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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF PROSO MILLET (*Panicum miliaceum* L.)

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ABSTRACT

Proso millet belongs to the Family Poaceae, Subfamily Panicoideae, Genus Panicum and Species *Panicum miliaceum* L. Its most popular common name 'proso millet' comes from the pan-Slavic general and generic name for millet (Croatian: proso, Serbian: просо). The vernacular names Chena, Barri (Hindi), Vari (Marathi), Baragu (Kannada), Variga (Telugu), Pani Varagu (Tamil), Cheena (Bengali), Cheno (Gujrati), Bacharibagmu, *china bachari bagmu* (Oriya), Cheena (Punjabi). Proso millet has a chromosome number of 2n = 36 with basic chromosome number of x = 9. It is suggested that proso millet may have allotetraploid origins with Panicum capillare (or a close relative) as a maternal ancestor and the other genome coming from *Panicum repens* based on its nuclear and chloroplast genomes. Proso millet is still widely considered as a self-pollinated crop despite the possibility of natural cross-pollination. Proso millet is not easily amenable to crossing and hybridisation due to smaller size of inflorescence and high rate of self pollination. Proso millet seeds exhibit a variety of colours, from white, cream, yellow, orange, red, black, to brown and are generally smaller than pearl millet seeds. Proso millet is a C_4 crop with short-duration grown for food and forage purposes and can efficiently fix carbon under drought conditions, high temperatures, and limited nitrogen and carbon dioxide. Proso millet is an annual cereal crop domesticated approximately 10,000 years ago in the semiarid regions of China. It is primarily grown in India, Nigeria, Niger, and China. Proso millet is used in Europe and North America as fodder and birdseed despite its highly nutritive and health-promoting benefits. Due to the crop's remarkably high water-use efficiency and short growing season (60–100 days), it can escape drought. These attributes also make it suitable for crop rotation. Proso millet grows well on marginal lands with low input and water. Proso millet has been used as a rotational crop in the winter wheat-fallow cropping system in the western Great Plains of the USA owing to its high water-use efficiency. This practice not only prevents the loss of organic matter from the no-till soil but also reduces weed and disease pressure. Regardless of the impeccable environmental and health benefits of proso millet, it remains as an under researched and underutilized crop. There are more than 29,000 germplasm collections of proso millet conserved worldwide. China, India, Russia, and Ukraine have the key collections. The development of proso millet cultivars which are high yielding, lodging and seed-shattering tolerant, direct combine-ready and nutrient enriched, would promote its increased cultivation, and use in the food industry. In India, there are currently 24 varieties of proso millet. Varieties released in India through hybridization are 25% of all proso millet varieties. Majority of the varieties have been developed through selection from landraces. India is the largest producer of millets in the world, producing 11.64 million tonnes. In India, important states cultivating the crop are Madhya Pradesh, Eastern Uttar Pradesh, Bihar, Tamil Nadu, Maharashtra, Andhra Pradesh, and Karnataka. Proso millet is ready for harvest after 65-75 days of sowing in most of the varieties. Harvest the crop when it is about to mature. The seeds in the tip of upper heads ripe and shatter before the lower seeds and later panicles get matured. 10-15 q grain and 30-40 q of fresh straw per ha under rainfed condition can be obtained. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Proso Millet are discussed.

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INTRODUCTION

Proso millet belongs to the Family Poaceae, Subfamily Panicoideae, Genus Panicum and Species *Panicum miliaceum* L. (Wikipedia, 2023). Its most popular common name 'proso millet' comes from the pan-Slavic general and generic name for millet (Croatian: proso, Serbian: просо)

(Joshi *et al*., 2021; Wikipedia, 2023). Proso millet is known by various names across different regions of the world. In English it is called as proso millet, common millet, broomtail millet, hog millet, yellow hog, hershey, white millet, French white, wild millet, black seeded proso millet, panic millet, broomcorn millet, Kashfi millet, red millet, and white millet (Tran , 2017; Joshi *et al*., 2021; Narciso and Nystrom, 2023). The plant grows to 45–130 cm and has a shallow fibrous root system. The resemblance of the mature panicle to a broom gives it the common name broomcorn millet (Rajasekaran *et al.,* 2023). The vernacular names Chena, Barri (Hindi), Vari (Marathi), Baragu (Kannada), Variga (Telugu), PaniVaragu (Tamil), Cheena (Bengali), Cheno (Gujrati), Bacharibagmu, china bachari bagmu (Oriya), Cheena (Punjabi) (Chapke *et al.,* 2020; Wikipedia, 2023; Plantsusda, 2023; Rajasekaran *et al*., 2023). Proso millet is an important ancient crop mostly grown for food, feed, and fodder purposes largely in China, Russia, India, and the USA. It is an under-researched and under-utilized crop (Vetriventhan *et al.,* 2019).

Proso millet has a chromosome number of $2n = 36$ with basic chromosome number of $x = 9$. It is suggested that proso millet may have allotetraploid origins with *Panicum capillare* (or a close relative) as a maternal ancestor and the other genome coming from *Panicum repens* based on its nuclear and chloroplast genomes (Narciso and Nystrom, 2023). Proso millet is still widely considered as a self-pollinated crop despite the possibility of natural cross-pollination (Narciso and Nystrom, 2023). Proso millet is not easily amenable to crossing and hybridisation due to smaller size of inflorescence and high rate of self pollination (Gopinath and Kumar, 2023). It is an annual plant that reaches up to a height of two feet having a cylindrical and hollow stem. Leaves arranged alternately on the stem. Both the leaves and the stem are covered with fine hair (Trichomes). The plant has a panicle inflorescence that can be erect or drooping and the roots are fibrous and shallow (NVT, 2019). Proso millet seeds are small, oval shaped and differ in their colour based upon the variety. They are smaller than millets like sorghum and pearl millet and have a similar size to that of finger millet. Proso millet is a warm season grass with a growing season of 60–100 days (NVT, 2019). Proso millet seeds exhibit a variety of colours, from white, cream, yellow, orange, red, black, to brown and are generally smaller than pearl millet seeds (Narciso and Nystrom, 2023). The crop has its importance among growers because of its extremely short lifespan, with some varieties producing grain only 60 days after planting, and its low water demanding requirements, producing much more efficiently per unit of soil moisture than any other grain species (Joshi *et al.,* 2021).

Proso millet is a C_4 crop with short-duration grown for food and forage purposes and can efficiently fix carbon under drought conditions, high temperatures, and limited nitrogen and carbon dioxide (Narciso and Nystrom, 2023; Rajasekaran *et al*., 2023). Proso millet is an annual cereal crop domesticated approximately 10,000 years ago in the semiarid regions of China. It is primarily grown in India, Nigeria, Niger, and China. Proso millet is used in Europe and North America as fodder and birdseed despite its highly nutritive and health-promoting benefits (Santra *et al*., 2019). Proso millet is a food crop domesticated around 10,000 years ago, that has been prevalent thoughout ancient civilization. However, use of millets on the diets has drastically been reduced owing to the addition of cereals such as rice and wheat. At present, proso millet is being cultivated and consumed by a marginal population. Irrespectiothelack of popularity, the crop is well known for its climate resilience traits as well as nutritional properties. Noteworthy, the crop is low on glycemic index, gluten-free, possesses good quality protein, vitamins, minerals, and other nutraceutical properties. Being a C_4 panicoid species, proso millet possesses better water-use and nitrogen-use eiciency, thus promising this an ideal crop for cultivation in the scenario of global climate change. The extent of food insecurity among the ever-growingpopulation, as well as the prevalence of malnutrition and undernutrition among the children, reinstate the requirement of a nutritious diet that millets and other traditionally important crops can address (Rajasekaran and Neethu-Francis, 2020). Proso millet is a food crop domesticated around 10,000 years ago, that has been prevalent throughout ancient civilization. However, use of millets in the diets has drastically been reduced owing to the addition of cereals such as rice and wheat. At present, proso millet is being cultivated and consumed by a marginal population. Irrespective of the lack of popularity, the crop is well known for its climate resilience traits as well as nutritional properties (Rajasekaran and Francis, 2021). Proso millet is known to be the oldest of the cultivated millets in Asia, even older than rice, which originated around 9000 years ago in the Yangtze Valley. The earliest evidence for domesticated proso millet dates back to 10,000 years ago in northern China (Narciso and Nystrom, 2023).

It is a highly nutritious cereal grain used for human consumption, bird seed, and/or ethanol production. Unique characteristics, such as drought and heat tolerance, make proso millet a promising alternative cash crop for the Pacific Northwest (PNW) region of the United States. Development of proso millet varieties adapted to dryland farming regions of the PNW could give growers a much-needed option for diversifying their predominantly wheat-based cropping systems (Habiyaremye *et al*., 2017). Due to the crop's remarkably high water-use efficiency and short growing season (60–100 days), it can escape drought. Proso millet seeds exhibit a variety of colours, from white, cream, yellow, orange, red, black, to brown and are generally smaller than pearl millet seeds (Narciso and Nystrom, 2023). Broomcorn millet played a crucial role in supporting the population, especially during hard times, throughout Chinese history. This has resulted in a number of food uses, colorful traditions, and culture associated with the crop. Improved knowledge on these aspects would be helpful to understand the selective pressure that may have shaped the diversity of current germplasm collections (Wang *et al*., 2016). For non-waxy broomcorn millet, dry-fried millet (stir fried without oil) is the main type of food in the northwest of China (Inner Mongolia, Ningxia, and Gansu). It can be prepared in bulk and kept for consumption over a relatively long time period, functioning like modern instant noodles, convenient for nomads such as Mongolians (Wang *et al.,* 2016).

Proso millet possesses many unique characteristics that makeit a promising rotational crop. Proso millet can utilize moisture more efficiently than wheat and long-season crops such as corn, grain sorghum, or sunflower because it has one of the lowest water requirementsof any grain crop. Proso millet could help improve wheat productivity through its capacity to control winter annual grassy weeds, reduce insect and disease pressure, and preserve deepsoil moisture for the subsequent wheat crop. In addition, proso millet can provide a rotational benefit to the dryland farming of the Palouse region of Washington, Oregon, and Idaho, where wheat is the keystone crop. Proso millet cultivation could promote diversification of wheat-based cropping systems and provide a regionally available source of a highly nutritious cereal grain (Habiyaremye *et al*., 2017). Proso millet has been used as a rotational crop in the winter wheat-fallow cropping system in the western Great Plains of the USA owing to its high water-use efficiency. This practice not only prevents the loss of organic matter from the no-till soil but also reduces weed and disease pressure. Regardless of the impeccable environmental and health benefits of proso millet, it remains as an under researched and underutilized crop (Santra *et al.,* 2019). Proso millet is the best rotational crop in most dry land production areas in the semiarid US High Plains because of the highest water use efficiency among all cereal crops and short growing season. In the United States, it is used for birdseed, but it is used mostly for human consumption in Asia and Europe (Rajput and Santra, 2016). Proso millet lowers glucose and cholesterol, thereby maintaining overall health. It is rich in fiber, protein, minerals, and trace elements like iron, copper, zinc, manganese, and soluble fiber (Indianmed, 2023). Our first target crop is proso millet which requires less water than any other cereal to produce a harvest. This makes it an ideal crop for the arid great plains of North America, as well as for dry lands in Australia, and northern China. Proso millet is grown on hundreds of thousands of acres in Nebraska, Colorado and South Dakota, yet this crop has missed out on the breeding revolutions which have allowed other crops to increase theiryields per acre 4x or more over thepast century (DG, 2023.).

Proso millet germplasm representing a wide genetic diversity is conserved in gene banks maintained by several countries. The development of proso millet cultivars which are high yielding, lodging and seed-shattering tolerant, direct combine-ready and nutrient enriched, would promote its increased cultivation, and use in the food industry (Santra *et al.,* 2019). There are more than 29,000 germplasm collections of proso millet conserved worldwide. China, India, Russia, and Ukraine have the key collections. Recent reviews and research studies published on the characterisation and identification of germplasm accessions for stress tolerances, both abiotic and biotic, and agronomic and nutritional traits were reported (Narciso and Nystrom, 2023). Traditional landraces and wild species are vital sources of genetic variation, which is a significant factor in crop improvement. The loss of genetic diversity can be attributed to non-usage of the traditional landraces in favour of modern high-yielding cultivars. In addition, traditional landraces of proso millet are grown mainly under subsistence farming, which also results in genetic erosion (Narciso and Nystrom, 2023). The development of proso millet cultivars which are high yielding, lodging and seed-shattering tolerant, direct combine-ready and nutrient enriched, would promote its increased cultivation, and use in the food industry (Santra *et al.*, 2019). In India, there are currently 24 varieties of proso millet. Varieties released in India through hybridization are 25% of all proso millet varieties. The important varieties are Co (PV), TNAU 151, TNAU 164 and TNAU 202. Majority of the varieties have been developed through selection from landraces (Gopinath and Kumar, 2023).

Proso millet can be used in many food applications. Food applications can depend on the properties and amylose content of the proso millet starch. Less amylose (≤10%) means a lower peak temperature during pasting. Higher amylose starches exhibit higher cold paste viscosity. Wax starch breaks down more than non-waxy starch. Waxy starches also retrograded more slowly during pasting, indicating greater stability. Waxy millets are therefore good raw materials for beverages due to their low retrogradation. Based also on these properties, the cultivar Earlybird, a low-amylose proso millet, is suggested for bread making, whilst cultivars Sunrise and Sunup, for example, are good for gluten-free pasta because of their higher cold paste viscosity. The undesirable bitterness of proso millet remains an obstacle to its widespread consumption. It is unclear which constituents contribute most to its bitterness because even in food products made of proso millet that have low tannins exhibit a degree of bitterness. Different processing strategies such as sprouting or fermentation can be used and assessed to reduce bitterness (Narciso and Nystrom, 2023). Proso Millet is usesd in the preparation of Upma, Dosa, Rice (NVT, 2019).

