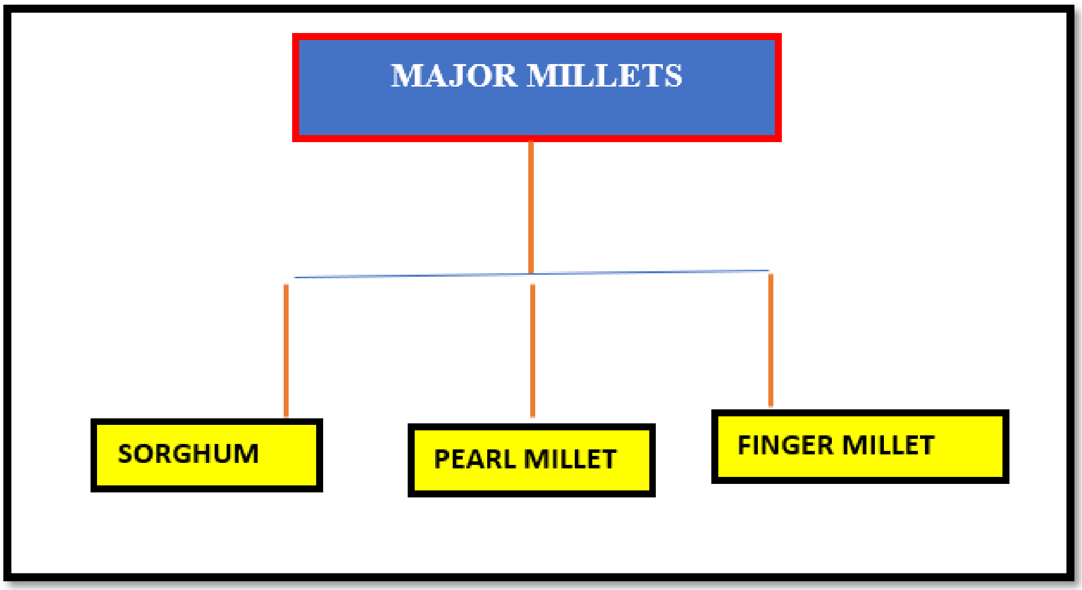


Figure 5.1: Major Millets

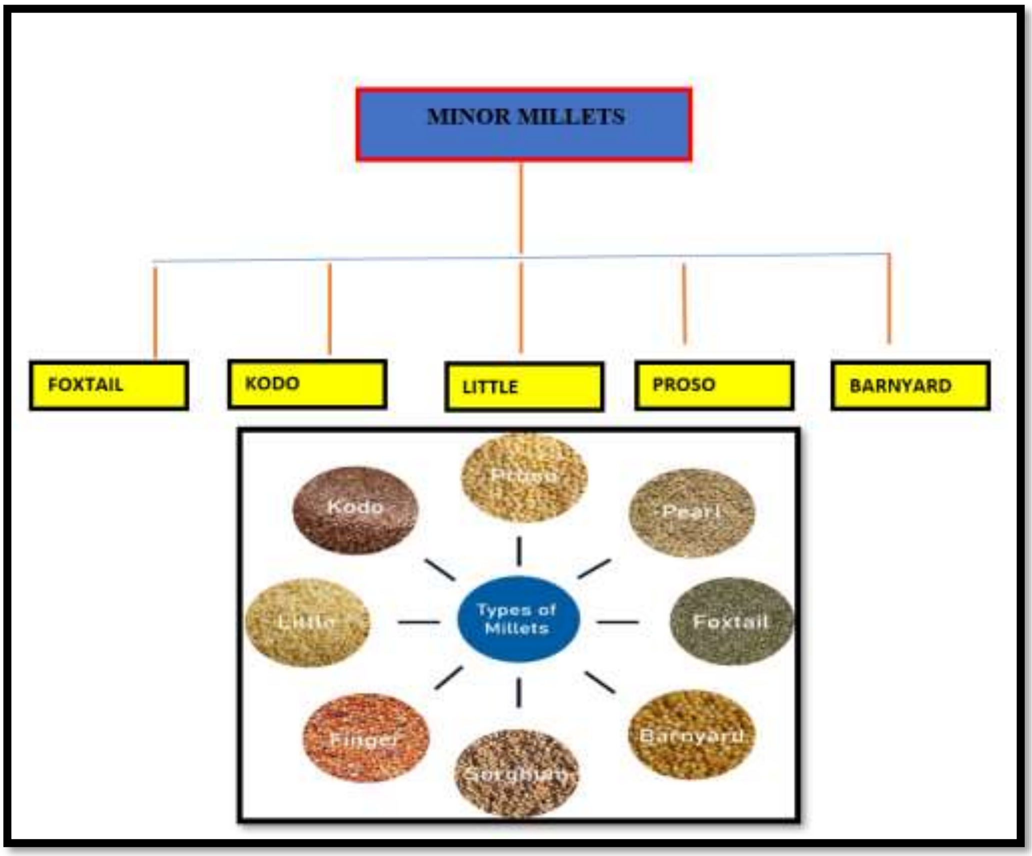


Figure 5.2: Minor Millets

5.3 Anatomy: A Whole Millet Grain Kernel:

a. **Bran:** Bran of a millet consists of multi-layered exterior skin that provides shielding to the other two kernel segments from various factors like disease, water, pests, and sunlight. There is presence of important antioxidants, as well as other micronutrients like vitamins and minerals such as iron, zinc, copper, and magnesium, as well as fibre and phytonutrients, are there in the bran portion.
b. **Germ:** Germ is the embryo that develops and fortify a new plant after being fertilized by pollen. B vitamins, vitamin E, antioxidants, phytonutrients, and unsaturated fats are abundantly present in the germ.
c. **Endosperm**: Endosperm serves as a source of energy and serves as nourishment for germs. Starchy carbs, proteins, and trace amounts of vitamins and minerals can also be found in the endosperm.

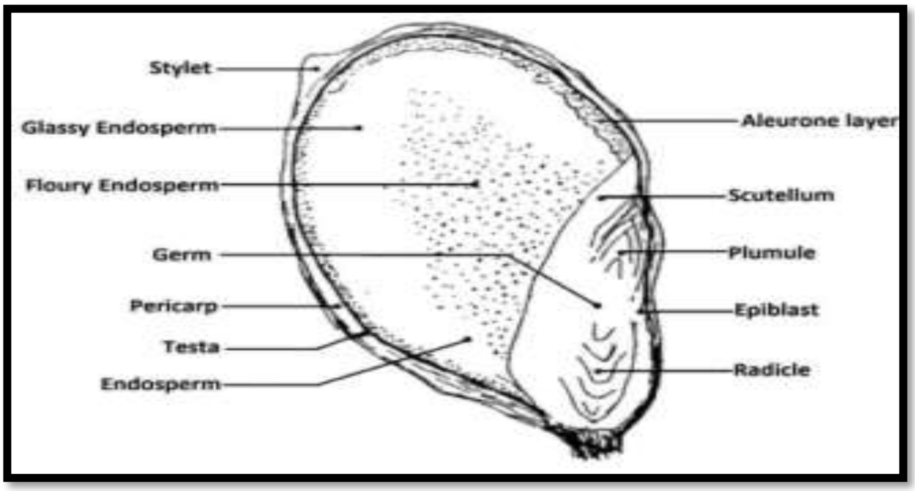


Figure 5.3: General Structure of Millet Grain

5.4 History:

Ethiopia is the place where millet originated and evidence suggests that people have been eating it there since the dawn of time. One of the primary crops in Africa is millet, which serves as the foundation for the Injera, a type of traditional flatbread. Since ancient times, millet has been consumed frequently in both Asia and India. In the Middle Ages, millet was becoming a common grain in Europe, particularly in Eastern European nations. The Setaria variety of millet was brought into America sometime in the 19th century. While millet has primarily been used in Western Europe and North America as birdfeed and livestock fodder, it is now becoming more and more popular as a healthy grain. Millet is replaced due to its unique virtues as well as the fact that it is coming under grain those are gluten-free an alternative to wheat or other gluten rich grains. The majority of the world's commercial millet production is found in India, China and Nigeria.

Regions	AREA (lakh ha)	Production (lakh ton)
Africa	489 (68%)	423 (49%)
Americas	53 (7%)	193 (23%)
Asia	162 (23%)	215 (25%)
Europe	8 (1%)	20 (~2%)
Australia & New Zealand	6 (~1%)	12 (~1%)
India	138 (20%)	173 (20%)
WORLD	718	863

- India produces >170 lakh ton (80% of Asia's & 20% of global production)
- Global average yield: 1229 kg/ha, India (1239 kg/ha)

Figure 5.4: Global Scenario of Millets

Source: FAO Statistics 2021

There are top 5 States in India for producing Millet Crops-

A. Rajasthan Bajra/Sorghum
B. Karnataka Jowar/Ragi
C. Maharashtra Ragi/Jowar
D. Uttar Pradesh Bajra
E. Haryana Bajra

5.5 Nutrients in Millet:

Millets include 2-7% crude fibre, vitamins, and minerals, as well as 65% carbs, 9% proteins, and 3% fat. They are an excellent source of iron, manganese, phosphorus, magnesium, vitamin B, and antioxidants. With the exception of lysine and threonine, millets are a strong supply of essential amino acids; nonetheless, they are also high in the sulfur-containing amino acids methionine and cysteine (Singh KP et al., 2012).

Millets are a fair supply of phosphatidylethanolamine, phosphatidyl serine, and phosphatidyl choline, as well as important fatty acids including linoleic, oleic, and palmitic acids that can be found both in their free form and bound form. Arachidic acid, behenic acid, and erucic acid are among the other fatty acids that are present in minute levels.

Linoleic acid and tocopherols, two important fatty acids, may also be present in millet fats. Gluten-free millet is an alkaline-forming grain. Millets include phosphorus and vitamin B compounds like niacin, folacin, riboflavin, and thiamine that are essential for the creation of energy (Sarita, et al., 2016).

Millet is rich in important vitamins like thiamine, riboflavin, folic acid, and niacin. Similar to rice and wheat, millets are rich in certain minerals and fatty acids. The edible millet kernel contains 0.2-0.3% polyphenols and dietary fibre, among other phytochemicals.

A. Phytochemicals in millets:

Millets contain more than 50 phenolic compounds from various classes, including phenolic acids and their derivatives, dehydro-triferulates and dehydro diferulates, flavan-3-ol monomers and dimers, flavones, flavonols, and flavanonols. Whole kodo, finger, foxtail, proso, little, and pearl millets were also found to contain these compounds. Anthocyanins, condensed tannins, and finger millet are all present in sorghum and furthermore a strong source of phenolic compounds is the finger millet seed coat.

B. Importance of Millets in terms of Health:

Millets contribute in many nutritional, nutraceutical and healthwellness industries,

- Particularly because of its high fibre content, starch plays a critical function in preventing degenerative diseases and maintaining the health of our gastrointestinal tract.

- About 65% of the carbohydrates in the millet grain are in the form of non-starchy polysaccharides and dietary fibre, which help to i. avoid constipation.
- Decreasing cholesterol levels
- Triglyceride and C-reactive protein levels are managed, preventing cardiovascular disease.
- Reduced glycemic load as a result of the bloodstream's gradual absorption of glucose after digestion.
- Regular millet eaters who meet the aforementioned parameters have lower rates of diabetes, duodenal ulcers, and cardiovascular illnesses.
- Millets do really maintain the health of the microflora in our gut by acting as a prebiotic and feeding it.
- Millet contains a lot of tryptophan, which turns into the neurotransmitter serotonin.
- Vitamin B3 present in millet can help lower cholesterol.
- All millet varieties show high antioxidant property due to presence of phytochemicals.
- Millet is also gluten free and non-allergenic to celiac other antinutritional problems.

Antioxidant, antibacterial, protein glycation inhibition, and enzyme inhibitory capabilities are a few of the health-beneficial qualities that have been discovered in considerable amounts. Moreover, millet aids in wound recovery. As previously indicated, this characteristic lower cholesterol while also reducing blood sugar.

- A problem with cataractogenesis that develops slowly.
- Anti-carcinogenic and anti-ulcerative.
- Homemade remedies for diarrhea using probiotics

Children's hemoglobin levels are improving, and their insulin sensitivity is also improving.

Parameter	Protein (g)	Fat (g)	Minerals (g)	Total Dietary fiber (g)	Insoluble Dietary fiber (g)	Soluble Dietary fiber (g)	CHO (g)
Rice milled	7.94	0.52	0.6	2.81	1.99	0.82	78.2
Whole Wheat	10.6	1.5	1.4	11.2	9.6	1.6	64.0
Finger	7.2	1.9	2.0	11.2	9.5	1.7	66.8
*Proso	12.5	1.1	1.9	-	-	-	70.4
*Foxtail	12.3	4.3	3.3				60.9
*Little	10.4	3.9	1.3	7.7	5.5	2.3	65.6
*Kodo	8.9	2.6	1.7	6.4	4.3	2.1	66.2
*Barnyard	6.2	4.4	2.2		-	-	65.5
pearl	11.0	5.4	1.4	11.5	9.1	2.3	61.8
Sorghum	10.0	1.7	1.4	10.2	8.5	1.7	67.7

Figure 5.5: Macro Nutrient and Fiber composition of millets and cereals (100gm raw form)

Source: IFCT 2017, Nutritive value of Indian foods, 2009.

Parameter	Finger	Proso	Foxtail	Little	Kodo	Barnyard	Pearl	Sorghum	Rice raw milled	Wheat
Vitamins										
Total Carotenoids	154	-	32	120	272	-	293	212	16.9	287
Thiamine	0.37	0.20	0.59	0.26	0.29	(0.33)	0.33	0.35	0.05	0.45
Riboflavin	0.17	0.18	0.11	0.05	0.20	(0.10)	0.25	0.14	0.05	0.17
Niacin	1.34	2.3	3.2	1.29	1.49	4.2	2.3	2.1	1.69	5.5
Minerals and trace elements										
Calcium	364	14	31	16.06	15.27	20	42	27.6	7.49	41
Phosphorus	283	206	290	220	188	280	296	274	160	306
Iron	4.62	0.8	2.8	1.26	2.34	5.0	8.0	3.95	0.65	5.3
Magnesium	137	153	81	133	147	82	137	1.33	64	138
Sodium	11	8.2	4.6	8.1	4.6	–	10.9	5.42	–	17.1
Potassium	408	113	250	129	144	–	307	328	–	284
Copper	0.67	1.60	1.40	0.34	0.26	0.60	1.06	0.45	0.23	0.68
Zinc	2.3	1.4	2.4	3.7	0.7	3.0	3.1	1.96	1.3	2.7

Figure 5.6: Vitamins and Minerals Composition of Millets, 100gm

Source: IFCT 2017, Nutritive value of Indian foods, 2009.

Table 5.1: Glycemix Index of Some Millet Based Foods

Sr. No.	Millets	Glycemic Index
1.	Foxtail barnyard millet upma	17.6
2.	Foxtail millet ladoo	23.5
3.	Foxtail barnyard millet dhokla	35
4.	Heat treated and dehulled barnyad millet	41.7
5.	Sorghum flakes poha	45
6.	Sorghum pasta	46
7.	Foxtail millet biscuit	50.8
8.	Sorghum course semolina upma	53
9.	Sorghum biscuits	54
10.	Bajra roasted bread	55
11.	Sorghum fine semolina upma	56
12.	Multigrain sorghum roti	68
13.	Barnyad millet biscuit	68
14.	Jowar roasted bread	77
15.	Barnyard and kodo millet-based noodles	84
16.	Finger millet roasted bread	104

Source: IFCT 2017, Nutritive value of Indian foods, 2009.

5.6 Millets in Relation to Different Health Conditions:

A. Millets-Diabetes:

Millets have been seen to reduce levels of -glucosidase and pancreatic amylase, which in turn decreased postprandial hyperglycemia by slowing down the enzymatic degradation of complex carbs. Certain enzymes, such as aldose reductase, which stop the accumulation of sorbitol also lower the risk of cataract illnesses brought on by diabetes. Millets are therefore beneficial for regulating blood sugar levels and, thanks to their antioxidant content, for promoting cutaneous wound healing (Rajasekaran NS, *et al*., 2004).

After evaluating the Glycemic Index (GI) of foods based on sorghum in 2010 as part of the National Agricultural Innovation Project (NAIP), the National Institute of Nutrition (ICMR) and the Indian Institute of Millets Research, Hyderabad, concluded that these foods have a low GI and lower postprandial blood glucose levels. Due to the high fibre content of finger millet, diets also demonstrated reduced glycemic response.

They aid in the healing of cutaneous wounds as well. There is good evidence from studies indicating the finer millets' proteins play a significant role in preventing the development of cataracts in people. Since diabetes is a lifestyle disease, it affects millions of individuals worldwide.

Millets aid in the prevention of Type II Diabetes because they contain considerable amounts of magnesium, a vital element that enhances the effectiveness of insulin and glucose receptors by generating numerous enzymes that manage insulin action. 2017 (O.S.K. Reddy).

B. Millets-CVD:

Consuming porso-millet protein concentrate has a very positive influence on plasma lipid levels, according to millets, which also clearly demonstrated that adiponectin and high-density lipoprotein cholesterol levels are enhanced (Kyung, et al., 2008). Millets are an excellent source of magnesium, which helps to prevent heart attacks. By lowering plasma triglycerides, millets, which are known to be rich in phytochemicals containing phytic acid, aid in lowering cholesterol and preventing cardiovascular disease (Lee, et al., 2010).

This is why regular ingestion of whole millet grains lowers the risk of CVD, according many research. Magnesium, a vital trace element for lowering blood pressure and the risk of heart attacks and strokes, especially in the case of atherosclerosis, is abundant in millet. Moreover, millets are a good source of potassium, a vasodilator that further lowers blood pressure.

One of the finest strategies to safeguard cardiovascular health is to manage your blood pressure and improve your circulatory system. Additionally, millets contain plant lignans that are rich in prebiotic fibre. These lignans are fermented by bacteria in our intestines and can then be changed back into animal lignans by the microflora in our digestive system. Animal lignans have been shown to act as barriers against a number of chronic diseases.

They are fermented to produce enterolactone, a substance with a reputation for preventing heart disease and some types of breast cancer. O.S.K. Reddy (2017).

C. Millets and Cancer:

Millets have demonstrated in studies that their abundance in phenolic acids, phytates, and tannins reduces the chance of developing colon and breast cancer. It has been demonstrated that the phenolics in millets are efficient at stopping the development and spread of cancer in test tubes (Chandrasekara A, et al., 2011). Linoleic acid, an important fatty acid found in millets, has anti-tumor properties (nubiform, et al., 2007). Sorghum's anti-carcinogenic qualities are well established. In addition to having positive melanogenic activity, the polyphenols and tannins found in sorghum exhibit anti-mutagenic and anti-carcinogenic qualities (Grimmer et al., 1992). They can also work against human melanoma cells. Sorghum has been discovered to reduce the incidence of esophageal cancer in China and other regions of the world (Van Rensburg, 1981). t is also observed consumption of sorghum demonstrated lower mortality against esophageal cancer than wheat and corn. Several of the antioxidants present in millets not only have a positive effect on scavenging free radicals, which can result in cancer, but they also have the ability to remove other toxins from the body, including those found in the human kidney and liver. By encouraging correct excretion and reducing enzymatic activity in those organs, quercetin, curcumin, ellagic acid, and a number of other advantageous catechins can aid in the removal of any foreign substances and toxins from the human system. O.S.K. Reddy (2017).

D. Millets and Celiac Disease:

Celiac disease is a genetically predisposed condition brought on by the impact of the plant protein gluten. Millets, which don't contain gluten, aid in lowering celiac disease by lessening the irritation brought on by popular cereal grains that do. Saleh ASM, et al. (2013). Consuming millets helps regulate the digestive system very well, boosts nutrition retention, and lowers the risk of developing more serious gastrointestinal diseases like gastric ulcers or colon cancer. Millets' high fibre content aids in preventing problems including constipation, excessive gas, bloating, and cramps. Celiac disease is an immune-mediated enteropathic condition that, in susceptible people, is typically brought on by consuming gluten (Catassi and Fasano, 2008). A gluten-free diet mainly influences how much food is consumed. A gluten-free diet can be followed by substituting rice, corn, sorghum, millet, amaranth, buck wheat, quinoa, and wild rice for gluten-containing cereals like wheat, barley, and rye. 2009 (Thompson). Millets have a lot of potential in the food and beverage industries thanks to their gluten-free characteristics.

They can meet the rising demand for gluten-free diets and will be suitable for people with celiac disease. Millets are a good source of micronutrients and phytochemicals like dietary fibre, carotenoids, phenolics, sterols, lignans, inulin, resistant starch, and -glucan. The polyphones include phenolic acids, tannins, and flavonoids, which are key components of the body's immunological system and act as antioxidants (Chandrasekara A, et al., 2010). Many of the anti-oxidants in millet have a positive effect on scavenging the cancer-causing free radicals and clearing other toxins from the body that are eliminated through the kidney and liver.

By encouraging appropriate excretion and reducing enzymatic activity in those organs, quercetin, cucurmin, ellagic acid, and numerous other advantageous catechins can aid in the removal of unwanted substances and toxins. As a result of their importance to human health, polyphenol has received a lot of attention (Tsao R, 2010).

The soluble and insoluble bound phenolic extracts of numerous types of millet (kodo, finger, foxtail, proso, pearl and small millets) provide evidence of antioxidant, metal chelating, and reducing properties (Chandrasekara and Shahidi, 2010).

Proso millet contains 29 mg polyphenolics per 100 g and 2.22 mg tocopherol per 100 g, compared to foxtail millet's 47 mg polyphenolics and 3.34 mg tocopherol per 100 g (on a wet basis) (wet basis). Millets are very nutrient-dense and provide a number of health advantages. Millets support the fight against obesity (Ambati K., andSharita K V, 2019).

5.7 Millets in Food Industry:

The main diet in many Asian and African nations is millet. People in millet-producing regions used to make a variety of traditional dishes and drinks such idli, dosa, papad, cookies, porridges, breads, infant's food, and snack foods, which is a reflection of Asia Pacific's urban population's growing preference for healthy cuisine. Iron, calcium, and fibre found in millets aid to reinforce other nutrients necessary for children's healthy growth and development. Millets are increasingly being used in baby food and nutrition products.

Long-term strategies are being planned by several developing countries and their governments to implement nutrition programmes to combat malnutrition. The scale of the business is projected to increase due to the backing of government efforts and a variety of food and beverage items. Millets like quinoa and buckwheat are frequently utilized in the preparation of well-known foods including waffles, pizza, pasta, and sandwiches.

A shift in consumer preference for low-cholesterol and fat-free foods as well as increased awareness of healthy eating practices could increase millet demand. Manufacturers are being encouraged to utilize millet since consumers are becoming more and more interested in healthy baking products.

Growing consumer preference for low-calorie foods and the adoption of healthy eating practices might likely increase market share. Moreover, it has been used in drinks like beer. For people with celiac disease or gluten intolerance who need to reduce their intake of gluten, gluten-free beers are developed especially for them. A significant amount of millet is being produced, farmed in local level, and either consumed by humans or utilized as animal feed.

The remaining produce is utilized to make breakfast, baby food, and beer. Millets' typical grain texture and hard seed coat improve their ability to retain, but at the same time make them challenging to process and prepare in a convenient way. Absence of suitable primary processing technologies for ready-to-use or ready-to-cook (RTC) items as well as secondary and tertiary processing for ready-to-eat value added products has been one of the main obstacles to their increased economic status and wider range of food uses (Malleshi, 2014).

A barrier to entry into the urban food sector is high product prices. Thus, increased public knowledge of the health benefits of eating millets will spur industry expansion (Jaybhaye R.V., 2014). The challenges in millet grain processing create a difficulty, but at the same time consumer demand for healthy foods, nutritional benefits, and processing requirements necessitate the development of appropriate technologies for novel products and process mechanization.

This shift in technology and consumer food preferences will undoubtedly contribute to expanding the uses for millets, preserving the ecological balance, guaranteeing food security, preventing malnutrition, and expanding the potential for millet grains to be used on an industrial scale. Millets have so far been successfully used in a variety of traditional as well as fast-food health dishes, according to several studies on their processing. Based on this, numerous researchers have attempted to create processed goods like weaning foods, fermented, malted, flaked, puffed, extruded, and roller dried products.

Figure 5.6: Different Food Products with Technologies Based on Millets

Source: IIMR, 2023

5.8 Steps Taken for Promoting Millets Since 2018:

As millets like jowar, bajra, ragi, and other millets are nutrient powerhouses and are referred to as super foods, the government decided to drop the term "coarse cereals" and rename them as "Nutri Cereals." This movement aims to dispel the myth that these grains are less valuable than rice and wheat, despite the fact that they contribute more to our health and nutrition. Millets have a big potential to significantly improve the food and nutritional security of the nation and the planet.

There are many initiatives undertaken by Government based on different interventions-

- On production through technology backstopping

- Diversification of processing technologies in contradiction with inconveniences, and development and standardization of millet-based value-added product technologies.

a. More than 60 processing technologies has been developed by retrofitting the existing machinery available for other cereals.
b. Primary processing and secondary processing methods developed and fine-tuned, with 32 commercialized products.
c. Processing innovations improved the nutritional value, convenience and shelf life of the products.

- Improvisation of processing technologies with value addition
- Nutritional Evaluation and Certification,
- Commercialization
- Promotion and Popularization
- Entrepreneurship Development

There are several Government initiative programs to secure millets and promote the popularity-

A. National Year for Millets 2018:

The "Sub Mission on Millets" under National Food Security Mission Named Sorghum (Jowar), Pearl Millet (Bajra), Finger Millet (Ragi/Mandua), Minor Millets i.e., Foxtail Millet (Kangani/Kakun), Proso Millet (Cheena), Kodo Millet (Kodo), Barnyard Millet (Sawa/Sanwa/ Jhangora), Little Millet (Kutki) and two Pseudo Millets (Buck-wheat (Kuttu) and Ameranthus (Chaulai) as “Nutri cereals” since 2018 and gave popularity. Several State initiatives have also been established, such as the POSHAN MISSION Abhiyan by the Ministry of Women & Child Development to promote. One type of quinoa (Him Shakti) was introduced by ICAR as a novel crop; ICAR also supported marketing it as nutri-cereals.

B. International Year of Millets (IYoM)-2023:

The Indian government had asked the UN to declare 2023 the International Year of Millets (IYOM). Then it was supported by the General Assembly of the United Nations and 72 nations worldwide (UNGA). Consequently, on March 5, 2023, the International Year of Millets was proclaimed. Following the mission, the Indian government has also planned to celebrate IYOM in 2023 in order to start a movement that will lead to the global acceptance and favouritism of Indian millets, their recipes, and value-added products.

C. Seven sutras based on theme by government of India:

- Harnessing the enhancement of production and productivity
- Focusing on Nutrition and health benefits.
- Prioritizing Value addition, processing and recipe development.
- Promoting areas of Entrepreneurship, startup and collective development.
- Working on Awareness creation, branding, labeling and promotion.
- Emphasizing International outreach.
- Implementation of Policy intervention for mainstreaming.

5.9 Conclusion:

Rich soils are not necessary for the life and development of millet. Therefore, it's a blessing for the large region of dry land. Synthetic fertilizers are not necessary to produce millet. So, use of farmyard manures and household-produced bio fertilizers are in trend by the majority of millet producers.

As a result, they can drastically lessen the government's enormous fertilizer subsidy burden. No pests are drawn to millet when it is grown using traditional techniques. These might be considered crops. Millets are also not getting affected by bugs during storage. As a result, they hardly ever need pesticides. As a result, they greatly benefit the agricultural environment. Millets provide an incredible amount of nourishment. In terms of nutrients proteins, minerals, and vitamins, each of the millets has three to five times the nutritional value of the extensively advertised rice and wheat. So, it is necessary to improve the miracle of millet grains, their processing capacity, the status of the current food product lineup, and the potential for future development of millet-based health, functional, and RTE goods.

5.10 References:

1. Ambati, K., & Sucharitha, K. V. (2019). Millets-review on nutritional profiles and health benefits. *International Journal of Recent Scientific Research*, *10*(7), 33943-33948.
2. Behera, M. K. (2017). Assessment of the state of millets farming in India. *MOJ Ecology & Environmental Science*, *2*(1), 16-20.
3. Dayakar Rao, B., & Nune, S. D. (2021). Role of Nutrihub Incubation for the Development of Business Opportunities in Millets: An Indian Scenario. *Millets and Millet Technology*, 413-438.
4. Garg, S., Muthukumar, M., Balam, D., & Mohanty, B. (2022). A transformative food system for mainstreaming sustainable diets. *Routledge Handbook of Sustainable Diets*, 340.
5. Karuppasamy, P. (2015). Overview on Millets. *Trends in Biosciences*, *8*(13), 3269-3273.
6. Malhotra, S. (2021). India experience in diversifying staples with millets-a government perspective.
7. Jaybhaye, R. V., Pardeshi, I. L., Vengaiah, P. C., & Srivastav, P. P. (2014). Processing and technology for millet-based food products: a review. *Journal of ready to eat food*, *1*(2), 32-48.
8. Raina, R., Mishra, S., Ravindra, A., Balam, D., & Gunturu, A. (2022). Reorienting India's Agricultural Policy: Millets and Institutional Change for Sustainability. *Journal of Ecological Society*.
9. Reddy, O. S. K. (2017). Smart millet and human health. *Green Universe Environmental Services Society*.
10. Shobana, S., Gayathri, R., Anitha, C., Kavitha, V., Gayathri, N., Bai, M. R., ... & Mohan, V. (2018). Finger millet (Eleusine coracana L.) and white rice diets elicit similar glycaemic response in Asian Indians: Evidence from a randomised clinical trial using continuous glucose monitoring. *Malaysian Journal of Nutrition*, *24*(3), 455-466.

ISBN: 978-81-19149-19-3

6. History and Domestication of Millet Crops

Dr. Santosh Bhadkariyaa, Mr. Arif Khana

Shri Ramnath Singh Institute of Pharmaceutical Science & Technology, Sithouli, Gwalior (M.P).

6.1 History of Millets in India:

6.1.1 Introduction of Millets:

The proso millet and foxtail millet, which were domesticated in China, travelled to India probably through trade routes. Archeological data of proso millet and other crops suggested that the Indian valley of Kashmir was integrated into a wider network of crop exchange in the mountainous regions of South and Central Asia during the 3000-2000 BC period.

6.1.2 Millets from China:

Foxtail millet spread from China to south and westward to reach India. In Sanskrit, it has been referred to as BhAvajJA, PriyaGgukA, Rajika, etc. confirming its ancient cultivation. It occurred in Harappa levels (2500-2200 BC) at Shikarpur (Kutch) and late Harappan levels (1900-1400 BC) at Punjab. Also, it was recovered from the earliest strata of Rojdi (Saurashtra), placed within 400 years of the oldest find of domestication. Carbonized seeds were reported from Jorwe culture levels (Ahmadnagar, 1500 BC) and Daimabad in Mahararashtra.

The mention of millets in Indian Sanskrit text Yajurveda's verses- of foxtail millet (priyangava), proso millet (aanava) and Barnyard millet (shyaamaka), indicated that millets culture and consumption was very common, dating to the Indian Bronze Age (1,500BC).

Archaeobotanical remains have also been found from upper and middle Gangetic Plains. It was also grown at Manjhi (Saran, Bihar) during the red ware levels (250 BC-250 AD). In South India, foxtail and proso millets were the staple diet for the people from the Sangam period (300 BC to 300 AD). Sushruta (Sushruta Samhita, 600-500 BC) classified cereals as dhanya varga, khudhanya varga and samidhanya varga. Khudhayna varga includes, among others millets viz., kodo millet (kodrusaha), barnyard millet (syamaka), and coix (gavedhuka).

Kalidasa (4-5th AD), in his legendary literary masterpiece 'Abhijnana Shakuntalam', has sage Kanva pouring foxtail millet while bidding farewell to Shakuntala in Dushyanta's court, which indicates the auspicious nature attributed to this millet. In the 10th-12th Century AD Varaha purana, it is mentioned that God Srinivasa is favourable to the one who offers foxtail millet. According to Dakar Bachan, composed sometime in early medieval Bengal (8th to 13th Century AD), cultivation of proso millet (china kaon) was advised if it rained during Phalgun month (February-March).

6.1.3 African Millets Transformed Late Harappan Agriculture in Western and Peninsular India:

The Saurashtra Center was dominated by little millet, native small Setaria spp. and brown top millet during the Mature Harappan period, 2500–2000 BC.

Arrival of high-yielding African millets led to increase in settlements in the Gujarat region and expansion of cultivation. It is believed that there was a distinct climate change in Gujarat region around 2000 BC and the region became more arid. At this time millet became more predominant in the Harappan subsistence system.

Pearl millet and sorghum from Africa also appear during this time, besides finger millet. Pearl millet was known in the later 3rd millennium BC in Saurashtra and moved to South India where it was known around 1800 BC. Pearl millet was a noticed in Neolithic South India (2000-1200 BC) and Narhan culture (1300-800 BC). However, the millet finds it's mentioning in Ayurvedic texts only since the 14th Cen. AD. It is known to be Nali in Sanskrit and the very first mentioning of the word Nali is found in Madanapala Nighantu (1374 AD) under Truna Dhanya category. The presence of finger millet in India dated to approximately 2300 BC at Hallur, Karnataka, during Harappan levels. This suggests direct or indirect connections with African populations prior to 2600 BC Finger millet has also been reported from late Harappan levels in Northern and Western India. Finger millet was the staple of Neolithic Karnataka.

African cultivars moved to southern India and southern Indian cultivars to Africa as early as the second millennium BC, testament to active networks of exchange and innovation. It is believed that arrival of African millets to India coincided with an increase in sedentism and agriculture in Peninsular India. The Hallur site in Haveri district of Karnataka yielded crop cultivation pattern during 2000-1000 BC, comprising of Neolithic-Chalcolithic and early Iron Age. Brown top millet, bristly foxtail (Setaria verticillata) and pearl millet (African origin) seeds pertained to Neolithic age (2000-1200 BC), while finger millet (African origin) and kodo millet were Early Iron age dated (1200 to 1000BC).

In the excavations of Oriyo Timbo in the Shavnager district of Gujarat state, 77% of seeds were found to be millets comprising proso millet, little millet, foxtail millet and finger millet. The site has been dated to the first half of second millennium B.C. and the excavators believe that it was a seasonal encampment occupied every year during the months of March to July. The evidence is suggestive of a primarypre-Harappan agricultural tradition based on native monsoon-adapted crops. As with South India, however, there is no archaeobotanical evidence for the earlier stages of this tradition or for the transition from collecting to farming these species. Evidences indicate cultivation of sorghum during pre-Harappan period (2300-2000 BC) in Punjab.

Late- Harappan phase (1800-1700 BC) of Indus valley civilization was marked by diversification of agriculture, perhaps as a response to climate change to cooler and drier seasons. At Pirak in Baluchistan, double cropping system was in place with pearl millet and sorghum being grown in summer. Excavations at Hulas (Saharanpur) yielded evidence for sorghum and finger millet grains.

Outside of the Indus Valley area of influence there were two regions with distinct agricultures dating back to around 2800-1500 BC. These are the Deccan Plateau and an area within the modern states of Odisha and Bihar.

Within the Deccan, the ashmound tradition developed around 2800 BC. The people of the ashmound tradition grew millets and pulses, some of which were domesticated in this part of India, for example, brown top millet, Setaria verticillata, green gram and horse gram. They also herded cattle, sheep and goat and were largely engaged in pastoralism. This era may be seen as establishing the basic South Indian repertoire of rainfed millets and pulses, sown in synchrony with the southwest monsoon.

In the east of India Neolithic people grew rice and pulses, as well as keeping cattle, sheep and goat. By 1500 BC a distinct agriculture focused on summer crops, including Vigna and little millet was developed.

Among the chalcolithic culture of the Deccan, the Jorwe farmers (1400-1000 BC) in Malwa practiced kharif and rabi crop rotation, where sorghum and finger millet were grown along with wheat, barley and rice.

Greek historian Megasthenes (350-290 BC) Mentioned that millets are grown after summer solastice, foxtail millet and sorghum are grown, among others.

During Satavahanas (1st to 3rd century AD) and Vataka dynasty (250-270 AD), sorghumwas abundantly used over rice in the Deccan region, which changed gradually The term ‘yavanaala’ mentioned in Indian text Charaka Samhita (100-200 AD) is attributed to sorghum. Greek author Pliny wrote about introduction of sorghum from India to Italy during 60-70 AD. In Vishnu purana (450 AD), gramausadhi group of plants includes cereals, including priyangu (foxtail millet), hyudar’sa (sorghum), korusa (kodo), yajgnausadhis includes priyangu (foxtail millet), syamaka (barnyard), gavedhu (coix), etc.

6.1.4 Millets in The Vijayanagara Empire:

The Kannada language composition ‘Ragi thandheera’ written by Purandara Dasa, a 15th century Indian poet, is much celebrated in Karnataka to highlight the popularity of finger millet (ragi) during those times. The Telugu poet Srinatha, who lived in the first half of the 15th century described of the people food habit of Palnadu area in Andhra, a part of the then Vijayanagara Empire, as entire subsistence on sorghum and pearl millet for porridge, fermented products, cooking, etc. and that except millets they have nothing to eat. Fernao Nuniz, a Portugese traveller, who visited Vijayanagar Kingdom in 16th century AD, mentioned that sorghum was the major food grain consumed in South India.

Kannada poet Kanakadasa (16th Century) has immortalised finger millet in his ‘Ramadhanya Charithre’; it is an allegory on the conflict between the socially strong and weak castes and classes, presented as an argument between two food grains, rice and finger millet (ragi), a most creative literary piece with a powerful social message. Sarvajna, a 17th century Kannada poet who belonged to this period, speaks in glowing terms of sorghum which was and is the staple food of the common people in North Karnataka districts.

6.2 Indian Millets:

6.2.1 Kodo Millet:

Chalcolithic 1800-1200BC era findings reported kodo millet from Northern and eastern India. The first report of kodo millet from South India is during megalithic age (1000-300 BC) from various places in Maharashtra and Andhra Pradesh. The record from Ganga valley pertained to cultivation during Narhan culture (1300-800 BC). In the Arthashastra of Mauryan age (200-300 AD), kodo millet has been referred to as kodrava, grown along with other crops. Ibn Batuta from Morocco who visitedIndian during the times of Muhammad-bin-Tughlak (1325-1351 AD) recorded that kodo millet was the commonest grain.

Kautilya’s Arthashastra says….

Kodrava (kodo millet), … and priyangu (foxtail millet) will increase three times the original quantity when cooked; … Grains will increase twice the original quantity when moistened; and two and half times when soaked to sprouting condition.

6.2.2 Little Millet:

The Saurashtra Center was dominated by little millet, native small Setaria spp. and brown top millet during the Mature Harappan period, 2500–2000 BC. In the excavations of Oriyo Timbo in the Shavnager district of Gujarat state dating to 2000- 1500 BC, 77% of seeds were found to be of millets comprising little millet, among others. This site was believed to be a seasonal encampment occupied every year during the months of March to July. The evidence is suggestive of a primary preHarappan agricultural tradition based on native monsoon-adapted crops.

6.2.3 Brown Top:

millet This was a major millet in the Mature Harappan period. The Hallur site in Karnataka yielded the evidence for its cultivation in neolithic period of 2000-1500 BC.

6.3 Millets and Mughals:

During Mughals period, in 16-17th Century AD, Pearl millet was grown in dried areas of the northwest and western zones. Further, millets were also cultivated in wheat dominant areas and other drier districts. Sorghum and pearl millet were the two main millets.

The Ain-i-Akbari (16th century AD) written by Abul Fazl, records that millets which included sorghum, pearl millet, kod millet, barnyard millet and finger millet formed the kharif crops and were cultivated in Malwa, Gujarat, Ajmer, Khandesh, Lahore, Agra, Allahabad, Awadh and Multan.

Abul Fazl has given statistics on yields of crops on Bigha basis in different cultivation conditions, including that of sorghum and pearl millet.

Francisco Pelsaert of Dutch East Indian Company at Agra (1621-1627 AD) writes that sorghum, pearl millet and foxtail millet were the food grains eaten by the poor in the 17th century.

Mughal emperor Jahangir (1569-1627 AD), in his autobiography Tusk-e-Jahangir, talks about laziza (tasty), a kind of khichdi he encountered in Gujarat. Laziza was a mixture of bajra (pearl millet) and peas cooked together. He writes: 'It was not devoid of good flavour and it suited me well. I ordered that on the days of abstinence, when I partake of dishes not made with flesh, they should frequently bring me this khichdi.'

Mahabat Khan, the Mughal noble who served under Jahangir and Shah Jahan, used to eat only once in 24 hours, and during this meal, his table was laden with two trays each of pulao, ash-ha (broths), and trays of rice and millet khichdi.

6.3.1 Kingdom of Hyder Ali:

Hyder Ali Khan (1720 – 1782 AD), the Sultan of the Kingdom of Mysore was, at times, known to consume dry roti of finger millet or sorghum with just water. However, the finger millet, the staple food of his subjects, was always a part of his menu.

James Scurry (1766–1822 AD), a British soldier who was held captive by Hyder Ali and Tipu Sultan for 10 years (1780–1790) at Srirangapatam, wrote that during his march from Bengaluru prison to another place, he was fed with food made from finger millet flour.

6.4 The Colonial India:

During the colonial period when European nations controlled India, there was no emphasis on millets as the colonizers manipulated agricultural production to suit their needs of imports which included spices, cotton, indigo and other commercial crops. Evidences indicate that from 17th century to 20th century, the productivity of food grains including millets did not rise. Scottish physician Francis Buchanan, who toured across South India in 1807, writes "The crop of Ragy [finger millet] is by far the most important of any raised on dry field, and supplies all the lower ranks of society with their common food. Among them, it is reckoned the most wholesome and invigorating food for labouring people; and in every country, most fortunately, a similar prejudice appears to prevail, the most common grain always reckoned the nourishment most fit for the labourer... My Bengal and Madras servants, who havebeen accustomed to live upon rice, look upon the Ragy as execrable food, and, in fact, would experience great inconvenience were they compelled to live upon it."

It is recorded that when the Tungabhadra dam was built in the 1940s near Hosapete, Karnataka, "surveyors recall that rice was difficult to obtain; they found eating millets distasteful, an enduring memory of a hardship posting".

It was the interest of Leslie Coleman, a Canadian scientist, who worked for British as the second director of agriculture in Mysore State, when posted in Bengaluru, to initiate research on finger millet. He was farmer-friendly and also ate finger millet 'mudde' with them. He contributed the first finger millet variety too.

6.5 Domestication of Millets:

6.5.1 Introduction:

The origins of agriculture in North China were underpinned by millet cereal grasses, including foxtail millet (Setaria italicssp. Italic) and broomcorn millet (Panicum miliaceum; Crawford, 2006; Hunt et al., 2011; Zhao, 2011). Other wild grasses were likely also eaten and are frequent components of Neolithic Chinese sites (Crawford et al., 2005; Lee et al., 2007). At the western end of Eurasia, late Upper Paleolithic seed remains in the Near East indicate that early farming and agriculture was based around.

wheat and barley (Wilcox et al., 2012) domesticated after millennia of use (Weiss et al., 2004). However, no charred seed evidence exists for millets in East Asia before 10,000–8000 BP (Bettingeret al., 2007; Crawford, 2006; Crawford et al., 2013). Micro fossil research has been used to inform the origins of agriculture in China (Liu et al., 2010; Lu et al., 2009; Yang et al., 2012a, 2012b) but is problematic.

Domestication evidence from starch grainsand phytoliths is either not species specific (Liu et al., 2013) or iscontroversial like the phytolith and starch evidence of early milletat Cishan (Lu et al., 2009; Yang et al., 2012b) and debated (Zhao,2011). In addition, multiple starch grain studies on the same site (Donghulin) have yielded contradictory results from differentresearchers (Liu et al., 2010; Yang et al., 2012a).

Grass identification based on charred seeds is less controversial and more specific. Here, we present Late-Paleolithic seeds recovered from theShizitan Locality 9 site in North China and discuss these in relation to worldwide debate on the origins of agriculture. These arethe only late Upper Paleolithic seeds ever recovered from NorthChina. We suggest that food patterns which show a preference formillet grasses and which are evident in China during the latePaleolithic (Liu et al., 2011, 2013) continued into the Neolithic.

6.5.2 Shizitan Locality:

Shizitan Locality 9 is a late Upper Paleolithic occupation and one of more than 25 localities which form the Shizitan site cluster in Jixian county, Shanxi Province. These localities extend along a15 km stretch of the Qingshui River, a tributary of the Huanghe. Chinese archaeologists have suggested that micro liths in the upper 17,000 to 11,900 cal. BP layers of the site complex indicate that the site is transitional between the Paleolithic and Neolithic (Shizitan kaogudui, 2010; Xia et al., 2002). Seeds are too small to be directly dated at this time, however, charcoal from the same flotation samples as theseeds was accelerator mass spectrometry (AMS) dated.

The uppersection of layer IV returned AMS dates between 12,700 and11,600 cal. BP, while the lower strata of layer IV dates between13,800 and 12,700 cal. BP (Liu et al., 2011; see also Table 1). Overall, charcoal andburnt bone fragments from the site are AMSdated between 13,800 and 8500 cal. BP (Liu et al., 2011). Seedswere collected through flotation of 225 L of sediment taken fromlayer IV and processed using a 0.212-mm sieve and bucketflotation.

6.5.3 Charred Seeds:

In all, 6 of the 16 Shizitan Locality 9 flotation samples preserved a total of 28 charred seeds, half of which are unidentifiable due to the loss of diagnostic features (Table S2). The other 14 seeds are from two families: Chenopodiaceae (goosefoot) and Poaceae (grasses; Table S2). Most are grass seeds (caryopses missing their palea and lemma or husks) among which all but two are from the millet tribe (Panicoideae subfamily, Paniceae tribe). These two are broken seeds that are not further identifiable. Four goose foot seeds were recovered. The Paniceae includes 27 genera and 145 species in China, mostly tropical and subtropical. Only six genera are common today in north temperate Shanxi province: *Digitaria*, *Echino-chloa*, *Oplismenus*, *Panicum*, *Pennisetum*, and *Setaria* (Chen etal., 2013). Wild Paniceae or millet tribe grass seeds are identified by their small grain size (<3 mm long), dorsal compression, dorsal ridge absence, lateral groove absence, and embryo shape and size (Nesbitt, 2006). Two important crops in ancient North China belong to the Paniceae: foxtail millet (*S. italicssp. italica*) and broomcorn/common millet (*P. miliaceum*). Late Neolithic foxtail and broomcorn millet grains are larger and more spheroidal (expanded along the dorsal–ventral axis) compared with the dorsally compressed seeds of the weedy/wild members of the two genera. The husks, particularly the lemmas of Paniceae grasses, also aid in distinguishing genera (Nasu et al., 2013); however, no husks are in the Shizitan flotation samples. Imprints of the husk pattern may sometimes be visible on the grain under high magnification; however, this is not the case for the Shizitan specimens. The Paniceae specimens are dorsally compressed and shorter than 3.0 mm with no ridges or grooves. None of the charred specimens areDigitaria, Oplismenus, Panicum, or *Pennisetumcaryopses*. Three of the grass specimens compare best with green foxtail grass (*S. italicsubsp. viridis*), while three others are broken seeds that are only identifiable to Paniceae tribe. The specimen with a well-preserved embryo compares well with those of the green foxtail grass reference sample and not with domesticated foxtail millet. The embryos of the potentialSetariaseeds are about half the length of the seed or slightly longer. Two specimens are comparable to barnyard grass (*Echino-chloasp*.) except that they are significantly smaller. Several species of Echinochloa grow in the Shizitan area today (Chen and Phillips, 2006). The caryopsis-to-embryo length ratio is significantly higher than inSetaria, and the caryopsis width-to-length ratio is also higher than that ofSetaria. Wild-type barnyard grass seeds are reported from several sites, including the Peiligang Period Jiahu site (Zhao and Zhang, 2009), the Houli culture Yuezhuang site (Crawford et al., 2006, 2013), and Liangchengzhen (Crawford et al., 2005). Barnyard grass (*Echinochloa crus- galli*) is the wild progenitor of *Echinochloa esculenta* (*syn. Echinochloa utilis*; Japanese millet; Crawford, 2008), and evidence for its domestication is based on a population with significantly larger seeds than in wild populations present at the Middle Jomon Usujiri B site in Japanc. 4000–3800 BP (Craw-ford, 1983). No evidence for barnyard grass domestication exists from China in the Neolithic period, but in the historic Jin Dynasty,11 seeds of large-sized, possibly domesticated barnyard grass were recovered from the Lichunjiang site near Dehui City in north-eastern Jilin province (Yang et al., 2004). Chenopod or goosefoot seeds are present in both upper and lower strata of layer IV at Shizitan. They may have been cultivated for a long period in China (Lee et al., 2007: 1090), although direct evidence of chenopod domestication in the form of a thinner testa has not yet been demonstrated. This does not invalidate the hypothesis that chenopods were purposefully managed or grown. Research on Chenopodium in the Chinese archaeological record is on-going.

6.6 Discussion:

This research demonstrates that late Upper Paleolithic plant macrofossils are recoverable using flotation and complements the growing record of starch grains and phytoliths from the same period. Grass seeds recovered by flotation from locality 9 of the Shizitan site (13,800–11,600 BP) are mainly green foxtail grass, the ancestor of foxtail millet (Harlan and De Wet, 1971; Prasada Rao et al., 1987). The oldest clearly identified foxtail millet grains exhibiting signs of increase in seed size and shape so far reported are from the 8000–7700 cal. BP Yuezhuang site (Craw-ford et al., 2013) and the*c.* 7600 cal. BP Xinglonggou site in north and north-east China, respectively (Zhao, 2011). Wild-type Paniceae caryopses are found in high densities in Neolithic sites in dry farming contexts in North China post-dating 8000 cal. BP.

The most common genera are Digitaria, Panicum, Setaria, and rarely Echinochloa (Crawford et al., 2005; Lee et al., 2007). These are all associated with disturbed habitats, including humanly disturbed sites and millet fields. The narrow range of grasses recovered from Shizitan indicates that people were tar-getting the wild ancestor of foxtail millet and possibly the wild ancestor of Japanese millet as opposed to other grasses. Future research should explore whether this selectivity also involves management. Pollen analysis (Xia et al., 2002) indicates that grasses were predominant from 30,000 cal. BP onward at the Shizitan site in a mild and semi-arid steppe type environment with some broad-leaved species also present. This indicates the type of environment preferred by late Upper Paleolithic humans. The wildSetaria from Shizitan Locality 9 represent the earliest association of panicoid grasses and people in North China.

This association between wild millets and human's dates at least 4000 years prior to the first clear evidence of the domesticated crop in North China. The similarity between the wildSetariafrom Shizitan Locality 9and the wildSetariafrom nearby Peiligang sites, such as Fudian Dong where the only Peiligang domesticates in the Yiluo region were recovered, suggests continuity of use of these taxa from the late Upper Paleolithic into the early agricultural Neolithic. Starch residues from grinding stones at the earlier locality 14of Shizitan dating to approximately 23,000–19,500 cal. BP include Paniceae (millet) tribe and Triticeae (wheat and wild wheat) tribe grasses (Liu et al., 2013). These starch grains are not further identifiable. The starch evidence for use of at least two different grass tribes at Shizitan suggests that people were experimenting with or auditioning a range of different types of grasses during the late Upper Paleolithic. Eventually, only millets were domesticated in North China. Triticeae grasses were never domesticated in China, although domesticated Triticeae were introduced to Chinac. 4500–4000 BP (Zhao, 2009). The evidence for use of several different types of grasses in at least two distinct grass tribes mirrors the evidence from the Ohalo II site, Israel (Weiss etal., 2004) where a range of both large and small-grained grasses were utilized. The use of small-grained grasses gradually decreased at Ohalo II, and only large-grained grasses were eventually domesticated in the Levant. In North China, large-grained grasses were used sparsely, and two millets became the focus of human cropping and management. Combined with starch grain and phytolith evidence, this suggests thatSetariaandEchino-chloaspp. grasses were associated with people and potentially part of their diet from at least 23,000 years ago. Starch residues from grinding slabs located near the sampled sediment at Shizitan indicate that in addition to grasses, a corn sand tubers were utilized (Liu et al., 2011). Other plant remains from S9 include chenopods and unidentified seeds as well as rind type fragments, all attesting to the importance of plants in the diet. The first systematic flotation at a Paleolithic occupation in North China, Shizitan Locality 9, demonstrates the effectiveness of the technique in providing important data complementary to the recovery of starch grains and phytoliths. The data indicate that panicoid grasses were specifically targeted and associated with human habitation at least 4000 years prior to the grasses' cultivation and eventual domestication. The dual trajectory of experimentation with different types of grass at opposite ends of the Eurasian continent resulted in different types of grasses being domesticated in the Near East and in Asia.

6.7 Sorghum, Pearl Millet and Finger Millet Were Domesticated in Africa:

The most prominent and well known millets are the large or great millets of Africa, Sorghum and Pennisetum. These two taxa account for the majority of millet grain produced around the world. While these small seeded grasses account for less than one per cent of food grain produced in the world today, they are essential food crops in some regions today. Ethiopia and Eritrea have been a pivotal region for prehistoric contacts between Africa, Asia, Egypt, and Southwest Asia for the past 4000 years. Evidences indicate an early dispersal (before 2000 BC), of sorghum, finger millet, and tef out of Ethiopia and Eritrea regions of Africa suggesting the existence of earlier local domestication events. Although the African origin of these species has been established by botanical and cytogenetic studies, in several cases the earliest evidence for these crops is outside Africa.

For example, the earliest known archaeological finger millet is found in India dating to the second millennium BC. Tef appears in the form of pottery impressions at Hajar bin Humeid, a site in southern Yemen dating to the first century BC. Although there is a report of sorghum in the Khartoum area dating to the sixth millennium BC, the earliest confirmed archaeological specimens appear in India by at least 2000 BC, probably arriving via trade routes from Yemen or other parts of the Arabian Peninsula. Claims have been made for the presence of sorghum in North and South Korea during the Plain Pottery Period (ca. 2000-500 BC).

6.7.1 Sorghum:

Sorghum domestication started in Ethiopia and sub-saharan Africa some 5,000 to 6,000 years ago. The largest diversity of cultivated and wild sorghum is also found in this part of Africa. Based on the presence of wild sorghums, the possible areas of domestication of sorghum have been predicted to be the eastern Sahara-Nile valley, the lake Chad region and the inland Niger delta.

Another report indicated that the origin and early domestication of sorghum took place in north-eastern Africa, north of the Equator and east of 10°E latitude, approximately in 3000 BC. Archeological evidences in Sudan indicate sorghum cultures around 2100BC. Sorghum adapted to a wide range of environments throughout Africa, spreading from the highlands of Ethiopia to the semi-arid Sahel. Through farmer selection numerous improved sorghum typeswere developed, which then spread via trade routes into other regions of Africa and India and eventually worked its way into Australia.

6.7.2 The Indian Domestication of Sorghum:

The secondary center of origin of sorghum is the Indian Subcontinent, with evidence for early cereal cultivation dating back about 4,500 years. It has been hypothesized that the first truly domestic sorghums came from the Durras of India. According to this theory, the early Bicolors were transported from Africa along the Sind-Punjab trade routes to India around 1000 BC and the Durras later came in from India through the Middle East and down the Nile.

ISBN: 978-81-19149-19-3

7. Field Cultivation Practices for Different Types of Millets

Abhishek Sharma, Shani Gulaiya,

Priya Kochale

Department of Agronomy,
Jawaharlal Nehru Krishi Vishwa Vidyalaya,
Jabalpur (M.P.), India.

Parikha P. Singh

Department of Plant Physiology,
Jawaharlal Nehru Krishi Vishwa Vidyalaya,
Jabalpur (M.P.), India.

Abstract:

Millets are one of the oldest cultivated cereals in the world. Millets are a group of small grained cereals having nutritionally rich grains cultivated under poor soil fertility conditions and are low input demanding crops. They are staple crops in the semi-arid tropics and largely found in low rainfall receiving areas, and consequently assume larger position in sustainable agriculture and nutritional security in the drylands. Most of the millets complete their life cycle in 60 to 120 days, acclimatizing to the brief cropping periods that endure unpredicted climatic vagaries and shifting.

The broader classification of millets puts these crops into two groups – major and minor millets. It is rich in proteins, fibre, vitamins, minerals like iron and is a better option on the nutritional test. Seeing their health benefits, millets are also being called the super foods. Millets can play a huge role in taking India towards food and nutritional security. Millets are extremely beneficial for the consumer, the farmer and the climate. Today the craze for millets is increasing all over the world. On India's initiative, the United Nations has declared the year 2023 as the International Year of Millets.

Keywords:

Millets, nutritional security, sustainability, staple food, low input crops

7.1 Introduction:

Millets are recently recognized as *'Nutri-cereals'* due to their superiority in terms of dietary value to other cereals. India has the heritage to grow different kinds of millets since the ancient time (Gowda NAN, *et al.* 2022; Maitra S, 2020). The term *"millet"* comes from the French word *"Mile,"* which means *"thousand,"* suggesting that a small number of millets contains many thousands of grains. Millets are frequently produced in marginal or degraded lands with very low nutrient contents and semi-arid conditions with minimal rainfall.

The crops provide food for people in areas where hunger is a common occurrence, and millets produce a more consistent harvest than other crops in low rainfall areas (Tadele, 2016). Millets are C4 plants with very superior photosynthetic efficiency, short duration, higher dry matter production capacity, and a high degree of tolerance to heat and drought. They also easily adapt to degraded saline, acidic and aluminium toxic soils (Yadav and Rai 2013).

People are being encouraged to seek out healthy and nourishing diets due to the modern sedentary lifestyle's association with a number of health issues. Millets are good for those who cannot consume gluten because they are gluten-free, but millet flour cannot be used to make bread that is raised (Amadou et al., 2013; Santra, 2013).

Millets are a storehouse of nutrients, and finger millet grains in particular have a remarkable high calcium content (>350 mg/100 g); foxtail millet, barnyard millet, and proso millet are prosperous in protein (>10%); little millet and foxtail millet are rich in fat (>4.0%); little millet, barnyard millet, and foxtail millet are superior in crude fiber (6.7-13.6%) (Kam *et al*. 2016). Globally, India is the largest producer of millets accounting for about 41% of the world production in 2020 and 83% of Asia's millet cropping area. India produces around 12 million MT of millets annually, according to Ministry of Agriculture and Farmers Welfare data. In India, millets have been an integral part of tribal food in the states of Odisha, Madhya Pradesh, Jharkhand, Rajasthan, Karnataka, and Uttarakhand.

In India, millets are cultivated in an area of 12.45 million hectares, producing 15.53 million tonnes with a yield of 1247 kg/ha. The state of Rajasthan has the highest area under millets cultivation (29.05%) followed by Maharashtra (20.67%), Karnataka (13.46%), Uttar Pradesh (8.06%), Madhya Pradesh (6.11%), Gujarat (3.94%) and Tamil Nadu (3.74%) (ASSOCHAM 2022). Though India cultivates a large variety of millets, bajra contributes to more than 50 percent cultivation of millets in India. Further, it is interesting to note that, India is the topmost producer of Barnyard, Finger, Kodo, Little millet and pearl millet globally (ASSOCHAM, 2022).

7.2 Global Scenario of Millets:

Table 7.1: Millet's Area and Production Region Wise (2019)

Regions	Area (lakh ha)	Production (lakh ton)
Africa	489	423
America	53	193
Asia	162	215
Europe	8	20
Australia & New Zealand	6	12
India	**138**	**173**
World	**718**	**863**

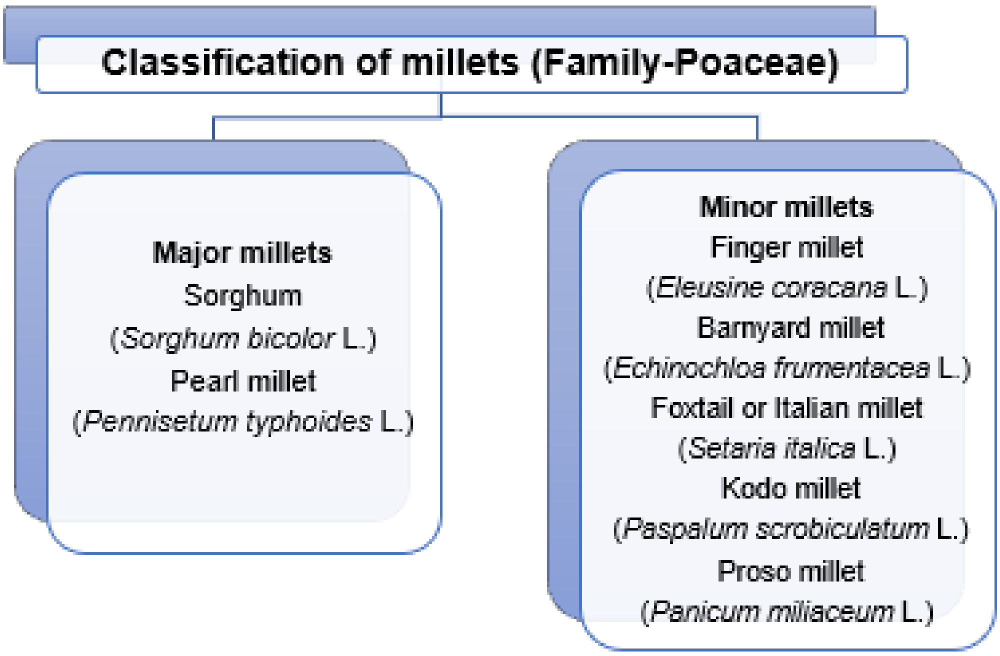
(Source: FAO Stat 2021)

According to ICMR-National Institute of Nutrition, the percentage of millet in the overall amount of cereal consumed during the day should be around 33%. For instance, 275 g of cereals, including Nutri Cereals, are advised for a reference man who engages in sedentary exercise. (Millets). Therefore, if an individual consumes millets, he can take in about 1/3 or 33% (90 to 100g of millets per day) of the recommended quantity.

