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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF BARNYARD MILLET (*Echinochloa frumentacea* Link.)

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ABSTRACT

Foxtail millet or oodalu belongs to the Family Poaceae, Subfamily Panicoideae, Genus *Echinochloa* and Species Echinochloa frumentacea Link. Two barnyard millet species namely *Echinochloa* frumentacea and E. esculenta are under cultivation in the different parts of world. *Echinochloa frumentacea* (Indian barnyard millet, sawa millet, or billion dollar grass) is a species of *Echinochloa*. Both *Echinochloa frumentacea* and *E. esculenta* are called Japanese millet. This millet is widely grown as a cereal in India, Pakistan, and Nepal. Its wild ancestor is the tropical grass *Echinochloa colona*, but the exact date or region of domestication is uncertain. *Echinochloa frumentacea* is generally known by a few names like sanwa and jhangora (Hindi), shyama (Sanskrit), oodalu (Kannada), kuthiravaali (Tamil), kavadapullu (Malayalam), udalu and kodisama (Telugu), shamul (Marathi), sama (Gujarati), shamula (Bengali), kira (Oriya), bhagar or varai (Marathi & Chhattisgarh) and swank (Punjabi). Indian barnyard millet most probably originated from India where it has been domesticated from the wild *E. colona*. Wild *E. colona* originated from the tropics and subtropics of the Old World but can now be found in the tropics and subtropics all over the world and is very common in South-East Asia. Indian barnyard millet is known from ancient Egypt and East Africa but is at present widely grown as a cereal only in India, Kashmir and Sikkim. It has been introduced into the United States, Canada and Australia, especially as a forage. In continental South-East Asia, Indian barnyard millet is quite commonly cultivated but in Peninsular Malaysia it only occurs as a rare weed in cultivated fields. Japanese barnyard millet most probably originated from Japan where it was domesticated from the wild *E. crus-galli* some 4000 years ago, and was later introduced into Korea, China and adjacent Russia as a cultivated cereal. Wild *E. crus-galli* is native to temperate Europe and Asia but has spread to temperate and tropical areas all over the world; it is also very common in South-East Asia. Japanese barnyard millet is only extensively cultivated in Japan, Korea and northern China. Barnyard millet is an ancient millet crop grown in warm and temperate regions of the world and widely cultivated in Asia, particularly India, China, Japan, and Korea.Madhya Pradesh, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, and Bihar are among the Indian states where it is cultivated. Barnyard millet has a sweet, nutty flavour, and is easy to cook with different spices. Apart from being delicious, Barnyard millet benefits heart and kidney health. The presence of a high amount of fibre, iron, and phosphorus in Barnyard millet is helpful in controlling blood sugar, blood pressure, and cholesterol levels. It has gained more popularity in the Sattvic movement to embrace native gains that are good for both humans and the environment. It is the fourth most produced minor millet, providing food security to many poor people across the world. Globally, India is the biggest producer of barnyard millet, both in terms of area (0.146 m ha^{-1}) and production (0.147 mt) with average productivity of 1034 kg/ha during thelast 3 years. Yields of Indian barnyard millet amount to 700-800 kg/ha of grain and 1000-1500 kg/ha of straw. It is believed that it can reach a grain yield of more than 2 t/ha. As a forage crop in the United States it can produce as many as eight crops per year. Average yield of Japanese barnyard millet is 1.65 t/ha. The milling process of Foxtail millet may include husking, debranning and grinding. The husked grains are polished. Polished grain may be ground to flour. The grain can also be cooked like rice or processed for flaking. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Barnyard Millet are discussed.

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INTRODUCTION

Foxtail millet or oodalu belongs to the Family Poaceae, Subfamily Panicoideae, Genus *Echinochloa* and Species Echinochloa frumentacea Link (Sood *et al.,* 2015; Wikipedia, 2023; Wikipedia, 2023a). Two barnyard millet species namely *Echinochloa frumentacea* and *E. esculenta* are under cultivation in the different parts of world. *Echinochloa frumentacea* (Indian barnyard millet, sawa millet, or billion dollar grass) is a species of *Echinochloa*. Both *Echinochloa frumentacea* and *E. esculenta* are called Japanese millet. Synonym for *Echinochloa frumentacea* is *Panicum crus-galli* var. *edule* (FOI, 2023). Sawa millet, Sanwa millet, poor man's millet, billion dollar grass, Japanese barnyard millet, barnyard millet and Japanese millet, have been applied as the popular name to *Echinochloa frumentacea* (Yabuno, 1962). *Echinochloa frumentacea* is generally known by a few names like sanwa and jhangora (Hindi), shyama (Sanskrit), oodalu (Kannada), kuthiravaali (Tamil), kavadapullu (Malayalam), udalu and kodisama (Telugu), shamul (Marathi), sama (Gujarati), shamula (Bengali), kira (Oriya), bhagar or varai (Marathi & Chhattisgarh) and swank (Punjabi) (Jhawer, 2017; Vanniarajan *et al*., 2018; Vincent, 2023; Wikipedia, 2023;). It is also called as Japanese Millet, Japanese Barnyard Millet, billion dollar grass. Hindi: Banti, Kannada: Kaadu haaraka hullu, Marathi: Jangli sama, Samul, Sanskrit: Syamaka , Tamil: Chamai, Kudiravalli pulllu, Rail pullu (FOI, 2023). Indian barnyard millet most probably originated from India where it has been domesticated from the wild *E. colona*. Wild *E. colona* originated from the tropics and subtropics of the Old World but can now be found in the tropics and subtropics all over the world and is very common in South-East Asia. Indian barnyard millet is known from ancient Egypt and East Africa but is at present widely grown as a cereal only in India, Kashmir and Sikkim. It has been introduced into the United States, Canada and Australia, especially as a forage (Partohardjono and Jansen, 2023).

Barnyard millet is valued for its drought tolerance, rapid maturation, and superior nutritional qualities and it is one of the most under researched crops with respect to characterization of genetic resources and genetic enhancement (Manimekalai *et al.,* 2018). Barnyard millet is one of the hardiest, climate resilient and fast growing crop that is bestowed with high nutrient content in grains (Dhanalakshmi *et al*., 2019). Barnyard millet (*Echinochloa* species) is an ancient millet crop grown in warm and temperate regions of the world and widely cultivated in Asia, particularly India, China, Japan, and Korea.It is the fourth most produced minor millet, providing food security to many poor people across the world (Renganathan *et al*., 2020). Globally, India is the biggest producer of barnyard millet, both in terms of area (0.146 m ha^{-1}) and production (0.147 mt) with average productivity of 1034 kg/ha during the last 3 years (IIMR, 2018) (Renganathan *et al.,* 2020). Barn yard millet is primarily cultivated for human consumption, though it is also used as a livestock feed. Among many cultivated and wild species of barnyard millet, two of the most popular species are *Echinochloa frumentacea* (Indian barnyard millet) and *Echinochloa esculenta* (Japanese barnyard millet). Barnyard millet is a short duration crop that can grow in adverse environmental conditions with almost no input and can withstand various bioticand abiotic stresses. All these features make barnyard millet an ideal supplementary crop for subsistence farmers and also as an alternate crop during the failure of monsoons in rice/major crop cultivating areas (Renganathan *et al.,* 2020). Barnyard millet is a small seeded cereal grown in India, China, and Japan as a substitute for rice in dry areas. It has the fastest growing character among all millets and is generally cultivated in hill slopes and undulating fields of hilly, tribal, or backward areas, where few options exist for crop diversification (Sood et al., 2020). Barnyard Millet (*Echinocloa esculenta* and *Echinocloa colona*) is a multi-purpose crop that is cultivated for food and fodder (Tripathi and Vyas, 2023).

Recently, demand for barnyard millet has increased due to is nutritious grain with high levels of anti-oxidative compounds. Most of the released varieties are non-waxy (non-glutinous), which give a poor texture to the food products. In Asian countries, including India and Japan, a glutinous texture as in rice is preferred, and so incorporating the waxy trait into the elite cultivars, thereby imparting the glutinous texture to the food preparations, would be highly beneficial to making barnyard millet popular (Ganapathy *et al*., 2021). In Malaysia, the East Indies, China, Japan, and India, barnyard millet is cultivated. When the rice harvest fails, it is said that it is produced as a replacement crop in China and Japan. Africa and the United States of America are somewhat affected by it as well. Madhya Pradesh, Uttar Pradesh, Tamil Nadu, Andhra Pradesh, Karnataka, Maharashtra, and Bihar are among the Indian states where it is cultivated (Krishijagran, 2023). The details on major areas of cultivation are presented in Fig.1.

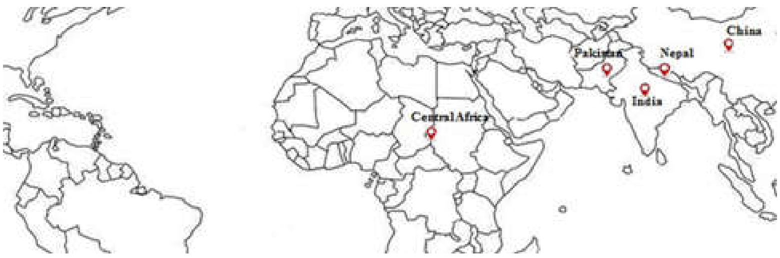

Fig. 1. Major areas of cultivation

Echinochloa frumentacea (Indian barnyard millet, sawa millet, or billion dollar grass) is a species of *Echinochloa*. Both *Echinochloa frumentacea* and *E. esculenta* are called Japanese millet. This millet is widely grown as a cereal in India,Pakistan, and Nepal. Its wild ancestor is the tropical grass *Echinochloa colona*, but the exact date or region of domestication is uncertain (Wikipedia, 2023) It is cultivated on marginal lands where rice and other crops will not grow well. The grains are cooked in water, like rice, or boiled with milk and sugar. Sometimes it is fermented to make beer. While also being part of staple diet for some communities in India, these seeds are, in particular, (cooked and) eaten during religious fasting (willingly abstaining from some types of food / food ingredients). For this reason, these seeds are commonly also referred to as "*vrat ke chawal*" in Hindi (*i.e.,* "rice for fasting", literally) (Wikipedia, 2023). It is referred to by the common names Japanese barnyard millet or Japanese millet, is a species of *Echinochloa* that is cultivated on a small scale in India, Japan, China and Korea, both as a food and for animal fodder. It is grown in areas where the land is unsuitable or the climate too cool for paddy rice cultivation (Wikipedia, 2023a). Barnyard millet has two cultivated species. *Echinochloa frumentacea* (Indian barnyard millet) and *E. utilis* (Japanese barnyard millet) which are grown widely as minor cereal in India, China, Japan, Africa and Nepal. In India, the cultivation of barnyard millet is mainly confined to Tamil Nadu, Andhra Pradesh, Karnataka and Uttarakhand (Ganapathy *et al.,* 2021). Barnyard millet is grown for human consumption as well as fodder. It is generally cultivated in areas where climatic and edaphic conditions are unsuitable for rice cultivation. In India, it is mainly cultivated in two different agro-ecologies, one in mid hills of Himalayan region of Uttarakhand in the North and another in Deccan plateau region of Tamil Nadu in the south (Sood *et al.,* 2015). It is grown in different regions, including India, China, Africa, East Indies, Japan, the United States, and Malaysia. In India, it is mainly cultivated in Orissa, Bihar, Madhya Pradesh, Tamil Nadu, Punjab, Maharashtra, Gujarat, and on the slopes of Uttarakhand (Kumari *et al.,* 2021). The Barnyard crop is one of the most archaic crops cultivated in warm and temperate regions across the world, especially in the semi-arid tropics of Asia and Africa including the countries like India, China, Japan and Korea. Talking about India the millet is grown in Himalayan region from North to the Deccan plateau in south *i.e.,* from hilly areas to marginal areas (Bharath *et al*., 2022). Barnyard millet is grown in India, Japan and China as a substitute for rice under natural precipitation. It has a wide adaptation capacity and grown up to an altitude of 2000 m above mean sea level during summer season. Among small millets, barnyard millet is the fastest growing millet and produces a crop in 6 weeks from sowingto maturity. The plant has attracted some attention as a fodder crop in the United States and Japan (Gupta et al., 2012). Barnyard millet is primarily cultivated for human consumption, though it is also used as a livestock feed. Two barnyard millet species namely *Echinochloa frumentacea* and *E. esculenta* are under cultivation in the different parts of world (Joshi et al., 2021). In India, barnyard millet is grown in Himalayan territory in the north to the Deccan region of the south. This underutilized kharif millet grows well under rainfed conditions in slopes up to an elevation of 2,000 meters above sea level. It is usually found in the hilly areas and undulating fields of sloping, minimal, or ancestral zones, where scarcely any choices exist for crop improvement (Kumari *et al.,* 2021).

The nutritional profile of farm millet per 100 grams is: 10.1% protein, 8.7% water, 3.9% fat, 6.7% unrefined fiber, 68.8% starch, 398 kcal energy, total dietary fiber content 12.5% out of which 4.2% is soluble while 8.4% is insoluble (Kumari *et al.,* 2021). Barnyard millet has a sweet, nutty flavour, and is easy to cook with different spices. Apart from being delicious, Barnyard millet benefits heart and kidney health (Food-Health, 2023**).** The presence of a high amount of fibre, iron, and phosphorus in Barnyard millet is helpful in controlling blood sugar, blood pressure, and cholesterol levels. It has gained more popularity in the Sattvic movement to embrace native gains that are good for both humans and the environment (Food-Health, 2023**).** Barnyard millet is a hardy crop that is drought-resistant, low maintenance, and packed with nutrients. Let's see more of its nutrients to understand how Barnyard millet benefits different aspects of our life (Food-Health, 2023**).**

Propagation is usually by seed, but is also possible by planting rooted tillers. If stored dry, seed can remain viable for several years. At the beginning of the rainy season, seed is broadcast or drilled in rows 20-25 cm apart and 10-15 cm within the rows, at a seed rate of 7-10 kg/ha. A density of at least 15 000 plants/ha is required. It is usually grown as a rainfed crop, but can be grown under irrigation and in waterlogged areas as well (Partohardjono and Jansen, 2023). The yield level of barnyard millet is as high as 10 t ha^{-1} in Japan, whereas in India it is 1.5–2 t ha^{-1}. Hence, there is great scope for exploiting its potential in Indian conditions (Channappagoudar *et al.,* 2008). Yield potential of the popular released barnyard millet variety (PRI-1) is more than 2500 kg ha^{-1}, but the present maximum state average yields are very low, around 1138 kg/ha (Ganapathy *et al*., 2021). Yields of Indian barnyard millet amount to 700-800 kg/ha of grain and 1000-1500 kg/ha of straw. It is believed that it can reach a grain yield of more than 2 t/ha. As a forage crop in the United States it can produce as many as eight crops per year. Average yield of Japanese barnyard millet is 1.65 t/ha (Partohardjono and Jansen, 2023).

Naked grains are three common types that are without the hard, indigestible husk that some millets possess. Specifically, such millet categories include, Ragi, Jowar, and Bajra. These millets don't demand processing after harvest. They can directly be utilized after being washed. These are the significant types that are extensively cultivated and entirely popular due to the availability and easy procedure as compared to the other millet and their long processes. The second kind of millets is the Barnyard Millet, Kodo millet, Foxtail millets and Little millets. These millets have an indigestible seed coat. The husk on them needs to be separated prior they are fit for consumption. Millets include a multitude of micronutrients such as iron. Also, they take time to digest, which doesn't cause the blood sugar spike associated with easily digestible food. Adding millets into your diet can help you control diabetes (Vincent, 2023). The milling process may include husking, debranning and grinding. The husked grains are polished. Polished grain may be ground to flour. The grain can also be cooked like rice or processed for flaking (Partohardjono and Jansen, 2023). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Barnyard Millet are discussed.