About 500,000 acres (200,000 hectares) are grown each year. The crop is notable both for its extremely short lifecycle, with some varieties producing grain only 60 days after planting, and its low water requirements, producing grain more efficiently per unit of moisture than any other grain species tested (Wikipedia, 2023). Proso millet is grown in temperate climates. It is widely cultivated in the Russian Federation, the Ukraine, Kazakhstan, USA, Argentina and Australia (Léder, 2004) and also plays an important role in the central and southern states of India and Eastern Europe (Arendt and Zannini, 2013). Proso millet is a quick growing, drought resistant crop that had been utilised as human food from ancient times. Presently this millet is mainly cultivated in countries like India, China, Russia, United States, Pakistan, Afghanistan, some Middle East and European countries. With recent advancements in agriculture, Proso millet a staple food for many of us is now mostly replaced by cereals like Rice and Wheat. However, it still holds great importance as a food source in certain parts of the world. Proso millets are excellent plants with minimal water requirements and produce good amounts of grains in short duration. They can be distinguished from other millets mainly by its large, heavily branched head (seed-bearing part) (NVT, 2019). Until the start of the twentieth century, proso millet was a highly significant crop in China, but recently higher-yielding varieties of other crops (such as rice, maize, wheat) have replaced proso millet and led to a significant decline in its cultivation. Extensive cultivation areas for proso millet are present in East Asia (China), South Asia (India and Nepal), Eastern Europe (Ukraine and Belarus), Africa, Russia, Middle East, Turkey, and Romania. Proso millet spread to North America through German-Russian immigrants who arrived in North America in 1875. The immigrants cultivated proso mill*et al*ong the eastern Atlantic coast. The areas in the states of Colorado, Nebraska, and South Dakota in the Central Great Plains of North America are the main producers of proso millet (Narciso and Nystrom, 2023).

India is the largest producer of millets in the world, producing 11.64 million tonnes (Fig. 1) (Rajasekaran and Neethu-Francis, 2020). In India, important states cultivating the crop are Madhya Pradesh, Eastern Uttar Pradesh, Bihar, Tamil Nadu, Maharashtra, Andhra Pradesh, and Karnataka (Fig. 2) (Rajasekaran and Neethu-Francis, 2020). Proso millet is ready for harvest after 65-75 days of sowing in most of the varieties. Harvest the crop when it is about to mature. The seeds in the tip of upper heads ripe and shatter before the lower seeds and later panicles get matured. Therefore, the crop should be harvested when about two thirds ofseeds are matured. Crop is threshed with hand or bullocks. With improved package of practices, it is possible to harvest 20-23 q of grain and 50-60 q of straw per hectare under irrigated condition and 10-15 q grain and 30-40 q of fresh straw per ha under rainfed condition (Chapke *et al.,* 2020).

In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Proso Millet are discussed.

ORIGIN AND DOMESTICATION

Proso millet is likely to have originated in Manchuria, and it is widely grown in temperature climates across the world. It is an important crop in northwest China and is grown in Kasakhastan, the central and southern states of India and eastern Europe, USA, and Australia (Taylor and Emmambux, 2008). Broomcorn millet or proso millet is one of the world's oldest cultivated cereals, with several lines of recent evidence indicating that it was grown in northern China from at least 10 000 cal BP . Additionally, a cluster of archaeobotanical records of *P. miliaceum* dated to at least 7000 cal BP exists in eastern Europe. These two centres of early records could either represent independent domestications or cross-continental movement of this cereal that would predate that of any other crop by some 2 millennia (Hunt *et al.,* 2011). Itis currently grown USA, Asia (China, Russia, Ukraine, Korea, and India) and Africa (Rajput *et al*., 2012). The origin of proso millet is thought to be in China. There, proso millet was considered to be the most important grain until the introduction of barley and wheat. Since the Middle Ages, proso millet has spread throughout Central and Western Europe, but its importance declined with the introduction of the potato. The small areas used to cultivate proso millet had almost disappeared entirely by World War I. There are isolated efforts to renew cultivation of this grain in Germany. Proso millet is widespread in areas of the world with arid and semiarid climates (Zarnkow, 2014). Broomcorn millet was one of the most important staple food crops in ancient northern ChinaArcheobotanical evidence of broomcorn millet has been found in at least five sites of various Early Neolithic cultures in northern China from around 6000 B.C.E., including Dadiwan (Gansu), Xinglonggou (Inner Mongolia), Xinle (Liaoning), Cishan (Hebei, middle valley of the Yellow River), and Yuezhuang (Shandong, lower valley of the Yellow River). Millet farming hadbecome established as the major subsistence strategy of the Middle Neolithic Yellow River Yangshao (5000–3000 cal B.C.E.) and Late Neolithic Longshan (3000–2000 B.C.E.) cultures (Wang *et al*., 2016).

Fig. 1. Global millet production countries

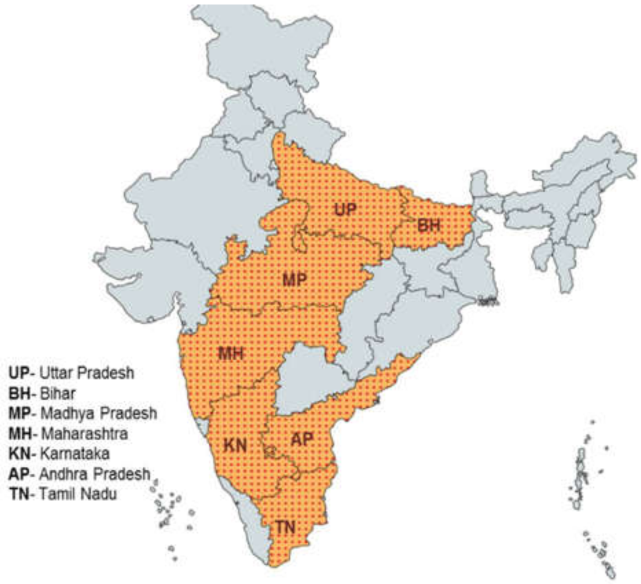


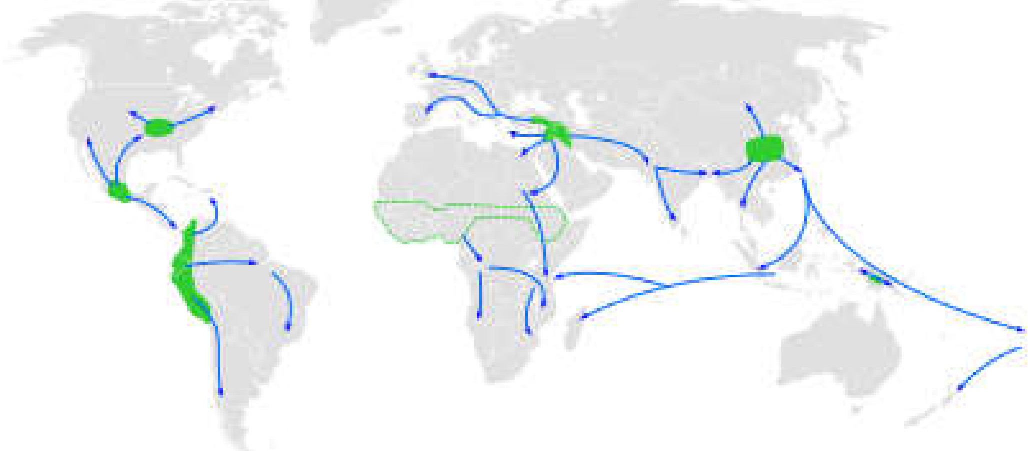
Fig. 2. Major proso millet producing States in India

The oldest historical reports of broomcorn millet (Bsu^ in Chinese) are from China 5000–3200 B.C.E. (Ho 1977). About 3000 years ago (Shang Dynasty), broomcorn millet varieties were recorded in inscriptions on bones (Yu 1957). About 1700 years ago (West Jin Dynasty), 14 varieties of broomcorn millet were recorded in the book *Guangzhi* written by Yigong Guo (Wang *et al.,* 2016). *Panicum miliaceum* has been cultivated in eastern and central Asia for more than 5000 years. It later spread into Europe and has been found in agricultural settlements dating back about 3000 years. *Panicum miliaceum* is the Roman *milium* and the true historical millet. It was introduced into North America in the 16th century. Its popularity declined in Europe and the United States after the introduction of the potato and maize. It remains cultivated for human consumption mainly in eastern and central Asia, and to a lesser extent in eastern Europe (Russia, Danube region) and from western Asia to Pakistan and India. *Panicum miliaceum* is occasionally grown in other parts of Europe, Asia and in North America, mainly as a source of feed for pet birds and poultry, and as fodder. In Africa, it is cultivated in Ethiopia, eastern Kenya, Malawi, Botswana, Zimbabwe and Madagascar. It is widely naturalized, and is sometimes invasive, *e.g.* in the United States and Russia (Tran , 2017). Proso millet was likely domesticated in China sometime around 10,000 BP. Current archeological theorists believe that proso millet domestication took place around the beginning of the Holocene as global temperatures became warmer and hunter- gatherers were exposed to new plants and environments. Although archeologists have yet to agree on the exact timing of millet domestication, they generally agree that domestication likely took place separately in three different centers: (1) Northwest China, (2) Central China, and (3) Inner Mongolia. From these centers of domestication, millet spread widely throughout East Asia, including high-altitude areas such as the Tibetan Plateau. By the end of the 2nd millennium BP, the cultivation of proso millet had spread to the rest of Central Eurasia and to Eastern Europe. However, during the 4th millennium BP, worldwide temperatures became cooler and may have led to difficulties in millet cultivation. Evidence shows major shifts in proso millet farming on the Tibetan Plateau until its cultivation was abandoned in Eastern Tibet. Later, proso millet was largely replacedby wheat and barley on the Tibetan Plateau; however, it continued to be a popular crop in low-lying plains of northern China well after its introduction. Warming temperatures in the Himalayan region today may allow farmers to cultivate millet in this area once more. By the fifth millennium BP, proso millet cultivation appears to have spread to Kazakhstan and Pakistan, but whether this crop was grown in these countries before this time is unclear. Site evidence for several finds of proso millet in these areas dates to as early as 8000-7000 BP (Habiyaremye *et al.,* 2017).

Proso millet is one of the first domesticated cereals, dating back to Neolithic times 10,000 years ago. The earliest clear evidence of its use is from husk phytoliths found in pits at the Cishan site in Northern China and have been dated between ca. 10,300 and 8700 BP. Evidence of proso millet has also been found in Western Asia and Europe dating back to ca. 7000 BP. However, as with foxtail millet, it is not clear whether there was a single domestication event followed by diffusion or multiple domestication events. Today, proso millet cultivation is still very largely in Eurasia, in China, in particular, Kazakhstan, Afghanistan, India, Turkey, and Romania. In the United States, proso millet is grown for forage/fodder and the grain for livestock and birdseed (Taylor, 2019). Proso millet is an annual cereal crop domesticated approximately 10,000 years ago in the semiarid regions of China. It is primarily grown in India, Nigeria, Niger, and China. Proso millet is used in Europe and North America as fodder and birdseed despite its highly nutritive and health-promoting benefits (Santra *et al.,* 2019). Proso millet is one of the ancient crops to be domesticated. It is believed to be domesticated in China around 10,000 years Before Present (BP) based on the various archaeological evidence and historical records. The millet is believed to have earmarked a transition from hunter-gatherers to millet farmers in Northern China based on traditional wisdom. Interestingly, noodles, a favorite dish across the globe, have also contributed to tracing back the domestication history of proso millet. Noodles sample (dating 4000 years BP) of Late Neolithic China—Lajia archaeological site excavations (Northwestern China), when subjected to phytolith and starch grain analysis, confirmed the presence of *P. miliaceum* and *S. italic.* Domestication process is divided in the Dadiwan site of Northwest China into two phases (phase I: non-intensive, 7900–7200 calendar years BP and Phase II: intensive, 5900 years BP) based on stable isotope analysis and carbon dating of bones of animals and humans. Other evidence throwing light into the domestication history of the crop includes macrofossils from Loss plateau site of Dadiwan, China, carbonized grains from Eastern Inner Mongolia, China (Xinglonggou site) and charred grains from Europe. Genetic diversity and phylogeographic studies of proso millet in Eurasia, attempting to understand the archaeobotanical records of the millet discovered from Eastern Europe and the possibility of multiple domestication Centers was undertaken. Their studies had identified one Western and one Eastern gene pool, but more research efforts and evidence would be required to establish a second domestication center (Eastern Europe or Central Asia) (Rajasekaran and Neethu-Francis, 2020).

As per the Archaeological evidences, the crop was first domesticated before 10,000 BC in Northern China (Lu *et al.,* 2009). The proso millet is comprehensively cultivated in China, India, Nepal, Russia, Ukraine, Belarus, the Middle East, Turkey, Romania, and the United States, where approximately it is grown on half a million acres each year (Joshi *et al.*, 2021). Initially, weedy forms of proso millet were found throughout central Asia, covering a widespread area from the Caspian Sea to Mongolia, which ultimately represent the wild progenitor of proso millet from domesticated production. It is widely grown in northern china, Mongolia, Korea, Russia, Afghanistan, Pakistan, India, and southern Europe. It was also introduced to North America (Joshi *et al.*, 2021). Its origin goes back in history at least as far as 2000 B.C. when it is reported to have been grown in the central regions of Europe. This plant is especially well suited to dry climates such as central Russia, the Middle East, northern India, Africa, Manchuria, and the Great Plains area of North America. Proso millet was first introduced to Canada in the 17th century, and was used in a limited way as a forage crop in the early 1900's. It apparently did not produce sufficiently high yields of either forage or grain to compete with the established cereals and forages of that time so it gradually disappeared (UOM, 2022).