Table 7.2: Nutritional content in 100 gm of dry grains

Crop	Protein (gm)	Carbohydrate (gm)	Fat (gm)	Minerals (gm)	Fiber (gm)	Calcium (mg)	Iron (mg)	Energy (Kcal)
Sorghum	10.4	70.7	3.1	1.2	2.0	25	5.4	329
Pearlmillet	11.8	67	4.8	2.2	2.3	42	11	363
Foxtail	12.3	60.2	4.3	4.0	6.7	31	2.8	351
Little	7.7	67	4.7	1.7	7.6	17	9.3	329
Kodo	8.3	65.9	1.4	2.6	5.2	35	2.9	353
Proso	12.5	70.4	1.1	1.9	5.2	8.0	2.9	354
Barnyard	6.2	65.5	4.8	3.7	13.6	22	18.6	300
Finger	7.3	72	1.3	2.7	3.6	344	3.9	336

(Mishra *et al.* 2021; NIN 2003)



(Muthamilarasan et *al*, 2019; Kumari *et al.* 2016; Goron and Raizada, 2015)

Figure 7.1: Classification of Millets (Family Poaceae)

- All India Coordinated Sorghum Improvement Project (AICSIP) - **New Delhi (1969)**
- International Crops Research Institute for Semi-Arid Tropics (ICRISAT) - **Hyderabad (1972)**
- National Research Centre for Sorghum **– Hyderabad (1987)**

7.3 Major Millets

Table 7.3: Major Millets

Crop	Origin	Seed rate	2n	Varieties
Sorghum	Africa	10-12 kg/ha Spacing- 45X12 cm^2 **Forage-** 40 kg/ha Spacing- 30x10-15 cm^2 row to row	20	**Hybrids-** (Kharif) CSH 1,5,6,9,10,11 (Rabi)-CSH 7R, CSH 14R, DSH 4 Mahalaxmi 296, CSH 15R **Composite-** (Kharif) CSV 10,11,13,15,17,20 (Rabi)- CSV 8R, 14R, 18 **Forage-** MP Chari, Jawahar chari 69 (JC 69), Pusa chari 23, Hara sona, PCH 106, CSH 20MF
Pearl millet	Africa	4-5 kg/ha Spacing- 45X15 cm^2	14	**Hybrids-** HB 2,3, BJ 104, CJ104, RHB 30, 90, GHB 15,27,32, NHB 3,4,5 **Composite-** Pusa 266, Pusa safed, PCB 15,164, HC 4, 10

(Bernji *et al*. 2011; Kimber 2000)

7.3.1 Sorghum:

Figure 7.2: Sorghum

Sorghum is one of the finest millet crops for food and forage (fodder for livestock). This offers staple foods in Asia's densely populated nations. In India, this grain is also referred to as *"Jowar" (*Kumari *et al.* 2016; Bantilan et al., 2004). The production of sorghum benefits the income and exports of the nation. Sorghum is a traditional staple food of the dry land regions of the world, a warm season crop intolerant to low temperatures, resistant to pests/ diseases and is highly nutritious. It ranks fifth in terms of cereals produced world-wide and fourth largest produced millet in India (Malabadi *et al.* 2022).

A. Health Benefits:

- By lowering the amount of free radicals, one can lower their chance of developing a number of illnesses, such as cataracts, rheumatoid arthritis, inflammatory bowel disease, atherosclerosis, and cancer.
- Anti-inflammatory & anti-carcinogenic properties due to high riboflavin content.
- Helps in improving blood circulation as it is rich in folic acid.
- Aids in cell regeneration (Thakur *et al*. 2006)

B. Soil and Climate:

Sorghum is grown in the semi-arid tropics variable rainfall areas. Sorghum plants can tolerate high temperatures and dry conditions better than any other cereal crop because of its extensive root system (absorb moisture from deeper soil layer), waxy leaf surface, small leaf area, and ability to curl leaves (that reduces transpiration loss of water). In addition, during a growing season, sorghum can survive periods of moisture stress by becoming dormant and then resuming growth when conditions become favourable. That's why it is referred to as *"the camel"* crops.

Almost all types of soil can be used to produce sorghum, but in India, the soil types that can be used to grow sorghum are classified as vertisols and alfisols, respectively. Sandier soils are not ideal for it to grow. Best adapted are soils that have high levels of organic matter and have a high-water retention capacity and pH levels of 6.0 to 8.5 are ideal for growing crops. The finest soils for its cultivation are regarded as the central India's black cotton soils with good drainage.

C. Field Preparation:

The field is prepared by deep summer ploughing every year in shallow to medium deep soils, and once in 3 years in deep to very deep soils. This should be done soon after harvest of rabi crop in double cropped regions, immediately after cessation of S-W monsoon. This leaves the field cloddy, exposing weed and other pests to high temperatures. The cloddy field also helps in moisture conservation.

With the onset of monsoon, the field is prepared by one deep ploughing followed by 2-3 harrowing or ploughing with country plough. Planking should be performed after each ploughing to break the clods and to level the field. In heavy soils prone to water logging, levelling is necessary to facilitate easy drainage (Bhat *et al.* 2019).

D. Sowing Time:

Sorghum is sown thrice in a year. It is sown in kharif and summer in north. In south and west, it can be grown in kharif, rabi as well as in summer seasons. In kharif under rainfed situations, the onset of monsoons is the single most factors deciding sowing time. The sowing time of sorghum is important aspect in increasing the crop yield. Experiments conducted in major kharif sorghum tracts suggested that last week of June to first week of July (onset of monsoon) is the optimum time of sowing (Aruna *et al.* 2020).

Crop establishment prior to the start of the monsoon is ideal in cases where irrigation is present. Sowings before the monsoon are therefore done 1-2 weeks in advance. Crops that were planted late are similarly vulnerable to midge and shoot fly infestations. Additionally, extra early seeding in April or May causes plant roots to produce *Dhurin*, which is then transported to stems and leaves as hydrocyanic acid (HCN), which is extremely deadly if fed to cattle (Malabadi *et al.* 2022). In the states of Maharashtra and Karnataka, rabi sorghum is farmed. In Andhra Pradesh, it is called *Maghi* season. Under rainfed conditions, the second fortnight of September to mid-October is the best period to seed rabi sorghum. Under irrigated conditions, as in Dharwad (Karnataka), sowings can be delayed and second week of October is the optimum time.

E. Irrigation Management:

Due to its ability to efficiently use water and resilience to drought, sorghum is known as a water sipping crop. Critical stages of irrigation are 30-45 days (seedling elongation stage); 60-65 days (reproductive or heading stages); 70-75 days (panicle emergence); and 90-95 (grain development stage). However, if only one irrigation is available, this should be applied just before booting (40-50 days) from flowering at 10 days' interval or Dithane M 45 – 0.2 % + Bavistin 0.2 % twice at 10 days' interval after commencement of flowering (Solaimalai *et al.* 2001).

F. Fertilizer Management:

It is suggested to apply 10 tons/ha of FYM and 40 kg/ha of nitrogen fertilizer at the last ploughing. It is advised to apply 80 kg of N and 40 kg of P_2O_5 per hectare in the absence of FYM. At sowing, 40 kg of N and all of the P_2O_5 must be applied; the remaining 40 kg must be applied 30 to 40 days later. It is advised to use 60 kg of N and 30 kg of P_2O_5 on light soils with minimal rainfall (IIMR- Sorghum).

G. Weed Management:

Summer ploughing for destroying stubbles and perennial weeds. Timely sowing of crop to minimize crop weed competition. Two weeding with one shallow hoeing up to 3 weeks after sowing will keep the field free from weeds. To check severe weed infestation, apply Atrazine @ 0.25-0.50 kg a.i. per ha against broad leaves weeds and grasses. Pendimethalin @ 1 kg a.i. per ha is applied as per emergence to control grasses. 2,4-D is applied as post emergence at the plant height of 10-30 cm to control broad leaved weeds @ 0.5-0.75 kg/ha (Das TK. 2008). 2,4-D injury in sorghum is known as buggy whipping or onion leafing.

H. Insect Pest Management:

Table 7.4: Insect Pest Management

Insect	Description	Management
Shoot fly (*Atherigona socata*)	Plants are more sensitive up to 4 weeks to this insect, Maggot feed on growing part of plant results in wilting followed by drying of central leaf, known as dead heart.	Early planting in kharif season avoids shoot fly attack. Only for crops sown late, apply spray Cypermethrin 10 EC @ 0.02% at the time of shoot fly oviposition Treat seeds with thiamethoxam 30 FS @ 3g/ kg seeds before sowing or treat seeds
Stem borer (*Chilo partellus*)	This attack on plant in entire growing season, Larvae feed on the upper surface of whorl leaves. Sometimes dead heart also appears on younger plant due to early attack.	Destroy thrashed sorghum ear heads before the onset of monsoon; use high seed rate and thin out the infected plants after 10-12 days of sowing, apply Endosulfan 4G/Carbonfurn 2 gm @ 8- 10 kg/ha in plant rows at 20th and 35th days after germination.
Sorghum midge (*Contarinia sorghicola*)	They attack at blooming Female midge lays eggs between the glumes of floret singly. Larvae destroy the seed causing blank or shrivelled seed coat.	Set up of light traps till mid night to monitor, attract and kill adults of stem borer, grain midge and ear head caterpillars. Neem seed kernel extract 5% (or) Spray malathion 50 EC @ 1600 ml/ha or phosalone 1150 ml/ha

(Aruna *et al.* 2020)

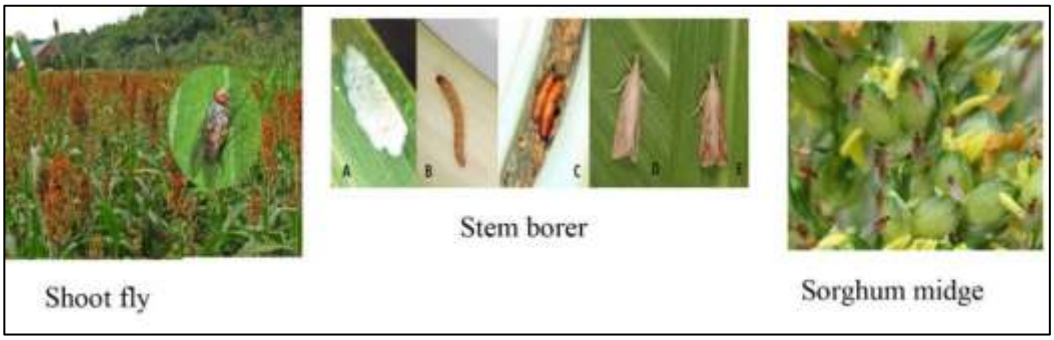


Figure 7.3: Insect Pest Management

I. Disease Management:

Table 7.5: Disease Management

Disease	Symptoms	Management
Loose smut (*Sporisorium cruenta)*	The ears come out much earlier than the healthy. The glumes are hypertrophied and the ear head gives a loose appearance than healthy. The sorus is covered by a thin membrane which ruptures very early, exposing the spores even as the head emerges from the sheath.	Seed treatment with Carboxin (Vitavax) @ 2g/kg or Captan/Thiram 4g/kg of seed. Collect smutted earheads in cloth bags and destruct by dipping in boiling water.
Head smut (*Sporisorium relianum*)	The entire ear head is either completely or partially replaced by a large whitish gall. The spores are blown away, exposing the dark filaments	
Long smut (*Tolyposporium ehrenbergii)*	Relatively small proportion of the florets are infected. The sori or spore sacs are cylindrical, elongate, usually slightly curved with a relatively thick creamy-brown covering membrane.	
Downy mildew (*Pernosclero sporasorghii*)	Green white strips on leaves and white patches of oospores, chlorotic plants.	Seed dressing with ridomil 25 @ 1 g a.i./kg seed.

(IIMR- Sorghum)

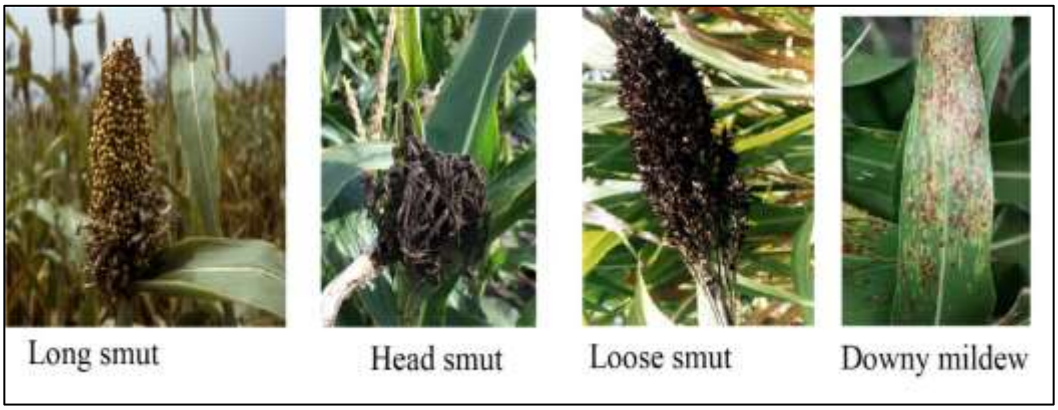


Figure 7.4: Disease Management

J. Harvesting and Yield:

The yield of sorghum crop varies from variety to variety and soil to soil. It also depends on other factors such as climate, irrigation and crop management practices. The grain yield of improved sorghum varieties under assured water supply ranges between 25-40 quintals / ha and 150-180 quintals / ha of hay can be obtained.

7.3.2 Pearl Millet:

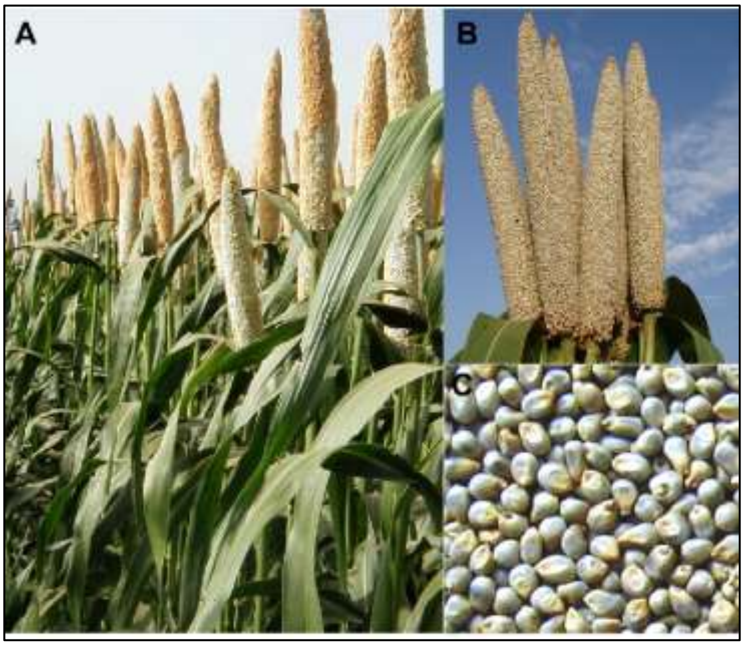


Figure 7.5: Pearl Millet

Pearl Millet is an annual grass which is grown widely in Africa and India for its grain which can be used to make flour and other foodstuffs. Pearl millet is an upright bunch grass that tillers from the base and has an extensive root system that provides drought tolerance (Satyagopal *et al*., 2014). Pearl millet is used by livestock producers for grazing, silage, hay, and green chop (Newman *et al.*, 2010). When compared to other warm-season millets including Japanese, and proso millet, it is the best option for forage. Pearl millet is safe to feed because it does not produce prussic acid or contain tannins like sorghum does.

In India, pearl millet is the fourth-most significant cereal after rice, wheat, and sorghum and a major source of dietary energy (360 kcal/kg) for the rural population (Nambiar *et al*. 2014). It contains a lot of iron, calcium, phosphorus, and protein.

Thiamine, riboflavin, and niacin are present in pearl millet grain in quite high concentrations. Moreover, pearl millet grain is utilised for non-food applications such the production of ethanol and animal feed. (Basavaraj *et al*. 2010). For a prolonged period of time, diabetes patients can effectively maintain their blood sugar levels with pearl millet (Dayakar Rao *et al.* 2017).

A. Time of Sowing: Sowing of *kharif* pearl millet should be done with the onset of monsoon i.e. first fortnight of July in north and central parts of the country. First fortnight of October is appropriate time for rabi season in Tamil Nadu. Gap filling should be done by transplanting seedlings after 2-3 weeks of sowing if scanty population exists.

B. Soil and Climate: Pearl millet is widely cultivated in India's semi-arid and arid regions in lighttextured red sandy, red loamy, alluvial, and coastal alluvial soils, as well as on mixed black, red, and medium black soils. It can be grown as well on medium-black soils, deep alluvial loams, and sandy and gravelly soils with low organic matter, but the yield is low. When the atmospheric temperature is between 30-34 °C, pearl millet thrives.

Compared to other significant grown cereals, it is more resistant to higher temperatures. Pearl millet seed germinate best at temperature between 23-32 °C. If seeds are planted before soil reaches 23°C, they may not emerge properly. At the time of flowering and grain filling stage there should be no rainfall and weather should be dry and clear (Khairwal *et al.* 2007).

C. Land Preparation: For the cultivation of millet, one ploughing should be done with a soil turning plough. After this, do 2 to 3 ploughing with country plough or harrow, keeping in mind that planking must be applied after each ploughing. If there is a problem of termite pest in the field, then neem cake should be used at the rate of 20 to 30 kg per hectare.

D. Irrigation: Pearl millet is generally grown during the kharif season under rainfed conditions in areas of low rainfall. It is given supplemental irrigation when long dry spell prevails. Water requirement of this crop is much lower (250- 350 mm) than maize, sorghum, finger millet (500-600 mm) (IIMR- Pearlmillet). Though pearl millet is rainfed crop, irrigation at anthesis or flowering is beneficial.

E. Nutrient Management: Application of 40 kg N + 20 kg P_2O_5/ha for arid regions and 60 kg N/ha + 30 kg P2O5/ha for semi-arid regions is recommended for sole pearl millet as well as intercropping system. In light soils (sandy loams) the applied nitrogen may be lost due to leaching with heavy rains. So, only about half of the recommended nitrogen dose should be applied at seedbed preparation.

The remaining half of nitrogen dose is side-dressed when the crop is 25 days old. On soils which do not leach easily like black soils, all of the nitrogen may be applied during seedbed preparation (IIMR- Pearlmillet).

G. Weed Management: The herbicidal weed control achieved by pre-emergent application of atrazine @ 0.5 kg ha^{-1} combined with one hand weeding is similar to the effectiveness of two hoeing and weeding at 15 and 30 days after sowing. Atrazine is more efficient for weed control as compare to simazine in dryland areas.

To preserve soil hydration, do a second round of weeding. Pendimethalin apply for the control of annual grasses and some broad leaves weeds @ 0.75-1.0 a.i. kg ha^{-1} (Das TK. 2008).

H. Insect Management:

Table 7.6: Insect Management

Insect	Description	Management
Shoot fly (*Atherigona approximate*)	Pest of N-India, attack up to 3-week plant, lays eggs singly on either lower side of leaf or base of plant, cut the apical points results in dead heart cut off panicles.	Early plantig. Two dusting of 5% malathion @ 25 kg/ha at 10 & 20 DAS
Grain midge (*Geromyia penniseti*)	Attack on developing grains, lays egg in flower, grain less glumes with white purple case on tip of spikelet	Spray metacide 250 cc or thiodan 625cc
White grub (*Holotrachia spp*.)	Feed on roots of young seedling results in wilting like appearance, maximum damage in July august	Intercropping with legumes Seed treatment with chlorpyriphos 20 EC @ 12.5 ml/kg seed.

I. Disease Management:

Table 7.7: Disease Management

Disease	Symptoms	Management
Downy mildew or green ear disease *(Sclerospora graminicola*)	Downey growth on lower leaf surface wrinkled and split leaves profuse the tillering, ears either not produced or abnormal ear which transferred into twisted leafy structure,	Use of hybrid and composite varieties, seed treatment with Apron 35D @ 8 gm per kg seed.
Smut (*Tolyposporium penicillariae*)	Grains are replaced by powdery material, initially these are green later become dark black that cause secondary infection	Spray Vitavax or Plantavax 0.25% on panicle at booting stage
Ergot (*Claviceps fusiformis*)	Small droplets of pinkish or light honey-like fluid exuding from infected spikelet of ear, which dried at become hard	Use 105% salt solution remove sclerotia, Use a mixture of ziram 2 g/liter (0.1%) + benlate (0.1%).

Source : AESA; IIMR- Pearlmillet)

Figure 7.6: Disease Management

J. Harvesting:

The best stage to harvest pearl millet is when the plants reach physiological maturity determined by the black spot at the bottom of the grain in the hilar region. When the crop matures, the leaves turn yellowish and present a nearly dried up appearance.

The grains are hard and firm. The usual practice of harvesting pearl millet is cutting the ear heads first and the stalks later. The stalks (straw) are cut after a week, allowed to dry and then stacked. Grain at or below 14% moisture is considered dry. For long-term storage (more than 6 months), grain moisture content should be less than 12%.

7.4 Minor Millets:

Table 7.8: Varieties

Crop name	Origin	2n	Seed rate kg/ha		Sowing time	Spacing (cm)
			Line sowing	Broadcasting		
Finger millet	Africa	40	6-8	5-5 (Transplanting)	June-July	22.5x7.5-10
Foxtail millet	Eastern Asia	18	8-10	15	TN- Aug.-Sep. UP, BH – Mid June AP - 1st fortnight of July	25-30x10
Kodo millet	India	40	10	15	June-July	22.5x10

Crop name	Origin	2n	Seed rate kg/ha		Sowing time	Spacing (cm)
			Line sowing	Broadcasting		
Proso millet	Egypt	36	10	15	TN- Sep.-Oct. KR, AP- July UK- May-June	25x10
Barnyard millet	India	54	8	10-12	Sept.-Oct. & Feb-March	22.5x10
Little millet	India	36	8	10	June-July	22.5x10

(Hatakeyama *et al*. 2017; Saha *et al.* 2016; Jia *et al*. 2013; Bennetzen *et al*, 2012)

7.4.1 Varieties:

Table 7.9: Varieties

Crop	Varieties
Finger millet	GPU 67, 48, VR 847 (Chaitanya), PRM 1, ML 365, MR 6 (Divya), VL 315, VR 762 (Bharathi), Vegavathi (VR 929), CFMV 1 (Indravathi), CFMV 2, Dapoli 1, Phule Nachani,
Foxtail millet	PS 4, Sri Lakshmi, SR 16 (Meera), 51, PRK 1, TNAU 43
Kodo millet	KK2 Jawahar kodo 48,13,65,439, RMV 20
Proso millet	Pratap chena 1, TNAU 145, 164, 151, PRC 1
Barnyard millet	Pratap sanwa 1, VL Madira 172, 181, 207, PRJ 1
Little millet	Paiyur 2, OLM 20, 36, 203, 208, Co 4, CLMV 1, Sree Neelima

7.4.2 Description:

Among millets, ragi or finger millet has a unique place and is the only millet which has been able to touch an average productivity level of more than a tonne per hectare. About 60% of finger millet is produced by the state of Karnataka which account for about 34% of global production (Chandra *et al.*, 2016; Upadhyaya *et al.*, 2007). Finger millet is a dwarf, highly tillering plant with characteristic finger like terminal inflorescences.

A minor millet called barnyard millet has a calcium concentration that is about ten times higher than that of rice or wheat. The millet that contains the most carbohydrates is finger millet (Gulla *et al.* 2014). Micronutrients like magnesium, calcium, manganese, serotonin, phosphorus, fiber, and B vitamins are also abundant in minor millets. These micronutrients act as antioxidants which are essential to human body.

Minor millets also have the advantage of requiring very little water for cultivation and being able to endure harsh climatic conditions. To attain nutritional security and maintain rain-fed farming in the nation, new high-yielding crops are required. Promotional strategies and policies are also required (Singh *et al.* 2020).

Proso millet's common name, "*broom corn,"* derives from the compact panicle's top, which droops like an old broom (Changmei and Dorothy, 2014). It is well suited for many soil types and climate conditions. Proso millet is highly drought resistant, which makes it of interest to regions with low water availability and longer periods without rain.

Little millet but the plant is generally shorter in stature, has smaller panicles and seeds, and is grown on a limited scale voluntarily or with minimum care on poor lands. Little millet matures quickly and withstands both drought and water logging. It is generally consumed as rice and any recipe that demands staple rice can be prepared using little millet (Prasad and Staggenborg, 2009).

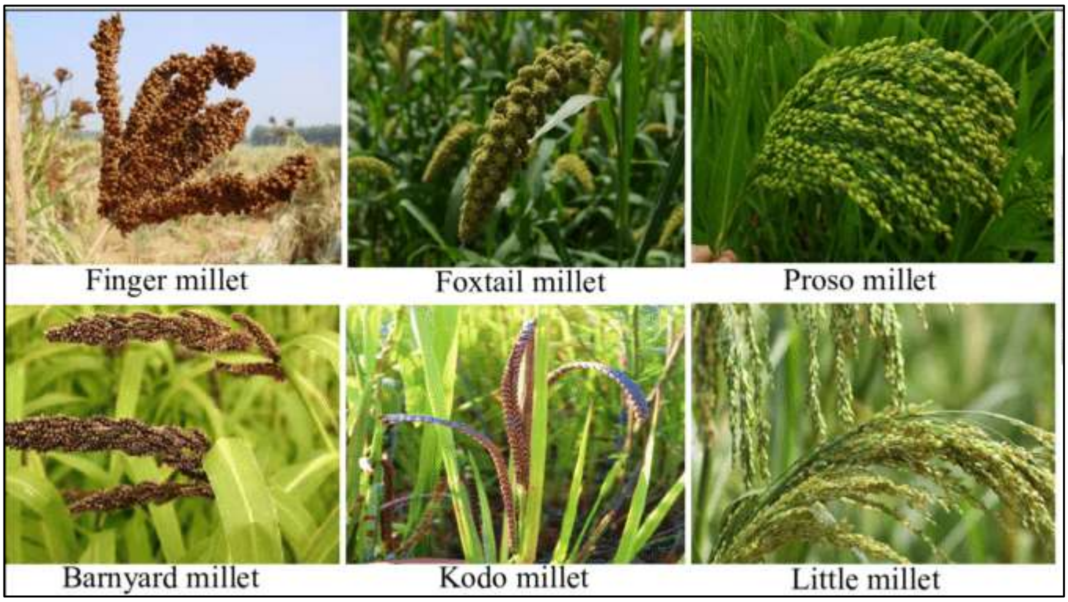


Figure 7.7: Description

Kodo is known to be extremely hardy, drought resistant and grows on stony or gravelly soils which do not support other crops. It is relatively long in duration requiring four to six months to mature compared with two to four months for the other millets. It has the highest dietary fiber among stall the millets (Prasad and Staggenborg, 2009).

7.4.3 Climate and Soil:

These crops have a wide range of seasonal adaptation and is grown in varying soil and temperature conditions. These can be grown throughout the year if moisture is adequate and if temperatures are above 15°C. Alluvial and black soils are also suitable provided the soils are well drained.

7.4.4 Tillage:

Fall ploughing is advantageous for moisture conservation. In the month of April or May, one deep ploughing should be done with a soil turning plough. Followed by country ploughing twice is necessary. Before sowing secondary tillage with cultivator and multiple tooth hoe to prepare smooth seed bed is necessary.

7.4.5 Manures and Fertilizers:

Adequate application of FYM, 7.5 to 10 tonnes per hectare help in better development of root growth. The general recommendation in finger millet is 40, 20, 20 kg N, P_2O_5 and K_2O for rainfed and 60:30:30 N, P_2O_5 and K_2O for irrigated conditions. All P_2O_5 and K_2O are to be applied at sowing whereas, nitrogen is applied in split doses. And recommended N, P_2O_5 and K_2O dose for remaining millets is 40:20:0. The small millets respond well to moderate application of N and P_2O_5. The response to K has not been observed. (Source: IIMR).

7.4.6 Weed Control:

Weed free condition throughout the crop growth period was essential for obtaining significantly higher grain yield in small millets. The critical period for crop with competition is initial 45 days in all the small millets. Two manual weeding at 15-20 days and 30-35 after sowing are sufficient to control the weeds. Isoproturon @ 0.5-0.75 kg a.i./ha applied as pre-emergence spray or mixed with sand or soil along with one hand weeding 30-45 days after sowing has been found effective in controlling weeds in finger, kodo, foxtail and barnyard millet (AICSMIP, 2005).

A. Pre-emergence spray: Oxyflurofen @ 0.1 lt a.i /ha (Irrigated areas)

B. Post-emergent spray: 2, 4-D sodium salt @ 0.75 kg a.i./ha Spraying around 20-25 days after sowing effectively control weeds.

7.4.7 Water Management:

Foxtail millet is grown in dry areas as a rainfed kharif crop, but if water is available, irrigation that can save lives can be provided during intermittent dry periods between rainy spells. Chapke et al. (2018) suggested providing two irrigations, at 25–30 and 45–50 days after sowing. Proso millet- Kharif crop does not require any irrigation. During prolonged dry spells, protective irrigation at tillering, flowering and grain formation stage need to be given.

Summer crop require 4 to 6 irrigations depending upon soil type and climatic conditions (Prabhakr *et al*. 2017). Kodo millet - Irrigations are necessary during dry spells depending on the soil type and the severity of the drought, first irrigation should be done at 25–30 days after sowing and after 40–45 days of sowing second irrigation should be done. When it rains heavily and continuously, drain the excess rainwater from the field (Prabhakar *et al*. 2017; Dwivedi *et al.*, 2012).

Barnyard millet - During kharif season, the crop does not require irrigation but at the time of long dry spells, first irrigation at 25-30 days after sowing (tillering stage) and second irrigation at 45-50 days after sowing (panicle initiation stage) needs to be given.

7.4.8 Harvesting and Threshing:

Harvesting should be done when the ear head colour starts fading or grains at low portion of ear head mature. Grain maturity is not uniform in proso millet. Delayed harvesting causes considerable yield losses due to shattering and bird damage. Well dried gains can be stored for long period. All the small millets (except finger millet) have outer tough seed coat layer. The separation of seed coat from endosperm is usually done by repeated ponding in mortar.

7.5 References:

1. All India Coordinated Small Millet Improvement Programme (AICSMIP). 2005.
2. Amadou I, Gounga ME, and Le G W. 2013. Millets: nutritional composition, some health benefits and processing-A review. *Emirates Journal of Food and Agriculture,* 25, 501–508.
3. Aruna C, Deepika C, Raghavendra Rao KV and Tonapi VA. 2020. Golden Jubilee Publication: 50 Years of Sorghum Research: Contribution of AICRP-Sorghum Centres, *ICAR-Indian Institute of Millets Research, Hyderabad*, PP: 233
4. ASSOCHAM. 2022. Knowledge paper on Millets by The Associated Chambers of Commerce and Industry of India, Available at https://www.assocham.org/uploads/files/Report_Millets%202022%20(Print%20Version)%20(1).pdf
5. Bantilan, M.C.S., Gowda, C.L.L., Reddy, B.V.S., Obilana, A.B., Evenson, R.E., 2004. Sorghum Genetic Enhancement: Research Process, Dissemination and Impacts. Monograph. International Crops Research Institute for the Semi-Arid Tropics.
6. Basavaraj G, Parthasarathy RP, Bhagavatula S andS Ahmed W. 2010. Availability and utilization of pearl millet in India. *Journal of SAT Agriculture Research,* 8:1–6.
7. Bennetzen JL, Schmutz J, Wang H, Percifield R, Hawkins J and Pontaroli AC. 2012. Reference genome sequence of the model plant Setaria. *Nature Biotechnology,* 30:555–561
8. Berenji J, Dahlberg J, Sikora V, and Latkovic D. 2011. Origin, History, Morphology, Production, Improvement, and Utilization of Broomcorn [Sorghum bicolor (L.) Moench] in Serbia, *Economic Botany*, **65**(2):190–208
9. Bhat BV, Ratnavathi CV, Rao BD, Chapke R, Swarna R, Padmaja PG, Prasad GS, Das IK, Aruna C, Venkateswarlu R, Kannababu N, Sooganna, Rao SS, Singode A, Talwar HS, Babu KS and Tonapi VA. 2019. Manual on Good Agricultural Practices in Millets, *ICAR-Indian Institute of Millets Research*, PP 53.

10. Chandra D, Chandra S and Sharma AK. 2016. Review of Finger millet (Eleusine coracana (L.) Gaertn): a power house of health benefiting nutrients. Food Science and Human Wellness, 5:149-155.
11. Changmei S, and Dorothy J. 2014. Millet- the frugal grain, *International journal of science research and review*, 3:75-90.
12. Chapke, R.R., Prabhakar, Shyamprasad, G., Das, I.K. and Tonapi, V.A. 2018. Improved millets production technologies and their impact. Technology Bulletin, *ICAR-Indian Institute of Millets Research*, pp. 52-56.
13. Das TK. 2008. Weed science: Basics and applications, Jain Brothers (New Delhi), PP 640-802.
14. Dayakar Rao B., Bhaskarachary K., Arlene Christina G.D., Sudha Devi G., Vilas, A. Tonapi, (2017). Nutritional and Health benefits of Millets. *ICAR_Indian Institute of Millets Research (IIMR)* Rajendranagar, Hyderabad, PP 112.
15. Dwivedi, S., Upadhyaya, H., Senthilvel, S., Hash, C., Fukunaga, K., Diao X. 2012. Millets: Genetic and genomic resources. *Plant Breeding Reviews*, 35:247–375.
16. FAO Statistical Yearbook 2021 - World Food and Agriculture.
17. Goron TL AND Raizada MN. 2015. Genetic diversity and genomic resources available for the small millet crops to accelerate a new green revolution. *Frontiers Plant Science*; 6:157.
18. Gowda NAN, Siliveru K, Prasad PVV, Bhatt Y, Netravati BP, Gurikar C. 2022. Modern Processing of Indian Millets: A Perspective on Changes in Nutritional Properties. *Foods*;**11**(4):499.
19. Gull A., Jan R., Nayik G.A., Prasad K and Kumar P. 2014. Significance of finger millet in nutrition, health and value added products: A Review. *Journal of Environmental Science, Computer Science and Engineering & Technology*; 3:1601–1608.
20. Hatakeyama M, Aluri S, Balachadran MT, Sivarajan SR, Patrignani A and Grüter S. 2017. Multiple hybrid de novo genome assembly of finger millet, an orphan allotetraploid crop. *DNA Research*. 25:39–47.
21. https://vikaspedia.in/agriculture/crop-production/package-of-practices/cereals-and-millets/bajra-1
22. Indian Institute of Millet Research, Technologies-Recommended packages and practices: Finger millet. *IIMR*, Pp 1-6
23. Indian Institute of Millet Research, Technologies-Recommended packages and practices: Pearlmillet. *IIMR*, Pp 1-6
24. Indian Institute of Millet Research, Technologies-Recommended packages and practices: Sorghum. *IIMR*, Pp 1-5
25. Indian Council of Medical Research. 2020. Recommended Dietary Intakes for Indians, Report of an Expert Group. *ICMR, New Delhi.*
26. Jia G. Huang X, Zhi H, Zhao Y, Zhao Q and Li W. 2013. A haplotype map of genomic variations and genome-wide association studies of agronomic traits in foxtail millet *(Setaria italica*). *Nature genetics*. 45:957–961.
27. Kam J, Puranik S, Yadav R, Manwaring HR, Pierre S, Srivastava RK and Yadav RS. 2016. Dietary interventions for type 2 diabetes: how millet comes to help. *Front Plant Science* 7:1454.
28. Khairwal IS, Rai KN, Diwakar B, Sharma YK, Rajpurohit BS, Bindu N and Bhattacharjee R. 2007. Pearl millet: Crop management and seed production Manual, *International Crops Research Institute for the Semi-Arid Tropics*, 104 pp.

29. Kimber, C. T. 2000. Origins of Domesticated Sorghum and its Early Diffusion to India and China. Pages 3–98 in C. W. Smith and R. A. Frederiksen, eds., Sorghum: Origin, History, Technology, and Production. John Wiley & Sons Inc, New York.
30. Kumari P, Pahuja SK, Arya S, and Patil JV. 2016. Broadening the Genetic Base of Grain Cereals: Sorghum, *Springer India* 163-203
31. Maitra, S. 2020. Potential horizon of brown-top millet cultivation in drylands: *A review, Crop Research*. **55** (1 & 2): 57-63.
32. Malabadi RB, Kolkar KP and Chalannavar RK. 2022. Sweet Sorghum for Biofuel Energy: Grain Sorghum for Food and Fodder- Phytochemistry and Health Benefits, *International Journal of Innovation Scientific Research and Review,* **4**(9):.3305-3323.
33. Mishra P, Prakash HG, Devi S, Sonkar S, Yadav S, Singh HC and Singh D R. 2021. Nutritional Quality of Millets and their Value Added Products with the Potential Health Benefits: A Review. International Journal of Current Microbiology amd Applied Science, **10**(10): 163-175.
34. Muthamilarasana M, Dhakaa A, Yadav R & Prasad M. 2016. Exploration of millet models for developing nutrient rich graminaceous crops. *Plant Science,* 242, 89-97.
35. Nambiar SV, Dhaduk JJ, Sareen N, Shahu T and Desai R. 2014. Potential Functional Implications of Pearl millet (Pennisetum glaucum) in Health and Disease, *Journal of Applied Pharmaceutical Science,* **1**(10); 2011: 62-67
36. National Institute of Nutrition 2003. Indian Foods Nutritional Value
37. Newman YE, Jennings, JV, and Blount A, 2010. Pearl millet (Pennisetum glaucum): overview and management. Univ. of FL. IFAS Extension. Publication #SS-AGR-337.
38. Prabhakar, Ganiger PC, Boraiah B, Bhat S, Nandini C, Kiran, Tippeswamy V and Manjunath HA. 2017. Improved production technology for kodo millet. *ICAR-All India Coordinated Research Project on Small Millets, pp 18.*
39. Prabhakar, Ganiger PC, Boraiah B, Bhat S, Nandini C, Kiran, Tippeswamy V and Manjunath HA. 2017. Improved production technology for proso millet. *ICAR-All India Coordinated Research Project on Small Millets, pp 18.*
40. Prasad PVV and Staggenborg AS. 2009. Growth and production of sorghum and millets, in Soils, Plant Growth and Crop Production, [Ed. Willy H. Verheye], in Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, Eolss Publishers, Oxford, UK.
41. Press Information Bureau. 2022. Exports of millets to increase exponentially as Indian exporters find new markets Government working aggressively to facilitate and boost exports India is the fifth largest exporter of millets in 2020- 21, India's millets exports were valued at USD 26.97 million. Available at: https://pib.gov.in/PressReleaseIframePage. aspx? PRID=1796514.
42. Saha, D, Gowda MVC, Arya, L, Verma M and Bansal K.C. 2016. Genetic and genomic resources of small millets. *Critical Reviews in Plant Science* 35:56–79
43. Santra, DK. 2013. Proso Millet Varieties for Western Nebraska. Lincoln, NE: *University of Nebraska-Lincoln.*
44. Satyagopal K, Sushil SN, Jeyakumar P, Shankar G, Sharma OP, Sain SK, Boina DR, Lavanya N, Rao NS, Sunanda BS, Asre R, Murali R, Kapoor KS, Arya S, Kumar S, Patni CS, Yadava, Naik BG, Deshmukh S and Gangopadhyay AK. 2014. AESA based IPM package for Pearl Millet. pp 34.
45. Singh A, Kumar M and Shamim Md. 2020. Importance of minor millets (Nutri Cereals) for nutrition purpose in present scenario, *International Journal of Chemical Studies*, **8**(1): 3109-3113

46. Solaimalai A, Ravisankar N and Chandrasekaran B. 2001. Water management to sorghum, Agriculture *Review*, **22** (2): 115 - 120
47. Tadele Z. 2016. Drought adaptation in millets. In: Shanker AK, Shanker C (eds) Abiotic and biotic stress in plants: recent advances and future perspectives, *InTech*, *Rijeka*, pp 639–662.
48. Thakur RP, Reddy BVS, Indira S, Rao VP, Navi SS, Yang XB and Ramesh S. 2006. Sorghum Grain Mold Information Bulletin No. 72. Patancheru, Andhra Pradesh, India: *International Crops Research Institute for the Semi-Arid Tropics*. Pp 32.
49. Upadhyaya H, Gowda C, Reddy V. 2007. Morphological diversity in finger millet germplasm introduced from Southern and Eastern Africa. *Journal of Agricultural Resreach;***3**(1):1-3.
50. Yadav OP and Rai KN. 2013. Genetic improvement of pearl millet in India, *Agriculture Research,* **2**(4):275–292.

ISBN: 978-81-19149-19-3

8. Agronomic Practices for Enhancing Millet Productivity

Varsha Pandey

Assistant Professor,
School of Agricultural Sciences GD Goenka University,
Sohna road, Gurugram, Haryana.

Abstract:

Millets are a group of small grained cereals, termed as "Nutri cereals" having nutritionally rich grains and can be cultivated under poor soil fertility and low moisture conditions. These crops assume a large portion of the nutritional security in the drylands.

They have a short life cycle and can adapt to harsh climatic conditions. Major millet crops cultivated in India include sorghum or jowar, pearl millet or bajra and minor or small millet include finger millet or ragi, barnyard millet or sawan, foxtail millet or kakum, kodo millet or koden, little millet or kutki and proso millet or cheena.

Despite the climate friendly cultivation and highly nutritious nature of millets, the area under millets cultivation is drastically declining. Thus, adoption of improved agronomic practices is the key to sustain millets productivity at desired levels and for ensuring long term ecological and economic sustainability in rainfed millet systems.

Keywords:

Agronomic, enhancing, millets, productivity.

8.1 Introduction:

The word millet is derived from the French word "mille" meaning a handful of millets contain thousands of seed grains. Millets are a group of small grained cereals belonging to the grass sub-family Panicoideae, generally termed as "Dryland cereals" or "Nutri-cereals" which were found to be domesticated around 8000 years ago in the highlands of central China [1]. Millets are low input requiring crops which are nutritionally rich and can be cultivated under poor soil fertility conditions. Life cycle of most of the millets is completed in 60 to 120 days and can endure unpredicted climatic conditions. Millets are staple crops in the semi-arid tropics, found in low rainfall areas and assume an important position for nutritional security in the dryland areas. Due to their inherent drought tolerance and pests and disease resistance mechanism, millets are well considered as the "crops of antiquity" [2]. In India different types of millets are grown and broadly millets are classified into two groups- major and minor millets. Major millets comprise sorghum and pearl millet and minor or small millet comprise finger millet or ragi, barnyard millet, foxtail millet, kodo millet, little millet, proso millet and brown top millet (Table 8.1). With the ever-increasing global population, agrifood systems in India are facing major challenges.

Millets being climate resilient, drought tolerant and eco-friendly crop provides an affordable and nutritious option and efforts are required to promote its cultivation and ensure sustainable income for resource poor and marginal farmers. According to FAO Director-General QU Dongyu, “Millets can play an important role and contribute to our collective efforts to empower smallholder farmers, achieve sustainable development, eliminate hunger, adapt to climate change, promote biodiversity and transform agrifood systems”.

Table 8.1: General Information About Millets.

Sr. No.	Crop	Scientific name	Common name	Place of origin	Major growing states in India	Scientific name	Common name
1.	Pearl millet	*Pennisetum glaucum*	Bajra	Africa	Rajasthan, Maharashtra, Gujrat, Uttar Pradesh, Haryana, Karnataka, Madhya Pradesh, Tamil Nadu, and Andhra Pradesh.	*Pennisetum glaucum*	Bajra
2.	Sorghum	*Sorghum bicolor*	Jowar	Northeastern Africa	Maharashtra, Karnataka, Madhya Pradesh, Tamil Nadu, Andhra Pradesh, Rajasthan, Uttar Pradesh and Gujarat.	*Sorghum bicolor*	Jowar
3.	Finger millet	*Eleusine coracana*	Ragi/ Mandua	East Africa	Karnataka, Uttarakhand, Maharashtra, Tamil Nadu, Odisha, Andhra Pradesh and Gujarat.	*Eleusine coracana*	Ragi/ Mandua
4.	Foxtail millet	*Setaria italica*	Kangni or Kakum	Central Asia (India)	Andhra Pradesh, Bihar, Karnataka, Rajasthan, Tamil Nadu, Telangana, Uttarakhand and Uttar Pradesh.	*Setaria italica*	Kangni or Kakum
5.	Kodo millet	*Paspalum scrobiculatum*	Koden	India	Madhya Pradesh, Chhattisgarh, Maharashtra, Tamil Nadu, and Karnataka.	*Paspalum scrobiculatum*	Koden

Sr. No.	Crop	Scientific name	Common name	Place of origin	Major growing states in India	Scientific name	Common name
6.	Barnyard millet	*Echinochloa frumentacea*	Sawan	India	Karnataka, Madhya Pradesh, Uttarakhand, Uttar Pradesh and North-eastern India.	*Echinochloa frumentacea*	Sawan
7.	Proso millet	*Panicum miliaceum*	Cheena	Central Asia (India)	Bihar, North-eastern India and Maharashtra.	*Panicum miliaceum*	Cheena
8.	Little millet	*Panicum sumatrense*	Kutki	India	Karnataka, Madhya Pradesh, Andhra Pradesh, Tamil Nadu, Jharkhand, Odisha, Maharashtra and Chattisgarh.	*Panicum sumatrense*	Kutki

8.2 Nutritional Importance of Millets:

Millets play an indispensable and significant role in traditional diets of many Indians. When compared to nutritional content of rice and wheat, millets are three to five times higher, making it yield of agricultural security.

Millets are treated as nutri-cereals due to the presence of different antioxidants and detoxifying agents in millet grains.

These are also rich in different minerals and dietary fibres and used as a livestock feed both grain and forage. There are multiple health benefits of millets:

- Millets contain copper and iron, which are required for improving blood oxygen level by producing more blood cells.
- Phosphorus in millets also helps in maintaining blood pressure. Millets when consumed in large quantities also helps in reducing triglyceride content in the body, thereby reducing the risk of coronary artery diseases.
- Millets contain vitamin B which helps in easy breakdown of carbohydrates and fats in body. Niacin in millets helps in increasing the HDL level of blood streams. They contain no saturated fats and are gluten free grains.
- They are also good source of essential fatty acids like linoleic acid, oleic acid and palmitic acid. Being gluten free, millets are perfect food for people suffering from celiac disease.
- Millets contain an amino acid Tryptophan and high fibre content which helps in maintaining body weight by lowering the appetite and helps in weight management. The fiber content in millets is higher than rice and wheat. Nutritive value of various millets has been summarized in **Figure 8.1**.

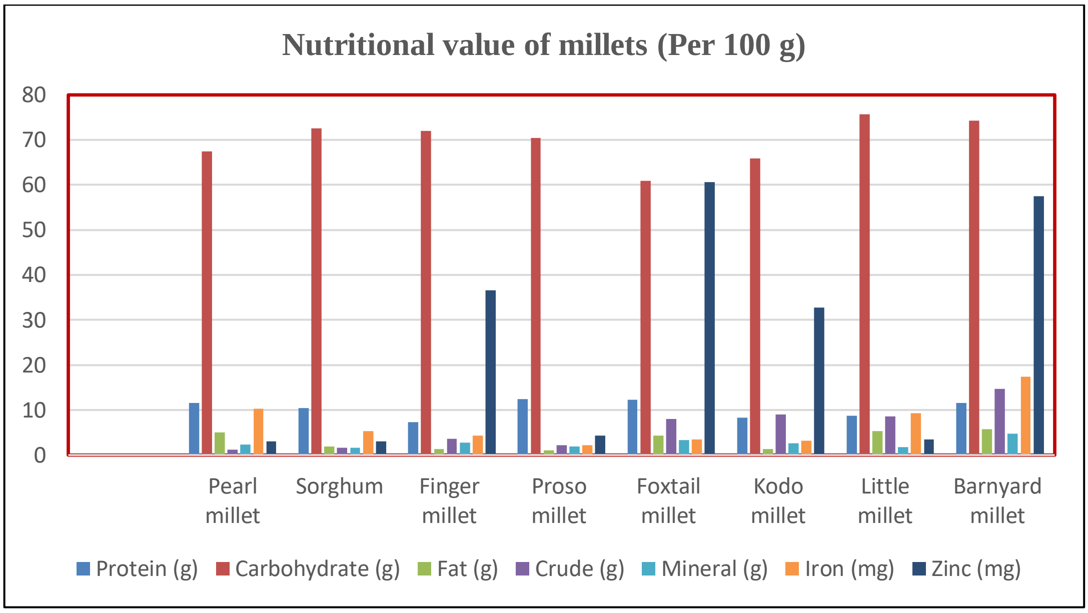


Figure 8.1: Nutritional Value of Different Millets.

8.3 Millet's Cultivation in India:

Millets are gaining massive attention due to their nutritional advantage and gluten free nature. They are low input requiring crops and at the same time eco-friendly and they provide food security to the dryland agricultural communities.

They are considered as the most secure crop for small and marginal farmers as millets are adaptable to harsh, hot and drought climatic conditions.

India is the leading producer and consumer of various millet crops and their products. Pearl millet and Sorghum together constitutes approximately 19 percent in world production in 2020. The major millets producing states in India are Rajasthan, Maharashtra, Karnataka, Gujarat, Uttar Pradesh, Tamil Nadu and Uttarakhand. Area for small millets is maximum in Madhya Pradesh, Uttarakhand and Chattisgarh (Figure 8.2).

A total of about 16.9 million tonnes of millets food grains are produced in India from nearly 12.7 million ha area, which constitutes about 6% of the national food grain basket (Table 8.2). 95% of the total area under millets is constituted by pearl millet, sorghum and finger millet whereas less than 5% of the area is constituted by small millets (barnyard millet, foxtail millet, little millet, kodo millet and proso millet) (Directorate of Economics and Statistics, DA&FW 2021). Millets are highly suitable for contingency crop planning due to their fast growth and short crop cycle.

The area under millets is shrinking due to lack of high-quality seeds and confinement to poor and marginal farmers only.

Table 8.2: Millet Crops Area and Yield During 2009-22

Millet	**Area ('000 ha)**			**Yield (kg/ha)**		
	2009-13	2014-18	2019-22	2009-13	2014-18	2019-22
Sorghum	6684	4910	4355	913	897	1064
Bajra	8480	7142	74151	1065	12231	13691
Ragi	1211	1104	1097	1580	1549	1647
Small millets	773	570	436	554	707	800
Total millets	17149	13726	12680	1019	1111	1273

(Source: Estimations of Dept. of Economics & Statistics, DAC&FW, GoI, New Delhi)

(Source: agricoop.nic.in)

Figure 8.2: Millets map of India

8.4 Agronomic Practices for Enhancing Yield of Millets:

8.4.1 Sowing Dates, Sowing Methods and Improved Varieties:

One of the most important inputs influencing the crop yield is sowing time. Sowing of millets during appropriate time improves its productivity as it provides suitable environment to millets at all the growth stages.

There has been observed a reduction in grain yield with delayed sowing. Millets are grown during all the seasons of the year. *Kharif* crop should be grown from last week of June to first week of July depending on the onset of monsoon. Whereas *Rabi* crop should be grown during the month of October-November and summer crops during January – February. Optimum spacing and seed rate also enhances yield of millets. Optimum line to line distance at the time of sowing should be 20-30 cm and plant to plant distance should be 10-15 cm. The recommended seed rate for finger millets under line sowing should be 5-6 kg/ha and under transplanted conditions, it should be 4 kg/ha. For other small millets, it should be 5-6 kg/ha under line sowing and 8-10 kg/ha under broadcasted conditions. Direct sowing of millets offers some advantages like easier and faster planting, crop matures earlier, efficient utilisation of water. In case of direct seeded millets, time of sowing plays a vital role in enhancing the productivity of crops. The use of transplanting method of planting in millets is helpful for late maturing and high yielding varieties. It improves the establishment of seedlings in the field and affects the growth cycle of millets. As millets are confined mostly to marginal lands, less attention is given to the crop improvements in comparison to cereals. After the launch of AICRP-Small millets, several high yielding varieties of millets with tolerance to various insects, pests and diseases have been released for cultivation across the country (Table 8.3).

Table 8.3: High Yielding Varieties of Millets and Their Characteristics

Sr. No.	Crop	Some of the improved and high yielding varieties and hybrids of millets	Special features of the improved varieties and hybrids
1.	Sorghum	CSH 1, CSH 5, CSH 6, CSH 9, CSH 14, CSH 16, CSH 35 and CSH 4, CSV 1 to CSV 41	Resistance against major pests and diseases, superior quality grain and fodder yield.
2.	Pearl millet	MPMH 21, RHB 223, MBC 2, ICTP 8203, GB 8735, ICMV 221, Pusa 1201	high grain Fe content, highly resistant to downy mildew, smut and rust and highly resistant to pests
3.	Proso millet	PMV 442, DHPM-2769, TNAU 202, TNAU 151, PRC 1, TNAU 164	Resistance to brown spot, sheath blight, leaf blight, rust, non-lodging and non-shattering.
4.	Barnyard millet	Phule Barti-1, DHBM 93-3, MDU-1, Co 2, DHBM-23-3	non-lodging and non-shattering, Resistance to shootfly, suitable for contingency planting.
5.	Foxtail millet	Renadu, Garuda, Hagari, Suryandi, RAU-2	High yielding, tolerant to blast and downey mildew, rust and smut.
6.	Kodo millet	ATL 1, Gujarat Kodo millet 4, CKMV 1, Chattisgarh Kodo-03, Jawahar Kodo-137	Tolerant to shoot fly, grain smut, sheath blight, brown smut and shootfly, lower incidence of diseases.

Sr. No.	Crop	Some of the improved and high yielding varieties and hybrids of millets	Special features of the improved varieties and hybrids
7.	Finger millet	Phule Kasari, Birsa Marua, Dapoli 3, CFMV-1, CFMV-1, VR-988, VL Mandua-348	Resistant to finger blast, neck blast, brown spot, foot rot, ear head caterpillars and aphids, suitable for organic cultivation
8.	Little millet	Kalinga Suan 217, CLMV 1, GNV-3, DHLM-14-1, BL 6, Jawahar Kutki 4	Resistant to rust and grain smut, tolerant to shoot fly, leaf blight and brown spot disease, reisitant to drought and lodging

(Source: Hariprasanna 2023[3] and Aruna *et al*. 2023[4])

8.4.2 Intercropping System:

Due to unpredictable weather conditions, growing of millets in their pure stands is quite risky. Under such conditions, to achieve sustained productivity from a land, diversification of crops is mu st. Among the various options of crop diversification, intercropping is the most suitable method. Intercropping is a system of crop production which is aimed at maximizing production and profits over time and space [5].

It is the practice of growing more than one crop on the same field simultaneously in a definite row pattern. Advantages of intercropping includes effective utilization of water, nutrients, land, increased profitability, maximize resource use efficiency, better exploitation of sunlight, risk reduction of insects and pests, maintenance of soil health and ultimately increased profitability, productivity and leading agriculture towards sustainability.

It also checks runoff of water. Complementarity among the species is very important for improving crop yield under intercropping system. Also intercropping provides natural insurance against total crop failure under unfavourable conditions. Different crops which are grown under intercropping system must require dissimilar agronomic practices (Figure 8.3).

A. Some of The Millet-Based Intercropping System Includes:

a. Finger millet-legume (pigeon pea/black gram)
b. Finger millet-groundnut
c. Finger millet + soybean
d. Foxtail millet + pigeonpea
e. Soybean + foxtail millet
f. Groundnut + foxtail millet
g. Little millet + Sesamum
h. Proso millet + black gram
i. kodo millet + soybean
j. Foxtail millet + Castor

Under millets + legume intercropping system, millet component gets additional benefits due to legume effect. It also provides benefit in terms of total productivity of crops, maintenance of soil fertility, requirement of less chemicals for enhancing crop production and control of erosion. Ultimately it provides better ecosystem services which leads agriculture towards sustainability [6].

Use of legumes in the intercropping system had an added advantage of higher soil fertility by Biological Nitrogen Fixation (BNF), low soil and nutrient losses, efficient use of soil moisture and deep-rooted system, enhancement of microbial biodiversity and leaf fall. Development of Sorghum hybrids with erect leaves and greater yield potential will help decrease the competition among intercrops and improve productivity of the system. Combining improved and early maturing Sorghum hybrids with photosensitive pigeon pea has been found to be successful across Karnataka and Maharashtra [7]. Intercropping also enhances the resource use efficiency under millet based cropping system which is depicted in the higher LER (Land Equivalent Ratio).

Figure 8.3: Intercropping of finger millet with soybean (4:1) and intercropping of finger millet with field bean (8:1).

8.4.3 Nutrient Management:

Nutrient stress is one of the greatest constraints in millet productivity. To cope with this stress, recommended doses of fertilizers for the various millets should be given (Table 4). Nitrogen fertilizers are more prone to volatilization, leaching and denitrification loses.

Therefore, should be applied in 2-3 split doses. At planting, half dose of nitrogen and full dose of P and K are applied and are placed below the seed. Remaining nitrogen is used as side dressing. In general, the recommendation of nutrients for crops also depends on soil type, crop type and nutrient source. Nutrient management for millets should be realistic and environmental friendly. Integrated Nutrient Management (INM) can also help to sustain crop productivity, enhance quality of crops and maintain profitability of the system. Integrated Nutrient Management refers to the maintenance of soil fertility and of plant nutrient supply at an optimum level for sustaining the desired productivity through optimization of the benefits from all possible sources of organic, inorganic and biological components in an integrated manner. INM practices are more effective and widely used in millet crops.

Table 8.4: Recommended doses of fertilizers for different millets.

Sr. No.	Crop	Recommended Doses of Fertilizers (N: P_2O_5:K_2O) (kg ha^{-1})
1.	Sorghum	80-100:40-50:40
2.	Pearl millet	60-100:40-50:40-50
3.	Finger millet	40-60:20:20
4.	Other millets	40:20:00

A. Use of Compost and Combined Application of Inorganic and Organic Sources of Nutrients:

Several research has concluded that application of compost in millet has a beneficial effect on crop yield due to

- Improvement in soil microbial activity as compost acts as a source of carbon for the microbes. Also, it provides congenial conditions required for microbial growth.
- Compost application provides plants with all the essential nutrients required for crop growth.
- It also improves the physical condition of soil like water holding capacity, soil structure, soil aeration, soil temperature which is optimum for root growth and plant development.
- Use of compost has also enhanced nutrient uptake in plants.
- Use of organics in nutrient management also enhances photosynthetic activity of millets resulting in higher accumulation of photosynthates ultimately leading to improved yield of millets.
- The presence of vermicompost in soil also acts as a soil conditioner by supplying nutrients to plants, lowering C to N ratio, improving the soil fertility, increasing soil porosity and water holding capacity, thereby requiring less tillage and irrigation (Figure 8.4). The average nutrient content of vermicompost is 0.6-1.2% N, 0.13-0.22% P_2O_5, 0.4-0.7% K_2O, 0.4% CaO and 0.15% MgO.
- Combined application of organic and inorganic sources of nutrients helps in balanced supply of macro and micronutrients and will maintain the growth, yield and yield attributes of the crop. It also has a positive effect on the physiological process of plant metabolism thereby influencing shoot and root growth enhancing absorption of water and other nutrients.

B. Use of biofertilizers:

Biofertilizers are defined as biological products containing living microorganisms that, when applied to seed, plant surfaces or soil promote growth of plants by several mechanisms such as enhancing the supply of nutrients, increasing root area or root biomass, and enhancing nutrient uptake capacity of plants [8].

Most of the biofertilizers either belongs to Nitrogen fixers, phosphorus solubilizers, potassium solubilizers or PGPR (Plant Growth Promoting Rhizobacteria). Biofertilizers can be considered as an alternative source of plant nutrition as these acts as bioinoculants which on application improves the growth and yield of crop plants.

C. Advantages of Use of Biofertilizers Under Millets Are:

- It can contribute to higher yield and substitute 20-25% of RDF leading to increased sustainable and environmental friendly productivity and soil fertility.
- Inoculation of nitrogen fixing and phosphate solubilising microbes alone or in combination increases plant height, number of tillers in plants and ultimately the yield of plants.
- Use of biofertilizers also leads to enhanced availability of the primary nutrients nitrogen, phosphorus and potassium that promoted growth and development of the crops.
- Biofertilizers also releases phytohormones which are similar to plant hormones like gibberellic acid and Indole acetic acid which stimulates nutrients absorption and plant growth. Use of phosphate solubilizing bacteria improves solubilization of the fixed phosphorus, enhancing the availability of phosphorus for plants.
- Use of biofertilizers narrows down the C: N ratio, thus enhancing carbon and nitrogen mineralization and promoting soil microbial activity.

The various biofertilizers which can be used with millets includes *Pseudomonas fluorescens, Azotobacter chroococcum, Azospirillum lipoferum* and *Acetobacter diazotrophicus* along with *Trichoderma viride*.

Figure 8.4: Seed treatment with biofertilizers in millets and vermicompost as a source of organic nutrient for plants.

8.4.4 Management of Abiotic and Biotic Constraints:

Abiotic constraints associated with millets production are environmental factors which includes climate, temperature, rainfall, sunlight and soil factors which includes acidity, alkalinity, drought, salinity, nutrient stress, moisture stress flooding or water logging stress.

Drought is considered as one of the most important stresses for millet production [9]. Terminal drought stress in Sorghum post rainy season leads to its low productivity. In pearl millet, the estimated yield loss due to drought was about 51 percent [10]. Drought stress in millets impacts the crop growth, crop yield, membrane integrity, osmoregulation, pigmentation and photosynthetic activity of crops. During the seedling emergence stage, poor drainage and soil salinity affects the crop growth.