ORIGIN AND DOMESTICATION

Japanese barnyard millet (*Echinochloa crusgalli*) is native to temperate Eurasia and was domesticated in Japan some 4000 years ago. Barnyard (sawa) millet (*E. colona*) is widely distributed in the tropics and subtropics of the Old World, and was domesticated in India (Gomez and Gupta, 2003). Barnyard millet (*Echinochloa* sp.) is one of the oldest domesticated millets in the semi-arid tropics of Asia and Africa (Sood *et al.,* 2015). *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. 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 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. 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. 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 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. 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 (Sood *et al*., 2015). The original archaeological evidence of the crop is from China, where it was cultivated since 4100 BC. *E. frumentacea* showed parallel line of evolution both in India and Africa (Joshi *et al.,* 2021). *E. esculenta* is annual crop cultivated mostly in the temperate regions of Japan, Korea, China, Russia, and Germany. It is grown in India, Japan, and China as a substitute to rice when the paddy crop cannot be grown. The crop has gained attention as a fodder in the United States and Japan (Joshi et al., 2021). *Echinochloa* genus includes 35 species that are out there in warmer and temperate regions and Barnyard millet is the usual name given to the most of these species, all of them being native to Southern or eastern Asia. It is believed that the Indian based millet was originated from undomesticated species of *Echinochloa i.e*., *Echinochloa Colona* (jungle rice) and displays a simultaneous evolution in India and Africa. Regardless of barnyard millet being an ancient crop, there are no evidence till date that shows genetic source or origin of this crop and this obscurity hinders the way of having better understanding of this species through morphological perspective, because there are almost negligible mutants phenotypically. In India barnyard millet stands to be the 2nd most significant minor millet following the finger millet (Bharath *et al*., 2022).

The earliest records of the domesticated form date to 2000 BC from the Jōmon period of Japan. Japanese barnyard millet was domesticated from *Echinochloa crus-galli*. As is common for grain domestication, it underwent grain enlargement. That part of the process took one to two thousand years, occurring in Japan (Wikipedia, 2023a). Indian barnyard millet is one of the oldest domesticated crops and archaeological records of its cultivation date back to 5000 B.C. in India and 3000 B.C in China (Bhinda *et al.,* 2023). Barnyard millet is mentioned in ancient Indian literature. More than 2000 years have passed since it was first grown in China. Some researchers believe that central Asia is where barnyard millet most likely originated. Then from Central Asia, it spread to Europe and America (Krishijagran, 2023). Barnyard millet is native to India and has been cultivated for over 4,000 years. It is widely grown in India, especially in the eastern and central regions (Tripathi and Vyas, 2023). Indian barnyard millet most probably originated from India where it has been domesticated from the wild *E. colona*. Wild *E. colona* originated from the tropics and subtropics of the Old World but can now be found in the tropics and subtropics all over the world and is very common in South-East Asia. Indian barnyard millet is known from ancient Egypt and East Africa but is at present widely grown as a cereal only in India, Kashmir and Sikkim. It has been introduced into the United States, Canada and Australia, especially as a forage. In continental South-East Asia, Indian barnyard millet is quite commonly cultivated but in Peninsular Malaysia it only occurs as a rare weed in cultivated fields. Japanese barnyard millet most probably originated from Japan where it was domesticated from the wild *E. crus-galli* some 4000 years ago, and was later introduced into Korea, China and adjacent Russia as a cultivated cereal. Wild *E. crus-galli* is native to temperate Europe and Asia but has spread to temperate and tropical areas all over the world; it is also very common in South-East Asia. Japanese barnyard millet is only extensively cultivated in Japan, Korea and northern China (Partohardjono and Jansen, 2023).

TAXONOMY

Barnyard millet belongs to Domain: Eukaryota, Kingdom: Plantae, Phylum : Spermatophyta, Subphylum: Angiospermae, Class: Monocotyledonae, Order: Cyperales, Family: Poaceae, Genus: *Echinochloa* (Sood *et al.,* 2015; Bharath *et al.,* 2022). Barnyard millet or oodalu belongs to the Family Poaceae, Subfamily Panicoideae, Genus *Echinochloa* and Species Echinochloa frumentacea Link (Sood *et al.,* 2015; Wikipedia, 2023; Wikipedia, 2023a). Two barnyard millet species namely *Echinochloa frumentacea* and *E. esculenta* are under cultivation in the different parts of world. *Echinochloa frumentacea* (Indian barnyard millet, sawa millet, or billion dollar grass) is a species of *Echinochloa*. Both *Echinochloa frumentacea* and *E. esculenta* are called Japanese millet. Synonym for *Echinochloa frumentacea* is *Panicum crus-galli* var. *edule* (FOI, 2023).

Barnyard Millet (*Echinochloa* spp.): Although sometimes referred to as a single taxonomic group, barnyard millet is composed of two separate species belonging to the genus *Echinochloa*. *Echinochloa esculenta* (syn. *Echinochloa utilis, Echinochloa crusgalli*) is cultivated in Japan, Korea, and the northeastern part of China while *Echinochloa frumentacea* (syn. *Echinochloa colona*) is found in Pakistan, India, Nepal, and central Africa. Both species have overlapping morphological traits that make differentiation problematic. Visual identification is only possible based on the presence or absence of an awn and subtle differences in spikelet and glume morphology. Consequently, the common names Japanese and Indian barnyard millet have been suggested to simplify research and investigation of their phylogeny. Despite having such strong phenotypic similarities, cytology and marker work have shown the two millets to be genetically distinct; F_1 hybrids of the two species are sterile. Both species are known for their fast maturity, high storability, and the ability to grow on poor soil. ICRISAT currently holds 743 accessions of these barnyard millets from nine countries, with a core collection of 89 varieties recently established. In addition to the two cultivated species, research has also been conducted on 20–30 wild *Echinochloa* barnyard millet relatives, some of which have agriculturally interesting traits including rice-mimicry and perennial growth habit. Hybridization within the genus is rampant, and is thought to have contributed to the evolution and current diversity of barnyard millets (Goron and Raizada, 2015).

Japanese Barnyard Millet (*Echinochloa esculenta*): Japanese barnyard millet originated in eastern Asia from its wild counterpart *E. crus-galli*, "barnyard grass". It can be differentiated from the Indian species by its larger, awned spikelets with glumes that appear papery instead of membranous. It is tolerant to cold and was historically grown in areas where the climate or land did not suit rice production, particularly in the north of Japan. In Japan, folklore states that barnyard millet originated from the dead body of a god. Along with proso millet, it makes up part of the "Gokoku," a general term for five staple grains. Japanese barnyard millet has been found in the coffins of 800-year-old mummies from the Iwate prefecture, and documents from the 1700s list different cultivars organized by maturity time. Its historical importance might be attributed to the relief it provided in times of rice crop failure. However, Japanese barnyard millet production has sharply decreased in the last century due to the introduction of cold-tolerant rice varieties and better irrigation practices. Nevertheless, today it remains the most common millet consumed in Japan, with reported health benefits common to many of the small millets such as its ability to lower plasma glucose concentration, insulin, adiponectin and tumor necrosis factor-α when fed to diabetic mice. The protein content of Japanese barnyard millet is twice as high as that of rice. Across genotypes there is diversity in the levels of proteins and healthy lipids, with one genotype suggested as having particularly beneficial antioxidant activity. The morphological and physiological diversity of Japanese barnyard millet is suggested to be high. Flowering time, inflorescence shape, and spikelet pigmentation, among other features, vary across landraces. The species can be grouped into the races *utilis* and *intermedia*. Molecular diversity studies for Japanese barnyard millet have begun using the non-coding regions of chloroplast DNA as well as nuclear molecular markers (RAPDs, SSRs) and isozymes, although these studies appear to be limited in their sample number. Though DNA sequence information in Japanese barnyard millet is otherwise lacking, studies performed on the closely related barnyard grass (*E. crus-galli*) have generated important sequence information. For example, extensive transcriptomic profiling and annotation have been performed on herbicide resistant varieties of barnyard grass resulting in 74 ESTs, which might be adapted to the study of the cultivated relative (Goron and Raizada, 2015).

Indian Barnyard Millet (*E. frumentacea*): Indian barnyard millet, or sawa, was domesticated in India across its current range from its wild counterpart *E. colona*, "jungle rice". In India, this millet is either harvested as a weed along with a main crop or is grown in a mixture with finger millet and foxtail millet. It is generally cultivated on hilly slopes in tribal areas where few other agricultural options exist and is indispensible in the northwest Himalayan region. Quick maturity makes the species well-adapted to regions with little rainfall. Indian barnyard millet contains antifeedants which are present at concentrations higher than in rice, and it displays resistance to the feeding activity of brown plant hopper. In central Africa it is fermented to make beer or used for food, and has been found in the intestines of pre-dynastic Egyptian mummies. When fed to diabetic humans, significant reductions of blood glucose levels and LDL cholesterol have been reported. Significant phenotypic variation is observed in Indian barnyard millet. Four morphological races (*laxa, robusta, intermedia*, and *stolonifera*) were recognized by de Wet in 1983 based on the lengths of flag leaves, peduncles, inflorescences, racemes, as well as plant height and basal tiller number. Race *laxa* is endemic to the Sikkim Himalayas and only available in a few collections. More recently, a variety of morphological parameters were examined, and principle component analysis (PCA) indicated three morphotypes corresponding to races *robusta, intermedia*, and *stolonifera; laxa* was absent suggesting that efforts must be made to collect more of this race. The authors saw high variability in grain yield, straw yield, and number of productive tillers. They report that the number of racemes, flag leaf width, and internode length showed high correlation with grain yield and should be considered by breeders when performing selections, and promising donor genotypes of these and other traits have been reported. Variation across genotypes in photosynthesis and related traits such as transpiration and stomatal conductance has also been observed. Grain smut (*Ustilago panici-frumentacei*) is a major hindrance of yield, but progress has been made in advanced breeding lines which display low susceptibility when compared to other accessions in which high variability remains. An early study using RAPD markers suggested that the sequence diversity of Indian barnyard millet is significantly higher than the Japanese species, perhaps because of multiple domestication events in different locations across India. Variation of markers was 44%, which is high when considering the inbreeding nature of the crop. However, more comprehensive studies are needed that utilize a greater number of molecular markers and genotypes. Similarly, DNA sequence analyses are lacking in Indian barnyard millet (Goron and Raizada, 2015).

Two species are included in barnyard millet: *Echinochloa utilis* and *E. frumentacea*. These differ from each other in their genomic constitution and phylogeny. The former species originated from *E. crus-galli* probably in eastern Asia, and is grown in Japan, Korea, and the northeastern part of China; the latter originated from *E. colona* probably in tropical Asia, and is grown in Pakistan, India, and Nepal. "Japanese barnyard millet" is suggested as a suitable English common name for *E. utilis*; "Indian barnyard millet," for *E. frumentacea* (Yabuno, 1987). Of around 35 species, two main species, *E. esculenta* (A. Braun) H. Scholz; syn. *E. utilis* Ohwi et Yabuno (Japanese barnyard millet) and *E. frumentacea* Link; syn. *E. colona* var *frumentacea* (Link) Ridl. (Indian barnyard millet), are cultivated as minor cereals in Japan, Korea, the north-eastern parts of China and India, Pakistan and Nepal, respectively. Besides these two species *viz*., allohexaploid *E. crus-galli*, Lijiang millet and allotetraploid *E. oryzicola*, Mosou barnyard millet are under cultivation in China (Sood *et al.,* 2015).

The genus *Echinochloa* consists of approximately 250 annual and perennial species that are widely distributed in the warmer and temperate parts of the world. However, the lack of clarity over the *Echinochloa* species makes it hard to differentiate themselves via the morphological markers due to low interspecific and intraspecific variations in nature and their phenotype plasticity. Despite this challenge, 35 species have been identified to date for their taxa and phylogenetic relationship through morphological, cytological, and molecular marker studies. Among them, most of the *Echinochloa* species, including *E. crus-galli* (allohexaploid, $2n = 6x = 54$), *E. colona* (allohexaploid, $2n = 6x = 54$), *E. oryzicola* (allotetraploid, $2n = 4x = 36$), and others, have been designated as problematic weeds in major crop fields. *E. crus-galli* is a predominant weed in rice fields in more than 60 countries, due to its quick germination, rapid growth, mimicking character of rice, broad ecological tolerance, and profuse seed production (Renganathan *et al.,* 2020).

Echinochloa species have very few cultivatable forms and thereby are cultivated as minor millet by marginal farmers in warmer and temperate regions of the world. *E. frumentacea* (Roxb.) Link; syn. *E. colona* var. *frumentacea* (allohexaploid, $2n = 6x = 54$), commonly known as Indian barnyard millet, originated from wild *E. colona* (L.) (Jungle rice), and exhibits a parallel line of evolution in India and Africa. Another cultivated allohexaploid species, *E. esculenta* (A. Braun) H. Scholz; syn. ×*E. utilis* var. *esculenta*; known as Japanese barnyard millet, originated from wild *E. crus-galli* (L.) (Barnyard grass) was domesticated some 4,000 years ago in the temperate regions of Japan. *utilis* and *intermedia* are two races of *E. crus-galli*, widely cultivated in Japan, Korea, China, Russia, and Germany. Both wild and cultivated *Echinochloa* species are different from each other in terms of growth habitat, general morphology, and other characteristics. The interspecific relationship between *Echinochloa* species was unclear till a series of prominent taxonomic reports. The interspecific hybrids between wild species and its progenitor, *i.e*., *E. crus-galli X E. esculenta* and ×*E. colona X E. frumentacea* produce normal meiotic division (27 bivalents) *i.e.,* fertile. But, interspecific hybrids between two cultivated species and their respective wild counterparts, *E. esculenta* × *E. frumentacea* and *E. crus-galli* × *E. colona*, showed irregular meiotic division that leads to sterility. Collectively, all the cytological studies reveal the poor genomic affinity among species of *Echinochloa* (Renganathan *et al.,* 2020).

The Genus *Echinochloa* comprises about 250 enduring species that are broadly cultivated in different agro- climatic conditions around the globe. The scarcity of information about the various species of *Echinochloa* leads to difficulty in identifying its morphological characteristics as well as its aggregate versatility due to its insignificant interspecific-intraspecific variation. Thirty-five species have been identified to date by morphological, cytological, and subatomic marker examination for their taxa and phylogenetic relationship. Different species of *Echinochloa* include *E. crus-galli* (allohexaploid*), E. colona* (allohexaploid), and *E. oryzicola* (allotetraploid), while the rest are identified as weeds. *E. crus-galli* is the fastest growing weed in rice fields and is found in more than in 60 nations due to its capability to grow even in extreme conditions; it can grow in hypoxic conditions and can penetrate a depth of 100 mm, it has extensive natural resistance, lavish seed production, and imitates the characteristics of rice. Most of its species are not commercially cultivatable but are grown as minor millets by a few ranchers around the globe. *E. frumentacea,* commonly referred to as Indian farm millet, is derived from a wild species *E. colona* (L.) and shows an equal cultivation trend in India and Africa. Both wild and developed *Echinochloa* species do not contain the same morphological and developmental characteristics (Kumari *et al.,* 2021). The genus *Echinochloa* includes about 20 species which are distributed in tropical parts of the world (Joshi et al., 2021). *Echinochloa* genus includes 35 species. Under the genus *Echinochloa* on the basis of inflorescence it is divided into two species, four subspecies and eight races and its inflorescence pattern is simple and reliable and it aids us to understand not only patterns of variation but also helps in knowing their evolutionary paths (Bharath *et al*., 2022).

The genus *Echinochloa* includes 250 described annual and perennial species, of which *E. frumentacea* (Indian barnyard millet) and *E. esculenta* (Japanese barnyard millet) are the most important and widely cultivated. All the species of genus *Echinochloa* have wide adaptation and scattered throughout the warmer and temperate regions of the globe. *Echinochloa frumentacea* (Roxb.) Link; syn. *E. colona* var. *frumentacea* is generally acknowledged as Indian barnyard millet and thought to have originated from its wild hexaploid ($2n = 6x = 54$) progenitor *E. Colona*. The wild barnyard millet (*Echinochloa colona*) is a common weed of rice fields, and in several parts of India, it is used as a food source during extreme drought spells (Bhinda *et al*., 2023). *Echinochloa* is a difficult genus, forming a complex of probably 30-40 species which are not reliably distinguishable from each other because of numerous intermediate forms. Its great diversity is caused by self pollination combined with easy adaptation to a wide range of aquatic and ruderal habitats. The genus can usually be recognized by its bristly sharp-pointed or awned spikelets in 4 rows with a recurved palea tip as best diagnostic character. Much confusion about names and identities exists and a thorough taxonomic revision is urgently needed. The taxa and culta of *E. colona* and *E. crus-galli* are not easy to distinguish from each other. In general, *E. colona* is a more tropical grass with awnless, smaller spikelets having membranous glumes and *E. crus-galli* is a more temperate grass with awned, larger spikelets having chartaceous glumes, although awnless *E. crus-galli* occurs as well. In general, the culta are robuster plants, with larger and denser inflorescences bearing persistent spikelets. Hybrids between *E. colona* and *E. crus-galli* are sterile (both the wild and cultivated forms), but within each individual species, hybrids between the wild and cultivated forms are fully or at least partly fertile (Partohardjono and Jansen, 2023).