Archaeobotanical evidence suggests millet was first domesticated about 10,000 BP in Northern China. Major cultivated area include Northern China, Himachal Pradesh of India, Nepal, Russia, Ukraine, Belarus, the Middle East, Turkey, Romania, and the Great Plains states of the United States **(Fig. 3)** (Wikipedia, 2023). Proso millet , commonly known as hog millet or broom corn millet, was initially domesticated in central Asia and Europe (Hunt *et al.,* 2011). Cultivation of proso millet is distributed across India, China, Russia, Japan,Mongolia, USA, Iran, Afghanistan, Iraq, and other EastAsian countries (Gopinath and Kumar, 2023).



The Yangtze and Yellow River basins (9,000 BP),
The New Guinea Highlands (9,000–6,000 BP),
Central Mexico (5,000–4,000 BP),
Northern South America (5,000–4,000 BP),
Sub-Saharan Africa (5,000–4,000 BP, exact location unknown), and
Eastern North America (4,000–3,000 BP).
BP= Before present; BC= Before Christ=BCE

Fig.3. Map of the world showing approximate centers of origin of agriculture and its spread in prehistory: The Fertile Crescent (11,000 BP)

Weedy forms of proso millet are found throughout central Asia, covering a widespread area from the Caspian Sea east to Xinjiang and Mongolia. These may represent the wild progenitor of proso millet or feral escapes from domesticated production. Indeed, in the United States, weedy proso millet, representing feral escapes from cultivation, are now common, suggesting current proso millet cultivars retain the potential to revert, similar to the pattern seen for weedy rice. Currently, the earliest archeological evidence for domesticated proso millet comes from the Cishan site in semiarid north east China around 8,000 BC. Because early varieties of proso millet had such a short lifecycle, as little as 45 days from planting to harvest, they are thought to have made it possible for seminomadic tribes to first adopt agriculture, forming a bridge between hunter-gathererfocused lifestyles and early agricultural civilizations. Archaeological evidence for cultivation of domesticated proso millet in east Asia and Europe dates to at least 5,000 BC in Georgia and Germany (near Leipzig, Hadersleben) by Linear Pottery culture (Early LBK, Neolithik 5500–4900 BC),https://en.wikipedia.org/wiki/Proso_millet#cite_note-15 and may represent either an independent domestication of the same wild ancestor, or the spread of the crop from east Asia along trade routes through the arid steppes. Evidence for cultivation in southern Europe and the Near East is comparatively more recent, with the earliest evidence for its cultivation in the Near East a find in the ruins of Nimrud, Iraq, dated to about 700 BC (Wikipedia, 2023). This millet is believed to be domesticated around 10,000 years ago in China. The crop is distributed globally in Asia, Australia, Africa, North America, South America, Europe, and the former USSR (Rajasekaran *et al.,* 2023). Proso millet is known to be the oldest of the cultivated millets in Asia, even older than rice, which originated around 9000 years ago in the Yangtze Valley. The earliest evidence for domesticated proso millet dates back to 10,000 years ago in northern China (Narciso and Nystrom, 2023). Proso millet is also known as common millet. It is believed to have been domesticated in central and eastern Asia and, because of its ability to mature quickly, was often grown by nomads. This type of millet is of ancient cultivation and is known to be grown in China since 3000 BC. It is the milium of the Romans and the true millet of history in the Old Testament. It was cultivated by the early Lake Dwellers in Europe. Proso millet is widely grown in northern China, Mongolia, Korea, south-eastern Russia, Afghanistan, Pakistan, India, and southern Europe. It was also introduced to North America (Gobotany, 2023).

TAXONOMY

All millets belong to the order of *Poales*, and there to the family of *Poaceae* (also *Gramineae* or true grasses). They belong to either of the two subfamilies of *Panicoideae* or *Chloridoideae* (Milletprojet, 2023).

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

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

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

- *Panicum miliaceum:* proso millet, common millet, broom corn millet, hog millet, yellow hog, white millet
- *Pennisetum glaucum*: pearl millet (kambu or bajra in India)
- *Setaria italica:* foxtail millet, German millet (thinai, kang or rala in India)
- *Digitaria* spp.: white fonio, black fonio, raishan, Polish millet
- *Echinochloa* spp.: Japanese barnyard millet, Indian barnyard millet, sawa millet, burgu millet (kuthirai vaali, bhagar or varai in India)
- *Panicum sumatrense*: little millet (samai in India)
- *Paspalum scrobiculatum*: kodo millet (varagu in India)
- *Urochloa* spp. (also known as *Brachiaria*): browntop millet (*U. ramosa*, dixie signalgrass), Guinea millet

***Andropogoneae* tribe (*Panicoideae* subfamily):**

- ***Coix***: Job's tears.

Proso millet belongs to the Family Poaceae, Subfamily Panicoideae, Genus Panicum and Species *Panicum miliaceum* L. (Wikipedia, 2023). Its most popular common name 'proso millet' comes from the pan-Slavic general and generic name for millet (Croatian: proso, Serbian: просо) (Joshi *et al*., 2021; Wikipedia, 2023). Proso millet is known by various names across different regions of the world. Proso millet is a tetraploid crop (2n =4x = 36) and belongs to the genus *Panicum*, tribe *Paniceae,* family *Poaceae* and order *Poales. Panicum capillare* (witch grass) and *Panicum repens* (Torpedo grass) are weedy forms of *P. miliaceum* that are reported to be contributing to its allotetraploid origin. Still, a wild ancestor of the crop is yet to be identified. The species *Panicum* has two subspecies (subspp), *i.e.,* subspp. *ruderale*, which has weedy forms and natural variants and subspp. *miliaceum* that has cultivated types. The subspecies *miliaceum* is further subdivided into five races based on the type of inflorescence, i.e., *miliaceum, patentissimum, contractum*, *compactum*, and *ovatum* (Rajasekaran and Neethu-Francis, 2020). There are five races of cultivated proso millet based on their panicle traits namely, *miliaceum*, *patentissimum*, *contractum*, *compactum*, and *ovatum*. The characteristics of the different races are presented in Fig. 4. Race *miliaceum* has large, open inflorescences and sub-erect branches, whilst race *patentissimum* has slender and diffused panicle branches. Races *contractum*, *compactum*, and *ovatum* have compact inflorescences (Rajasekaran and Neethu-Francis, 2020).

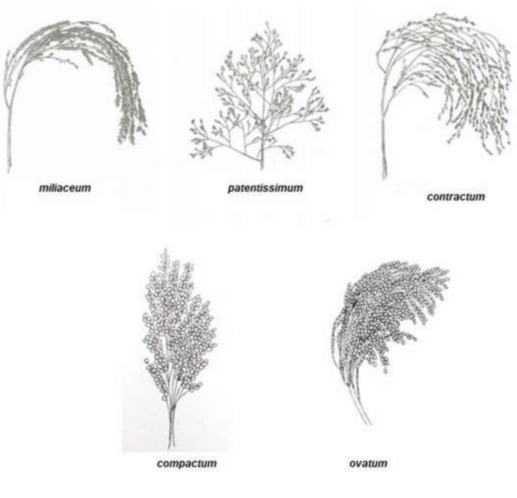


Fig. 4. Different races of proso millet based on panicle (inflorescence) shape: Races *miliaceum, patentissimum, contractum, compactum* and *ovatum*

The morphology and shape of panicle subdivides cultivated type races that include *miliaceum, patentissimum, contractum, compactum* and *ovatum* (Lu *et al*., 2009; Vetriventhan *et al.,* 2019).

Botanical Varieties (Plantsusda, 2023)

Panicum miliaceum var. *aureum* Alef.;
Panicum miliaceum var. *flavum* Schur;
Panicum miliaceum var. *sanguineum* Alef.

Synonyms (Tran , 2017).

- *Leptoloma miliacea* (L.) Smyth;
- *Milium esculentum* Moench;
- *Milium paniceum* Mill.;
- *Panicum asperrimum* Fischer ex Jacq.;
- *Panicum densepilosum* Steud.;
- *Panicum miliaceum* Blanco, nom. illeg., non
- *Panicum miliaceum* L.;
- *Panicum miliaceum* Walter, nom. illeg., non
- *Panicum miliaceum* L.;
- *Panicum miliaceum* var. *miliaceum*;
- *Panicum milium* Pers.

Synonyms (Wikipedia, 2023)

- *Leptoloma miliacea* (L.) Smyth
- *Milium esculentum* Moench nom. illeg.
- *Milium panicum* Mill. nom. illeg.
- *Panicum asperrimum* Fisch.
- *Panicum asperrimum* Fischer ex Jacq.
- *Panicum densepilosum* Steud.
- *Panicum milium* Pers. nom. illeg.
- *Panicum ruderale* (Kitag.) D.M.Chang
- *Panicum spontaneum* Zhuk. nom. inval.

BOTANICAL DESCRIPTION

The proso millet is a cereal plant cultivated for its grain, mostly in Asia and North America. It is a warm-season grass with a short growing season and low moisture requirement that is capable of producing food or feed where other grain crops would fail. Proso millet is an erect annual grass up to 1.2-1.5 m tall, usually free-tillering and tufted, with a rather shallow root system. Its stems are cylindrical, simple or sparingly branched, with simple alternate and hairy leaves. The inflorescence is a slender panicle with solitary spikelets. The fruit is a small caryopsis (grain), broadly ovoid, up to 3 mm x 2 mm, smooth, variously coloured but often white, and shedding easily (Tran, 2017). Proso millet is a summer annual grass, most frequently grown as a late-seeded summer crop, and can complete its life cycle within 60–100 days. A compact panicle droops at the top like an old broom, hence proso millet's common name, "broom corn". Grains are round, about 3 mm long and 2 mm wide, and enclosed in a smooth hull, which is typically white or creamy-white, yellow, or red in color, but may be gray, brown, or black. White-seeded varieties are most often grown in the U.S., followed by red-seeded varieties. Proso millet ranges from 30 to 100 cm tall, with few tillers and an adventitious root system(Habiyaremye *et al.,* 2017). The plant grows to a height of (30–100) cm, with hollow, hairy or glabrous stem, swollen internodes, and a shallow root system. It is a short day, short duration (60–90 days) crop. It is tolerant to drought, but sensitive to frost and waterlogged conditions. The crop is harvested at its physiological maturity to avoid shattering of grain. The plant reaches maturity early during drought. It flowers naturally between 10:00 am and 12:00 noon. Bright sunlight and low humidity may advance, and cloudy days may delay flowering. The inflorescence is a drooping panicle and looks like a broom with basipetal opening of florets, *i.e.*, from top to bottom. A single spikelet contains two glumes and two lemmas. The lower lemma has a sterile floret, and upper lemma has a fertile floret. It has three anthers and two feathery stigmas. The anther dry within a few minutes (within 5–7 min) of flower opening, turned orange, and then to brown. It may take about 12–15 days for a panicle to complete flowering. Though self- pollination is predominant, more than 10% cross-pollination may occur. These flowering features make it challenging to employ crossing in proso millet without damaging the stigma and without shedding of pollen before emasculation. Crossing techniques in proso millet using hand emasculation, and cold spray technique for emasculation and crossing is reported. Seeds of proso millet are oval 3 mm long, and colour varies from white, golden yellow, orange, red, brown to black. Among the collections in China, the thousand-grain weight is reported to be between 1.5 and 10 g **(Fig. 5)** (Rajasekaran and Neethu-Francis, 2020).