Heat stress in millets induces various physiological alterations and affect photosynthetic and respiration in crops. As millets are usually grown on marginal lands, low nutrient status and low organic carbon content of the soil also leads to low productivity. Crop more sensitive to salinity is finger millet when compared with other millets. Millets are grouped into glycophytes which are destroyed by the application of high amount of salts. Salinity restricts plant growth, productivity and injurious to most plants at all the growth stages.

The most common biotic constraints associated with the millets are diseases, insects and pests, birds, parasitic plants and weeds. Though millets have less incidence of pests and diseases, the most common insects are shoot fly and stem borer in sorghum. The important diseases of millets are downey mildew in sorghum and pearl millet, blast in finger millet, smut in foxtail millet, barnyard millet and sorghum, rust in sorghum and foxtail millet and ergot in pearl millet and sorghum. Nymphs and adults of sucking pests like aphids and bugs sucks the sap from leaves causing yellowing, distortion and wilting of plants leading to less productivity. Pests like white grub are specific to certain regions. Yield losses in millets due to insects and pests attack in India have been reported to be 10-20%. More than 29% of the reduction in millets yield is due to weed infestation only. The initial vigour of the millets is poor, resulting in more growth of weeds and competition for nutrients, sunlight, space and resources during early growth stages resulting in low productivity of millets [11].

A semi root parasitic weed, Striga also causes yield losses in millets especially sorghum and pearl millet [12]. Bird damage is also a major biotic constraint affecting crop productivity.

A. Some of The Practices for Management of Abiotic and Biotic Constraints Are:

- Deep ploughing before planting should be done to expose the immature stages of insects. Burn the stubbles and diseased ear heads to prevent carryover of the pests.
- Development of stress tolerant and high yielding varieties. Application of Plant Growth Promoting Rhizobacteria (PGPR) can help to improve yield of millets and provide stress tolerance.
- Crop rotation with non-host plants is recommended to break the cycle of insects and diseases. It also helps in managing weeds and soil borne diseases of millets like wilt, foot rot and downy mildew of millets.
- Intercropping of millets with legumes reduces damage by stem borers in sorghum.
- Light traps can be used to attract and kill adults of insects and reduce incidence of stem borers, grain midge and other moth pests.
- Integrated nutrient management and balanced fertilization helps to promote growth of millets resulting in reduced damage by insects and pests.
- Neem seed kernel suspension can be used for management of sucking pests.

- Clean cultivation practices should be followed which includes activities that keeps the field clean and removal of crop residues, weeds, alternate hosts from the field. Incidence of diseases like downy mildew, rust, sheath blight and bacterial diseases can be minimised using clean cultivation.
- Disease suppressive properties can be improved by treatment of soil with green manures, animal-based soil amendments or other manures. Downy mildew, root and stalk rot can be managed by soil treatment with manures.
- Seed treatment can also be done using organic products like beejamrit. Bio control agents like Trichoderma and Pseudomonas are useful for sheath rot and foot rot in millets.
- Timely or early sowing and proper spacing, seed rate and use of resistant cultivars will also help in managing insects, pests and diseases.
- Weed management using manual methods will also help in weed control.

8.4.5 System of Millet Intensification (SMI):

Crop production is affected by various biotic and abiotic factors which is made adverse by changing and unpredictable climatic factors. Improved agronomic practices can help in sustaining agricultural productivity under such adverse conditions. System of Millet Intensification (SMI) is one such agro-ecological innovative approach whose basic objective was to enhance productivity and production in finger millet contributing to food and nutritional security of the tribal households of Koraput in the Indian states of Odisha even under extreme weather conditions.

This innovative method depends more on endogenous processes than on external inputs. Millets are staple food for tribal people of Odisha. As per the traditional method land is ploughed and seeds are directly broadcasted, due to which production is less.

So, to enhance the yield of finger millet, SMI was developed. This method was developed on the lines of System of Rice Intensification (SRI) for paddy. SMI leads to lower seed requirement, easier intercultural operations, more tillers and panicles and ultimately higher yield. SMI includes raising nursery, transplanting young seedlings, weeding by weeders and application of organic manures (Figure 8.5).

A. The Various Steps Involved Are:

- 400 to 500 grams of seeds are required per acre of land. For selection of seeds, they are soaked in 10% salt solution. Remove the seeds that will float.
- Seed treatment is done using manures/ Jeevamrut and then spread the seeds in shade to drain water. To make the seedlings more vigorous and resistant to insects, pests and diseases microbes and nutrients are also used.
- Soil and compost are used in the ratio 2:1 for preparation of raised seed bed. Seeds are put into nursey seed bed with spacing of about 3 to 4 inches and depth of 1/2 inch.
- Vermicompost or powdered FYM is spread over the seed bed in a thin layer and then it is covered with straw. Watering of the seed must be done once in a day. Seedlings are ready for transplanting in about 15 days or when two leaves come out.

- Properly plough the main transplanting land and mix cow dung powder or neem cake into top layer of soil. Maintain 25 cm distance from plant to plant and line to line when transplanting. Plant one or two saplings in each mark along with soil. While transplanting drain water completely from land. Manures are applied in the pits at the time of planting. Roller weeder or cycle hoe is used for weeding. Vermicompost/ pot manure/ Jeevamrut is applied after each weeding. To control pests, neem oil solution is sprayed.

B. Few Things Should Be Kept in Mind While Adopting Smi Technique.

- Transplanting of seedlings should be done within 15 minutes of taking it out from the nursery bed.
- While transplanting make sure roots of the saplings do not come out of the soil.
- Always clean the boundary of the transplanted field so that attack of insect, pests and diseases is minimum.

The average yield in SMI comes out to be 12-14 quintals per hectare which is double as compared to traditional methods. SMI is emerging as a solution to enhance the productivity of millets and to address the climatic change conditions.

Figure 8.5: SMI being practised in the field.

8.4.6 Adaption to Modern Agroecosystems and Mechanization:

Agricultural mechanization is the use of different machinery ranging from basic hand tools to motorized machinery and equipments to reduce human labour use and aid in agricultural operations. Mechanization is common in cereals like rice, wheat, sugarcane but it is still lacking in millets. Mechanization in millets has encouraging outcomes as briefed below:

- Use of multi crop seed cum fertilizer drill, tractor drawn seed drills and bullock drawn planter for millets have been observed to enhance the millet grain and straw yield.
- Intercultivation operation such as hoeing has been found to replace weeding in rainfed finger millets.
- Superior performance of petrol engine reaper in finger millets lead to high field efficiency, lesser fodder and low shattering losses.
- Studies on finger millet cultivation has indicated that use of tractor drawn seed drill along with machine harvesting proved to be a better option than manual operations.

8.5 Other Production Constraints in Millets:

Millet productivity is mainly concentrated in the developing nations where markets system is not well developed resulting in less economic returns to the farmers. Also, there is less availability of improved and high yielding varieties of millets.

Grain size is also an issue for small millets. Due to very small seeds of small millets, it causes difficulty in mechanical planting. Due to changing food habits and preferences of consumers, it has led to more cultivation of high value cereals and thus lowered the production of millets. Lack of policy support is also a major factor affecting millets productivity.

8.6 Conclusion:

By virtue of their high nutritional content and ability to adapt to harsh climatic conditions, millets should become an integral part of subsistence agriculture. Also, millets can easily thrive under stress conditions like drought and some varieties can even prevail under flooded areas and swampy grounds.

Despite this, area under millets have been decreasing drastically over the years. So, it is important to make use of improved agronomic practices, technologies and high yielding varieties to enhance the productivity and profitability from cultivation of millets.

Millet nutrition future research should be focused for enhancing the nutrient use efficiency of millets by using various INM practices, gadgets and tools.

Millets are now considered as nutri-cereals under National Food Security Mission the United Nations has decided to commemorate 2023 as the International Year of Millets and increase awareness about millets across the world. This would help increase or expand the area under millets cultivation and enhance their productivity.

8.7 References:

1. Louhar, G., Bana, R. S., Kumar, V. and Kumar, H. 2020. Nutrient management technologies of millets for higher productivity and nutritional security. *Indian Journal of Agricultural Sciences* 90 (12): 2243–50.
2. Devi, P.B., Vijayabharathi, R., Sathyabama, S., Malleshi, N.G. and Priyadarisini, V.B. 2014. Health benefts of finger millet (Eleusine coracana L.) polyphenols and dietary fiber: A review. *J Food Sci Technol* 51(6):1021–40.
3. Hariprasanna, K. 2023. High yielding varieties for enhancing the production of small millets in India. *Indian Farming 73*(1): 42–46.
4. Aruna, C., Madhusudhana, R., Bhat, B. V., & Umakanth, A. V. 2023. Improved varietal technology for enhanced productivity in sorghum. *Indian Farming 73*(1): 22–29.
5. Manjunath, M.G., Salakinkop, S.R. and Somanagouda, G. 2018. Productivity and profitability of soybean-based millets intercropping systems. *Research on Crops* 19: 43-47.
6. Maitra, S., Hossain, A., Brestic, M., Skalicky, M., Ondrisik, P., Gitari, H., Brahmachari, K., Shankar, T., Bhadra, P., Palai, J.B., Jena, J., Bhattacharya, U., Duvvada, S.K., Lalichetti, S. and Sairam, M. 2021. Intercropping—A Low Input Agricultural Strategy for Food and Environmental Security. *Agronomy* 11(2):343.
7. Aruna, C., Madhusudhana, R., Bhat, B. V., & Umakanth, A. V. 2023. Improved varietal technology for enhanced productivity in sorghum. *Indian Farming*, *73*(1): 22–29.
8. Vessey, J.K. 2003. Plant growth promoting rhizobacteria as biofertilizers. *Plant and Soil* 255: 571–586.
9. Gebretsadik, R., Shimelis, H., Laing, M.D., Tongoona, P., Mandefro, N. 2014. A diagnostic appraisal of the sorghum farming system and breeding priorities in striga infested agro-ecologies of Ethiopia. *Agric Syst* 123:54–61.
10. Ashok, S., Senthil, A. Sritharan, N., Punitha, S. Divya, K. and Ravikesavan, R. 2018. Yield Potential of Small Millets under Drought Condition. *Madras Agric. J*., 105 (7-9) (2): 370-372.
11. Meena, R. P., Joshi, D., Bisht, J. K. and Kant, L. 2021. Global Scenario of Millets Cultivation *in* book: Millets and Millet Technology (pp.33-50).
12. Ejeta, G. 2007. Breeding for Striga resistance in sorghum: exploitation of an intricate host–parasite biology. *Crop Science* 47, S-216–S−227.

ISBN: 978-81-19149-19-3

9. Millets in Crop Diversification

Sarilla Jeannie, Sanapala Swetha

Teaching Associate,
Polytechnic of Organic Farming,
Regional Agricultural Research Station,
Acharya N. G. Ranga Agricultural University,
Chintapalle, Andhra Pradesh.

B. Sriram Kumar

Ph.D. Scholar,
Genetics and Plant Breeding,
Agricultural College,
Acharya N. G. Ranga Agricultural University,
Bapatla, Andhra Pradesh.

Abstract:

Global food production ought to increase in order to feed a population that will top 8.5 billion by 2030 and 9.7 billion by 2050. With the climate issue getting worse and environmental stressors getting worse, there is a greater need for agricultural diversity through supporting crops that can be grown in the harshest of situations. In addition, sedentary lifestyles today and an overdependence on cereals after the green revolution have led to an increase in health-related diseases.

Only by integrating millets, which are rich in nutrients, in our daily meals will we be able to counteract this. The production of the main basic grains has decreased as a outcome of the current worldwide phenomena known as climate change. Millets are C4 plants that have very superior photosynthetic efficiency, a short lifespan, a higher dry matter production capacity, and a high level of heat and drought tolerance.

These characteristics have paved the way for their beginning into agricultural production systems to create cropping systems that are climate resilient. This chapter mainly focused on crop diversification, millets and their characters, millets in crop diversification and constrains.

Growing "climate-resilient millets" might be a pleasant answer since they are able to handle agricultural, climatic, and nutritional obstacles in addition to lowering under nutrition among communities to boost food security.

Keywords:

Millets, Crop diversification, Sustainability, Climate resilience and Food security.

9.1 What Are Millets?

Figure 9.1: Millets

The word millet is derived from the French word “mille” which means that a handful of millet contains thousands of seed grains (Taylor and Emmambux, 2008). They are a member of the Poaceae family. Millets are a category of small-seeded annual grasses that are produced as grain crops, paSrticularly on marginal land in dry zones of temperate, subtropical, and tropical countries. They can be by and large separated into two groups A. major millets and B. minor or small millets. The major millets include sorghum and pearl millet. Whereas, finger millet, foxtail millet, little millet, kodo millet, barnyard millet, proso millet and brown top millet are categorized under minor millets. The abundance of dietary fibres, antioxidants, minerals, phytochemicals, polyphenols, and proteins in millets makes them special in the battle against diseases.

9.2 What’s The Peculiarity of Millets?

According to the ancient author Strabo, "millet" is the best famine preventative since it can resist any unfavourable weather and never falters, despite the scarcity of every other grain. Throughout the beginning of time, Asia, Africa, and Europe have all enjoyed brewing and eating millets as a staple cereal. These could have been among the first crops to be farmed during the "Hoe Age," the period before the "Plow Age." Due to its drought-resistant growth characteristics, millet proven to be a highly significant staple grain in African and Asian societies before effective irrigation systems were developed. It remained significant until the art of cultivating wheat and rice was fully developed. According to estimates, millets are an important part of the diets of more than 90 million people in Asia and Africa. Africa is responsible for more than 55% of the world's output, followed by Asia with about 40%, and Europe with only 3% of the total market. India still leads the world in millet production after years of neglect. While it produces less than water-hungry cereals like rice and wheat, it is more nutritious.

Millets, which have long been a staple crop for millions of farmers, are thought to be among the oldest domesticated plants. These millets develop more quickly and finish their life cycle in 2-4 months. They also fit into a variety of cropping systems and are able to adapt to shifting environmental circumstances, particularly during monsoon season.

One of the first grains that can be grown in rain-fed locations with low soil fertility and moisture levels is millets. It can withstand problems like climate change, drought, low moisture, poverty, and hunger since it is a water-wise crop.

The root system's effectiveness allows it to handle 28% of the rainfall required for paddy. In other words, on the equivalent plot of land, millet may be grown for 30 years straight using the same sum of water required for an acre of summer rice. Little millets are produced in a range of agro-ecological settings, including plains, the coast, and hills, as well as in soils with variable properties, get altering amounts of rainfall, and experience significantly different temperature and photoperiods.

They are well-known for their hardiness, ability to withstand drought, and relative resistance to serious pests and diseases. In tribal and hill agriculture, where crop replacement is challenging, they are essential. These plants, which are C_4's, are added eco-friendly due to their high water usage efficiency and low input needs, however they are still responsive to high input management.

"Millets can help contribute to some of the most difficult areas where it will take longer to achieve the sustainable development goals, such as the needs for nutrition and health, the mitigation and adaptation to climate change, and the poverty of smallholder and marginalised farmers in the dry zones." According to research, "the high carbon concentration of crop leftovers makes them particularly essential for maintaining and increasing soil carbon levels, vital for sustainable cropping systems, and, when applicable, significant for simultaneously supplying fodder for animals."

9.3 How Millets Help in Food Security?

Global food security has been viewed as potentially being challenged by the shrinking diversity of crop species that contribute to the world's food sources. Just 12 crops account for 75% of the world's food production, while the three primary crops of rice, wheat, and maize provide for 50% of nutritional needs on a worldwide scale. While these crops are the main sources of carbohydrates, they are deficient in crucial minerals and amino acids for a balanced diet. Millions of individuals throughout the world suffer from hidden hunger as a result of inadequate intake of vitamins and micronutrients including zinc (Zn), magnesium (Mg), and iron (Fe).

This nutritional deficiency in human diet affects millions of people globally. For instance, budding nations are home to about half of the worlds micronutrient malnourished people. This is mostly due to an over reliance on starchy foods like rice, wheat, and maize. This is an example of how supplementing main cereals with millets that have superior nutritional content and nutraceutical characteristics might be a successful method for increasing dietary variety and decreasing secret hunger. Table 9.1 lists specific properties of several millets.

Table 9.1: Different Millets and Their Special Characteristics

Millet	Common name	*Botanical name*	Special characteristics
Sorghum	Great millet, Jowar, Kafir corn, Guinea corn, Kaolin in China, and Milo in Spain	*Sorghum bicolor*	Tolerate moisture stress and high temperature better than any other crop
Pearl millet	Bajra, Cattail millet, Black millet, German millet	*Pennisetum glaucum*	Grow in arid and semi-arid region, richest source of folic acid
Finger millet	Ragi, Wimbi, Mandua, Nachni, Kapai, Nagli, Marua	*Eleusine coracana*	Wider adaptability, rich source of calcium
Proso millet	Cheena, Common millet, Broom millet	*Panicum miliaceum*	Short duration, tolerant to heat and drought
Foxtail millet	Indian paspalum, Kangni, Water couch, Italian millet	*Setaria italica*	Short duration, tolerant to low soil fertility and drough
Kodo millet	Kodo, Ditch millet, Creeping paspalum	*Paspalum scrobiculatum*	Long duration, grown well in shallow and deep soil, rich in folic acid
Barnyard millet	Sawan, Jhingora, Kudraivali, Oodalu	*Echinochloa frumentacea*	Fastest growing, voluminous fodder
Little millet	Kutki, Samai, Samalu, Hog millet	*Panicum sumatrense*	Short duration, withstand both drought and waterlogging
Browntop millet	Korale in Kannada	*Brachiaria ramosa*	Rapidly maturing, best suited for catch crop
Teff	Teff, lovegrass, annual bunch grass, Williams love grass	*Eragrostis tef*	Massive fibrous rooting system, drought tolerant, ephemeral nature
Fonio	Fonio, Acha, Hungry rice	*Digitaria exilis* (White fonio) *Digitaria iburua* (White fonio)	Smallest seeds among millets, fast growing and highly nutritious

Millet	Common name	*Botanical name*	Special characteristics
Job's tears	Adlag, Adlay millet	*Adlag, Adlay millet*	Grown in higher areas, used in folk medicine
Guinea millet	False signal grass, Babala, Bajra/Bajira	*Urochloa deflexa*	Potential as grain crop

Source: Kumar *et al*., 2021

Millets are highly nutritious and also rich in protein, dietary fiber, vitamins, and minerals. Due to their great nutritional content, they are frequently referred to as "Nutri-Cereals." Along with those, they have immense health benefits. These medicinal importances of different millets are given in Table 2. Millets have lately gained weight due to their high nutritional content, proven health advantages, adaptability to a variety of environmental conditions, sustainability in low input agriculture, and suitability for organic growing. As millets are the only crops that guarantee yields in famine circumstances, they are occasionally referred to as "famine crops." Being the last alternative for cultivation, these crops were formerly referred to as orphan crops. Nonetheless, these underutilised crops are crucial for the livelihood, food, and nutritional security of the underprivileged across the world, as well as for diversifying our food supply.

Table 9.2: Medicinal Value of Different Millets

Millet	Medicinal importance
Pearl millet	Turns the gut condition to alkaline and cures stomach ulcers, high amounts of magnesium and potassium control blood pressure and relieve heart diseases, magnesium also reduces respiratory problems and migraine attack, high phosphorous content helps in bone growth and development in kids, high amount of dietary fiber and slow release of glucose maintains blood sugar level and more suitable for diabetic patients, phytic acids reduce the cholesterol levels of body, hypoallergic properties make it a suitable diet for lactating mothers, infants, elderly people, and convalescents.
Finger millet	High amounts of phenolic acids have anti-ulcerative properties, lower blood sugar level and cholesterol, phenolic compounds are nephron protective and anti-cataractogenic, germinated seeds improved hemoglobin level in infants, protection against epithelialization, mucosal ulceration, increases the synthesis of collagen, activation of fibroblasts and mast cells, tryptophan lowers appetite and keeps weight in control, high amount of calcium strengthens bones, lecithin, and methionine eliminate excess fat from liver and thus reduce cholesterol level in the body, high amount of iron protects from anemia.
Foxtail millet	Soluble and insoluble bound phenolic extracts present in the seeds show antioxidant, metal chelating, and metal reducing powers, they reduce

Millet	Medicinal importance
	toxicity caused by xenobiotics and toxins in the body, high amount of proteins and essential amino acids helps in building body tissues and advised for infants and elderly people.
Proso millet	High amount of copper facilitates the body to form red blood cells, helps maintain blood vessels, healthy bones, nerves, and immune function, and contributes to iron assimilation. Sufficient copper in the diet prevents cardiovascular diseases and osteoporosis. Magnesium reduces respiratory problems and migraine attack, potassium controls blood pressure and relieves heart diseases
Kodo millet	Phenolic compounds have antiulcerative properties, lower blood sugar level and cholesterol, Magnesium and potassium control blood pressure and relieve heart diseases, magnesium also reduces respiratory problems and migraine attack
Barnyard millet	The richness of phenolic acids, tannins, phytates, and dietary fibers show antimutagenic and anti-carcinogenic properties, high amounts of dietary fiber reduce the risk of colon cancer and oesophageal cancer, phosphorous content helps in bone growth and development in kids
Little millet	High amounts of iron help to safeguard many fundamental functions in the body, including general energy and focus, the immune system, gastrointestinal processes, and the regulation of body temperature. Higher amounts of zinc aid in enzymatic reactions, immune function, wound healing, DNA and protein synthesis, and normal biological development and growth.

Source: Kumar *et al.*, 2021

9.4 What Is Crop Diversification?

According to ICAR, "Crop diversification involves addition of new crops or cropping systems to agricultural production taking into account the different returns from value-added crops with complementary marketing opportunities. Inclusion of the new crops can be one of the important technologies in escalating the farmers' income.

The aim of crop diversification is to increase crop portfolio so that farmers are not dependent on a single crop to generate their income"**.** It is a shift from less remunerative and less sustainable crop or cropping system to more remunerative and more sustainable crop or cropping system (Barman *et al.*, 2022) Shift from the regional dominance of one crop to the regional production of several crops can greatly help to reduce the vulnerability of small farmers towards climate change.

Diversification is a spatial or a temporal process of creating a heterogenous farming system through activities within or outside a farm to build resiliency of the ecosystem (Kremen *et al.*, 2012). Crop diversification may be defined as the shifting from one crop or cropping system of traditionally grown less profitable crops to another crop or cropping system that consists more profitable crops (Feliciano, 2019).

9.4.1 What Is the Extent of Crop Diversification Status in India?

In India, diversification varies by regions and lower crop diversification is more common among poor and smallholder farmers. However, studies that show the connection between crop diversification and nutritional status in India are limited. District-wise diversification indices were estimated for the states considering the area under food crops. The study found that: The districts with low to medium degree of food crop diversification included the northern states of Punjab, Haryana, Jammu and Kashmir, Uttar Pradesh and Uttarakhand; the eastern states of Bihar and Odisha and central states of Chhattisgarh and Jharkhand. The southern states of Karnataka, Tamil Nadu, Kerala and the central state of Madhya Pradesh showed very high diversification index and rice, maize, pulses, oilseeds, and fruits and vegetables were the major crops cultivated in this region. As more than 90% of the land in Punjab and Haryana was planted with rice and wheat, the degree of diversification was particularly low in these states. This was also found to lead to degradation of natural resources. About 80 percent of the gross cultivated area in Odisha and Bihar was under cereals and millets, indicating low level of diversification in the region. The study found a strong negative relationship between food crop diversification and under nutrition status of the districts. Thus, higher degree of diversification within food crops was linked to the reduced probability of under nutrition. In India during 1990 the most important cause of agrarian calamity was low level of income and huge difference of income between the farmer and non-agricultural worker and it has become a serious problem in the recent years. In such condition a target has set in double the farmer`s income by 2022-23 that will help to flourish farmer`s prosperity, reduce agrarian calamities and will maintain the equality between the income of farmer and non agricultural worker. In an effort to boost the income strong measures should be taken to improve the agricultural productivity, efficient use of resources, and saving in production cost. In such condition crop diversification comes into existence to provide sustainability in the production as well as to improve farm income.

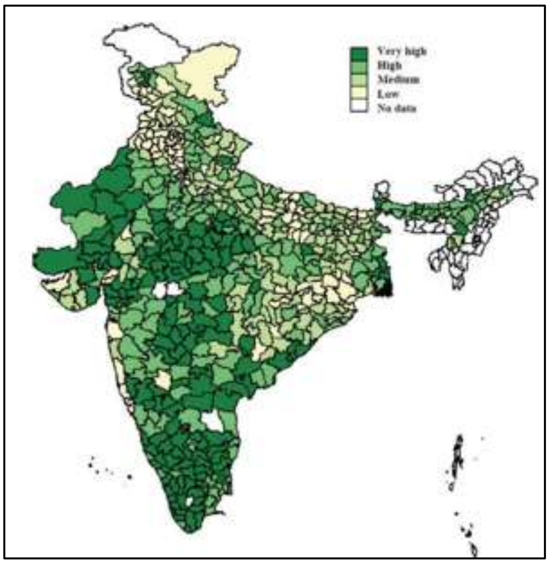


Figure 9.2: District-Wise Diversification Index for Food Crops 2015-16. (Anuja Et Al., 2022)

9.4.2 What Is the Need of Crop Diversification and How It Can Benefit Farmers, Consumers and The Environment?

Out of the 6,000 plant species cultivated for food globally, 66 per cent come from just 9 species, according to a 2019 report of the Food and Agriculture Organisation (FAO). These include sugar cane, maize, rice, wheat, potatoes, soybeans, oil-palm fruit, sugar beet and cassava. Titled State of the World's Biodiversity for Food and Agriculture, the report highlights how the mass production of some crops, driven by global demands, is depleting the biodiversity of our agricultural landscapes. As major producers of wheat, sugarcane and paddy, Indian farmlands contribute to this trend, compromising biodiversity that could otherwise thrive in our tropical climate.

Focusing on one crop or mono cropping as it's called, depletes nutrients in the soil, drains the land of water, compels the use of synthetic fertilizers and pesticides and thus negatively impacts the quality of the yield. Needless to say, it also negatively impacts those who consume it. That's not all. It limits farmers' income, increases cost of production and provides no safety net against price fluctuation or the growing threat of the climate crisis. It is time we diversify our crops with traditional farming practices such as multi-cropping and inter-cropping (growing more than one crop on a piece of land during the same season or in succession). These practices were largely abandoned during the Green Revolution to aid mass production, but we must make a concerted effort to revive them. Cropping patterns have traditionally been dominated by food needs. Commercial crops were confined to some regions and on relatively larger farms. Not just were traditions getting lost, also ignored was the looming climate change that poses a major threat for most modern crop varieties that cannot cope with the anthropocentric rise of temperature, sudden floods, erratic rainfall and such phenomenon. The system we inherited at the time of independence became unsustainable as rapid population growth outstripped our capacity to produce food.

A food insecure nation, despite devoting bulk of its agricultural resources to food production, became chronic importer of food. Even extension of cultivation to marginal and sub-marginal lands did not help. The Green Revolution transformed this scene. In less than a decade we were able to achieve reasonable food security. High growth in productivity of cereals spurred agricultural growth and incomes. Rising incomes prompted shifts in consumption patterns and demand for non-cereal food became buoyant. By mid-eighties expansion of area under cereals ceased. Producers too began to look for alternatives and the process of diversification set in. It became the mantra for agricultural development in the nineties. States which diversified the crop sector in a big way have attained relatively higher growth in the net state domestic product of agricultural sector during the past two decades. The factors that led to diversification of agriculture have varied, over time. During the first 15 years following the onset of Green Revolution, irrigation played the most important role, predominance of small holdings discouraged it. Abundant and cheap supply of electricity also fostered specialisation. Since early eighties, credit availability emerged as a significant determinant of diversification. Smaller farms continued to face rigidity in cropping patterns because of binding food production constraint. In this scenario, diversification paves the new pathway for income growth in agricultural and rural sector.

This would also help in bridging the quality gaps in terms of nutrition. the expansion of the agriculture industry is a vital tool for escaping poverty in most developing countries, particularly among the rural poor with small or no lands (World Bank, 2008). Diversifying crops is an important strategy having several benefits, including reducing the reliance on a single crop, reducing the risk of crop failure besides increasing soil fertility, improving soil health, reducing pest and disease pressure, and increasing farm income by having a variety of crops to sell. With widespread cultivation of major cereal crops, there has been a reduced focus on domesticating the minor crops which enhance human health and build the resilience within the people. Through its constant efforts and steps like green revolution, India has been able to mitigate the hunger problem to some extent but failed in providing the necessary nutrients which are needed for all round development of an individual, due to which a big chunk of population still remains undernourished. In recent years, there has been a renewed interest in crop diversification as a sustainable agriculture strategy, and it has become an essential component of many agricultural policies and programmes.

Crop diversification is also less water intensive and therefore does not drain the water of the land. Additionally, it brings down the use of chemical fertilizers making the yield healthier for consumption. Promote diversification among food crops to improve the nutritional outcomes of districts showing under performance. Crop diversification can directly influence the access, variety and affordability of a diverse diet (Ecker *et al.* 2011; Chinnadurai *et al.,* 2016). It is positively correlated with the household-level food consumption by improving the quantity and variety of food (Mango *et al.,* 2018; Adjimoti and Kwadzo, 2018). Lack of a diverse diet leads to an increase in the proportion of malnourished people (Johns and Sthapit, 2004). Higher crop diversification also increases the resilience of households to short-term agricultural shocks (Mofya-Mukuka and Kuhlgatz, 2015).

This system has usually been done by the farmers to enhance nitrogen in the soil and to replenish the soil fertility, and thus maintenance of a good crop rotation. This generates more employment as the farmers including family labourers and agricultural workers remain busy in different farming operations of different crops throughout the year. Crop diversification helps divide the risk posed by fluctuating market prices. If in one season one crop does not perform well, the farmer can sail through by the income brought in by the second / multiple crop mix in that year. And when both the crops get a good price, there is also an opportunity to maximize the earnings.

9.4.3 Why Millets Are Reliable Choice in Crop Diversification?

Here's how crop diversification by including millets can help restore the ecological balance, boost farmer income and provide us a more nutritious meal.

A. Nutritious: They are very nutrient-dense and abundant in minerals, fibre, and protein. They are also gluten-free, so those who have a gluten allergy can eat them. They are a great source of micronutrients including iron, calcium, and magnesium, which are frequently lacking in the diets of poor communities. They also contain a number of vital amino acids.

B. Drought Resistance: They may be cultivated in regions with little rainfall since they are extremely drought-resistant. They are hence the perfect crop for dry land farming and for drought-prone locations.

C. **Low input requirement:** In contrast to other cereal crops like rice and wheat, they require less input like water, fertiliser, and pesticides. They are thus a financially sensible choice for farmers.
D. **Reduce Risk:** Farmers can lower the likelihood that their crops will fail due to unfavourable weather, pests, or illnesses by varying their crop rotation. As millets are well known for their resilience to unfavourable climatic circumstances, they make a fantastic crop for agricultural diversification.
E. **Increase Income:** Farmers may boost their revenue by selling various crops at different periods of the year by diversifying their crop production. Millets are in high demand worldwide and may help farmers make a decent living.
F. **Economic Benefits:** They are in high demand on the market and may bring in good revenue for farmers. They are a cost-effective crop for farmers because of their minimal input needs and cheap cost of production.
G. **Soil Health:** Through lowering soil erosion, raising soil organic matter, and enhancing soil structure, they are known to enhance soil health. The production of other crops planted in the same field may benefit as a result.
H. **Food Security:** They are a significant source of nourishment for several millions of people worldwide. Crop diversification can increase food security by encouraging the growth of millets.
I. **Gluten-Free:** They are naturally gluten-free, makes them a great option for peoples with gluten allergies or gluten intolerance.
J. **Low Glycemic Index:** Because to their low glycemic index, they release glucose into the circulation gradually, limiting sharp increases in blood sugar levels. As a result, they are a nutritious meal option for those with diabetes.
K. **Eco-friendly:** Compared to other cereal crops, they require less input like water, fertiliser, and pesticides, making them a more ecologically friendly crop. Also, they are ideally suited to organic agricultural methods.
L. **Crop Diversity:** Millets are grown because they encourage agricultural variety, which can reduce the dangers of monoculture and dependency on a single crop. Crop diversification can also aid in enhancing soil health and lowering pest and disease occurrence.
M. **Affordable and Accessible:** Because to its low input requirements for resources like water, fertiliser, and pesticides, millets are economical and accessible to small-scale farmers and underprivileged communities. They are an important food source during times of food shortage since they can be kept for extended periods of time.
N. **Climate Resilience:** As millets are C_4 plants, they efficiently utilise nutrients and water for development. They can resist severe weather conditions including heat waves, floods, and droughts. In areas vulnerable to such climatic calamities, this can assist assure food security. They produce exceptionally excellent plant stands during the seedling and germination phases because to their resistance to salt. Millets are the most potential sources of food under climate change because they have physiological mechanisms for quick recovery from abiotic challenges like heat and drought.
O. **Medicinal value:** Millets are chosen over other main wholegrain cereals due to their better nutritional qualities and a number of health advantages. These qualities are due to their richness in polyphenols, dietary fibres, non-glutinous, and non-starchy carbohydrate content.

9.4.4 Constraints in Crop Diversification:

Although millets have been called the poor man's crop and are a staple food for more than 60% of the world's poor, their productivity remains a major obstacle to their widespread cultivation. This obstacle must be overcome by stepping up efforts to use germplasm that is widely accessible to create high yielding varieties that have all the desirable morpho-physiological characteristics and superior agronomic traits. Also, in order to attain food and nutritional security, commercial and public entities have made significant innovations in millets' cultivation, value addition, and marketing. Moreover, recent study has focused more on utilising millets' neutraceutical properties and bio-fortifying them in order to use them in the battle against malnutrition, micronutrient deficiencies, and other health-related illnesses. Even though the demand for millets and millet-based food products is increasing in national and international markets, the area under cultivation is not seeing any rise because of changing climatic conditions, non-availability of improved high yielding varieties and hybrids that are apposite for mechanized farming, lack of favourable government policies to support cultivation and marketing of millets, non inclusion of millets in public distribution system and not fixing minimum support price for millets.

In contrast, it was discovered that the lack of price incentives and input subsidies, the subsidised supply of fine grains through PDS, and changes in consumer tastes were the primary causes of the decline of millets crops in India. Because of the small market and lack of market connections for less well-known products, millet growing remains difficult. Governments must assist in establishing a strong network of connections that can guarantee smallholder farmers will be capable to sell their products in the right markets. As an alternative, develop a hyper-local ecosystem that will make it easier to acquire and sell fresh food at the neighbourhood market.

9.5 Conclusion:

A variety of agro-climatic conditions may be found in India. Different crops are grown in various regions due to these variances. Higher yields have been seen thanks to the advance of new technology including irrigation systems and other agronomic methods. Crop diversity is a novel way to keep agricultural output sustainable. It aids in raising production's quality, quantity, and revenue in order to safeguard farmers' financial situation. Crop diversification should adhere to a plan to increase output, employment, and input efficiency. Millets are an important crop for crop diversification. They are highly nutritious, require low inputs, are resilient to adverse weather conditions, and can improve soil health. By promoting the cultivation of millets, crop diversification can help enhance food security, reduce risks, and increase income for farmers. The cultivation of millets can help mitigate the risks associated with monoculture and the dependence on a single crop. Millets should be given due importance in agriculture policies and programs for achieving sustainable agriculture and food security.

Crop diversification if adopted well can be a win-win situation that will benefit the producer, consumer and the environment. Further, as farmer’s worldwide experience more frequent drought and erratic rainfall linked to climate change, the race to find and improve drought-resistant crops grows ever more important.

Hence, naturally resilient plants that can endure very demanding environmental circumstances are a priority. Millets can thrive under drought circumstances, without irrigation, even in very low rainfall regimes, and have a lower water footprint than more well-known cereals like wheat, rice, or maize. Due to their nutritional density and ability to reduce the stress of food insecurity, these crops are also referred to as "super food crops." Broader cultivation of these minor crops will diversify plant agriculture and the human diet, and will therefore help to improve national food security and human health.

Therefore, boosting millet cultivation will empower the average farmer and achieve the objectives of enhancing incomes and improving crop diversification. With the purpose of minimising over-reliance on more widely cultivated crops, promoting diversified diets, and ensuring food security, there has to be a renewed emphasis on increasing millets' production and publicising their advantages. According to Dr. Nancy Aburto, a specialist in agriculture at the Food and Agriculture Organization, this is particularly true when food is in short supply due to natural disasters (FAO).

In conclusion, millets' planting and use can significantly contribute to boosting food security and strengthening the nutrition of disadvantaged groups. To increase demand for all foods, including locally grown fruits, green leafy vegetables, cereals, pulses, and millets, we must continue to expand our palates beyond the basic staples. It will boost the nutritional value of our food and inspire our farmers to plant a wider variety of crops.

9.6 References:

1. Adjimoti, G. O., & Kwadzo, G. T. M. (2018). Crop diversification and household food security status: evidence from rural Benin. *Agriculture & Food Security*, *7*(1), 1-12.
2. Anuja, A. R., Shivaswamy, G. P., Ray, M., & Singh, K. N. (2022). Pattern of crop diversification and its implications on undernutrition in India. *Current Science*, *122*(10), 1154.
3. Barman, A., Saha, P., Patel, S. and Bera, A. (2022). Crop Diversification an Effective Strategy for Sustainable Agriculture Development.Agriculture Letters, 3(03),2022
4. Chinnadurai, M., Karunakaran, K. R., Chandrasekaran, M., Balasubramanian, R., & Umanath, M. (2016). Examining linkage between dietary pattern and crop diversification: An evidence from Tamil Nadu §. *Agricultural Economics Research Review*, *29*(conf), 149-160.
5. Ecker, O., Mabiso, A., Kennedy, A., & Diao, X. (2011). Making agriculture pro-nutrition: opportunities in Tanzania.
6. Feliciano, D. (2019). A review on the contribution of crop diversification to Sustainable Development Goal 1 “No poverty” in different world regions. Sustainable development, 27(4),795-808.
7. Johns, T., & Sthapit, B. R. (2004). Biocultural diversity in the sustainability of developing-country food systems. *Food and nutrition bulletin*, *25*(2), 143-155.
8. Kumar, A., Tripathi, M. K., Joshi, D., & Kumar, V. (Eds.). (2021). *Millets and Millet Technology* (p. 438). Springer Singapore.
9. Kremen, C., Iles, A., & Bacon, C. (2012). Diversified farming systems: An agroecological, systems-based alternative to modern industrial agriculture. Ecology and Society, 17(4), 44.

10. Mango, N., Makate, C., Mapemba, L., & Sopo, M. (2018). The role of crop diversification in improving household food security in central Malawi. *Agriculture & Food Security*, *7*(1), 1-10.
11. Mofya-Mukuka, R., & Kuhlgatz, C. H. (2015). *Child malnutrition, agricultural diversification and commercialization among smallholders in Eastern Zambia*. Indaba Agricultural Policy Research Institute.
12. Taylor JRN, Emmambux MN (2008) Gluten-free cereal products and beverages. In: Arendt EK, Bello FD (eds) Gluten-free foods and beverages from millets. Elsevier, Amsterdam, p 464.
13. World Bank. (2008). World development report 2008: Agriculture for development. Washington, DC: World Bank.

ISBN: 978-81-19149-19-3

10. Crop Breeding Strategies to Enhance Inherent Adaptability and Productivity of Millets

Jyoti

PhD Scholar Department of Genetics and Plant Breeding
Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya,
Palampur, HP.

Gopal Katna

Principal Scientist Department of Genetics and Plant Breeding
Chaudhary Sarwan Kumar Himachal Pradesh Krishi Vishvavidyalaya,
Palampur, HP.

Om Prakash Raigar

PhD Scholar Plant breeding and Genetics
Punjab Agricultural University Ludhiana,
Punjab.

Nitesh Kushwaha

PhD Scholar Division of Genetics
ICAR-Indian Agricultural Research Institute,
Pusa, New Delhi.

Abstract:

In the developing world, particularly in the arid regions of Africa and Asia, millets are a staple meal. The majority of millets are native to Africa and were domesticated there before spreading to other regions of the world. Millets are also known as nutricereals because they provide more nutrients overall than traditional food grain crops like paddy and wheat. A range of small-seeded cereal crops belonging to the Poaceae grass family are referred to as small millets. These contains millet varieties like kodo, proso, foxtail, finger, and barnyard. Little millets ability to withstand climate change and consumers growing interest in healthy diets highlight the need for greater research and development on these crops. Proso millet and other small millets, with the exception of finger millet and foxtail millet, have gotten very little attention from researchers in terms of developing genetic and breeding for yield enhancement.

There have been significant breeding efforts in foxtail millet, finger millet, and proso millet in China, India, and the United States of America, respectively. In order to improve small millets, recent developments in phenotyping and genomics technology as well as the diversity of available germplasm can be used. To create drought or heat-tolerant lines, breeding operations have taken advantage of limited features with limited genetic and genomic resources.

Keywords:

Small millets, Nutricereals, Genetics, Breeding

10.1 Introduction:

Millets is a collective term referring to a number of small-seeded annual grasses that are cultivated as grain crops and represented by sorghum (jowar), pearl millet (bajra), finger millet (ragi) and minor millets like banyard millet, proso millet, kodo millet and foxtail millet. Being excellent source of essential nutrients to the millions of rural poor in India, they are also called as 'nutritious cereals'. Millets are the staple food for the world's poorest and most food insecure populations across the semi-arid tropics. The crop development initiatives on Millets and Directorate of Sorghum Research, under the umbrella of Indian Council of Agricultural Research, and other institutions in both public and private sector are aiming to enhance livelihood of dryland farmers through improvement of millet yield.

Millets are better adapted to dry, infertile soils than most other crops, and are therefore often cultivated under extremely harsh conditions - for example, high temperatures, low and erratic precipitation, short growing seasons and acidic and infertile soils with poor water-holding capacity. The majority of millets have short life cycles, robust, deep root systems, and can expand quickly when moisture is present. As a result, they can survive and reliably produce small quantities of grain in areas where mean annual precipitation is as low as 300 mm.

This compares with a minimum water requirement of 400 mm for sorghum and 500-600 mm for maize. Despite not tolerating prolonged drought, some species (such as pearl and proso millets) appear to tolerate temperatures that are higher than those of sorghum and maize.

In developing countries, millet cropping systems tend to be extensive, with limited application of improved technologies, except in some of the more commercialised farming regions in India. In Asia, millet is restricted almost exclusively to two countries, India and China, although Myanmar, Nepal and Pakistan also produce small quantities. India is the world's largest producer, harvesting about 170 lakh tons, nearly 20 percent of the world's output (FAO Stat, 2021).

Pearl millet, which accounts for about two-thirds of India's millet production, is grown in the drier areas of the country, mainly in the states of Rajasthan, Maharashtra, Gujarat, Uttar Pradesh and Haryana. Finger millet is produced mainly in the state of Karnataka, but also in Orissa, Uttar Pradesh and Tamil Nadu.

Crop improvement is generally more difficult in millet than in most other crops, largely because of the nature of the environment in which they are grown. Hybrid breeding programmes have traditionally targeted the relatively better environments, although even these environments are harsher than those for most other crops. Hybrid grain cultivars have been developed for pearl millet in India and the United States, but perform best in areas where rainfall is reliable.

10.2 Global Scenario of Millets:

Table 10.1: Global Scenario of Millets

Regions	Area (lakh ha)	Production (lakh ton)
Africa	489	423
Asia	162	215
India	138	173
World	718	863

(Source: FAO Stat 2021)

Crop genetic improvement and breeding aim to increase genetic gain, which is defined as the amount of increase in performance achieved over generations through artificial selection [1]. Since the invention of DNA technologies, plant breeding has transformed, from conventional breeding which primarily relies on visual phenotypical selection and experience, into the era of molecular breeding [2].

Crop genetic improvement and breeding have been greatly advanced by harnessing and integrating the theories and technologies of DNA markers, marker-assistant selections (MAS) and genetic engineering, as envisaged by more precise foreground and background selection, discovery and utilisation of more diverse genetic stocks and shortening of breeding cycles [3,4]. Yet, agronomically important traits are often so-called complex traits controlled by poly- and/or oligo-genic loci.

So far, the success of molecular plant breeding is restricted to limited traits governed by major effect genes due to the intrinsic downsides of low genome coverage of molecular markers, difficulties in exploring a wider range of genetic resources and unavoidable linkage drag associated with selection of large segments of chromosomal regions [5].

Hence, breakthroughs in theoretic framework and technologies are required to further speed up breeding practice. Since 2005, the invention of next generation (massively parallel) and third generation (single molecular) sequencing technologies, genome-wide association studies (GWAS), genome editing (GE), molecular modules (MMs), genome selection (GS), as well as non-invasive high throughput phenomics, has revolutionised the scope and toolkits of crop breeding, allowing much more effective exploitation of historically preserved natural and/or artificially generated variation, minor effects of poly- and oligo-genic genes/alleles, and phenotyping and selection of large scale breeding populations in an unprecedented manner[6,7,8,9,10].

Crop scientists at ICRISAT are striving to achieve disease resistance, stress tolerance and nutritional improvement in our mandate crops. Modernization of the breeding programs includes rapid generation advancement methods, utilization of data-driven decision making digital platforms, molecular tools and advanced phenotyping technologies. These are the key areas of focus for enhancing productivity and boosting varietal development in a demand-driven approach.

10.3 Why Millets Are Called as Nutri-Cereals?

Because millets are exceptionally nutrient-dense cereals that significantly contribute to consumers' food and nutritional security, millets are known as Nutri-cereals. Because they are a natural source of iron, zinc, calcium, and other nutrients essential for easing India's malnutrition epidemic, millets are a nutritional powerhouse. Millets are not only more nutrient-dense than traditional cereal crops (wheat and rice), but they are also good sources of carbohydrates, minerals, and phytochemicals with nutraceutical advantages. Dietary fibre (15–20%), protein (7–12%), fat (2–5%), and carbohydrates (65–75%) are all abundant in millets. Anemia affects 40% of preschoolers, according to estimates, because of an iron deficiency in their bodies. Moreover, 250–500 thousand kids are thought to lose their vision each year as a result of vitamin A insufficiency. The world's anaemia problem can be efficiently solved by consuming millets (NIN, 2019). In addition, they are essential components of numerous multigrain and gluten-free cereal products, as well as conventional meals and drinks. Moreover, millets are consumed as fermented beverages, improving their digestibility, increasing the availability of nutrients like protein and minerals, and reducing antinutritional effects. Because of the rising prevalence of sedentary lifestyles and the resulting health issues, consumers are seeking out foods that are more nutrient-rich, flavourful, and healthy [11]. Little millets are an ideal choice for a nutritious food since they provide considerable amounts of calories, dietary fibre, protein with a balanced amino acid profile, various essential minerals, vitamins, antioxidants, and a low glycemic index (GI). [12, 13, 14, 15]. They are referred to as "Smart-Food Crops" and "Nutri-Cereals," respectively, because of these qualities. There are various varieties of millets, each having a unique nutritional profile. Regardless of variety, however, finger millet grains have exceptionally high calcium content (>350 mg per 100 g), followed by tef (159 mg per 100 g); proso millet, job's tears, foxtail millet, and barnyard millet are rich in protein (>10%); foxtail millet, little millet, and job's tears are rich in fat (>4.0%); barnyard millet, little millet, foxtail millet and fonio are rich in crude fibre (6.7–13.6%), little and barnyard millets are rich in iron (9.3–18.6 mg per 100 g) compared to other major cereals such as rice, wheat and sorghum[16, 15].

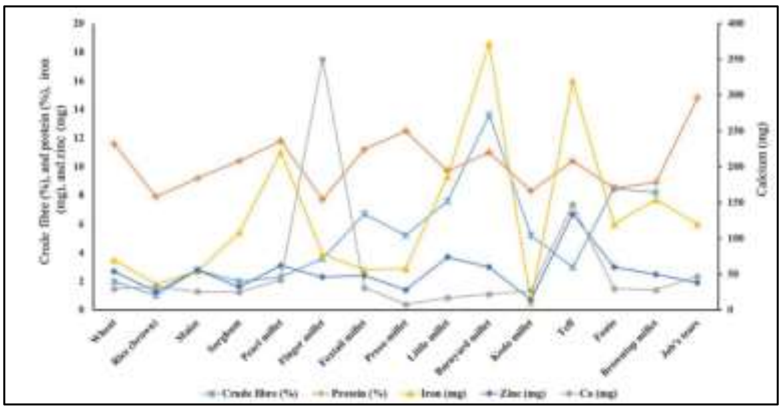


Figure 10.1 displays the protein, crude fibre, iron, zinc and calcium content of small millets. Small millets serve as a strategic food source for the impoverished and, more recently, as a nutritious diet for people living in cities, underscoring the need to focus more research and development on these crops.

10.4 Conventional Breeding Strategies in Millets:

Millets also use a variety of breeding techniques, including pure line selection, pedigree selection, mass selection, and mutation breeding, which are relevant to crops that self-pollinate. According to reports on millets cultivars issued over time, the majority of them were released following pedigree selection, then selection from local landraces and cultivars (hybridization and selection).

For instance, in India, out of the 248 varieties of six millets (finger millet—121, foxtail millet—32, proso millet—24, kodo millet—33, barnyard millet—18, and little millet—20), approximately 65% were released after selection from landraces, approximately 30% through pedigree selection, and 5% through mutation breeding. [17]. 11 proso millet cultivars were released in the USA by landrace selection, and 8 through pedigree selection. [18,19].

An essential breeding technique for millets, particularly for finger millet, foxtail millet, and proso millet, involves hybridization to promote variety followed by selection in a population that is segregating. Whereas 22% of foxtail millet cultivars and 29% of proso millet cultivars followed the hybridization and selection breeding strategy, 45% of the finger millet cultivars released in India [17]. Millets floral shape and anthesis behaviour, on the other hand, make them difficult to hybridise.

Due of difficulties in hybridization, there is a limited amount of hybrid vigour that can be utilised in small millets. Hence, creating male sterile lines would be a practical way to exploit heterosis, which is effectively used in important crops for the generation of commercial hybrid seeds. In finger millet, just one male sterile line (INFM 95001), with a GMS system created from the source parental line IE 3318 (germplasm), has so far been recorded (EMS) [20]. In foxtail millet, various types of male sterile lines have been created in China [21]. However only partially genetic male sterility lines have been effective in producing hybrid seed. [22].

In general, self-pollinated crops where hybridization is exceedingly difficult to induce variety have benefited greatly from mutant breeding. 13 millet cultivars (including Finger Millet 8, Kodo Millet 3, and Little Millet 2) have been released in India as a result of mutation breeding.

It is necessary to investigate the use of chemical hybridising agents (CHAs) to cause male sterility in small millets. In finger millet, the early-maturing mutant lines with high yield and yield component characters were found to be responsive to 500 Gy and 600 Gy. [23], and the treatments using 0.30% and 0.45% EMS [24], 0.03% nitroso guanidine (NG), and a combination of 300 Gy gamma ray and 0.30% EMS were shown to be more successful at causing beneficial mutations. For barnyard millet, 500 Gy and 600 Gy of gamma irradiation produce good variability, and 0.3% of EMS was identified as the LD50 value. A dose of 0.4% EMS was found to be ideal for the best recovery of viable mutants in kodo millet. [25]. The characterization of small millets germplasm and their usage in creating and releasing a number of cultivars, especially for resistance/tolerance to biotic and abiotic stresses, have both been successful using traditional breeding methods.

10.5 Current Breeding Strategies in Millets:

10.5.1 Sorghum- Jowar (*Sorghum Bicolor*):

Two product categories are the focus of sorghum breeding programmes: variety (using a population enhancement strategy) and hybrid (using a heterosis breeding approach). The type of product also depends on the additive and non-additive trait inheritance patterns, the homogeneity or heterogeneity of the growing environment, and the accessibility of agricultural inputs like irrigation and nutrients. A long-term breeding objective for sorghum has been to increase its tolerance to drought. Because to the shifting climate in sorghum-growing countries, breeding for HT tolerance is a new focus in sorghum research. As a result, comprehension of drought tolerance (staying green and producing under stress) is somewhat better than that of HT tolerance. Yet, in order to address the necessary tolerance levels in cultivated sorghum varieties or hybrids, there are genetic as well as breeding gaps in both stresses.

A. Genetic Analysis of Important Agronomical and Adaptive Traits in Sorghum:

Figure 10.2: Sorghum- Jowar (*Sorghum Bicolor*)

In the past few decades, a number of significant genetic loci and genes affecting sorghum agronomical and adaptive qualities have been discovered, mostly by GWAS, QTL mapping, and mutant analysis. This has been made possible by the rapid development of sequencing and phenotyping technologies. Despite the fact that the control mechanism of these genes is still largely unknown, the knowledge amassed to date and the genetic resources produced are sufficient to permit the development of super sorghum for a variety of end purposes. The sorghum breeding team at ICRISAT conducts research to improve precision and genetic gain. All market sectors (post-rain, rain, forage, sweet sorghum/high biomass sorghum) have unique breeding strategies, and hybridity testing (QC) is routinely carried out in F1s, which aids in the early identification of bogus hybrids. In order to anticipate the performance in isolation as well as the values in hybrid combinations (GCA, SCA) of the future fixed inbred lines, testcross, early yield trial, disease, and pest screening are routinely carried out in F6. For GCA, yield potential is the main attribute of interest. "Testing GCA in early generations assists in creating superior hybrids while saving time and money," said

Dr. Ephrem Habyarimana, principal scientist-sorghum breeding team, of ICRISAT. Using heterosis is yet another critical element in the production of sorghum. It is well-known breeding for drought and high temperature stress tolerance. The two primary methods used to screen and generate genetic material for drought tolerance are direct and indirect traits-based selective breeding. The most favoured form of selection based on developmental features or monitoring the water status and function of plants is indirect selection breeding. [26]. Sorghum cultivars that are evolving and carrying several productivity features can also be more drought tolerant. For instance, under field conditions, the presence of epicuticle wax on leaf and stalk may inhibit evapotranspiration in sorghum. [27]. In the sorghum drought-tolerant breeding programme, which is helpful for post-rainy breeding pipelines in India, the "Physiological Breeding" approach is gaining ground. The remain green phenotype of sorghum is the most important drought tolerance characteristic. [28,29,30]. Many sorghum hybrids with the stay green trait introgressed have been developed and are being successfully grown all over the world. While keeping an eye on sterility, grain quality, and heterosis, a breeding strategy with other important agronomic traits is needed to increase the rate of genetic gain in remain green and drought resistance traits. The proposed fast-track varietal and hybrid breeding approaches for drought tolerance in sorghum are depicted in Figure 10.3.

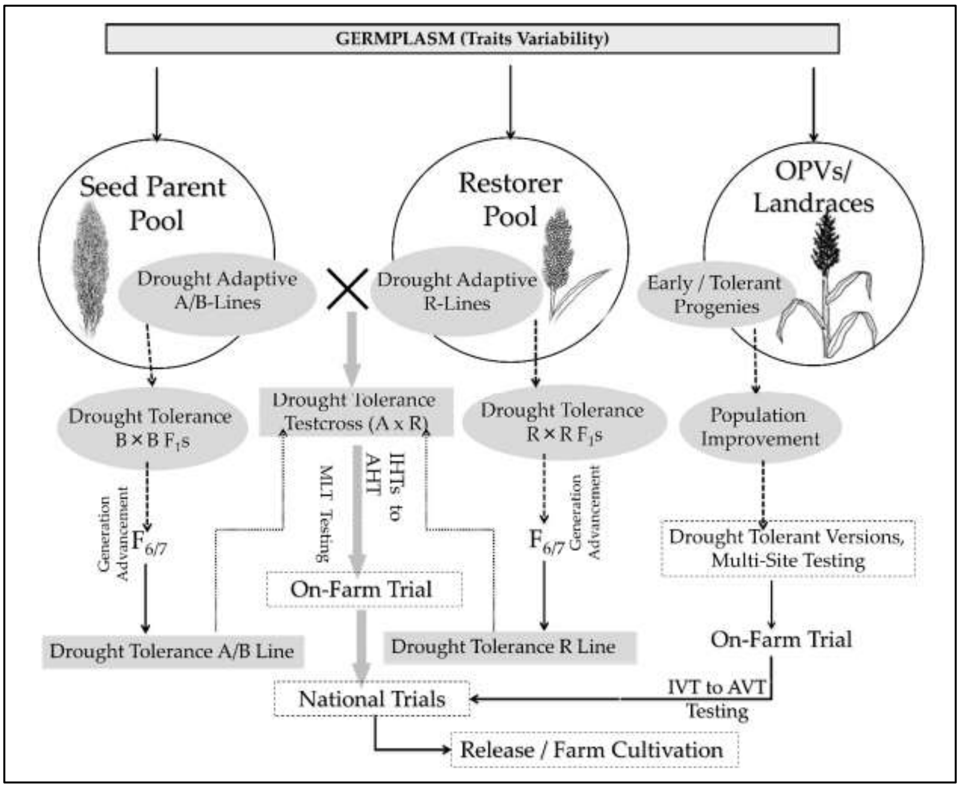


Figure 10.3: Fast-track breeding approaches for developing variety and hybrids for drought tolerance in sorghum. Briefly, genetic variation for drought tolerance in sorghum is sourced from elite breeding populations or germplasm. In sorghum, development of hybrid requires a male sterile line (A-line), a maintainer line (B-line), and a restorer line (R-line). A-line is male sterile and used as female; B-line is an isogenetic line of A-line and serves as

maintainer line, and R-line is a male fertile line used as pollen parent. Identified tolerant lines will be crossed within gene pool (B-lines/R-lines) of sorghum (without interrupt maintainer or restoration genes) to produce recombinants to select and fix in subsequent generations (i.e., F2–F7). At ≥F7 stage, crosses between two gene pool rewards the hybrids population to test in target sites to release a candidate hybrid with tolerance and on parallel, respective B lines to be converted to its male sterile version (A-line) for commercial production. Various test crosses between A and R lines go through testing at initial hybrid trials (IHTs) to advanced hybrid trials (AHTs) in on-farm tests, whereas in open pollinated varieties (OPVs) breeding, the selected intra-population progenies crosses were recommended to be released as a final product after sequential testing at multiple locations under initial variety trials (IVT) and advanced variety trials (AVT). There are around five different cytoplasmic male sterility (CMS) lines in sorghum; A1 CMS are widely used in commercial hybrid breeding and are being examined for other CMS lines' potential uses. Variations have considerable masking epistasis effects when researching the genetics of HT tolerance features since HT effects are thought to be of a geographical and temporal nature. Generally speaking, low to moderate heritability, such as that found in sorghum or other comparable crops, implies the viability of genetic modification, such as open-pollinated varieties or broad-based hybrids (top-cross and three-way cross) that depend on characteristics gene effects. In sorghum improvement projects, two lines, B35 and BTx3197, were used as HT tolerant sources. [31,32]. The proposed breeding plan (Figure 10.4) can be enhanced with further understanding of linked traits and their effective screening techniques. However, it is still in the early phases of comprehending the crop variability spectrum to HT. [33].

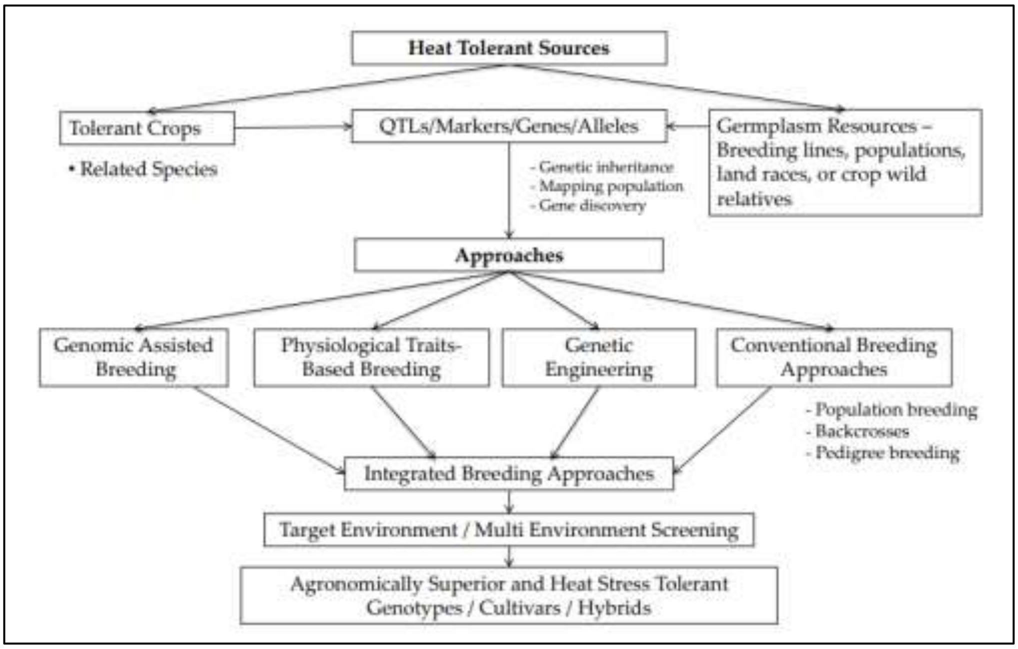


Figure 10.4: Proposed breeding approaches for development of sorghum heat (high) temperature (HT) stress tolerant cultivar. Briefly, HT breeding requires HT sources from the breeding lines or germplasm collections from the source; dissecting HT trait genetics and inheritance in the future will guide the discovery of the candidate genes and loci (QTLs)

in future. Identified sources/QTLs/genes can be transferred to elite cultivars that require HT for wider cultivation. To date, no straightforward breeding approach is available for HT. The proposed model is a combination of pre-breeding to product development. Breeding approaches will depend on the mode of trait inheritance (few/major genes or many/minor genes) in conventional breeding or physiological traits-based breeding methods. Genomic approaches will assist the breeding HT sorghum through advanced markers association studies, diagnostic markers, whereas, genetic engineering method helps in gene editing, provided a key candidate gene is identified for HT in sorghum.