Major taxa and synonyms (Partohardjono and Jansen, 2023)

- *Echinochloa colona* (L.) Link cv. group *frumentacea*, Hort. Berol. 2: 209 (1833); cv. group name proposed here.

Synonyms

- *E. frumentacea* (Roxb.) Link (1827),
- *E. crus-galli* (L.) P. Beauvois var. *frumentaceum* (Link) Trimen (1885),
- *E. colona* (L.) Link var. *frumentaceum* (Roxb.) Ridley (1925).
- *Echinochloa crus-galli* (L.) P. Beauvois cv. group *esculenta*, Ess. *agrost*.: 53, 161 (1812); cv. group name proposed here.

Synonyms

- *Panicum esculentum* A. Braun (1861),
- *E. utilis* Ohwi & Yabuno (1962),
- *E. esculenta* (A. Braun) H. Scholz (1992).

The names in different countries are as follows (Partohardjono and Jansen, 2023):

***E. colona* cv. group *frumentacea*:**

- Indian barnyard millet, sawa millet, shama millet (En). For wild *E. colona* : jungle rice (En)
- Indonesia: tuton, watuton (Javanese), jajagoan leutik (Sundanese)
- Malaysia: padi burong, rumput kusa-kusa
- Philippines: pulang-puwit (Tagalog), guinga (Visaya), dakayang (Ilokano)
- Burma (Myanmar): myet-thi, pazun-sa-myet
- Laos: khau znôk
- Thailand: ya-noksichomphu (central), ya-nokkhao (northeastern)
- Vietnam: cỏ lồng vực, cỏ núc, cỏ lồng vực hạt.

***E. crus-galli* cv. group *esculenta*:**

- Japanese barnyard millet, Japanese millet (En). For wild *E. crus-galli* : barnyard grass, cock's foot (En). Crête-de-coq, pattes de poule (Fr)
- Indonesia: jawan (Javanese), jajagoan (Sundanese), gagajahan (Sundanese)
- Malaysia: padi burong, rumput kekusa besar
- Philippines: bayokibok (Tagalog), lagtom (Bikol), marapagay (Ilokano)
- Burma (Myanmar): myet-ihi
- Cambodia: smao bek kbol
- Thailand: ya-plonglaman, ya-khaonok (central)
- Vietnam: cỏ lồng vực.

The species of *Echinochloa* are given in Table 1 (Sood *et al.*, 2015).

Table 1. *Echinochloa* species

1) *Echinochloa brevipedicellata*
2) *Echinochloa callopus*
3) *Echinochloa chacoensis*
4) *Echinochloa colona*
5) *Echinochloa crus-galli*
6) *Echinochloa cruspavonis*
7) *Echinochloa telmatophila*
8) *Echinochloa elliptica*
9) *Echinochloa esculenta*
10) *Echinochloa frumentacea*
11) *Echinochloa haploclada*
12) *Echinochloa helodes*
13) *Echinochloa holciformis*
14) *Echinochloa inundata*
15) *Echinochloa jaliscana*
16) *Echinochloa jubata*
17) *Echinochloa kimberleyensis*
18) *Echinochloa lacunaria*
19) *Echinochloa macrandra*
20) *Echinochloa muricata*
21) *Echinochloa obtusiflora*
22) *Echinochloa oplismenoides*
23) *Echinochloa oryzoides*
24) *Echinochloa paludigena*
25) *Echinochloa picta*
26) *Echinochloa pithopus*
27) *Echinochloa polystachya*
28) *Echinochloa praestans*
29) *Echinochloa pyramidalis*
30) *Echinochloa rotundiflora*
31) *Echinochloa stagnina*
32) *Echinochloa telmatophila*
33) *Echinochloa turneriana*
34) *Echinochloa ugandensis*
35) *Echinochloa walteri*

Synonyms of barnyard millet are given in Table 2 (Wikipedia, 2023; Wikipedia, 2023a).

Table 2. Synonyms of barnyard millet

1)	*Echinochloa colona* var. *frumentacea* (Link) Ridl.
2)	*Echinochloa crus-galli* var. *edulis* Hitchc. nom. illeg.
3)	*Echinochloa crus-galli* var. *edulis* Honda
4)	*Echinochloa crus-galli* var. *frumentacea* (Link) W.F.Wright
5)	*Echinochloa crusgalli* var. *frumentacea* W. Wight
6)	*Echinochloa glabrescens* var. *barbata* Kossenko
7)	*Oplismenus frumentaceus* (Link) Kunth
8)	*Panicum crus-galli* var. *edule* (Hitchc.) Thell. ex de Lesd.
9)	*Panicum crus-galli* var. *edulis* (Hitchc.) Makino & Nemoto
10)	*Panicum crus-galli* var. *frumentacea* (Link) Trimen
11)	*Panicum crus-galli* var. *frumentaceum* (Roxb.) Trimen
12)	*Panicum frumentaceum* Roxb. nom. illeg.

Cultivar groups: Based on the morphology of inflorescence, *E. frumentacea* has been classified into four races, namely, *stolonifera*, *intermedia*, *robusta,* and *laxa,* which are widely distributed in India, Nepal, China, Central Africa, Malawi, and Tanzania (Renganathan *et al*., 2020; Bhinda *et al*., 2023). In India, 4 cultivar subgroups (races) can be distinguished within Indian barnyard millet (*Intermedia, Laxa, Robusta, and Stolonifera*), differing in qualitative and quantitative characteristics; some differences are (average values given in the sequence in which the 4 cv. subgroups were mentioned above): days to 50% flowering: 46, 63, 60, 46; plant height: 81, 111, 128, 70 cm; number of basal tillers: 11, 7, 6, 21; panicle length × width: 13 cm × 3 cm, 22 cm × 3 cm, 21 cm × 4 cm, 11 cm × 2 cm; number of primary inflorescence branches (racemes): 23, 39, 47, 16; raceme length: 28, 69, 31, 22 mm; number of spikelet rows: 5, 4, 5, 4. Farmers commonly grow several different subgroups together in the same field (Partohardjono and Jansen, 2023).

Fig. 2: Panicles of two cultivated species

(a) *Echinochloa esculenta* (b) *Echinochloa frumentacea*

BOTANICAL DESCRIPTION

Barnyard millet has a wide adaptation capacity and can grow up to an altitude of 2000 m above mean sea level during summer season. It is variable in flowering time, inflorescence shape, morphological features, pigmentation of spikelets, plant type and other plant traits. The crop plant is a tall, robust annual and grows up to 220 cm high. It has a short generation time, fastest growth among all small millets and completes the life cycle from seed to seed in 45–60 days (depending upon accession and growth environment), however, may take longer time under northern hill ecosystem. *Echinocloa* millets grow well in different seasons but at high elevations may require 3–4 months to mature. Leaf blades are flat and wide with no ligules. The inflorescence is a terminal panicle 10–25 cm long with dense racemes of 3- to 4-mm-long spikelets. The inflorescence is usually erect, rarely drooping with shapes varying from cylindrical, pyramidal and globose to elliptic. Racemes are few to numerous, densely crowded with spikelets arranged in four irregular rows on the triquetrous rachis and are loosely or tightly appended on the rachis. The spikelets are green, brown to purple in colour and crowded on one side of the rachis. Spikelets are two flowered, awnless or awned, with red or green awns and placed on short rough pedicels subtended by two glumes. Lower floret is neuter (sterile) with lemma and small palea, and upper floret is bisexual. The sterile lemma is 5-veined. Fertile lemma is plano-convex, elliptic, smooth and shiny, abruptly sharp-pointed or cuspidate, and margins are inrolled below over palea with apex of palea not enclosed. The palea is flat, and surface texture is similar to fertile lemma. Stamens are three in number, and ovary superior contains two distinct styles with plumose stigma. Grain is 2–3 mm long and 1–2 mm wide and enclosed in white shinning hardened lemma and palea. The flowering starts from top of the inflorescence and moves downward completing in 10–15 days. Flowers open from 5 to 10 am with maximum number of flower opens between 6 and 7 am. In the individual raceme, the flowering first starts at marginal ends and then proceeds to the middle of the raceme.

The flowers are hermaphrodite (have both male and female organs). Before the anthers dehiscence, the stigmatic branches spread and flower opens. Late season florets are cleistogamous (not opening). It is primarily self-pollinating and self-compatible. Some degree of outcrossing recorded which was facilitated by wind pollination. Hot water treatment of inflorescence at 48°C for 4–5 min (personal observation) was effective in inducing male sterility under hill condition in both the cultivated species (Fig. 3, 4) (Sood *et al.,* 2015).

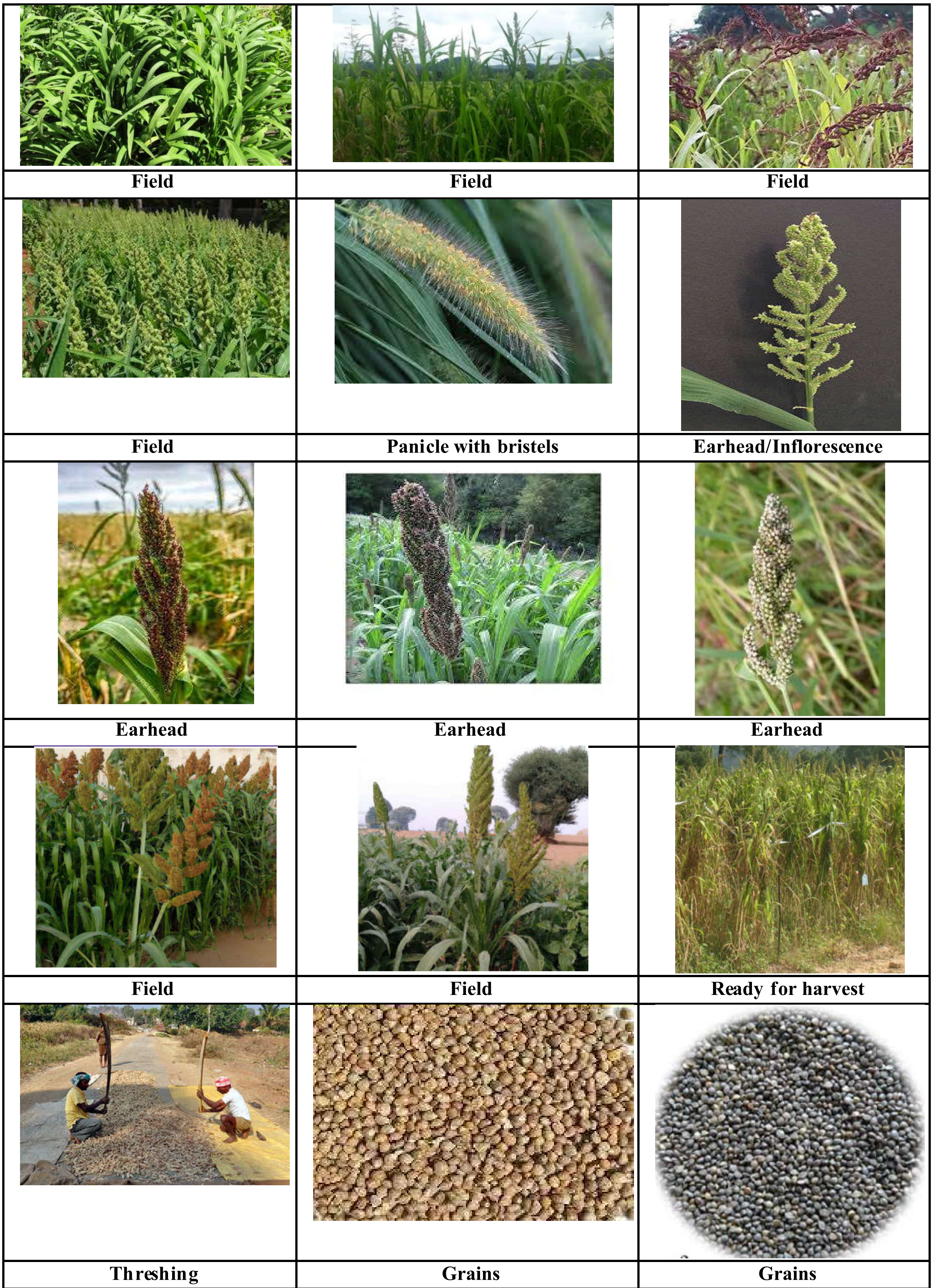

Fig. 3 : Botanical Description

Fig. 4. Grain with husk and Grain without husk

Cultivated plants of *E. colona* (L.) Link. are erect or geniculate ascending, often tufted, annual, and up to 242 cm tall. Culms are slender to robust. Slender plants are decumbent, with the culms strongly branched and rooting from the lower nodes. Stout plants are erect, with a few culm branches from the upper nodes. Inflorescences are variable; decumbent plants are characterized by short racemes that are appressed to the primary axis, whereas more robust plants have larger, pyramidal inflorescences with spreading lower racemes. Inflorescences are usually erect, rarely drooping, and can be up to 28 cm long. Spikelets are persistent at maturity, 2–4 mm long, acute but never awned. The grain is 2–3 mm long and 1–2 mm wide (Gomez and Gupta, 2003). Cultivated plants of *E. crusgalli* (L.) P. Beauv. are erect, tufted, annual and up to 100 cm tall. Culms are mostly robust, simple, or branched from the upper nodes. Inflorescences are erect or slightly nodding, well exertion from the upper leaf sheath, with the spike-like racemes more or less erect and sometimes incurved at the tip. Spikelets are persistent at maturity, very crowded, 3–4 mm long, shortly cuspidate but rarely awned. The grain is 2–3 mm long and almost as wide (Gomez and Gupta, 2003). Japanese Millet is a robust annual herb with stems 30-150 cm high, erect. Leaf-blades often broad, 5-30 cm long, 3-20 mm wide; ligule absent; sheaths hairless. Flower-clusters are lanceshaped, 6-20 cm long, the racemes several-rowed with crowded spikelets, 1-3 cm long, simple, closely spaced and overlapping. Spikelets are broadly elliptic to rotund, 2.5-3.5 mm long, plump and sometimes gaping, tardily deciduous, mostly yellowish or pallid, velvet-hairy to bristly; lower lemma pointed; upper lemma 2-3 mm long. Japanese Millet is found in Tropical East Africa, India, Pakistan and Australia. This millet is widely grown as a cereal in India, Pakistan, and Nepal (FOI, 2023)

Annual or perennial herbs. Leaves usually without a ligule. Inflorescence consists of racemes arranged along a central axis; spikelets paired or in short secondary small racemes, typically densely packed in 4 rows, narrowly elliptical to subrotund, flat on one side, gibbous on the other, often hispidulous, sometimes prolonged at the base into a short cylindrical stipe, cuspidate or awned at apex. Florets 2, the lower staminate or neuter, the upper perfect; glumes acute to acuminate, about one third the length of the spikelet; lower lemma often stiffly awned; upper lemma terminating in a short membranous, laterally compressed, incurved beak; upper palea acute, the tip briefly reflexed and slightly protuberant from the lemma (Partohardjono and Jansen, 2023). *E. colona* cv. Group *frumentacea*: Erect or geniculate ascending, often tufted annual, 0.6-2.4 m tall. Culm slender to robust; slender plants decumbent with strongly branched culms, rooting from the lower nodes; robust plants erect, only branching at the upper nodes. Leaf sheath glabrous, usually longer than the internode; ligular area minutely pubescent; leaf blade linear, 8-38 cm × 0.6-4 cm, subglabrous. Inflorescence usually erect, in decumbent plants with short racemes appressed to the triquetrous rachis, in erect plants with spreading lower racemes giving the inflorescence a larger pyramidal shape; pedicel 2-4-nate, up to 2 mm long; spikelet persistent, 2-4 mm long, acute but never awned; glumes and lower lemma typically membranaceous; lower glume about one third the length of the spikelet, upper glume somewhat shorter than the spikelet, ciliolate; lower lemma similar to upper glume; lower floret sterile, upper floret bisexual. Caryopsis broadly ellipsoid, 2-3 mm long, 1-2 mm wide. The 1000-grain weight of barnyard millet is 3-4 g (Partohardjono and Jansen, 2023). *E. crus-galli* cv. group *esculenta*: Erect, tufted annual, up to 1 m tall. Culm usually robust, simple or branched from the upper nodes. Leaf sheath glabrous, usually longer than the internode; ligular area glabrous; leaf blade linear, 15-40 cm × 0.5-2.5 cm, glabrous. Inflorescence erect or slightly nodding, with spike-like racemes that are erect or sometimes incurved at the tip; primary axis densely white setose at the nodes; racemes 10-25, 1-5 cm long, purple, subsessile, densely multispiculate; rachis compressed and angular; pedicel short and mostly 2-nate; spikelet persistent, 3-4 mm long, shortly cuspidate, rarely awned; glumes and lower lemma chartaceous; lower glume about one third the length of the spikelet; upper glume usually shorter than the spikelet, cuspidate, veins and margins sometimes subspinulose; lower lemma similar to upper glume; lower floret sterile, upper floret bisexual. Caryopsis 2-3 mm long and wide (Partohardjono and Jansen, 2023).