Germinatng seeds

Seeds

Seedling

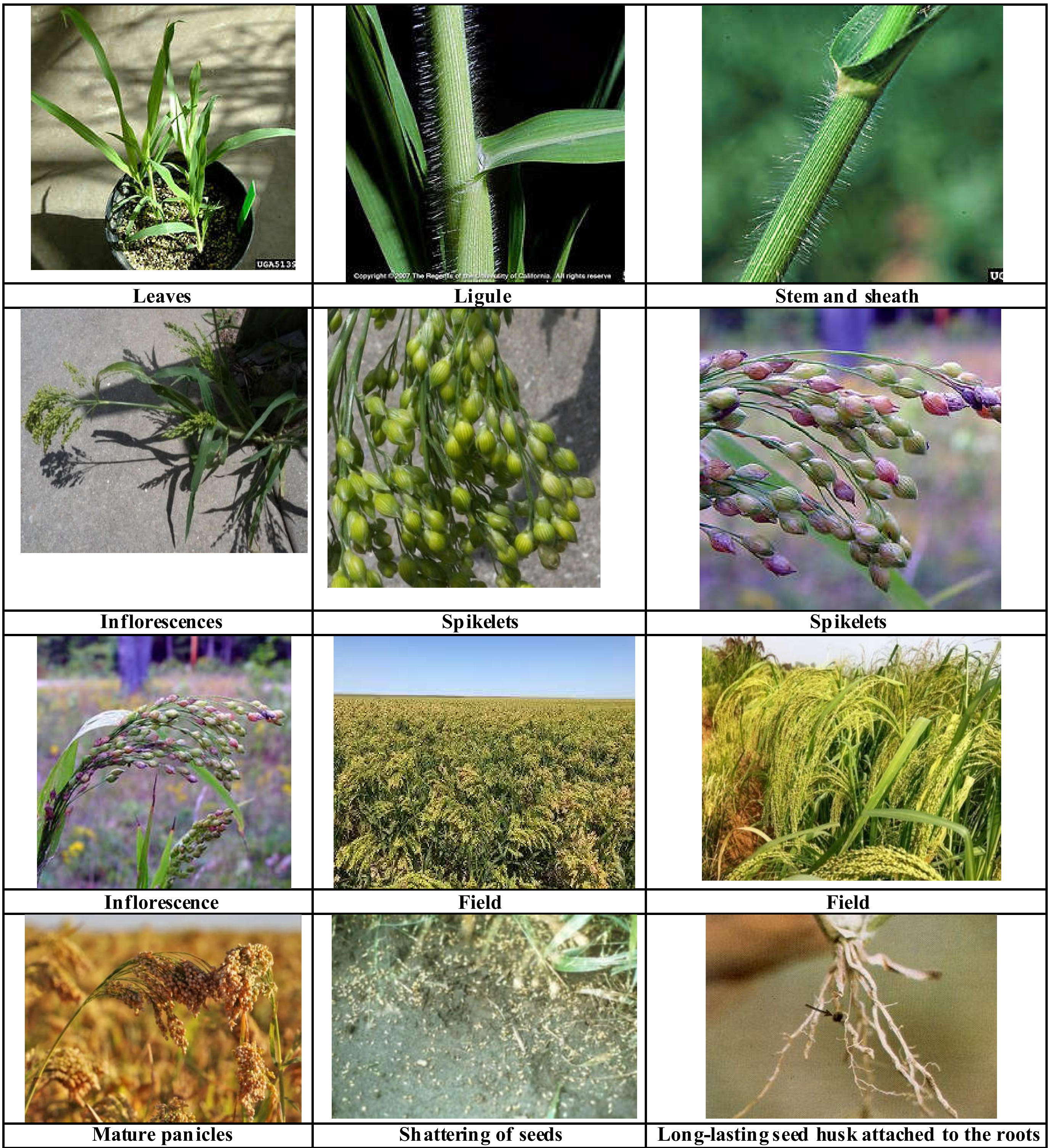


Fig. 5. Botanical Description

Proso millet is an annual warm season grass. The seedlings grow rapidly into upright plants which may tiller at low densities. Leaf blades are more or less hairy on both surfaces and the edges. They are 1 to 2 cm wide and up to 30 cm long. Leaf sheaths are densely hairy and have overlapping margins. The ligule (projection from the inner surface of the leaf sheath at the point where the leaf blade meets the stem) consists of a line of dense hairs. There are no auricles. The much branched panicle, 15 to 30 cm long (at the top of the stem) is compact in some populations and loose in others. The spikelets are borne singly at the ends of the branches. Each is about 5 mm long and consists of a fertile floret and a sterile floret enclosed between two pieces of chaff (the outer glumes). The so-called "seed" or "grain" is the somewhat egg-shaped fertile floret in which the hull (lemma and palea) is hard and shiny and firmly encloses the seed when it is shed. The grains are about 3 mm long by 2 mm wide and their color varies from brownish black through olive brown, orange-red, golden and light cream. Positive identification can be made by carefully removing the plant from the soil and observing the large seed which remains attached to the roots until maturity (UOM, 2022). The proso plant is considered a short-day plant and usually an erect annual, 30 to 100 cm tall with few tillers and an adventitious root system. Proso stems and leaves are covered with slight hairs. The leaves may be up to 30 cm long with a short ligule but no auricles. The stem is terminated by a drooping panicle 10 to 45 cm long that may be open or compact. The vegetative phase covers the period from germination to panicle initiation, depending on the cultivar used and climate in the area, may be completed 16 to 20 days after planting. An increase in number of leaves, tiller buds, and plant height are characteristics of this phase. The period, about 20 to 25 days, from panicle differentiation to flowering of the main culm is the reproduction phase. This phase initiates when the panicle primordium is greater than 0.5 mm. Rapid elongation of stem internodes and an increase in leaf area accompanied by more tillers are noticed in this phase.

The ripening phase starts at flowering or blooming and continues to the end of physiological maturity, which covers a period of 20 to 30 days. Throughout this period, the plant actively accumulates dry matter, particularly in the grains. Physiological maturity proceeds from top to bottom of the panicle. The ripening of the seed is not uniform throughout the panicle and delay in harvesting may cause losses due to shattering. The grains from the main panicle reach maximum dry weight and a small dark layer at the hilar region of the seed is formed. At maturity, the grain generally includes about 20% or less moisture (Gobotany, 2023). Common millet is an annual reaching to a height of 90 to 120 cm. with a shallow adventitious rooting system. The stems are slender, glabrous or slightly hairy, with hollow internodes, branching occasionally and tillering weakly. But, the Indian cultivars are strongly hairy with profuse branching and tillering. The plant has long, soft, narrow, pointed leaves, sparsely hairy on the upper surface, expanded from leaf sheaths which are open and strongly hairy at the junction of blade and sheath. The inflorescence is a drooping panicle varying in the degree of compactness, and often one-sided, with more or less naked branches hearing the ovate, pointed spikelets. The main rachis of the panicle is glabrous, the laterals being ridged and hairy and swollen at the tip where the spikelets are borne. The spikelets are about half a centimetre long and contain two flowers, partially enclosed by the plumes. The outer glume is short and broad and five--nerved; the inner glume is almost as long as the spikelet, and is a broad, pointed, many-nerved structure. The lower flower of the spikelet is sterile, consisting of a lemma and a very much reduced palea only, while the upper flower is perfect with a stiff, broad, shining lemma and an equally stiff, broad palea, which also becomes shining as the grain matures. The perfect flower contains two lodicules, three stamens and an ovary with two long styles and feathery stigmas. The flowers are almost completely self-fertilized, and produce a nearly globular grain, enclosed tightly in the persistent lemma and palea. Anthesis and Pollination Flowers open between 10 AM and 12 noon, as the day temperature rises. The spikelets open and close within about seven minutes and hence selfpollination is predominant, though a very small amount of cross pollination cannot be ruled out. Anthes is basipetallic (Gobotany, 2023). Proso millet is an introduced, warm-season annual grass that grows 30-100 cm tall. Stems are light green, erect, sometimes branched at the base, and grow 20–60 in (0.5–1.5 m) tall. Leaves alternate along the stem and are covered with short, stiff hairs. The wide-spreading or arching leaves may reach approximately 30 cm long, have a short ligule (outgrowth at junction of grass leaf and blade) and no auricles (ear-like appendage at the base of leaf). Plants have shallow, fibrous root systems and produce few tillers. Proso millet has a drooping, branched, compact inflorescence 10–45 cm long made of many stalked, ovoid spikelets. The panicles may be spreading, loose and one-sided, or erect depending on the variety. Proso millet reproduces by seeds, which are shiny, yellow to brown, smooth, oval and 2.4–3 mm long. Domestic proso millet has yellow or light brown seeds, while the weedier wild-proso has brown to black seeds (Plantsusda, 2023). It is an erect herbaceous annual which tillers profusely. Its plant grows up to a height of 45-100 cm. Stem is slender with distinctly swollen nodes. The roots are fibrous and shallow. The leaves are linear, slender and the leaf sheath encloses the entire internode. The inflorescence is a much branched panicle without bristles having spikelets at the tips of the branches. Usually the last or the fourth glume encloses a perfect flower which sets grain. The glume and palea are firmly attached to the grain. The seeds may be creamy white, yellow, red or black (Agritech, 2023).

Proso Millet grass is a summer annual that often branches at the base. It is highly variable in size, ranging from 15-90 cm tall. The culms are erect to barely ascending; they are light green, glabrous to sparsely pubescent, and terete. Alternate leaves occur along the entire length of each culm, becoming less abundant above. The leaf sheaths are whitish green, swollen, and terete to slightly compressed; they are covered with long spreading hairs (hispid-papillose). The leaf blades are ascending, widely spreading, or arching; they are up to 20 mm, 30 cm long, and widest near their bases. The surfaces of leaf blades are medium green and glabrous, sparsely pubescent, or sparsely long-hairy; hairs are especially likely to occur near the bases of leaf blades. The margins of the leaf blades feel rough from minute teeth. Each culm terminates in a panicle of spikelets that is 7.5-25 cm long. Because the base of each panicle is partially enclosed by the uppermost sheath, its branches are contracted to a greater or lesser extent, forming a conic, obconic, or rhombic shape that nods from the weight of numerous spikelets. The central axis and branches of each panicle are light to medium green, somewhat wiry, and glabrous or scabrous (rough-textured and clinging). The outer branches terminate in pedicellate spikelets; the spikelets are ovoid in shape and whitish green while they are immature. Each spikelet is 4.5–5 mm long, consisting of 2 outer glumes, a sterile outer lemma, a fertile inner lemma, and a floret. One glume is 2.5–3 mm in length, while the other glume is the same length as the spikelet. The outer lemma is also the same length as the spikelet. Both the glumes and lemmas are glabrous and longitudinally veined; the shorter glume has 3-5 dark green veins, while the longer glume and outer lemma have 7-11 dark green veins. The outer sides of both glumes and lemmas are convex. Each floret has an ovary with a pair of feathery stigmas and 3 stamens. The blooming period can occur from early summer into the autumn. However, individual plants remain in bloom for only 1 week; they are cross-pollinated by the wind. Afterwards, the florets are replaced by grains (one grain per spikelet). Mature grains are about 3 mm long, ovoid or broadly ellipsoid in shape, partially flattened on one side, glabrous, and nearly white to reddish brown. The root system is fibrous. This grass reproduces by reseeding itself (IWF, 2023)

Floral Biology: Proso millet is still widely considered as a self-pollinated crop despite the possibility of natural cross-pollination (Narciso and Nystrom, 2023). Primary mode of pollination is self-pollination (Rajasekaran *et al*., 2023). Proso millet inflorescence is a drooping panicle, 10-45 cm long that may be open or compact, primary branches spreading or ascending or appressed, terminating in a spikelet.

The bristles below the spikelets are absent. The spikelets are generally solitary and about 0.5cm long. Each spikelet contains two glumes and two lemmas. The glumes are unequal in length, outer glume is short, while the inner glume is as long as the spikelet. Each lemma contains one floret. The floret in lower lemma is sterile without stamen; upper lemma is fertile and shorter than lower lemma (Fig. 6).

The palea of lower lemma (sterile floret) is very much reduced, while the palea of upper lemma (fertile floret) is well present. It has three stamens; anthers are tan or amber or blackish or dark brown in colour. The ovary has bifid style and plumose stigmas. Proso millet starts flowering from top to downward to the bottom of the panicle. The timing of anthesis in proso millet between 10.00 a.m. and 12 noon. It takes 12-15 days from the start of the anthesis of the first flower to the last floret on the panicle. In proso millet, the receptivity of stigma coincides with the shedding of pollen from anthers. When the florets were open, the anthers were sticky and pollen did not shed. Within minutes after the opening of florets, the anthers dried out and begin to shed pollen. The florets remain open for 10-15 minutes. The factors such as high temperatures, low humidity and bright sunlight promote the flowering. Flowering gets reduced on cloudy days. It can be stimulated by heating a panicle with lens (Gupta *et al*., 2012).

(A) Inflorescence; (B) Opened spikelet; (C) Outer glume; (D) Inner glume; (E) Inner lemma; (F) Palea; (G) Inner glume; (H) Outer glume; (I) Upper lemma; (J) Anther; (K) Grain enclosed in lemma and palea; (L) Grain

Fig.6. Proso millet inflorescence and its parts

GENETICS AND CYTOGENETICS

Though there is great advancement in genomics, however, genomic resources in proso millet are very limited. The efficient and cheapest way to develop large numbers of DNA markers and other genomic tools in proso millet is using genomic resources in related grasses (Rajput *et al*., 2012). Proso millet is considered a minor crop compared to wheat, barley and potatoes, and this status is reflected not only in the amount of land cultivated but also in the extent of research in its genetics, genomics and breeding. It was estimated that the haploid genome size of *Panicum miliaceum* to be 1.04 pg or 1017.2 Mb (1C value). The use of molecular markers, generation of sequence information, creation of mapping populations and mutants, and construction of genetic maps, are prerequisites for genetic studies and molecular plant breeding in any crop.

At present, the genomic resources available for *P. miliaceum* are several types of molecular markers such as simple sequence repeat (SSR) and single nucleotide polymorphism (SNP) markers, expressed sequence tags (ESTs), sequences of the Waxy gene, miRNAS, gene-based markers, a genetic linkage map, and an assembled and characterized transcriptome (Habiyaremye *et al.,* 2017). The broomcorn millet or proso millet genome of the landrace (accession number 00000390) was sequenced. A chromosome-scale assembly was obtained using PacBio (single-molecule long-read sequencing) and Illumina (short-read sequencing). More than 55,000 protein-coding genes and microRNA genes (339) were identified with sequenced genome size 923 Mb. Two sets of homologous chromosomes showing strong synteny with other grass species were revealed. BTB (broad complex/tramtrack/bric-a-brac) subunit of ubiquitin E3 ligases was also reported which may be involved in broomcorn millet evolution. A high-density genetic map (18 linkage groups) was constructed based on 221,787 SNP markers generated by sequencing F_6 population of recombinant inbred lines (RIL) comprising 132 individuals. Chloroplast genome was assembled into a single contig with a length of 140,048 bp and 116 genes were identified (Arya *et al*., 2021).

Panicum miliaceum is a tetraploid species with a base chromosome number of 18, twice the base chromosome number of diploid species within its genus *Panicum*. The species appears to be an allotetraploid resulting from a wide hybrid between two different diploid ancestors. One of the two subgenomes within proso millet appears to have come from either *P. capillare* or a close relative of that species. The second subgenome does not show close homology to any known diploid *Panicum* species, but some unknown diploid ancestor apparently also contributed a copy of its genome to a separate allotetraploid species *P. repens* (torpedo grass).