The reported 26 QTLs for HT in sorghum can be validated and used in regular breeding with support of diagnostic markers (for screening), and forward through genomic selection in breeding pipelines is recommended. Integrated breeding approaches with appropriate testing and screening in target and multi-environments are needed to identify and develop agronomically superior heat tolerant cultivars or hybrids. Approximately 1000 breeding lines (600 B-lines, 300 R-lines, and 100 variations) are evaluated at ICRISAT for seed set and blooming. Just eight of the 1000 lines (ICSR 14001, ICSR 8, ICSR 21, ICSB 55, ICSB 84, ICSB 603, ICSV 162, ICSV 376) maintain their flowering times throughout the rainy and post-rainy seasons with 100% seed set, suggesting that these lines may be HT-tolerant [34]. In order to attain a greater rate of seed set under HT, HT tolerance breeding involves systematic relevant features discovery more than pollen germination and its viability. The proposed breeding plan and selection procedures can make significant use of the primary (directly contributing to HT tolerance) and secondary (indirectly contributing to HT tolerance) features.

The incorporation and validation of the reported 26 QTLs for five phenotypes claimed for HT tolerance in breeding pipelines may be made possible by the integrated breeding of phenomics and genomics, which could result in a wider range of HT tolerance progenies with improved agronomic features. In order to evaluate the co-segregation pattern of several QTLs to pyramid HT tolerance traits in breeding pipelines, the maximal QTLs found for leaf firing as an HT tolerance trait may attract rapid validation in various genetic backgrounds. In comparison to conventional breeding pipelines, HT tolerance breeding pipelines are probably smaller. In order to comprehend the desired level of HT (average higher temperature prevalence in the target growing crop ecosystem), they can be managed independently during the early phases of breeding.

To estimate the potential advantages of changing the crop cycle, improving yield potential characteristics, and incorporating drought and HT tolerance in India and Mali [35], a simulation study was carried out using a sorghum model. Several locations saw increased grain yield as a result of drought and HT tolerance. Overall, they came to the conclusion that a variety of features would need to be combined in order to boost and maintain sorghum output in both current and future climates.

B. Population Breeding Approach for Development of Sorghum Genotypes for Improved Yield and Resistance to Grain Mold:

Infected sorghum grown during the rainy season suffers from physical and chemical quality problems that result in smaller grains, blackening, and unfitness for human consumption. Hence it has become essential to breed for grain mold resistance. Grain mold is a problem that has been extensively addressed by pedigree breeding all across the world. To create genotypes resistant to grain mold, a population breeding strategy was used in the current study. Finding stable grain mold-resistant lines with good grain yield (GY) is difficult due to the complicated genotype environment interactions (GEIs). Assessment of the efficacy in 33 population breeding derivatives chosen from the 2017 evaluation of 150 genotypes across four locations.

A substantial genotype-environment interaction (GEI) was found for grain mold resistance, GY, and all other associated variables. This GEI was examined using the genotype plus genotype-by-environment interaction (GGE) biplot approach. Compared to genotype (G) location (L), which accounted for 21.9% of the variation in GY, the location explained 51.7% of the variation, while the genotype accounted for 11.2%. G and L were more significant (30.7%) contributors to variance in grain mould resistance. The identification of promising genotypes for GY and grain mould resistance was aided using a graphical biplot technique. Dharwad proved to be the best test site for both GY and grain mould resistance.

During a "which-won-where" investigation, the test areas were divided into three clusters for GY and two clusters for grain mould resistance. optimal genotypes for each The Genotype plus genotype-by-environment interaction (GGE) biplot analysis was used to analyze a significant GEI observed for GY, grain mold resistance, and all other associated traits. For GY, the location explained a higher proportion of variation (51.7%) while genotype (G) × location (L) contributed to 21.9% and the genotype contributed to 11.2% of the total variation. For grain mold resistance, G × L contributed to a higher proportion of variation (30.7%). A graphical biplot approach helped in identifying promising genotypes for GY and grain mold resistance. Among the test locations, Dharwad was an ideal location for both GY and grain mold resistance. During a "which-won-where" investigation, the test areas were divided into three clusters for GY and two clusters for grain mould resistance. In each of these clusters, the top genotypes were chosen. It is advised to breed for a certain cluster. GY is regulated by blooming time, 100-grain weight (HGW), and plant height (PH), whereas grain mould resistance is influenced by glume coverage and PH, according to genotype-by-trait biplots. There is potential to increase both yield and resistance at the same time because GY and grain mould score were independent of one another.

C. ICRISAT Work on Sorghum with Different Countries:

Two stay-green QTLs (stg3A and stg3B encoding transpiration efficiency and Water Usage Efficiency) were backcrossed into three genetic backgrounds using marker assistance at ARI-Makutupora in Tanzania. In Senegal, similar efforts are being made to introduce stg3A and stg3B QTLs in three genetic backgrounds. The markers used in each of these introgression systems were created by ICRISAT. In the ICRISAT Kiboko station, 44 landraces and their wild relatives were tested for drought resistance under both well-watered and drought-stressed situations. In the ICRISAT Alupe station, 64 genotypes, including 17 wild relatives, 8 landraces, 13 improved varieties, and 26 F4 offspring of chosen parents, were screened for strigo resistance. Particularly among the F4 crosses, more resistant and high-yielding genotypes were discovered than the standard checks. Future research must search for more varied sources of Striga resistance and pyramid several resistance mechanisms into farmer-favored cultivars.

10.4.1 Pearl Millet- Bajra (*Pennisetum Glacum*):

The Indian Prime Minister on September 28, 35 new crop varieties and hybrids were presented to the country by Mr. Narendra Modi, of which three were the result of the work with ICRISAT. Two chickpea types and a hybrid of pearl millet were created by genomic-assisted breeding. The cultivars are climatically adaptable, mature earlier, produce more, and are immune to serious illnesses.

A. Extra-Early Pearl Millet with Increased Disease Resistance and Higher Yield:

Because to HHB 67 Improved, more than two million people in India have access to food security. Out of the 7–7.5 million hectares that are used to cultivate pearl millet each year, more than 800,000 ha are planted with this extra-early (76 days to maturity), Downy mildew-resistant, farmer and consumer–preferred variety. This well-liked hybrid has assisted in preventing the annual losses of US$ 8 million that mildew might bring about in Rajasthan and Haryana.

Figure 10.5: Pearl Millet- Bajra

However, before the illness takes hold, the lifespan of any pearl millet hybrid is often no longer than 4-5 years. The second cycle of this hybrid, known as HHB 67 Improved 2, was created by Chaudhary Charan Singh Haryana Agricultural University (CCSHAU) and ICRISAT and recently released by the Indian Government. It has 12% more blast resistance, 15% more grain yield, and 21% more dry fodder yield while still maintaining its early-maturity trait. In India's parched north and northwest, this hybrid has the potential to improve food, fodder, nutritional, and economic security. HHB 67 Improved 2 was created through translational genomics and cooperation between the ICRISAT, Chaudhary Charan Singh Haryana Agricultural University, and the Indian Council of Agricultural Research (ICAR).

10.5.2 Finger Millet (*Eleusine Coracana*):

Eleusine coracana (L.) Gaertn., often known as ragi, is crucial to the dryland agricultural system. It is a crop that is grown in some regions of the world for both food and forage. It is grown in Africa, as well as in Uganda, Tanzania, Kenya, Ethiopia, Rwanda, Zaire, Eritrea, and Somalia, as well as in Asia's India, Burma, Nepal, Sri Lanka, China, and Japan. The primary main meal for the people of South Karnataka in India is finger millet. It offers a wide range of nutritional advantages and contains roughly 30 times as much calcium as rice. The cattle industry makes substantial use of finger millet straw as feed. Depending on the moisture available, finger millet can be grown all year round. Crop improvement and management tactics require fresh attention due to changes in climatic conditions, biotic and abiotic yield limiting factors, and other considerations.

Figure 10.6: Finger Millet (Eleusine Coracana)

At Hebbal School (now University of Agricultural Sciences, Bangalore), Dr. Leslie Coleman started a finger millet development effort that led to the introduction of the first finger millet variety H22 in India. The All India Coordinated Small Millets Improvement Project (AICSMIP), which has its headquarters at the University of Agricultural Sciences, GKVK, Bengaluru, was subsequently started in 1986. The primary goal of breeding was to create strains with high grain production and blast resistance that would work in habitats that were both rainfed and irrigated. There are currently 135 different types of finger millet available. Indaf (like Indaf 7 and Indaf 9) and KMR (like KMR-301, KMR 630, KMR-316, KMR-204 & KMR 340) series varieties from ZARS, Mandya and GPU series varieties (like GPU-28, GPU-45, GPU-48, GPU-66) from PC unit, AICRP on Small Millets, UAS, Bangalore were identified as a result of the groundbreaking work on finger millet.

10.5.3 Foxtail Millet (*Setaria Italica*):

One of the oldest crops in the world, foxtail millet ranks second in overall millet production and provides six million tonnes of grain to populations in southern Europe and Asia. [36,37]. The hardy weed *Setaria viridis*, which is thought to be the progenitor of foxtail millet, is closely related to this plant. With several reports of herbicide resistance, *S. viridis*, or green foxtail, is a problem throughout Eurasia and North America where it frequently coexists with its domesticated cousin [38,39,40]. The global distribution of two phenotypically distinct kinds of foxtail millet-the waxy grain type and the non-waxy grain type-is an intriguing aspect of the variety of modern foxtail millet [41]. Low amounts of amylose in the grain endosperm, which results in waxiness in cereal grains, giving the grain a sticky texture when cooked [41]. Due to its significance in China, the Chinese National Genebank (CNGB), which as of 2012 had 26,670 accessions, appears to preserve the largest collection [65]. Genebanks in Japan (National Institute of Agrobiological Sciences, NIAS) and the USA (USDA, Plant Genetic Resources Conservation Unit, PGRCU) provide access to a wide range of foxtail millet variation. ICRISAT maintains germplasm from 26 different nations. There have been some core and mini-core collections put together [43,44].

Figure 107: Foxtail Millet (Setaria Italica)

The foxtail millet molecular genomics field is advancing quickly as a result of the recently made sequence data available. In order to create maps, examine DNA polymorphisms, evolutionary origins, and relatedness to other cereals for future crop development initiatives, numerous genetic markers have been identified and used in foxtail millet [45,46,47,48]. It has become possible to create a huge library of markers made up of intron-length polymorphisms (ILPs) thanks in part to the amount of EST data that can be utilised to create flanking primers [49]. Marker-based, high-throughput genotype identification has made some early advances [50,51]. One study found an association between stress tolerance and an allele-specific single nucleotide polymorphism (SNP) encoding for the dehydration responsive element binding (DREB) gene [52]. The SNP was validated in a foxtail millet core collection, where it was discovered that the allele accounted for 27% of the overall variation of stress-induced lipid peroxidation. The SNP shows potential in marker-assisted breeding selection [53]. Both callus bombardment reported [55,56,57]and agrobacterium methods [53] have been discussed for foxtail millet transgenic protocols enabling some potentially useful molecular analyses. A pollen-specific gene has been modified in one study [58]to impair anther function through a co-suppression mechanism. This modification may have been made to enable the creation of male-sterile plants, which are useful for breeding foxtail millet hybrid variants.

10.5.4 Kodo Millet (*Paspalum Scrobiculatum*):

The only nation where it is being harvested as a grain in substantial amounts, primarily on the Deccan plateau, is India. India is where kodo millet was domesticated approximately 3000 years ago [59]. The grain has a wide variety of high-quality proteins [60,61] and, especially when compared to other millets, has a high antioxidant activity (anti-cancer) [62,63,64]. Kodo is high in fibre and, like finger millet, may be beneficial for diabetes [60]. It may be grown in a range of poor soil types, from gravelly to clay, and is drought-tolerant [65,66].

Kodo is high in fibre and, like finger millet, may be beneficial for diabetes [60]. It may be grown in a range of poor soil types, from gravelly to clay, and is drought-tolerant [59,66]. There has been significant variation reported in numerous phenotypic measures, including time till blooming, tiller number, and yield, indicating that general morphological variability is substantial [67,68].

Figure 10.8: Kodo Millet (Paspalum Scrobiculatum)

Kodo millet's genome does not appear to have any genetic or molecular maps, which is unfortunate [13]. This is probably because of the issue of recurrent cross-hybridization with its wild relatives. Kodo millet has a limited number of molecular markers, yet these markers have been used to characterise diversity and phylogeny [66,70]. There has been some preliminary work in miRNA target site prediction using ESTs from kodo [71]. Using ESTs from kodo, there has been some preliminary work on predicting the miRNA target site [71]. Target genes were discovered to be involved in the metabolism of carbohydrates, cellular transport, and the production of structural proteins, but this study was severely constrained due to a severe lack of kodo DNA information; instead, the closely related rice genomic sequence was used for binding-site prediction. The media conditions for callus regeneration protocols have been studied with regard to transgenic methods for kodo, and regenerated plantlets were successfully raised from seed to maturity in soil [72]. Kodo millet is a species that ICRISAT conserves, and a core collection that captures the phenotypic diversity of the entire collection has been formed [68].

Several universities also maintain sizable kodo millet seed banks; the University of Agricultural Sciences in Bangalore is an excellent example of this [72]. Few reports of other banks with considerable numbers of accessions exist because the crop is not significant outside of India. To research the plant as a weed, certain agencies do maintain collections;

the US Department of Agriculture, for instance, has 336 accessions in its National Plant Germplasm System (GRIN)2. Although some of these sources do contain seed with an African provenance, it is uncommon. Improved ecological research and coverage of the African continent would aid in revealing and preserving a variety of important features that international scientists might otherwise overlook.

10.5.5 Proso Millet (*Panicum Miliaceum*):

Proso millet, also known as broomcorn and common millet, was cultivated as early as 10,000 years ago in Neolithic China [73]. Proso has several advantages, including a high protein content that ranges from 11.3 to 17% of the dry matter of the grains [74]. Protein composition and amino acid profile exhibit genotypic variability [74]. The grain's potential for avoiding cancer, heart disease, managing liver disease, and controlling diabetes has been researched, and the findings are encouraging [75,76,77,78]. Five races of proso millet are grown in cultivation [79]. Race miliaceum has sub-erect branches with few subdivisions and big, open inflorescences that resemble wild proso. Miliaceum and patentissimum both have slender, spreading panicle branches. These two races, which are thought to be primitive, are present over the whole Eurasian range of proso. More compact inflorescences with drooping, cylindrical, and curving shapes can be seen on contractum, compactum, and ovatum, respectively [79].

Figure 10.9: Proso Millet (Panicum Miliaceum)

The 842 accessions that ICRISAT has from the five races [79]. Inflorescence length, plant height, panicle exertion, and flowering period have all been used to describe the collection's diversity [79]. The list of more noteworthy proso collections is in Table 2. The N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry in St. Petersburg is home to what is likely the largest collection of proso, with over 8778 accessions as of 2012[13]. There don't seem to be many core collections of proso millet for breeding outside of ICRISAT [68]. For the goal of SSR-based characterization, preliminary diversity clustering based on agronomic parameters was carried out on the Chinese collection [80]. It might be possible to repurpose and slightly alter the 118 landraces from China that make up the subset to create a true core collection.

10.5.6 Barnyard Millet (*Echinochloa* Spp.):

Barnyard millet is made up of two distinct species that belong to the genus Echinochloa, despite the fact that it is commonly referred to as a single taxonomic group. Whereas *Echinochloa frumentacea* (syn. *Echinochloa colona*) is found in Pakistan, India, Nepal, and central Africa, *Echinochloa esculenta* (syn. *Echinochloa utilis*, *Echinochloa crusgalli*) is grown in Japan, Korea, and the north-eastern region of China [81,82]. Differentiation is difficult since the morphological characteristics of the two species coincide. Only the presence or absence of an awn and minute variations in spikelet and glume shape allow for visual identification [83]. Thus, to facilitate research and analysis of their phylogeny, the common names Japanese and Indian barnyard millet have been proposed [81].

Figure 10.10: Barnyard Millet (Echinochloa Spp.)

The two millets are genetically separate despite sharing such striking morphological resemblance, as demonstrated by cytology and marker research; F1 hybrids of the two species are sterile [84,85]. Both species are well known for their rapid maturation, superior storage ability, and inclination to flourish in poor soil [81]. ICRISAT presently has 743 accessions of these barnyard millets from nine different countries, including a core collection of 89 varieties that was just recently produced [68].

The NIAS and the USDA both have more important collections [85]. Both millets have relatively limited availability of genetic maps and sequence data [13]. Callus regeneration procedures have been described for both species, but initial transgenic work has only been published on the Japanese version [86,55].

10.6 Future Prospects:

Farmers in drylands and tribal populations with less resources who live in unstable ecosystems produce millets. Millets, however, have experienced a revival as a result of rising public awareness of their potential health advantages and commercial use. Because of their similarity in usage and preparation, variety in their resistance to adversity, and nutritional value, small millets have the potential to replace or supplement major cereal mainstays. Small millets can be included into a variety of cropping systems both in irrigated and rainfed environments. To speed up the improvement of small millets, genomic assisted breeding will make it easier to identify novel alleles and genes with higher agronomic performance and resilience to biotic and abiotic challenges. In order to increase and maintain sorghum output in both present and future climates, a number of traits would need to be combined and improved. It would be ideal to examine current finger millet advancements both nationally and internationally, pinpoint any gaps, and sketch out a strategy for crop improvement in the face of climate change. In the future, transgenic work can be investigated to published explant regeneration procedures for proso millet.

10.7 References:

1. Xu YB, Li P, Zou C, Lu YL, Xie CX, Zhang XC, Prasanna BM, Olsen MS. Enhancing genetic gain in the era of molecular breeding. Journal of Experimental Botany. 2017; 83:2641-2666. DOI: 10.1093/jxb/erx135
2. Moose SP, Mumm RH. Molecular plant breeding as the foundation for 21st century cropimprovement. PlantPhysiology. 2008; 147:969-977. DOI: 10.1104/pp.108.118232.
3. Bruce TJA. GM as a route for delivery of sustainable crop protection. Journal of Experimental Botany. 2012; 63:537-541. DOI: 10.1093/jxb/err281.
4. Collard BC, Mackill DJ. Marker-assisted selection: an approach for precision plant breeding in the twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences. 2008;363(1491):557-72. DOI: 10.1098/rstb.2007.2170
5. Gupta PK, Kumar J, Mir RR, Kumar A. Marker-assisted selection as a component of conventional plant breeding. Plant Breeding Reviews. 2010; 33:145-217
6. Zhou XC, Bai XF, Xing YZ. A rice genetic improvement boom by next generation sequencing. Current Issues in Molecular Biology. 2018; 27:109-126. DOI: 10.21775/cimb.027.109
7. Chen KL, Wang YP, Zhang R, Zhang H, Gao C. CRISPR/Cas genome editing and precision plant breeding in agriculture. Annual Review of Plant Biology. 2019; 70:667-697. DOI: 10.1146/annurev-arplant-050718-100049. [
8. Godwin ID, Rutkoski J, Varshney RK, Hickey LT. Technological perspectives for plant breeding. Theoretical and Applied Genetics. 2019; 132:555-557. DOI: 10.1007/s00122-019-03321-4.
9. Xue YB, Duan ZZ, Chong K, Yao Y. Next-generation biotechnological breeding technologies for the Future-Designer breeding by molecular modules. Bulletin of the Chinese Academy of Sciences. 2013; 28:308-314.
10. Xu YB, Liu XG, Fu JJ, Wang HW, Wang JK, Huang CL, Prasanna BM, Olsen MS, Wang GY, Zhang AM. Enhancing genetic gain through genomic selection: from livestock to plants. Plant Communications. 2020; 1:100005. DOI: 10.1016/j.xplc.2019.100005.
11. Nkhata SG, Ayua E, Kamau EH, Shingiro JB. Fermentation and germination improve nutritional value of cereals and legumes through activation of endogenous enzymes. Food Science and Nutrition. 2018; 6:2446-58
12. Chandel G, Meena RK, Dubey M, Kumar M. Nutritional properties of minor millets: neglected cereals with potentials to combat malnutrition. Current Science. 2014; 107:1109-11
13. Dwivedi S, Upadhyaya HD, Senthilvel S, Hash CT, Fukunaga K, Diao X, et al. Millets: genetic and genomic resources. Plant Breeding Reviews. 2012; 35:247-375

14. Kam J, Puranik S, Yadav R, Manwaring HR, Pierre S, Srivastava RK, et al. Dietary interventions for type 2 diabetes: how millet comes to help. Frontiers of Plant Science. 2016; 7:1-14
15. Saleh ASM, Zhang Q, Chen J, Shen Q. Millet grains: nutritional quality, processing, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety. 2013; 12:281-95
16. Brink M, Plant Belay G. Resources of tropical Africa 1 cereals and pulses. Wageningen: PROTA Foundation/Backhuys Publishers/CYA; 2006
17. AICSMIP. Report on compendium of released varieties in small millets [Internet]. Banglore,India;2014.http://www.dhan.org/smallmillets/docs/report/Compendium_of_ Released_Varieties_ in_Small_millets.pdf. Accessed 13 Mar 2019
18. Santra DK, Khound R, Das S. Proso Millet (*Panicum miliaceum* L.) breeding: progress, challenges and opportunities. In: Al-Khayri J, Jain SM, Johnson DV, editors. Advances in plant breeding strategies: cereals. Cham: Springer; 2019. p. 223-57
19. Santra DK. Proso millet varieties for western Nebraska. Lincoln: NebGuide, University of Nebraska; 2013. p. G2219
20. Gupta SC, Muza FR, Andrews DJ. Registration of INFM 95001 finger millet genetic male-sterile line. Crop Science. 1997; 37:1409
21. Wang J, Wang Z, Yang H, Yuan F, Guo E, Tian G, et al. Genetic analysis and preliminary mapping of a highly male-sterile gene in foxtail Millet (*Setaria italica* L. Beauv.) using SSR markers. Journal of Integrated Agriculture. 2013; 12:2143-8
22. Diao X, Jia G. Foxtail millet breeding in China. Genetics and genomics setaria (plant genetics and genomics crop model 19). 2017. p. 93-113
23. Ambavane AR, Sawardekar SV, Gokhale NB, Desai SAS, Sawant SS, Bhave SG, et al. Studies on mutagenic effectiveness and efficiency of finger millet [*Eleucina coracana* (L.) Gaertn] in M1 generation and effect of gamma rays on its quantitative traits during M2 generation. International Journal of Agricultural Sciences. 2014; 10:603-7
24. Muduli KC, Misra RC. Efficacy of mutagenic treatments in producing useful mutants in fnger millet (*Eleusine coracana* Gaertn.). Indian Journal of Genetics and Plant Breeding. 2007; 67:232-7.
25. Jency JP, Ravikesavan R, Sumathi P, Raveendran M. Determination of lethal dose and effect of physical mutagen on germination percentage and seedling parameters in kodomillet variety CO3. International Journal of Chemical Studies. 2016; 5:166-9
26. Ludlow MM, Muchow RC. A critical evaluation of traits for improving crop yield in water-limited environments. Advances in Agronomy. 1990; 43:107-153
27. Jordan WR, Shouse PJ, Blum A, Miller FR, Monk RL. Environmental physiology of sorghum. II. Epicuticular wax load and cuticular transpiration. Crop Science. 1984; 24:1168-1173
28. Jordan DR, Hunt CH, Cruickshank AW, Borrell AK, Henzell RG. The relationship between the stay-green trait and grain yield in elite sorghum hybrids grown in a range of environments. Crop Science. 2012; 52:1153-1161
29. Borrell AK, Hammar GL, Henzell RG. Does maintaining green leaf area in sorghum improve yield under drought II. Dry matter production and yield. Crop Science. 2000; 40:1037-1048
30. Khizzah BW, Miller FR, Newton RJ. Inheritance and heritability of heat tolerance in several sorghum cultivars during the reproductive phase. African Crop Science Journal 1993; 1:81-85

31. Kumar A, Sharma HC, Sharma R, Blummel M, Reddy P, Reddy BVS. Phenotyping in Sorghum [*Sorghum bicolor* (L.) Moench]. In Phenotyping for Plant Breeding; Springer: New York, USA; 2013. pp. 73-109
32. Govindaraj, M.; Pattanashetti, S.K.; Patne, N.; Kanatti, A.A. Breeding cultivars for heat stress in staple food crops. In Next Generation Plant Breeding; Ciftci, Y.O., Ed.; Intech Open: London, UK; 2018. pp. 45-76
33. Kumar A, Reddy BVS, Grando S. Global millets improvement and its relevance to India and developing world. In Millets: Promotion for Food, Feed, Fodder, Nutritional and Environment Security, Proceedings of Global Consultation on Millets Promotion for Health & Nutritional Security; Society for Millets Research, Indian Council of Agricultural Research Indian Institute of Millets Research: Hyderabad, India; 2015. pp. 154-172.
34. Singh P, Nedumaran S, Traore PCS, Boote KJ, Rattunde HFW, Prasad PVV, Singh NP, Srinivas K, Bantilan MCS. Quantifying potential benefits of drought and heat tolerance in rainy season sorghum for adapting to climate change. Agricultural and Forest Meterology. 2014;185: 37-48
35. Nataraja KN, Reddy YAN, Naika MBN, Gowda MVC. Transcriptome analysis of finger millet (*Eleusine coracana* (L.) Gaertn.) reveals unique drought responsive genes. Journal of Genetics. 2019; 98:46
36. Li Y, and Wu S. Traditional maintenance and multiplication of foxtail millet (*Setaria italica* (L.) P. Beauv.) landraces in China. Euphytica. 1996; 87:33-38. DOI: 10.1007/BF00022961
37. Yang X, Wan Z, Perry L, Lu H, Wang Q, Zhao C, et al. Early millet use in northern China. Proceedings of the National Academy of Sciences. 2012;109: 3726-3730. DOI: 10.1073/pnas.1115430109
38. Morrison IN, Todd BG and Nawolsky KM. Confirmation of trifluralin-resistant green foxtail (Setaria viridis) in Manitoba. Weed Technology. 1989; 3:544-551
39. Marles MAS, Devine MD and Hall JC. Herbicide resistance in *Setaria viridis* conferred by a less sensitive form of acetyl coenzyme a carboxylase. Pesticide Biochemistry and Physiology. 1993;46: 7
40. Heap IM. The occurrence of herbicide-resistant weeds worldwide. Pesticide Science. 1997;51: 235-243.-14. DOI: 10.1006/pest.1993.1031
41. Van K, Onoda S, Kim MY, Kim KD and Lee SH. Allelic variation of the Waxy gene in foxtail millet (*Setaria italica* (L.) P. Beauv.) by single nucleotide polymorphisms. Molecular Genetics and Genomics. 2008;279: 255-266. DOI: 10.1007/s00438-007-0310-5
42. Wang C, Jia G, Zhi H, Niu Z, Chai Y, Li W, et al. Genetic diversity and population structure of Chinese foxtail millet [*Setaria italica* (L.) Beauv.] landraces. Genes, Genomes, Genetics. 2012; 2:769–777. DOI: 10.1534/g3.112.002907
43. Upadhyaya HD, Pundir RPS, Gowda CLL, Gopal Reddy V and Singh S. Establishing a core collection of foxtail millet to enhance the utilization of germplasm of an underutilized crop. Plant Genetic Resources. 2008; 7:177-184. DOI: 10.1017/S1479262108178042
44. Upadhyaya HD, Ravishankar CR, Narasimhudu Y, Sarma NDRK, Singh SK, Varshney SK, et al. Identification of trait-specific germplasm and developing a mini core collection for efficient use of foxtail millet genetic resources in crop improvement. Field Crop Research. 2001; 124: 459-467. DOI: 10.1016/j.fcr.2011.08.004

45. Wang ZM, Devos KM, Liu CJ, Wang RQ and Gale MD. (1998). Construction of RFLP-based maps of foxtail millet, *Setaria italica* (L.) P. Beauv. Theoretical and Applied Genetics. 1998; 96:31-36. DOI: 10.1007/s001220050705
46. Schontz D and Rether B. Genetic variability in foxtail millet, *Setaria italica* (L.) P. Beauv.: identification and classification of lines with RAPD markers. Plant Breeding 1999;118: 190-192. DOI: 10.1046/j.1439-0523.1999. 118002190.x
47. Jia X, Zhang Z, Liu Y, Zhang C, Shi Y, Song Y, et al. Development and genetic mapping of SSR markers in foxtail millet [*Setaria italica* (L.) P. Beauv.]. Theoretical and Applied Genetics. 2009;118: 821-829. DOI: 10.1007/s00122-008-0942-9
48. Yadav CB, Muthamilarasan M, Pandey G, Khan Y and Prasad M. Development of novel microRNA-based genetic markers in foxtail millet for genotyping applications in related grass species. Molecular Plant Breeding. 2014; 34:2219-2224. DOI: 10.1007/s11032-014-0137-9
49. Muthamilarasan M, Venkata Suresh B, Pandey G, Kumari K, Parida SK and Prasad M. Development of 5123 intron-length polymorphic markers for large-scale genotyping applications in foxtail millet. DNA Research. 2014; 21:41-52. DOI: 10.1093/dnares/dst039
50. Gupta S, Kumari K, Sahu PP, Vidapu S and Prasad M. Sequence based novel genomic microsatellite markers for robust genotyping purposes in foxtail millet [*Setaria italica* (L.) P. Beauv]. Plant Cell Reports. 2012; 31: 323-337. DOI: 10.1007/s00299-011-1168-x
51. Pandey G, Misra G, Kumari K, Gupta S, Parida SK, Chattopadhyay D, et al. Genome-wide development and use of microsatellite markers for largescale genotyping applications in foxtail millet (Setaria *italica* (L.)). DNA Research. 2013; 20:197-207. DOI: 10.1093/dnares/dst002
52. Lata C, Bhutty S, Bahadur RP, Majee M and Prasad M. Association of an SNP in a novel DREB2-like gene SiDREB2 with stress tolerance in foxtail millet [*Setaria italica* (L.)]. Journal of Experimental Botany. 2011;62: 3387–3401. DOI: 10.1093/jxb/ err016
53. Lata C and Prasad M. Validation of an allele-specific marker associated with dehydration stress tolerance in a core set of foxtail millet accessions. Plant Breeding. 2013; 132: 496-499. DOI: 10.1111/j.1439-0523.2012. 01983.x
54. Wang M, Pan Y, Li C, Liu C, Zhao Q, Ao GM, et al. Culturing of immature inflorescences and Agrobacterium-mediated transformation of foxtail millet (*Setaria italica)*. African Journal of Biotechnology. 2011; 10: 16466-16479. DOI: 10.5897/ajb10.2330
55. Kothari SL, Kumar S, Vishnoi RK, Kothari A and Watanabe KN. Applications of biotechnology for improvement of millet crops: review of progress and future prospects. Plant Biotechnology. 2005;22: 81-88. DOI: 10.5511/plantbiotechnology.22.81
56. Ceasar SA and Ignacimuthu S. Genetic engineering of millets: current status and future prospects. Biotechnology Letters. 2009; 31: 779-788. DOI: 10.1007/s10529- 009-9933-4
57. Plaza-Wüthrich S and Tadele Z. Millet improvement through regeneration and transformation. Biotechnology and Molecular Biology Reviews. 2012;7: 48-61. DOI: 10.5897/BMBR12.001
58. Qin FF, Zhao Q, Ao GM and Yu JJ. Co-suppression of Si401, a maize pollen specific Zm401 homologous gene, results in aberrant anther development in foxtail millet. Euphytica. 2008; 163:103-111. DOI: 10.1007/s10681- 007-9610-4

59. de Wet JMJ, Rao KEP, Mengesha MH and Brink DE. Diversity in kodo millet, *Paspalum scrobiculatum.* Economic Botany. 1983a; 37: 159-163. DOI: 10.1007/BF02858779
60. Geervani P and Eggum BO. Nutrient composition and protein quality of minor millets. Plant Foods for Human Nutrition. 1989; 39: 201-208. DOI: 10.1007/BF01091900
61. Kulkarni LR and Naik RK. Nutitive value, protein quality and organoleptic quality of kodo millet (*Paspalum scrobiculatum*). Karnataka Journal of Agricultural Sciences. 2000; 13: 125-129
62. Hegde PS and Chandra TS. ESR spectroscopic study reveals higher free radical quenching potential in kodo millet (*Paspalum scrobiculatum*) compared to other millets. Food Chemistry. 2005; 92: 177-182. DOI: 10.1016/j.foodchem.2004. 08.002
63. Hegde PS, Rajasekaran NS and Chandra TS. Effects of the antioxidant properties of millet species on oxidative stress and glycemic status in alloxan-induced rats. Nutrition Research Reviews. 2005; 25: 1109-1120. DOI: 10.1016/j.nutres.2005.09.020
64. Chandrasekara A and Shahidi F. Determination of antioxidant activity in free and hydrolyzed fractions of millet grains and characterization of their phenolic profiles by HPLC-DAD-ESI-MS. Journal of Functional Foods. 2011;3: 144-158. DOI: 10.1016/j.jff.2011.03.007
65. de Wet J MJ, Rao KEP, Mengesha MH and Brink DE. Diversity in kodo millet, *Paspalum scrobiculatum.* Economic Botany. 1983b;37: 159-163. DOI: 10.1007/BF02858779
66. M'Ribu H K and Hilu KW. Application of random amplified polymorphic DNA to study genetic diversity in *Paspalum scrobiculatum* L. (Kodo millet, Poaceae). Genetic Resources and Crop Evolution. 1996; 43: 203-210
67. Subramanian A, Nirmalakumari A and Veerabadhiran P. Trait based selection of superior kodo millet (*Paspalum scrobiculatum* L.) genotypes. Electronic Journal of Plant Breeding. 2010;1: 852-855
68. Upadhyaya HD, Dwivedi SL, Singh SK, Singh S, Vetriventhan M and Sharma S. Forming core collections in barnyard, kodo, and little millets using morphoagronomic descriptors. Crop Science. 2014;54: 1-10. DOI: 10.2135/cropsci2014.03.0221
69. Kushwaha H, Jillo KW, Singh VK, Kumar A and Yadav D. Assessment of genetic diversity among cereals and millets based on PCR amplification using Dof (DNA binding with One Finger) transcription factor gene-specific primers. Plant Systematics and Evolution. 2015;301: 833-840. DOI: 10.1007/s00606-014-1095-8
70. Babu RN, Jyothi MN, Sharadamma N, Sahu S, Rai DV and Devaraj VR. Computational identification of conserved micro RNAs from kodo millet (*Paspalum scrobiculatum*). African Crop Science Journal. 2013; 21: 75-83
71. Ceasar SA and Ignacimuthu S. Effects of cytokinins, carbohydrates and amino acids on induction and maturation of somatic embryos in kodo millet (*Paspalum scorbiculatum* Linn.). Plant Cell, Tissue and Organ Culture. 2010;102: 153-162. DOI: 10.1007/s11240-010-9716-6
72. Lu H, Zhang J, Liu K, Wu N, Li Y, Zhou K, et al. Earliest domestication of common millet (*Panicum miliaceum*) in East Asia extended to 10,000 years ago. PNAS 2009;106: 7367-7372. DOI: 10.1073/pnas.0900158106
73. Kalinova J and Moudry J. Content and quality of protein in proso millet (*Panicum miliaceum* L.) varieties. Plant Foods Hum. Nutr.2006; 61: 45-49. DOI: 10.1007/s11130-006-0013-9

74. Nishizawa N and Fudamoto Y. (1995). The elevation of plasma concentration of high-density lipoprotein cholesterol in mice fed with protein from proso millet. Biosci. Biotechnol. Biochem. 1995; 52: 333-335. DOI: 10.1271/bbb.59.333
75. Nishizawa N, Sato D, Ito Y, Nagasawa T, Hatakeyama Y, Choi MR, et al. Effects of dietary protein of proso millet on liver injury induced by D-galactosamine in rats. Bioscience, Biotechnology and Biochemistry. 2002;66: 92-96. DOI: 10.1271/bbb.66.92
76. Park KO, Ito Y, Nagasawa T, Choi MR and Nishizawa N. Effects of dietary Korean proso-millet protein on plasma adiponectin, HDL cholesterol, insulin levels, and gene expression in obese type 2 diabetic mice. Bioscience, Biotechnology and Biochemistry 2014;72: 2918-2925. DOI: 10.1271/bbb.80395
77. Zhang L, Liu R and Niu W. Phytochemical and antiproliferative activity of proso millet. PLoS ONE 9: e104058. 2014. DOI: 10.1371/journal.pone.0104058
78. Reddy VG, Upadhyaya HD and Gowda CLL. Morphological characterization of world's proso millet germplasm. Journal of SAT Agricultural Research. 2007; 3: 1–4
79. Hu X, Wang J, Lu P and Zhang H. Assessment of genetic diversity in broomcorn millet (*Panicum miliaceum* L.) using SSR markers. Journal of Genetics and Genomics. 2009;36: 491-500. DOI: 10.1016/S1673-8527(08) 60139-3
80. Yabuno T. Japanese barnyard millet (*Echinochloa utilis*, Poaceae) in Japan. Economic Botany. 1987;41: 484-493. DOI: 10.1007/BF02908141
81. Wanous MK. Origin, taxonomy and ploidy of the millets and minor cereals. Plant Varieties and Seeds. 1990;3: 99-112
82. de Wet JM J, Rao KEP, Mengesha MH and Brink D E. Domestication of sawa millet. Econ. Bot. 1983b; 37: 283-291. DOI: 10.1007/BF02858883
83. Yabuno T. Cytotaxonomic studies on the two cultivated species and the wild relatives in the genus Echinochloa. Cytologia. 1962;27: 296-305. DOI: 10.1508/cytologia.27.296
84. Hilu KW. Evidence from RAPD markers in the evolution of Echinochloa millets (Poaceae). Plant Systematics and Evolution. 1994;189: 247-257. DOI: 10.1007/BF00939730
85. Gupta P, Raghuvanshi S and Tyagi AK. Assessment of the efficiency of various gene promoters via biolistics in leaf and regenerating seed callus of millets, *Eleusine coracana* and *Echinochloa crusgalli*. Plant Biotechnology. 2001;18: 275-282. DOI: 10.5511/plantbiotechnology.18.275

ISBN: 978-81-19149-19-3

11. Biotic Stresses in Millets and Their Management

Ippa Vinay

Department of Genetics and Plant Breeding,
Professor Jayashankar Telangana State Agricultural University,
Hyderabad, Telangana.

Singarapu Snigda Srilaasya

Department of Seed Science and Technology
Professor Jayashankar Telangana State Agricultural University,
Hyderabad, Telangana.

Patel Supriya

Department of Genetics and Plant Breeding,
Acharya N.G. Ranga Agricultural University,
Tirupati, Andrapradesh.

Thalari Vasanthrao

Department of Genetics and Plant Breeding
Professor Jayashankar Telangana State Agricultural University,
Hyderabad, Telangana.

Abstract:

Millets are the most climate-resilient crops when compared with cereals, pulses and other crops. While biotic and abiotic stresses can affect millet yields to some extent, they generally tolerate changes in the environment well.

Biotic stresses, such as pests, diseases, and birds can significantly reduce the yields and quality of millets. Given that millets are nutrient-rich superfoods; it is important to protect them from these biotic stresses. This chapter discusses the nutritional benefits of the millets, pests and diseases that affect the millet crops, as well as their management strategies.

The management of the pests and diseases in millets can be mostly done by sowing the resistant varieties of the millets, rather than using the chemicals. Scientists have developed many resistant varieties, and host plant resistance is an eco-friendly and less expensive option for poor farmers. Effective management of biotic stresses is critical for maximising millet yield and ensuring food security.

Keywords:

biotic stresses, millets, pest and disease management.

11.1 Introduction:

The major millets, which include sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*), as well as minor millets such as foxtail millet, proso millet, barnyard millet, kodo millet, little millet and brown top millet, are small-seeded tropical grasses that are primarily cultivated for food, feed and forage. These crops provide a significant source of dietary energy and protein for the majority of individuals living in semi-arid tropics (Chandrashekar and Satyanarayana, 2006).

There are at least 10 genera and 14 species of identified millets belonging to the family Poaceae (Gramineae) (Kumar *et al*., 2005). Due to high importance of millets in human nutrition, the year 2023 has been declared as the "International year of millets". Small millets are packed with the goodness of B-vitamins, minerals like calcium, iron, zinc, and potassium. They can also provide essential nutrients. In agriculture, omics tools have been widely used to identify genomic sequences governing crucial agronomic characteristics such as grain yield, resistance to biotic and abiotic stresses, and more. Integration of functional analysis with genomic sequence data provides more accurate gene annotations, functional markers, quantitative trait loci (QTL) maps which helps to improve the development of crop varieties. Further improvement is needed to make millets more resilient to the biotic stresses, unprecedented impacts of climate change and associated environmental stresses although they are tolerant to most abiotic stresses, including drought and high temperatures" (Numan *et al*., 2021).

Table 11.1: Most Commonly Grown Millets in India and Their Nutritional Benefits

Sr. No.	Crop	Botanical Name	Family	Benefits
1.	Sorghum	*Sorghum bicolor*	Poaceae	Rich in vitamins and many minerals like magnesium, potassium, zinc and iron. It also contains anti-oxidant properties.
2.	Pearl millet	*Pennisetum glaucum*	Poaceae	Good source of carbohydrates, rich in dietary fibre and have cholesterol lowering properties.
3.	Finger millet	*Eleusine coracana*	Poaceae	Rich source of protein and also contains minerals like phosphorous, iron and magnesium.
4.	Barnyard millet	*Echinochloa frumentacea*	Poaceae	Rich source of highly digestible protein and contains low glycemic index.
5.	Proso millet	*Panicum miliaceum*	Poaceae	Rich source of essential phosphorous. Contains lecithin which supports the neural health system.

Sr. No.	Crop	Botanical Name	Family	Benefits
6.	Foxtail millet	*Setaria italica*	Poaceae	Rich source of Vitamin B_{12} helps in maintaining healthy heart and smooth functioning of nervous system.

11.2 Biotic Stresses:

Although abiotic stresses affect millet production, biotic stresses are major constraints that affect production. These biotic stresses are likely to increase due to the changing weather. Losses due to biotic stresses may vary depending on the stage of the crop, the plant part affected, the type of disease etc.,

Biotic stresses are mainly due to:

A. Diseases
B. Pests
C. Birds damage

11.2.1 Diseases of Millets:

Many diseases infect cultivated millets, some of which regularly appear in a severe form which ultimately cause huge economic losses to the crop. Fungal diseases are common on millets than bacterial and viral diseases.

Some of the major diseases of millets are grain mold, ergot, smut, blast, rust, anthracnose, downy mildew, charcoal rot and sheath rot. Pest and/or pathogen attacks can cause a 10-40% reduction in crop yield depending on the geographical location (Repellin *et al.*, 2001).

Seedling diseases: Seedling blight, damping off, anthracnose, root rot of seedling appear mainly during the seedling stage of the crop and severe infection can damage the roots and tender leaves and often kill the seedling ultimately leading to the low plant stand in the crop. Seedlings may die prematurely depending on the intensity of the infection.

Grain diseases: The most important part of the millet crops-florets or developing grains, are infected by many pathogens. The most important grain disease is grain mold and then ergots and smuts. Grain mold infection on the grain surface becomes visible in pink, orange, gray, white, or black colored fungal bloom and these molded grains often contain mycotoxins which may be harmful even to humans and birds. Ergot is another important serious issue in hybrid seed production which is a sugary disease commonly affects grain, the symptoms of this disease include honey dew like droplets that are thick, viscous and sweet, which may vary in colour, such as pink or red. Infected florets usually fail to produce grains, and if they do, the grains exhibit reduced germination. Smut is another common grain disease that converts part of the head or whole head into fungal structure. The different types of smuts that occur in millets are head smut, loose smut, covered smut and long smut.

Leaf diseases: Leaf diseases, such as rusts and blights, destroy the leaf surfaces that perform photosynthesis and lower the crop yield. There are various types of leaf diseases that are occurring in millets. Some of them include downy mildew, anthracnose, blast, rust, leaf spots and leaf blight.

Downy mildew mostly occurs in sorghum, pearl millet and foxtail millet. The infection starts off in the seedling stage and eventually spreads to the entire leaf, ultimately killing the plant. Symptoms of downy mildew include white discoloration on the leaf blade, which is caused by the presence of conidia and conidiophores with downy growth. Apart from the downy mildew, rust also occurs in millets but it occurs during later stages of crop growth. Symptoms include reddish brown pustules on both surfaces of the leaves.

Root and stalk diseases: Most root and stalk diseases in millets are soil-borne, with charcoal rot being the most common. Symptoms first appear in the root and then destroy the cortical tissue, affecting water movement and ultimately resulting in rotting that can impact the quality of millet fodder (Das *et al*., 2023).

Table 11.2: Fungal diseases of millets

Sr. No.	Millet crop	Disease	Causal organism
1.	Finger millet	Grain smut	*Melanopsichium eleusinis*
2.	Foxtail millet	Grain smut	*Ustilago crameri*
3.	Barnyard millet	Grain smut	*Ustilago panici-frumentacei*
4.	Barnyard millet, Kodo millet and Proso millet	Head smut	*Sorosporium paspalithunbergii*
5.	Foxtail millet, Kodo millet and Little millet	Udabetta	*Ephelis oryzae*
6.	Foxtail millet	Downy mildew	*Sclerospora graminicola*
7.	Finger millet	Blast	*Pyricularia grisea*
8.	Foxtail millet	Blast	*Pyricularia setariae*
9.	Finger millet	Rust	*Uromyces eragrostidis*
10.	Foxtail millet	Rust	*Uromyces setariae italiae*
11.	Little millet	Rust	*Uromyces linearis*
12.	Finger millet and Little millet	Helminthosporium leaf spot	*Drechslera nodulosum*
13.	Foxtail millet	Helminthosporium leaf spot	*Cochliobolus setariae*
14.	Finger millet	Cercospora leaf spot	*Cercospora eleusinis*

Table 11.3: Bacterial diseases of millets

Sr. No.	Millet crop	Disease	Causal organism
1.	Finger millet	Bacterial leaf spot	*Xanthomonas eleusinae*
2.	Finger millet	Bacterial leaf stripe	*Pseudomonas eleusinae*

A. Management of Millet Diseases by Resistant Varieties:

Resistance or tolerance of millet crop varieties to diseases can vary depending on the specific pathogen strain and environmental conditions. Farmers should, therefore, choose the appropriate variety based on the specific disease pressures in their area and consult with their local agricultural extension services for advice on the best management practices for disease control.

One of the effective management for disease free millet crops is by growing of disease resistant varieties released and identified in India, some of them are:

a. Sorghum:

Sorghum (*Sorghum bicolor*) is susceptible to various diseases that can cause significant yield losses. However, several varieties of sorghum have been developed that are resistant or tolerant to different diseases.

Charcoal rot: CSV 17, CSV 22, CSV 26 and CSV 29R

Grain mold: CSH 25, CSV 27, CSV 28 and CSV 31

Anthracnose: CSV 17 and CSV 31

Leaf blight: CSV 31

Sugary disease: CSV 17

Rust, rough leaf spot, zonate leafspot, and gray leafspot: CSV 17 and CSV 18

b. Pearl Millet:

The pearl millet crop is susceptible to many diseases among them downy mildew is a significant disease of pearl millet that can cause yield losses of up to 50%. Several pearl millet varieties have been developed with resistance to downy mildew, including ICTP 8203, 86001B, and 843A.

Downy mildew: BHB-1202, GK 1116, JKBH 1008, MPMH 21, Proagro Tejas, HHB 234, Bio 70, HHB -226, RHB -177, HHB 216, RHB 154, JKBH 1326, DHBH 1397, PROAGRO 9450, Pusa 1201, XMT 1497, KBH 3940, Bio 8145, KBH 108, Phule Mahashakti,86M64, AHB 1200 Fe, Nandi-75, MP 535 (Pusa Composite 701), Pearl Millet CO 10 and Dhan shakti (ICTP 8203 Fe 10-2)

Blast: BHB-1202, (MH 1831), Central Pearl Millet Hybrid RHB 223, JKBH 1008, MPMH 21, HHB 272, PB 1852, DHBH 1397, PROAGRO 9450, XMT 1497, Bio 8145, 86M84 (MH 1890), KBH 108, 86M88 (MH 1816) and ABV 04 (MP 552)

Rust: 86M88 (MH 1816), JKBH 1105, JKBH 1105, Bio 8145, JKBH 1100 and 86M82.

c. Finger Millet:

Blast: GPU 26, GPU 45, Chilika (OEB 10), VL 315, GPU 48, PRM 1, Bharathi (VR 762), Srichaitanya, KOPN 235, OEB 526, OEB 532, PPR 2700 (Vakula), VL 352, GNN - 6, GN - 5, VL Mandua - 348, KMR 340, Dapoli – 2 (SCN – 6) and CO 15

d. Foxtail Millet: *Downy mildew*: Meera (SR 16), SiA 3085 and RAU (Rajendra Kauni 1- 2)

Rust: TNAU 196 and RAU (Rajendra Kauni 1- 2) ″ Blast: RAU (Rajendra Kauni 1- 2) and SiA 3085

e. Barnyard Millet: *Grain smut*: VL Madira

f. Little Millet:

Grain smut: Tarini (OLM 203), OLM 217 and GNV - 3

Blast: Tarini (OLM 203) and GNV - 3

Rust: OLM 217 ″ Brown spot: Kolab (OLM 36)

Head smut: Jawahar Kutki 4 (JK 4)

g. Kodo Millet: *Head Smut*: Jawaharkodo 155(RBK 155), Jawaharkodo 48(JK 48), JK 13, JK 106, JK 65, JK 98 and Jawaharkodo 137. (Rawat *et al*.,2022)

B. Management of Millet Diseases by Cultural and Chemical Methods:

a. Cultural methods: Regularly following some agricultural practices can greatly reduce disease problems in the field. These practices include deep ploughing during the summer season, cleaning field bunds after every crop season, removing crop debris from the field, burning diseased plants, and restricting irrigation water entry from adjacent fields.

- Eradication of host plants from the field bund and surrounding, aids in the control of diseases like ergot, downy mildew, rust, blast, leaf spots and bacterial and viral diseases as these alternate and collateral host plants harbour pathogens.

- To reduce the soil-borne diseases that affect the crops, such as downy mildew, smut, charcoal rot and some leaf diseases caused by fungi and bacteria, it is helpful to do the following: till the soil deeply in summer, remove crop residues, and rotate the crops with non-host plants for these diseases.
- To reduce the incidence of diseases like blast, downy mildew and charcoal rot, it is essential to maintain the optimum plant spacing between plants and control the amount of nitrogenous fertilizer by following specific recommendations.
- To reduce the infection of ergot caused by seed contamination, it is helpful to remove the sclerotia from the seeds mechanically, by washing them in salt water with 30% concentration and then rinsing them in plain water.

b. Chemical methods: Chemicals are not typically used to manage millet diseases due to their expensive nature and labour-intensive requirements.

- Treating the seed with Ridomyl-MZ at 6g per kg of seed and then spraying it once with Ridomyl-MZ at 3g per liter of water helps to lower the occurrence of downy mildew.
- Treating the seed with propiconazole at 1 ml per kg of seed was effective in lowering the occurrence of banded sheath blight in finger millet.
- Loose and covered smuts are seed-borne on the outside and can be easily controlled by dressing the seed with sulphur at 4g per kg of seed.
- Spraying the leaves with Mancozeb at 0.2% concentration helps to prevent the rust effectively. (Das *et al*., 2016)

11.2.2 Pests of Millets:

- **Soil pests:** The majority of soil pests include white grubs. Species of Holotrichia and Anomala are known to occur. C shaped grubs affect the roots and causes them to die and there will be loss of plant stand.
- **Seedling pests:** These shoot pests include shoot flies which belong to the genus Atherigona. The female deposits eggs in the young leaves and hatches in 2-3 days by cutting growing point and producing dead heart. Seedlings are also infested by leaf beetles, menolepta species etc.,
- **Foliage pests:** Foliage pests commonly include leaf caterpillars, army worms, grasshoppers and sap sucking pests. Leaf caterpillars include *Amsacta albistriga Moore, Estigmene lactinea Cram., A. moorei Butler* etc., Because they live in groups and eat a lot, these animals can quickly strip the millet plants of their leaves or ruin the seedling of young plants. On the lower side of leaves, yellowish eggs are deposited in clusters. A reddish body with many blackish hairs is what the large larvae have.
- **Armyworms:** *Mythimna loreyi Dup., Spodoptera exempta Wlk.,* are widely distributed in African tropics. These cause ragging and crop failure.
- **Grasshoppers:** The crop can be destroyed by young and adult grasshoppers, who eat the leaves like locusts do. *Hieroglyphus nigrorepletus Bol., H. banian Fb., Chrotogonus spp.,* are known to cause to destruction to millet crops.
- **Sap sucking insects:** Both nymphs and adult aphids, *Peregrinus maidis*., shoot bugs, plant bugs are some of the majorly occurring sap sucking pests. They make the plants wilt, turn yellow and twist by feeding on the juice from young leaves and the part where the leaves join. This results in dry and empty grains.

- **Stem borers:** Attacking millets, stem borers are a destructive group of insects. *Acigona ignefusalis Hmps.*, *Sesamia calamistis Hmps.*, *Chilo partellus Swinhoe* and *Sesamia inferens* are some of the stem borers commonly occurring in the millets. *Sesamia inferens* occurs most frequently in finger millet. The stem gets pierced and the central part dies, causing many branches to grow with spikes that don't produce anything. When they attack later, they damage the stalk that holds the flower and make the plant break. This also causes less grains and animal feed to be produced. *Sesamia inferens,* they lay their round yellow-white eggs in groups of 30 to 100 eggs. The eggs are arranged in two or three lines on the part of the leaf that wraps around the stem or on the top of the leaf. The larva is pinkish and the young insect pierces the stem right away without eating the leaf when it is in its early stages of growth.
- **Earhead pests:** Earhead pests commonly include spike worms, head beetles, head bugs, grain midges, thrips and earwigs. The number of grains produced is lower because the young insects eat the grains that are growing.
- **Storage pests:** Stored millets suffer significant losses due to insects, fungal and rodent attack. Angoumois grain moth, *Sitotroga cerealella Oliv.* are commonly occurred as stored grain pests (Gahukar.,1989).

A. Management of millet pests:

- Treating the seed with imidacloprid 600FS at 10-12 ml per kg of seed is an effective way to control white grubs.
- To protect pearl millet from shoot fly and stem borer, spray profenophos 50EC at 0.05% or fenobucarb 50EC at 0.1% twice, once at 20 days after germination and again at 40 days. (Gahukar and Reddy., 2019)
- Thrips are regarded as minor pests, can be effectively controlled by malathion 0-05% or carbaryl 0-7% sprays.
- Dusts of a mixture of methyl parathion + DDT or sprays of fenitrothion or phosalone reduces the grain midges.
- Use of resistant cultivars are also known to reduce the pest incidence.

11.2.3 Birds Damage in Millet Crops and Their Management:

Grain eating birds pose a serious threat to millet production both in India and Africa. The most notorious avian pest in the world, the Red-billed Quelea, is a major threat to pearl millet production. Other important bird pests of millets include various species of weavers, sparrows, parakeets, pigeons, crows, mynas and doves (Sharma & Davies, 1988). Some common bird pests of millets include:

- Sparrows (*Passer spp*): These birds feed on millet seeds and can cause significant damage to the crop.
- Baya weavers *(Ploceus philippinus)*: are small bird species which are widely distributed in India and are known to feed on the seeds of millet crops. They can cause damage by feeding on the grain heads, which can result in reduced yields.
- Rose-ringed parakeets (*Psittacula krameri*) are grass-green coloured birds that can cause damage to millet crops in several ways. They primarily feed on the grain heads

of the plants, which can cause yield losses and reduced crop quality. They may also cause damage by pecking at the tender shoots and leaves during the early growth stages.

- Crows (*Corvus spp*): Crows are opportunistic feeders and can attack millet crops, especially during the maturation stage. They can cause damage by pecking at the mature seed heads.
- Pigeons (*Columba spp*): Pigeons are known to attack millet crops, especially during the seedling stage. They can cause damage by pecking at the tender shoots and leaves.

A. Control Measures:

a. **Traditional Methods:** Bird scaring through shouting, beating empty tin cans, pelting stones or mud pellets at the flocks of birds, bursting firecrackers, covering crop heads with bags, hanging dead birds, cutting or burning nest bearing trees, and using bird scaring devices etc., have proven to be useful on small areas, but they are impractical on large farms.

b. **Physical Barriers:** Fish nets or nylon nets can be used to cover the millet crop to prevent birds from accessing it.

c. **Plant Phenology:** To protect millet crops from bird damage, farmers can plant long or short duration varieties such that they mature during low bird activity. Compact earheads with small grains and earheads with awns are less damaged. Plant characteristics such as bristles and anther covering of the grain may also be associated with resistance to birds.

d. **Bioacoustics**: Using distress alarms or warning calls to scare some bird species such as parakeets. The bird damage to millet crops may vary according to the location and stage of the crop. Among the different types of millet crops, pearl millet is more susceptible to bird damage.

11.3 Conclusion:

To protect millet crops, it is important to identify and manage the range of biotic stresses that affect crop production, using a variety of approaches such as cultural, biological, chemical control methods, and resistant varieties. Integrated plant disease management approaches that combine multiple control methods are particularly effective in minimizing the impact of biotic stresses on millet production. Recent advances in biotechnology and genomics are helping to identify novel sources of resistance to biotic stresses in millets. The sequencing cost has come down due to identification of the new sequencing technologies and quicker identification of the genes for the resistance has led to the early development of the varieties. Understanding host plant resistance has been instrumental in developing of these varieties. However, further research is necessary to develop effective and sustainable management strategies for biotic stresses in millets.

11.4 References:

1. Chandrashekar, A. and Satyanarayana, K. V. (2006). Disease and pest resistance in grains of sorghum and millets. *Journal of Cereal Science*. *44*(3): 287-304.
2. Das, I. K., Palanna, K.B., & Rajesh, G. (2023). Disease management for improved millet production.

3. Das, I.K., Rao, T. N. and Nagaraja, A. (2016). Diseases of millets and their management. *Indian Council of Agricultural Research*.
4. Gahukar, R. T. and Reddy, G. V. (2019). Management of economically important insect pests of millet. *Journal of Integrated Pest Management*, *10*(1):28.
5. Gahukar, R.T. (1989). Insect pests of millets and their management: a review. *International Journal of Pest Management*, *35*(4):382-391.
6. Kumar, S., Kothari, A., & Watanabe, K. N. (2005). Applications of biotechnology for improvement of millet crops: review of progress and future prospects. *Plant Biotechnology*. *22*(2): 81-88.
7. Numan, M., Serba, D. D., and Ligaba-Osena, A. (2021). Alternative strategies for multi-stress tolerance and yield improvement in millets. *Genes*.*12*(5): 739.
8. Rawat, L., Bisht, T. S., and Kukreti, A. (2022). Potential of seed biopriming with Trichoderma in ameliorating salinity stress and providing resistance against leaf blast disease in finger millet (*Eleusine coracana* L.). *Indian Phytopathology*, *75*(1): 147-164.
9. Repellin, A.M., Baga, P.P., Jauhar, P.P. and Chibbar, R.N., (2001). Genetic enrichment of cereal crops via alien gene transfer, new challenges. Plant Cell Tissue Organ Culture 64:159-183.
10. Sharma, H. C., & Davies, J. C. (1988). Insect and other animal pests of millets.

ISBN: 978-81-19149-19-3

12. Post-Harvest Management in Millets

Palli Susan Grace, Kobagapu Maniratnam,

Buriga Teja Swaroop, Lakshmi Sowmya

M.Sc. (Agri.)
Sam Higginn Bottom University of Agriculture and
Technology Sciences Prayagraj,
Uttar Pradesh, India.

Abstract:

Millets are an important part of many people's nutritional diets around the world. Despite the fact that millets are more nutritious than other cereals, their use as a food in the diet is still mostly limited to the poor and traditional people. Millets are high in carbohydrates, energy, and protein, as well as fat, iron, calcium, and dietary fibre, all of which help to prevent diseases such as diabetes, cataract genesis, and cardiovascular disease. Environmental changes, water scarcity, population growth, and decreasing cereal yields present a challenge to nutritionists and researchers to investigate the potentials of production, processing, and using other prospective food sources to end poverty and hunger. The current paper examines various postharvest technologies, processing, and convenience food products made from millets.

Keywords:

Millets, Post-harvest management, Value addition, Nutritional values.

12.1 Introduction:

Millets are group of small grained cereal food crops which are highly nutritious and are grown under marginal/low fertile soils with very low inputs such as fertilizers and pesticides. These crops largely contribute to food and nutritional security of the country. Most of millet crops are native of India and are popularly known as Nutri-cereals as they provide most of the nutrients required for normal functioning of human body. Millets are rain fed crops and are grown in regions with low rainfall and thus resume greater importance for sustained agriculture and food security. Based on area grown and its grain size the millets are classified as major millet and minor millets.

The major millets include sorghum (jowar) and pearl millet (bajra). The finger millet (ragi/mandua), foxtail millet (kangni/Italian millet), little millet (kutki), kodo millet, barnyard millet (sawan/jhangora), proso millet (chena/common millet), and brown top millet (korale) are categorized under minor millets. In certain countries of Africa, other millets such as fonio and tef are grown. Millets were the first crops to be domesticated by the mankind in Asia and Africa which later on spread across the globe as critical food sources to the evolving civilizations.

All these millets have shorter growing duration complete their life cycle in 2-4 months, fit wide range of cropping systems and also adapt themselves to the changing environmental conditions especially during vagaries of monsoon. Millets are major energy source and staple foods for people living in the dry and arid regions of the world. The stover after harvest of grains is a source of nutritive fodder to animals apart from its industrial use as bird feed, brewing, potable alcohol etc.