The *E. frumentacea* plant is an annual herb growing 1.0-2.2 m tall characterized by slender to strong culm. In general, plants are green in color, but there are violet tinges in the somatic as well as sexual parts. The plants are generally characterized by smooth, glabrous, and liguleless leaves with slight hairiness and an arc of 15-40 cm long and 1-2.5 cm wide. The inflorescence is a typically erect and terminal panicle (10-28 cm long) of green to violet color, with numerous and 1-3 cm long racemes, seldom drooping, and mostly awnless . The spikelet present on the panicle is small, unbranched, densely packed in three to five rows, 2-4 mm long, acute, and awnless on the rachis. The spikelet is occupied with stiff bristles and congested. The spikelets are subsided by two glumes within which there are two florets. The upper floret is bisexual, while the lower floret is sterile. The color of the glume varies from white to red. There are three stamens present, and two distinct types of styles each with plumose stigma are found on the superior ovary. The blooming begins at the inflorescence apex and progresses down and usually takes 10-15 days to complete. Anthesis starts from 5 to 10 a.m., while most of the flowers open between 6 and 7 a.m. Flowering begins first at the marginal ends of each raceme and progresses to the individual raceme's center. The stigmatic branches extent and the hermaphrodite flower opens afore the anthers dehisce. *E. frumentacea* has smaller, awnless spikelets, with membranous glumes, whereas *Echinochloa esculenta* has large generally awned spikelets with cretaceous upper glumes and lower lemma. Contact method is the traditional hybridization method followed in barnyard millet. However, growing all seeds harvested from female panicle for identification of few hybrid plants in contact method requires more resources time, space, and labor. Hot water treatment of inflorescence at 48^0 C for 4-5 min was also found effective for the emasculation under hill conditions (79^039' E and 29^035' altitude 1250 m amsl) in barnyard millet.

In contrast to the contact method, only few seeds set in the female panicle in hot water treatment, most of which give rise to hybrid plants. Grain is around 2-3 mm in length and 1-2 mm in width and bounded by hardened lemma and palea with white shining. The grain color is generally yellow or white (Bhinda *et al.,* 2023).

Floral Biology: The cultivated barnyard millet is an annual, robust, and tall crop that grows up to a height of 220 cm. The inflorescence is a terminal panicle with varying shapes (cylindrical, pyramidal, and globose to elliptic), colors (green, light purple, and dark purple) and compactness (compact, intermediate, and open). Racemes are present in one side, two sides, or around the axis of rachis and vary from 22 to 64 numbers per inflorescence. The arrangement of spikelets is either on one side or around the rachis of the raceme. Each spikelet contains two florets in which the lower floret is sterile and consists of lemma with small palea, while the upper floret is bisexual with a shiny lemma that partially encloses palea. Fertile lemma and palea have three stamens varying from a white color to a dark purplish color with stigma plumose and bifid, ranging from white to dark purple. The two unequal glumes further enclose the seed kernel. Anthesis and pollination progress in the direction from top to bottom of the inflorescence in the early morning (5 am) and reaches a maximum during 6 am to 7 am, while it closes at 10 am. It was further reported on the requirement of 10–14 days of duration for the flowering process. Though self-pollination is a strict rule, the reception of stigmatic branches before dehiscence of anther provides some chances for cross- pollination. Barnyard millet grains are less hard. The mature pericarp of the seed consists of two epidermal layers with cells of the inner epidermis completely compressed over the outer epidermis. The cell wall of the aleuronic layer cutinized and also contains a maximum amount of carbohydrate (57–66%), followed by fiber (6.4–12.2%), protein (5–8.5%), fat (3.5–4.6%), and ash (2.5–4.0%) content. Starch granules are simple and are spherical to polygonal shapes with a diameter of 1.2–10 μm, which is larger than other small millets. The pericarp color of grain differs among genotypes from straw white to light gray and dark gray (Fig. 5, 6, 7) (Renganathan *et al.*, 2020).

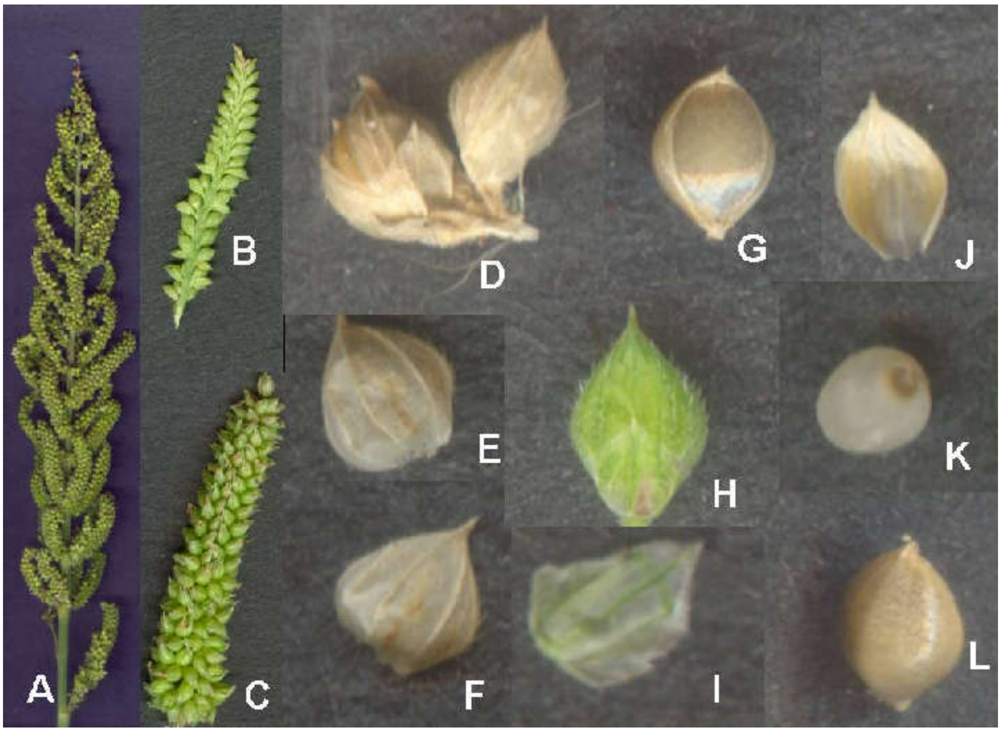

Fig. 5. Barnyard millet inflorescence and its parts. (A) Inflorescence; (B) Arrangement of spikelet in raceme; (C) Raceme; (D) Spikelet; (E) Lower lemma; (F) Upper glume; (G) Side view of fertile lemma enclosing grain; (H) View of spikelet from lower glume side; (I) Lower glume; (J) Fertile lemma; (K) Grain; (L) Grain enclosed in lemma and palea

Fig. 6. Variation in anther color a) White, b) Light purple, c) Dark purple

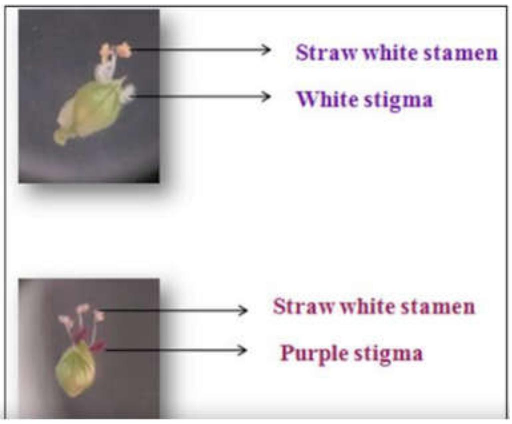

Fig.7. Stamen and stigma color

Barnyard millet inflorescence is usually erect, rarely drooping terminal panicle. The racemes are few to numerous, densely crowded at the apex with spikelets arranged in 4 irregular rows on the triquetrous rachis. The spikelets are two-flowered, 2-3 mm long, ovate to elliptical, lower lemma awnless but sharp pointed, sub-sessile, and placed on short rough pedicels subtended by two glumes. The lower glume is about one third of spikelet, while upper glume is somewhat shorter than spikelet. The glumes and lower lemma are slightly pubescent.The lower floret is neuter (sterile) having lemma and small palea, while upper floret is bisexual. The sterile lemma is 5-veined. The fertile lemma is plano-convex, elliptic, smooth and shiny, abruptly sharp-pointed or cuspidate, margins are inrolled below over palea with apex of palea not being enclosed. The palea is flat and surface texture is similar to fertile lemma. The stamens are three in number, ovary superior contains two distinct styles with plumose stigma. The grain is tightly enclosed in white shinning hardened lemma and palea (Gupta *et al.,* 2012). The flower opens in the upper raceme first and flowering is from the top of inflorescence to downwards. The panicle takes 10-14 days for emergence and takes 10-15 for com- pletion of flowering under the hill conditions. The maxi- mum number of florets opens during 6-8 days after flowering. Flowers open from 5-10 a.m. with maximum number of flower opens between 6-7 a.m. Within a individual raceme the flowering first starts at both the marginal ends first and then proceed to the middle of the raceme. Before the anthers dehiscence, the stigmatic branches spread and flower opens. The flower closes within half an hour. It is highlyself-pollinated species. Hot water treatment of inflorescenceat 48°C for 4-5 min was also found effective in inducing male sterility under hill condition in barnyard millet (Gupta *et al.,* 2012).

GENETICS AND CYTOGENETICS

Not much genetic work has been done on this crop. The basic number of *Echinochloa* is 9, and Japanese wild species, *E. crus-galli* (Linn.) Beauv., contains tetra- and hexaploid varieties, and Japanese cultivated strains are hexaploid. At the same time it was concluded that Japanese cultivated strains and Japanese hexaploid varieties of *E. crus-galli* have the same genome constitution in common, and it was further assumed that hexaploid varieties of *E. crus-galli* is an ancestral form of the cultivated species (Yabuno, 1962). Barnyard millet is an important crop for many smallholder farmers in southern and eastern Asia. It is valued for its drought tolerance, rapid maturation, and superior nutritional qualities. Despite these characteristics there are almost no genetic or genomic resources for this crop in either cultivated species [*E. colona* (L.) Link and *E. crus-galli* (L.) P. Beauv.]. Recently, a core collection of 89 barnyard millet accessions was developed at the genebank at the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT). To enhance the use of this germplasm and genomic research in barnyard millet improvement, we report the genetic characterization of this core collection using whole-genome genotyping-by-sequencing. We identified several thousand single-nucleotide polymorphisms segregating in the core collection, and we use them to show patterns of population structure and phylogenetic relationships among the accessions. We determine that there are probably four population clusters within the *E. colona* accessions and three such clusters within *E. crus-galli.* These clusters match phylogenetic relationships but by and large do not correspond to classification into individual races or clusters based on morphology. Geospatial data available for a subset of samples indicates that the clusters probably originate from geographic divisions. In all, these data will be useful to breeders working to improve this crop for smallholder farmers. This work also serves as a case study of how modern genomics can rapidly characterize crops, including ones with little to no prior genetic data (Wallace *et al.,* 2015).

Muthamilarasana et al. (2016) reported variation in ploidy levels and chromosome numbers in barnyard millet (Table 3).

Table 3. Variations in ploidy levels and chromosome numbers among different barnyard millet

Millet species	Ploidy	Chromosome numbers
Barnyard millet (Subfamily: Panicoideae; Tribe: Paniceae)		
Echinochloa colona	Tetraploid, hexaploid, octaploid	36, 54, 72
E. crus-galli	Hexaploid	36
E. crusgalli	Tetraploid, hexaploid	36, 54
E. oryzoides	Tetraploid	36

Millets thus constitute the most important cereal food source in the developing countries particularly in the arid and semi-arid regions of the world. Millets belong to the family Gramineae and important cultivated millet species include *Echinochloa frumentacea* (barnyard millet). This millet species is often referred to as minor millet.

This minor millet is the principal source of cereal to the people of rural working class in Asia and Africa, but their improvement has received little attention. Information on cytogenetics of cultivated species and their wild relatives is essential for any sound plant improvement programme (Chennaveeraiah and Hire math, 1991). With an objective to identify potential parents and crosses for quantitative and nutrient related characters and to understand the gene action for different traits for further improvement, an investigation was carried out in barnyard millet with diallel analysis involving five parents (CO 2, ACM 145, ACM 161, ACM 331 and ACM 332). Five parents and twenty crosses were evaluated for thirteen quantitative and four nutrient traits. The GCA, SCA and RCA variances were significant for almost all the characters suggesting the importance of both additive and non-additive gene action with pre-ponderance of non-additive gene action and significant reciprocal differences indicating the inter action between cytoplasm and the nuclear gene effects. However, for single plant yield the gene action was additive as the ratio of GCA to SCA variances was more than one. In the evaluation of parents, taking per se performance and gca effects as criteria the parents in the order ACM 145, ACM 161 and CO 2 were identified as the best general combiners. The crosses ACM 145/CO 2 and ACM 145/ACM 161 were selected as superior over others based on per se performance, SCA effects and heterosis percent together and are suggested for utilization in heterosis breeding. Non-significant SCA effect was possessed by CO 2/ACM 145 and CO 2/ACM 161 and they could be used for improvement of grain yield by recombination breeding to isolate useful segregants (Vishnuprabha and Vanniarajan, 2019). Current agricultural and food systems encourage research and development on major crops, neglecting regionally important minor crops. Small millets include a group of small- seeded cereal crops of the grass family *Poaceae*. This includes finger millet, foxtail millet, proso millet, barnyard millet, kodo millet, little millet, teff, fonio, job's tears, guinea millet, and browntop millet. Small millets are an excellent choice to supplement major staple foods for crop and dietary diversity because of their diverse adaptation on marginal lands, less water requirement, lesser susceptibility to stresses, and nutritional superiority compared to major cereal staples. Growing interest among consumers about healthy diets together with climate-resilient features of small millets underline the necessity of directing more research and development towards these crops. Except for finger millet and foxtail millet, and to some extent proso millet and teff, other small millets have received minimal research attention in terms of development of genetic and genomic resources and breeding for yield enhancement. Considerable breeding efforts were made in finger millet and foxtail millet in India and China, respectively, proso millet in the United States of America, and teff in Ethiopia. So far, five genomes, namely foxtail millet, finger millet, proso millet, teff, and Japanese barnyard millet, have been sequenced, and genome of foxtail millet is the smallest (423-510 Mb) while the largest one is finger millet (1.5 Gb). Recent advances in phenotyping and genomics technologies, together with available germplasm diversity, could be utilized in small millets improvement. This review provides a comprehensive insight into the importance of small millets, the global status of their germplasm, diversity, promising germplasm resources, and breeding approaches (conventional and genomic approaches) to accelerate climate-resilient and nutrient-dense small millets for sustainable agriculture, environment, and healthy food systems (Vetriventhan *et al*., 2020). The two species (*Echinochloa crusgalli* and E. colona) have different chromosome numbers (2n = 54 and 2n = 36, respectively), and hybrids between them are sterile (Gomez and Gupta, 2003).