Fig. 7. Three types of proso millet panicles

The two subgenomes within proso millet are estimated to have diverged 5.6 million years ago. However, the species has experienced only limited amounts of fractionation and copies of most genes are still retained on both subgenomes. A sequenced version of the proso millet genome, estimated to be around 920 megabase pairs in size, was published in 2019 (Wikipedia, 2023). Proso millet has a chromosome number of $2n = 36$ with basic chromosome number of $x = 9$. It is suggested that proso millet may have allotetraploid origins with *Panicum capillare* (or a close relative) as a maternal ancestor and the other genome coming from *Panicum repens* based on its nuclear and chloroplast genomes (Narciso and Nystrom, 2023). *Panicum miliaceum* is a tetraploid crop of family Poaceae with a chromosome number of $2n = 4x = 36$ (Rajasekaran *et al*., 2023) and $2n = 36$ or 72 (Narciso and Nystrom, 2023).

GENETIC DIVERSITY

Genetic divergence study is very essential for the selection of genetically diverse parents from existence germplasm for conducting successful hybridization program (Uddin *et al.,* 2020). Understanding the amount and nature of genetic variation is vital for any crop enhancement (Anuradha *et al.,* 2020). Waxy/non-waxy grain is a variable trait for proso millet or broomcorn millet. According to the consumer's taste, some like the waxy broomcorn millet, which tastes glutinous and others prefer the non-waxy. The earliest evidence we have of waxy millet is □2000 years ago, according to historical sources. Waxy or non-waxy just presents the amylose content of starch in endosperm. As to the importance of waxy or non-waxy grains, by investigating of the ecological characters of broomcorn millet varieties, it was found that the broomcorn millet with waxy grains evolved from that of non-waxy grains during the artificial selection. Because the glutinous character of food made from waxy grains suits to consumer's taste, broomcorn millet varieties with waxy grain were selected during the history of cultivation. For non-waxy grains, it was often fried as snack food (Wang *et al*., 2016). As for the weight of 1000 grains among all the collections in China, it is within the range of 1.5 and 10.0 g. Generally speaking, broomcorn millet palea/lemma are of six colors—yellow, white, red, brown, grey, and black (Wang *et al*., 2016). Grain shattering is a major problem in broomcorn millet production. Generally, the shattering property of accessions is classified into three grades—light (shattered grains <5 %), medium (6–10 %), heavy (>11 %) (Wang *et al.,* 2016). here are three types of panicle among the accessions: lateral, vertical-loose, and dense panicle types in the collections (Wang *et al.,* 2016) **(Fig.7).**

Proso millet grain varies in color from white cream, yellow, orange, red, brown to black. The grains are spherical to oval in shape, about 3 mm long and 2 mm diameter. The 1000 kernel weight is about 7.1 g (Taylor and Emmambux, 2008). Proso millet seeds exhibit a variety of colours, from white, cream, yellow, orange, red, black, to brown and are generally smaller than pearl millet seeds **(Fig.8, 9)** (Narciso and Nystrom, 2023).

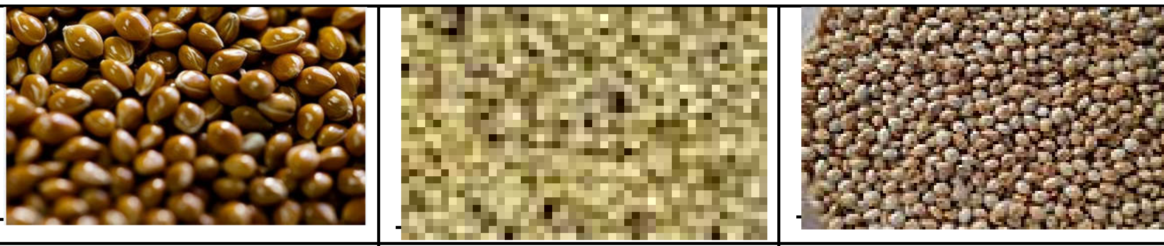


Fig. 8. Variability for seed size, color and shape of proso millet

Fig. 9. Variability in the proso millet germplasm accessions for seed color

One hundred proso millet (*Panicum miliaceum* L.) germplasm which included 50 from erstwhile USSR and 50 from India, were evaluated for variability and magnitude of genetic divergence using Mahalanobis's []^2 analysis. Genetic variability was substantial for nodal, basal and main tiller yield in both Indian and USSR accessions, while for grain yield per plant, it was high in USSR accessions and moderate in Indian germplasm. In contrast, it was high for flag leaf area in Indian' and moderate in USSR accessions. For number of basal tillers, it was moderate in both groups of accessions. For rest of the characters variability was low in both the groups. The 1)2 analysis grouped all accessions into 8 clusters. The USSR accessions were distributed in 4 clusters and Indian in 6 clusters. The characters days to 50 percent flowering, days to maturity, peduncle length, nodal tiller yield, basal tiller yield, main tiller yield and flag leaf area, which showed high genetic variability also contributed for genetic divergence. Geographical diversity was found associated with genetic diversity (Prasad *et al*., 1992). Proso millet occurs both as a crop and a weed in North America. In 1970, an olive-black seeded biotype called 'wild proso millet' was found as an aggressive weed in row crops in Minnesota and Wisconsin and has since spread over a large area. We used Random Amplified Polymorphic DNA (RAPD) to assess genetic relationships among biotypes, measure genetic variation within wild proso millet across its range, and detect hybridization between wild proso millet and crop biotypes of proso millet. We found 97 RAPD genotypes among 398 individuals: 69 wild proso millet genotypes, 26 crop and crop-like weed genotypes, and two hybrid genotypes. Five RAPD markers consistently differentiated wild proso millet from crop cultivars and crop-like weeds. About 10% of the genotypes had at least one marker of the other type, suggesting possible hybridization between wild proso millet and crop biotypes. Most genotypes occurred in only one or two of the over 100 populations tested. The most widespread wild proso millet genotype occurred in 12 populations distributed in North Dakota, Minnesota, Illinois, and Wisconsin. More genetic variation exists among populations of wild proso millet than expected for a plant that presumably experienced a severe genetic bottleneck only 20 generations ago. Hypermutation rates and crossing between wild proso millet and crop cultivars could not account for the degree of genetic variation found in wild proso millet. The pattern of genetic variation among wild proso millet populations suggests multiple introductions of wild proso millet to North America (Colosi and Schaal, 1997). The Amplified Fragment Length Polymorphism (AFLP) technique was used to assess genetic diversity between three domestic and nine wild proso millet biotypes from the United States and Canada. Eight primer combinations detected 39 polymorphic DNA fragments, with the genetic distance estimates among biotypes ranging from 0.02 to 0.04. Colorado-Weld County black seeded and Wyoming-Platte County were the most distinct biotypes according to the dissimilarity level. A UPGMA cluster analysis revealed two distinct groups of proso millet without any geographic association. Six weed biotypes exhibiting some characters of cultivated plants were grouped together with domesticated biotypes of proso millet while the three typical wild phenotypes were clearly clustered into another group according to AFLP markers (Karam *et al.,* 2004).

Analysed genetic diversity among 98 landrace accessions from across Eurasia using 16 microsat-ellite loci, to explore phylogeographic structure in the Old World range of this historically important crop. The major genetic split in the data divided the accessions into an eastern and a western grouping with an approximate boundary in northwestern China. A substantial number of accessions belonging to the 'western' genetic group were also found in northeastern China. Further resolution subdivided the western and eastern genepools into 2 and 4 clusters respectively, each showing clear geographic patterning. The genetic data are consistent with both the single and multiple domestication centre hypotheses and add specific detail to what these hypotheses would entail regarding the spread of broomcorn millet. Discrepancies exist between the predictions from the genetic data and the current archaeobotanical record, highlighting priorities for investigation into early farming in Central Asia (Hunt *et al*., 2011).

A total of 624 SSR markers (548 from switchgrass, 25 from proso BAC library, 21 from rice, 15 from wheat, 9 from oat and 1 from barley) were used. Total of 66 proso germplasm from 28 countries were used for genetic diversity analysis. Only 8 lineswere initially tested to identify polymorphic markers. Cluster analysis (based on UPGMA) was done using NTSYS-pc. Out of 624 SSR primers tested, 464 amplified SSR markers in proso millet. A majority (~62%) of these 464 markers were from switchgrass. Of these 464 markers 283 were polymorphic among 8 lines and 120 of these 283 polymorphic markers were used in 66 germplasm. The 120 SSR markers amplified 730 different alleles. The DNA marker basedgenetic analysis grouped 66 germplasm into different clusters. Switchgrass genomic information seems to be the most useful for developing DNA markers in proso millet. The marker analysis illustrated high level of diversity among the germplasm. Thegenotypes were clustered into three groups:

Group 1 consisted of 5 lines (3 from USA, 2 from other countries)
Group 2 consisted of 60 lines. This major group consisted of 4 sub-groups - 2a,2b, 2c, and 2d
Group 3 consisted of only one line from China (Rajput *et al.,* 2012) **(Fig. 10).**

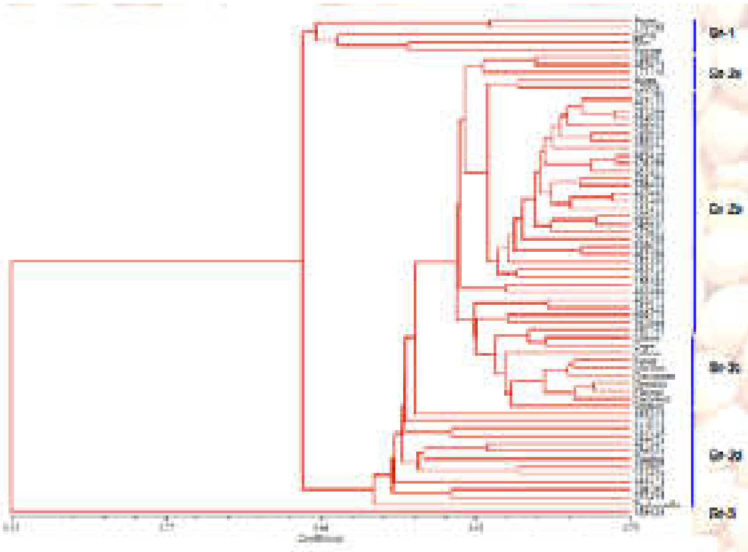


Fig.10 : UPGMA dendrogram showing the genetic relationships of 66proso millet genotypes

Through genetic diversity analysis of the nine phenotypes of proso millet, it was known that the spike weight and grain weight per plant of genetic variation were the most abundant. Phenotypic traits were more concentrated and most of which were apparently interrelated. Genetic diversity of phenotypic traits of germplasm from Shanxi was the richest. Genetic diversity of phenotypic traits was different in different provinces. Principal component analysis and comprehensive evaluation were done for 9 phenotypic traits of 96 copies of proso millet germplasm resources. Comprehensive evaluation value of Neimi No.1 was the lowest, while that of Ningmi No.15 was the highest. Genetic diversity of 96 copies of proso millet germplasm resources was detected by 19 pairs of SSR primers and 112 allelic variation genes were found. The number of alleles per locus ranged from 3 to 9 and the average was 5.9, the average major allele frequency was 0.7045, the average gene diversity index was 0.4097, and the average percentage of polymorphism information content sites was 39.2%. Genetic diversity analysis of germplasm from different regions showed a close relationship among the regions. Genetic diversity index and polymorphic information content percentage of proso millet germplasm resources in Shanxi were 0.357 and 33.01%, respectively. Experimental materials were divided into three groups by genetic structure analysis based on modules and cluster analysis based on genetic distance. Results of these two division methods have similarity. Resources in three groups were connected with geographical environment closely.The results showed that proso millet is rich in genetic variation and has a high diversity. What's more, genetic diversity of proso millet germplasm resources in Shanxi is the most abundant (Jun-Li *et al.*, 2015).

A set of 90 proso millet genotypes (landraces and cultivars) and 100 simple-sequence repeat (SSR) markers were used. Cluster analysis was based on unweighed pair-group method with arithmetic average (UPGMA) and principal component analysis (PCA) using NTSYSpc software. A total of 1287 alleles with size range from 40 to 1500 bp were amplified by the 100 SSR markers. The US proso millet germplasm used in this report is highly genetically diverse. The genotypes formed one major and two minor groups, which correspond to their geographic origin, pedigree, and morphoagronomic traits with few exceptions. All the cultivars developed in the United States remained together in a subcluster within Group 2. Many of these SSR markers with high resolving power were very informative and could be useful for further genetic diversity studies of proso millet (Rajput and Santra, 2016).

42 accessions of proso millet were characterized in Khumaltar (1360 m a.s.l.), Lalitpur in 2015 that were collected from the Humla (1900–2800 m a.s.l.) and Jumla (2300–2600 m a.s.l.) districts of the Western Himalayas of Nepal. Seven quantitative and nine qualitative traits were recorded using standard descriptors. The accessions were found to be diverse using Shannon–Weaver diversity indices (H′) for the quantitative traits of days to heading and maturity, plant height, panicle length, panicle exertion, flag leaf length and grain yield, whereas low diversity was observed for the qualitative traits of leaf sheath colour, flag leaf angle, grain shape, and grain colour, and no diversity was observed for leaf pubescence. The accessions were grouped in five clusters where an accession in Cluster-5 and six accessions in Cluster-4, all from Humla, were found to be high-yielding, early-maturing and of taller plant height. In contrast, 4 accessions in Cluster-2 (3 from Jumla) were low-yielding, late-maturing and of shorter plant height. Accessions H237, H176, H311, H489, H490, H643 and H653, all from the Humla district, performed better in the preliminary evaluation (Ghimire *et al.*, 2018).

The authors genotyped six Slovenian landraces of proso mill*et al*ong with one Slovene autochthonous cultivar, Sonček. The chosen set of 11 SSR markers showed that there is low overall heterozygosity (0.561) among Slovenian landraces of proso millet. However, we were able to determine distinct groups on the dendrogram for different landraces and the cultivar by using UPGMA clustering. The PCoA scatter plot showed dispersion of unique individuals. The SSR markers used proved to be efficient for assessing the genetic diversity of Slovenian landraces of proso millet. Furthermore, we performed a 3-year field experiment and determined grain yield (ranging from 1032 to 1667 kg ha^{-1}) and yield stability using Kang's yield stability index (YSi). The morphology of panicles and grain was described as well (Flajšman *et al.*, 2019).