Millets had been the lifeline of dry regions of Asia and Africa for food and fodder. Most of the millets are kharif season crops (sown during May-June) and come to maturity during September to October. Most of these crops give good yields during rabi season (October-March) and summer season (January-April). Millets require very less water as compared to rice and wheat and considered drought tolerant crops. These crops are majorly grown in regions receiving less than 450 mm rainfall (compared to about 700 mm minimum for maize). About 50% of sorghum and 80% of millet production is used for human consumption while the rest is used for poultry feed, potable alcohol and other industrial purposes. Millets are sometimes referred to as famine crops since they are the only crops that assure yields in famine situations. Earlier, these crops were also called as orphan crops since they are the last option for cultivation as they have less demand in the market and profits earned are also lower than other crops.

However, these neglected crops are important by virtue of their contribution to the means of livelihood, food and nutritional security of the poor in various parts of the world and they diversify our food basket. Before getting to more about the utility of millets and the story of their domestication, let us know briefly about each of the common millets grown today. Millets were the oldest foods known to humans but their importance and cultivation reduced due to large scale cultivation of rice and wheat because of urbanization and industrialization.

With diabetes, hypertension and cardiovascular disease becoming more prevalent, as gifts of newly acquired life-styles and food habits, millets have returned as a viable option to live healthy life and can reduce the incidence of these lifestyle diseases. Millets have many nutritional, nutraceutical and health promoting properties especially the high fibre content, nature of starch has major role in reducing the risk of diabetes other related diseases. Indeed, millets act as a prebiotic feeding micro-flora in our inner ecosystem. Millet will hydrate our colon to keep us from being constipated. The high levels of tryptophan in millet produce serotonin, which is calming to our moods. Niacin in millet can help lower cholesterol. Millet consumption decreases triglycerides and C-reactive protein, thereby preventing cardiovascular disease. All millet varieties show high antioxidant activity. Millet is gluten free and non-allergenic. The beneficial effects of millets on human health are reported in many literatures and are available online.

12.2 Post-Harvest Technology:

Postharvest technology is interdisciplinary science and technique applied to agricultural produce after harvest for its production, conservation, processing, packaging, distribution, marketing and utilization to meet the food and nutritional requirements of the people in relation to their needs. Postharvest technology involves all treatments or processes that occur from time of harvesting until the foodstuff reaches the final consumer.

Efficient techniques for harvesting, conveying / transportation, handling, storage, processing / preservation, packaging, marketing and utilization etc. are components of the postharvest chain. Post harvest technology is inter-disciplinary "Science and Technique" applied to agricultural produce after harvest for its protection, conservation, processing, packaging, distribution, marketing, and utilization to meet the food and nutritional requirements of the people in relation to their needs.

12.2.1 Harvesting:

Many millets are harvested by removing the individual heads using sickles or small hand knives. This is sometimes preceded by the stems being broken (Aucland, 1921). According to Esele (1989), finger millet is harvested in Uganda with a sharp hand or finger knife.

The ears are trimmed to leave roughly 2 cm of stalk. The harvested ears are stored in a pile for a few days to further mature the grain and provide the desired flavour. They are then dried in the sun. Hulse et al. (1980) observed that proso (common) millet is harvested by taking out the entire plant by the roots as soon as the grain is ready to minimise excessive shattering and is threshed immediately.

Although there is no evidence of automated harvesting of millets in the literature reviewed, it is thought that combine harvesting of millets is possible. That may be especially true for millet types with uniform heights. Therefore, the screen in order to keep excellent seed in the combine harvester would have to be extremely compact, much smaller than the maize and rice.

12.2.2 Transport:

Millet transportation begins shortly after harvesting on the farm. Farmers who prefer not to dry their grain in the field take the millet in bags to their farmhouse, where the heads are laid out to dry in the sun.

Several farmers in Tanzania's central regions They convey their millet by wrapping it in fabric, which is then loaded onto donkeys and hauled to the homestead. Alternately, the entire harvest can be roped together and delivered with donkeys.

12.2.3 Threshing:

Threshing is the process of removing grain from a harvested plant or plant component (Acland, 1921). Millet is threshed by hand by both men and women. It requires repeatedly striking the millet heads with wood or clubs until practically all of the grains are separated from the heads. Depicts the beating method of threshing millet.

The beating action can be performed on a mat, canvas, or the bare ground. Millet heads may be placed into bags prior to beating to facilitate grain collection after beating. Tanzania, Kenya, Malawi, Mozambique, Zimbabwe, and Uganda are all familiar with this approach. The straw that remains after threshing can be burned as fuel. Straw is used as a material for thatching.

Figure 16.1: Threshing

Figure 16.2: Winnowing

12.2.4 Drying:

There is little information available about millet drying (McFarlane et al., 1995). Millet grains picked during the rainy season can be kept to dry for up to two weeks in the field. If necessary, additional drying is conducted after threshing on sun-dried mats or plastic sheets. Many Africans believe that dishes produced from rain-beaten grains have higher quality and palatability (Vogel and Graham, 1928; McFarlane *et al.*, 1995). Mechanical drying can be used to dry millet grains, but it is expensive and should only be used when the returns are favourable. In addition to typical sun drying, unheated air drying could be used. This is a basic procedure that requires little attention to obtain uniform results.

12.2.5 Cleaning:

Cleaning is the process of separating contaminants from produce and completely removing the impurities so that the cleaned food is free of contamination. Sand (soil), small stones, leaves, shrivelled seeds, off-type seeds, broken seeds, and other pollutants may be present in millets.

Glumes, sticks, chaff, stem portions, insects, animal hair, animal excreta (e.g. rodent and bug faeces), and, most vexingly, metal fragments. Metal fragments that are not removed may damage the milling machine sieves if automated grinding is utilised. If sand and soil are not removed, secondary goods such as ugali, porridge, and other products will taste gritty. Contamination from small stones, sand, off-type seeds, and other contaminants may occur on the drying ground, where farmers in rural regions distribute the millet heads. Winnowing: A millet cleaning procedure in which around 2 to 3 kg of threshed millet grains are placed on a flat reed- or raffia-woven basket (known as ungo in Tanzania, Kenya, and Uganda) and winnowed by up and down strokes (known as kupepeta is Swahili). The basket is pulled up and down throughout this operation, causing the grains to fly into the air and then land back onto the basket. Sand and other light pollutants are separated to the front of the basket and tossed off with a jerky action or removed by hand. Light pollutants are frequently blown off by the mouth. Women in both rural and urban areas It's a little breezy, so the wind current sweeps the light pollutants away from the comparatively heavy grains (personal experience). Approximately 10 kg of threshed millet grains are placed in a tin or basket and spilled from above the head to fall on the ground, which is normally lined with either a cloth or a rug. Canvas or carpet? The chaff is blown away by the wind, leaving a pile of clean grains. This procedure is much faster than traditional winnowing, and it is possible to winnow up to 4 or 5 bags in 1 hour. The approach, however, is ineffective in separating sand, stone, and metal impurities that are as heavy as (or even heavier than) millet grains. Screening is another method of cleaning that uses a collection of sieves.

12.2.6 Storage:

Millets are often wrapped in 100 kilogramme hessian/sisal bags after threshing, drying, and washing and sealed for delivery to distant markets (personal experience). Millet grains are sometimes bundled in bags stitched from artificial polythene bags for either storage or transport. transportation or storage. Crop storage is a crucial component of the entire production chain.

It serves various farmer aims, including supplying food for the future and avoiding food shortages, providing seed for the following growing season, and allowing the farmer to sell at a time when the market is low.

The price is reasonable. Sorghum storage, particularly millets, has received far less scientific study than other grains (McFarlane, *et al.*, 1995). The fundamental reason for this is because sorghum and millets are considered minor grain crops, despite their importance as a food staple in many expanding countries. Another noteworthy factor is that farmers in arid and semi-arid locations where millets are grown accomplish pretty outstanding grain storage performance using quite basic conventional methods.

Figure 12.3: Traditional Millet Grain Storage Structures

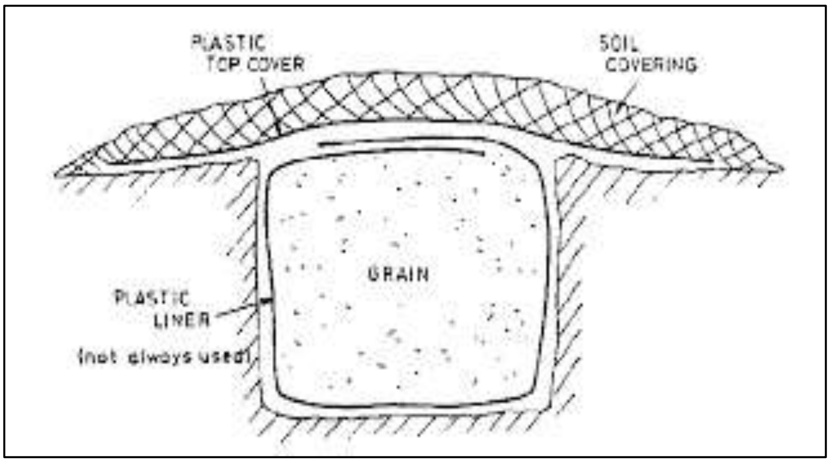


Figure 12.4: Traditional Underground Grain Storage Structures

Most millets have excellent storage qualities and can be preserved in modest storage facilities such as traditional granaries for up to 4-5 years. This is because the hard hull covering the endosperm protects the seeds from insect attack, and grain is often harvested and kept in a dry environment (FAO and ICRISAT, 1996). Consequently, despite huge year-to-year differences in production, stock can be easily built up over time. Millets can be stored as loose grain in bags or loose containers after drying and threshing (McFarlane *et al.,* 1995). Prior to threshing, they are sometimes left on the pitch in stacks or mounds of harvested plants. Detached heads can also be stored away from the field, either in an exposed stack or in typical storage containers. Nonetheless, the main requirements for millets storage are the same as those for other grains. According to Esele (1989), finger millet is stored in granaries made of reeds and mud walls in Uganda.

Other traditional millet storage structures include sealed storage drums, mud straw bins, and earthenware pot and jars. Underground grain storage of millet, sorghum, and maize has been documented in nations such as Somalia and Sudan.

Millets have an inverse relationship with storage temperature and relative humidity. Quality can be preserved by lowering the storage temperature, humidity, or moisture content (or all three) (McFarlane, 1995). Millet mould growth and inherent degradation When the grains are sufficiently dry, the losses in storage are insignificant. A relative humidity of 20% is slightly acceptable for storage, and a relative humidity of 60-65 percent is preferred. Less typically, millets can be stored via admixture with beans (as in Botswana), which minimises the intergranular spaces between the beans, preventing braccate beetle infestation and optimising storage space (McFarlane, 1995).

12.3 Dehulling and Milling:

12.3.1 Machinery of Primary Processsing:

A. Dehulling:

Upon cleaning of millet grains, the grains are dehulled – the outer indigestible husk layer from the grains, improving its overall digestibility.

Increased: Protein digestibility Starch Digestibility Mineral Bioavailability

Decreased: Protein Dietary/crude fiber Fat Vit. E Iron Calcium Phenolic Content Ant-nutrients (phytate, tannins).

Figure 16.5: De-Stoning Cum Grader **Figure 16.6: Mille Single Stage**

Figure 16.6: Single Stage Dehuller

Figure 16.7: Double Stage Dehuller

Advantages: Less labour required

De-hulling efficiency range - 50% to 70%

B. Milling:

Process of separating the bran and germ from the starchy endosperm so that the endosperm can be ground into flour and rawa using different types of sieves in a hammer mill.

Increased: Protein digestibility Starch digestibility.

Decreased: Protein Dietary Fiber Fat Vit. B, E Iron Calcium Phenolic Content Anti-nutrients (phytate, tannins)

Processing	Protein	Dietary	Fat	Vitamins	Iron	Calcium	Phenolic Content	Protein Digestibility	Starch Digestability	Anti-Nutrients	Mineral Bioavailability
De-hulling	↓	↓	↓	↓	↓	↓	↓	↑	↑	↓	↑
Soaking	-	-	-	-	↓	↓	↓	↑	↑	↓	↑
Germination	↑	↑	↓	↑	↑	↑	↑	↑	↑	↓	↑
Milling/Sieving	↓	↓	↓	↓	↓	↓	↓	↑	↑	↓	-
Cooking	↑ or ↓	↑	↑	-	-	-	↑	↓	↓	↓	-
Fermentation	↑	↓	↓	↑	↑	↑	↑ or ↓	↑	↑	↓	-
Roasting	↓	↑ or ↓	↓	-	↑	↑ or ↓	↑ or ↓	↑	-	↓	-
Parboiling	↑	-	↑	↑	-	-	-	-	-	-	-
Puffing	↑	↓	↓	-	↑	↓	↑	↑	↑	↓	-
Extrusion	-	-	-	-	-	-	-	↑	-	-	-
Irradiation	-	↓	-	-	-	-	-	-	-	-	-
Microwave cooking	-	-	-	↑	-	-	-	-	-	-	-
Nixtamalization	-	↑	-	↑	-	↑	↑	-	-	↓	↑

12.4 Value Addition of Millets:

Millets are renamed as "Nutri Cereals", since they are the powerhouse of nutrient, dispensing with the nomenclature "coarse cereals". The move is aimed at removing a lingering perception that these grains are inferior to rice and wheat, even as their health benefits are larger.

Millets hold great potential in contributing substantially to food, nutritional security, safety from diseases and economic security of the country and thus they are not only a powerhouse of nutrients, but also are climate resilient crops and possess unique nutritional characteristics.

12.5 Nutritional Quality:

Millets are highly nutritious, non-glutinous and not acid forming foods. They are soothing and easy to digest. They contain high amounts of dietary fibre, B-complex vitamins, essential amino and fatty acids and vitamin E.

They are particularly high in minerals, iron, magnesium, phosphorus, potassium and release lesser percentage of glucose over a longer period of time causing satiety which lowers the risk of diabetes. The millet grain is rich in fibre and minerals.

These grains are high in carbohydrates content varying from 60.9 to 72.6 percent, with protein content varying from 6 to 11 percent and fat varying from 1.5 to 5 percent. Nutritional compositions of different millets compared to fine cereals are mentioned in table 2. Starch is the major constituent of the grain.

The grain contains protein, albumin, globulin, prolamin and glutelin. Millets do not contain gluten and its slower hydrolysis makes it attractive to diabetics, celiac and ethnic groups. Particularly in developed countries, there is a growing demand for gluten free foods from people with celiac disease and other intolerance to wheat. Though millets nutritionally superior, its consumption has been decreased gradually due to the non- availability of processed clean grain in markets.

To increase millet consumption among the urban population, development of processing technologies is a prerequisite. As a step towards this, under the NAIP project, IIMR has taken up the millet processing, and developed value added millet products.

Around 30 machineries for different processes were procured and retrofitted. Millets have unique nutrients value which is good for physical and mental health as described in figure 16.1.

They have high fibre content, low sugar, vitamins and if consumed regularly they promote movement of the bowels, help detoxify the system, renders less blood sugar and cholesterol than eating fine flour or rice.

Millets are used for food, fodder, biofuel and alcohol. That's why millets are called smart foods because they are better for consumers, better for farmers and better for the planet.

Millets are very useful for human body development and control many diseases because they are gluten free. How different millets help human body development and make us healthy is shown below.

Table 12.2: Nutrient Composition of Millets Compared to Fine Cereals (Per 100 G)

Millets /Cereals	**Carbo-Hydrates (g)**	**Protein (g)**	**Fat (g)**	**Energy (Kcal)**	**Crude Fibre(G)**	**Mineral Matter (g)**	**Ca (Mg)**	**P (Mg)**	**Fe (Mg)**
Rice	78.2	6.8	0.5	345	0.2	0.6	10	160	0.7
Wheat	71.2	118	1.5	346	1.2	1.5	41	306	5.3
Sorghum	72.6	10.4	1.9	349	1.6	1.6	25	222	4.1
Bajra	67.5	11.6	5	361	1.2	2.3	42	296	8
Finger millet	72	7.3	1.3	328	3.6	2.7	34	283	3.9
Foxtail millet	60.9	12.3	4.3	331	8	3.3	31	290	2.8
Proso millet	70.4	12.5	1.1	341	2.2	1.9	14	206	0.8
Kodo millet	65.9	8.3	1.4	309	9	2.6	27	188	0.5
Little millet	67	7.7	4.7	341	7.6	1.5	17	220	9.3
Barnyard millet	65.5	6.2	2.2	307	9.8	4.4	20	280	5

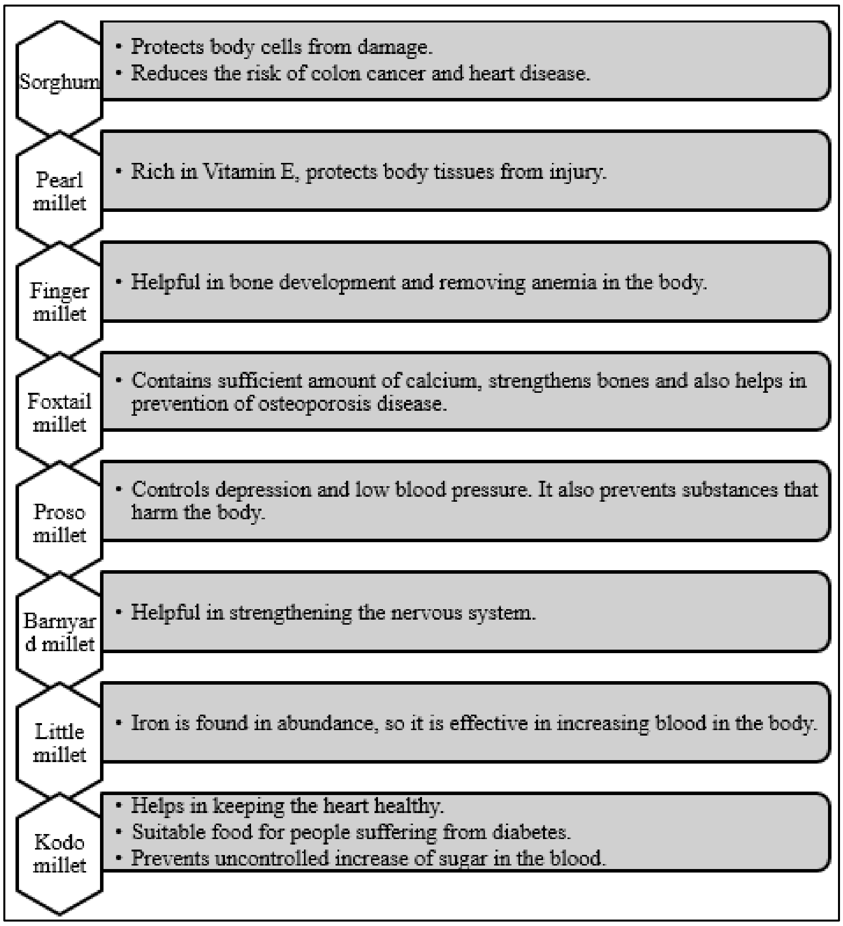


Figure 16.8: Millets Make the Body Strong

12.6 Value Addition Technologies:

A. Puffing technology
B. Flaking technology
C. Baking technology
D. Fortified food technology
E. Instant mixes

12.6.1 Puffing Technology:

Millet puffs are the products which is a result of gun puffing or explosive puffing where the millet grain is expanded to maximum expansion consistent with the grain identity.

These are the ready-to-eat snacks which is developed using this technique. The puff gun machine is loaded with dehulled millets grain onto a rotating barrel and the mixture is roasted and fried resulting in a puffed millets product. Puffs yield is 94%; by-product yield is 6% (small puffs and un-puffed grains) which varies according to millets.

A. Process of Puffing Technology:

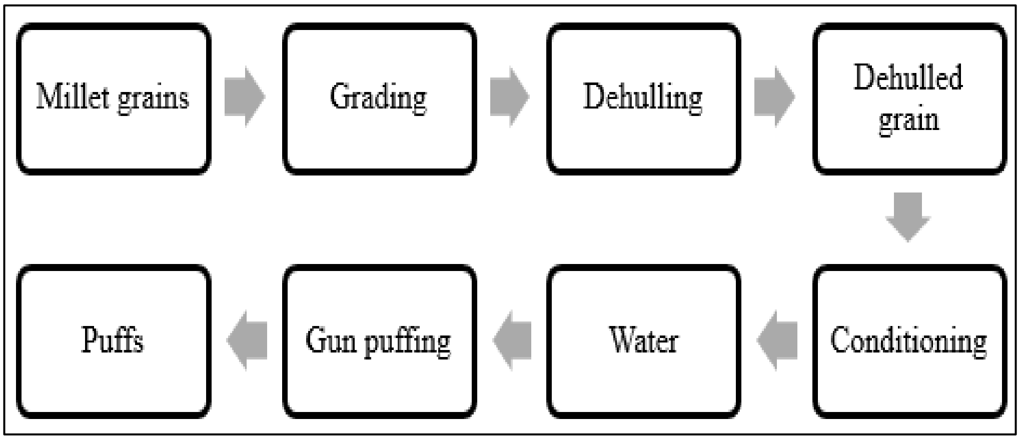


Figure 12.9: Process of Puffing Technology

12.6.2 Flaking Technology:

Extruded flakes are ready-to-eating products prepared using twin-screw hot extruder which combines heating with the act of extrusion to create round-shaped product which is further flattened in roller flaker machine. The extruded flakes are made from sorghum grits, wheat and corn flour. The snack can be coated with desired spices to create variations in the taste and flavour. Flakes yield is 88% and by-product yield is 12% obtained (Extruded by-product, un-flattened flakes) which varies according to millets.

A. Process of Flaking Technology:

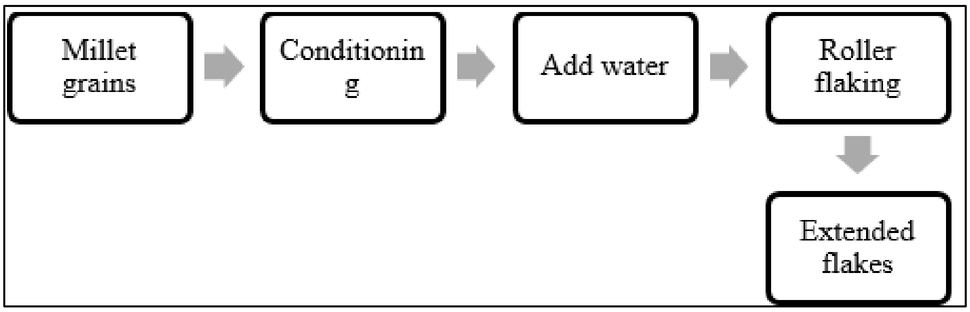


Figure 12.10: Process of Flaking Technology

12.6.3 Baking Technology:

Baking product are also ready-to-eating products which is prepared by mixing a mixture of flour, water, salt/sugar, yeast etc. Consumers prefer healthy products to conventional foods, hence are these days showing preference to millet-based bakery foods. The products like cookies, bread/bun, cakes, pizza base.

In the preparation of products different flavours and baking machines are used. Product yield is 92% and by-product yield is 8% obtained which varies according to millets. These products have different shelf-life. The entry in bakery world creates good potential for millets with superior in terms of micronutrients and fibre content.

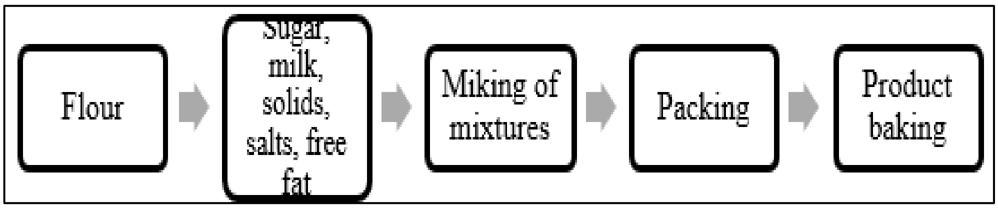


Figure 12.11: Baking Technology

12.6.4 Fortified Food Technology:

Increasing nutrient levels on food products by the process called bio-fortification. By incorporating millet seeds with gingelly seeds for enrichment of zinc ang garden cress for iron rich. Garden cress is rich in iron, magnesium, zinc, calcium and protein rich.

It helps recover from atony, reduces muscle tension, increases appetite, helps asthma sufferers, alleviates breathing difficulties and purifies the lungs. Gingelly seed is rich in iron, magnesium including vitamins, minerals, natural oils, and organic compounds which consist of calcium, iron, magnesium, phosphorous, manganese, copper, zinc, fiber, thiamin, vitamin B6, folate, protein, and tryptophan.

Gingelly incorporate Sorghum products are highly nutritional and digest slowly, which is why it is suitable for diabetics. It has a shelf life of 3 months and shelflife studies are in progress.

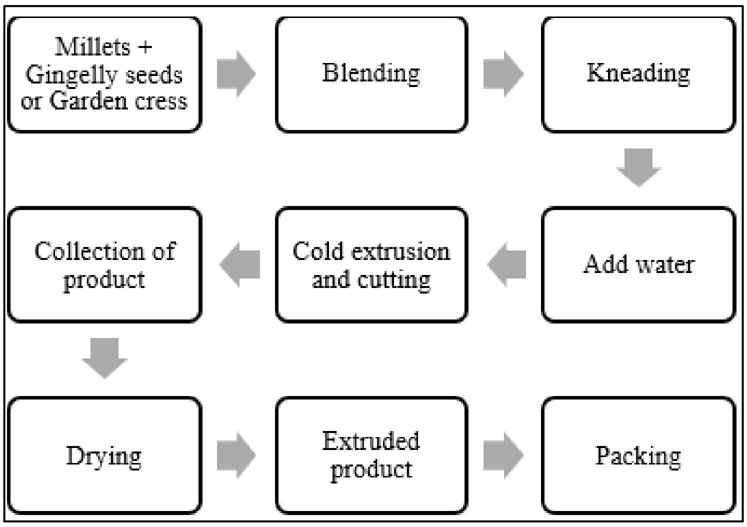


Figure 12.12: Fortified Food Technology

12.6.5 Instant Mixes:

In today's fast-paced world, where time is precious to everyone, "Instant Foods" play an important role in everyone's day-to-day life. In Western countries, instant and ready-to-reconstitute foods have become well-established products. It is critical to develop traditional foods as convenience foods, and IIMR has conducted research in developing millet-based instant mixes, such as Idle mix, Upma mix, Pongal mix, Laddu mix, etc are ready to eat foods.

12.7 Losses During Post-Harvest Management:

Postharvest loss can be defined as the degradation in both quantity and quality of a food production. Postharvest loss includes the food loss across the food supply chain from harvesting of crop until its consumption. The losses can broadly be categorized as weight loss due to spoilage, quality loss, nutritional loss, seed viability loss, and commercial loss. Magnitude of postharvest losses in the food supply chain vary greatly among different crops, areas, and economies.

In developing countries, people try to make the best use of the food produced, however, a significant amount of produce is lost in postharvest operations due to a lack of knowledge, inadequate technology and/or poor storage infrastructure. On the contrary, in developed countries, food loss in the middle stages of the supply chain is relatively low due to availability of advanced technologies and efficient crop handling and storage systems.

However, a large portion of food is lost at the end of the supply chain, known as food waste. “Food waste” can be defined as food discarded or alternatively the intentional non-food uses of the food or due to spoilage/expiration of food. In 2010, estimates suggested that about 133 billion pounds of food (31% of the total available food) was wasted at retail and consumer level in the United States.

Among different agricultural commodities, the studies estimated that on a weight basis, cereal crops, roots crops, and fruit and vegetables account for about 19%, 20%, and 44% losses respectively. On a calorific content basis, losses in cereal crops hold the largest share (53%). Cereal grains, such as wheat, rice, and maize are the most popular food crops in the world, and are the basis of staple food in most of the developing countries. Minimizing cereal losses in the supply chain could be one resource-efficient way that can help in strengthening food security, sustainably combating hunger, reducing the agricultural land needed for production, rural development, and improving farmers’ livelihoods.

Postharvest loss accounts for direct physical losses and quality losses that reduce the economic value of crop, or may make it unsuitable for human consumption. In severe cases, these losses can be up to 80% of the total production. These losses play a critical role in influencing the life of millions of smallholder farmers by impacting the available food volumes and trade-in values of the commodities. In addition to economic and social implications, postharvest losses also impact the environment, as the land, water and energy (agricultural inputs) used to produce the lost food are also wasted along with the food. Unutilized food also results in extra CO_2 emissions, eventually affecting the environment.

12.7.1 Main Stages Where Postharvest Losses Occur:

A. Harvesting
B. Transportation
C. Drying
D. Threshing/winnowing
E. Storage
F. Milling
G. Marketing

A. Harvesting: Time of harvest is determined by maturity. Millets should be harvested between maturity of straw, earheads, for all that affects successive operations, particularly storage and preservation. Mostly losses during this stage occur because edible crops left in field, ploughed into soil, eaten by pests; timing of harvest not optimal, crop damaged during harvesting. Bird damage also seen during this stage. Because of this yield and quality of grain decreases.

B. Transportation: Much care is needed in transporting a really mature harvest, in order to prevent detached grain from falling on the road before reaching the storage or threshing place. Collection and initial transport of the harvest thus depend on the place and conditions where it is to be stored, especially with a view to threshing.

C. Drying: The length of time needed for full drying of ears and grains depends considerably on weather and atmospheric conditions. In structures for lengthy drying such as cribs, or even unroofed threshing floors or terraces, the harvest is exposed to wandering livestock and the depredations of birds, rodents or small ruminants. Apart from the actual wastage, the droppings left by these marauders often result in higher losses than what they actually eat. On the other hand, if grain is not dry enough, it becomes vulnerable to mould and can rot during storage. Moreover, if grain is too dry it becomes brittle and can crack after threshing, during hulling or milling.

During winnowing, broken grain can be removed with the husks and is also more susceptible to certain insects (e.g flour beetles and weevils). Lastly, if grain is too dry, this means a loss of weight and hence a loss of money at the time of sale.

D. Threshing / Winnowing: Separation of grain from plant stalks is called threshing. During threshing some grains are wasted due to manual threshing. If a harvest is threshed before it is dry enough, and we heaped up or stored immediately then it will be more susceptible to attack by micro-organisms and this is all due to poor technique. During winnowing and cleaning loss of seed not that much than threshing.

E. Storage: Storage is the art of keeping the quality of agricultural materials and preventing them from deterioration for specific period of time, beyond their normal shelf life. Different millet crops are harvested and stored by various means depending on the end utilization. Whether the seed will be used for new plantings the following year, for forage being processed into livestock feed, or even for crops to be developed for a special use, the grower must be aware of harvesting and storage requirements toward a quality product.

After determining the prescribed use for the crop, timing for harvest and storage is of important consideration. Along with an assessment of when to harvest, the farmer needs to determine the method of harvesting. Pests and disease attacks, spillage, contamination; natural drying out of food. The grains of pearl millet are sufficiently large for the destructive attack by the major pests such as *Rhyzopertha dominica* and *Trogoderma granarium* (McFarlane *et al.*, 1995). For this reason, the popular concept that millets are hardly susceptible to damage by storage insect pests is erroneous, except for the very small grained millets such as tef and fonio. Another factor contributing to a general myth that millets are immune to susceptibility to insect pest attack is the fact that millets are grown in semi-arid climates, where stored grain is typically very dry, with moisture contents often in equilibrium with humidities below 40 percent. In such conditions, the warehouse moths and most secondary beetle pests do not thrive. However, the major pests *R. dominica* and *T. granarium* are relatively well adapted to extremely dry conditions and will cause serious damages (McFarlane, 1995). The control of such pests as *Rhyzopertha dominica* (Lesser grain borer) and *Trogoderma granarium* (Khapra beetle) may be achieved through sealed storage e.g. in drums or underground storage. In Sudan for example, an underground storage may carry up to 30 tonnes of grains. Alternatively, Khapra beetle may be controlled by dusting the grains with Pirimiphos Methyl (Actellic) which has a wide spectrum of activity against beetles, bruchids, moths and mites (Odogola and Henriksson, 1991).

Population control of *Rhyzopertha dominica* and *Trogoderma granarium* during drying of millet can be achieved by lowering the drying temperature. For example, the optimum reproduction temperature for *Rhyzopertha dominica* is 30-35 ^{0}C. Therefore, a temperature around 21 ^{0}C could check reproduction and therefore control the pest (Odogola and Henriksson, 1991). Likewise, *Trogoderma granarium* reproduces well in temperature range of between 33 and 32 ^{0}C. Lowering this temperature to around 22-25 ^{0}C during drying would check the reproduction.

F. Milling: Causes of post-harvest loss in this stage include limited availability of suitable varieties for processing, lack of appropriate processing technologies, inadequate commercialization of new technologies and lack of basic infrastructure, inadequate facilities and infrastructure, and insufficient promotion of processed products. During dehulling seeds are breaked and become flour and wasted.

G. Marketing: In this stage due to improper packing and damage during transport, spoilage at retailer level.

12.8 Conclusion:

In some ways, finding and developing economic uses for coarse cereals/millet is critical. The demand for pre-processed and convenience foods is increasing as urbanisation and disposable incomes rise. This is one of the reasons why commercially milled wheat and maize flour are becoming more popular. Millet is substantially less expensive, but it is unprocessed and so less convenient to use. As a result, markets for locally grown millet are shrinking, incentives for local production are worsening, and foreign exchange reserves are depleting to meet expanding pre-processed flour demand. As a result, in dry locations, processing facilities are especially important for the future of local cereal cultivation.

As a result, millets are appealing enough to agree on the need to educate consumers on the health benefits and encourage higher use. This will necessitate a collaborative effort by health, food, and nutrition professionals, as well as industry, government, and health promotion organisations.

As part of this endeavour, we need nutrition educators from industry, academia, and government to help us establish clear and consistent consumer messages about the health benefits of millets. Efforts to work with industry leaders to increase their understanding of the benefits of millets and encourage them to overcome barriers to including more whole grains in their products, as well as to continue developing fortified products to meet consumer needs. Commercial opportunities would emerge that had not previously been considered.

12.9 References:

1. Mirza Hasanuzzaman, Associate Professor, Department of Agronomy, Sher-e-Bangla Agricultural University. Postharvest Technology.
2. Agricultural Marketing Information, Post harvest technology, http://www.tnagmark.tn.nic.in/
3. Sathish, The Story of Millets, Karnataka State Department of Agriculture in association with ICAR-Indian Institute of Millets Research, Hyderabad.
4. S. D. Deshpande and P. K. Nishad, Technology for Millet Value-Added Products, ICAR-Central Institute of Agricultural Engineering, Bhopal, Madhya Pradesh, India. https://doi.org/10.1007/978-981-16-0676-2_14.
5. Silas T.A.R. Kajuna, MILLET: Post-harvest Operations Organization: Sokone University of Agriculture (SUA) (http://www.suanet.ac.tz).
6. Technologies of Millet Value Added Products, Director, ICAR- Indian Institute of Millets Research Rajendranagar, Hyderabad - 500 030. India. www.millets.res.in.
7. Value Addition & Market Linkages in Millets – A success story from Nutrihub.
8. Coarse Grains Diet Rich Grains, New India Samachar, International Year of Millets-2023, volume 3, Issue 15.
9. Rajendra R. Chapke., G. Shyam Prasad., I.K. Das., Hariprasanna K., Avinash Singode., B.S. Kanthi Sri., Vilas A. Tonapi., Latest Millet Production and Processing Technologies (under Farmer FIRST Programme). ISBN:81-89335-90-X.
10. S. Balasubramanian, R. Viswanathan and Rajiv Sharma. Post Harvest Processing of Millets: An Appraisal. Agricultural Engineering Today Vol 31(2) 18-23, 2007

ISBN: 978-81-19149-19-3

13. Mitigating Biotic and Abiotic Stresses: Biotechnological Strategies for Improving Millet Productivity

Ipsita Samal

Scientist (on probation),
Naarm, Hyderabad.

Tanmaya Kumar Bhoi

Forest Protection Division,
Indian Council of Forestry Research and Education (ICFRE) - Arid Forest Research Institute (AFRI),
Jodhpur, Rajasthan, India.

Deepak Kumar Mahanta

Department of Entomology,
Dr. Rajendra Prasad Central Agricultural University,
Pusa, Bihar, India.

J. Komal

Department of Entomology,
Navsari Agricultural University,
Navsari, Gujarat, India.

Prasanta Kumar Majhi

Department of Plant Breeding and Genetics,
Odisha University of Agriculture and Technology,
Bhubaneswar, Odisha, India.

Abstract:

Millets are staple crop that is cultivated all over the world, especially in dry and semiarid climates. Millions of people, especially in developing countries, rely on it as a primary source of nutrition, and it is also widely used as animal feed. Nevertheless, millet has a number of problems, such as low yields, disease susceptibility, and a lack of genetic variety.

Several of these issues with millet production have been dealt with by the application of biotechnological methods. Methods for improving millet include introducing genes from other creatures into millet plants through genetic engineering. In addition to traditional breeding methods, molecular markers can be used in a biotechnological process called marker-assisted selection (MAS) to choose millet plants with desirable characteristics. Plants with high production potential and those that are resistant to disease, insect pests, drought, or other challenges can be selected using MAS.

As the selection of desirable features can be time-consuming and expensive, this method can be very helpful in breeding operations. Tissue culture, which involves the growing of millet cells in a laboratory setting, is another biotechnological technique to millet improvement alongside genetic engineering and MAS. In conclusion, biotechnology methods may help alleviate some of the problems associated with millet cultivation. The advantages of these methods should be weighed against their disadvantages, such as any unforeseen consequences for the environment or human health. Thus, this chapter elucidate and track the progress of millet enhancement efforts that employ biotechnology methods.

Keywords:

Millets, disease, insect pests, drought, genetic engineering, biotechnological methods

13.1 Introduction:

Millets are extremely hardy crops that can flourish on poor soil and with little water and have been grown for thousands of years all across the world, especially in less developed regions. Millets are a vital part of a balanced diet since they include essential elements like carbs, fibre, protein, vitamins, and minerals (Gupta et al., 2015). Millets' high nutrient content is one of its key advantages. Carbohydrates, the primary source of energy in the body, can be found in plenty in millets. Also, the fibre content of these foods has been shown to aid in the reduction of cholesterol and the promotion of healthy gastrointestinal function. Furthermore, these are beneficial to one's health and well-being and provide protein, vitamins (especially the B-complex), and minerals (including calcium, iron, and zinc) (Gupta et al., 2020). Millets are significant not just because of their nutritional worth, but also because of the positive effects they may have on one's health.

Millets have been linked in several studies to a lower chance of developing diabetes, cardiovascular disease, and even some cancers, so they're worth considering as a part of a healthy diet. Millets are low on the glycemic index; thus they don't raise blood sugar levels quickly after being ingested. For this reason, millets are a great choice for those with diabetes and for those who are watching their weight (Saleem et al., 2020). In addition, millets are a crop that doesn't negatively impact the environment. Millets are suitable for growing in arid and semiarid environments because they can withstand drought and need less water than other crops. Millets are better for the environment because they need fewer inputs like fertiliser and herbicides (United Nations, 2018).

According to the Food and Agriculture Organization of the United Nations (FAO), millets are grown in various parts of the world and total millet production was approximately 29 million tonnes in 2020. The top five millet-producing countries are India, Nigeria, Niger, China, and Mali, of which, India alone accounts for around 40% in the world. Other major millet-producing countries include Ethiopia, Burkina Faso, Sudan, and Uganda. Amongst diverse countries, India is the largest producer of millets in the world. According to the Department of Agriculture and Farmers Welfare, the total area under millet cultivation in India was around 17.3 million hectares, and the total millet production was approximately 28 million tonnes in 2020-21. The major millet-producing states in India are Rajasthan, Karnataka, Maharashtra, Andhra Pradesh, and Telangana (ASG, 2021).

Despite being a resilient crop, the productivity of millets is observed to be relatively low compared to other major foodgrains. The average yield of millets in India is around 1 tonne per hectare, which is much lower than the global average of 1.7 tonnes per hectare.

The low productivity of millets is mainly due to the lack of proper infrastructure, low investment in research and development, and limited availability of high-quality seeds and fertilizers (Bhatia and Swaminathan, 2013; Bhattacharya and Gupta, 2017).

The production of millets is subject to both biotic and abiotic constraints, which can limit their yield and quality (Ceccarelli, 2015). Biotic constraints refer to the impact of pests, diseases, and weeds on millet plants, while abiotic constraints refer to environmental factors such as soil fertility, water availability, temperature, and light intensity (Shiferaw, 2013; Reddy et al., 2017).

13.2 Genetic Transformation of Millets for Enhancing Biotic and Abiotic Stress Tolerance:

Millet is an important crop grown across the globe, particularly in Africa and Asia. The crop is well adapted to harsh environments, and its ability to grow in areas of low rainfall and poor soil quality has made it a staple food for many people living in diverse arid and semi-arid regions. However, millet production and productivity can be affected by a range of biotic and abiotic factors.

Biotic factors that affect millet production include pests, diseases, and weeds. Millet is susceptible to a number of pests, including stem borers, armyworms, and termites, which can cause significant damage to crops.

Diseases such as blast, downy mildew, and rust can also affect millet yields. Weeds are also a major problem for millet farmers, as they can reduce crop yields by competing with the crop for water and nutrients. Abiotic factors that affect millet production include climate, soil quality, and water availability. Millet is a crop that is well adapted to harsh environments, but it requires a certain amount of rainfall to grow properly.

In areas with low rainfall, millet crops may suffer from water stress, which can reduce yields. Soil quality is also important for millet production, as the crop requires well-draining soil with good fertility. Salinity and alkalinity can also affect millet productivity, as high levels of these minerals can be toxic to the crop (Kumar et al., 2018).

Many researches were conducted on the biotic and abiotic factors influencing millet production and productivity (Okoruwa and Omoregie, 2008) and it was found to be limited by pests and diseases in India; while, soil fertility and weed infestation were reported to be the main barriers to millet production in diverse African countries (Traoré et al., 2001).

So, farmers need to be cognizant of these issues and efforts must be taken to minimise their effects on crop yields. In spite of these problems, millet productivity can be increased by making resistant varieties, using integrated pest management, and managing soil fertility (Figure 13.1).

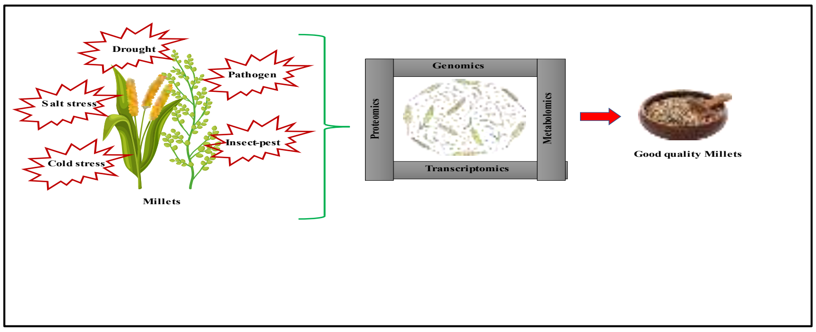


Figure 13.1: Depicts diverse biotechnological approaches like genomics, transcriptomics, proteomics and metabolomics approaches for millet improvement to tolerate abiotic and/or biotic stresses.

13.2.1 Genetic Transformation of Millets for Disease Resistance:

Genetic transformation is a technique used to introduce foreign genes into an organism's genome. In agriculture, genetic transformation has been used to improve crop yields, enhance nutritional content, and provide resistance to pests and diseases. Millets are a group of small-seeded grasses that are grown for food and fodder in many parts of the world, particularly in dry regions with low soil fertility. Millets are known for their hardiness, drought tolerance, and pest resistance. However, pests and diseases still pose a threat to millet production, leading researchers to explore genetic transformation as a means of enhancing crop protection. One approach to genetic transformation of millets for crop protection is to introduce genes encoding for insecticidal proteins. The most widely used insecticidal proteins are the Bacillus thuringiensis (Bt) toxins, which specifically target insect pests and have been shown to be effective against a wide range of insects.

Researchers have successfully introduced Bt genes into various millet species, including pearl millet (*Pennisetum glaucum*), foxtail millet (*Setaria italica*), and finger millet (*Eleusine coracana*), resulting in increased resistance to insect pests such as stem borers and head feeders (Upadhyay et al., 2011; Sharma et al., 2013; Thakur et al., 2014). Another approach is to introduce genes that enhance disease resistance in millets. For example, researchers have successfully introduced genes encoding for chitinase, a protein that degrades chitin in fungal cell walls, into finger millet, resulting in increased resistance to blast disease caused by the fungus *Magnaporthe grisea* (Mohan et al., 2007). Overall, genetic transformation of millets for crop protection shows promise as a means of enhancing resistance to pests and diseases. However, there are still challenges to be overcome, including regulatory barriers, social acceptance, and concerns over potential environmental impacts (Devos et al., 2014). Another example is the introduction of genes encoding for plant lectins, such as rice bean lectin (RBL) and wheat germ agglutinin (WGA) (Kumar et al., 2019). Plant lectins are proteins that bind to specific sugars on the surface of insects' digestive systems, causing damage and death to the insects (Niranjan-Raj et al., 2017). When these lectin genes are introduced into millets, the plants produce the lectin proteins themselves, which can protect the plants from insect pests (Arora et al., 2020). By introducing the Bt gene into the pearl millet genome, researchers have developed plants that are resistant to pests such as stem borers and head bugs (Seck et al., 2012).

Another example of genetic transformation in millets is the development of transgenic finger millet expressing the cowpea trypsin inhibitor (CpTI) gene. The CpTI protein is a potent insecticide that inhibits the digestion of plant proteins in the gut of insect pests. By introducing the CpTI gene into finger millet, researchers have developed plants that are resistant to the spotted stem borer (Reddy et al., 2006). These genetic transformation studies in millets have shown promising results for improving crop protection against pests and diseases. However, further research is needed to assess the safety and efficacy of transgenic millets in the field.

Genetic transformation involves the transfer of genes from one organism to another, often to confer a new trait or characteristic. In millets, this can be done using a variety of techniques, including Agrobacterium-mediated transformation and particle bombardment. These techniques have been used to introduce genes for disease resistance from various sources, including other plants and bacteria. One example of genetic transformation in millets for disease resistance is the introduction of the Xa21 gene from rice into finger millet (*Eleusine coracana*). The Xa21 gene encodes a receptor-like kinase that provides resistance against bacterial leaf blight disease caused by Xanthomonas oryzae pv. oryzae in rice. The transformed finger millet plants showed increased resistance to Xanthomonas oryzae pv. oryzae, demonstrating the potential for genetic transformation to enhance disease resistance in millets (Nageswara-Rao et al., 2017). Researchers were reported to genetically transform pearl millet, *Pennisetum glaucum* with the chitinase gene from *Trichoderma virens*, which is known to provide resistance against fungal pathogens.

The transgenic pearl millet showed increased resistance to downy mildew disease caused by *Sclerospora graminicola*, which is a major pathogen of pearl millet in sub-Saharan Africa (Kumar et al., 2017). In another study, the foxtail Millet (*Setaria italica*) was modified with the rice chitinase gene OsCHI11, which helps plants fight off blast disease caused by *Magnaporthe oryzae*, a major disease-causing organism that attacks rice and other cereal crops (Li et al., 2014). Finger millet (*Eleusine coracana*) that has been genetically changed with the maize ribosome-inactivating protein (RIP) gene ZmRIP has been shown to be resistant to blast disease caused by *Pyricularia grisea* and smut disease caused by *Tolyposporium penicillariae*. It also has antifungal and antiviral properties (Bhattacharyya et al., 2007).

A study reported in the journal Plant Molecular Biology showed that millet plants with a gene from Arabidopsis thaliana that made them resistant to blast disease were successfully engineered (Chakraborty et al., 2017). Genome-wide association mapping (GWAS) is a powerful tool for identifying genetic variants associated with disease resistance. Researchers have used GWAS to identify genes associated with resistance to diseases in millets. For example, identification of genes associated with resistance to downy mildew in pearl millet was done using GWAS (Rajaram et al., 2017). Moreover, a study by Yadav et al. (2020) used GWAS to identify genomic regions associated with resistance to rust disease in finger millet. Furthermore, molecular markers are used to identify genetic variations associated with disease resistance. Researchers have developed molecular markers for identifying genes associated with resistance to head smut in sorghum (Kumari et al., 2017; Singh et al., 2017; Singh et al., 2023)). The bacterial blight resistance gene (Xa21) was inserted into pearl millet (*Pennisetum glaucum*) to make it resistant to bacterial leaf blight caused by *Xanthomonas axonopodis pv. Penniseti* (Xap).

This is another way that genetic engineering is used to make plants resistant to disease (Kumar et al., 2018). These examples show how genetic modification could be used to make millets more resistant to diseases. But it's important to remember that genetically modified crops should be carefully tested for safety and compliance with rules before they are offered for sale.

A. RNA interference (RNAi) technology: RNAi technology involves the use of small RNA molecules to silence specific genes, which can help to improve disease resistance in plants. For example, RNAi-mediated silencing of the chitinase gene in foxtail millet (*Setaria italica*) has been shown to make the plant more resistant to fungal pathogens (Ghanti et al., 2018). Moreover, RNAi technology has been used to make pearl millet plants resistant to downy mildew, which is caused by the fungus *Sclerospora graminicola*. The RNAi construct was made to target a pathogenesis-related gene in the fungus. Transgenic plants that expressed this RNAi construct were much less likely to get infected with downy mildew. RNAi technology has been used to make finger millet more resistant to blast disease, which is caused by the fungus *Magnaporthe grisea*. RNAi technology has also been used to make foxtail millet more resistant to smut disease, which is caused by the fungus *Ustilago crameri*.

B. Marker-assisted selection (MAS): Molecular marker-assisted selection (MAS) is a process that uses molecular markers to choose plants with desirable traits, such as resistance to disease. For example, MAS has been used to make blast-resistant varieties of finger millet (*Eleusine coracana*) by finding and choosing plants with the RGA2 gene, which gives resistance to the blast fungus (*Magnaporthe oryzae*) (Sharma et al., 2017). MAS is a powerful plant breeding technique that enables the identification and selection of desirable traits, such as disease resistance, using molecular markers. In a study published in the journal Plant Breeding, researchers used MAS to develop pearl millet varieties with resistance to downy mildew, a devastating disease caused by the fungus *Sclerospora graminicola.* Diverse studies have molecular markers linked to the resistance gene and used them to select resistant plants in breeding populations. The resulting varieties showed high levels of resistance to downy mildew and performed well in field trials (Gupta et al. (2012). Furthermore, finger millet is susceptible to blast disease, caused by the fungus *Magnaporthe grisea*. In a study published in the journal Molecular Breeding, researchers used MAS to identify markers linked to blast resistance genes in finger millet and the same markers were further used to select resistant plants in breeding populations and developed finger millet varieties with enhanced blast resistance (Ramakrishnan et al., 2017). Moreover, researchers have reported to use MAS to identify markers linked to smut resistance genes in proso millet (Jia et al., 2016). Moreover, a study by Kumar et al. (2021) concluded that MAS can be used to select finger millet varieties with resistance to blast disease.

C. Genome editing: Genome editing involves the precise modification of DNA sequences within an organism's genome to introduce new traits, including disease resistance. For example, the use of the CRISPR-Cas9 system to edit the genome of finger millet has been shown to confer resistance to the blast fungus (Shrawat et al., 2021). Genome editing technology has great potential to enhance disease resistance in millets by introducing or modifying specific genes involved in disease resistance pathways. For instance, CRISPR/ Cas9 genome editing technology was used to modify the SWEET gene in foxtail millet, which is involved in sugar transport and is a target for downy mildew infection.

The edited plants showed reduced susceptibility to downy mildew compared to the wild-type plants (Liu et al., 2020). Additionally, EF-Tu gene editing in finger millet using CRISPR-Cas9 boosted resistance to blast disease compared to wild-type plants, which is a pathogen that specifically targets this particular gene (Gupta et al., 2021). Downy mildew is a problem in pearl millet, thus the PDS gene, which is involved in chlorophyll biosynthesis, was knocked out in the genome using CRISPR/Cas9.

The edited plants showed reduced susceptibility to downy mildew compared to the wild-type plants (Suresh et al., 2018). Moreover, editing of the ERF109 gene in foxtail millet was reported to enhance resistance to blast disease (Zhang et al., 2021); while, genetic modification of the PDS gene in pearl millet was reported to enhance resistance to downy mildew (Suresh et al., 2018). Furthermore, the editing of the ZmNAC111 gene in finger millet was documented to enhance resistance to blast disease (Niranjana et al., 2021).

D. Conventional and new breeding approaches in enhancing disease resistance in millets: Millets have been improved for disease resistance using a combination of conventional and new breeding approaches. This part of the chapter provides some recent studies that have used conventional and new breeding approaches in millets for enhancing disease resistance. Researchers have used diverse conventional breeding techniques to develop finger millet varieties with improved blast disease resistance.

They crossed resistant and susceptible varieties and selected for resistant progeny through field screening. The resulting varieties showed significantly reduced blast disease incidence and severity (Biruma et al., 2019).

Moreover, genomic selection, a new breeding approach that uses genomic information to predict the breeding value of individuals, to develop pearl millet varieties with improved downy mildew resistance and the resulting varieties were found to have significantly reduced disease severity compared to susceptible varieties (Sehgal et al., 2018).

Furthermore, hybrid breeding, that involves crossing two genetically diverse parents to produce hybrids with improved traits, was reported to be used to develop foxtail millet varieties with improved rust resistance (Chen et al., 2021). New breeding techniques have been applied to enhance disease resistance in millets, including gene editing, genome-wide association studies (GWAS), and marker-assisted selection (MAS).

CRISPR/Cas9-mediated mutagenesis was used to introduce mutations in the candidate blast resistance gene (EcPi21) of finger millet and several mutant lines with improved blast resistance and no yield penalty compared to the wild type. This study demonstrates the potential of gene editing for developing disease-resistant millet varieties (Sharma et al., 2020).

Further, genome-wide association (GWAS) study was used to identify rust resistance genes in pearl millet and several genomic regions associated with rust resistance were identified and molecular markers for marker-assisted selection of resistant varieties were developed (Sehgal et al., 2015). Moreover, use of marker-assisted selection had led to development of smut-resistant barnyard millet varieties (Raju et al., 2020).

E. Omics Approaches in Enhancing Disease Resistance:

a. Transcriptomic Approaches in Enhancing Disease Resistance in Millets:

Transcriptomic approaches have been applied to study the gene expression patterns in millets under disease stress conditions and to identify candidate genes involved in disease resistance. Transcriptome analysis of finger millet was carried out in response to blast disease and several differentially expressed genes involved in defense responses, including pathogenesis-related genes, transcription factors, and hormone-related genes were identified and provided insights into the molecular mechanisms of blast resistance in finger millet (Ponnaiah et al., 2021). Moreover, transcriptomic analysis of pearl millet revealed several differentially expressed genes involved in defense responses, including peroxidases, chitinases, and pathogenesis-related genes and candidate genes associated with the jasmonic acid pathway, which plays a crucial role in plant defense responses (Pandey et al., 2021); while, transcriptome analysis was carried out to study the gene expression patterns in barnyard millet in response to smut infection and several differentially expressed genes involved in defense responses, including pathogenesis-related genes, heat shock proteins, and protein kinases along with candidate genes associated with the salicylic acid pathway, which plays a crucial role in plant defense responses were identified (Kumar et al., 2021). Moreover, a study by Bonthala et al. (2016) used transcriptome analysis to identify genes involved in resistance to blast disease in finger millet.

b. Proteomics Approaches in Enhancing Disease Resistance in Millets:

Proteomics approaches have been used to study the proteins involved in disease resistance in millets. Proteomics involves the identification and quantification of proteins in a biological sample, and can provide insights into the molecular mechanisms of disease resistance. Proteomic analysis of pearl millet under rust infection identified several differentially expressed proteins involved in defense responses, including chitinases, peroxidases, and heat shock proteins along with diverse candidate proteins associated with the jasmonic acid pathway, which plays a crucial role in plant defense responses (Kumar et al., 2021). Moreover, proteomic analysis of finger millet in response to blast disease deciphered several pathogenesis-related proteins, chitinases, and heat shock proteins along with candidate proteins associated with the salicylic acid pathway, which plays a crucial role in plant defense responses (Ponnaiah et al., 2021); whereas, proteomic analysis of barnyard millet under smut infection provided insights into the molecular mechanisms of smut resistance in barnyard millet (Kumar et al., 2021).

c. Bioinformatics Approaches in Enhancing Disease Resistance in Millets:

Bioinformatics is a powerful tool that can be used to enhance disease resistance in millets. Bioinformatics was used to identify candidate resistance genes in millets. For example, a study by Srinivasachary et al. (2018) used bioinformatics to identify potential resistance genes in pearl millet against downy mildew disease. One of the bioinformatics approaches used to enhance disease resistance in millets is genome sequencing. Several millet species, including foxtail millet, proso millet, and pearl millet, have been sequenced in recent years (Zhang et al., 2012a, b; Varshney et al., 2017).

The availability of these genome sequences has allowed researchers to identify the genes involved in disease resistance and to develop markers that can be used for breeding programs. Another bioinformatics approach used to enhance disease resistance in millets is transcriptome sequencing. Transcriptome sequencing allows researchers to identify the genes that are being expressed in a particular tissue or under a particular condition. By comparing the transcriptomes of resistant and susceptible millet varieties, researchers can identify the genes that are responsible for disease resistance. For example, a recent study identified several candidate genes for rust resistance in pearl millet using transcriptome sequencing (Kumar et al., 2021).

Bioinformatics approaches are also being used to study the interactions between millets and pathogens. For example, researchers have used transcriptome sequencing to study the interaction between foxtail millet and the fungal pathogen *Sclerospora graminicola* (Wang et al., 2022). By analyzing the transcriptomes of both the host plant and the pathogen, researchers were able to identify the genes involved in the defense response of the host plant and the virulence factors of the pathogen. Machine learning (ML) is another advanced bioinformatics approach that has been used to enhance disease resistance in millets. Machine learning algorithms can be trained to identify patterns in large datasets, including genomic data. By analyzing genomic data from millet varieties with varying levels of disease resistance, researchers can train machine learning algorithms to identify the genetic variations that are associated with disease resistance.

This approach has been used to identify candidate genes for resistance to sorghum midge in sorghum (Haghighattalab et al., 2019) and could be applied to millets as well. One example of the application of ML methods to predict disease resistance in millets is a study conducted by Kuchanur et al. (2021) that used a Random Forest (RF) algorithm to predict resistance to blast disease in pearl millet. The study utilized data from a collection of 443 pearl millet accessions, including 242 resistants and 201 susceptible genotypes. The authors used single nucleotide polymorphism (SNP) data from the millet accessions to train the RF algorithm to predict disease resistance. The results showed that the RF algorithm had a high accuracy of 91.8% in predicting resistance to blast disease in pearl millet. Another study by Manivannan et al. (2021) used a Gradient Boosting Machine (GBM) algorithm to predict resistance to rust disease in finger millet. The authors used a dataset of 268 finger millet accessions, including 135 rust-resistant and 133 susceptible genotypes. The GBM algorithm was trained using SNP data from the finger millet accessions to predict disease resistance. The results showed that the GBM algorithm had an accuracy of 91.8% in predicting resistance to rust disease in finger millet. In addition to predicting disease resistance, ML methods can also be used to identify the genetic factors underlying resistance. A study by Ahmed et al. (2021) used a Support Vector Machine (SVM) algorithm to identify SNP markers associated with resistance to downy mildew disease in pearl millet. The authors used a dataset of 144 pearl millet accessions, including 72 resistants and 72 susceptible genotypes.

The SVM algorithm was trained using SNP data from the pearl millet accessions to identify the genetic markers associated with resistance. The results showed that the SVM algorithm was able to identify 102 SNP markers associated with resistance to downy mildew disease in pearl millet. In conclusion, the application of machine learning methods has great potential for predicting disease resistance in millets.

These methods can be used to analyze large and complex datasets to identify genetic and environmental factors that contribute to disease resistance. As these methods continue to evolve, we can expect to see even greater progress in predicting and enhancing disease resistance in millets and other important food crops.

- **Machine Learning (ML) Approaches in Enhancing Disease Resistance in Millets:**

ML algorithms were reported to be used to predict resistance to downy mildew in pearl millet. Disease incidence and severity from multiple locations over several years were used this data to train the algorithms. The models were able to accurately predict disease incidence and severity in new locations, suggesting that they could be used to guide breeding efforts for disease resistance (Mallikarjuna et al., 2020). Another study published in Plant Methods used a combination of AI and high-throughput phenotyping to predict resistance to blast disease in finger millet and computer vision algorithms were used to analyze images of plants and identify disease symptoms, and then used machine learning algorithms to predict disease severity. It was found that the models were able to accurately predict disease severity in new locations, suggesting that this approach could be used to screen large numbers of plants for disease resistance (Das et al., 2021). Furthermore, a combination of AI and genomics were used to identify genes associated with resistance to blast disease in foxtail millet. Machine learning algorithms were utilized to analyze genomic data and identify candidate genes, which were then validated using gene editing techniques.

The identified genes were found to be associated with resistance to blast disease, which could be used in breeding programs to develop new varieties with improved disease resistance (Zhang et al., 2020).

Artificial intelligence (AI) has the potential to revolutionize the way we predict disease resistance in millets by enabling faster and more accurate identification of resistant varieties. Diverse deep learning models were used to predict blast resistance in finger millet, a major millet crop in India. The researchers have trained the models using images of leaves infected with blast disease, and achieved an accuracy of up to 96% in predicting resistance to the disease (Kumar et al., 2019). Furthermore, ML models have been used to predict downy mildew resistance in pearl millet, another important millet crop in India. The models were trained using both phenotypic and genotypic data, and were able to accurately predict resistance in a diverse set of pearl millet germplasm (Sehgal et al., 2018). Moreover, Convolutional neural networks (CNNs) have been used to predict rust resistance in foxtail millet, a minor millet crop in China. The CNNs were trained using images of leaves infected with rust disease, and achieved an accuracy of up to 94% in predicting resistance to the disease (Yao et al., 2020).