GENETIC VARIABILITY

The inflorescence is a terminal panicle with varying shapes (cylindrical, pyramidal, and globose to elliptic), colors (green, light purple, and dark purple) and compactness (compact, intermediate, and open). Racemes are present in one side, two sides, or around the axis of rachis and vary from 22 to 64 numbers per inflorescence. The arrangement of spikelets is either on one side or around the rachis of the raceme. Each spikelet contains two florets in which the lower floret is sterile and consists of lemma with small palea, while the upper floret is bisexual with a shiny lemma that partially encloses palea. Fertile lemma and palea have three stamens varying from a white color to a dark purplish color with stigma plumose and bifid, ranging from white to dark purple. The two unequal glumes further enclose the seed kernel **(Fig. 8-14)** (Renganathan *et al*., 2020).

Fig. 8. Variation in tillering and pigmentation a) High tillers, Green, b) Medium tillers, Light pigmentation, c) Low tillers, Dark pigmentation

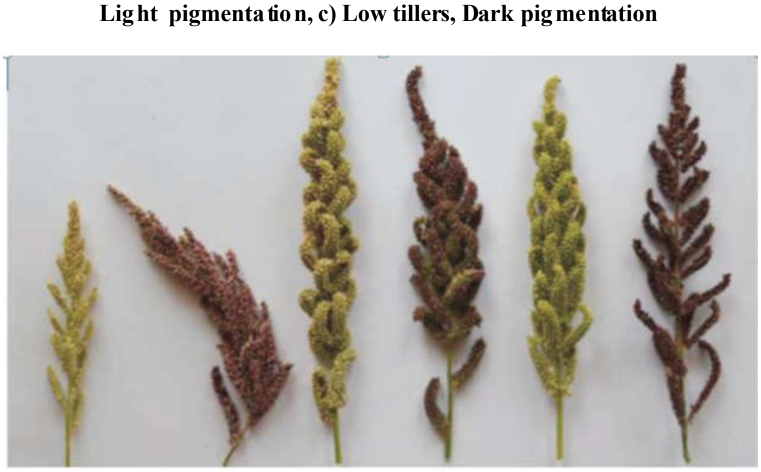

Fig. 9. Different shapes of the panicle

Fig. 10. Panicle compactness. 1) Open 2) Intermediate 3) Compact

Fig. 11. Variation in earhead color a) Green, b) Medium purple, c) Dark purple

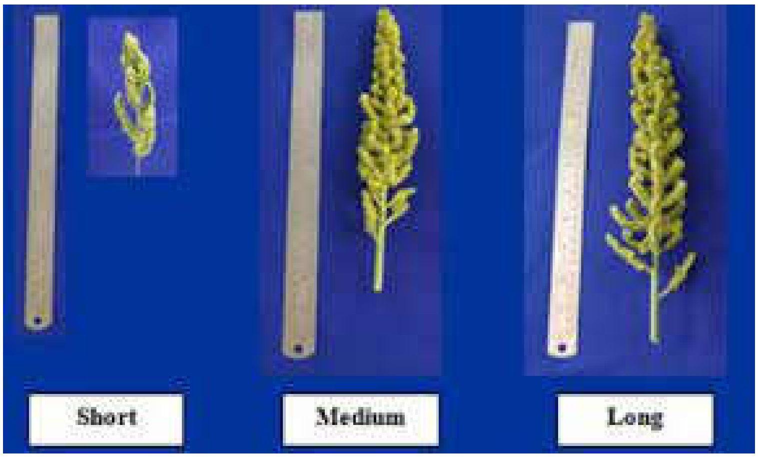

Fig. 12. Panicle length

Fig. 13. Spikelet arrangement

Fig. 14: Genetic Diversity of seeds

Eighteen improved strains of barnyard millet, including 3 local controls, were grown in Uttaranchal, India. Observations were recorded 14 morpho-physiological and yield-related characters. Highly significant differences were observed for all characters, indicating substantial divergence in the collection. D^2 analysis grouped the 18 genotypes into 8 clusters, with cluster II consisting the most number of genotypes (10). Intercluster distance was highest between clusters VI and VIII and lowest between clusters I and II. Path analysis showed that heat units at maturity, photothermal units at 50% flowering, plant height and panicle weight had high direct effects on grain yield. Thus, selection for these characters may result in yield improvement in barnyard millet (Mehta *et al*., 2005). One hundred ninety four accessions of barnyard millet collected from different eco-geographical regions of India were evaluated for 14 quantitative traits. These accessions were grouped into 5 groups on the basis of place of collection. These groups differed significantly in their mean values for quantitative traits and magnitude of correlation among traits indicates origin based association. The group 'C' (source of origin is unknown) was found most diverse group (mean coefficient of variation 17.67%), while rest of the groups recorded mean coefficient of variation between 12 and 13%. Correlation studies indicate that flag leaf width, number of racemes along with internode length should be considered while performing selection in segregating generations. The plotting of first and second principal component axes scores suggests that presence of three distinct morphotypes in the present study. These morphotypes are quite similar to three botanical varieties viz., var. *robusta*, var. *intermedia* and var. *stolonifera* in their morphological traits, while botanical variety *laxa* (endemic to Sikkim area of India) was completely absent from the present study (Gupta *et al*., 2009). Study was conducted to access genetic diversity among 33 accessions of two cultivated species of barnyard millet *i.e.*, *Echinochloa crus-galli* (15 accessions) and *E. frumentacea* (18 accessions). Though crop possesses great nutritional value, little attention has been paid for the improvement of this crop. We assessed genetic diversity on the basis of morphological and RAPD analysis. Morphological analysis suggested that EC-545 is superior for grain yield, whereas VRS-MB-1202 and VRS-MB-889 were found to be good for fodder yield. On the other hand, RAPD primers were able to segregate the accessions in two groups at a similarity level of 34% with clear demarcation of inter and intra species diversity. The data would be important in detailing the level of variation and relationship within and between species to plan future domestication trials and to manage the wild species collection that is available in the gene banks (Deepti *et al*., 2012). The investigation was conducted at V. C. S. G. Uttarakhand University of Horticulture and Forestry, College of Forestry, Ranichauri Campus with 35 diverse genotypes of barnyard millet including three checks *viz*., VL-172, VL-207 and PRJ-1. The data was utilized for estimation of mean, range, coefficients of variation, heritability and genetic advance, correlation coefficients, path coefficient and genetic divergence. The genotype exhibiting high mean performance for grain yield along with high performance for some other yield components were PRJ-1, RAU-11, VL-239, EC-134192 and VL-230. The genotypes PRJ-1 was highest for standard germination percentage, root length, shoot length, seedling length, seedling fresh weight, seedling dry weight, vigour index-I and vigour index-II while the genotype IEC-546 was found highest for rate of germination. Phenotypic and genotypic variances were highest for plant height. Moderate values of phenotypic coefficients of variation were noticed for flag leaf area, number of fingers per ear, 1000 seed weight, biological yield per plant and peduncle length while low values of genotypic coefficients of variation for all the traits was observed. High heritability along with high genetic advance in per cent of mean was observed only for finger length while moderate estimates of heritability coupled with high genetic advance in per cent of mean were recorded for flag leaf area and biological yield per plant. Biological yield per plant, number of fingers per ear, number of leaves on main tiller and 1000 seed weight exerted a very strong positive association towards grain yield per plant at phenotypic and genotypic level (Arya, 2015).

Morphological and molecular markers (RAPD primers) were used to analyze the genetic diversity and genetic relationships among 21 accessions of *Echinochloa* spp. complex comprising the wild and cultivated species collected from Melghat and adjoining regions of Vidarbha, Maharashtra. The availability of diverse genetic resources is a prerequisite for genetic improvement of any crop including barnyard millet. A high degree of molecular diversity among the landraces was detected. Among the 21 genotypes, two major groups (A and B) were formed, at 67.28 % similarity, which clearly encompasses 15 accessions of E. frumentacea and 6 accessions of *E. colona*. Higher similarity was observed in accessions of *E. frumentacea*. The accessions IC 597322 and IC 597323 also IC 597302 and IC 597304 showed more than 94% similarity among themselves. The classification of genetic diversity has enabled clear-cut grouping of barnyard millet accessions into two morphological races (*E. frumentacea* and *E. colona*) (Moharil et al., 2016). The mountain ecosystem of the Central Himalayan Region is known for its diversity of crops and their wild relatives. In spite of adverse climatic conditions, this region is endowed with a rich diversity of millets. Hence, the aim of the present study was to explore, collect, conserve and evaluate the diversity of barnyard millet (*Echinochloa frumentacea*) to find out the extent of diversity available in different traits and the traits responsible for abiotic stress tolerance, and to identify trait-specific accessions for crop improvement and also for the cultivation of millets in the region as well as in other similar agro-ecological regions. A total of 178 accessions were collected and evaluated for a range of morpho-physiological and biochemical traits. Significant variability was noted in days to 50% flowering, days to 80% maturity, 1000 seed weight and yield potential of the germplasm. These traits are considered to be crucial for tailoring new varieties for different agro-climatic conditions. Variations in biochemical traits such as lipid peroxidation (0·552–7·421 nmol malondialdehyde formed/mg protein/h), total glutathione (105·270–423·630 mmol/g fresh weight) and total ascorbate (4·980–9·880 mmol/g fresh weight) content indicate the potential of collected germplasm for abiotic stress tolerance. Principal component analysis also indicated that yield, superoxide dismutase activity, plant height, days to 50% flowering, catalase activity and glutathione content are suitable traits for screening large populations of millet and selection of suitable germplasm for crop improvement and cultivation. Trait-specific accessions identified in the present study could be useful in crop improvement programmes, climate-resilient agriculture and improving food security in areas with limited resources (Trivedi *et al.,* 2017).

Genetic diversity among 61 barnyard millet genotypes from southern India, was investigated using 10 morpho-nutritional traits and 51 expressed sequence tag (EST)-simple sequence repeat (SSR) markers. A large variability was observed for morpho-agronomic and grain nutritional traits including for the important traits such as flowering (49.50–82.00 cm), plant height (58.17–152.38 cm), grain yield (12.52 g–41.25 g), Fe (11.05–21.51 mg/100 g) and Zn (2.46–5.91 mg/100 g). Among 51 EST-SSR primers, 14 primers were polymorphic and produced a total of 29 alleles. Polymorphism information content (PIC) value ranged from 0.276 to 0.652 with a mean of 0.43. Clustering of based on Jaccard's coefficient grouped 61 genotypes into 12 clusters. The study reveals genetic relationships among the southern India barnyard millet genotypes, it can be helpful in planning the utilization patterns and management of barnyard millet germplasm existing in southern India (Manimekalai *et al.,* 2018). Investigation of genetic variability, heritability and genetic advance for yield and yield contributing characters in thirty-five diverse genotypes including three checks *viz*., VL-172, VL-207 and PRJ-1 of barnyard millet was conducted. Observations were recorded for different type of growth, yield and quality morpological characters. From the observation analysis of variance was recorded highly significant variation among all the thirty-five genotypes with a wide range of mean values for all the traits studied. The plant height was recorded highest genotypic and phenotypic variances while the magnitudes of genotypic and phenotypic variances low for number of productive tillers per plant. High heritability attached with high genetic advance in per cent of mean was recorded by finger length while moderate estimates of heritability coupled with high genetic advance in per cent of mean was observed for flag leaf area and biological yield per plant. Direct selection for different characters would be effective as heritability and genetic advance might be due to additive gene interaction (Arya *et al.,* 2018).

With an objective to identify potential parents and crosses for quantitative and nutrient related characters and to understand the gene action for different traits for further improvement, an investigation was carried out in barnyard millet with diallel analysis involving five parents (CO 2, ACM 145, ACM 161, ACM 331 and ACM 332). Five parents and twenty crosses were evaluated for thirteen quantitative and four nutrient traits. The GCA, SCA and RCA variances were significant for almost all the characters suggesting the importance of both additive and non-additive gene action with pre-ponderance of non-additive gene action and significant reciprocal differences indicating the inter action between cytoplasm and the nuclear gene effects. However, for single plant yield the gene action was additive as the ratio of GCA to SCA variances was more than one. In the evaluation of parents, taking per se performance and gca effects as criteria the parents in the order ACM 145, ACM 161 and CO 2 were identified as the best general combiners. The crosses ACM 145/CO 2 and ACM 145/ACM 161 were selected as superior over others based on per se performance, SCA effects and heterosis percent together and are suggested for utilization in heterosis breeding. Non-significant SCA effect was possessed by CO 2/ACM 145 and CO 2/ACM 161 and they could be used for improvement of grain yield by recombination breeding to isolate useful segregants (Vishnuprabha and Vanniarajan, 2019). An experiment was carried out in barnyard millet under natural sodic soil condition to study the genetic variability and association for different morphological and yield contributing traits. Ninety nine barnyard millet genotypes including two commercial check varieties *viz.,* MDU1 and CO (KV) 2 were evaluated under sodic soil condition. Analysis of variance revealed significant variation for all the characters studied. High phenotypic coefficient of variation, genotypic coefficient of variation and heritability were recorded for plant height, ear width, lower raceme length, flag leaf length, flag leaf width and grain yield per plant. Association studies indicated that grain yield per plant had highly significant positive correlation with days to fifty percent flowering, days to maturity, ear width and thousand grain weight. Path coefficient analysis indicated that the highest direct and indirect effect on grain yield per plant was exhibited by days to fifty percent flowering. Thus, days to fifty percent flowering, days to maturity, ear width and thousand grain weight can be used as selection indices for increasing grain yield of barnyard millet in sodic soil (Dhanalakshmi *et al*., 2019).

Barnyard millet has a potential to withstand salinity. The existing genetic variability for salinity tolerance in 32 barnyard millet accessions was assessed based on the morpho-physiological parameters governing salt tolerance *viz*., germination percentage, relative germination rate, root length, shoot length, seedling length, vigour index, relative salt injury rate and relative water content. Under gradual increase in the intensity of salt stress, decrease in germination percentage, relative germination rate, root length, shoot length, seedling length, vigour index, relative water content and increase in relative salt injury rate was observed. The antioxidant assay also revealed that catalase and peroxidase activity increased with rise in salt level in tolerant genotypes (ACM161, ACM295, ACM335, GECH10, IEc167) but the enzyme activity in the salt sensitive genotypes (IEc134, IEc348, IEc607) declined with increase in salt concentration, when compared to control. The salt tolerant genotypes maintained higher relative water content and enzyme activity under salt stress (Williams et al., 2019). The present study was aimed to estimate the nature of genetic diversity existing in 99 barnyard millet genotypes including two commercial check varieties *viz*., MDU1 and CO (KV) 2 under sodic soil condition. Mahalanobis D^2 analysis grouped the genotypes into 13 clusters with respect to 12 biometrical traits. Cluster I was the largest, consisting of 39 genotypes followed by cluster XIII with 35 genotypes. Cluster XII and XI had 4 and 3 genotypes, respectively. The remaining (9) clusters II, III, IV, V, VI, VII, VIII, IX and X included only 2 genotypes per cluster. Cluster XI recorded the highest intra-cluster distance followed by cluster XIII. The maximum inter-cluster distance was observed between clusters I and XI followed by clusters VIII and XI. The traits grain yield per plant and plant height contributed maximum to the genetic diversity. Principal component analysis revealed that the traits plant height, flag leaf length, lower raceme length and ear length contributed maximum towards variability in PCA axis I and II. Thus, selection of genotypes as parents from these genetically diversified clusters for breeding programmes could result in heterotic hybrids and could generate good amount of genetic variability in barnyard millet genotypes under the sodic soil condition (Dhanalakshmi *et al*., 2019).