The genetic diversity and antioxidant potential of *Panicum miliaceum* L. accessions collected from different geo-ecological regions of South Korea were evaluated and compared. Antioxidant potential of seeds was estimated by the 1,1-diphenyl-2-picrylhydrazyl (DPPH) and 2,2′-azino-bis-3-ethylbenzthiazoline-6-sulfonic acid (ABTS) radical scavenging assays and total phenolic content was determined by the Folin–Ciocalteu method. Total phenolic content (TPC) in 80% methanolic extracts ranged from 16.24 ± 0.86 to 58.04 ± 1.00 mg gallic acid equivalent (GAE)/g of the sample extracts and total flavonoid content (TFC) varied from 7.19 ± 1.05 to 52.56 ± 1.50 mg quercetin equivalents (QE) mg/g of the sample extracts. DPPH radical scavenging capacity of the extracts from the 15 accessions of *P. miliaceum* varied from 206.44 ± 7.72 to 2490.24 ± 4.641 mg GAE/g of the sample extracts and ABTS radical scavenging capacity ranged from 624.85 ± 13.1 to 1087. 77 ± 958 mg GAE/g of the sample extracts (Ghimire *et al*., 2019).

The genebank at the International Crops Research Institute for the Semi-Arid Tropics conserves 849accessions of proso millet originating from 30 countries and represents all five races. Characterization of these germplasm accessions revealed large variability for morpho-agronomic traits, including fordays to 50% flowering (26 to 50 days), plant height (20 to 133 cm), and inflorescence length (22 to 400 mm). On average, the race *miliaceum* was tall (62 cm) with long panicles (209 mm) and *ovatum* had short plants (46 cm) with small panicles (108 mm). The average Gower's distance based on 18 morpho-agronomic traits on 841 accessions was 0.261. The race *miliaceum* had the highest among accessions within race average pairwise distance (0.254), while the distance was the lowest in *ovatum* (0.192). The races *miliaceum* and *ovatum* showed the highest divergence with each other (0.275), while the lowest divergence was observed between *compactum* and *ovatum* (0.229). Trait-specific sources were identified for early maturity, tall plants, long inflorescences, and greater seed size. The information on variability and trait-specific sources identified could potentially support proso millet improvement (Vetriventhan *et al*., 2019).

Proso millet starch granules were found to have a bimodal distribution with two basic shapes and sizes—small spherical and large polygonal. Large spherical granules were rarely present. Many large polygonal granules showed indentations due to dense packing of the endospermwith protein bodies. Size of starch granules ranged from 1.3 to 8 µm. Proso millet starch was also found to have higher water-binding capacities and gelatinization temperatures than wheat starch and a comparable or slightly lower swelling power at 90°C than that of rye starch. Interestingly, the amylograph viscosities of proso millet starches were higher compared with wheat starch at all reference points. Compared with regular proso millet starch, the starch from a waxy type with only 0.2% amylose had higher peak and hot paste viscosities and as expected, lower set back viscosity values (Serna-Saldivar and Espinosa-Ramírez, 2019.).

The EST-SSR molecular markers of proso millet were developed by high-throughput sequencing. Using these markers, we assessed the genetic diversity in a panel of 144 common millet accessions collected from different ecotopic regions in China and abroad. It was shown that 80 pairs of these markers were polymorphic, with the efficiency of approximately 40%. The resolution power (Rp) was 0.67-4.67 (mean 2.00) and the amplified product sizes ranged from 50 to 500 bp. Among the examined 144 accessions, 206 allelic variations were identified in 80 loci, with 2-3 alleles at each locus. The Shannon's diversity index (*I*) ranged from 0.659 3 (RYW108) to 1.087 2 (RYW124) with an average of 0.859 9. The range of polymorphism information content (*PIC*) was 0.222 9 (RYW98) -0.717 2 (RYW124) with an average of 0.457 3. Based on UPGMA, these 144 accessions were classified into 3 groups, two of which belonged to the the Northern China spring-sowing ecotopes and one group was mainly from the Loess Plateau spring-summer-sowing ecotopes. Based on Structure (*K*=4), all the accessions were divided into four groups, of which two groups represented the gene pool originated from the Northern China, whereas the other two groups from the Loess Plateau and abroad accessions. Based on principal component analysis (PCA), the accessions were clustered into seven groups, consistent with their geographic origins (Jieli He *et al*., 2019).

An investigation with one hundred nineteen genotypes of proso millet was carried out in Bangladesh to study the nature and magnitude of genetic divergence following Mahalanobis D^2 statistics. The 119 genotypes of proso millet were assembled into eight clusters. Among the eight clusters, cluster VI was found to be largest having 27 germplasm followed by cluster V having 20 germplasm. While the minimum number of germplasms was observed in cluster II noted as 7. High degree of genetic diversity was revealed by the genotypes of cluster III and cluster IV. Cluster III was appropriate for filling period, height of plant, weight of seed per panicle, yield of straw /plant and yield of grain /plant. Cluster VIII is suitable for early flowering and short duration proso millet variety. Cluster III is best suited for the development of dwarf variety. Weight of seed/ panicle (g) and flag leaf area (cm^2) contributed most towards genetic diversity of proso millet. Analysis confirmed the lack of association between geographic origin and hereditary assortment, as germplasm from the unalike area clustered into same groups and the germplasm of alike area were congregated into different clusters. Therefore, plant breeder should assess their material for genetic diversity and should not purely depend on their geographical origin (Uddin *et al*., 2020).

Seventeen proso millet advanced breeding lines developed across the country were evaluated during kharif, 2019 at Agricultural Research Station, Vizianagaram to assess genetic variability, heritability and genetic advance for seven yield contributing traits. The characters included under study were days to 50 % flowering, plant height, days to maturity, number of productive tillers per plant, panicle length, grain yield and fodder yield per plant. The ANOVA revealed significant differences among seventeen genotypes for all the characters included under study. Fodder yield and grain yield showed high variability indicating the scope of improvement of these characters by simple direct selection. Narrow range of variations for PCV and GCV were observed for days to 50% flowering, days to maturity, indicating less variation for these traits. High heritability and high GAM were recorded for grain yield, fodder yield and plant height indicates preponderance of additive gene action and additive gene action is very much selection responsive (Anuradha *et al*., 2020).

The genebank in ICRISAT, India holds nearly 850 accessions. These accessions were evaluatedand a core collection was generated comprising of 106 accessions representing all the five races. Evaluation of several proso millet germplasm collections consisting of landraces, wild types, varieties and advanced breeding lines provides diversity scenario and line based trait profile for further utilisation in breeding programs. Evaluated 200 accessions of proso millet including the 106 representative core of ICRISAT, India for diversity in morpho-agronomic and nutritional traits. The study identified potential nutrient rich lines with high yielding traits. However, the lines are yet to be tested for regional adaptation that would further enhance their breeding utilization purposes. Proso millet is well adapted to drought areas where the water availability can be as low as 20-50 cm. Identified GR665 and Minsum varieties as good performers in non-irrigated areas. Primary evaluations of 360 proso millet accessions reported high variability, high geneticadvance and high heritability for yield contributing traits studied (Gopinath and Kumar, 2023). Traditional landraces and wild species are vital sources of genetic variation, which is a significant factor in crop improvement. The loss of genetic diversity can be attributed to non-usage of the traditional landraces in favour of modern high-yielding cultivars. In addition, traditional landraces of proso millet are grown mainly under subsistence farming, which also results in genetic erosion (Narciso and Nystrom, 2023).

Genetic variations of 42 varieties of proso millet, which are conserved in the National Agriculture Genetic Resource Centre in Japan and are cultivated in the western part of Himalayas, were assessed. Seven quantitative and nine qualitative traits were analysed. High variation was noted in quantitative traits like days to heading and maturity, plant height, panicle length, panicle exsertion, flag leaf length and grain yield. Variation was low for the qualitative traits of leaf sheath colour, flag leaf angle, grain shape, and grain colour. The declining diversity of proso millet, specifically in Western Himalayas of Nepal may be due to farming preferences, including market demand for the crop, farmer interest in growing the crop, available suitable area for crop cultivation, and the choice of easily manageable variety. Farmers prefer varieties that are higher yielding, easy to dehusk, early to mature and flower, great tasting, and have high biomass. In addition, early flowering varieties are preferred by farmers in the high mountainous region of Western Himalayas of Nepal due to the early start of cold weather and which is now becoming more susceptible to drought due to climate change (Narciso and Nystrom, 2023). The exact centre of millet domestication in China is still disputed. The presence of early millet sites in Dadiwan in the Loess Plateau and Xinle and Xinglonggou in northeast China, far from the Yellow River valley, does not seem to support the view of a north Chinese agricultural origin for proso millet and foxtail millet that is centred around the central Yellow River valley. However, it can also mean that a different location is the focus of proso millet domestication or there are multiple foci within China. Based on comparisons of landrace genetic diversity between regions in China, it was inferred that a centre of proso millet domestication is in the Loess Plateau. The level of landrace genetic diversity from the Loess Plateau was not significantly higher than those from other regions of China. Sufficient precise geographical information is needed to enable analyses of phylogeography or genetic diversity of many accessions from China (Narciso and Nystrom, 2023).

BREEDING

Germplasm

Due to its long cultivation history and wide distribution, broomcorn millet possesses abundant germplasm resources. The N. I. Vavilov Research Institute of Plant Industry, St Petersburg, Russia,holds over 9000 accessions collected from most regions where it was cultivated in the former USSR and from 60 foreign countries (Kurzeva *et al.* 2012).About 6 % of these are improved cultivars, 87.4 %are local varieties, 4.8 % are breeding source mate-rials, and 1.8 % are mutant/genetic materials (Kurzeva *et al.*2012). In the National Centre forPlant Genetic Resources of Plant Production Insti-t ute, Ukraine, there are 7169 accessions from 36countries, of which 29 % are selected varieties, 45 % local varieties, 18 % breeding lines, and 2.3 % mutants (Kobyzeva *et al.* 2012; Wang *et al.*, 2016). China has 8515 accessions, held in the National Germplasm Resources Bank, which were accumulated over a 22-year period from 1982 to 2003 (Wang *et al.* 2005). Of these, 8331 accessions, accounting for about 98 % of the collection, are from 23 provinces of China, with the rest from 14 other countries. Among the collections from China, 99.4 % are landraces, and 0.6 % (54 accessions) are cultivars or breedinglines (Wang *et al.* 2012). These collections werecharacterized on a large scale between 1982 and 2003. Here, we analyze the data and summarizethe characteristics of broomcorn millet genetic re-sources in China (Wang *et al.*, 2016).Proso, barnyard, little,and kodo millets are highly nutritious crops and have climate-resilient traits. Globally, about 50,000 germplasm accessions of these crops have been conserved, and the largest collections of proso millet are in the Russian Federation and China, barnyard millet in Japan, and kodo millet and little millet in India. These crops have larger variation for yield and its component traits including stress tolerance related characters. Core collections representing diversity of entire collections of these crops have been developed for identification of new sources of variation for major prevailing biotic and abiotic stresses, and for quality as well as important agronomic traits. Globally, more than 29,000 accessions of proso millet, 8,000 accessions each of barnyard and kodo millet, and more than 3,000 accessions of little millet have been conserved. The ICRISAT gene bank in India conserves 849 accessions of proso millet, 749 accessions of barnyard millet, 665 accessions of kodo millet, and 473 accessions of little millet under medium- and long-term storage. Limited research works have been done on germplasm characterization and evaluation of various agronomic traits, nutritional traits, and biotic and abiotic stresses (Singh and Upadhyaya, 2016).

Maintaining genetic variability among the cultivated varieties of a crop is essential to have a stable production system. The success of any plant breeding program depends on the variability exhibited by the germplasm. Eforts to collect, characterize, and document germplasm collections from across the globe are essential for crop improvement programs. Work on proso millet has been sidelined due to the focus on major crops. The most extensive collection of proso millet germplasm accessions (8778) is maintained in Rus- sia. Other major gene banks conserving the crop's genetic variability are in China, Ukraine, India, and USA. In India, two national institutes All India Coordinated Research Project on Small Millets (AICRP-small millets), National Bureau of Plant Genetic Resources (NBPGR)] and one international institute International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) are involved in plant genetic resource maintenance. AICRP established a separate unit in Bengaluru in 1976. This unit is actively engaged in the collection, evaluation, and documentation of small millet germplasm in India. AICRP also maintainsa collection of 920 accessions of Proso millet. NBPGR is the nodal organization in India for the management of plant genetic resources of agri-horticultural crops and has about 994 accessions of proso millet. ICRISAT with 849 accessions is involved in germplasm characterization and evaluation of proso millet. ICRISAT developed a core collection of106 accessions from 833 proso millet accessions of 30 coun-tries based on 20 qualitative and quantitative traits. Random selection of 10% accessions from each of the 101 clusters was employed to develop the core set (Rajasekaran and Neethu-Francis, 2020). Proso millet germplasm representing a wide genetic diversity is conserved in gene banks maintained by several countries (Santra *et al.,* 2019). Over 29,000 germplasm accessions have been conserved in genebanks globally (Vetriventhan *et al.,* 2019). Around 28,000 germplasm lines are maintained at various gene banks around the world, and Russia has the biggest collection. However, these resources remain underexploited. More efforts to characterize these sources and mine them for trait-based donors are essential (Rajasekaran *et al*., 2023). There are more than 29,000 germplasm collections of proso millet conserved worldwide. The major genebanks of proso millet germplasms are listed in Table 1. China, India, Russia, and Ukraine have the key collections. Recent reviews and research studies published on the characterisation and identification of germplasm accessions for stress tolerances, both abiotic and biotic, and agronomic and nutritional traits were reported (Narciso and Nystrom, 2023).