- **Application of Deep Learning to Predict Disease Resistance in Millets:**

Deep learning was to predict resistance to downy mildew disease in pearl millet (*Pennisetum glaucum*). They trained a convolutional neural network (CNN) using images of pearl millet leaves inoculated with the pathogen, and achieved an accuracy of 89% in predicting disease resistance. The authors suggest that this approach could be used to rapidly screen large populations of millet varieties for resistance to downy mildew (Rai et al., 2020).

Furthermore, finger millet (*Eleusine coracana*) a deep learning approach was used to predict resistance to head blast disease in. CNN was used to analyze images of finger millet panicles inoculated with the pathogen, and achieved an accuracy of 91% in predicting disease resistance. They suggest that this approach could be used to develop more resilient finger millet varieties that can withstand head blast disease (Gupta et al., 2021).

Furthermore, CNN hyperspectral pictures of infected pearl millet leaves were used to examine the plant's resistance to the rust disease, with the resulting prediction accuracy reaching 94%. This method was proposed as a way to help pearl millet farmers better manage disease (Namburu et al., 2020). Finally, these studies demonstrate the potential of deep learning to predict disease resistance in millets, which could help breeders develop more resilient varieties and improve food security in regions where millets are a staple crop.

13.2.2 Genetic Transformation of Millets for Insect Pest Resistance:

Millets are a group of cereal crops grown mainly in semi-arid regions of the world. They are important sources of food, feed, and income for millions of people, especially in developing countries. However, insect pests pose a significant threat to millet production, causing substantial yield losses each year. To address this problem, scientists have been working to develop millet varieties with enhanced insect pest resistance through genetic transformation. Insect pests are one of the major constraints in millet production worldwide. To address this issue, researchers have been developing transgenic millets with insect-resistant traits. Transgenic millets expressing insecticidal proteins from Bacillus thuringiensis (Bt) and other genes involved in defense against insect pests have been successfully developed. One of the earliest attempts to develop transgenic millets for insect pest management was reported in 2003. These can be achieved by modifying the existing genes in the millets involved in defense against insect pests, using RNA interference (RNAi) technology in millets for insect pest management, applying the breeding approaches alongwith New breeding approaches and Marker-assisted selection (MAS) in millets including genome editing, omics approaches in millets for insect pest management (Table 13.1).

13.2.3 Biotechnological Approaches in Millets for Enhancing Abiotic Stress Tolerance:

Millets have a distinction for being hardy in the face of a variety of abiotic challenges. Yet, as these challenges become more frequent and severe as a result of climate change (Singh et al., 2023), there is a need to cultivate millet cultivars with increased tolerance to these shocks. Millet varieties with enhanced resistance to abiotic stresses have been developed with the use of biotechnological technologies including genetic engineering and genome editing. Overexpressing genes for resistance to abiotic stress in millets, improving millets' tolerance to abiotic stress through the introduction of genes from other plants known to confer stress tolerance, and employing genome editing are all viable options. The transfer of genes from other plants that are known to confer stress resistance is another strategy for improving abiotic stress tolerance in millets. Researchers at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), for instance, have successfully transferred a gene encoding a late mbryogenesis abundant (LEA) protein from chickpea into pearl millet, leading to enhanced tolerance to drought stress in both species (Serraj R, et al., 2011). Millets' abiotic stress tolerance has been greatly enhanced through the introduction of stress-tolerant genes from other plants. Arabidopsis thaliana's AtDREB1A gene has been introduced. One such transcription factor is encoded by the AtDREB1A gene, and it controls the expression of stress-responsive genes. A study found that overexpressing the AtDREB1A gene in pearl millet (Pennisetum glaucum) increased the plant's resistance to drought and salt stress (Sinha et al., 2017). Table 13.2 lists the specifics of how stress-tolerant genes from other plants were introduced into millets. To sum up, increasing millets' resistance to abiotic stress through the transfer of genes from other plant species has proven to be a beneficial technique. This strategy has been effective in enhancing millet productivity in the face of various abiotic challenges, and it may help in the breeding of stress-tolerant millet cultivars.

13.2.4 Biotechnological Approaches in Millets for Enhancing Nutritional Quality in Millets:

Millets are an important source of nutrition for millions of people around the world. However, they are often lacking in certain essential nutrients, such as iron, zinc, and amino acids. Biotechnological approaches have been used to enhance the nutritional quality of millets, with some promising results. Here are some examples:

A. **Biofortification of Millets with Iron and Zinc**: Biofortification refers to the practise of using plant breeding or genetic engineering to increase the concentration of micronutrients in the edible sections of crops. In order to boost millets' iron and zinc content, scientists have used both traditional breeding methods and transgenic techniques. For example, in pearl millet, researchers have used marker-assisted selection to develop high-iron and high-zinc varieties (Govindaraj et al., 2016). In finger millet, researchers have used transgenic approaches to increase the iron content by overexpressing the ferritin gene (Nair et al., 2017). Moreover, in finger millet, researchers have used transgenic approaches to increase the iron content by overexpressing the ferritin gene (Nair et al., 2017). Many researchers have used conventional breeding and transgenic approaches to increase the zinc content of millets. In foxtail millet, researchers have used transgenic approaches to increase the zinc content by overexpressing the ZIP gene (Liu et al., 2020). Similarly, vitamin A deficiency is a major public health problem in developing countries, particularly in children. Researchers have used genetic engineering to enhance the vitamin A content of millets. For example, in pearl millet, researchers have used a combination of genetic engineering and marker-assisted selection to develop high-provitamin A variety (Sudhakar et al., 2021). Thus, iron, zinc, and vitamin A are essential micronutrients that are often lacking in the diets of people in developing countries, and biofortification of millets with these nutrients has the potential to improve the nutritional status of vulnerable populations.
B. **Enhancing The Amino Acid Profile of Millets**: Millets are often lacking in certain essential amino acids, such as lysine and tryptophan. Researchers have used genetic engineering to enhance the amino acid profile of millets. For example, in foxtail millet, researchers have overexpressed the lysine-rich protein gene, OsLysRS, which has led to an increase in lysine content (Chandel et al., 2015). In pearl millet, researchers have used RNA interference to downregulate the expression of the prolamin gene, which has

led to a reduction in the content of anti-nutritional factors and an increase in the content of lysine and other essential amino acids (Mittal et al., 2018).

C. **Improvement of Millet Quality Traits Using Omics Approaches:** Genomics, transcriptomics, and metabolomics are just some of the omics methods that have been applied to the study of millets in order to pinpoint the genes and pathways responsible for the plants' ability to biosynthesize and store nutrients. Genes involved in the manufacture of amino acids like lysine and tryptophan were found using transcriptomics in finger millet, and those genes were then overexpressed using genetic engineering (Kumar et al., 2015). The genetic and molecular mechanisms behind the quality features of millets have also been studied using omics methods, including as genomics, transcriptomics, proteomics, and metabolomics. Millet quality traits like grain protein content, grain size and shape and grain phytochemical content can be targeted to enhance nutritional quality of millets. Grain protein content is an important quality trait of millets, as it determines the nutritional quality and processing properties of the grains. Researchers have used transcriptomics and proteomics approaches to identify genes and proteins involved in grain protein accumulation in millets. For example, in foxtail millet, researchers used transcriptomics to identify candidate genes involved in grain protein accumulation, and validated their function by overexpressing them in transgenic plants (Zhao et al., 2016). In finger millet, researchers used proteomics to identify proteins that are differentially expressed during grain development and maturation, and identified several candidate proteins that may be involved in grain protein accumulation (Hemalatha et al., 2017). Moreover, grain size and shape are another important quality traits of millets, as they affect yield, processing, and consumer preferences. Researchers have used genomics and transcriptomics approaches to identify genes and pathways involved in grain size and shape determination in millets. For example, in proso millet, researchers used genomics to identify candidate genes involved in grain size and shape, and validated their function by overexpressing them in transgenic plants (Li et al., 2020). In pearl millet, researchers used transcriptomics to identify differentially expressed genes during grain development and maturation, and identified several candidate genes that may be involved in grain size and shape determination (Sinha et al., 2017). Furthermore, phytochemicals, such as phenolics and flavonoids, are important quality traits of millets, as they have antioxidant and health-promoting properties. Researchers have used metabolomics approaches to identify and quantify phytochemicals in millets, and to understand the genetic and environmental factors that affect their accumulation. For example, in finger millet, researchers used metabolomics to identify and quantify several phenolic compounds, and identified several candidate genes involved in their biosynthesis and regulation (Liu et al., 2019). In pearl millet, researchers used metabolomics to identify and quantify flavonoids, and identified several candidate genes involved in their biosynthesis and regulation (Deshpande et al., 2018).

Thus, it can be concluded that, biotechnological approaches have shown promise in enhancing the nutritional quality of millets. Biofortification, genetic engineering, and omics approaches have been used to increase the iron and zinc content, enhance the amino acid profile, and improve the overall quality traits of millets.

These approaches have the potential to address the issue of malnutrition in millet-consuming populations.

Table 13.1: Genetic Transformation of Millets for Insect Pest Resistance Development of Transgenics in Millets for Insect Pest Management

Sr. No.	Description	Trait	Introduced in millets	References
1	transformed pearl millet (Pennisetum glaucum) with the Bt cry1Ac gene	resistance to the pink stem borer *(Sesamia inferens*) and the spotted stem borer (*Chilo partellus*)	pearl millet	Sehgal et al., 2003
2	transformed pearl millet (*Pennisetum glaucum*) with a Bt gene	resulting plants for resistance to the stem borer (*Chilo partellus*).		Saxena et al., 2017
3	introduce a Bt gene into finger millet (Eleusine coracana).	resistance to the spotted stem borer (*Chilo polychotes*) and the rice weevil (Sitophilus oryzae), two important insect pests of finger millet	Finger millet	Ndimbo et al., 2020
4	finger millet (Eleusine coracana) was transformed with the Bt cry1Ac gene	showed resistance to the stem borer (*Chilo partellus*) and the shoot fly (*Atherigona spp*.)		Veerakumar et al., 2007
5	transformed finger millet with two genes: cry1Ab, which encodes an insecticidal protein, and Mci1, which encodes a protease inhibitor	transgenic plants exhibited resistance to the spotted stem borer (*Chilo polychotes*) and the rice weevil (*Sitophilus oryzae*)		Ndimbo et al., 2020
6	a gene encoding a proteinase inhibitor from cowpea (Vigna unguiculata)	showed resistance to the spotted stem borer (Chilo partellus)	Pearl millet	Kumar et al., 2015
7	transgenic finger millet expressing a gene called SiMYB56, which regulates the production of flavonoids, compounds that can deter insect feeding	resistance to the fall armyworm (*Spodoptera frugiperda*	Finger millet	Zhang et al., 2021

Sr. No.	Description	Trait	Introduced in millets	References
Modify existing genes in the millets involved in defense against insect pests				
1	a gene in foxtail millet (Setaria italica) called SiMYB56 that is involved in regulating the production of flavonoids, compounds that can deter insect feeding	enhance the plant's resistance to the fall armyworm (Spodoptera frugiperda),	Foxtail millet	Zhang et al., 2021
2	CRISPR/Cas9 to modify a gene called OsTFX1 in finger millet	resulting in increased resistance to the shoot fly (Atherigona spp.)	Finger millet	Ramkumar et al., 2020
3	TALENs to modify a gene called cytochrome P450 in pearl millet,	resulting in increased resistance to the spotted stem borer (Chilo partellus)	Pearl millet	Kumawat et al., 2018
4	transformed pearl millet with a gene encoding a proteinase inhibitor from cowpea,	resulting in increased resistance to the spotted stem borer (Chilo partellus)	Pearl millet	Kumar et al., 2015
RNA interference (RNAi) technology in millets for insect pest management				
1	used RNAi to target the expression of the laccase gene in pearl millet,	resulting in increased susceptibility to the stem borer (Chilo partellus)	Pearl millet	Khare et al., 2016
2	used RNAi to target the expression of a chitinase gene in finger millet,	resulting in increased susceptibility to the finger millet stem borer (Sesamia inferens)	Finger millet	Chakraborty et al., 2019
3	RNAi to silence the expression of a gene involved in the replication of the yellow mosaic virus in pearl millet	resulting in reduced virus infection and improved plant growth	Pearl millet	Bhattacharyya et al., 2017
Breeding approaches in millets for insect pest management				
1	used MAS to develop downy mildew-resistant pearl millet varieties (Yadav OP, et al., 2016).	Marker Assisted Selections	Pearl millet	Sreenivas et al., 2017

Sr. No.	Description	Trait	Introduced in millets	References
2	CRISPR-Cas9 gene editing to introduce mutations into the fatty acid desaturase gene in foxtail millet.	resulting in increased resistance to the spotted stem borer	Foxtail millet	Das et al., 2021
New breeding approaches and Marker-assisted selection (MAS) in millets for insect pest management				
1	MAS to select for resistance to the shoot fly in sorghum,	resulting in the development of resistant varieties	Sorghum	Muthusamy et al., 2014
Genome editing in millets for insect pest management				
1	CRISPR-Cas9 to develop a foxtail millet variety with resistance to the spotted stem borer.	They targeted the fatty acid desaturase 2 (FAD2) gene, which plays a role in the biosynthesis of fatty acids, including those that are involved in the insect's reproductive processes. (Das S, et al., 2021).	Sorghum	Das S, et al., 2021
2	CRISPR-Cas9 to develop pearl millet varieties with resistance to the stem borer.	They targeted the C-terminal domain phosphatase-like gene (CPL1), which is involved in the plant's immune response to insect pests.	Sorghum	Gupta SK, et al., 2020
Omics approaches in millets for insect pest management				
1	transcriptomic analysis to identify genes involved in the response of foxtail millet to the spotted stem borer.	They found that genes involved in the jasmonic acid and ethylene signaling pathways were upregulated in response to borer infestation, suggesting their involvement in the plant's defense response.	Foxtail millet	Muthusamy et al., 2020

Sr. No.	Description	Trait	Introduced in millets	References
2	metabolomic analysis to identify metabolites involved in the resistance of pearl millet to the stem borer.	They found that the levels of certain amino acids, fatty acids, and phenolic compounds were significantly different between resistant and susceptible varieties. The researchers suggested that these metabolites could be used as markers for developing insect-resistant varieties.	Pearl millet	Krishnamurthy et al., 2018
3	Proteomic analysis has also been used in millets to identify proteins involved in insect resistance.	In a study on finger millet, researchers from the University of Hyderabad identified several proteins that were differentially expressed in response to infestation by the stem borer. They suggested that these proteins could be used as targets for developing insect-resistant varieties.	Finger millet	Gopalakrishnan et al., 2018
Biotechnological approaches in millets for enhancing abiotic stress tolerance				
Overexpression of abiotic stress resistance genes in millets				
1	overexpressed a gene encoding a transcription factor called DREB1A in finger millet	resulting in improved tolerance to drought and salt stress	Finger millet	Nagaraju et al., 2018
2	overexpressed a gene encoding a protein kinase called OXI1 in foxtail millet	resulting in improved tolerance to drought and salt stress	Foxtail millet	Agarwal et al., 2018
3	overexpression of the OsDREB1F transcription factor from rice in finger millet	improved drought tolerance in this crop	Finger millet	Ramamoorthy et al., 2018

Sr. No.	Description	Trait	Introduced in millets	References
4	Overexpression of the HSP101 gene from sorghum in pearl millet (Pennisetum glaucum)	improved the tolerance of transgenic plants to drought, heat, and salt stress.	Pearl millet	Reddy et al., 2018
5	overexpression of the genes encoding SOD (superoxide dismutase) and CAT (catalase) enzymes in foxtail millet (Setaria italica)	improved the plant's tolerance to drought stress	Foxtail millet	Wang et al., 2016

13.3 Major Constraints in Achieving Sustainability in Millet Production in The International Year of Millets and Future Thrusts:

The International Year of Millets, designated by the United Nations General Assembly for the year 2023, aims to raise awareness about the nutritional, health, and environmental benefits of millets, promote their cultivation, consumption, and trade, and enhance their contribution to food security and sustainable development (FAO, 2023).

Although the International Year of Millets has certain significant targets like, promoting food and nutrition security, enhancing biodiversity and ecosystem services, supporting smallholder farmers and rural livelihoods and strengthening research and innovation (ICRISAT, 2023).

Overall, the International Year of Millets provides an opportunity to promote millets as a sustainable, healthy, and culturally important food crop, and to enhance their contribution to achieving the Sustainable Development Goals (Deshpande et al., 2019; Satapathy et al., 2020). Despite the numerous benefits of millet production, there are some constraints that limit its sustainability. Some of the major constraints include:

13.3.1 Lack of Improved Varieties:

There is a limited availability of improved varieties of millets that are high-yielding, disease-resistant, and tolerant to abiotic stress. This limits the productivity of millet crops, which can affect the income of farmers.

13.3.2 Limited Mechanization:

Most of the millet farming in developing countries is done manually or with traditional tools, which limits the efficiency and scale of millet production.

13.3.3 Low Market Value:

Millet crops often have a lower market value compared to other crops like rice and wheat, which reduces their profitability and discourages farmers from investing in millet production.

13.3.4 Limited Access to Credit and Inputs:

Smallholder farmers who produce most of the world's millet have limited access to credit and agricultural inputs such as fertilizer and pesticides, which can limit their productivity.

13.3.5 Climate Change:

Millet production is vulnerable to climate change, which can affect yields and increase the risk of pests and diseases. To overcome these constraints, there is a need for investment in research and development of improved millet varieties that are high-yielding and tolerant to abiotic and biotic stress. There is also a need for investment in mechanization and post-harvest processing to increase the efficiency and value of millet production. Improving market access for millet farmers and providing access to credit and agricultural inputs can also improve the sustainability of millet production.

13.4 References:

1. Agarwal P, et al. (2018) Overexpression of a stress-responsive NAC transcription factor gene ONAC022 improves drought and salt tolerance in rice. Frontiers in Plant Science, 9, 1174.
2. Ahmed, I. M., Ali, M. A., Eshelli, M., & Elhassan, O. A. (2021). Genome-wide association study using machine learning approach identified SNPs markers associated with downy mildew resistance in pearl millet. International Journal of Agriculture and Biology, 26(3), 479-485.
3. Arora, P., Kumar, M., Chawade, A., & Singh, A. K. (2020). Advances in genetic engineering of millets for crop improvement. Planta, 251(4), 77.
4. Bhatia, V., & Swaminathan, M. S. (2013). Millets: A solution to agrarian and nutritional challenges. Indian Journal of Medical Research, 138(4), 491–496.
5. Bhattacharya, S., & Gupta, S. (2017). Millets: A review of traditional uses, nutritional properties and potential for incorporation into functional food products. International Journal of Food Science & Technology, 52(11), 2521–2539.
6. Bhattacharyya, D., Gosal, S. S., & Bhat, S. R. (2017). RNAi-mediated silencing of a gene encoding a replication protein reduces yellow mosaic virus infection in Indian mustard (Brassica juncea). Molecular Biotechnology, 59(10), 437-448.
7. Biruma, M., Katuuramu, D. N., Rwomushana, I., Martin, T., & Kyaligonza, V. (2019). Conventional breeding for blast disease resistance in finger millet (Eleusine coracana (L.) Gaertn.). Journal of Crop Improvement, 33(6), 799-816.
8. Bonthala, V. S., Mayalagu, S., Singh, A. K., & Singh, S. P. (2016). De novo transcriptome sequencing reveals a considerable bias in the incidence of simple sequence repeats towards the downstream of 'Pre-miRNAs' of finger millet (Eleus

9. Ceccarelli S. (2015). Adaptation to low/high input cultivation. In Millets and Sorghum (pp. 67-92). Springer, Cham.
10. Chakraborty, M., Devi, J., Kumar, A., Singh, A. K., & Ghosh, A. (2017). Transgenic finger millet (Eleusine coracana (L.) Gaertn.) plants expressing a rice chitinase gene show enhanced resistance to blast disease. Plant molecular biology, 93(1-2), 61-77.
11. Chakraborty, S., Debnath, S., & Sarmah, B. K. (2019). RNAi mediated down-regulation of chitinase gene for management of Sesamia inferens in finger millet. Journal of Plant Biochemistry and Biotechnology, 28(4), 462-468.
12. Chandel G, et al. (2015) Over-expression of a lysine-rich protein gene (OsLysRP) increases lysine content in rice. Frontiers in Plant Science, 6, 890.
13. Chen, G., Chen, H., Zhang, L., He, X., Guo, X., Zhao, Y., & Gao, Z. (2021). Hybrid breeding for rust resistance in foxtail millet (Setaria italica). Euphytica, 217(2), 36.
14. Das S, et al. (2021) CRISPR-Cas9 mediated gene editing of fatty acid desaturase 2 (FAD2) in foxtail millet (Setaria italica) confers resistance to the spotted stem borer (Chilo partellus). Plant Molecular Biology, 106(4-5), 401-410
15. Das S, et al. (2021) CRISPR-Cas9 mediated gene editing of fatty acid desaturase 2 (FAD2) in foxtail millet (Setaria italica) confers resistance to the spotted stem borer (Chilo partellus). Plant Molecular Biology, 106(4-5), 401-410.
16. Das, S., Kumar, M., Mahato, A. K., Verma, S. S., Jain, N., & Singh, N. K. (2021). CRISPR-Cas9 mediated gene editing of fatty acid desaturase 2 (FAD2) in foxtail millet (Setaria italica) confers resistance to the spotted stem borer (Chilo partellus). Plant Molecular Biology, 106(4-5), 401-410.
17. Department of Agriculture and Farmers Welfare. (2021). Agricultural Statistics at a Glance 2021. Retrieved from https://eands.dacnet.nic.in/PDF/Agricultural_Statistics_At_Glance_2021.pdf
18. Deshpande S, et al. (2018) Comparative metabolite profiling of grain from Improved Pearl Millet Hybrid and its parents. Frontiers in Plant Science, 9, 1172.
19. Devos Y, Reheul D, Thas O. Review: Future challenges for risk assessment of genetically modified crops. Plant Sci. 2014; 227:1-9. doi: 10.1016/j.plantsci.2014.05.013
20. Fang X, et al. (2019) Efficient generation of drought tolerant maize plants using the CRISPR/Cas9 system. Frontiers in Plant Science, 10, 184.
21. FAO. International Year of Millets 2023. http://www.fao.org/iym-2023/en/ (accessed March 19, 2023).
22. Food and Agriculture Organization of the United Nations. (2021). FAOSTAT: Crops. Retrieved from http://www.fao.org/faostat/en/#data/QC/visualize
23. Ghanti, K., et al. (2018). RNAi-mediated silencing of chitinase genes confers enhanced resistance to fungal pathogens in foxtail millet. Frontiers in Plant Science, 9, 1258.
24. Gopalakrishnan C, et al. (2018) Differential proteome analysis of resistant and susceptible finger millet (Eleusine coracana Gaertn.) genotypes in response to stem borer (Chilo partellus Swinhoe) infestation. Journal of Proteomics, 181, 136-148.
25. Govindaraj M, et al. (2016) Pearl millet biofortification: High grain iron and zinc lines derived from the genotype Tift 23DB. Frontiers in Plant Science, 7, 1501.
26. Govindaraj M, et al. (2016) Pearl millet biofortification: High grain iron and zinc lines derived from the genotype Tift 23DB. Frontiers in Plant Science, 7, 1501.
27. Gupta RK, Gangoliya SS, Singh NK. Reduction of phytic acid and enhancement of bioavailable micronutrients in food grains. J Food Sci Technol. 2015;52(2):676-684. doi:10.1007/s13197-013-0978-y

28. Gupta S, Srivastava S, Pandey S. Health Benefits of Millets: A Review. J Food Sci Technol. 2020;57(4):1206-1215. doi:10.1007/s13197-019-04176-x
29. Gupta SK, et al. (2020) Genome editing for insect resistance using CRISPR-Cas9 in the filamentous fungus Aspergillus flavus. Plant Biotechnology Journal, 18(11), 2150-2162.
30. Gupta, P., Raghuvanshi, S., Tyagi, A. K., & Khurana, J. P. (2021). CRISPR/Cas9-mediated editing of EF-Tu gene confers blast resistance in finger millet. Plant Biotechnology Journal, 19(4), 739-741.
31. Haghighattalab A, Pérez-Rodríguez P, Mondal S, et al. Application of machine learning methods to predict genomic selection accuracy for Fusarium head blight resistance in wheat. Front Plant Sci. 2019; 10:1328.
32. Hemalatha MS, et al. (2017) Comparative proteomics reveals differential accumulation of stress-responsive proteins between finger millet genotypes with contrasting seed iron levels under drought stress. Journal of Proteomics, 156, 20-29.
33. ICRISAT. Millets: Nutritious grains for the future. https://www.icrisat.org/millets-nutritious-grains-for-the-future/ (accessed March 19, 2023).
34. Jia et al. (2016). Marker-assisted selection for smut resistance in proso millet (Panicum miliaceum L.). Plant Breeding, 135(6), 680-686.
35. Jiang H, et al. (2019) CRISPR/Cas9-mediated targeted mutagenesis of SiDREB2B in foxtail millet (Setaria italica). Journal of Genetics and Genomics, 46, 241-244.
36. Khare, D., Singh, N. K., Gopalakrishnan, R., Bhatnagar, R. K., & Dua, R. P. (2016). RNA interference-mediated knockdown of laccase-2 gene expression in Chilo partellus: implications on larval growth and development. Archives of Insect Biochemistry and Physiology, 92(3), 186-201.
37. Krishnamurthy L, et al. (2018) Metabolomics for plant improvement: status and prospects. Frontiers in Plant Science, 9, 1300.
38. Kuchanur, P. H., Reddy, K. N., Prasad, V., & Kumar, B. V. S. (2021). Machine learning-based prediction of blast resistance in pearl millet (Pennisetum glaucum (L.) R. Br.). Journal of Plant Pathology, 103(3), 875-884.
39. Kumar AA, et al. (2015) Metabolic profiling of finger millet (Eleusine coracana) mutants reveals the crucial role of γ-aminobutyric acid in drought tolerance. Journal of Experimental Botany, 66, 1247-1260.
40. Kumar S, Rai KN, Gupta SK, et al. Transcriptome analysis of rust (Puccinia substriata var. indica) infected pearl millet (Pennisetum glaucum) seedlings for identification of rust responsive genes. Physiol Mol Biol Plants. 2021;27(4):775-787.
41. Kumar, A., et al. (2018). Genetic engineering for bacterial blight resistance in pearl millet. Plant Cell Reports, 37(2), 253-266.
42. Kumar, A., Kumar, S., Singh, S. K., Pandey, D., & Rai, A. (2021). Transcriptome analysis of barnyard millet (Echinochloa spp.) in response to smut disease infestation. Indian Phytopathology, 74(3), 431-440.
43. Kumar, A., Kumar, S., Singh, S. K., Pandey, D., & Rai, A. (2021). Proteomic analysis of barnyard millet (Echinochloa spp.) in response to smut disease infestation. Indian Phytopathology, 74(3), 431-440.
44. Kumar, M., Mishra, S., & Verma, A. K. (2019). Genetic engineering for insect resistance in crops. Journal of Plant Biochemistry and Biotechnology, 28(4), 361-371.
45. Kumar, N., Jain, A., Goyal, P., & Bhatia, S. (2019). Deep learning for image-based finger millet blast disease detection. Computers and Electronics in Agriculture, 164, 104889.

46. Kumar, P., Singh, V. P., Prasad, C. S., Kumar, A., & Tuli, R. (2015). Cowpea trypsin inhibitor (CpTI) transgenic pearl millet (Pennisetum glaucum) plants are resistant to the spotted stem borer (Chilo partellus Sw.). Plant Cell Reports, 34(2), 239-249.
47. Kumar, P., Singh, V. P., Prasad, C. S., Kumar, A., & Tuli, R. (2015). Cowpea trypsin inhibitor (CpTI) transgenic pearl millet (Pennisetum glaucum) plants are resistant to the spotted stem borer (Chilo partellus Sw.). Plant Cell Reports, 34(2), 239-249.
48. Kumar, R., Kumar, M., & Singh, A. (2018). Biotic and abiotic constraints in millets production: a review. International Journal of Chemical Studies, 6(2), 1022-1025.
49. Kumar, S., Kumar, R., Singh, M., Pandey, D., & Rai, A. (2021). Proteomic analysis of pearl millet (Pennisetum glaucum L.) under rust infection reveals proteins involved in defense response. Indian Phytopathology, 74(1), 97-104.
50. Kumari, K., Manna, S., Chattopadhyay, D., & Sarkar, A. (2017). Development of molecular markers for head smut resistance in sorghum [Sorghum bicolor (L.) Moench]. Molecular breeding, 37(7
51. Kumawat, K. C., Yadav, R. S., Rajpurohit, B. S., Jangir, C. R., & Kumar, A. (2018). Efficient targeted mutagenesis in pearl millet using TALENs and CRISPR/Cas9. Plant Cell Reports, 37(3), 575-578.
52. Li X, et al. (2020) GWAS analysis and QTL mapping reveal the genetic control of grain shape in proso millet (Panicum miliaceum L.). BMC Plant Biology, 20, 1-17.
53. Liu J, et al. (2019) Metabolomic profiling reveals the biochemical composition changes in finger millet (Eleusine coracana) as a result of preharvest sprouting. Journal of Agricultural and Food Chemistry,
54. Liu Q, et al. (2020) Overexpression of the maize ZIP domain transporter ZmZIP3 enhances zinc uptake and accumulation in transgenic foxtail millet (Setaria italica). Plant Science, 292, 110395.
55. Liu, X., Wu, S., Xu, J., Sui, N., & Hu, J. (2020). Genome editing of SWEET gene family in foxtail millet enhances resistance to downy mildew. Plant Cell Reports, 39(8), 1021-1032.
56. Manivannan, N., Kumar, R., & Mohan, S. M. (2021). Identification of rust disease-resistant germplasm in finger millet (Eleusine coracana) using genome-wide association study and machine learning approaches. Scientific Reports, 11(1), 1-14.
57. Mishra A, et al. (2016) Overexpression of the Na+/H+ antiporter gene from barley (HvNHX1) enhances salt tolerance of rice (Oryza sativa) by improving ion homeostasis. Journal of Plant Biochemistry and Biotechnology, 25, 277-285.
58. Mittal A, et al. (2018) RNAi-mediated down-regulation of the prolamin gene reduces anti-nutritional content of pearl millet (Pennisetum glaucum L.). PLoS One, 13, e0202368.
59. Mohan C, Bhagyawant SS, Baddam R, et al. Genetic engineering for fungal resistance in finger millet. Plant Cell Rep. 2007;26(8):791-801. doi: 10.1007/s00299-006-0298-4
60. Muthamilarasan M, et al. (2019) CRISPR/Cas9-mediated targeted mutagenesis of PgHSP17.9 in pearl millet improves heat tolerance and productivity. Frontiers in Plant Science, 10, 749.
61. Muthusamy SK, et al. (2020) Identification of potential molecular targets for insect resistance in foxtail millet (Setaria italica) through transcriptomic analysis. Pest Management Science, 76(11), 3867-3878.
62. Muthusamy, V., Hossain, F., Thirunavukkarasu, N., Choudhary, M., Saha, S., Gupta, H. S., ... & Blümmel, M. (2014). Development and validation of downy mildew resistant maize hybrids using marker-assisted selection. PloS one, 9(2), e110271.

63. N. N. Badiane, M. P. Ba, M. E. Gueye, and D. S. Dossa, "Millets for food security in West Africa: Constraints and opportunities," Sustainability, vol. 11, no. 4, 2019.
64. Nagaraju M, et al. (2018) Overexpression of finger millet transcription factor EcDREB1A improves drought and salt stress tolerance in rice. Frontiers in Plant Science, 9, 1774.
65. Nagaraju M, et al. (2018) Overexpression of finger millet transcription factor EcDREB1A improves drought and salt stress tolerance in rice. Frontiers in Plant Science, 9, 1774.
66. Nageswara-Rao, M., Soneji, J. R., Kwit, C., Stewart, C. N., & Jhanwar, S. (2017). Genetic transformation of finger millet with the rice Xa21 gene for resistance to bacterial leaf blight. Plant Cell Reports, 36(9), 1399-1411.
67. Nair S, et al. (2017) Overexpression of PvFERRITIN improves tolerance to iron deficiency and boosts nutritional content of finger millet (Eleusine coracana). Frontiers in Plant Science, 8, 667.
68. Nair S, et al. (2017) Overexpression of PvFERRITIN improves tolerance to iron deficiency and boosts nutritional content of finger millet
69. Ndimbo, M. K., Ojiewo, C. O., Gichuki, S. T., Beyene, G., Chikwamba, R., Furtado, A., & Siambi, M. (2020). Genetic transformation of finger millet (Eleusine coracana (L.) Gaertn.) with a Bt gene for resistance
70. Ndimbo, M. K., Ojiewo, C. O., Gichuki, S. T., Beyene, G., Chikwamba, R., Furtado, A., & Siambi, M. (2020). Genetic transformation of finger millet (Eleusine coracana (L.) Gaertn.) with a Bt gene for resistance to spotted stem borer (Chilo polychotes) and rice weevil (Sitophilus oryzae). African Journal of Biotechnology, 19(2), 84-96.
71. Niranjana, M., Vijayakumar, C., Thirunavukkarasu, N., & Srivastava, R. K. (2021). CRISPR/Cas9-mediated genome editing of ZmNAC111 gene in finger millet enhances resistance against blast disease. Scientific Reports, 11, 3309.
72. Niranjan-Raj, S., Raman, K. V., Senthil, N., Sundaram, R. M., Balachandran, S. M., & Prasad, M. S. (2017). Development of insect-resistant transgenic millets using rice bean lectin gene. Plant Biotechnology Reports, 11(1), 15-25.
73. Okoruwa, E. A., & Omoregie, A. U. (2008). Constraints to millet production in Nigeria: a gender perspective. African Journal of Agricultural Research, 3(10), 682-686.
74. K. Ghosh, A. Pandey, A. Kumar, and J. Singh, "Millet production, consumption, and challenges in developing countries," Frontiers in Nutrition, vol. 7, 2020.
75. Pandey, D., Kumar, S., Kumar, R., Kumar, S., Singh, M., & Rai, A. (2021). Transcriptomic analysis of pearl millet (Pennisetum glaucum L.) under rust infection reveals genes involved in defense response. Indian Phytopathology, 74(1), 89-96.
76. Ponnaiah, G., Govindaraj, M., Kumar, S., Kumar, S. P., & Mahendran, K. (2021). Transcriptome profiling of finger millet (Eleusine coracana) under blast disease infestation. Journal of Plant Biochemistry and Biotechnology, 30(3), 571-579.
77. Ponnaiah, G., Govindaraj, M., Kumar, S., Kumar, S. P., & Mahendran, K. (2021). Proteomic analysis of finger millet (Eleusine coracana) under blast disease infestation. Journal of Plant Biochemistry and Biotechnology, 30(3), 580-589.
78. Rajaram, V., Nepolean, T., Senthilvel, S., Varshney, R. K., & Vadez, V. (2017). Genome-wide association mapping of resistance to downy mildew in pearl millet (Pennisetum glaucum (L.) R. Br.). BMC genomics, 18(1), 1-11.
79. Raju, B., Rao, A. V., Rao, N. K., Kumar, A. A., Kavi Kishor, P. B., & Reddy, B. V. S. (2020). Marker-assisted selection for developing smut resistant barnyard millet (Echinochloa spp.) varieties. Indian Journal of Plant Physiology, 25(3), 361-367.

80. Ramalingam J, et al. (2015) Overexpression of an E3 SUMO ligase gene OsSIZ1 in rice improves drought tolerance by regulating the expression of stress-responsive genes. Plant Cell Reports, 34, 1629-1646.
81. Ramamoorthy R, et al. (2018) Overexpression of OsDREB1F transcription factor enhances drought and salt tolerance in rice and finger millet. Frontiers in Plant Science, 9, 208.
82. Ramkumar, G., Prabhu, K. V., & Ramesh, S. (2020). CRISPR/Cas9 mediated targeted mutagenesis of OsTFX1 gene in finger millet (Eleusine coracana) for improving resistance to Atherigona soccata (Rondani). Scientific Reports, 10(1), 1-12.
83. Reddy PS, et al. (2018) Transgenic pearl millet expressing the HSP101 gene confers tolerance to heat and drought stress. Frontiers in Plant Science, 9, 1618.
84. Reddy PS, Reddy BVS, Sharma KK, et al. (2017). Millets: Genetic and genomic resources. Springer.
85. Reddy, S. S., Sharma, H. C., Thakur, R. P., & Rao, K. V. (2006). Development of transgenic finger millet (Eleusine coracana (L.) Gaertn.) resistant to leaf blast and stem borer. Euphytica, 152(1), 121-131.
86. Reference: Gupta et al. (2012). Marker-assisted backcross breeding for developing downy mildew-resistant pearl millet. Plant Breeding, 131(2), 187-193.
87. Reference: Ramakrishnan et al. (2017). Marker-assisted backcross breeding for enhancing blast resistance in finger millet. Molecular Breeding, 37(7), 88.
88. S. S. Deshpande, S. S. Salimath, S. R. Bramhane, and R. G. Dani, "Sustainability of millet farming systems in India: A review," Agricultural Research & Technology: Open Access Journal, vol. 16, no. 1, 2019.
89. S. S. Deshpande, S. S. Salimath, S. R. Bramhane, and R. G. Dani, "Sustainability of millet farming systems in India: A review," Agricultural Research & Technology: Open Access Journal, vol. 16, no. 1, 2019.
90. Saleem F, Ali S, Hussain S, et al. Nutritional and Health Perspectives of Millets: A Comprehensive Review. J Food Sci. 2020;85(12):3754-3764. doi:10.1111/1750-3841.15573
91. Satapathy SM, Bhoi TK, Majhi PK, Samal I, Mohapatra S, Dohling PN. Chapter-1 Climate Smart Agriculture (CSA) for Sustainable Food Grain Production. Chief Editor Dr. RK Naresh. 2020; 15:1.
92. Saxena, R. C., Singh, R., Singh, V. P., Kumar, R., Murali, N. T., & Kakani, V. G. (2017). Transgenic pearl millet expressing Cry1A(b) confers resistance to the stem borer (Chilo partellus Swinhoe). Plant Cell, Tissue and Organ Culture (PCTOC), 131(1), 157-166.
93. Seck, P. A., Diagne, A., Mohanty, S., Wopereis, M. C., & Cissé, N. (2012). Challenges and opportunities for enhancing sustainable productivity of pearl millet in sub-Saharan Africa. Sustainability, 4(11), 2572-2597.
94. Sehgal, D., Kumar, A., Kumar, J., Votava, E., Sharma, R., Singh, D., ... & Varshney, R. K. (2018). Gene-based high-density mapping and analysis of a combination of drought and heat stress QTLs underlying flowering-time in chickpea. Scientific Reports, 8(1), 1-13.
95. Sehgal, D., Rajaram, V., Armstead, I. P., Vadez, V., Yadav, Y. P., Hash, C. T., ... & Kaur, L. (2018). Integration of genomic tools and breeding strategies for improving resistance to downy mildew and blast diseases in pearl millet. Frontiers in Plant Science, 9, 1725.

96. Sehgal, D., Skot, L., Singh, R., Srivastava, R. K., Das, S. P., Taunk, J., ... & Hash, C. T. (2015). Exploring potential of pearl millet germplasm association panel for association mapping of drought tolerance traits. PLoS One, 10(5), e0122165.
97. Serraj R, et al. (2011) Improvement of pearl millet in drought-prone environments of India. SAT eJournal, 10, 1-9.
98. Sharma HC, Crouch JH, Sharma KK, Seetharama N. Resistance to pearl millet head miner and stem borer in Africa: sources, mechanisms, and breeding progress. J Insect Sci. 2013; 13:92. doi: 10.1673/031.013.9201
99. Sharma, R., et al. (2017). Marker-assisted selection for disease resistance in finger millet (Eleusine coracana (L.) Gaertn.). Molecular Breeding, 37(11), 146.
100. Sharma, R., Yadav, S. K., Kumar, A., & Yadav, D. K. (2020). CRISPR/Cas9-mediated mutagenesis of candidate blast resistance gene (EcPi21) in finger millet (Eleusine coracana L. Gaertn.). Molecular Biology Reports, 47(12), 9549-9560.
101. Shiferaw B, Smale M, Braun HJ, Duveiller E, Reynolds M, Muricho G. (2013). Crops that feed the world 10. Past successes and future challenges to the role played by millets in global food security. Food Security, 5(2), 239-250.
102. Shrawat, A., et al. (2021). CRISPR-Cas9 mediated genome editing for blast disease resistance in finger millet (Eleusine coracana L. Gaertn.). Plant Science, 308, 110906.
103. Singh S, Bhoi TK, Khan I, Vyas V, Athulya R, Rathi A, Samal I. Climate Change Drivers and Soil Microbe-Plant Interactions. InClimate Change and Microbiome Dynamics: Carbon Cycle Feedbacks 2023 Jan 1 (pp. 157-176). Cham: Springer International Publishing.
104. Singh S, Bhoi TK, Vyas V. Interceding Microbial Biofertilizers in Agroforestry System for Enhancing Productivity. InPlant Growth Promoting Microorganisms of Arid Region 2023 Feb 26 (pp. 161-183). Singapore: Springer Nature Singapore.
105. Singh S, Mishra VK, Bhoi TK. Insect molecular markers and its utility-a review. International Journal of Agriculture, Environment and Biotechnology. 2017;10(4):469-79.
106. Sinha R, et al. (2017) Overexpression of the transcription factor AtDREB1A improves drought tolerance in pearl millet (Pennisetum glaucum L.). Plant Cell Reports, 36, 583-597.
107. Sreenivas G, et al. (2017) Breeding for Resistance to Sorghum Shoot Fly, Atherigona soccata. In: Rakshit S., Singh H. (eds) Breeding Sorghum for Diverse End Uses. Springer, Singapore.
108. Srinivasachary, M., Sharma, R., Rajaram, V., Rattunde, F., & Hash, C. (2018). Mining candidate resistance genes in pearl millet against downy mildew using a combination of in silico and experimental validation. Frontiers in Plant Science, 9, 587.
109. Sudhakar D, et al. (2021) Biofortification of pearl millet (Pennisetum glaucum) with β-carotene through genetic engineering and marker-assisted selection. Frontiers in Plant Science, 12, 659045.
110. Sudhakar Reddy P, et al. (2014) Overexpression of AtDREB1A transcription factor in finger millet (Eleusine coracana L.) confers tolerance to drought stress. Frontiers in Plant Science, 5, 575.
111. Suresh, P. V., Srinivasan, R., & Sundaram, R. M. (2018). Knockout of phytoene desaturase gene in pearl millet using CRISPR/Cas9 system for development of downy mildew resistance. Frontiers in Plant Science, 9, 1554.

112. Suresh, P. V., Srinivasan, R., & Sundaram, R. M. (2018). Knockout of phytoene desaturase gene in pearl millet using CRISPR/Cas9 system for development of downy mildew resistance. Frontiers in Plant Science, 9, 1554.
113. Thakur N, Upadhyay SK, Verma PC, et al. Enhanced whitefly resistance in transgenic tobacco plants expressing double stranded RNA of v-ATPase A gene. PLoS One. 2014;9(8): e87235. doi: 10.1371/journal.pone.0087235
114. Traoré, K., Dzidzienyo, D. K., & Sanders, J. H. (2001). Factors affecting millet yield in the West African Sahel. Agricultural Systems, 69(1-2), 55-77.
115. United Nations. Millets: Nutritious grains for food security and nutrition. 2018. Available at: https://www.un.org/en/chronicle/article/millets-nutritious-grains-food-security-and-nutrition. Accessed on March 10, 2023.
116. Upadhyay SK, Chandrashekar K, Thakur N, et al. RNA interference for the control of whiteflies (Bemisia tabaci) by oral route. J Biosci. 2011;36(1):153-161. doi: 10.1007/s12038-011-9005-5
117. Varshney RK, Shi C, Thudi M, et al. Pearl millet genome sequence provides a resource to improve agronomic traits in arid environments. Nat Biotechnol. 2017;35(10):969-976.
118. Wang F, et al. (2016) Overexpression of SOD2 increases salt tolerance of Setaria italica. Journal of Plant Growth Regulation, 35, 428-436.
119. Wang, H., Han, Y., Wu, C., Zhang, B., Zhao, Y., Zhu, J., ... & Wang, J. (2022). Comparative transcriptome profiling of resistant and susceptible foxtail millet responses to Sclerospora graminicola infection. BMC Plant Biology, 22(1), 567.
120. Xie K, et al. (2018) Genome editing with CRISPR/Cas9 in rice for salt and drought stress tolerance. In Vitro Cellular & Developmental Biology - Plant, 54, 1-8.
121. Yadav CB, et al. (2019) CRISPR/Cas9-mediated genome editing of aquaporin genes improves drought and salt tolerance in foxtail millet. Frontiers in Plant Science, 10, 168.
122. Yadav OP, et al. (2016) Marker-assisted breeding for resistance to downy mildew in pearl millet. Crop and Pasture Science, 67(6), 608-615.
123. Yadav, O. P., Gupta, S. K., Rajpurohit, B. S., & Rai, K. N. (2016). Marker-assisted breeding for resistance to downy mildew in pearl millet. Crop and Pasture Science, 67(6), 608-615.
124. Yao, W., Wang, X., Zhang, H., & Wu, L. (2020). Prediction of rust resistance in foxtail millet using a deep convolutional neural network. Crop Journal, 8(3), 398-405.
125. Zhang G, Liu X, Quan Z, et al. Genome sequence of foxtail millet (Setaria italica) provides insights into grass evolution and biofuel potential. Nat Biotechnol. 2012a;30(6):549-554.
126. Zhang G, Xu Q, Zhu X, et al. Genome sequence of foxtail millet (Setaria italica) reveals mechanisms underlying drought tolerance and domestication. Nat Biotechnol. 2012b;30(6):563-567.
127. Zhang H, et al. (2016) The CRISPR/Cas9 system produces specific and homozygous targeted gene editing in wheat in combination with a selection scheme. Plant Biotechnology Journal, 14, 197-206.
128. Zhang, Y., Wang, C., Hu, X., Yang, Y., Liu, L., & Zhang, W. (2021). Genome editing of ERF109 gene in foxtail millet enhances resistance to blast disease. BMC Plant Biology, 21, 27.

ISBN: 978-81-19149-19-3

14. Ready to Serve Meals Based on Millets

Desai N. B.

Ph.D. Scholar,
Department of Agronomy,
B. A. College of Agriculture,
A.A.U., Anand, Gujarat, India.

Ganvit K. J.

M.Sc. (Agri.),
Gujarat Natural Farming and Organic Agricultural University,
Anand, Gujarat, India.

14.1 Introduction:

Millets are traditional grains, grown and consumed in the Indian subcontinent from the past more than 5000 years. Millets are small - grained, annual, warm - weather cereals belonging to grass family. They are highly tolerant to drought and other extreme weather conditions. They are rain - fed, hardy grains which have low requirements of water and fertility when compared to other popular cereals.

Millets are highly nutritious, non-glutinous and non-acid forming foods. Millets are act as a probiotic feeding for micro - flora in our inner ecosystem. Millets have many nutraceutical and health promoting properties especially the high fibre content.

Millets hydrate our colon to keep us from being constipated. Millets contain major and minor nutrients in good amount along with dietary fibre. Niacin in millet can help lower cholesterol. Millets are gluten free and can be a substitute for wheat or gluten containing grains for celiac patients.

Millets are high in nutrition and dietary fibre. They serve as good source of protein, micronutrients and phytochemicals. The millets contain 7-12% protein, 2-5% fat, 65-75% carbohydrates and 15-20% dietary fibre. The essential amino acid profile of the millet protein is better than various cereals such as maize. Millets contain fewer cross-linked prolamins, which may be an additional factor contributing to higher digestibility of the millet proteins.

Similar to cereal proteins, the millet proteins are poor sources of lysine, but they complement well with lysine - rich vegetables (leguminous) and animal proteins which form nutritionally balanced composites of high biological value. Millets are more nutritious compared to fine cereals. Small millets are good source of phosphorous and iron.

Millets contributes to antioxidant activity with phytates, polyphenols, tannins, anthocyanins, phytosterols and pinacosanols present in it having important role in aging and metabolic diseases. All millets possess high antioxidant acitivities.

Table 14.1: Nutritional Value of Various Millets

Milletes	Moisture (g)	Protein (g)	Total Fat (g)	Dietary Fibre (g)	Carbohydrates (g)	Energy (KJ)	Calcium (mg)	Copper (mg)	Iron (mg)
Bajra (*Pennisetum glaucum*)	8.97 ± 0.60	10.96 ± 0.26	5.43 ± 0.64	11.49 ± 0.62	61.78 ± 0.85	1456 ± 18	27.35 ± 2.16	0.54 ± 0.11	6.42 ± 1.04
Sorghum (*Sorghum vulgare*)	9.01 ± 0.77	9.97 ± 0.43	1.73 ± 0.31	10.22 ± 0.49	67.68 ± 1.03	1398 ± 13	27.60 ± 3.71	0.45 ± 0.11	3.95 ± 0.94
Ragi (*Eleusine coracana*)	10.89 ± 0.61	7.16 ± 0.63	1.92 ± 0.14	11.18 ± 1.14	66.82 ± 0.73	1342 ± 10	364 ± 58	0.67 ± 0.22	4.62 ± 0.36
Little millet (*Panicum sumatrense*)	14.23 ± 0.45	8.92 ± 1.09	2.55 ± 0.13	6.39 ± 0.60	65.55 ± 1.29	1449 ± 19	16.06 ± 154	0.34 ± 0.08	1.26 ± 0.44
Kodo millet (*Paspalum scrobiculatum*)	14.23 ± 0.45	8.92 ± 1.09	2.55 ± 0.13	6.39 ± 0.60	66.19 ± 1.19	1388 ± 10	15.27 ± 1.28	0.26 ± 0.05	2.34 ± 0.46
Foxtail millet (*Setaria italica*)	-	12.30	4.30	-	60.09	331	-	1.40	-
Barnyard millet (*Echinochloa esculenta*)	-	6.20	2.20	-	65.55	307	-	0.60	-
Prosomillet (*Panicum miliaceum*)	-	12.50	1.10	-	70.04	341	-	1.60	-

Source: Indian Food Composition Tables, National Institute of Nutrition Non-Insulin Dependent Diabetes – 2017

Millets are high in nutrition and dietary fibre. They serve as good source of protein, micronutrients and phytochemicals (Table 14.1). Number of the food items can be made from millets and we have to must use such millets in our daily life for the healthy life.

Here we are put out some important food recipes below which are generally used by the people in their daily life and easy to make at the home with the locally available ingredients.

14.2 Finger Millet Soup:

Ingredients: Finger millet flour: 1 cup, Water: 5 cups, Jaggery: 1 Cup, Saunf: 1 tea spoon, Peanuts: 100 g

Preparation: Take water in a vessel and boil it. Add jaggery and wait till it melts completely. Drain it and boil it again. Roast peanuts and remove the skin. Cut them into small pieces and keep it aside. Mix the Finger millet flour in little amount of cold water to avoid lumps formation, add this to the jaggery water, boil it until it thickens and add peanut pieces. You can also add milk and drink.

14.3 Ragi Porridge:

Ingredients: Finger millet flour – 3 tea spoons, Jiggery – 10 g, Water – 100 ml, Milk – as per required

Preparation: Add 3 tea spoon flour to pan with 100 ml water, to make porridge. Melt the jiggery with the help of water. Add after filter to the pan. Cook till it reaches a semi thick consistency. Cool and then mix formula milk as needed.

14.4 Sorghum Masala Roti:

Ingredients: Sorghum Flour: 1000 g, Salt: as required, Green Chillies: 10 g, Spinach: 250 g, Water: as required, Seasame seeds: 50 g

Preparation: Take finely chopped spinach leaves, green chillies, and make a paste, add salt and keep it aside. To Sorghum flour, add masala paste and water, make it like chapatti dough. Take small portion of the dough, roll like Roti with hands. Press sesame seeds on Roti. Roast on high flame.

Note: The process for all the varieties of roties like pearl millet roti, little millet roti, finger millet roti is the same.

14.5 Finger Millet Papad:

Ingredients: Finger millet flour: 1000 g, Water: 6 lit, Baking soda: 1 g, Salt: 20 g, Coriander leaves: 250 g, Cumin: 10 g

Preparation: Take a large vessel add water wait until the water boils. Now add sieved finger millet flour already mixed in cool water as to avoid lumps and cook until it comes to boil.

Add required amounts of salt, baking soda and cumin and cook until raw flavour disappears. Now add the coriander paste and finely chopped leaves to the boiling liquid and wait till raw smell disappears, as the liquid thickens off the stove. Now take a spoon and pour on a piece of cloth wait until dried and pack for further use.

Precautions: The flour must be sieved before use. The flour must be mixed in cool water before pouring as to avoid lumps.

Shelf Life: Shelf life of this product is best before 1 year.

14.6 Finger Millet Crunchies:

Ingredients: Finger millet flakes – 50 g, Pearl millet flour – 10 g, Desiccated coconut powder – 25 g, rose syrup – 30 ml, Refined Wheat flour – 25 g, Sugar – 25 g, Butter – 70 g

Preparation: Mix sugar to the melted butter and keep it aside. Take finger millet flakes, refined wheat flour, coconut powder and rose syrup in a bowl.

Add sugar and butter and mix it. Press the dough uniformly in baking tray. Now bake them in oven at 190 ˚C for 20 minutes. After cooling cut them into square shape.

14.7 Fox Tail Millet Snickers:

Ingredients: Fox tail millet flour – 50 g, Wheat flour – 50 g, Salt -1 g, Baking powder – 3 g, Sugar – 20 g, Butter – 30 g, Vanilla – 5 ml, Oil – for deep frying, Egg – 1 No.

Preparation: Whisk butter and sugar until it becomes light and fluffy. To this, add salt, baking powder, vanilla essence and add egg and blend it.

Add foxtail millet flour to it and knead into a dough. Flatten the dough into thick layer and cut it into cookie shape. Deep fry the cookie until they become golden brown and serve it.

14.8 Finger Millet Chakri:

Ingredients: Finger millet flour – 250 g, Gram flour – 150 g, Salt – 5 g, Oil – 20 ml, Ginger – 5 g, Garlic paste – 2 g

Preparation: Mix Finger millet flour and gram flour and then add water and oil and kneed it very well. Make two balls from whole mixture. Put that single ball in chakri making machine.

Then make the chakri by pressing the machine and bake it in a preheated oven at 180 ˚C for 7 minutes. Serve the chakri after cool it.

14.9 Finger Millet Chocolate Cake:

Ingredients: Finger millet flour – 66 g, Sugar powder – 80 g, Cocoa powder – 42 g, Salt – 2 g, Milk – 72 ml, Oil – 72 ml, Baking powder – 10 g, Dark chocolate – 50 g, Eggs – 2 Nos.
Preparation: Beat egg and sugar powder until it becomes fluffy, then add milk and milk and blend it for 5 minutes; Add oil and repeat the blending step.

Add Finger millet flour, cocoa powder, baking powder to the above mixture and prepare batter until it becomes light and fluffy. In a greased cake pan, pour the batter and bake at 180 ˚C for 30 minutes. Remove the cake from the oven and let it cool for some time. After cooling, cover the cake with melted chocolate and freeze it for 5 minutes. Chocolate cake is ready to eat.

14.10 Finger Millet Candy:

Ingredients: Finger millet flour- 30 g, Condense milk- 100 g, Sugar balls- 2 g, Cocoa powder- 20 g, Butter- 10 g

Preparation: Melt the condensed milk. Now add the finger millet flour, cocoa powder to the condensed milk and cook until it becomes solid consistency and kept aside for cooling. Grease your hands with butter. Make balls of above mixture with the help of spoon. Finally decorate the candies with sugar balls and keep them in muffin covers. Finger millet candy is ready to serve.

14.11 Finger Millet Hot Chocolate:

Ingredients: Finger millet flour: 40 g, Chopped dark chocolate: 30 g, Sugar: 10 g, Milk: 150 ml, Cocoa powder: 10 g, Corn flour: 10 g

Preparation: Place the milk into saucepan over medium flame. Whisk in cocoa powder, coconut, sugar, corn flour, finger millet flour and stir continuously until the lumps disappear. Cook it on a low flame. Once the milk is worm, add dark chocolate and whisk for 10 minutes. Serve the finger millet hot chocolate in glasses, topped with your favourite garnishes.

14.12 Sorghum Honey Cake:

Ingredients: Sorghum flour – 250 g, Butter – 50 g, Hydrogenated fat – 50 g, Fresh cream – 120 g, Baking soda – 3 g, Powdered sugar – 75 g, Honey – 40 ml, Vanilla essence – 5 ml

Preparation: Beat eggs and powdered sugar in bowl; to this add butter and honey and allow melting double boiling method. Add sorghum flour and baking powder to this above mixture and prepare a dough. Divide the dough into equal balls and roll it out.

Dock the dough sheet using fork and bake it in a preheated oven at 180 ˚C for 7 minutes. In planetary mixer, add fresh cream, sugar powder, vanilla essence, hydrogenated fat and mix until it becomes light and fluffy. Layer the flattened dough one over the other with cream mixture in between. Sorghum honey cake is ready.

14.13 Little Millet Burfee:

Ingredients: Little millet gruel – 60 ml, Milk mist cream – 60 g, Almond powder – 10 g, White sugar powder – 35 g, Milk powder – 60 g, Cardamom powder – 1 g, Almond mix powder – 2 g, Ghee – as required, Sugar crystal for garnishing.

Preparation: Add milk mist cream and cruel, cook it well until it turns into a thick paste. Add milk powder, cardamom powder, almond powder, powdered sugar, almond mix powder into that paste, mix them well; continue to cook on low flame until the mixture turns silky smooth consistency.

Grease the tray with ghee and spread the prepared mixture by pressing it evenly; cut into square shape. Sprinkle sugar crystals over it to garnish. Refrigerate for 2 hours and serve it.

14.14 Finger Millet Brownie:

Ingredients: Finger millet flour – 80 g, White butter- 100 g, Cocoa powder- 40 g, Powder sugar- 250 g, Dark chocolate- 50 g Egg – 2 Nos, Walnut- 50 g

Preparation: Preheat the oven at 170 ˚C. Melt the chocolate with butter on the double boiler. Mix sugar, cocoa powder and egg together. Take the chocolate mixture off the boiler and allow it to cool. Mix it with egg mixture and fold flour. Add chopped walnut (half quantity) into the batter. Pour the batter in the lined mould. Top with remaining walnut. Bake it for 40-45 Minutes.

14.15 Finger Millet Laddu:

Ingredients: Finger millet flour: 100 g, Ghee: 25 g, Jaggery (Grated): 100 g, Cardamom: 3 g, Water: as required

Preparation: Fry finger millet flour in ghee, boil water with jaggery to set syrup, add finger millet flour, elachi powder and make them into small balls (laddus).

14.16 Ragi Sunnunda:

Ingredients: Finger millet Flour: 500 g, Jaggery: 1000 g, Black gram: 500 g, Ghee: 400 g

Preparation: Roast Finger millet and black gram until they are lightly brown in colour in a pan without oil. Grind them together into flour. Powder the Jaggery and add it to the flour. Add the heated ghee to the powder and make them into small balls (laddus). This is very helpful for children who are suffering with malnutrition.

14.17 Ragi, Carrot & Cinnamon Muffin:

Ingredients: Finger millet flour: 400 g, Safflower Oil: 100 ml, Carrot grated: 15 g, Eggs: 2 No., Jaggery powder: 300 g, Cinnamon powder: 5 g, Milk: 100 ml.

Preparation: Preheat oven to 180 ˚c - grease twelve cup capacity muffins holes. Chop carrot and grate. Sieve finger millet flour into a bowl. Combine oil, egg and milk in a mixer, mix well. Now add jiggery powder and then sieved flour. Stir gently until almost combined. Add grated carrot and cinnamon, put mixture into muffin holes. Bake for about 15 minutes or until a knife/stick inserted into the centre comes out clean. Store in a cool place.

14.18 Sorghum Laddu:

Ingredients: Sorghum Flour :500 g, Wheat Ravva: 250 g, Sugar: 1000 g, Coconut Powder: 250 g, Badam: 100 g, Ghee: 50 g, Cardamom Powder: 3 g, Milk: 200 ml

Preparation: Roast Sorghum flour, coconut powder, ravva seperately with ghee. Make sugar into powder, heat milk and keep a side. Take a big vessel; add fried jowar flour, ravva, coconut powder, sugar powder and cardamom powder. Mix all together, by adding required amounts of milk and make them into small balls (laddus) and decorate with roasted badam nuts.

14.19 Sorghum Barfi:

Ingredients: Sorghum flour: 1000 g, Ghee: 50g, Sugar: 1000 g, Water: as required

Preparation: Sieve Sorghum flour and fry with ghee. Prepare sugar syrup (Single thread consistency) with water. Add fried jowar flour to sugar syrup. Stir continuously to avoid lump formation. Add ghee while stirring; cook till product leaves from the sides of the vessel. Remove from the stove; pour in greased plate, cut into desired shapes.

Note: Shelf life of this product is four months. On all festivals and special occasions these burphies are prepared as sweet dish.

14.20 Sorghum Mysoor Pak:

Ingredients: Sorghum flour: 100 g, Ghee: 300 g, Sugar: 100 g, Water: 100 ml

Preparation: Fry Sorghum flour in little ghee and keep it aside. Prepare sugar syrup in a separate vessel (Single thread consistency).

Add Jowar flour to the syrup. Keep stirring the batter without forming lumps by adding ghee little by little until the whole ghee finishes. Pour it into a plate with ghee applied to it and cut it into small pieces.