A total of 111 germplasm accessions of Millets with code no's have been assembled through formal process of Collaborative programme. The Germplasm has been evaluated for various Agronomic traits (biotic, abiotic, grain quality) (Das, 2021). This study was carried out to test the phenotypic diversity, character association and path coefficients, and stability of early maturing barnyard millet accessions. The MDU 1, a slightly late-maturing (95 days) cultivar, was used to identify early maturing accessions than the control with a considerably higher yield. Diversity as revealed by D^2 analysis indicated that the trait grain yield had contributed the most towards the diversity followed by the traits such as thousand-grain weight and fodder yield per plant. The accessions IEc 350 and IEc 356 showed the highest fodder yield and grain yield per plant, and higher per day productivity than the control, MDU 1. Genotypic correlations revealed a significantly positive correlation of the grain yield with most traits investigated including days to maturity and fodder yield, and the trait fodder yield per plant showed a highly positive indirect effect on grain yield. Hence, these traits could be considered during the selection process for improving grain yield. Stability analysis identified two accessions, IEc 350 and IEc 356, and the MDU 1, as the stable high-yielding accessions. Hence, these high-yielding stable accessions can efficiently be used in barnyard millet improvement for developing early maturing varieties (Kuraloviya *et al.,* 2022).

To study the genetic variability, correlation and path analysis for the yield contributing characters in barnyard millet mutants was conducted. Twenty-five mutants along with check-MDU 1 were studied for 12 biometrical traits. Analysis of variance showed significant for all the characters. High PCV and GCV indicates less influence of environmental effect. The correlation studies showed that there was significant positive correlation observed for plant height, number of tillers, number of productive tillers, number of racemes, single ear head weight, and thousand-grain weight. A positive direct effect was noticed in the path analysis for the traits such as number of productive tillers, number of racemes, days to maturity, single ear head weight and thousand-grain weight on the yield. Selection criteria based on these traits would be helpful for increasing the yield (Kumar *et al*., 2022). Investigated the genetic background and inheritance of different traits in barnyard millet genotypes. Forty germplasm accessions were evaluated in different ecological environments of southern India for 17 quantitative traits. Genetic variability analysis using GENSTAT and the pooled REML mean data results revealed that Phenotypic Co-efficient of Variation (PCV) was greater than the Genotypic Co-efficient of Variation (GCV) over the diverged ecological locations indicating the existence of environmental influence on all the biometric traits studied. In the Western Ghats region (E1), high heritability coupled with high genetic advance was exhibited for traits like days to flowering, plant height, days to maturity, number of nodes, length of nodes, number of basal tillers, stem diameter, flag leaf length, flag leaf width, inflorescence length, inflorescence width, length of peduncle, number of racemes, single ear head weight and grain yield per plant. Traits like thousand grain weight expressed moderate genetic advance with high heritability while, length of lower racemes expressed moderate heritability with high genetic advance. Similarly, high heritability coupled with high genetic advance was recorded for all the characters in valley region (E2) except thousand grain weight that showed high heritability but moderate genetic advance. In contrast, in the area of plains (E3), all the traits exhibited high heritability coupled with high genetic advance. Since, majority of the traits have shown high heritability with high genetic advance, selection might be effective in these traits irrespective of the environment (Raju *et al*., 2022). Fifty three barnyard millet genotypes including checks were characterized for morphological traits. The genotypes exhibited considerable variation for the phenotypic traits studied. Single plant yield recorded the highest coefficient of variation of 35.47 per cent, followed by lower raceme length (32.22%), and peduncle length (30.52%). The least coefficient of variation (CV) of 6.18 per cent was observed for plant height. PCA analysis revealed that the first four principal components contributed to a maximum of 70.98 per cent of the total variation among genotypes. Cluster analysis based on quantitative traits categorized the 53 barnyard millet accessions into four distinctive clusters. Cluster I and cluster II included high-yielding genotypes, while cluster III and cluster IV consisted of low-yielding genotypes. The genotypes *viz*., GECH758, GECH746, GECH27, CO(KV)2, MA1, GECH10 and TNEf192 were found to be superior in terms of yield attributing traits *viz.,* single plant yield and thousand-grain weight. The desirable genotypes can be utilized in hybridization programs for yield improvement in barnyard millet (Geethanjali *et al*., 2023).

BREEDING

Germplasm Resources andUtilization: The major collections of barnyard millet germplasm accessions are housed in India and Japan. Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), India; Indian Instituteof Millets Research (IIMR), India; National Institute of Agrobiological Sciences (NIAS), Japan, and Consultative Groupon International Agricultural Research like International Crop Research Institute for the Semi-Arid Tropics (ICRISAT), India are actively working on germplasm evaluation for various agronomic, biotic, and abiotic stresses, grain, and nutritional content traits in barnyard millet. India made a series of collaborative exploration missions (i.e., Indo-Australian missions, Indo-Japanese missions, and Indo-Soviet protocol) for the improvement of barnyard millet and other millets with different countries across the world. So far, six hundred andone exotic barnyard millet accessions have been introduced into India between the period of 1976 and 2007 to increase the food and fodder production. The major source of introduction was from Australia, Canada, France, Germany, Ghana, Italy, Japan, Kenya, Malawi, the Philippines, Russian Federation, South Africa, Spain, United States of America, and Yugoslavia. During this period, Indian barnyard millet accessionswere also introduced in the United States, Canada, and Australiafor feed and forage purposes. At present, 8,000 barnyard millet germplasms havebeen conserved at different centers throughout the world (Table 4) (Renganathan *et al.,* 2020).

Germplasm collections of barnyard millet in India (Bangalore, 800 accessions) and in Japan (National Northeast Agricultural Experiment Station Tohoku, 120 accessions) are maintained (Partohardjono and Jansen, 2023). Two main species, *Echinochloa esculenta* (Japanese Barnyard millet) and *Echinochloa frumentacea* (Indian Barnyard millet), are cultivated and grown as cereals. It has a wide adaptation capacity and grows up to a height of 2000 m during summer season. Globally, more than 8000 accessions of barnyard millet have been assembled and conserved (Sood *et al.,* 2020).

Diversity in barnyard millet is being fast eroded due to considerable reduction in acreage and changing sociocultural and economic dimensions of the farming community in India. Considerable efforts have been made to preserve the crop diversity *ex situ,* but the information regarding on-farm, *in situ* conservation is very scarce. The largest *ex situ* collection at international level is maintained by the Consultative Group on International Agricultural Research (CGIAR) with 2365 collections. A few of them (44 accessions) have been duplicated with the Global Crop Diversity Trust for safe storage at the Svalbard Gene Bank in Norway.

Table 4. Major Organisations conserving Echinochloa species in the World

Country	Number of accessions	Organization
India	1888	National Bureau of Plant Genetic Resources, New Delhi
	985	University of Agricultural Sciences, Bangalore
	749	International Crop Research Institute for the Semi-Arid Tropics, Patancheru
	300	Vivekananda Parvatiya Krishi Anusandhan Sansthan, Almora
	1561	Indian Institute of Millets Research, Hyderabad
Japan	3671	National Institute of Agrobiological Sciences, Kannondai
	65	Plant Germplasm Institute, Kyoto University
United States	232	USDA Agricultural Research Service, Washington
	306	National Centre for Genetic Resources Conservation, Collins
	304	North Central Regional Plant Introduction Station, Ames
China	717	Institute of Crop Science, Chinese Academy of Agricultural Sciences, Beijing
Kenya	208	National Gene bank of Kenya, Crop Plant Genetic Resources Centre, Muguga
Ethiopia	92	International Livestock Research Institute, Addis Ababa
Australia	66	Australian Plant Genetic Resource Information Service, Queensland
Pakistan	50	Plant Genetic Resources Program, Islamabad
Norway	44	Svalbard Gene Bank, Spitsbergen
United Kingdom	44	Millennium Seed Bank Project, Seed Conservation Department, Royal Botanic Gardens, London
Germany	36	Leibniz Institute of Plant Genetics and Crop Plant Research, Gatersleben

Source: http://apps3.fao.org/wiews/germplasm_report.jsp?

India holds the largest barnyard millet collection at National Bureau of Plant Genetic Resources (1718 accessions) followed by All India Coordinated Small Millet Improvement Project at the University of Agricultural Sciences, Bangalore, Karnataka (985 accessions). Vivekananda Parvatiya Krishi Anusandhan Sansthan (VPKAS), Almora, is manly maintaining more than 300 local collections of barnyard millet from Uttara khand. ICRISAT has a total of 743 active collections and 487 base collections from nine countries for research and distribution. In addition, the US GRIN database contains 306 accessions of 18 *Echinochloa* species from 33 countries housed at the National Centre for Genetic Resources Conservation (Fort Collins, Colorado) and a smaller collection of 67 accessions at Australian Plant Genetic Resource Information Service, Biloela. Notwithstanding the impressive size of global barnyard millet collection at both National and International organizations, it is imperative to analyse and fill germplasm gaps to make the collection more comprehensive. For example, accessions belonging to *laxa* race endemic to Sikkim state of India hitherto unrepresented in the *ex situ* collections need to be collected before it becomes extinct (Sood *et al.,* 2015).

Characterization and evaluation of germplasm for important agronomic traits constitutes the most critical component driving utilization of germplasm by crop breeders. Utilization of barnyard millet genetic resources for crop improvement falls far short of the desired. The release of variety PRJ 1, which was a direct selection from ICRISAT germplasm, in 2003 for Uttara khand state is among few notable examples of effective utilization of barnyard millet germplasm. The variety yielded 45.4% higher than the check variety VL 29. PRJ 1 belongs to *E. esculenta*, whereas all the existing adapted material in Uttarakhand hills was of species *E. frumentacea*. Much, therefore, needs to be carried out to enhance utilization of barnyard millet germplasm for genetic improvement of the crop (Sood *et al.,* 2015).

Uses of Genetic Resources: To obtain basic knowledge about germplasm, morphological characterization is the preliminary step for characterizing and classifying any collected/introduced materials. This not only provides the heritability of traits but also increases the utility of promising materials in breeding programs. In a study, evaluated barnyard millet germplasm at the Himalayan regions of Uttarakhand, India, and identified some promising donors for plant height (<120 and >200 cm), productive tillers (>4), inflorescence length (>28 cm), raceme number (>50), raceme length (>3.1 cm), and grain yield (>16 g). In another study, to enable efficient use of genetic resources and to increase its access for breeders, barnyard millet core collection comprising of 89 accessions had also been established based on phenotypic and genotypic characterization. It was revealed that the mean difference between 89 core accessions and 736 whole accessions for most of the agronomic traits were not significant, indicating that the entire genetic variation had been sufficiently preserved in this core collection (Renganathan *et al.,* 2020).

Breeding objectives (Mamo and Singh, 2016)

- High grain yield with compact head, more tillers, earliness and reduced plant height;
- High forage yield with high biomass and good digestibility;
- Resistance to diseases, insect pests and striga;
- Tolerance to drought, heat and acid soils.

Breeding for dual-purpose genotypes (grain and stover) is an important objective. Barnyard millet stover is as important as the grain. It is considered superior to rice and oat straws because of the high protein and calcium contents. While breeding for increasing grain yield, there is need to look for the high straw yield as well. Thus, the genotypic selection of barnyard millet could be practiced on the basis of its performance on both grain and fodder yield while, selection of genotypes on the basis of grain yield alone might not be suitable for the promotion of dual-purpose cultivars at higher elevation of hills as in this region fodder has great value. In Uttarakhand, barnyard millet contributes 11.5% of the total fodder consumption in the state (Ganapathy *et al.,* 2021). *Echinochloa* species show a high degree of autogamy, but the rate of cross-pollination is sufficient to assure gene exchange among their populations. Emasculation and artificial hybridization is difficult due to small flower size, early hours of flowering, short viability of pollen, non-availability of pollen grain and slight opening of flowers that too for a short period. The crop is still considered as a minor food and feed crop of poor tribal people, has not attracted research efforts like other major crop plants and very limited work has been carried out for its improvement. In India, barnyard millet breeding is carried out mainly in the states of Uttarakhand and Tamil Nadu. Thus far, more than 20 improved cultivars have been developed and released for different barnyard millet growing regions of the country. Mass selection and pure line selection have remained the major breeding strategies for the improvement of the crop; however, some varieties have been developed through hybridization followed by pedigree method of selection (Sood *et al*., 2015).

Breeding Methods (Mamo and Singh, 2016)

Mass selection: This is the most common type of cultivar development method being used in several African and Asian countries. In this method a group of barnyard millet plants are selected from open pollinated population and the seeds from selected plants are mixed and planted to begin the next cycle of selection. Mass selection in pearl millet has helped to improve traits with high heritability. The main criteria that have been taken in to consideration to improve grain yield in pearl millet are head characteristics such as compactness, length of ear, weight of grain and uniform maturity.

Synthetic cultivar development: Synthetic varieties are developed in open pollinated crops by mixing several hundred elite genetic stocks/germplasm with one or more important traits in common. The synthetic cultivar developed in the first generation or cycle exhibits considerable heterosis.

Hybrid breeding: The hybrid breeding program at ICRISAT and West Africa includes development of inbred lines and pure line selection, and the use of cytoplasmic male sterility. Cytoplasmic male sterility in barnyard millet has been used to produce hybrid for grain production in India and for forage production in USA. The CMS system involves the development of three line systems (A, B and R) in order to produce hybrid seeds. Line A is male sterile and serves as seed parent, line B has the recessive form of the fertility restorergene in the nucleus and does not have the capacity to restore fertility in A system; it maintains sterility. The R line has the dominant form o f the fertility restorer genes, and so reverses the effects of the CMS cytoplasm of the A line, therefore resulting in fertile hybrid seeds when used as a male parent. B and R lines should be multiplied in separate and isolated fields to maintain purity.

Breeding Achievements: Improvement in grain yield remains the most important breeding objective in barnyard millet. A wide production gap still exists between yields realized at farmer's fields because of prevalence of local cultivation practices. Most of barnyard-millet-growing areas are still under local cultivars and land races with low grain yields of 1.0–1.5 tons per hectare, whereas the crop has the potential of >2.0 tons/ha and yield levels of 3.0 tons/ha have been reported in the *E. esulenta* lines. Improved varieties coupled with modern agronomic practices can bring about significant improvement in barnyard millet productivity and bridge the production gap. Barnyard millet straw is preferred over rice straw. Therefore, selection of variety which could give high grain as well as high fodder is the best alternative (Sood *et al*., 2015).

Varieties released

Various varieties with high-yielding potential have been released for different states. The list of a few popular varieties is given in Table 5 (Krishijagran, 2023):

Table 5. Released varieties of barnyard millet for different States

Sl. No.	State	Varieties
1	Uttarakhand	VL 172, VL 207, PRJ 1 and VL 29, PRS 1
2	Uttar Pradesh	VL 172 and VL 207, Anurag, VL 29
3	Tamil Nadu	CO 1 and CO 2, VL 181, VL 29
4	Karnataka	VL 172, RAU 11, VL 181
5	Gujarat	Gujarat Banti- 1

The Indian cultivars include "Anurag" (matures in 80 days), "Gujarat" and "Banti" (maturing in 80-90 days) and "VI Madira" (matures in 90-100 days) (Partohardjono and Jansen, 2023).

Barnyard millet varieties releasd for different States are given in Table 6 (Agrifarming, 2023)

Table 6. Barnyard millet varieties released for different States

State Varieties;

- Uttarakhand – VL 207, PRJ 1, VL 172 and VL 29, PRS 1
- Uttar Pradesh – VL 172 and VL 207, VL 29, Anurag
- Tamil Nadu – CO 1 and CO 2, VL 29, VL 181
- Karnataka – RAU 11, VL 172, VL 181
- Andhra Pradesh – Co 1, VL 29
- Bihar – VL 29, VL 181, RAU 2, RAU 3, RAU 9,
- Jharkhand – RAU 9, VL 29, RAU 2, RAU 3,
- Gujarat – VL 172
- Maharashtra – VL 29
- Madhya Pradesh – VL 181, VL 29, VL 172
- Chattisgarh – VL 172, VL 29
- Uttaranchal – VL 172, VL 21, VL 29

Popular Indian Varieties of Barnyard Millet are given in **Table 7** (Kumari *et al.*, 2021)

Table 7. Popular Indian Varieties of Barnyard Millet

State	Varieties
Uttar Pradesh	DHBM-93-3, VL 172 and VL 207, Anurag, Kanchan, VL 29 Tamil Nadu
	VL 181, VL 29, CO 1, CO 2, DHBM-93-3
Gujarat	DHBM-93-3, VL-172, Gujarat Banti- 1
Karnataka	RAU 11, DHBM-93-3, VL 172, VL 181, DHB-93-2
Bihar	VL Madira 181
Uttarakhand	VL 172, PRJ 1, VL 207, VL 29, DHBM-93-3, PRS 1

Improved varieties of barnyard millet in India is furnished in Table 8 (Sood et al., 2020).