Breeding Objectives: The primary objective of crop improvement programs in the crop is increasing yield and making cultivation more remunerative. Developing nonshattering and nonlodging genotypes are also being focused. Further improving the nutritional content, abiotic and biotic stress tolerances of the crop and considering regional consumer preferences can increase the adaptability and acceptability of the corp (Rajasekaran *et al*., 2023). Considering the demand, grain yield is the major breeding objective in proso millet improvement programs in addition to heat and drought stress (Gopinath and Kumar, 2023).

Table 1. Major genebanks conserving germplasm of proso millet worldwide

Country	Institute	No. of accessions
Australia	Australian Tropical Crops and Forages Genetic Resources Centre	228
Bangladesh	Plant Genetic Resources Centre, BARI	198
Bulgaria	Institute for Plant Genetic Resources "K. Malkov"	489
China	Institute of Crop Science, Chinese Academy of Agricultural Sciences	8451
Czech Republic	Genebank Department, Division of Genetics and Plant Breeding, Research Institute of Crop Production	171
Germany	Genebank, Leibniz Institute of Plant Genetics and Crop Plant Research	165
Hungary	Institute for Agrobotany	243

India	AICRP on Small Millets	920
	International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)	849
	National Bureau of Plant Genetic Resources	994
Japan	Department of Genetic Resources I, National Institute of Agrobiological Sciences	516
Mexico	Estación de Iguala, Instituto Nacional de Investigaciones Agrícolas	400
Poland	Botanical Garden of Plant Breeding and Acclimatization Institute	354
	Plant Breedingand Acclimatization Institute	359
Russia	N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry	8778
Ukraine	Institute of Plant Production n.a. V.Y. Yurjev of UAAS	1046
	Ustymivka Experimental Station of Plant Production	3975
USA	North Central Regional Plant Introduction Station, USDA-ARS,	717

Table 2.Proso millet varieties recommended for different states

States	Varietie
Tamilnadu	ATL 1 (TNPm 230), Co5, TNAU 151, TNAU 164, TNAU 145, TNAU 202, CO 4, K2, CO 3,CO 2, GPUP 21, GPUP 8
Uttarakhand	PRC 1, TNAU 145, TNAU 164, TNAU 151
Karnataka	ATL 1 (TNPm 230), DHPM-2769, GPUP 8, GPUP 21, TNAU 145, TNAU151, TNAU 164, TNAU 202
Bihar	ATL 1 (TNPm 230), BR 7, TNAU 164, 145, PR 18, TNAU 202
Andhra Pradesh& Telangana	TNAU 202, TNAU 164, TNAU 151, Sagar, Nagarjuna, CO 4, CO 3, TNPm230
Uttar Pradesh	Bhawna, PRC 1, TNAU 145, 164, 151
Madhya Pradesh	TNAU 202
Chattisgarh	TNAU 202
Gujarat	TNAU 202

Plant breeders across the globe are trying to develop superior varieties using both classical and advanced breeding procedures. However, the lack of a genetic map and adequate genomic resources has slowed the crop improvement process (Santra *et al.,* 2019). The development of proso millet cultivars which are high yielding, lodging and seed-shattering tolerant, direct combine-ready and nutrient enriched, would promote its increased cultivation, and use in the food industry (Santra *et al.*, 2019).

Breeding: Regardless of the impeccable environmental and health benefits of proso millet, it remains as an under researched and underutilized crop. Plant breeders across the globe are trying to develop superior varieties using both classical and advanced breeding procedures. However, the lack of a genetic map and adequate genomic resources has slowed the crop improvement process. Proso millet germplasm representing a wide genetic diversity is conserved in gene banks maintained by several countries. The rapid growth in genomic research in the form of a linkage map development, novel molecular marker identification and availability of next-generation sequencing, together with high-throughput phenotyping promise to accelerate proso millet breeding. The development of proso millet cultivars which are high yielding, lodging and seed-shattering tolerant, direct combine-ready and nutrient enriched, would promote its increased cultivation, and use in the food industry (Santra *et al.*, 2019). Proso, little, barnyard, and kodo millets are also affected by abiotic stresses, though they are generally considered well-adapted to abiotic stresses as compared to most other cereals. Barnyard millet is reported to be tolerant to drought and waterlogging , while proso millet is susceptible to drought. Lodging is a constraint in many crops, including proso, little, barnyard, and kodo millets, causing substantial losses in grain yield and quality. Use of lodging-resistant cultivars along with good crop husbandry is the most effective way to minimize losses due to lodging. Proso millet lines developed in the United States have had strong selection for lodging resistance. Sources for salinity tolerance have been reported (Acc. No. 008211, 008214, and 008226) in proso millet (Upadhyaya *et al.*, 2016). In proso millet, crop improvement programs are focused on improving traits like yield, lodging resistance, non- shattering, early maturity, panicle type, waxiness, etc. Through conventional methods like pure-line selection, pedigree breeding, and backcrossing, improved varieties have been developed in proso millet. China, India, USA, Russia, and Kenya are major countries involved in proso millet breeding. In India, K2 is a variety developed through pure-line selection, which is non-lodging and non- shattering. The varieties TNAU 202 and ATL 1 are high yielding varieties developed through hybridization program. Dawn and Early-bird are early maturity varieties developed from the USA. Russian variety Alba is known to have non-shattering property. ‘Plateau’ is an amylase free or waxy cultivar developed by the Nebraska Agricul- tural Experiment Station, USA. Waxy forms of millet are preferred in the food industry for their glutinous nature and beverage industry for their fermentation eiciency. Studies to understand the genetics and inheritance of waxy traits have been carried out. Waxy trait in proso millet is reported to be controlled by duplicate recessive alleles. GBSSI gene (with two loci-S, L) mutations are identi- fied to be resulting in waxiness, and the GBSSI-S locus is mainly contributing to the trait. Rajput *et al.* used molecular breeding to identify eighteen quanti- tative trait loci (QTL) for eight important phenotypic traits like heading date, 100-grain weight, grains per panicle, lodging, peduncle length, plant height, grain shattering, and panicle length. These QTLs can be used for marker- assisted selection (Rajasekaran and Neethu-Francis, 2020). Using innovative genotyping, breeding, and selection strategies employing natural genetic diversity in proso millet collected from around the world, Dryland Genetics is already seeing significant yield improvements relative to the best lines currently on the market in trials conducted in Colorado and Nebraska (DG, 2023). The use of molecular markers give molecular fingerprint of the accessions and collections in crop improvement. Proso millet accessions have be evaluated for genetic diversity using molecular markerssuch as AFLP, RAPD, ISSR and SSRs. SSR markers were derived from sequences of related plant species and utilised to study diversity and genetic similarity coefficient. These SSR were able group the accessions into clusters that corresponded to ecological areas of collection. SSR based molecular studies aiming for line based DNA profiling identified numerous alleles across accessions and relative geographic structuring. Diversity analysis using markers derived from coding genomic regions such as intron splice junctions, clustered landraces and varieties differently besides clustering relative to geographic locations. Similar study based on 5S ribosomal sequences constructed phylogenicrelationships that clustered accessions from China and Russia together and Korean accessions separately (Gopinath and Kumar, 2023).

Varieties: Landraces haven been primary source of varieties in proso millet and a few more resulted from hybridization efforts (Gopinath and Kumar, 2023). The list of latest and popular varieties recommended for different states are given in the **Table 2** (Chapke *et al.,* 2020). A number of varieties with high yield potential have been released for different states. The list of latest and popular varieties recommended for different states are given in **Table 3** (Viaspedia, 2023; Millets, 2023):

Table 3. Proso millet varieties recommended for different states

State	Varieties
Tamil Nadu	Co-5, TNAU 151, TNAU 164, TNAU 145, TNAU 202, CO 4, K2, CO 3,CO 2, GPUP 21, GPUP 8
Uttarakhand	PRC 1, TNAU 145, 164, 151, CO 4
Karnataka	GPUP 8 and GPUP 21, TNAU 145, 164
Bihar	BR-7, TNAU 164, 145, PR 18
Andhra Pradesh	Sagar, Nagarjuna, CO 4, CO 3

Salient features of released varieties of proso millet in India are given in **Table 4** (IIMR, 2023).

Table 4: Salient features of released varieties of proso millet in India

Name of variety	Pedigree	Institute where developed	Year of release	Maturity (days)	Av. Yield (Q/ha)	Area of adaptation
TNAU 202	PV 1453 x GPUP 16	TNAU, Coimbatore	2011	70-75	18-20	National
TNAU 164	TNAU 137 x CO 4	TNAU, Coimbatore	2009	70-75	18-20	National
PRC 1	Selection from GPMS 519	Ranichauri, GBPUA&T, Pantnagar	2008	70-75	10-12	Uttarakhand hills
TNAU 151	TNAU 96 x PV 1673	TNAU, Coimbatore	2008	72-75	18-20	National
TNAU 145	PV 1454 x TNAU 96	TNAU, Coimbatore	2007	70-72	18-20	Tamil Nadu
CO(PV) 5 (TNAU 143)	PV 1403 x GPUP 21	TNAU, Coimbatore	2007	70-75	23-25	National
PratapCheena-1 (PR-18)	Pureline selection	MPUA &T, Udaipur	2006	65-70	15-17	National
GPUP 21	GPUP 14 x K 1	PC Unit, UAS, Bangalore	2003	65-75	15-18	Karnataka, Tamil Nadu
GPUP 8	S 7 x L 111	UAS, Dharwad	2001	85-90	15-16	Karnataka
Bhawna	Pureline selection	CSAUAT, Kanpur	1992	65-70	12-15	Uttar Pradesh
Co 4	Pureline selection	TNAU, Coimbatore	1989	70-75	12-15	Tamil Nadu
Nagarjuna	Pureline selection	ANGRAU, Hyderabad	1989	60-65	15-18	Andhra Pradesh
Sagar	Selection from Local	ANGRAU, Hyderabad	1989	85-90	18-20	Andhra Pradesh
K 1	Selection from Local	TNAU, Coimbatore	1982	65-70	9-10	Tamil Nadu

In western Nebraska, commonly cultivated proso millet varieties are Horizon, Sunrise, Huntsman, Earlybird, Sunup, Dawn, and with Dawn being the parent of most cultivars released in Nebraska.

These varieties have been selected for cream/white seeds, and many studies on the characteristics of proso millet were performed using these varieties. The genetic base of the cultivars widely cultivated in the United States is narrow due to the limited number of varieties used as parents during breeding (Narciso and Nystrom, 2023).

USES

Processing: Milling of the grain yields about 79% flour, with removal of the bran and the husk. The starch granules in proso millet starchy endosperm are mostly small and spherical rather than large and polygonal, and range from 1.3 to 8.0 µm diameter . The endosperm protein bodies are globular in shape and about 2.5 µm in diameter. Prolamin accounts for up to 80% of the total protein (Taylor and Emmambux, 2008). Millets, the nutri-cereals, have the potential to play a crucial role in the fight against food insecurity and malnutrition. Nutri-cereals are an abundant source of essential macro- and micronutrients, carbohydrates, protein, dietary fiber, lipids, and phytochemicals. The nutrient content and digestibility of millets are significantly influenced by the processing techniques. The processing techniques of millets such as fermentation, germination, dehulling, extrusion, cooking, puffing, popping, malting, milling, etc. were reviewed. Germination and fermentation showed a positive improvement in the overall nutritional characteristics of millets, whereas excessive dehulling, polishing, and milling resulted in reduction of the dietary fiber and micronutrients (Nanje Gowda *et al*., 2022). The bulk of proso millet sold in cash trade is marketed through elevators in counties where it is grown most extensively. This grain is cleaned further, processed, and used for bird seed. Both domestic and wild bird seed is packaged by adding other grains for color and nutrition. Some proso millet goes through a dehulling process and supplies both human and animal needs. Some is exported and some used for specialty purposes. India and several African nations are large proso millet producers and consumers, mainly using proso millet for human consumption (EP, 2023). There is proso millet that has a hard cellulosic husk layer that humans cannot digest. Together it is sometimes referred to as small millet. The removal of the husk layer thus becomes the primary task of processing this grain. Once removed, we get the proso millet rice. To remove the husk from the grain, one can use two forces – impact or shear. A stone grinding mill, manual or motor powered, employs the shear force while manual pounding or centrifugal hulling machines use the impact force. Large scale processing of proso millet compromises on the nutritional value of the millet rice output by removing the bran layer completely. But the pest infestation problem continues to be severe and most processors resort to chemical methods of cleaning their products pest free (Fig. 11) (MF, 2023). Millet pounding setup in an adivasi family.

A centrifugal millet huller: At the other end of the supply chain, the lack of small scale processing has adversely affected the availability of the processed millets for use by the farming communities themselves – a rural household cannot afford to buy millet rice from the market. Small scale processing machines and process flows have been developed. But the inherent variations in the harvested grains' characteristics is significant. This problem magnifies when the small millets are aggregated for processing. So in that sense, there is an inherent advantage in small scale processing.

Millet pounding setup in an adivasi family

A centrifugal millet huller

Fig. 11. Processing of proso millet

But a big stumbling block in achieving good quality millet output, *i.e.* clean small millet rices with minimum bran loss, is the lack of skilled operators who understand the grains and are trained in using the right tools and machines (MF, 2023).