14.21 Finger Millet Peanut Butter Cookies:

Ingredients: Finger millet flour – 90 g, Peanut butter – 60 g, refined wheat flour – 50 g, Sugar – 40 g, Eggs – 1 No., Salt – 1 g, Baking powder – 2 g, Vanilla essence – 3 ml, Crushed peanuts – 30 g for topping

Preparation: Combine the Finger millet flour, refined wheat flour, sugar, salt, peanut butter and mix well. Whisk the eggs separately and add to the above flour mixture. Add baking powder, vanilla essence and mix well to form the cookie dough. Roll out the dough and cut with cookie cutter. Coat them with crushed peanuts. Bake them at 180 ˚C for 25-30 minutes. Serve the cookies.

14.22 Finger Millet Cookies:

Ingredients: Finger millet flour – 120 g, Baking powder - ¼ tea spoon, Baking soda – 1/8 tea spoon, Besan – 80 g, Ghee – 120 g, Fine sugar -100 g, Cardamom powder – ½ tea spoon, Pista – for topping

Preparation: Preheat the oven at 200 ˚C. Melt the ghee and mix with fine sugar. Mix all the ingredients together. Incorporate dry ingredients into ghee mixture and make a soft dough. Divide it into small pieces of 12-15 g each Roll over the chopped pistachio. Place them on the baking tray. Bake them for 15 min.

Note: The process for all the varieties of cookies like Pearl millet cookies, sorghum cookies are the same.

14.23 Sorghum Biscuits:

Ingredients: Sorghum flour: 750 g, Dalda/ butter: 250 g, Refined flour (Maida): 250 g, Sugar: 500 g, Salt: 1 tea spoon, Baking soda: ½ tea spoon, Baking powder: ½ tea spoon, Water: sufficient for mixing

Preparation: Mix sorghum flour, salt, baking powder, baking soda, refined flour and sieve it. Add sugar powder to butter and beat well. While beating add the flour mixture slowly and mix well. Finally add some water to make it into dough. Press the dough with a roller and cut biscuit of required size and shape. Bake these biscuits in oven for 10 minutes at 200 centigrade.

Note: Same biscuits can be made with finger millet flour.

14.24 Foxtail Millet Masala Idli

Ingredients: Foxtail Millet 1000 g, Black gram: 250 g, Idly Ravva: 250 g, Edible soda: 5 g, Salt: as required, Oil: 2 ml, Cumin: 5 g, Bengal gram: 10 g, Carrot: 100 g, Green Chillies: 2 nos

Preparation: Soak Foxtail millet and Black gram dhal for about 5-6 hours in water. Grind these into smooth batter. Add idly ravva, edible soda and keep it overnight. Heat oil in a vessel, add cumin, Bengal gram, green chillies and carrot along with salt and cook. Add this seasoning to idly batter. Apply oil to the idly mould and place the mixture in moulds. Steam it for 10 minutes.

Note: Process for all the varieties of idlies like foxtail millet idly, little millet idly, finger millet idly is the same.

14.25 Foxtail Millet Onion Vada

Ingredients: Foxtail Millet: 1000 g, Black gram: 250 g, Baking soda: 5 g, Oil: 500 ml, Green Chillies: 10 g, Onion: 20 g

Preparation: Soak foxtail millet and black gram for 5-6 hours in water; grind it into a thick batter. Add little salt, green chillies, onion and baking soda to the batter. Heat oil in pan and make the batter into small vada and deep fry until they turn golden brown.

Note: Little millet and finger millet vada can also be prepared in the same way.

14.26 Foxtail Millet Upma:

Ingredients: Foxtail millet Ravva: 500 g, Oil: 50 g, Cumin and Mustard seeds: 5 grams, Green chillies: 10 g, Bengal gram: 50 g, Peanuts: 50 g, Curry Leaves: 1 bunch, Water: 1 Litre.

Preparation: Heat oil in a pan, add mustard, cumin seeds and fry for a while, now add groundnuts and bengal gram, fry them, add curry leaves, green chillies, onion and fry them all until they turn to brown. Add water and let it boil. To the boiling water add the ravva and cook on low flame until the ravva is cooked. Serve hot.

14.27 Foxtail Millet Dhosa:

Ingredients: Foxtail millet: 500 g, Blackgram dal: 250 g, Bengal gram dal: 10 g, Fenugreek seeds: 1 g, Oil: 250 ml, Salt: as required

Preparation: Clean black gram dhal and Bengal gram dhal. Soak in water for 4 hours separately. Soak foxtail millet in water for four hours with fenugreek seeds. Grind the dhals and the foxtail millet separately to fine batter. Mix all into a smooth batter, add salt and leave it to ferment overnight. Next day mix batter by adding water, just enough to get dhosa batter consistency. Heat a pan, smear a little oil, and spread a large scoop of batter on it evenly to make the dhosa. Serve hot with any pickle or chutney.

Note: Little Millet and finger millet dhosa can also be prepared in the same way. For mixed millet dhosa add all millets *i.e.* foxtail, finger millets, little millets and bajra to this recipe, remaining ingredients remain same.

14.28 Ragi Malt:

Ingredients: Ragi: 1000 g, Green gram: 500 g, Jowar: 500 g

Preparation: Wash and soak separately Ragi, Green gram and Jowar for 12 hours. Take clean cloth and put the grams in it and tie them, hang the cloth for two days until the grains are sprouted. (Please check them and sprinkle some water so that they sprout). The sprout has to be ½ inch long. Once this is done put them in a bowl and wash them until the sprouts are separated from the grains and dry them for two days. Take a pan and without oil fry the grains and grind them into powder.

ISBN: 978-81-19149-19-3

15. Emerging Trends and Current Scenario in Millet Processing

Yagini Tekam

Ph.D. Scholar
Department of Soil Science
College of Agriculture,
JNKVV, Jabalpur (Madhya Pradesh).

Deepak Singh

Ph.D. Scholar
Department of Horticulture
College of Agriculture,
JNKVV, Jabalpur (Madhya Pradesh).

Muskan Porwal

Ph.D. Scholar
Department of Agronomy
College of Agriculture,
JNKVV, Jabalpur (Madhya Pradesh).

Gaurav Singh Rathore

Ph.D. Scholar
Department of Biotechnology
College of Agriculture,
JNKVV, Jabalpur (Madhya Pradesh)

Abstract:

Millets are significant grain for the global food production and nutrition industry as well as considered an important food grain for balanced diet. They play a major role in food security owing to the ability to grow under diverse adverse agro-climatic conditions. Millets have recently received a lot of attention due to their remarkable nutritional profile and easiness of intake in any effective form. Also, they contribute to national food security as well as have health benefits. One of the richest natural food sources, millets are filled with enough minerals, vitamins, fibre, proteins, carbs, and fats might therefore act as a natural cure for the promotion of improved health. However, the consumption of millets requires processing and value addition so that large populations can benefit from ready-to-eat and ready-to-cook products. The processing of millets and the establishment of their complete value addition chain could give greater potential for the development of rural livelihoods and entrepreneurship. In industries for the large-scale commercial processing of millets, each of these unit operations soaking, dehulling, grinding, roasting, puffing, germination, fermentation, malting, etc. is well-established. This chapter highlights about the current scenario in processing of millets, the need of processing of millets, the effect of processing

of millets on chemical composition of millets, the initiatives taken by government in processing of millets. Millets may be more effectively used to support the countries where the prospect of poverty, starvation, and economic crises is ever-present because of their short growth season and ability to withstand dry and hot environments. Thus, the processing of millets into diverse products can improve their value and will certainly contribute to farmer's income and nation's economy.

Keywords:

Food security, Malnutrition, Millet processing, Puffing, Value addition.

15.1 Introduction:

Millets are widely distributed across the world. Millions of people who live in the dry and semi-arid tropics, Asia, Africa, and parts of Europe provide the majority of their nourishment. Little millets including finger millet, kodo millet, foxtail millet, proso millet, and tiny millet are produced in large quantities in India, which accounts for 20% of global output and 80% of that in Asia. Millets are chosen over other grains because they have a short life cycle, need little maintenance, and have resistance to abiotic and biotic stresses.

Promoting millets production and value addition helps achieve several of the Sustainable Development Goals (SDGs) (figure 15.1).

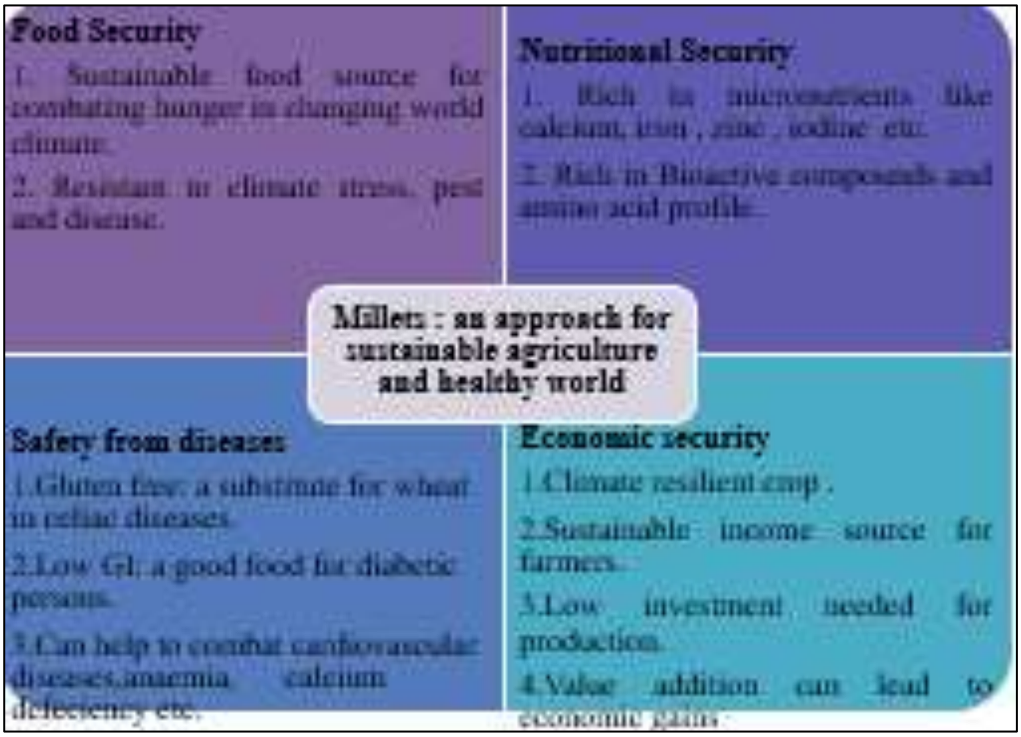


Figure 15.1: Strategy for sustainable agriculture and healthy environment: Millets

Millets have drawn attention recently because of their remarkable nutritional profile and ease of consumption in any appropriate form. Millets have a low glycaemic index and are a good source of protein, fibre, minerals, iron, and calcium. Millets may be made into a number of different types of value-added products due to their high nutritional and functional characteristics [1].

Millets are used as a staple meal only by traditional consumers, despite their high nutritional content because of the absence of consumer-friendly and ready-to-eat food goods is the primary reason [2].

Millets low-quality characteristics and their typical pre-consumption form, such as flours, have restricted their utilisation. These qualities include dark, lifeless colour, coarse, grittier texture, high fibre content, astringent flavour, prolonged cooking time, antinutritional ingredients, and a short shelf life. However, the maximum limitations could be removed by more effectively utilising the right processing technology. Millets are potentially beneficial material for many traditional farmers and ready-to-eat health meals when processed properly. A variety of products have been made from millets, including composite flours, popped, flaked, puffed, extruded, roller dried, fermented, and weaning meals. Probiotic fermentation and germination of some millets improved the protein composition and increased the availability of minerals [3].

Millets' nutritional value may be further enhanced by using appropriate and efficient processing techniques. Worldwide availability of millets has increased, which has speed up production, processing, and value addition. To produce high-quality millet goods, modern processing companies employ higher milling, grading, and sorting (colour sorter) machinery.

15.2 Need of Processing of Millets:

Processing refers to a variety of methods used to transform raw millet grains into edible forms with improved quality. Before eating, millets are often processed to eliminate the undesirable parts, lengthen the shelf life, and enhance the nutritional and sensory qualities. To make millets appropriate for food, primary processing methods such dehulling, soaking, germination, roasting, drying, polishing, and milling (size reduction) are used. At the same time, millet-based value-added processed food items are created using modern or secondary processing techniques such fermentation, parboiling, frying, puffing, popping, malting, baking, flaking, extrusion, etc. The digestibility and nutritional bioavailability are intended to be improved by these processing methods, although substantial amounts of nutrients are lost during further processing [4].

The rapid urbanization, increased rice and wheat production, poor government supplies, lack of processing facilities, low investments and remuneration, poor demand and supply chain are some of the primary causes of low millet production. however, in this modern era of development and technologies and health and environment threats due to climate change consumer preferences are changing which is shifting the preferences from rice-wheat to millet-based diet. The products made of millets has more remunerative values than the most of the commercial crops (rice, wheat and maize).

Thus, the processing of millets could make the farmers self-reliant and self-sufficient. The millet-based products having more value can also increase the economy of the farmers and nation as well.

Millets production gradually decreased during the green revolution as a consequence of the increasing production of staple grains like rice and wheat under conditions of intensive cultivation and irrigation. Millets are difficult to process and reliably prepare because of their usual grain shape and robust seed coat. The main obstacles facing value-added or ready-to-eat items Lack of public knowledge and suitable processing techniques prevent cereals from having a larger range of food applications and better economic position than other cereals. The tough, fibrous seed coating, the colourful pigments, and the poor storage quality of the processed goods are the main obstacles to millet's widespread usage [5].

However, apart from that, millets have anti-nutritional substances that are a major challenge to its use. In particular, the multivalent cations of calcium, iron, zinc, magnesium, and the monovalent cation of potassium phytic acid quickly form complexes with each of these lowering their bioavailability and reducing their absorption [6].

In addition to phytic acid, goitrogenic polyphenols may also have a role in various health problems. Epidemiological studies suggested that a diet with millet as a main meal, such that have seen in rural villages in Africa and Asia, contributes to the appearance of endemic goitre in these regions [7].

The bioavailability of minerals and carbohydrates is increased by technological advancements in processing (decortication, soaking, germination, fermentation, puffing, and boiling) that result in lower levels of anti-nutritional compounds like tannins and phenols. Thus, it is imperative to develop processing methods that are dependable as well as cost-effective in order to remove the challenges to the industrialization and use of millets flour for the manufacturing of products with added value.

15.3 Millet Processing by Using Machinery in Current Scenario:

Millets the yesterday’s coarse grains, today’s nutri-cereals, and tomorrow’s "superfoods" are abundant in minerals, phytochemicals, and other healthy substances for people. They are harvested manually or with the aid of a mechanised harvester-cum-thresher after the crop reaches the proper stage of maturity. Millet processing involved a series of post-harvest unit operations such as cleaning, drying, pre-treatment, decortication, polishing, grading and milling. The degree of moisture, type of variety, genotype, stage of maturity, location, agricultural techniques, and many other factors greatly affect how millets are processed.

Abrasive polishers and rubber roll shellers are typically used for millet decoration, which is a difficult operation. The increased demand for millets has encouraged improvements in production, processing, and value addition.

Small millet grains could be processed using main processing methods to create a wide range of foods that are edible, including flour, sprouts, salty ready-to-eat items, flaked, popped, porridge and fermented products.

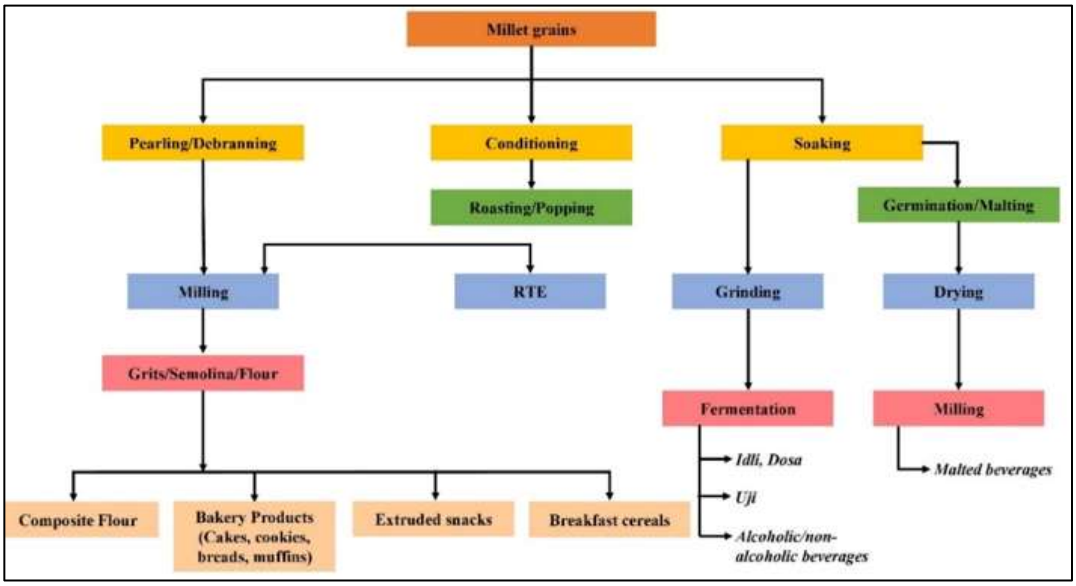


Figure 15.2: Schematic Diagram for Developing Millet Based Composite Foods

15.3.1 Grading:

The grader is used to separate millet grains from inert materials such as big stones, sticks, sand, grass and so on. To separate them, sieves of different sizes are used. The most common grader is a triple-deck grader with three sieves.

Large sticks, stones, and grasses are separated by the top sieve, good millet grains are separated by the middle sieve, and fine and coarse sand is separated by the bottom sieve. Dust and light particles are sent to the rear of the aspirator by a little fan. It is important to select the appropriate sieve size, and the operator must make sure the sieve's openings are not clogged. Brush should be used by the machine operator to prevent material clogging.

15.3.2 Destoner/Destoning:

The Destoner, which removes small stones and mud balls which are identical in size as the millet grains and destoner receives the material from the Grader. Destoner utilise the gravity concept to work.

Two sieves beneath the hopper of a destoner are used to grade the output material. The destoner bed receives the graded material, which is deposited with the lighter material falling to the front and the heavier material to the rear.

The air adjustment hole may need to be carefully adjusted according to material. If there is no flow backward, we should open the slot and make modifications to allow the stones to flow backward. Destoner can be used to remove stones and other impurities from a variety of millets, including small millet, kodo millet, barnyard millet, proso millet, finger millet, and foxtail millet.

15.3.3 Dehulling:

Dehulling or dehusking of the millet crop is an important step in the post-harvest processing because it eliminates the outer, inedible layer (pericarp and testa) and makes the grains suitable for milling and consumption. Dehulling removes the pericarp (bran), which is high in fibre and anti-nutritional elements, and the testa, which promotes the digestion of the grains. The production of millet-based items is made easier by immediately milling the dehulled millet grain into flour. Dehulling is one of the crucial processing stages done to remove the husk from millets. The non-edible parts of millets are removed during dehulling, which also increase the bioavailability of the nutrients present, and decrease the amount of anti-nutritional components and increase consumer acceptability. For various kinds of millets, several decorticators and pearlers, dehullers are available.

A. Dehuller-Cum-Aspirator: Raw materials are transferred to the huller for husk removal after being properly cleaned. Nevertheless, depending on the millet type and hull hardness, several dehulling techniques may be used. For example, foxtail millet is dehulled using an abrasive process while being rolled from one side to the other by a large boulder-like stone [8]. There are two categories for dehullers under millet processing technologies that are centrifugal dehullers and abrasive dehuller.

- ***Centrifugal Dehullers:*** An impeller on a centrifugal dehuller removes the husk. The material is sent to the hopper, which sends it to the impeller, where it is flung into the impeller casing with a lot of centrifugal force. The millet grain separates from the husk as a result of the forceful impact and is then delivered to the aspirator, where the lighter husk is gathered at the back and the millet is gathered at the front.
- ***Abrasive Dehuller:*** Rubber rollers and Emery abrasives are the two categories into which they are classified. Both are working in abrasion principle. With the Emery type, there are two grinding stones. When the other stone rotates continuously, the first stone stays motionless. When using a roller mill, the pearling process typically involves passing the grain between a pair of steel rollers that are revolving inside a cylindrical chamber at equal or differing speeds in a cocurrent manner.

15.3.4 Soaking:

In order to eliminate potentially harmful chemicals and other substances from food, soaking is a safe method of processing. Soaking grains is a common method for increasing the bioavailability of minerals and lowering the amount of substances which are harmful for nutrition, such as phytic acid because phytic acid prevents the absorption of nutrients and minerals including calcium, iron, and zinc from diet. Phytase binds to minerals and nutrients, which makes it difficult for the stomach to absorb them Moreover, the human body cannot metabolise them. Soaking has an impact on the breakdown and leaching of substances like phytates, modifications in phytase activity and concentration of minerals like iron, zinc, etc.

When dehulled and milled grains were soaked, it was observed that the loss caused by this leaching is more severe. In contrast, a large proportion of nutritious constituents were seen to be leached from grains after they had been cooked by soaking them in water.

15.3.5 Grinding:

One of the beneficial unit operations for the secondary processing of millets is grinding. When being ground, the millet grains actually become smaller. The key features of the grinding process are particle size and fineness modulus. Based on the products, different types of particle sizes are chosen. The millets should be ground in a type of mills, including burr mills, hammer mills and attrition mills. For preserving the final size of output particles in the ground sample, such as flour, every grinding machine has a specific form of adjustment. The shelf life of millet is drastically shortened after grinding. Rancidity in millet flour is caused by an increase in free fatty acids (FFA), which is the main cause of shortened shelf life. The millets should be ground in a variety of mills, including burr mills, hammer mills and attrition mills and pulverizer.

15.3.6 Pulverize:

The most recent innovation for new flour mill entrepreneurs is the pulverizer because it requires no maintenance compared to traditional flour mills and can be installed with simply a plug and play setup. Pulverizing or grinding millets into powder to be utilized for making flour for human consumption and it is the secondary process for millets processing. Two chambers are used in double stage pulverizers for the purpose of grinding. Initial crushing takes place in the first chamber. Moreover, millets like jowar and bajra that have been partly ground are utilised as animal feed and the next chamber, grains are processed into a fine powder. Hence the functionality of pulverizer machine plays an important role and the pulveriser machine are suitable for all types of millets.

15.3.7 Sprouting:

Sprouting is the germination of grains under controlled conditions. The dormant embryo in the millet grain becomes active during sprouting under specific climatic and moisture conditions (temperature and humidity). The millets germinate about 48 to 72 hours at a temperature of 25 to 30º C. Sprouting millets significantly improve the availability of the vitamins and minerals present in them while significantly reducing the amount of tannin and phytic acid, which are anti-nutritional compounds. The dry weight of the source grain decreased after sprouting for longer than 48 hours with little to no nutritional benefit [9]. To maintain the necessary nutrition in sprouted millets, the process temperature and duration must be properly regulated. Millets were traditionally sprouted in atmospheric chambers, but presently there are specialised grain sprouters that provide the capacity of adjusting microclimate, such as the source of light, illumination, wavelength etc., to obtain a quality product with proper safety and storage stability.

15.3.8 Roasting:

A conductive heat medium is utilized in this traditional technique to expose millet grains with the proper quantity of moisture content to high temperatures (between 160 and 200°C) for varying times. By pre-soaking and shade drying, the necessary moisture in the grain is preserved. It is simpler to separate the husk from the cotyledon when the cotyledons of the grain that are roasted during the roasting process shrink more than the outer husk and form a gap between them. Husk removal during dehusking or pearling is made easier by this husk loosening. Also, by removing undesirable anti-nutritional and harmful components from millets, this heat treatment successfully provides a distinctive flavour. Different types of roasters specifically designed for millets are available depending on their mode of heat transfer operation. The performance of roasting equipment based on the conduction heating principle as better in terms of roasting strength and quality of the product. Nowadays, equipments which is equipped with suitable instrumentation for precise control of operating parameters (time, temperature) are trendy due to the uniform output quality and flexibility to utilise various types of commodities.

15.3.9 Puffing:

Puffing is a processing technique utilized to produce enlarged snacks and other items from any type of grain that are ready to eat. The millets were pre-soaked at the correct moisture content and subjected to hot sand in a ratio of 1:6 at high temperature (230-250 C) and brief duration for the process of popping or expansion (20–30s). When raw millet grains were heated to high temperatures and short time duration to create the appropriate enlarged shape, popping of the decorticated finger millet was relatively prevalent among millets Raw grains need to be flattened to the desired shape and kept at the desired moisture content before being exposed to a heating environment in order to achieve the highest expansion ratio [10].

The expansion properties of the grains are significantly improved by this popping process, in addition to their physical form and functional qualities. Moreover, the millet grains' availability of several anti-nutritional substances are reduced significantly [11].

Due to its puffing, the millet grains' physical and textural properties also undergo substantial transformation. According to their expansion and puffing abilities, common millets like sorghum, pearl millet, and finger millet are commonly utilized for puffing. Among Asian nations, puffing is a typical practise not just for millet but also for grains like maize, chickpeas, horse gram etc.

The equipment or machine required for puffing differs from a traditional individual home level system to a large industrial level system with varied capacity. These days, popping guns that use hot air are widely used because of their compact size, light weight, robust design, and desired output for domestic usage.

15.3.10 Malting:

The nutritional value, sensory qualities, and digestibility of millet grains are improved throughout the malting process, along with a substantial decrease in antinutrients, when processing conditions are appropriate. The process consists of three steps that are completed in the following order: (1) steeping (dipping grains in water), (2) germination (promoting the rise of sprouts and enzymatic activity), and (3) kilning (grain drying and stopping the enzymatic activity). The three processes might be carried out in separate equipment or in a single integrated system. These days, an integrated single system is highly common since it is quick, simple, and cost effective for manufacture. To maintain a uniform layer thickness in the integrated single malting unit, the grains are spread out on grain holding sieves [12].

The water spraying systems constructed at the top provide the water required for the grains to soak. Throughout the steeping process, this soaking water is changed three to four times through opening the bottom valve, which also allows freshwater to aerate the soaked grains. The bottom valve is opened to let all the water out after the steeping process is complete, and the grain is then left to germinate on sieves.

After the germination process is complete, the side valve is opened for the last malting step, or drying. Hot air of the proper temperature comes from the side and travels through the sieves so that it distributes evenly across all sieves and the grain is dried. We obtain malt following the removal of sieves from the apparatus. Malt is obtained once sieves are removed from the apparatus.

15.3.11 Fermentation:

One of the oldest methods of food preservation, that has been practised for ages is fermentation. Millets are used to make a number of traditional dishes across the world. The physiochemical properties of millet grains and the final fermented product are significantly altered during the fermentation process.

The fermentation process has a number of benefits, including a decrease in antinutrients, an increase in protein availability, enhanced protein digestibility, and an overall improvement in nutritional profile. There was a noticeable decrease in the proportion of anti-nutritional elements in pearl millet grains after fermentation [13].

This method also significantly increased the amount of starch and protein that was available for processing at the same time. Although some specific flavonoids and past behaviour were discovered to diminish after the fermentation of millet grain, some vitamins were also found to rise in addition to the amino acids [14].

Due to certain fermentation circumstances for a particular type of millet, some nutrients were found to be increasing at the same time as others were reported to be decreasing. During the pearl millet grain fermentation, observable changes in the macronutrients such as fibre, protein, and fat as well as the micronutrients such as Mg, Fe, K, Cu, Na, Mn and Zn were noticed. When some of the millets were fermenting, particularly after 16 hours, an increase in amount of crude proteins and crude fibres was being noted. Phytic acid was shown to decrease and zinc availability to rise during the finger millet's 24-hour fermentation [15].

According to the properties of the raw material and the desired processing of foods product, the suitable microbe’s population for the processing of different types of millets may be chosen [16]. The literature claims that millet-based end products with high nutritional value may be produced using fermentation separately or in conjunction with other methods. Moreover, only a small number of unique millet products have been developed using these processes on a large scale, and the majority of them are used in households to create traditional foods. Thus, for industrial manufacture of thus products, the establishment of present technology and careful optimisation of mechanical and physical properties are vital and essential.

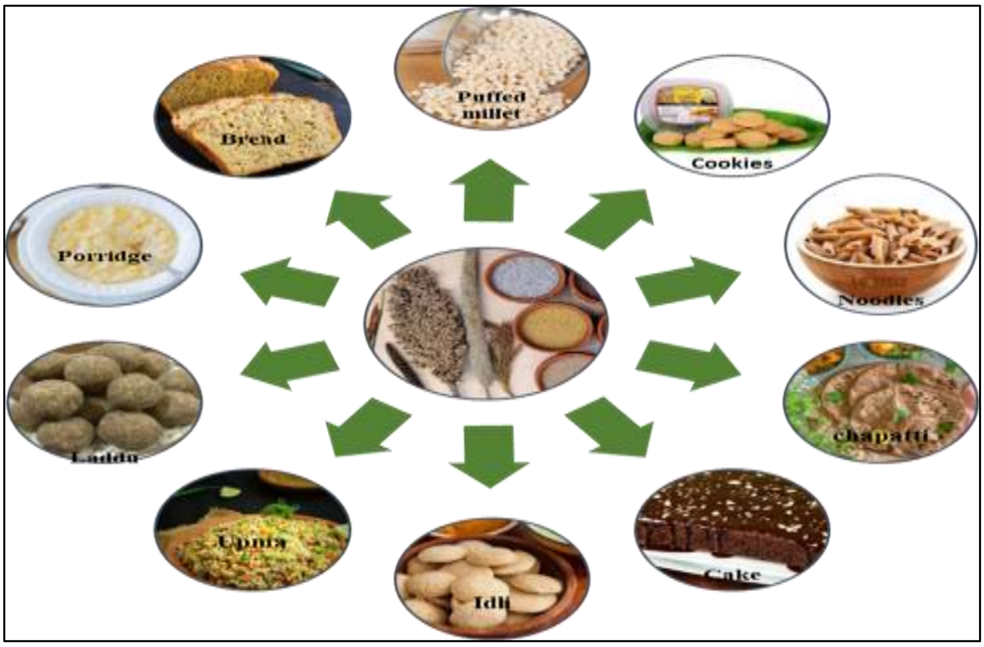


Figure 15.3: Diverse Millet-Based Food Products

15.3.12 Flaking:

One of the special food products of millets is flaked millets. Millets need a particular machine for processing, such as flaking, because they have different physical features than the primary cereals like rice and wheat. Up until now, millets have been flaked using rice flaking machines; however, millets have not been given their own unique design. Flaking machine developed by CIAE is a small machine that presses conditioned millet between two textured stainless-steel rollers is powered by a 2 hp single phase electric motor to produce millet flakes. It is appropriate for use with various sizes of millets/cereals and other food/feed products to produce flakes of varying thickness due to the movable spacing between the rollers. The mounted acrylic inspection window facilitates machine maintenance and operation monitoring. For safe food manufacturing, all machine parts that come into touch with food products are constructed of food grade 304 stainless steel. The machine can produce 100 kilogramme per hour.

15.4 Effect of Processing on Nutritional Properties of Millets:

Proteins- Millets are a popular food among vegans and are a great source of protein. They are regarded as a superior plant protein and contain fewer saturated fats than animal proteins. Reducing the quantity of antinutrients is crucial since their presence prevents protein digestion. Dehulling, grinding, soaking, and heating are easy methods that reduce antinutrient levels and improve in vitro protein digestibility. Foxtail millet's protein quality was increased by fermentation, germination (for 40 hours at 25 degrees Celsius), popping, and alkaline cooking. Kodo millet was puffed or "popped," which raised the protein percentage from 7.92 to 8.12% [17].

The protein content of pearl millet may be greatly increased by spontaneous fermentation [18]. Due to the microflora's production of proteolytic enzymes, antinutritional components like phytate are broken down during fermentation and the insoluble protein is transformed to soluble protein [19]. Due to the mobilization of stored nitrogen, the straightforward method of soaking pearl millet for 24 hours led to an increase in protein [20].

Decortication reduces the considerable loss of proteins and amino acids like histidine, lysine, and arginine by removing around 12% to 30% of the outer husk, bran, and germ component of grains.

Carbohydrates- The millets' carbohydrate contents range from 60 to 75 percent, with small millet having the highest carbohydrate content and foxtail millet having the lowest. Like other cereals, the main source of carbohydrates in millets is starch. Several home processing and cooking techniques, like as soaking, sprouting, pressure cooking, autoclaving, and others, have an impact on the amount of readily accessible carbohydrates in dietary grains. Parboiling considerably reduced the total starch by 5–10% as a result of starch leaching out during the soaking and boiling processes, according to a thorough research [21] on the starch digestibility of pearl and proso millet. In addition, they noted that parboiled proso and pearl millet had a lower readily digested starch percentage (18.2-19.1% to 17.4-18.3%), resulting in a 1.6-3.9% lower glycemic index. According to these findings, parboiling can considerably decrease the starch's ability to be digested, which makes it a useful technique for creating products to treat metabolic illnesses like diabetes and obesity.

Dietary Fiber- Dietary fibre is classified as complex polysaccharides that are not easily accessible, and the millet bran fraction is a significant and plentiful source of this type of fibre. Thus, the fibre component is significantly reduced as a result of the removal of the bran portion during decortication and dehulling. According to a research, millet grains may be dehulled between 12% and 30% to remove the kernel without suffering a major loss in fibre. Dehulling grains more than 30%, however, causes a significant loss of nutritional fibre [22]. Controlling the amount of dehulling in order to increase the fibre content is crucial because the majority of millets are ingested in their decorticated condition. While high temperature extrusion methods result in the thermal destruction of dietary fibre, dehulling and milling (debranning) activities diminish dietary fibre. Dietary fibre is essential for lowering type 2 diabetes and constipation, especially the fibre found in the outer bran layer. It is crucial to educate customers to choose entire (unpolished) millets and their byproducts for a healthy millet diet and to dissuade millers from polishing millets.

Minerals- Millets are a rich source of vitamins that are mostly deposited in the aleurone, germ, and pericarp, as well as minerals including K, Mg, Fe, Ca, and Zn [23]. Prior to cooking, soaking millet grains helps to minimise antinutrients and increases the bioavailability of minerals. Minerals may have leached into the soaking water as evidenced by the lower Zn and Fe content of millet grains after being soaked in water [24]. The "in vitro solubility" of minerals like Fe and Zn increases by 2-23% when millet grains are soaked. The bioavailability of the millet grains significantly increased and phytic acid levels were decreased when they were soaked in hot water (45 to 65 °C, pH 5–6) [25]. The antinutrients, which prevent mineral bioavailability by forming complexes, are lessened during the decortication process. The bioavailability of minerals improves as antinutrient levels are reduced.

Vitamins- As the bran and germ components of refined millet flour are removed, vitamins are lost, which results in a lower nutritional value of polished/debranned millets. Regarding the amount of vitamins and other elements, such as lipids, proteins, and minerals, millets are regarded as being superior to wheat, sorghum, and maize. In the aleurone, germ, and pericarp, vitamins and minerals naturally accumulate. Vitamins including riboflavin, thiamine, niacin, and folic acid are abundant in millet grains [26]. A 67% decrease in vitamin E was seen in little millet that had decortication [27]. The milling process alters the millet grains' bran, which lowers the amount of vitamins that have mostly gathered there. The bulk of vitamins are concentrated in the outer layer of millets, hence research on milling or dehulling imply that vitamins are lost during these processing activities. By germinating the millets and creating byproducts from germinated millets, the availability of essential vitamins can be increased. *Fats*- Fats are important for the body to absorb and transport the vitamins A, D, E, and K as well as to produce calories and the development of the brain. The amount of fat depends on the germination period. In contrast to the non-germinated sample, the raw and optimized flour of germinated foxtail millet exhibited fat contents of 4.4% and 3.6%, respectively. This is because the decline occurs after germination since the fat is utilized as an energy source during the germination process [28]. The investigations offer significant proof of fat denaturation or degradation during high temperature processing (cooking and popping), as well as fat content reduction during milling, malting, and fermentation procedures. Manufacturers may find that using straightforward processing methods like soaking, germination, and malting will enable them to create millets-based low-fat food items. The high temperature processing would diminish the flavor and taste of the processed meals and harm the fat quality.

15.5 Initiatives Taken by Government of India for Production and Processing of Millets:

In India, there are several Organizations and government programs in place to increase the area, output, and productivity of millets farming.

- millets were designated as nutri-cereals by the government in April 2018 because of their nutritious content.
- As part of the National Food Security Mission (NFSM)-Nutri Cereals Sub Mission, the government is educating farmers about nutri cereals (millets) such ragi, sorghum, bajra, and micro millets through demonstrations and training.
- Incentives are given to farmers through the state governments under NFSM-Nutri Cereals for crop production and protection technologies, cropping system-based demonstrations, production and distribution of seeds for recently released varieties and hybrids, Integrated Nutrient and Pest Management techniques, improved farm implements/tools/resource conservation machinery, water saving devices, etc. The creation of Farmer Producer Organizations (FPOs) for Nutri Cereals, Centers of Excellence (CoE), and Nutri Cereals seed hubs are just a few of the efforts in which the NFSM has been instrumental.
- The Government is making people aware of nutri-cereals by funding for Research & Development. Also, support is provided to startups and entrepreneurs that create recipes and value-added items that encourage the use of millets. During 2018 up till the present, eight bio-fortified Bajra types and hybrids have been made available for cultivation.

- Under the All India Coordinated Research Project (AICRP) on small millets, sorghum, and pearl millet, the Indian Council of Agricultural Research (ICAR) supports 45 collaborating Centers located in various State Agricultural Universities (SAUs) and ICAR Institutes for the development of new varieties and hybrids of millets.
- A Memorandum of Understanding (MoU) was signed by ICAR-Indian Institute of Millet Research (ICAR-IIMR) and Agricultural and Processed Food Products Export Development Authority (APEDA) to increase exports through quality production and processing, which is expected to increase value addition and farmers' income. The primary objective of the Agreement is to promote the commercial cultivation of export-oriented processable varieties developed by ICAR-IIMR, which is anticipated to boost millets production and add value. The Agreement also encourages the development of links between farmer-producer associations and farmers' markets.
- To market millets and millet value-added products, APEDA is preparing programmes for the UAE, Indonesia, USA, Japan, UK, Germany, Australia, Republic of Korea, South Africa, and Saudi Arabia. The promotion campaign will include BuyerSeller Meetings, Road Shows, and participation in key international events to promote millets and value-added products of millets.
- On December 20, 2021, The United Nations World Food Program (WFP) and NITI Aayog signed a Statement of Intent (SoI), By utilising the potential of 2023 as an International Year of Millets, the cooperation is focused on mainstreaming millets and aiding India in taking the lead globally in knowledge exchange. With a strategic and technical cooperation between NITI Aayog and WFP, the Project's main objective is to build climate resilient agriculture for increased food and nutrition security in India.
- The Department of Agriculture & Farmers Welfare also provides aid to the States for a number of extension initiatives and agricultural breakthroughs that might help develop millet farming through a centrally funded programme called "Support to State Extension Programme for Extension Reforms." Moreover, the States can encourage millets under the Rashtriya Krishi Vikas Yojana (RKVY), Paramparagat Krishi Vikas Yojana (PKVY), and Mission Organic Value Chain Development for North Eastern Region (MOVCDNER).

15.5.1 Manufacturers of Millet Processing Technologies in India:

- Perfura Technologies (India) Pvt. Ltd
- Small Millet Foundation (Division of DHAN Foundation)
- AVM Engineering Industries
- Agromech Engineers
- KMS Industries
- Borne Technologies Private Ltd.

15.7 Conclusion

Millets the foods of twentieth century are given prime importance in this era of climate change. These are the foods with enormous amounts of nutrients, requiring minimal resources for cultivation and generating higher returns through the proper processing and marketing. Their antinutritional substances, off flavours and off tastes are all minimized when the proper processing method and instruments are used.

This transformation enhances the nutritional value of these smart foods while also allows farmers to improve their agricultural income. The development of millets' processing technology provides possibilities and will help millets become a more competitive source of staple food. Millet-based products with added value can support the economically poor masses and fight hidden hunger. There is still a need to concentrate on improving the processing methods for minor millets to make them more palatable without sacrificing the health advantages, given the variety of the influence of processing on the nutritional characteristics of millets. Also, in order to fight food poverty and malnutrition, information must be spread at the commercial and household levels about how processing affects the nutritional value and health advantages of millets.

15.8 References

1. Veena B (2003) Nutritional, functional and utilization studies on barnyard millet. MSc Thesis, University of Agricultural Sciences, Dharwad (Karnataka), India
2. Hulse JH, Laing EM, Pearson OE (1980) Sorghum and the millets: their composition and nutritive value. Academic press
3. Jaybhaye, Raghunath & Srivastav, Prem. (2015). Development of barnyard millet ready-to-eat snack food: Part II. FOOD SCIENCE RESEARCH JOURNAL.6.285-291.
4. Nazni S, Devi S (2016) Effect of processing on the characteristics changes in barnyard and foxtail millet. *Journal of Food Processing*. Technol., 7, 1–9.
5. Rao, B. Dayakar; Kulkarni, Dhanashri B.; C., Kavitha (2016). Study on evaluation of starch, dietary fiber and mineral composition of cookies developed from 12 sorghum cultivars. *Food Chemistry, S030881461632091X*
6. Raboy, V. (2009). Approaches and challenges to engineering seed phytate and total phosphorus. *Plant Sci.*177, 281-296
7. Boncompagni, Eleonora; Orozco-Arroyo, Gregorio; Cominelli, Eleonora; Gangashetty, Prakash Irappa; Grando, Stefania; Kwaku Zu, Theophilus Tenutse; Daminati, Maria Gloria; Nielsen, Erik; Sparvoli, Francesca; Kashkush, Khalil (2018). Antinutritional factors in pearl millet grains: Phytate and goitrogens content variability and molecular characterization of genes involved in their pathways. *PLOS ONE, 13(6)*
8. Pushpamma, P. (1993) Sorghum as Food in the Semi-Arid Tropics: Studies on the Dryland Communities of Andra Pradesh, India, IDRC, Ottawa.
9. Maatouk Khoukhi, Abeer Dar Saleh, Ameera F. Mohammad, Ahmed Hassan, Shaimaa Abdelbaqi (2022) Thermal performance and statistical analysis of a new bio-based insulation material produced using grain puffing technique, Construction and Building Materials, Volume 345, 128311, ISSN 0950-0618.
10. Sreerama YN, Sasikala VB, Pratape VM (2008) Nutritional implications and flour functionality of popped/expanded horse gram. Food Chem 108:891–899
11. Mbithi-Mwikya S, Van Camp J, Yiru Y, Huyghebaert A (2000) Nutrient and antinutrient changes in finger millet (Eleusine coracan) during sprouting. LWT-Food Sci Technol 33(1):9–14
12. Kumar S, Singh A, Kohli D, Mishra R (2016) Fabrication of integrated malting unit for production of malts. Int J Eng Res Appl 6(8):33–36.

A. Hassan AB, Ahmed IAM, Osman NM, Eltayeb MM, Osman GA, Babiker EE (2006) Effect of processing treatments followed by fermentation on protein content and digestibility of pearl millet (*Pennisetum typhoideum*) cultivars. Pak J Nutr 5(1):86–89.

13. Akingbala JO, Uzo-Peters PI, Jaiyeoba CN, Baccus-Taylor GSHP (2002) Changes in the physical and biochemical properties of pearl millet (*Pennisetum americanum*) on conversion to ogi. *J Sci Food Agric* 82:1458–1464.
14. Murali A, Kapoor R (2003) Effect of natural and pure culture fermentation of finger millet on zinc availability as predicted from HCI extractability and molar ratios. J Food Sci Technol 40(1):112–114.
15. Khetarpaul N, Chauhan BM (1991) Biological utilisation of pearl millet flour fermented with yeasts and lactobacilli. *Plant Foods Hum Nutr* 41:309–319.
16. Jaybhaye RV, Pardeshi IL, Vengaiah PC, Srivastav PP (2014) Processing and technology for millet based food products: A review nutrient composition of millets. *Journal of Ready to Eat Food*., 1, 32–48.
17. Chinenye OE, Ayodeji OA, Baba AJ (2017) Effect of fermentation (Natural and Starter) on the physicochemical, anti-nutritional and proximate composition of pearl millet used for flour production. *American Journal of Bioscience and Bioengineering.*, 5, 12–16.
18. Rani M, Amane D, Ananthanarayan L (2019) Impact of partial replacement of rice with other selected cereals on idli batter fermentation and idli characteristics. *Journal of Food Science and Technology*., 56, 1192–1201.
19. Iyabo OO, Ibiyinka O, Abimbola Deola O (2018) Comparative study of nutritional, functional and antinutritional properties of white sorghum bicolor (Sorghum) and pennisetum glaucum (Pearl Millet). *International Journal of Engineering Technology and Management Research.*, 5, 151–158.
20. Bora P, Ragaee S, Marcone M (2019) Characterisation of several types of millets as functional food ingredients. *International Journal of Food Science and Nutrition*., 70, 714–724.
21. Yousaf L, Hou D, Liaqat H, Shen Q (2021) Millet: A review of its nutritional and functional changes during processing. *Food Research International*., 142, 110197.
22. Rao DB, Malleshi NG, Annor GA, Patil JV (2017) Nutritional and health benefits of millets. In Millets Value Chain for Nutritional Security: A Replicable Success Model from India; Indian Institute of Millets Research (IIMR): Hyderabad, India, p. 112.
23. Bindra D, Manju D. (2019) Formulation and evaluation of foods from composite flour blends of sorghum, pearl millet and whole wheat for suitability in diabetic diet. *International Journal of Home Science*., 5, 220–229.
24. Ertop M, Bekta¸SM, (2018) Enhancement of bioavailable micronutrients and reduction of antinutrients in foods with some processes. *Food Health*., 4, 159–165.
25. Shahidi, F.; Chandrasekara, A. Processing of millet grains and effects on non-nutrient antioxidant compounds. In Processing and Impact on Active Components in Food; Academic Press: Cambridge, MA, USA, 2015; pp. 345–352.
26. Kamatar MY, Kundgol NG, Math KK (2013) Impact of decortication on chemical composition, antioxidant content and antioxidant activity of little millet landraces. *International Journal of Engineering Research and Technology*., 2, 1705–1720.
27. Sharma S, Saxena DC, Riar CS (2015) Antioxidant activity, total phenolics, flavonoids and antinutritional characteristics of germinated foxtail millet (Setaria italica). *Cogent Food and Agriculture*., 1, 1081728.

ISBN: 978-81-19149-19-3

16. Global Status and Constraints in Millet Production

Nikhil

School of Agricultural Economics and Horti-business Management, SKUAST Kashmir.

Suraj Kumar

Division of Soil Science
SKUAST Kashmir.

Abid Sultan, Kusumakar Gautam

School of Agricultural Economics and Horti-business Management, SKUAST Kashmir.

16.1 Introduction:

Millets also called small millets are cultivated for their small kernels which are the products of small grassy plants belonging to the Poaceae family. The other name minor millets may indicate them to be minor crops yet are important for their nutritional values, medicinal benefits, feed for animals, and saviours during food crisis (Joshi and Agnihotri 1984; Yenagi et al. 2010). The word "millet" has originated from the French word "Mile" meaning thousand which implies a handful of millets contain thousands of grains. Millets are often grown in semi-arid conditions with very less rainfall and marginal or degraded lands with very low nutrient contents. The crops support the livelihood of people in areas where famine is a regular phenomenon and the millets yield a more dependable harvest compared to other crops in low rainfall areas. Millets are C4 plants with very superior photosynthetic efficiency, short duration, higher dry matter production capacity, and a high degree of tolerance to heat and drought. They also easily adapt to degraded saline, acidic and aluminium toxic soils (Yadav and Rai 2013). Small millets are an excellent choice for promoting healthy eating in modern society due to their rich nutrient content.

Finger millet, in particular, stands out with its remarkably high calcium content, surpassing 350 mg per 100 g. Foxtail millet, barnyard millet, and proso millet are abundant sources of protein, containing over 10% protein content. Little millet and foxtail millet are also noteworthy for their healthy fat content, with more than 4.0% fat. Additionally, foxtail millet, barnyard millet, and little millet are superior sources of crude fiber, ranging from 6.7% to 13.6%. Barnyard millet and little millet are also rich in iron, containing between 9.3 mg to 18.6 mg per 100 g, which is higher than other major cereals such as rice, wheat, barley, maize, and sorghum. These findings are supported by studies conducted by (Dwivedi et al. in 2012; Kam et al. in 2016). The growing demand for millets in both national and international markets has spurred the interest of researchers in collecting, conserving, and utilizing the global germplasm available for these important crops. This has led to efforts in crop improvement, development of genomic resources, and value addition in millets.

Moreover, the involvement of private organizations in value addition and marketing of millets has further boosted their cultivation and consumption. In this process, governments have a crucial role to play by formulating appropriate policies to incentivize millet cultivation, marketing, and consumption.

These policies can help achieve food and nutritional security by promoting the production and consumption of millets, which are rich in essential nutrients. Such policies may include providing financial incentives to farmers for millet cultivation, establishing marketing chains and infrastructure for millet products, and creating awareness among consumers about the health benefits of millets. Government support can also facilitate research and development in millet agriculture and help in the conservation of genetic diversity in millet crops.

There are no less than 14 species of millets belonging to 10 genera, that include pearl millet (Pennisetum glaucum L.), foxtail millet (Setaria italica L. subsp. italica), Finger millet (Eleusine coracana L.), barnyard millet (Echinocloa esculenta A. and Echinocloa colona L.), proso millet (Panicum miliaceum L. subsp. miliaceum), kodo millet (Paspalum scrobiculatum L.), and little millet (Panicumsumatrense Roth.) that are cultivated widely throughout the world.

A. **Pearl millet (Pennisetum glaucum L.)**: Bajra or Pearl millet is estimated to be originated as early as 5000 years in Africa (Andrews and Kumar 1992) and was introduced to the Indian subcontinent around 3000 years ago. The crop is well adapted to adverse environmental conditions with rainfall less than 250 mm and temperature of 30 _C and above and mainly grown by subsistence farmers throughout Africa, Asia, and Australia. Recently the crop is gaining importance as a commercial crop in Australia and accounts for almost half of the world's area under millets (National Research Council 1996).
B. **Proso millet (Panicum miliaceum L. subsp. miliaceum):** Broom millet or Proso millet has probably originated in Manchurian region of China (House 1995) and presently cultivated in northwest China, southern and central parts of India, Australia, the USA, and Europe. It is the third most important millet crop cultivated after pearl millet and foxtail millet and it is well adapted to temperate climatic conditions up to altitudes of 3500 m and various soil types
C. (Baltensperger 2002).
D. **Finger millet (Eleusine coracana L.):** The ear heads of the crop resemble finger of human hand thus giving it the name. The probable origin of Ragi or Finger millet is highlands of Ethiopia and Uganda (National Research Council 1996). Asia and Africa are major centers of production and India is the leading producer in the world. The crop is adapted to tropical climates with an intermediate altitude (500–2400 m) and low to moderate rainfall (500–1000 mm). The crop can thrive under dry and hot conditions up to 35 _C in well-drained soils. The grains of finger millet can be stored for up to 50 years thus serving as a good reserve against famine (National Research Council 1996).
E. Barnyard Millet or Sawa millet (Echinocloa esculenta A. and Echinocloa colona L.): The Barnyard millet or Japanese millet has originated in Japan province, whereas sawa millet was domesticated in the Indian subcontinent (House 1995). Both millets belong to the same genus and their morphology is similar. The crops prefer warm climatic conditions but can be cultivated in cold temperatures too. The cultivation of

barnyard millet is mainly taken up in Japan, China, Korea, and India and the crop is known for its good storability.

F. **Kodo Millet (Paspalum scrobiculatum L.):** or Ditch millet is known to be domesticated 3000 years ago and is indigenous to India (House 1995). Kodo millet is majorly produced in India and the production accounts for 90% of total world production (Hedge and Chandra 2005). Although kodo millet is well adapted to tropical and sub-tropical climatic conditions, the crop takes 120–180 days to mature and the grain yields are very low (250–1000 kg/ha).

G. **Little millet (Panicum sumatrense Roth.):** Eastern Ghats of India are known to be the place of domestication of little millet as early as 2000 years ago and the crop is majorly cultivated in peninsular Indian states like Andhra Pradesh, Karnataka, Tamil Nadu, and Kerala. The crop is adapted to both dry and humid conditions and can be cultivated in drought-prone areas as well as water-logged conditions, as the crop matures early and withstands adverse conditions. The genetic diversity of this crop is very little because of its restricted cultivation in India, Sri Lanka, Nepal, and Myanmar, with India accounting for more than 98% of the area and production of little millet.

16.2 Global Scenario of Millets Cultivation:

Millets are a critical staple food source in the developing world, particularly in the drylands of Africa and Asia. Many millet varieties are indigenous to Africa and have been domesticated in other parts of the world. Currently, millets are cultivated in 93 countries, but only 7 countries have millet acreage exceeding 1 million hectares. Remarkably, over 97% of millet production and consumption occurs in developing nations. However, there has been a concerning trend in millet cultivation. From 1961 to 2018, there has been a decline of around 25.71% in the global area under millet cultivation across continents. This decline has been observed in most parts of the world, with the exception of Africa where millet production has shown an upward trend. Despite the decrease in millet cultivation area, there has been an increase in millet productivity globally.

From 1961 to 2018, millet productivity has risen by 36%, with the average yield increasing from 575 kg/ha to 900 kg/ha. This increase in productivity can be attributed to various factors, including improved farming practices, enhanced seed quality, and technological advancements. Africa has been a notable exception to the declining trend, with millet production expanding in the continent. This could be due to the fact that millets are well-adapted to the dryland regions of Africa and are an integral part of local diets and food systems. Additionally, efforts by local farmers, governments, and organizations to promote millet cultivation and utilization, as well as the recognition of millets' nutritional and ecological benefits, have contributed to the positive trend in Africa. In West Africa, millet cultivation has seen the highest increment, nearly doubling from the levels recorded in the 1960s. In Asia, although the area under millet cultivation has declined, the production trend has shown a gradual increase, leading to improved productivity.

In India, millet production peaked during the 1980s but has since decreased gradually due to a sharp reduction in cultivated area. Despite this, India remains the largest producer of millets, accounting for 37.5% of the total global output, followed by Sudan and Nigeria. In terms of millet trade, the years 2011-2017 saw the highest global import and export values recorded, with imports totalling 155.26 million US$ and exports reaching 127.60 million US$. This indicates the continued demand for millets in the international market. The decline in global millet cultivation can be attributed to various factors. One factor is the shifting of agricultural land to other crops, as well as changing food habits and preferences among consumers. Additionally, the availability of assured irrigation facilities and the perceived higher returns from major commercial crops may have led to a reduction in millet cultivation. It is important to address the challenges facing millet cultivation, such as changing agricultural practices and shifting food preferences, in order to promote their conservation and sustainable production.

This includes supporting farmers with access to improved agricultural practices, quality seeds, and market opportunities. Additionally, raising awareness about the nutritional benefits of millets and advocating for policies that support millet cultivation can contribute to their revival as an important staple food source in the developing world. Efforts should also be made to promote millet trade, both domestically and internationally, to ensure sustained demand and market access for millet farmers.

16.3 History of Millets in India and World:

Millets are among the oldest crops domesticated and cultivated in the world form human food and animal fodder and their cultivation dates back to 8700–10,300 years ago (Lu et al. 2009a, b). Millet species, such as Foxtail millet and Proso millet, were initially domesticated in different regions of the world, including South Asia, East Asia, East Africa, and West Africa. However, they spread beyond their original areas of domestication.

The earliest recorded evidence of millet domestication and cultivation comes from China around 3000-2000 BC. The Indian valley of Kashmir is considered a hub of integrated networks, where millets were traded between Asia, Europe, and Africa. (Oelke et al., 1990)

Table 16.1 Global Millets (Except Sorghum) Area and Production by Region.

	Area (lakh ha)						**Production (lakh tons)**					
	1971-1973	**1981-1983**	**1991-1993**	**2001-2003**	**2011-2013**	**2016-2018**	**1971-1973**	**1981-1983**	**1991-1993**	**2001-2003**	**2011-2013**	**2016-2018**
Africa	133.227	108.751	168.994	197,694	191.280	207.067	74.512	77.617	109,664	142.483	113.391	140.569
America	2.529	2.457	2.259	2149	1.670	1.676	2.983	3.067	3.355	2.885	2.448	3.628
Asia	272.350	229.054	174.644	144.703	121.958	109.255	181.630	178.191	142.069	137.569	142.501	139.522
Europe	26.865	28.023	22.453	8.182	6.278	4.029	26.753	21.400	16.277	9.043	8.363	6.237
Oceania	0.334	0.327	0.295	0.357	0.353	0.351	0.363	0.317	0.262	0.288	0.358	0.359
Australia & New Zealand	0.334	0.327	0.295	0.357	0.353	0.351	0.363	0.317	0.262	0.288	0.358	0.359
World	435,305	368.613	368.645	353.085	321.539	322.378	286.242	280.593	271.627	292.268	267.061	290.314

"Each figure is an average of 3 years for the respective period, for example, 1971-1973
Source: FAOSTAT 2018

16.3.1 History in India:

The cultivation of millets in India dates back to ancient times, with evidence of foxtail millet cultivation during the Harappan civilization, pearl millet in the Neolithic period in South India (2000-1200 BC), and kodo millet, finger millet, little millet, native small millet, browntop millet, and bristly foxtail millet during various periods in Indian history, including the early Iron Age and Neolithic-Chalcolithic period.

A. Harappan civilization: the foxtail millet spread from China and its cultivation started during Harappan civilization in India. Around 2500–2200 BC (Harappan levels) the cultivation of foxtail millet started in Shikarpur (Kutch) and around 1900–1400 BC (late Harappan levels) the cultivation began in Punjab.

B. Yajurveda or Indian Bronze age (1500 BC): The mention of millets foxtail millet (priyangava), proso millet (aanava), and Barnyard millet (shyaamaka) in Indian Sanskrit text Yajurveda's verses, indicated that millet cultivation and consumption was very common in India (Roy 2009).

CAncient Indian texts: There is a mention of millet cultivation in ancient Indian texts like Sushruta Samhita (600–500 BC)—classification of cereals into millets, Charaka Samhita (100–200 AD)—Sorghum, Vishnu Purana (450 AD)—classification of cereals and millets, Abhijnana Shakuntalam (400–500 AD)—foxtail millet and Ramadhanya Charithre (1600 AD)—finger millet.

16.4 Constraints in Millet Production:

Millet farming, which is primarily concentrated in developing nations, faces challenges with low productivity compared to the world average, as highlighted by (Sood et al. 2020). One of the key reasons for this is the lack of well-established markets for millet grains in these countries, resulting in poor economic returns for farmers.

Additionally, the availability of improved millet seeds is limited in many developing countries, as the seed supply is largely dependent on informal seed chains. The informal seed chain in developing countries often leads to the use of less productive and heterogeneous landraces or local cultivars for millet cultivation (Rakshit and Wang, 2016). This means that farmers may not have access to improved seeds that are bred for higher productivity, disease resistance, or other desirable traits.

As a result, the overall productivity of millet farming remains low, as farmers continue to rely on traditional landraces or local cultivars that may not perform well under changing environmental conditions or evolving market demands.

The lack of established markets for millet grains in developing countries further exacerbates the economic challenges faced by millet farmers. Without well-functioning markets, farmers may struggle to sell their millet grains at fair prices, or may face issues such as lack of price transparency, inadequate storage facilities, or limited access to transportation and distribution networks.

These challenges can result in reduced economic returns for farmers, discouraging them from investing in improved agricultural practices or technologies that could potentially increase millet productivity. In developed nations and some developing nations like India and China, the socioeconomic conditions of farmers are comparatively better, with well-developed marketing systems and improved accessibility to agricultural inputs, including improved millet varieties. These factors collectively contribute to a positive impact on millet production, resulting in higher productivity compared to Africa. One of the reasons for the higher productivity of millets in developed nations and some developing nations is the availability of improved agricultural technologies and mechanization.

However, many minor millet varieties are not well-adapted to modern agroecosystems and mechanization due to inherent problems such as high seed shattering and unsynchronized maturity. High seed shattering refers to the tendency of millet seeds to detach from the plant and scatter, making it difficult for farmers to harvest and collect seeds. Unsynchronized maturity, on the other hand, means that millet plants in a field may mature at different times, resulting in uneven harvesting and reduced yield.

Table 16.2 Area, production, and productivity of millets in India (1951-2018)

	Finger Millet			**Sorghum**			**Pearl Millet**			**Total Millets**
	Area (M/Ha)	**Production (Mt)**	**Productivity (Kg/Ha)**	**Area (M/Ha)**	**Production (Mt)**	**Productivity (Kg/Ha)**	**Area (M/Ha)**	**Production (Mt)**	**Productivity (Kg/Ha)**	**Area (M/Ha)**
1951-1960	2.33	1.70	725.4	17.09	7.65	446	10.66	3.21	300.00	30.08
1961-1970	2.49	1.86	746.8	18.30	9.29	506.9	11.58	4.00	345.0	32.37
1971-1980	2.51	2.41	956.3	16.36	9.75	596.6	11.97	5.35	444.40	30.84
1981-1990	2.43	2.57	1059.1	15.83	11.09	701.6	10.94	5.08	460.40	29.20
1991-2000	1.85	2.42	1319.5	11.76	9.80	831	10.32	7.33	64.60	23.92
2001-2010	1.48	2:07	1395	8.76	7.27	836.9	9.39	7.87	829.50	19.63
2011-2020	1.17	1.79	1591.375	6.07	5.07	883.375	8.05	9.02	1130.10	15.29

"Each figure is an average of 10 years for the respective period, for example, 1951-1960

Source: INDIASTAT 2020

Despite the challenges posed by high seed shattering and unsynchronized maturity, efforts are being made in developed nations and some developing nations to address these issues through research and innovation. For instance, research is being conducted to develop millet varieties with reduced seed shattering and improved maturity synchronization. Additionally, there are efforts to develop appropriate mechanization technologies that can be used for millet cultivation without causing excessive seed loss or damage.