Table : Improved varieties of barnyard millet in India

S. No.	Name of cultivar	Silent features
1.	VL *Madira* 172	Average grain yield is 2.2e2.3 t ha^{-1}. Mature in 75e80 days. Tolerant to grain smut and well suited to high cropping intensity.
2.	VL *Madira* 181	Average grain yield 1.6e1.7 t ha^{-1}. Mature in 90e95 days. Profuse tillering.
3.	VL *Madira* 207	Average grain yield is 1.6e1.9 t ha^{-1}. Mature in 80e90 days. Pyramidical shaped panicles. Tolerant to grain smut. Also having improved plant type with high harvest index.
4.	CO(KV) 2	Average grain yield is 2.1e2.2 t ha^{-1}. Mature in 95e100 days. Having branched panicles, nonlodging, profuse tillering, and suitable for contingency planting.
5.	ER 64 (Pratap *sawan* 1)	Dual-purpose variety giving fodder yield 5.0e5.5 t ha^{-1} and average grain yield is 1.5e1.7 t ha^{-1}. Resistant to smut and tolerant to shoot fly
6.	RAU 11 (*Sushrutha*)	Average grain yield is 2.0e2.2 t ha^{-1}. Erect plant type, compact panicles. Profuse tillering, high yielding, and very early duration (75e80 days).
7.	DHBM 93-3	Average grain yield is 2.2e2.4 t ha^{-1}. Mature in 90e95 days. Responsive to fertilizer application

USES

Postharvest Processing: Barnyard millet grain requires dehulling prior to making it suitable for human consumption. The dehulling is conventionally performed by repeated pounding in mortar, which is time consuming and also labour intensive as the grains are firmly encased in the lemma and palea. The drudgery involved in manual processing is an important factor contributing to reduction in consumption of millets. The small seed size also makes processing of these crops difficult. To reduce the drudgery, Vivek Millet Thresher 1 was developed, which can thresh 40–60 kg barnyard millet grains per hour. This machine is suitable for marginal farmers in hilly and tribal areas due to its low cost, small size, light weight and ability to do both threshing and dehusking. The machine can dehusk 5–6 kg grains per hour by changing the sieves but require 3–4 passes. Another similar easy-to-use affordable mill has been developed through collaborative efforts by Indian and Canadian researchers, which is 98% efficient in dehusking with <2% broken grains. This machine produces about 2 kg clean seed in an hour. Higher capacity machines/mills, which can process 100 kg/h, are also available for large farms. These machines with higher capacities have been designed for dehusking only. One such machine developed by Central Institute of Agricultural Engineering (CIAE, ICAR), Bhopal, India, has a capacity of dehusking and grinding 100 kg in an hour at 10–12% moisture content. It operates with one-horsepower single-phase electric motor and can even process one kg of grains also. These machines can significantly reduce the work load and time for postharvest processing of small millets (Sood *et al.*, 2015).

Processing

Processing of millets is generally carried out by traditional methods before its consumption and prepara- tion into various foods to improve nutritive and organoleptic properties. Processing reduces antinutrientcontents, which improves the bioavailability of essential micronutrients. The millet and its processed products are good resources to combat malnutrition. A major step of barnyard millet grain processing includes de-hulling, which improves its nutritional quality further. De-hulling is traditionally carried out by pounding and is very labor- intensive and time consuming. The small size and firm covering of the palea and lemma make manual grain de-hulling even more difficult and laborious. A small, lightweight threshing machine of low cost was designed to perform both de-husking and threshing and was found most suitable for small farmers in hilly areas. The threshing capacity of the machine was 40–60 kg/h and de- husking capacity was 5–6 kg/h for barnyard millet grain. Machines with a processing (de-husking) capacity of 100 kg/h are also available in the market for large-scale industry. Another affordable machine was developed by an Indian researcher in collaboration with Canadian researchers and had a de-husking efficiency of 98% with damaged grains of less than 2%. A similar machine operated with a single-phase electric motor of 1-horsepower was also manufactured by the ICAR-Central Institute of Agricultural Engineering in Bhopal, India. Its grinding and de-husking capacity was 100 kg/h at a moisture content of 10–12%. It significantly reduced the time and labor load for processing farm millet (Kumari *et al.,* 2021).

Utilization

Barnyard millet is generally used in the preparation of different value-added products such as vermicelli, roti/chapati, noodles, biscuits, cookies, malt-based weaning food, extruded products, snack food, ladoo, halwa, biryani, dosa (Tripathi and Vyas, 2023). In the Indian Himalayan region, barnyard millet is traditionally used a substitute for rice. The grains are dehulled, cooked and consumed like rice. Barnyard millet porridge (locally called *madira ki kheer*) is a popular sweet dish in Uttarakhand. In southern India, barnyard millet is used in traditional preparations such as idli, dosa and chakli. The millet has also been used to develop products such as biscuits, sweets, noodles, rusk, ready mix, popped products and some other speciality foods, but large-scale production needs industry involvement to commercialize the products globally. Barnyard millet is highly suitable for commercial foods for diabetics, infants and pregnant women because of high iron content. However, the non-availability of ready-to-use processed products has limited the usage and acceptability of barnyard millet, despite its nutritional superiority. There is a need to develop millet-based food products in the form of ready-to-use products and functional foods to meet the demands of the present-day consumers. Value addition to minor millets not only offers variety, convenience and quality food to consumers, but is important for revival of barnyard millet cultivation as well. Barnyard millet is also an important source of fodder in the Himalayan region.
Barnyard millet leaves are broad, and the plant picks up good growth in short time and thus produces voluminous fodder. Barnyard fodder is highly palatable and can be used for making hay or silage (Sood *et al.,* 2015).

Farm millet is traditionally used as substitute for rice in Indian Himalayan areas. Rice millet isde-hulled and processed in different products like barnyard millet porridge, and is consumed in Uttarakhand, while in south India, this millet is utilized in traditional dishes, such as dosa, idli, and chakli. In addition to these products, millet is used in the preparation of bread rolls, desserts, noodles, rusks, and popped items (Ugare, 2008), however, to scale-up this process will require substantial industry contribution to market the items universally. Barnyard millet is appropriate in the diets of diabetics, babies, and pregnant women due to its high iron content. Despite its potential, the lack of processed products is the major reason this crop is so underutilized. Therefore, to satisfy the health conscious consumers as well as maximize the utilization of this millet, more value-added and func- tional products need to be developed. Expanded use of minor millets not only provides the consumer with quality and assorted food, but is also significant for restoring farm millet production. Farm millet is a significant wellspring of grain in the Himalayan district. The leaves of farm millet are wide, and the plant grows quickly, subsequently delivering voluminous feed. Barnyard grain is an exceptional choice for making animal feed (Kumari *et al.,* 2021). In areas where the culta are grown as cereals, they are also used, prepared and eaten as cereals. The grains are cooked in water like rice, or parched and boiled with milk and sugar. They are also sometimes mixed with rice and fermented to make beer. In South-East Asia, both taxa and culta are used as grain crops in times of food scarcity. The coarse, tough seed coat and the characteristic flavour make barnyard millet less popular among rice and wheat eaters. The seed is used as a feed for cage birds. Although the wild taxa can be troublesome weeds, especially in paddy rice, they are used as excellent forages which can also be fed as hay. In Java, young shoots of both barnyard millets are eaten as a vegetable (Partohardjono and Jansen, 2023) **(Fig. 15).**

Food Applications: Millet-based biscuits were developed by incorporating refined wheat flour and barnyard/foxtail millet flour in a ratio of 55:45 and were subjected to sensory analysis and acceptability tests by diabetic subjectsand trained panels. Their nutritional profile and glycemic index were compared with control samples prepared using refined wheat flour. All three categories of biscuits were found acceptable by panelists and can be stored in polythene bags (thermally sealed) at room temperature up to 60 days. The glycemic index of barnyard millet biscuits was 68 and the lowest of 50.8 was found in those made from foxtail mil-let. Total dietary fiber, crude fiber, and ash content were reported higher in millet-incorporated biscuits in comparison to refined wheat-flour biscuits (Kumari *et al.,* 2021).

Polishing of de-husked barnyard millet can be done using a rice polisher. Maximum nutritional retention along with optimum polishing was attained at moisture level of 8–10% and the best recommended milling time for farm millet was 3 minutes. A decrease was noticed in protein, fiber, fat, and ash contentwith an increase in milling time and moisture content as it influenced bran removal. The degree of polishing negatively affected the milling yield and head recovery. The moisture level of millet plays a major role not only in storage, but also in influencing quality parameters in milling, de-husking, polishing,and in development of new machineries. Processing of barnyard millet is generallycarried out in a similar manner to rice (parboiling, de-hulling, cooking). However, various processing techniques influence nutritional, functional, pasting properties, and antinutrient levels in farm millet Polishing of de-husked barnyard millet can be done using a rice polisher. Maximum nutritional retention along with optimum polishing was attained at moisture level of 8–10% and the best recommended milling time for farm millet was 3 minutes. A decrease was noticed in protein, fiber, fat, and ash contentwith an increase in milling time and moisture content as it influenced bran removal. The degree of polishing negatively affected the milling yield and head recovery. The moisture level of millet plays a major role not only in storage, but also in influencing quality parameters in milling, de-husking, polishing,and in development of new machineries. Processing of barnyard millet is generally carried out in a similar manner to rice (parboiling, de-hulling, cooking). However,various processing techniques influence nutritional, functional, pasting properties, and antinutrient levels in farm millet (Kumari *et al*., 2021).

Barnyard millet can be utilized in preparation of antinutrient value-added products and can serve as a nutritional ingredient in preparation of baby food, dietary foods, and other nutritive products. Barnyard millet flour has a greater compatibility with other flours and can be utilized successfully in preparation of valued-added and novel food products without alteringnative taste and flavor (Kumari *et al*., 2021).

Idli	Sundal	Upma


Barnyard millet Fenugreek Gruel


Pongal


Upma Kozhukattai


pancake


neer dosai


Kuthiraivaali Buckwheat Upma


spicy bread


Barnyard Millet Coriander rice


Barnyard Millet Tamarind rice


Barnyard Millet Fried rice


Barnyard Millet Tomato rice


Barnyard millet Milk Payasam


Fried rice


Dosa


Pancake


Barnyard millet sweet pongal


Barnyard millet sweet bread


Barnyard millet sweet

Fig. 15 : Preparations from barnyard millet

NUTRITIONAL VALUE

Both the cultivated species have higher protein content than their wild ancestors. The protein content in barnyard millet ranged from 11.1% to 13.9% . However, the reverse is true for mineral content which suggests that wild species might consist of greater proportion of embryo/endosperm because of selection of larger seeds that increases endosperm size. The barnyard millet grain contains about 65% carbohydrate, majority of which is in the form of non-starchy polysaccharide and dietary fibre. This helps in the prevention of constipation, lowering of blood cholesterol and slow release of glucose into the blood stream during digestion. Barnyard millet has been found to be most effective in reducing blood glucose and lipid levels compared to other millets and rice. There are several other reports suggesting effectiveness of barnyard and its products for diabetics. Polishing barnyard millet results in loss of fibre and other nutritional components, and maximum loss occurs at 14% moisture level. Barnyard has non-glutinous type of endosperm. Starch of barnyard millets was more digestible than maize starch in terms of *in vitro* amylolysis by pancreatic amylase. However, high fibre content and poor digestibility of nutrients adversely affects consumer acceptability of all small millets. The nutritional potential of millets is limited by the presence of phytates, phenols and tannins. The tannin content was assessed in five minor millets *viz*., proso, kodo, Italian, little and barnyard millet and recorded lowest level in barnyard millet (102.96 mg). It has been shown that dehulling of the seeds reduces phytate and tannin levels. Recently, the demand of barnyard millet has increased due to its highly nutritious grains and presence of strong antioxidative compounds. Isolated three antioxidative phenolic compounds, one serotonin derivative and two flavonoids, from Japanese barnyard millet (cv. 'Kurohie') grains. High nutrient content and antioxidant effects make barnyard millet to be considered as a functional food crop and the crop has potential to be included in normal and therapeutic diet formulations. Gluten presence in main cereal crops such as wheat make them allergic to some people, but barnyard millet grains are gluten free and, therefore, offer good opportunity for their use as health foods also (Sood *et al.,* 2015).

In addition to these agronomic advantages, the grains are valued for their high nutritional value and lower expense as compared to major cereals like rice, wheat, and maize.It contains a rich source of protein, carbohydrates, fiber, and, most notably, micronutrients like iron (Fe) and zinc (Zn) that are related to numerous health benefits (Renganathan *et al.,* 2020). Nutritional Composition of Barnyard Millet in Per 100g is as follos**:** Moisure , 8.74%; Protein 10.1% ; Fat 3.9%; Crude fibre 6.7%; Total minerals 2.1%; Carbohydrate 68.8%; Total dietary fibre 12.5%; Insoluble dietary fibre 8.4%; Soluble dietary fibre 4.2%; Phosphorus 281 mg; Iron 5 mg; Magnesium 83mg; Calcium 19mg **(**Kaur and Sharma, 2020**).** Barnyard millet has the best nutritional profile among all millets. Farm millet contains adequate amountof iron, quality protein, fat, dietary fiber, calcium, magnesium, and zinc. The starch content of farm millet ranges between 51.5–62.0 g/100 g, which is significantly less than that of other millets. The total dietary fiber content of farm millet ranges 8.1–16.3% . This proportion of starch to total dietary fiber assures a slow rise of postprandial blood glucose levels, decreases LDL cholesterol, and removes other undesirable fatty substances from the body. Several clini- cal studies also reported similar findings, affirming that incorporation of this millet in the diet is helpfulin curing diabetes and cardiovascular disorders. Research studies havedemonstrated that barnyard milletcontains higher qualitative and quantitativeprotein as compared to other millets and oats **(Table 9)** (Kumari *et al*., 2021).

Table 9. Nutritional Profile of Barnyard Millet

Nutritional Component	Amount
Moisture	8.74%
Protein	10.1%
Fat	3.9%
Palmitic acid	10.80 mg/100 g
Oleic acid	53.80 mg/100 g
Linoleic acid	34.90 mg/100 g
Crude fiber	6.7%
Carbohydrate	68.8%
Total dietary fiber	12.5%
Insoluble fiber	8.4%
Soluble fiber	4.2%
Total minerals	2.1%
Phosphorus	281 mg/100 g
Iron	5 mg/100 g
Magnesium	83 mg/100 g
Calcium	19 mg/100 g
Thiamine	0.33 mg/100 g
Riboflavin	0.10 mg/100 g
Niacin	4.20 mg/100 g
Phenolic compounds	
Total phenols	0.8 mg/g
Flavonoids	0.6 mg/g
Total carotenoids	36.7–50.8 mg/100 g
Bioactive compounds	
GABA (gamma-Aminobutyric acid)	11.5–12.3%
β-glucan	5.0–6.0%
Antinutritional factors (Phytic acid)	3.30–3.70 mg/g

Barnyard millet grain is a good source of protein, carbohydrate, fibre, and most importantly it contains high quantity of micronutrients *i.e.,* iron and zinc. Despite its agronomical and nutritional benefits, barnyard millet has remain an underutilized crop. It contains protein (6- 13g), carbohydrates (55 - 65.5g), fat (2 - 4g), crude fibre (9.5 - 14g), mineral matter (3.8- 4.5g), calcium (11-27.1mg), phosphorous (280 - 340 mg), iron (15 – 19.5 mg), starch (51-62%). Starch is the primary source of energy. Starch composed of two polymeric molecules i.e., amylose and amylopectin. Starch consists 20.0% of amylase. The barnyard millet grain contains about 65% carbohydrate which is present in the form of non-starchy polysaccharide and dietary fibre. The three antioxidative phenolic compounds isolated *i.e.,* one serotonin derivative and two flavonoids from Japanese barnyard millet grains. The essential amino acids present in barnyard millet are lysine, methionine, threonine, isoleucine, leucine, histidine, tryptophan and the non-essential amino acids are aspartic acid, glutamic acid, arginine, alanine, cysteine, glycine, and proline (Bharath *et al.,* 2022). Barnyard Millet is a nutrient-dense grain that is high in iron, antioxidants, protein, calcium, dietary fibre, potassium, magnesium, and folic acid, which are all required during pregnancy. Due to its significant iron content, it enhances blood levels. Fibre content prevents constipation and assists to reduce blood sugar levels in women with gestational diabetes.