Uses

In Inner Mongolia and norwestern Shanxi, China, fermented proso millet porridge known as is popular. Millet is soaked to allow fermentation, then water is emptied to obtain porridge. The emptied water is served as a millet drink. The porridge is eaten alongside pickles, *e.g.,* turnips, carrots, radish and celery. The porridge may be stirred-fried.The porridge may also be steamed into solids. While the traditional grain is proso millet, it is mixed with rice when available. Many folk idioms of sourness derive from this dish. In Himachal Pradesh, India, lassi with proso millet is served as a drink, especially the Gaddi tribes. In the United States, proso millet is to brew gluten-free beer. It is often mixed with other grain to produce better texture (Wikipedia, 2023). Proso millet can be used in many food applications. Food applications can depend on the properties and amylose content of the proso millet starch. Less amylose (≤10%) means a lower peak temperature during pasting. Higher amylose starches exhibit higher cold paste viscosity. Wax starch breaks down more than non-waxy starch. Waxy starches also retrograded more slowly during pasting, indicating greater stability. Waxy millets are therefore good raw materials for beverages due to their low retrogradation. Based also on these properties, the cultivar Earlybird, a low-amylose proso millet, is suggested for breadmaking, whilst cultivars Sunrise and Sunup, for example, are good for gluten-free pasta because of their higher cold paste viscosity. The undesirable bitterness of proso millet remains an obstacle to its widespread consumption. It is unclear which constituents contribute most to its bitterness because even in food products made of proso millet that have low tannins exhibit a degree of bitterness. Different processing strategies such as sprouting or fermentation can be used and assessed to reduce bitterness (Narciso and Nystrom, 2023).Proso millet is primarily grown as livestock and poultry fodder. As food it is very deficient in lysine and needs complementation. Proso millet is also a poor fodder due to its low leaf-to-stem ratio and a possible irritant effect due to its hairy stem. Foxtail millet, having a higher leaf-to-stem ratio and less hairy stems, is preferred as fodder, particularly the variety called moha, which is a high-quality fodder (Wikipedia, 2023). Many preparations from Proso Millet viz., Proso Millet Rawa Idli, Proso Millet Khaja, Proso Millet Burfi, Proso Millet Samosa, Proso Millet Payasam, Proso Millet Cheese Balls, Proso Millet Manchuria, Proso Millet Shankarpala, Proso Millet Venpongal, Proso Millet Upma, Proso Millet Masala Dosa, Proso Millet Idli, Proso Millet Chapati and Proso Millet Kichri can be prepared.

NUTRITIONAL VALUE

The proximate nutritional composition of proso millet is similar to that of other millets. Its starch can vary from 62 to 68% and the amylose content expressed as percentage of the grain is about 17% on a dry basis. The rate of starch hydrolysis of proso millet is similar to that of maize. Concerning the nutritive value of protein, proso millet has an *in vitro* digestibility of about 80%. When compared with casein, proso millet protein has been reported to have beneficial effects by suppressing liver injury induced by D-galactosamine. In terms of the triglycerides, the most common fatty acids are linoleic acid (60%) followed by oleic acid (14%). Proso millet has been found to increase the level of the desirable high-density lipoprotein in the blood plasma of mice. The total polyphenolic and carotenoid contents of proso millet have been reported as 29 and 74 µg/100 g, respectively and a methanolic extract containing these compounds was found to have good antioxidant properties. With regard to anti-nutrients, proso millet apparently does not have protease inhibitory activity when compared with pearl millet, foxtail millet, and finger millet, however, chymotrypsin inhibitors have been detected ((Taylor and Emmambux, 2008). The following is characteristic for the chemical composition of proso millet: carbohydrate 69.8%, protein 6–16% (N × 6.25), fat 4.1–9.0%, and minerals 1.5–4.2%. (Zarnkow, 2014). The potential health benefit qualities of proso millet besides gluten free and mild flavour are increasing the preference for human consumption and food industries (Wang *et al*., 2016). Nutritional value of proso millet aerial part is given in **Table 5** (Tran , 2017).

Table 5. Proso millet (*Panicum miliaceum*), aerial part

Main analysis	Unit	Avg
Crude protein	% DM	10.1
NDF	% DM	73.7
ADF	% DM	36.0
Lignin	% DM	4.5
Ash	% DM	7.9
Minerals	Unit	Avg
Calcium	g/kg DM	3.6
Phosphorus	g/kg DM	1.6
Potassium	g/kg DM	13.6
Sodium	g/kg DM	0.1
Magnesium	g/kg DM	2.1
Manganese	mg/kg DM	132
Zinc	mg/kg DM	85
Copper	mg/kg DM	14
Iron	mg/kg DM	154

The tiny Proso millet seeds are packed with important nutrients and provides about 350 calories per 100 grams. The protein content of these millets (11.6%) is similar to that of wheat. However, the grains are significantly high in essential amino acids leucine, isoleucine and methionine making them a high-quality protein source. They are a rich source of vitamins like Thiamine, riboflavin, niacin, pyridoxine and Vitamin E along with minerals like phosphorus, manganese, iron and potassium. The mineral content in proso millets is similar or slightly higher to that of other cereals. These millets are also rich in soluble fibre and its fibre content in dehulled grains can be compared with that of oats. It also contains several bioactive compounds like polyphenols that have great nutritional importance (NVT, 2019). Recently, the high content of different minerals and amino acids along with a low glycemic index and gluten-free property of the grains have attracted the industry and scientific communities (Santra *et al*., 2019). Noteworthy, the crop is low on glycemic index, gluten-free, possesses good quality protein, vitamins, minerals, and other nutraceutical properties. Being a C_4 panicoid species, proso millet possesses better water-use and nitrogen-use efficiency, thus promising this as an ideal crop for cultivation in the scenario of global climate change (Rajasekaran and Francis, 2021). Proso millet is rich in protein (>10%)with higher amount of essential amino acids, minerals and vitamins (Gomesh *et al.,* 2017). Proso millet is majorly utilised as bird feed and cattle feed (Gopinath and Kumar, 2023).
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Table 6. Nutritional value per 100 g of Millet flour (Wikipedia, 2023).

Energy	1,597 kJ (382 kcal)
Carbohydrates	75.1 g
Dietary fiber	3.5 g
Fat	4.2 g
Protein	10.8 g
Vitamins	**Quantity % DV†**
Thiamine (B1)	35 %0.4 mg
Riboflavin (B2)	6% 0.07 mg
Niacin (B3)	40 %6 mg
Pantothenic acid (B5)	26 %1.3 mg
Vitamin B6	28 %0.37 mg
Folate (B9)	11 %42 μg
Vitamin E	1% 0.11 mg
Vitamin K	1% 0.8 μg
Minerals	**Quantity % DV†**
Calcium	1% 14 mg
Iron	30 %3.9 mg
Magnesium	34 %119 mg
Manganese	48 %1 mg
Phosphorus	41 %285 mg
Potassium	5% 224 mg
Sodium	0% 4 mg
Zinc	27 %2.6 mg
Other constituents	**Quantity**
Water	8.7 g

Starch derived from millets has been shown to be a good substrate for fermentation and malting with grains having similar starch contents as wheat grains. A recently published study suggested that starch derived from proso millet can be converted to ethanol with an only moderately lower efficiency than starch derived from corn. The development of varieties with highly fermentable characteristics could improve ethanol yield to that of highly fermentable corn. Since proso millet is compatible with low-input agriculture, cultivation on marginal soils for biofuel production could represent an important new market, such as for farmers in the High Plains of the US (Wikipedia, 2023). The demand for more diverse and healthier cereal-based foods is increasing, particularly in affluent countries. This could create new markets for proso millet products in human nutrition. Protein content in proso millet grains is comparable with that of wheat, but the share of some essential amino acids (leucine, isoleucine, and methionine) is substantially higher in proso millet. In addition, health-promoting phenolic compounds contained in the grains are readily bioaccessible, and their high calcium content favors bone strengthening and dental health. Among the most commonly consumed products are ready-to-eat breakfast cereals made purely from millet flour, and a variety of noodles and bakery products that are, however, often produced from mixtures with wheat flour to improve their sensory quality (Wikipedia, 2023). Proso-millet is an underutilized crop which is highly nutritious cereal grain used for human consumption, bird seed, and/or ethanol production. Grains of proso Millet are a rich source of vitamins (niacin, B-complex vitamins, and folic acid), minerals (PCa, Zn, Fe) and essential amino acids (methionine and cysteine), starch, and phenolic compounds like antioxidants and Beta-glucan. Seeds also contain components with healing benefits, which decrease the level of low-density lipoprotein cholesterol in blood and injury to the liver and high lecithin content which supports the neural health system **(Table 7)** (APEDA, 2023).

The millet is rich in protein, minerals, vitamins, fiber, carbohydrates, etc. The gluten-free protein, low glycemic index, and high antioxidants contribute to its nutraceutical property. Considering the nutritional superiority and climate-resilient features of proso millet, it can be a better climate-smart alternative to the predominant cereals (Rajasekaran *et al*., 2023). Proso millet lowers glucose and cholesterol, thereby maintaining overall health. It is rich in fiber, protein, minerals, and trace elements like iron, copper, zinc, manganese, and soluble fiber Indianmed, 2023).

Values for crude protein and amino acids are given in Table 8 (Narciso and Nystrom, 2023).

Table 7. Proso millet nutrient per 100g

Nutrient per 100g	
Energy (Kcal)	309
Protein	8.30g
Carbohydrate	65.90g
Crude Fibre	9.00mg
Calcium	27.00mg
Iron	0.50mg

Table 8 . Minimum and Maximum values for crude protein and amino acids in proso millet

Essential	Minimum	Maximum
Lysine (Lys)	1.60	3.48
Histidine (His)	2.30	3.94
Threonine (Thr)	3.70	4.50
Valine (Val)	4.69	7.30
Methionine (Met)	3.40	4.30
Isoleucine (Ile)	4.22	5.81
Leucine (Leu)	12.52	14.70
Tryptophan (Trp)	n.a.	n.a.
Phenylalanine (Phe)	5.62	6.82
Non-essential	**Minimum**	**Maximum**
Arginine (Arg)	4.00	4.30
Aspartic acid (Asp)	6.60	12.00
Serine (Ser)	4.43	7.90
Glutamic acid (Glu)	21.94	25.40
Proline (Pro)	7.60	7.90
Cysteine (Cys)	0.90	1.10
Glycine (Gly)	2.80	4.73
Alanine (Ala)	9.68	12.40
Tyrosine (Tyr)	4.30	4.70
Crude Protein	12.12[d]	16.30[d]

HEALTH BENEFITS

Health benefits of proso millet are given below (NVT, 2019):

A Healthy Type 2 Diabetes Diet: Several studies had shown low levels of adiponectin production is linked to type 2 diabetes. Good food and moderate physical activity are very important in managing type2 diabetes. Food sources like proso millets may benefit you in such a case. In one experiment, it was revealed that Korean proso millet protein concentrate was able to elevate the plasma levels of Adiponectin and HDL-cholesterol in obese type 2 diabetic mice and was also able to bring down glucose and insulin levels significantly.

It may protect Liver Health: Proso millet contains dietary proteins that can have a natural ability to protect the liver. Research conducted also suggest that proso millet protein can be considered as a preventive food for liver injury. Diet with 20% proso millet protein was fed for 14 days to the rats subjected to D-galactosamine liver injury. The protein diet showed a protective nature by suppressing several enzymes elevated due to D-galactosamine activity when compared with the rats fed with 20% casein diet.

It can regulate Cholesterol metabolism: Consuming healthy and nutritious food is very important in controlling cholesterol levels in your body. Research has shown that dietary proso millet protein is linked to elevate the HDL cholesterol levels in the plasma. Considering the activity of HDL against the formation of fat deposits in arteries, proso millets can be useful as a food that can regulate cholesterol metabolism in the body.

Anticancer Activity: Diet plays a very important role in cancer both positively and negatively. A healthy diet with good amounts of fruits, vegetables, fibre and less processed meats, fried foods and soda may help to reduce the risk of cancer. Proso millets are a fibre and nutrients rich food that can help to fight against cancer. Research conducted had shown that proso millet extracts had exhibited anti-proliferative properties against MDA human breast cells and human hepG2 liver cancer cells when tested *in-vitro*.

It may control Obesity: Out of several factors that were known to cause obesity, food habits play a major role. Including diet with Whole grains such as proso millets can be beneficial in weight management and other health conditions. When 1% Proso millet extract supplemented diet was fed to obese mice in an experiment, the extract was able to decrease the body weight and total cholesterol levels in the treated mice when compared with obese mice fed with normal diet.

Health benefits of proso millet are given below (ILF, 2023**):**
Nutrient-Rich: Proso millet is packed with essential nutrients, including carbohydrates, proteins, dietary fiber, vitamins (especially B vitamins), and minerals (like magnesium, phosphorus, and iron).

Gluten-Free: It is naturally gluten-free, making it a suitable grain for individuals with celiac disease or gluten sensitivity.

Weight Management: Proso millet is relatively low in calories and high in fiber, which can help you feel fuller for longer, aiding in weight management.

Beneficial for Health: The fibre in proso millet can help reduce cholesterol levels, potentially lowering the risk of heart disease.

Blood Sugar Control: It has a low glycemic index, which means it has a minimal impact on blood sugar levels. This makes it a good choice for individuals with diabetes or those looking to manage their blood sugar.

Digestive Health: The dietary fibre in proso millet supports healthy digestion and can help prevent constipation.

Proso millet or panivaragu is gaining importance as gluten-free food, antioxidant, anti-aging, low glycemic index, and high calcium content and is a component in multigrain gluten-free food products. It's basically a digestion-friendly millet. Panivaragu is rich in phytochemical, Phytate that helps in the reduction of cancer risks. It helps to reduce body weight which is most needed for obese people. Proso millet helps to overcome irregular period problems in women. It helps to reduce knee & joint pains. Also, Panivaragu is good for diabetic people. Panivaragu reduces nervous disorders, especially in the eyes (Indianmed, 2023).

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