Traditional methods of dehulling, or removing the outer husk from millet grains, followed in developing countries are often labor-intensive and time-consuming. These methods involve manual processing, which can be physically demanding and time-consuming, resulting in drudgery for the farmers and processors involved. This drudgery can be a significant deterrent to the consumption and commercialization of small millets at a large scale.

The labor-intensive nature of traditional dehulling methods can limit the scale of millet processing and commercialization, as it requires significant human effort and time. This can also result in higher production costs, as more labor is required, which may negatively impact the economic viability of millet production and processing enterprises. Additionally, the physical strain and time-consuming nature of manual processing can lead to reduced motivation among farmers and processors to engage in millet production and processing activities, which can further hamper the overall growth and development of the millet sector. To overcome these challenges, there is a need for appropriate and improved millet processing technologies that can reduce the labor-intensive nature of dehulling and other processing activities. For instance, mechanical dehulling machines or equipment can significantly reduce the manual effort and time required for dehulling millets, making it more efficient and less labor-intensive. Such technologies can improve the commercialization and consumption of millets by making processing more feasible at a larger scale, reducing the drudgery for farmers and processors, and increasing the economic viability of millet enterprises.

In addition to the factors mentioned earlier, climatic and edaphic factors, as well as the socioeconomic status of farming communities, play crucial roles in determining the performance of millet production systems. Climatic factors such as rainfall pattern and distribution are critical as millets are typically rainfed crops and their growth and yield are directly influenced by the availability and distribution of rainfall. Edaphic factors such as soil type and soil fertility also impact millet production, as millets have specific soil requirements for optimal growth and yield. Agronomic management practices, such as nutrient management, pest and disease control, and water management, also affect millet production. Moreover, the socioeconomic status of farming communities, including access to resources, knowledge, and markets, can influence their ability to adopt improved millet production practices and achieve better performance in terms of productivity and profitability. Therefore, a holistic approach that considers the interplay of climatic, edaphic, agronomic, and socioeconomic factors is essential for the sustainable and successful production of millets (Sood et al. 2019). The incidence of diseases, insect-pests, parasitic nematodes, birds, parasitic plants, and weeds pose significant biotic constraints to millet production. Millets are susceptible to various diseases such as downy mildew, blast, grain mold, smut, rust, ergot, and charcoal rot, depending on the specific type of millet. Weed infestation is also considered a major constraint in global millet production, as it can cause a significant reduction in millet grain yield, with studies indicating more than 29% reduction associated with weed infestation alone. Managing these biotic constraints is crucial for ensuring optimal millet production and maximizing yields, necessitating the adoption of appropriate pest and disease management practices and weed control strategies.

The poor initial vigor of small millets promotes excessive growth of weeds resulting in more competition for sunlight, nutrient, space, and water in early growth stage, which ultimately reduce crop productivity (Lall and Yadav 1982). Changing food habits and consumer preferences have led to a shift in land allocation towards the cultivation of other high-value cereal grains, resulting in a decline in millet production. This trend is evident in countries like India, where the millet cropping area has reduced from 8 million hectares during the late 1940s to 2.3 million hectares during 2011-2012. The reduction in millet cultivation can be attributed to the changing dietary preferences and increased demand for other cereal grains, which has led to farmers switching to more profitable crops. This shift in land allocation has contributed to the decrease in millet production, posing challenges to the conservation and promotion of these nutrient-rich crops, which have significant cultural, nutritional, and environmental value. Efforts to raise awareness about the nutritional benefits of millets and promote their consumption could help address this challenge and encourage their sustainable cultivation.

16.5 Conclusion:

Millets, with their unique nutritional profile, health benefits, and C4 photosynthetic pathway, are well-suited crops for diversifying cropping systems in climate-resilient agriculture. They have been traditionally grown by resource-poor farmers in drylands and tribal communities in less productive and fragile ecosystems. However, the growing awareness of their potential health benefits and industrial uses has led to a renaissance of millets. The main concern associated with millet production is the shrinking global millet cropping area. Limited availability of improved cultivars, agricultural inputs, and policy support are major limiting factors that contribute to lower productivity of millets and the reduction in their cultivation area. Addressing these challenges is crucial for promoting sustainable millet production and ensuring their continued cultivation for their nutritional, environmental, and cultural significance. To promote millets as "golden crops" of the future, well-planned and long-term public sector investments are needed for multidisciplinary research activities, especially in major millet-growing countries. For example, in India, the government has initiated the Initiative for Nutritional Security through Intensive Millet Promotion (INSIMP) and launched a national nutraceutical mission to harness the immense nutraceutical potential and climate-resilient nature of millets.

The national nutraceutical mission prioritizes eight millets (sorghum, pearl millet, finger millet, barnyard millet, foxtail millet, proso millet, kodo millet, and little millet) and two pseudocereals (amaranth and buckwheat) as "nutri-cereals" for their significant nutritional value. Collaborative efforts among countries, supported by sustained investments, are crucial for realizing the full potential of millets as future crops for nutritional security and climate resilience. National and international multidisciplinary public sector initiatives are essential for promoting and enhancing the consumption of millets in other major millet-growing countries. In addition, linking small millets to the industry through value addition can provide higher returns to marginal farmers in Asia and Africa.

Policy support, combined with focused crop improvement efforts and public awareness about the nutritive value of millets, can help regain the lost cultivated area under millets and ensure their sustainable cultivation for improved nutrition, livelihoods, and climate resilience.

16.7 References:

1. Andrews DJ, Kumar KA (1992) Pearl millet for food, feed, and forage. Adv Agron 48:89–139
2. Baltensperger DD (2002) Progress with proso, pearl and other millets. In: Trends in new crops and new uses. ASHS Press, Alexandria, pp 100–103
3. Dwivedi SL, Upadhyaya HD, Senthilvel S, Hash CT, Fukunaga K, Diao X, Prasad M (2012) Millets: genetic and genomic resources. Plant Breed Rev 35:247–375
4. FAOSTAT (2018) Production-yield quantities of millets in world + (total) 1962–2018. http://www.fao.org/faostat/en/#data/QC/visualize. Accessed 25 May 2020
5. Hedge PS, Chandra TS (2005) ESR spectroscopic study reveals higher free radical quenching potential in kodo millet (Paspalum scrobiculatum) compared to other millets. Food Chem 92:177–182
6. INDIASTAT (2020) Statistical information about India. https://www.indiastat.com/agriculture data/2/stats.aspx. Accessed 6 Apr 2020
7. Joshi PK, Agnihotri AK (1984) Millet production in India: problems and prospects. Agric Situation India 39:329
8. Kam J, Puranik S, Yadav R, Manwaring HR, Pierre S, Srivastava RK, Yadav RS (2016) Dietary interventions for type 2 diabetes: how millet comes to help. Front Plant Sci 7:1454
9. Lall M, Yadav LNS (1982) Critical time of weed removal in finger millet. Indian J Weed Sci 14:85–88
10. Lu H, Zhang J, Liu KB, Wu N, Li Y, Zhou K, Ye M, Zhang T (2009a) Earliest domestication of common millet (Panicum miliaceum) in East Asia extended to 10,000 years ago. Proc Natl Acad Sci USA 106(18):7367–7372
11. Lu H, Zhang J, Wu N, Liu KB, Xu D, Li Q (2009b) Phytoliths analysis for the discrimination of foxtail millet (Setaria italica) and common millet (Panicum miliaceum). PLoS One 4(2): e4448
12. National Research Council (1996) Lost crops of Africa, Grains, vol I. National Academies Press, Washington, DC
13. Oelke EA, Oplinger ES, Putnam DH, Durgan BR, Doll JD, Undersander DJ (1990) Millets. Alternative field crops manual. University of Wisconsin-Madison, Madison, WI
14. Rakshit S, Wang Y-H (2016) The Sorghum genome. Springer International Publishing, Singapore, p 284
15. Sood S, Joshi DC, Chandra AK, Kumar A (2019) Phenomics and genomics of finger millet: current status and future prospects. Planta 250:731–751
16. Sood S, Joshi DC, Pattanayak A (2020) Breeding advancements in barnyard millet. In: Gosal SS, Wani HS (eds) Accelerated plant breeding, Cereal crops, vol 1. Springer Nature, Switzerland, pp 391–410
17. Yadav OP, Rai KN (2013) Genetic improvement of pearl millet in India. Agric Res 2(4):275–292

18. FAOSTAT (2018) Production-yield quantities of millets in world + (total) 1962–2018. http://www.
19. fao.org/faostat/en/#data/QC/visualize. Accessed 25 May 2020
20. INDIASTAT (2020) Statistical information about India. https://www.indiastat.com/agriculture data/2/stats.aspx. Accessed 6 Apr 2020

ISBN: 978-81-19149-19-3

17. Bio Fortification of Millets

Doppalapudi Vijaya Rani

Ph. D. Research Scholar (ICAR),
Department of Agronomy,
Sardar Vallabhbhai Patel University of Agriculture & Technology,
Meerut, Uttar Pradesh.

Kaila Tara Meghana

Erasmus Mundus Scholar, IMSOGLO,
International Masters in Soil and Global Change,
University of Ghent,
Belgium, Austria, Germany.

Pemula Priyanka

Ph.D Scholar,
Department of Agronomy,
Junagadh Agriculture University,
Gujarat.

Sushmita Moi

Erasmus Mundus Scholar, IMSOGLO,
International Masters in Soil and Global Change,
University of Ghent,
Belgium, Austria, Germany.

Himanshu Thakur

J.R.F,
Department of Entomology,
CSK Himachal Pradesh Krishi Viswavidyalaya,
Himachal Pradesh.

Abstract:

In today's world, nutritional security is a crucial issue, particularly for millions of people who rely on a cereal-based diet that is deficient in micronutrients. Millets have emerged as a significant source of energy in the semi-arid regions and drought-prone areas of Asia and Africa, second only to cereals. Millets are recognized for their exceptional nutritional value, as they consist of high levels of proteins, vital amino acids, vitamins, and minerals. The HarvestPlus group recognized the significance of biofortification for millets and has released conventionally bred high-iron pearl millet in India to address iron deficiency. This approach has demonstrated the economic feasibility of biofortification as an effective tool to combat malnutrition caused by micronutrient deficiencies. Biofortification is a process *for improving the nutritional quality of crops through conventional breeding or genetic engineering. Millets have been biofortified to increase their iron, zinc, and vitamin A content, which can help alleviate micronutrient deficiencies. However, biofortification poses several challenges, including genetic uniformity, safety concerns, consumer acceptance, and cost. Therefore, future research and dissemination efforts should focus on addressing these challenges and promoting the sustainable production and distribution of biofortified millets.*

Keywords:

Biofortification, Millets, Micro nutrients, Nutrition security.

17.1 Introduction:

Biofortification: Biofortification or biological fortification refers to nutritionally enhanced food crops with increased bioavailability to the human population that are developed and grown using modern bio-technology techniques, conventional plant breeding, and agronomic practices.

From a broader perspective, biofortification aims to address malnutrition and hidden hunger, particularly for people who have limited access to a diverse and nutritious diet. Biofortification is a sustainable strategy for improving the nutritional quality of staple food crops, as no additional resources are required to apply this method. Hence biofortification is an innovative, sustainable, and cost-effective solution to address micronutrient deficiencies and malnutrition globally. By increasing the level of essential micronutrients in staple food crops, biofortification helps to enhance the nutritional status of populations, particularly those in low-income settings, ultimately contributing to a healthier and sustainable future.

History & Origin of Biofortification:

The term "biofortification" was first coined in 2001 by the HarvestPlus program, which is a global alliance of researchers and development partners that work together to improve the nutritional quality of staple food crops in developing countries. The HarvestPlus program was founded by the International Center for Tropical Agriculture (CIAT) and the International Food Policy Research Institute (IFPRI) in consultation with the Consultative Group on International Agricultural Research (CGIAR).

By creating and promoting biofortified crops, the HarvestPlus program aims to address the problem of hidden hunger or micronutrient deficiency that affects more than two billion people worldwide. The program uses conventional plant breeding techniques to enhance the nutritional content of staple food crops such as maize, rice, wheat, beans, and sweet potatoes to provide more essential micronutrients such as iron, zinc, and Vitamin A.

Since their inception, the HarvestPlus program has collaborated with various national and international research organizations, universities, NGOs, policymakers, and farmers to scale up biofortification programs and promote the concept of biofortification globally.

Today, biofortification has become an established nutrition intervention strategy and a promising solution to reduce micronutrient malnutrition and improve the health and well-being of populations, particularly in low-income settings.

Millets: Millets are a group of small-seeded grasses that are widely grown and consumed in many parts of the world. They are known for their drought resistance, short growing season, and versatility in different culinary preparations. In recent years, there has been a renewed interest in millets due to their high nutritional content and health benefits.

Millets are an excellent source of dietary fiber, vitamins, minerals, and essential amino acids. They are also gluten-free, making them an ideal choice for people with gluten intolerance or celiac disease. In many parts of the world, millets have been an important staple food for centuries, particularly in regions where other grains such as wheat and rice cannot grow.

Millets are highly nutritious and are an excellent source of several essential nutrients such as: 1. Carbohydrates 2. Fiber, 3. Vitamins (vitamin B-complex, folate, and Vitamin E), 4. Minerals (Iron, phosphorus, magnesium, zinc, and calcium), 5. Protein Millets are rich in proteins and are especially high in methionine and cysteine, which are usually lacking in cereal grains, and 6. Antioxidant.

Figure 17.1: Types of millets

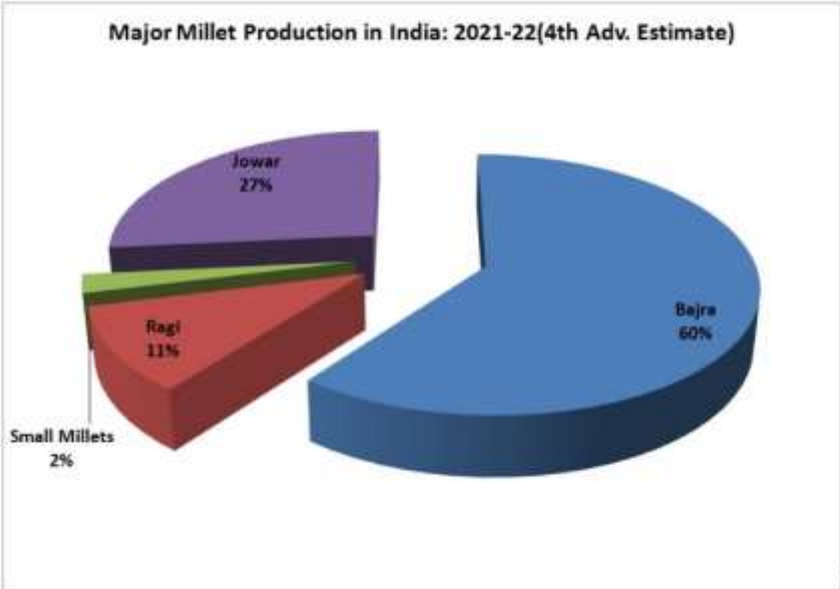


Figure 17.2: Major millet production in

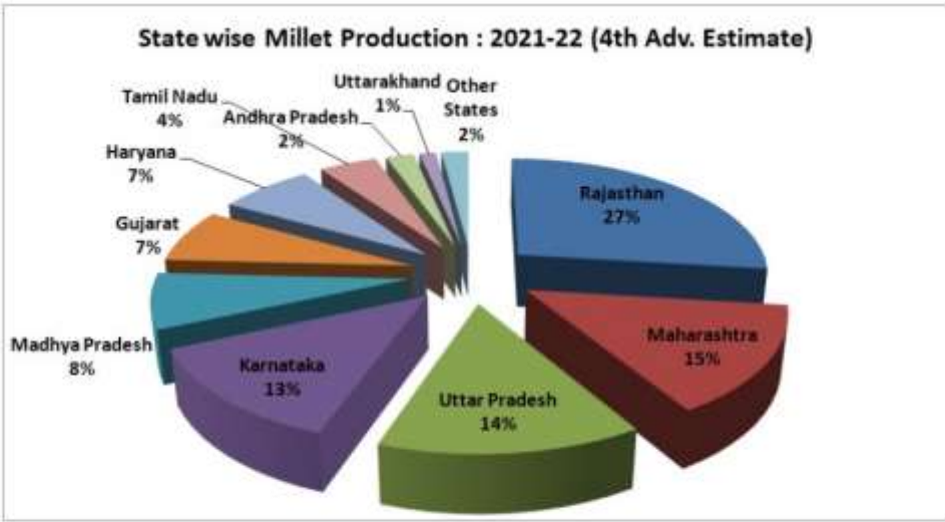


Figure 17.3: State Wise Millets Production

How does problem of micronutrients deficiency overcome by biofortification in millets ??

Micronutrient deficiencies, also referred to as hidden hunger, is a severe health problem that affects a large number of people globally, particularly in developing countries. Micronutrients, such as iron, zinc, and Vitamin A, are vital for good health and well-being, and their deficiency can lead to various health problems, including anemia, blindness, and stunted growth.

One solution to address micronutrient deficiencies is the concept of biofortification. Biofortification involves the breeding of crops to have higher levels of essential micronutrients, thus improving their nutritional quality. Biofortification has emerged as a cost-effective, sustainable, and viable solution to address hidden hunger, and it can significantly improve the nutritional quality of staple crops and improve the health and well-being of millions of people worldwide.

List of micronutrients that are commonly deficient in millets:

Micronutrient	Function	Deficiency symptoms
Iron	Formation of red blood cells, immune system support	Anemia, fatigue, weakness, impaired cognitive function
Zinc	Immune system support	Decreased growth and development, impaired immune function
Vitamin A	Eye health support	Vision impairment, impaired immune function
Vitamin B-complex	Energy production, immune system support	Weakness, fatigue, headaches, irritability, impaired cognitive function
Calcium	Bone and teeth health	Osteoporosis, weakened bones
Magnesium	Muscle and nerve’s function	Weakness, muscle cramps, twitching

It is important to note that the specific micronutrient content in millets can vary depending on the variety, and biofortification efforts are aimed at enhancing the micronutrient content.

17.2 Methods of Biofortification in Millets:

Several methods of biofortification in millets to have higher levels of micronutrients, including:

a. Conventional breeding: This method involves classical plant breeding techniques, such as crossbreeding, to select the best varieties of millets that have higher levels of micronutrients. Crossbreeding involves crossing plants that are rich in essential micronutrients with local, conventional varieties of millets to develop improved varieties that have higher levels of the desired micronutrients.
b. Marker-assisted selection: Marker-assisted selection is a breeding technique that involves the use of molecular markers to identify and select millet plants that have desired traits such as high levels of essential micronutrients.
c. Genetic engineering: Genetic engineering involves introducing specific genes that produce essential micronutrients into the millet genome. This method is still experimental, and its implementation is subject to rigorous testing and regulation.
d. Agronomic approaches: Agronomic approaches focus on improving soil fertility and crop management practices to increase the uptake and availability of essential micronutrients in the soil to improve the millet crop's nutritional quality.

e. Post-harvest interventions: Post-harvest interventions include processing techniques that improve the bioavailability of essential micronutrients in the millet crop. For example, fermentation can increase the availability of iron in millet and other cereals, thus improving their overall nutritional quality.

How does the above mentioned processes works to increase higher levels of micronutrients?

A. Conventional breeding process of biofortification works in by introducing or selecting genes that encode enzymes responsible for micronutrient synthesis or transport. For example, in millets, breeders can introduce or select genes that are responsible for the synthesis of phytase and phytase-like enzymes. These enzymes help to release essential micronutrients such as phosphorus, iron, and zinc in the digestive tract, making them more bioavailable for the body to absorb.

Using genetic markers and targeted breeding techniques, breeders can then isolate and propagate the millet plants, which have the desired properties, leading to a population with higher levels of the essential micronutrient.

Once the genetically improved crop has been developed, it can be propagated and planted in the same way as the original variety, providing farmers with improved, nutritionally rich crops.

Biofortified crops must undergo rigorous testing and regulation processes to ensure that they are safe for human consumption and that they retain the crop's desirable traits. Once the biofortified crop is approved, it is released to farmers, who can then grow the crop and sell it to markets.

B. Marker-assisted selection (MAS) is a process of selecting plants that have desirable traits, such as higher levels of essential micronutrients, using molecular markers. It is a type of genetic selection that enables breeders to select plants that have the desired traits without the need for lengthy and expensive phenotypic evaluations. Here is how marker-assisted selection works in the context of biofortification in millets.

The process of marker-assisted selection to have higher levels of micronutrients involves identifying and mapping the genes that are responsible for micronutrient levels in millets and selecting the plants that have these genes using DNA markers. Once the markers have been identified, breeders can use them to track the presence of the micronutrient genes throughout the breeding process.

Here is a step by step guide to how the process of marker-assisted selection works:

a. Identify molecular markers: The first step in marker-assisted selection is to identify molecular markers that are specific to the genes associated with the desired micronutrient, such as iron, zinc, and Vitamin A, in millet.
b. Develop breeding populations: Breeders then develop breeding populations that contain a large number of millet plants with diverse genetic backgrounds.

c. Genotyping: Using the molecular markers, breeders genotype the breeding population to determine the genetic makeup of each individual plant at the target gene's specific location.
d. Select plants: selecting the plants that have desirable genes that result in higher levels of micronutrients. The plants with favorable genotypes can then be selected for further breeding.
e. Breeding: The selected millet plants can now be crossed with other high-quality elite varieties to develop new varieties with high levels of the desired micronutrient.
f. Test new varieties: The newly developed millet varieties with higher levels of essential micronutrients can be tested in a field trial to confirm their nutritional values and performance.
g. Release biofortified millets: Once the new variety of biofortified millet has been successfully tested, it can be released to farmers and other stakeholders for cultivation and consumption.

C. Genetic engineering is a method of breeding crops to have higher levels of essential micronutrients, such as iron, zinc, and Vitamin A. The process of genetic engineering involves introducing or modifying specific genes into the crop genome to enhance the synthesis and accumulation of a particular micronutrient. Here is how the process of genetic engineering to have higher levels of micronutrients works:

a. Identifying specific genes: The first step is to identify specific genes responsible for the biosynthesis or accumulation of the desired micronutrient. This involves an understanding of the pathway of micronutrient synthesis and metabolism in the crop plant.
b. Isolation of genes: Once the specific genes have been identified, they are isolated from the donor organism. The source of these genes could be from the same or different plant species or even from other organisms such as bacteria.
c. Construction of a transformation vector: The isolated genes are then inserted into a transformation vector such as a plasmid, which is then introduced into the plant cells.
d. Transformation: Genetic transformation involves introducing the transformation vector carrying the desired genes into the plant cell using various techniques such as electroporation, biolistic bombardment, and Agrobacterium-mediated transformation.
e. Selection of transgenic plants: After genetic transformation, the plant cells are selected for successful integration of the desired genes. This selection is achieved by using antibiotic or herbicide resistance markers inserted into the transformation vector along with the desired transgenes.
f. Tissue culture and regeneration: Transformed plant cells are usually grown under tissue culture conditions to regenerate into whole plants.
g. Field testing: Genetically modified plants are then field tested to evaluate their micronutrient content and other agronomic traits.
h. Regulatory approvals: Once the field testing is completed, the genetically modified crop must be approved by the regulatory authorities and undergo rigorous safety and environmental impact assessments.

D. Agronomic biofortification through fertilizers works by adding specific fertilizers to the soil to increase the availability of essential micronutrients to the crops. Here's how it works:

a. Soil analysis: Soil analysis is conducted to determine the nutrient content, pH level, and any possible deficiencies that could affect the uptake of micronutrients by crops.
b. Identification of deficiency: Based on the soil analysis, the micronutrient that is deficient in the soil is identified.
c. Selection of fertilizers: Specific fertilizers containing the deficient micronutrient are then selected. For example, zinc and iron containing fertilizers are selected to address the deficiency of these micronutrients in the soil.
d. Application of fertilizers: The selected fertilizers are then applied to the soil at appropriate rates and times to ensure that the crops have sufficient access to the essential micronutrients.
e. Monitoring: Crops are monitored to ensure that they are absorbing the applied fertilizers properly and that the biochemical needs of the crop are met.
f. Harvesting: After the harvesting process, crops are checked for the presence and amount of the micronutrients specific to the fertilizer applied.

E. Post-harvest interventions refer to the processing and storage techniques that can be used to increase the bioavailability and concentration of essential micronutrients in millets after they have been harvested. Here are some of the post-harvest interventions that can be used to increase the micronutrient content in millets:

a. Fermentation: Fermentation is a process that can increase the bioavailability of micronutrients in millets. The fermentation process enhances the enzymatic activity, which increases the levels of micronutrients such as zinc and iron, making them more easily absorbed by the body.
b. Germination: Germination is another process that can increase the bioavailability of micronutrients in millets. During germination, enzymes become activated, which increases the bioavailable amounts of vitamins and minerals such as Vitamin A and iron.
c. Dehusking: Removing the hull or outer layer of the millet grain can increase the bioavailability of micronutrients. The hull is known to contain anti-nutritional factors that can reduce the bioavailability of nutrients in the millet grain.
d. Fortification: Fortification is a process where premixed powders containing vitamins and minerals, including essential micronutrients, are added to milled millet during processing to increase the nutrient content in the final product. The fortification process ensures that the micronutrients are present in the food in significant amounts, making them more accessible to the population.

17.3 Millets as Biofortified Crops:

Here is a list of millets and their nutritional content.

Please note that the figures below are approximate and may vary depending on the variety and cultivation methods:

A. Pearl Millet:

- Carbohydrates: 65g

- Protein: 11g
- Fat: 4g
- Fiber: 1g
- Vitamins: Thiamin (0.27mg), Niacin (2mg), Vitamin B6 (0.37mg), Folate (80mcg)
- Minerals: Calcium (37mg), Iron (2.8mg), Magnesium (114mg), Phosphorus (248mg), Potassium (280mg), Zinc (1.7mg)

B. Finger Millet:

- Carbohydrates: 72g
- Protein: 7g
- Fat: 1g
- Fiber: 3g
- Vitamins: Thiamin (0.33mg), Niacin (1.3mg), Vitamin B6 (0.13mg), Folate (44mcg)
- Minerals: Calcium (350mg), Iron (3.9mg), Magnesium (137mg), Phosphorus (287mg), Potassium (408mg), Zinc (2.2mg)

C. Foxtail millet:

- Carbohydrates: 60g
- Protein: 4g
- Fat: 1g
- Fiber: 2g
- Vitamins: Thiamin (0.19mg), Niacin (2.3mg), Vitamin B6 (0.08mg), Folate (19mcg)
- Minerals: Calcium (31mg), Iron (2.8mg), Magnesium (29mg), Phosphorus (216mg), Potassium (116mg), Zinc (0.9mg)

D. Barnyard Millet:

- Carbohydrates: 67g
- Protein: 10g
- Fat: 2g
- Fiber: 1g
- Vitamins: Thiamin (0.24mg), Niacin (5.2mg), Vitamin B6 (0.13mg), Folate (81mcg)
- Minerals: Calcium (11mg), Iron (6.3mg), Magnesium (99mg), Phosphorus (293mg), Potassium (195mg), Zinc (2.6mg)

E. Kodo Millet:

- Carbohydrates: 65g
- Protein: 8.3g
- Fat: 1.4g
- Fiber: 9.7g
- Vitamins: Thiamin (0.37mg), Niacin (1.8mg), Vitamin B6 (0.21mg), Folate (25mcg)
- Minerals: Calcium (35mg), Iron (1.7mg), Magnesium (37mg), Phosphorus (276mg), Potassium (143mg), Zinc (1.2mg)

F. Proso Millet:

- Carbohydrates: 77g
- Protein: 12g
- Fat: 2g
- Fiber: 7g
- Vitamins: Thiamin (0.33mg), Niacin (3mg), Vitamin B6 (0.35mg), Folate (23mcg)
- Minerals: Calcium (14mg), Iron (4.7mg), Magnesium (205mg), Phosphorus (333mg).

G. Little Millet:

Little Millet, also known as kutki, is a small-grained cereal that is similar in size to foxtail millet. It is a good source of dietary fiber, protein, and various essential minerals. Here are the approximate nutritional contents of little millet:

- Carbohydrates: 68g
- Protein: 7g
- Fat: 2g
- Fiber: 7g
- Vitamins: Thiamin (0.3mg), Niacin (2.3mg), Vitamin B6 (0.2mg), Folate (85mcg)
- Minerals: Calcium (17mg), Iron (9.3mg), Magnesium (116mg), Phosphorus (210mg), Potassium (207mg), Zinc (1.2mg)

H. Sorghum:

Carbohydrates: 75g

- Protein: 11g
- Fat: 3g
- Fiber: 3g
- Vitamins: Thiamin (0.4 mg), Niacin (2.5 mg), Vitamin B6 (0.4 mg), Folate (28 mcg), and Vitamin E (0.5 mg).
- Minerals: Calcium (28mg), Iron (4.2mg), Magnesium (127mg), Phosphorus (287mg), Potassium (350mg), and Zinc (2.7mg).

Sorghum is an excellent source of protein and carbohydrates, and it is also a rich source of essential minerals, especially iron, magnesium, and potassium, which are essential for vital organ functions. Additionally, sorghum is a good source of dietary fiber, which is important for maintaining digestive health and reducing the risk of heart disease and other chronic conditions.

17.4 Examples of Biofortified Millets:

a. Iron-biofortified Pearl Millet: This Pearl millet has been selectively bred to have higher levels of bioavailable iron. The iron-biofortified pearl millet was developed by ICRISAT and HarvestPlus, a public research program that aims to improve the nutritional content of staple crops. Iron-biofortified Pearl Millet has been shown to help combat iron-deficiency anemia, especially among women and children.

b. Zinc-biofortified Finger Millet: Finger Millet has been genetically modified to have higher levels of bioavailable zinc. The zinc-biofortified finger millet was developed by ICRISAT and HarvestPlus. Finger Millet is rich in calcium, iron, and fiber, and the biofortified version provides increased zinc intake, which is essential for optimal immune function, enhancing memory and learning capabilities, and for preventing diseases like diarrhea.

c. Provitamin A-biofortified Little Millet: Little Millet has been selectively bred to have higher levels of provitamin A carotenoids, which are important for vision and immune health. The provitamin A-b

Crop	Variety	Salient features
Pearl millet	HHB 299	Rich in Fe (73.0ppm), Zn (41.0 ppm)
	AHB 1200	Rich in Fe (73.0ppm)
	AHB 1269 Fe	Rich in Fe (91.0ppm), Zn (43.0 ppm)
	ABV 04	Rich in Fe (70.0ppm), Zn (63.0 ppm)
	RHB 233 (MH 2173)	High Fe (83ppm), Zn (46ppm)
	RHB 234 (MH 2174)	High Fe (84ppm), Zn (41 ppm)
	HHB 311 (MH 2179)	High Fe (83 ppm)
	Phule Mahashakti	Rich in Fe (87.0 ppm), Zn (41.0ppm)
Finger millet	Vegavathi (VR 929)	High content of Zn in grain (199.1%), high in Fe, Ca, Protein, dietary fibre & low in tannin content
	CFMV 1 (Indravathi)	Rich in Ca (428 mg/100g), Fe (58mg/kg) and Zn (44mg/kg)
	CFMV 2	Rich in protein (6.41%), Ca (654 mg/100g), Fe (39 mg/kg) and Zn (25 mg/kg)
Little millet	CLMV 1	Rich in protein (14.4%), Fe (59 mg/kg) and Zn (35 mg/kg)

Source: *www.icar.org* released on 16th October, 2020, New Delhi.

17.5 Challenges of Biofortification:

There are several potential challenges that could arise as a result of biofortification. Some of these challenges include:

- Genetic Uniformity: The development of biofortified millet varieties could lead to a loss of genetic diversity within the crop overall, which could threaten the long-term resilience of the crop to environmental changes.
- Safety Concerns: There is a possibility of unintended effects of the changed nutrient profile in the biofortified variety. Therefore, it is critical to ensure the safety of biofortified products before promoting their widespread adoption.

- Acceptance by Consumers: Different communities have different cultural preferences when it comes to food choices, and biofortification may not be accepted universally or be adopted by all communities. Hence it is essential to create awareness and generate demand through social marketing and promotion programs for biofortified food products.
- Cost: The costs of biofortification program implementation could be significant, including breeding, testing, and scaling-up of production, distribution, and marketing. This could make the biofortified millets more expensive and difficult for low-income and marginalized populations to access.

Assessment, monitoring, and evaluation are critical requirements to ensure the safety of bio-fortified products as well as the overall efficacy of implementing biofortification programs. It is also necessary to test for any potential negative impacts before launch, and evaluate the impacts of biofortification after launch.

To promote the adoption of biofortified millets, it is important to raise awareness among farmers and consumers by educating them on the nutritional benefits of these biofortified crops.

17.6 Summary & Conclusion:

Biofortification is a strategy that has proven to be effective in improving the nutritional content of food crops, and has been extended to improve the nutritional value of millets. Biofortification has resulted in new millet varieties with higher levels of iron, zinc, and vitamin A, which have proven effective in improving health outcomes in vulnerable populations. Biofortification of millets has the potential to address the triple burden of malnutrition, including undernutrition, obesity, and micronutrient deficiencies.

Future research and dissemination efforts should focus on addressing the challenges associated with biofortification, improving access and awareness among farmers and consumers, and promoting the sustainable production and distribution of biofortified millets.

17.7 References:

1. Burlingame, B., Dernini, S., & Nutrition and Consumer Protection Division of the Food and Agriculture Organization of the United Nations. (2013). Sustainable diets and biodiversity: Directions and solutions for policy, research and action. FAO
2. De Steur, H., Demont, M., Gellynck, X., & Stein, A. J. (2016). Biofortified crops for tackling micronutrient deficiencies: a review of gaps and opportunities. Frontiers in Plant Science, 7, 1138. doi: 10.3389/fpls.2016.01138.
3. Filho, J. T. S., Araújo Neto, R. B. , Braga Junior, J. M., & Campos, B. de L. (2019). Biofortification of Crops: Strategies, Advances, and Challenges. Sustainable Agriculture Reviews, 35, 55-106. doi: 10.1007/978-3-030-21272-4_3.
4. Harvest Plus. (2021). Biofortification. Harvest Plus. Retrieved September 14, 2021, from https://www.harvestplus.org/knowledge-market/information-resources/biofortification

5. Hotz, C., Loechl, C., de Brauw, A., Eozenou, P., Gilligan, D., Moursi, M., & Meenakshi, J. V. (2012). Biofortification: progress toward a more nourishing future. Global Food Security, 1(1), 40-48. doi: 10.1016/j.gfs.2012.12.001
6. Hurrell, R. F., Alejandra-Gonzalez, M., Cercamondi, C. I., Cook, J. D., Martinez-Torres, J., & Rodriguez-Barea, L. (2018). Biofortification: how can we exploit plant science to reduce micronutrient deficiencies? The Royal Society Publishing, Philosophical Transactions B, 373(1740), 20170410. doi: 10.1098/rstb.2017.0410
7. Indian Council of Agricultural Research (ICAR). (2020). Biofortified Varieties of Millets. Retrieved September 14, 2021, from https://www.icar.org.in/node/8485
8. Kumar, S., Gupta, S., & Kaushik, P. (2021). Millets: production, consumption, challenges and opportunities. Journal of Food Science and Technology, 58(2), 610-624. doi: 10.1007/s13197-020-04530-6.
9. Ndolo, V. U., Onyango, A. N., Njoroge, S. M., & Gichuki, S. T. (2021). Millet Consumption in Human Health and Disease Prevention: Properties, Processing, and Applications. Frontiers in Nutrition, 8, 647460. doi: 10.3389/fnut.2021.647460.
10. Raizada, A., Das, A., Yadav, R., & Pathak, H. (2019). Biofortification: A new approach to alleviate micronutrient malnutrition. Journal of agricultural and food chemistry, 67(36), 10060-10071.
11. Saleh, A. S., Zhang, Q., Chen, J., & Shen, Q. (2013). Millet grains: nutritional quality, processing, and potential health benefits. Comprehensive Reviews in Food Science and Food Safety, 12(3), 281-295. Doi: 10.1111/1541-4337.12012.

ISBN: 978-81-19149-19-3

18. Post Harvest Processing and Management of Millets

Ashish Kumar Nagar, Kalpna Shrivastava

Department of Extension Education,
College Of Agriculture, JNKVV,
Jabalpur (MP).

Badal Verma

Department of Agronomy,
College Of Agriculture,
JNKVV, Jabalpur (MP).

Siddharth Namdeo

Department of Extension Education,
College Of Agriculture,
RVSKVV, Gwalior (MP).

Abstract:

Millets have been cultivated since ancient civilizations by people across the globe. They have been around for 10,000 years in East Asia. A significant crop in the semi-arid tropics of Asia and Africa, particularly in India and Nigeria, millet is produced in 97% of the world's developing countries. Millets have a similar amount of energy as other cereals. Due to their rich fibre, mineral, vitamin, macro- and micronutrient, and phytochemical content, they also offer more substantial health advantages and can be used to treat chronic diseases. Millets can be a cheap, satisfying, and healthful addition to a normal diet. The nutritional fibre, mineral, and vitamin content of the majority of millets were shown to increase after germination and fermentation. By enhancing the protein digestibility and mineral bioavailability, straightforward processing methods like soaking,

germination/malting, and fermentation can assist address the issue of protein-energy deficiency. The total proteins, total dietary fibre, and micronutrients were shown to be decreased as a result of decortication, dehulling, milling, and extrusion. Millets can be made into flour, porridge, popped grains with salt that are ready to eat, cereals with sprouts, roasted, and malted delicacies. The first step in processing millet grains is to remove the husk, which has a tough seed covering. For further processing traditional methods are used. Cracked or broken grains, coarse meal, grits and fine flour are the products of dry-milled whole grain.

Keywords:

Biofortification, Millets, Micro nutrients, Nutrition security.

18.1 Introduction on Millets and History:

Millets are a family of small-seeded grasses that are widely cultivated as cereal grains for human and animal nourishment around the world. They comprise a functional or agronomic group rather than a taxonomic one. In practically every nation, millets are naturally grown or farmed for human consumption as food grains and as animal fodder. There are coolers of millet in cream, brown, red, and black because of the diversity of crops. From ancient times, millets have been grown by people all over the world. They have been around for 10,000 years in East Asia.

A significant crop in the semi-arid tropics of Asia and Africa, particularly in India and Nigeria, millet is produced in 97% of the world's developing countries. Because of its productivity and quick growth season in hot, dry conditions, the crop is recommended. Millets native to many regions of the world; its thought that their evolutionary history began in western Africa because that region has the most wild and domesticated varieties of millets.

Millions of the most vulnerable people in these regions still primarily rely on millet grains for their calories, protein, vitamins, and minerals. They are grown in hard conditions when other crops produce significantly less, which is noteworthy. A large number of small-holder farmers cultivate them using scarce water resources and typically without the use of any fertilizers or other inputs. They are sometimes referred to as "coarse grain" or "poor people's crop" since they are primarily consumed by underprivileged communities. In many nations, they are not typically traded on local or even international marketplaces. Because of this, farmers rarely have a guaranteed market in the case of a production surplus.

Figure 18.1: Types of Millets

A. **SORGHUM:** It is thought that sorghum, also known as "**JOWAR**" cereal, is a significant coarse-grained food crop. In addition to Rajasthan, it is commonly grown in Maharashtra, MP, UP, Telangana, Haryana, and AP. The traditional main food of the arid regions of the world is sorghum. It is a warm-season crop that is intolerant of cold temperatures, resilient to pests and diseases, highly nutritive, and climatically adaptable. It comes in fourth in India and fifth overall in terms of cereal production. Millions of people, particularly in semiarid regions, Major sources of minerals vitamins, and protein can be found in sorghum grains.

B. **BAJRA (Pearl millet):** (PENNISETUM GLAUCUM) is the millet that is grown the most far and wide. Bulrush millet, babala, bajra, cumbu, dukhn, sajje, souna are other names for it. Since ancient times, it has been grown on the African and Indian subcontinents. It is grown in Rajasthan, Gujarat, and Haryana in India and is known as "bird feed" because of its ability to thrive in nutrient-poor, sandy soils in low-rainfall regions. The plant develops a brownish flower with a thick panicle resembling a spike. It is well known that this millet has phytochemicals that decrease cholesterol. Folate, iron, magnesium, and vit. E and B are also present. When compared to other millets, pearl millet contains a lot of energy. Unsaturated fats and calcium are also abundant in it.

C. **FINGER MILLET: FINGER MILLET** (*ELEUSINE CORACANA*), known as ragi in India, is another significant staple food in Asia and Eastern Africa (India, Nepal). It grows in cooler, higher elevations up to 2000 metres above sea level and has a slightly higher water requirement than most other millets. Many spikes or "fingers" protrude from the plant's stem at the top. The grains are tiny. Finger millet is rich in calcium, protein with a balanced composition of key amino acids, vitamin A, vitamin B, and phosphorus. It also has a lot of calcium in it. In Karnataka, ragi flour is typically formed into balls, or "ragi mudde," which are then used to make flatbreads, leavened dosa, and thinner, unleavened rotis. Due to its high fibre content, it also prevents bowel cancer, high blood cholesterol, and constipation.

D. **FOXTAIL MILLET:** The gluten-free grain known as "Italian millet" or "foxtail millet" is also one of the oldest varieties still growing today. Also suited to temperate areas is **FOXTAIL MILLET (SETARIA ITALICA).** It results in lengthy, bristly, compact, cylindrical or lobed panicles. Foxtail millet production in the globe is dominated by China. There, it is farmed for both food and animal feed. The crop is also grown in several regions of southern Europe, Indonesia, Korea, and India. Outside of the eastern highlands, it isn't grown in any significant quantity in Africa. Before sorghum-sudangrass forage hybrids were accessible, foxtail millet was a significant species for short-term pastures.

E. **KODO MILLET:** Kodo millet was first domesticated almost 3,000 years ago in India. It is a tufted grass that is annual and reaches a height of 90 cm. Hard, corneous, persistent husks that are challenging to remove surround the grain. The colour of the grain can range from light red to dark grey. Of all millets, it has the most dietary fibre. Kodo millet has a high lecithin content, is very simple to digest, and is highly good for boosting the neurological system. It contains a lot of minerals like calcium, iron, potassium, zinc, and B vitamins like niacin, B6, and folic acid.

F. **BARNYARD MILLET:** In India's tropics and subtropics, barnyard millet (Echinochloa crusgalli, E. colona), is a significant crop. Barnyard millet is an excellent source of dietary fibre with a fair amount of soluble and insoluble fractions. It is also a strong source of highly digested protein. Barnyard millet is a natural gift from nature for modern individuals who spend their days sitting still because of its low carbohydrate content and slow digestion. Linoleic acid, followed by palmitic and oleic acids, is the main fatty acid in this millet. Moreover, it exhibits a strong retrogradation of amylase, which promotes the creation of more resistant starches.

G. **LITTLE MILLET:** (*Panicum sumatrense*) the traditional crops of Karnataka and is also farmed in India, Nepal, Sri Lanka, eastern Indonesia, and Burma. Little millet mostly mix cropped with other millets, pulses and oilseeds Millet is typically eaten as rice, and any recipe that calls for staple rice can be made with a small amount of millet. With the exception of the smaller grain, this cereal's habit is identical to that of proso millet. It is an annual herbaceous plant that can reach heights of 30 cm to 1 m and grows either straight or with folded blades. The leaves are linear and can have membranous hairy ligules and hairy lamina. Small millet is said to have the largest amount of dietary fibre among cereals—between 37% and 38%—and is referred to as a nutraceutical. As a result, it is a complete food ingredient that can be used on a big scale in processed goods, snacks, baby foods, and many other products. It also significantly promotes global food security.

H. **PROSO MILLET:** A short-season crop that flourishes in regions with little rainfall is proso millet. You can grow this millet alongside red gramme, maize, and sorghum. Because the seeds are encased in the hulls and are challenging to remove using traditional milling techniques, the grain has a relatively high percentage fibre.

18.2 Nutritional Profile of Millets:

Nutritive value of food has a significant role in the good and maintenance of the metabolism of the human body. For the genetic potential of humans to be developed and maximized, the food content is essential. Although millet is a plentiful source of carbs, protein, dietary fiber, minerals, vitamins, and phytochemicals, its nutrition is similar to main staple grains rice, wheat, and maize. High dietary fiber millets have a multitude of medical advantages, including improving plasma lipids, blood glucose clearance, and gastrointestinal health. Millets with low glycemic index and minimal gluten content are beneficial for people with diabetes and celiac disease. According to a study, millets contain over 50 distinct phenolic groups and their derivations, including ferulic acid, flavones, flavanols, and flavononols, which have strong antioxidant properties.

A. Millets Processing:

Millets find it challenging to eat the coarse cereals as entire, uncooked seeds. (Hulse et al., 1980). Originally, we come to know that millets have calorie and energy contributions and good for us; then we find that millets are rich source of fibres too, and we want to importance right now that millets are a fantastic resource of phytochemicals as well. Millets' 3 main parts—their starch-containing endosperm, protective pericarp, and germ—are partially separated or altered through processing. Offal consists of the pericarp and, occasionally, the germ. Offal removal is often referred to as dehulling or decortication. Millets' tough outer coat, distinctive flavor, and absence of processed millets products that are similar to rice and wheat are the main causes of their lower appeal among wheat and rice eaters. Much equipment is available for the process of grains, but there is no well-established procedure or method for producing white products from colored millets.

The loss of minerals was quite minimal. Moreover, decortication increases nutrient availability and customer appeal. Millets, whether in the form of processed or unprocessed grain, can be cooked decorously or whole and can be turned into flour using modern or conventional techniques. Therefore, it is necessary to identify alternative use scenarios. Unlike other flours like wheat flour and rice flour, millet flours are unable to produce elastic, cohesive, and expansive dough when combined with water because they lack gluten. Due to the lack of these features in millet flours, fortification is a method for employing millets to create processed foods that are prepared to eat.

The feasibility of combining high energy density and low viscosity green gram with malted finger millet weaning meal. For the important operation as food, inedible grains are converted into fresh form and also civilizing its value by the processing. Millets can be made into flour, porridge, popped grains with salt that are ready to eat, cereals with sprouts, roasted, and malted delicacies. The first step in processing millet grains is to remove the husk, which has a tough seed covering. For further processing traditional methods are used.

Dry-milled whole grains produce coarse meal, grits, cracked or broken grains, and fine flour. The flour can be used by addition with other flour to produce simple to complex food products like soft and stiff porridges.

B. Primary Operations of Millets:

Operations farm which improves grain quality / transforms the grain into more useful form.

A. CLEANING OF MILLTES
B. DEHULLING OF MILLTES
C. SORTING OF MILLTES
D. POLISHING / PEARLING OF MILLTES
E. GRADING OF MILLTES
F. SIZE REDUCTION /GRINDING OF MILLTES
G. DRYING OF MILLTES
H. STORAGE OF MILLTES

C. Millets Dehulling/ Decortication:

Traditionally, millets were decorticating by hand pounding at domestic level. These days, with slight modification of the process these are milled in rice milling machinery. Decortication of finger millets similar to other cereals is not possible, so its use is confined to flour based products. The endosperm texture hardened by hydrothermal treatment of millet and enabled its decortication. For soft texture like rice in 5 min, decorticated millet can be cooked which was not possible before (Saleh et al. 2013). Centrifugal sheller can be used to dehull/decorticate the small millets. The fractions of husk in small millet varied from 1.5 to 29.3% (Hadimani et al. 1993). With corresponding increase in protein digestibility it significantly decreases dietary fibre, polyphenols, total phytic acid, and the amount of tannins. To increase the appearance of millet grains food products and to improve their edible and sensory properties they are decorticated before consumption though some nutrients such as fiber and minerals were found to be reduced due to decortcstion.

D. Milling of Millets:

The little millets are ground using both rice milling and wheat milling procedures. The friable and soft endosperm of the finger millet is securely linked to the seed coat. The finger millet coloured pigments. Use of abrasive type milling machinery to debran finger millet are found ineffective. Flour of finger millet seed and whole meal is used for food yield. Nevertheless, adding together 2 to 5 percent moisture, tempering for 30 minutes (which will toughen the bran and reduce friability without compromising the endosperm properties), and screening after crushing produce fairly white flour and separate the majority of the bran. (Kurien et al., 1962). The fully refined millet flour can be made using a roller mill.

18.3 Secondary Post Harvest Operations:

Unit procedures on grains that turn them into goods typically for immediate consumption, either before or after primary processing. Often, they take place outside of farms, either in disorganized or organized sectors. Puffing, Milling, Baking, Flaking and Value Added Products of Millets.

Machines for Post-Harvest Handling of Millets:

For Primary Processing

A. GRAIN PRE-CLEANERS
B. DESTONER – GRAIN CLEANER
C. JOWAR POLISHER
D. RAGI PEARLER
E. MILLET RICE POLISHER
F. FLOUR MILLS
G. DEHULLER
H. SEPERATOR
I. SORTER

For Secondary Processing

A. TWIN SCREW EXTRUDER MACHINE
B. FLAKING MACHINE
C. GRAIN ROASTER
D. PASTA MACHINE
E. FOOD BLENDER

18.3 Conventional Food Products:

A. Roti (unleavened pan cake): The main food products of millets are roti, porridge and mudde as stated by (Devi et al., 2014). Millet as a sole material for bakery products is unsuitable as millet protein lacks gluten. Millet flour is combined with hot water to partially gelatinize the starch that gives dough its binding qualitie. Dough flattened into thin sheet and baked on hot metal plate. Roti be similar to maize tortilla or chapatti of wheat flour. By shaping the dough into balls and heating it, mudde is made.

B. **Multigrain flour:** Multigrain flour/composite flour is made from blended flours of millets, and pulses are rich in nutrients such as protein, minerals, vitamins, and dietary fiber and meet the changing dietary requirements of the population in light of the choice for contemporary, healthy eating habits for mass feeding and social programmes. Sorghum roti's flavour and nutritional value can be enhanced by using multigrain flour rich in sorghum. (Rao et al., 2014).

C. **Fermented foods:** Fermentation improves the taste and lowers the antinutrients but increases the value of food in terms of calcium fiber and protein. Idli and Dosa are fermented food, commonly used in breakfast and also in evening meals in southern states of India. Idli and Dosa are prepared by rice which can be completely substitute by millets (Desikachar, 1975).

D. **Parboiling of millets:** Parboiling is a traditional process used for hardness of endosperm of rice to lower the losses during milling. When finger millet is parboiled, the endosperm becomes harder, the mudde becomes less slimy, and grits can be made as reported by Desikachar (1976). Milling quality of kodo millet improved by parboiling as reported by Shreshta (1972). It is well known that parboiling of rice reduces the loss of thiamine during milling and improves milling quality. Precooked ready to eat product of rice is also prepared by parboiled rice.

E. **Papad:** Papad is a traditional food in south India that is produced by combining finger millet flour, up to 15-20%, with additional ingredients like spices, rice, and black gramme. Up to 55-60% of the flour in Karnataka is made from finger millet as reported by Begum, (2007).

F. **Non-conventional food products:** According to many research, processing millets leads to the use of traditional health foods. Several scientists have worked to create processed foods including weaning foods, puffed, popped, extruded, roller-dried, flaked products, malted, composite flours, etc.

G. **Millet flakes:** Millets should be used to make quick-cooking cereals since they cook softly in five to ten minutes when placed in boiling water. Pearled grains are boiled at high pressure to completely gelatinize the starch before being dried to a moisture percentage of 16-18% and pressed between heavy-duty rollers to create flakes. (Rao et al., 2016) Millets' small size makes them ideal for making flakes. Flakes hydrate quickly when milk or water is added to them.

H. **Puffing or popping:** For preparing the ready to eat products puffing or popping is a simple processing technique. Popped grain is a porous, precooked and crunchy product and also has a good taste by adding flavor. On popping, a highly acceptable flavor is developed by finger millet. Popping temperature of about 250° C and 19 % grain moisture content is maintained then that to obtained expanded millets as reported by Malleshi and Desikachar (1986). For preparing expanded millet decorticated finger millet required a hightemperature short-time treatment. For maximum expansion ratio the two factors play an important role first is flattening the grains to the desired shape and second is the moisture content.(Ushakumari et al., 2007).

I. **Weaning/Malting food:** On an industrial scale for brewing, malting of barley and sorghum is done in African nations. Finger millet malting is a traditional practice in some regions of India. In terms of amylase activity, finger millet is superior to sorghum and other millets. (Senappa, 1988). Malleshi and Desikachar (1986) It is said that finger millet malt has a very pleasant flavour when starch hydrolyzing enzymes are present in sufficient amounts. At 4 to 6 days of germination, amylase activity reaches its peak. It makes an excellent base for weaning food formulations since it is high in calcium and sulphur amino acids. With the addition of sugar, millet malt is used to make beverages with milk or lukewarm water as well as baby food. The sensory nutritional quality of finger millet grains is enhanced by malting, which also has a noticeable impact on reducing the ant nutrients. (Desai et al., 2010).

J. **Noodles-vermicelli:** The best application of extrusion technique is Kurkure. Ingredients are being transformed into products with value added using extrusion technology. With the shift in eating habits, extruded foods, which are RTE goods, have become a good option for snack foods. (Varma et al., 2012). Noodle demand has grown both domestically and internationally as a result of changes in eating patterns. The demand for finger millet is increasing as more people become aware of its nutritional benefits. Noodles are manufactured through a cold extrusion and are often known as handy foods. The nutritionally balanced noodles made from a blend of millet and bean flour can be used as a weaning food or as a supplement. The pearled grains are boiled, extruded, and dried after being soaked in water for between 24 and 48 hours. This gives the grains their great crispiness when fried. The equipment needed is fairly basic, thus small capital expenditure is also needed to make these goods at a reasonable cost. (Kumate et al., 1983).

K. **Bakery products:** For the creation of bakery goods including nankhatai, biscuits, bread, and muffins, millet flour is frequently utilized. Gluten is crucial for giving the dough extensibility and elastic qualities, however millet grains weak in gluten render them unsuitable for simple handling of pure millet solid food products, especially noodles or baked goods. Millets with superior fibre and micronutrient contents now have a better chance of entering the bakery market. In recent years, finger millet flour has gained popularity, and efforts have been made to offer it to customers in practical forms. (Singh et al., 2012). Breads made using millet-based composite flour have the same acceptance as bread made with wheat flour (Singh et al., 2012). Eneche, (1999) made biscuits from pigeon pea and millet flour blends with various millet/pea blending ratios.

18.4 Conclusion:

Since millets are more nutrient-dense than other grains, there is little question that developing products employing millets will have positive effects on health, nutrition, and quality. Although not yet widely accepted by the public, it can be a substitute for other cereals like rice and wheat. Millets are less expensive but less convenient to utilize because they are exclusively used in food by the impoverished and the traditionally dressed. There are various techniques and procedures for making products solely from millet and combining it with other ingredients. These techniques can be similar to those for making products from wheat and rice or they may differ because millet has different physical and chemical characteristics than the other cereal grains.

18.5 References:

1. Ashoka P., Gangaiah B., Sunitha N. Millets-foods of twenty first century. *Int. J. Curr. Microbiol. Appl. Sci.* 2020;9:2404–2410.

doi: 10.20546/ijcmas.2020.912.285. [CrossRef] [Google Scholar]
2. Azad M.O.K., Jeong D.I., Adnan M., Salitxay T., Heo J.W., Naznin M.T., Lim J.D., Cho D.H., Park B.J., Park C.H. Effect of different processing methods on the accumulation of the phenolic compounds and antioxidant profile of broomcorn millet (*Panicum Miliaceum* L.) Flour. *Foods.* 2019;8:230. doi: 10.3390/foods8070230. [PMC free article] [PubMed] [CrossRef] [Google Scholar]
3. Chandrasekara A., Shahidi F. Content of insoluble bound phenolics in millets and their contribution to antioxidant capacity. *J. Agric. Food Chem.* 2010;58:6706–6714. doi: 10.1021/jf100868b. [PubMed] [CrossRef] [Google Scholar]
4. Das S., Khound R., Santra M., Santra D.K. Beyond bird feed: Proso millet for human health and environment. *Agriculture.* 2019;9:64.doi: 10.3390/agriculture9030064. [CrossRef] [Google Scholar]
5. Gull A., Jan R., Nayik G.A., Prasad K., Kumar P. Significance of finger millet in nutrition, health and value added products: A Review. *J. Environ. Sci. Comput. Sci. Eng. Technol. Sect. C Eng. Technol.* 2014;3:1601–1608. [Google Scholar]
6. Kalinova J., Moudry J. Content and quality of protein in proso millet (*Panicum miliaceum* L.) varieties. *Plant Foods. Hum. Nutr.* 2006;61:45–49. doi: 10.1007/s11130-006-0013-9. [PubMed] [CrossRef] [Google Scholar]
7. Nainwal K. Conservation of minor millets for sustaining agricultural biodiversity and nutritional security. *J. Pharmacogn. Phytochem.* 2018;SP1:1576–1580. [Google Scholar]
8. Nambiar V.S., Dhaduk J.J., Sareen N., Shahu T., Desai R. Potential functional implications of pearl millet (*Pennisetum glaucum*) in health and disease. *J. Appl. Pharm. Sci.* 2011;1:62–67. [Google Scholar]
9. Neeharika B., Suneetha W.J., Kumari B.A., Tejashree M. Organoleptic properties of ready to reconstitute little millet smoothie with fruit juices. *Int. J. Environ. Clim. Chang.* 2020:78–82. doi: 10.9734/ijecc/2020/v10i930230. [CrossRef] [Google Scholar]
10. Sharma N., Niranjan K. Foxtail millet: Properties, processing, health benefits, and uses. *Food Rev. Int.* 2018;34:329–363. doi: 10.1080/87559129.2017.1290103. [CrossRef] [Google Scholar]
11. Rao D.B., Malleshi N.G., Annor G.A., Patil J.V. *Millets Value Chain for Nutritional Security: A Replicable Success Model from India.* Indian Institute of Millets Research (IIMR); Hyderabad, India: 2017. Nutritional and health benefits of millets; p. 112. [Google Scholar]
12. Zhang L., Liu R., Niu W. Phytochemical and antiproliferative activity of proso millet. *PLoS ONE.* 2014;9:e104058. doi: 10.1371/journal.pone.0104058. [PMC free article] [PubMed] [CrossRef] [Google Scholar]

ABOUT THE EDITORS

Badal Verma *is ICAR SRF Ph.D. Scholar, Department of Agronomy, JNKVV, Jabalpur. He is a recipient of the CSDA-NAHEP Fellowship Award. He has also qualified ASRB-NET exam in 2020 and 2021. He has been awarded Best Poster Award from the Indian Society of Agronomy, Best Oral Presentation Award, Best M.Sc. Thesis Award and the Outstanding Research Scholar Award. He is a life member of ISA and ISWS. He has published around 10 research papers, 03 book chapters, and many abstracts and popular articles.*

Dr. N. R. N. V. Gowripathi Rao *is presently working as an Assistant Professor of Research at Karnavati School of Research, Karnavati University Gandhinagar. He obtained his Bachelor of Technology in Agricultural Engineering from Junagadh Agricultural University (Gujarat) in 2012 and Master of Technology in Agricultural Engineering from (Maharana Pratap University of Agriculture and Technology Udaipur) with a specialization in Farm Machinery and Power Engineering in 2015. He completed his Ph.D. Doctorate degree in Mechanical Engineering Design from Malaviya National Institute of Technology Jaipur (MNIT Jaipur) in 2020. He has five years of work experience in teaching and research. He has published 10 international reputed journal papers of good quality, 3 book chapters, 1 book, and 12 conference papers on different platforms.*

Vishal Omprakash Kohire patil *is currently working as an Assistant Professor (Agronomy) at MGM Nanasaheb Kadam College of Agriculture, Gandheli, Aurangabad. He has 12 years of teaching experience. He has publsihed 14 research articles, 7 conference proceedings, 13 popular articles and 2 books in his academic carreer. He has been activiely involved recently in radio talks.*

I am ***Soumya Hiregoudar,*** *Ph.D. Scholar., Food Science and Nutrition, University of Agricultural Sciences, GKVK, Bengaluru. I Have been awarded with best M. Sc. Thesis award, Young researcher award, and best oral presentations for my master thesis. And I have been published more than six research papers in International and National journals. More than 10 abstracts were published in seminars souvenir. And four products millet based biscuits were commercialized to market*

Dr. Ankit Saini *currently working as Project Associate in CSIR-IHBT Palampur, Completed his B.Sc. (Ag.) in 2016, M.Sc. in 2018 and Ph.D. in 2022 from CSK HPKV, Palampur with specialization in Agronomy. He is a recipient of University Merit Scholarship. He has attended 9+ National and International Conferences with 2 "Best Poster Awards" in international Conferences. He has also published 13 research papers, 2 review papers, 2 book chapters and 1 popular articles.*

Bharat Bhushan Rana *obtained his B.Sc. (Hons.) Agriculture and M.Sc. in Agronomy from CSK HPKV Palampur in 2019 and 2021 respectively. His research work in master's thesis was on Phytosociology and diversity of weeds in different cropping system under natural farming. He has published 1 research paper, 2 popular articles and 2 Book Chapter in his academic career. Currently, he is pursuing his Ph.D. at Department of Agronomy CSKHPKV Palampur Himachal Pradesh, with the research area focussed on Weed management with new herbicides in conservation agriculture-based maize – gobhi sarson + toria system.*

KRIPA DRISHTI
PUBLICATIONS

Price: ₹500

Kripa-Drishti Publications
A-503 Poorva Heights, Pashan-Sus Road, Near Sai Chowk,
Pune – 411021, Maharashtra, India.
Mob: +91 8007068686
Email: editor@kdpublications.in
Web: https://www.kdpublications.in

ISBN: 978-81-19149-19-3
9 788119 149193