Calcium and folic acid assist in the growth of the embryo. Blood pressure is regulated by potassium and magnesium (Bnborganics, 2022). The approximate composition of the grain of Indian barnyard millet per 100 g edible portion is: water 11.9 g, protein 6.2 g, fat 2.2 g, carbohydrates 65.5 g, fibre 9.8 g and ash 4.4 g. Barnyard millet protein lacks gluten and therefore the millet alone is unsuitable to prepare bakery products. Compared with wheat and rice starches, the starch of barnyard millet has a higher gelatinization temperature, a higher water-binding capacity and a slower enzymatic hydrolysis. Because the release of sugars from millet-based diets is slow, millets are considered a good food for diabetics. The protein content of Japanese barnyard millet is nearly twice as high as that of polished rice. A mixture of 7 parts polished rice and 3 parts barnyard millet provides a favourable nutritive balance. The straw is considered superior to that of rice, oats or timothy in protein and calcium content (Partohardjono and Jansen, 2023).

Barnyard Millet Nutritional Value per 100g is furnished in Table 10 (Food-Health, 2023).

Table 10. Barnyard Millet Nutritional Value per 100g

Nutrients	Quantity
Protein	10.5
Fat	3.6
Crude Fibre	6.6
Total minerals	2.0
Total Carbohydrates	68.8
Calorific value	398.0
Total dietary fibre	12.6
Soluble dietary fibre	4.2
Insoluble dietary fibre	8.4
Phosphorus	281 mg
Iron	5 mg
Magnesium	83 mg
Calcium	19 mg

Barnyard millet's best quality is the good amount of dietary fibre, iron, phosphorus, and antioxidants in it. The presence of phenols makes it antibacterial, anti ageing, and antibiotic in nature (Food-Health, 2023). It is a good source of protein, which is highly digestible, and is an excellent source of dietary fiber with a good amount of soluble and insoluble fractions. The carbohydrate content of barnyard millet is low and slowly digestible, which makes barnyard millet a nature gift for modern mankind who is engaged in sedentary activities. Barnyard millet is most effective in reducing blood glucose and lipid level. Barnyard millet is also a good source of several important micronutrients such as iron, calcium, and phosphorus (Tripathi and Vyas, 2023).

HEALTH BENEFITS (Jhawer, 2017).

Low in Calories: Barnyard millet is a good source of highly digestible protein and at the same time is least caloric dense compared to all other cereals. It is a grain which makes one feel light and energetic after consumption. A serving of barnyard millets (25g, raw) gives 75 calories and 1.5g of protein.

Rich in Fiber: It is an excellent source of dietary fiber with a good amount of both soluble and insoluble fractions. The grain encompasses the highest amount of fiber in comparison to other grains and millets with a serve providing 2.4 grams of fiber. According to a study published in the *Journal of Food Science and Technology*, the dietary fiber content of barnyard millet was high (12.6%) including soluble (4.2%) and insoluble (8.4%) fractions. The high fiber content helps in preventing constipation, excess gas, bloating and cramping.

Low Glycemic Index: The carbohydrate content of barnyard millet is low and slowly digestible, making the barnyard millet a low glycemic index food. The carbohydrates in millet show a high degree of retrogradation of amylase, which facilitate the formation of higher amounts of resistant starch. Hence, it can be potentially recommended for patients with cardiovascular disease and diabetes mellitus. In today's scenario, this millet becomes one of the ideal foods for diabetics. A study published in the *Journal of Food Science and Technology* showed that supplementation of barnyard millets among diabetics for a period of one week can reduce blood sugar levels. The barnyard millet improved carbohydrate tolerance among the participants (both diabetic and non-diabetic) by significantly reducing fasting plasma glucose levels.

Gluten-Free Food: Like all millets, the barnyard millet is gluten-free. It is an appropriate food for patients who are intolerant to gluten (those with celiac disease) or looking to follow a gluten free lifestyle which eliminates wheat, barley, rye-based foods. The millet being easily available, quick to cook and good to taste proves to be an ideal wholesome alternative to rice, wheat and other less easily available millets.

Good Source of Iron: According to research on nutrient content on millets, some varieties of barnyard millet have shown to contain high amounts of iron (18.6 mg in 100g of raw millet) which was the richest amongst all millets and cereal grains. Barnyard millet could be a good source of iron for vegetarians.

Health Benefits: (Kaur and Sharma, 2020)

- Barnyard millet is recommended to patient who suffers from Cardiovascular diseases and diabetes. They are also most effective to reduce the blood glucose level and lipid level. The barnyard millet ideal millet for those patients who have gluten intolerance which cause celiac disease.
- Diabetes: In spite of the fact that barnyard millet comprises of good measure of starch, it is end up being low in sugar content. It makes barnyard millet as excellent for individuals with diabetes. It is conceivable since diabetic consume the food with low glycemic index. The diabetic can keep away from shoot up glucose by substituting white rice with barnyard millet. Lower occurrences of diabetes have been revealed in barnyard millet overwhelming populace. Millet phenolics constrains like alpha – glucosidase, pancreatic amylase decreases postprandial hyper glycemia by limited constraining the enzymatic hydrolysis of complex sugars (Shobana et al., 2009) [14]. Inhibiters like

aldose reductase avoids the aggregation of sorbital and decrease the risk of diabetes persuaded cateract illnesses (Chethan *et al*., 2008) [2]. Dehulled and heat-treated barnyard millet are beneficial for the Type II diabetes in which low glycemic index for dehulled millet (50.0±4.19) and heat rewarded was recorded (41.7±2.55) (Ugare et al., 2011) [22].

- Cardiovascular diseases: Obesity, smoking, undesirable eating routine and physical dormancy increment the danger of heart disease and strokes. A large portion of the world nations face high and expanding paces of disease related to cardiovascular. It has been exhibited that rodents feed with diet of native and treated starch from barnyard millet had the most minimal blood glucose, serum cholesterol and triglycerides as compared with and rice and other minor millets (Kumari and Thayumanavan 1997) [7]
- Celiac disease: In other words, celiac disease is also known as celiac sprue, nontropical sprue, and gluten-delicate enteropathy. The specific reason of celiac ailment isn't clear, yet it known to have a hereditary (inhibited) segment. Celiac illness is an autoimmune systemillness, where the immune system attacking the ordinary tissue, especially the inward lining tissue of the small intestine, because of eating gluten, the wheat protein. The particular response that prompts irritation is called prolamins. They are found in specific grains; such as gliadin in wheat, secalin in rye, horedin in grain, and venin in oats (Rao et al., 2018) [13]. According to Thompson (2009) [20] the products made from wheat, rye, barley is replaced with gluten free grains such as sorghum, barnyard millet; buckwheat is helpful for people to obeying gluten free diet.

Health Benefits (Kumari *et al*., 2021).

Barnyard millet is known to lower blood glucose and cholesterol levels, therefore it is beneficial for dia-betic and cardiovascular patients, while it can also be a boon for those that are gluten intolerant.

Diabetes: Despite the presence of starch, barnyard millet is suitable for people with diabetes because of its low sugar content, making it easy to incorporate into their diet. Millet phenolics, alpha-glucosidase, and pancreatic amylases lower the postprandial increase in blood glucose level by restricting the enzymatic hydrolysis of complex sugars. The presence of inhibitors like aldose reductase lowers the risk of cataract and other eye-related problems common to diabetes. De-hulled and processedmillet is known to reduce the risk of diabetes.

Cardiovascular Diseases: Obesity and smoking increase the risk of coronary illness and stroke. Currently, a major portion of the world's population faces a high risk of cardiovascular disease. Rodents fed with native and modified starches of barnyard millet showed insignificant alterations in serum cholesterol and blood glucose levelin comparison to rice and other millets.

Gluten Intolerance: Medically, gluten intolerance is called celiac disease. The particular explanation of celiac isn't clear,yet it has a genetic component. Gluten affects the internal lining of the digestive tract, which causes an allergic reaction in the body. Therefore, those allergic or sensitive to gluten are advised to supplement their diet with gluten-free grains like millets, pseudocereal.

Health Benefits (Bharath *et al*., 2022).

Millet is abundant source to bioactive compounds and antioxidant, which contribute in weight control and prevent from various health issues. The role of phenolic compounds such as flavonoids, anthocyanin and phenolic acid in millet act as an antioxidant and play crucial role in strengthening the body's immune system. Millets are considered as rich source of fibre content which helps out in maintaining the amount of sugar release in the blood streamand also prevent from constipation, bloating and cramping. Likewise, alkaloids, steroids, glycosides, tannins are also present in adequate amount in barnyard millet and thus contribute to various medical benefits like being anticarcinogenic, antiinflammatory, antimicrobial, having a wound healing capacity & constipation associated disease. They are highly popular for their low glycaemic index which help in facilitating the formation of resistant starch and therefore recommended for patients suffering with diabetes mellitus Phenolics present in millet inhibits like alphaglucosidase, pancreatic amylase reduce postprandial hyperglycemia by partially inhibiting the enzymatic hydrolysis of complex carbohydrates. Inhibitors like aldose reductase prevents the accumulation of sorbitol and reduce the risk of diabetes induced cataract diseases. Barnyard millet considered as a functional food which has a beneficial effect towards human health. As consumption of functional food in our diet improves immune system, prevent from lifestyle disease and maintain good physical and mental health. The presence of alphaamino butyric acid which is a free amino acid help in inhibiting cancerous cell proliferation and also reduces blood pressure. The presence of dietary fibre exerts beneficial effects is through undergoing fermentation in the large intestine (colon) and producing short-chain fatty acids such as butyrate, propionate and acetate. Some of the shortchain fatty-acid (butyrate) helps in the regeneration of colon mucosal cells by serving as a source of energy, thereby reducing the risk of colon cancer and inflammatory bowel disease. Some of the short-chain fatty acids produced are absorbed (especially propionate and acetate) into splenic circulation and transported to the liver where they are known to inhibit cholesterol synthesis by hepatocytes and also glucose release from the liver, due to which it contributing partly to the hypocholesterolaemia and hypoglycaemic effects of dietary fibre. Micronutrient present in millet play essential role for overall cellular function as in pregnant and nursing mothers, young children and the elderly population to prevent malnutrition, reduces the incidence of osteoporosis and osteopenia. Being non-glutinous and non- acid forming they are excellent nutraceuticals for people with digestive disorder. Millet possesses anti- hypertensive properties due to the presence of polyphenols and also tannins, which prevent from certain types of cancer. The renin released from the millet bioactive peptides ultimately leads to elevated blood pressure of the body The therapeutic compounds present in phytocyanin's, phytosterols and polyphenols acts as antioxidants and detoxifying system to reduce the risk of degenerative ailments such as Parkinson's disease and certain another metabolic syndrome. Besides this, millets contain fewer cross-linked prolamins, which may be an additional factor contributing to higher digestibility of the millet proteins. Presence of plant lignans in millets have the ability to convert into animal lignans in presence of microflora in digestive system and protect against certain cancers and heart disease. Millets plays a major role in lowering the cholesterol as it has good amount of fibre which help in eliminating LDL from the system and increasing the effects of HDL.

Health Benefits (Bnborganics, 2022).

- It's significant in Vitamin b like niacin, folate, and pantothenic acid. Such nutrients aid in the results of several enzyme reactions in our bodies as well as being needed for functional status.
- Millet includes probiotic bacteria, which are insoluble fibres. It encourages the development of advantageous bacteria in the intestines. Insoluble fibre soothes signs such as incontinence, bloating, gas, and cramps, among many others.
- If you want to keep your heart healthy, it is a healthy and nutritious grain to add to your nutrition.
- It has a high magnesium content, which assists in controlling blood pressure. Millets are also full of fibre (both insoluble and soluble fibre). As a result, it is an excellent option for people with high levels of cholesterol.
- It is lesser in simple carbs and strong in complex carbohydrates, causing it a low Glycemic index meal that tends to help regulate glucose level and assist in losing weight.

- Millets contain a significant amount of antioxidant properties and phenolic compounds, particularly catechins and ferulic acid. Antioxidant properties aid in reducing the body's oxidative stress and stimulate immune features. Darker millets have greater antioxidant levels than lighter millets.
- Barnyard millet's health benefits for enhancing immune function are evident as it is packed with iron and zinc. Both are advantageous to the body's opposition to foreign object threats or illness. If you wish to strengthen your immune system, look for vegetables and fruits high in iron and zinc like barnyard millet.
- Barnyard millet is a fibre-rich meal that encourages intestinal mobility and ends up wasting expulsion by enhancing the density of stools. Barnyard millet includes both insoluble and soluble fibre. The fibre content perks a person's intestinal health by enhancing the efflux of food or solid waste. Grains are full of fibre and thus helpful to gut health.

Health Benefits (Food-Health, 2023).

The scope of Barnyard millet benefits is not limited to one or two relieving health conditions; it helps in maintaining a balance between different metabolic functions, like reducing bad cholesterol and increasing good cholesterol. This is helpful in maintaining heart health and also keeping the weight in check.

Barnyard millet benefits in controlling diabetes: A study indicated that dehulled and heat-treated barnyard millet helps control type II diabetes. The low glycemic index of barnyard millet and the polyphenols present in Barnyard millet inhibit the hydrolysis of complex sugar, resisting the glucose spike that results in diabetic conditions. Barnyard millet benefits people with heart condition: IIMR stated in one of its Nutritional and Health benefits of millets that," Barnyard millet has a high degree of retrogradation of amylase, which facilitates the formation of higher amounts of resistant starches. Hence, it can be potentially recommended for patients with cardiovascular disease and diabetes mellitus". Being rich in magnesium, it helps reduce blood pressure. The higher dietary fibre helps lower bad cholesterol and increase good cholesterol. Barnyard millet fights anaemia: The high iron content in barnyard millet makes it an excellent source of food to cure anaemia. Eating Barnyard millet in controlled portions will provide the essential nutrients needed for a healthy metabolism. Especially in cases of anaemia, where the body constantly feels energy-deprived and fatigued, Barnyard millet can help with such symptoms. Barnyard millet benefits skin and hair health: Barnyard millet is full of phenols and flavonoids, which makes it a superior source of antioxidants that are good for maintaining skin health. Moreover, the presence of iron and zinc helps promote strong hair growth.

Barnyard millet benefits by helping manage gastrointestinal disorders: Being rich in fibre, Barnyard millet helps maintain regular bowel movements and eliminates constipation, acidity, bloating, and stomach cramps.

Barnyard millet is low in calorie compared to other cereals. The glycemic index of barnyard millet is low. So it is suitable for cardiovascular and Type 2 diabetes patients. A fairly significant amount of grain protein is present in minor millets compared to rice. Especially the amount of digestible protein present in kuthiraivaali is the highest among minor millet. The essential amino acids such as lysine and tryptophane are present in millets. Barnyard millet has higher amount of lysine than Little and Finger millet and more or less comparable amount like that of Foxtail millet and kodo millet. Iron is the most essential mineral to combat malnutrition of human being. Barnyard millet shows highest amount of iron followed by Little millet. The dietary fiber, both soluble and insoluble present in barnyard millet is high and thus it helps in preventing constipation, bloating and excess gas formation (Vincent, 2023).

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