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REVIEW ARTICLE

ORIGIN, DOMESTICATION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF KODO MILLET (*Paspalum scrobiculatum* L.)

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ABSTRACT

Kodo millet belongs to the Family: Poaceae, Subfamily: Panicoideae, Tribe: Paniceae, Genus: *Paspalum* and Species: *Paspalum scrobiculatum* L. Poaceae –The grass family is the fourth largest family of the flowering plants. It includes about 700-800 genera and 11000-13000 species distributed worldwide. Apart from a high degree of taxonomic diversity, the. family has unmatched ecological and economic diversity. Kodo millet is divided into three races (*regularis, irregularis*, and *variabilis)* based on panicle morphology. In southern India, there are small (*karu varagu*) and large seeded (*peru varagu*) varieties recognized, often grown together in the same field. Cytological studies have revealed the chromosome number as 2**n** =4x = 40. Kodo millet is indigenous to India, and it is believed to have been domesticated some 3000 years ago. It well adapted in the tropics and subtropics. Kodo millet is generally cultivated with its weedy species and no distinction is made between the species during harvest. It is also reported to be native to West Africa. It is grown as a minor crop in most of these regions, except in the Deccan Plateau of India, where it is grown as a major food source. It is a very hardy crop, drought tolerant, can survive in marginal soils where other crops cannot survive, and can provide 450-900 kg of grain per hectare. Vernacular names of Kodo millet is in Hindi - Kodon, Kodava; English - Kodo millet; Kannada - Araka,Haraka; Marathi - Kodra,Kodru; Tamil – Varagu; Malayalam – Varaku; Punjabi - Kodon,Kodra; Oriya – Kodua; Telugu – Arikelu; Gujarathi – Kodro; Bengali – Kodoaa dhaan,Urdu – Kodon. The cultivation of kodo millets started in India about 3000 years ago. Apart from India, it is cultivated in Russia, China, Africa and Japan. In India, it is widely grown in Madhya Pradesh, Tamil Nadu, Karnataka, Gujarat and Chhattisgarh. Among all millets available, it is well known for the highest drought resistance and produces high yield in a short duration thus is of great economic value. India is the world leader in the production of kodo millets, and thus its cultivation is of great economic significance. Kodo millets are cultivated in the kharif season (monsoon season) and Kodo millets are processed into high-value foods and drinks. Apart from economic and culinary benefits, kodo millets have numerous health benefits. Kodo millet also has considerable production potential in marginal, low fertility soils and chronic moisture deficient areas of the country and plays an important role for the food security of the people inhabiting dry and marginal lands. The seeds have an excellent storage life and can be stored for several years. Kodo is a popular fast or upvas food in some parts of India. The millet is certainly superior to rice, gluten free and rich in fiber, vitamins and minerals. It has large potential to provide nourishing food to subsistence farmers in Africa and elsewhere. It is eaten as a famine food in Africa. Kodo millet is ground into flour and used to make pudding in India. In Africa it is cooked like rice. It is economically important. Its uses include: human food (cereal), animal food (fodder, forage) and medicine. It is harvested as a wild cereal in West Africa and in India. Widely cultivated as a minor millet in Africa and Asia, especially India. Also used for forage and as a feed supplement. In India, it has been used as a substrate for mushroom production and for medicinal purposes. The plant is used to clear the corneal opacity, to treat stiffness of lower limb, polyuria, diabetes, obesity, epistaxis, wound, indigestion, excessive hunger, in diabetes, eye infections, dysuria, hydrocele. Typhoid and its leaf and root paste are used to relieve labour pain. The paste of the whole plant and grain flour is taken as anti-dysenteric and to cure the skin diseases. Tribal of southern Rajasthan in India boil the grains as rice and use in diabetes and dysentery. It is also used as delivery convalescence. Most interestingly, the Santal tribes use the grain to prepare a country liquor. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Kodo Millet are discussed.

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INTRODUCTION

Kodo millet belongs to the Family: Poaceae, Subfamily: Panicoideae, Tribe: Paniceae, Genus: *Paspalum* and Species: *Paspalum scrobiculatum* L. (Wikipedia, 2023; TNAU, 2023). Poaceae –The grass family is the fourth largest family of the flowering plants. It includes about 700-800 genera and 11000-13000 species distributed worldwide. Apart from a high degree of taxonomic diversity, the. family has unmatched ecological and economic diversity (Mall and Tripathi, 2016). Kodo millet is divided into three races (*regularis, irregularis*, and *variabilis)* based on panicle morphology. In southern India, there are small (*karu varagu*) and large seeded (*peru varagu*) varieties recognized, often grown together in the same field (Goron and Raizada, 2015). Cytological studies have revealed the chromosome number as 2**n** =4x = 40 (Gomez and Gupta, 2003; Hariprasanna, 2015; Upadhyaya *et al*., 2016). Kodo millet is indigenous to India, and it is believed to have been domesticated some 3000 years ago. It well adapted in the tropics and subtropics. Kodo millet is generally cultivated with its weedy species and no distinction is made between the species during harvest (Taylor and Emmambux, 2008). It is also reported to be native to West Africa. It is grown as a minor crop in most of these regions, except in the Deccan Plateau of India, where it is grown as a major food source. It is a very hardy crop, drought tolerant, can survive in marginal soils where other crops cannot survive, and can provide 450-900 kg of grain per hectare (Academic, 2023). This species is found throughout the Paleotropics and in south-eastern USA. It is widely cultivated in India, which is probably its centre of origin. It is native to Africa, tropical Asia and Australia **(**CABI, 2021**).** *P. scrobiculatum* has been introduced to many parts of the world as an agricultural crop either as a grain crop or as a pasture species **(**CABI, 2021**).** *Paspalum scrobiculatum*, commonly known as Scrobic, kodo millet, koda millet, kodra, ditch millet, ricegrass, Indian paspalum, creeping paspalum, water couch, Indian crown grass [English]; herbe à épée [French]; jaringan [Indonesian]; rebu bawang, rumput kinangan [Javanese]; Ọkànli [Yoruba]. (Heuzé *et al*., 2015). It is also known as water couch (English), creeping paspalum (English), kodo-millet (English), rice grass (English), native Paspalum (English), kodo (Hindi), tho nduru levu (Fijian), tho ndina (Fijian), co duru levu (Fijian), kodo millet (English), tho ni ndina (Fijian), cow grass (English), mijo koda (Spanish), desum (Palauan), Kodohirse (German), ditch millet (English), ricegrass paspalum (English), kodomillet (English), kodra (Hindi), Indian paspalum (English), Indian crown grass (English) (Mall and Tripathi, 2016; GISD, 2023). Vernacular names of Kodo millet is in Hindi - Kodon, Kodava; English - Kodo millet; Kannada - Araka,Haraka; Marathi - Kodra,Kodru; Tamil – Varagu; Malayalam – Varaku; Punjabi - Kodon,Kodra; Oriya – Kodua; Telugu – Arikelu; Gujarathi – Kodro; Bengali – Kodoaa dhaan,Urdu – Kodon (Karnam, 2020; Wikipedia, 2023;). It is also known as Kodo Millet, Rice grass, Creeping paspalum, Ditch grass • Bengali: Kodoa dhan • Hindi: Kodo, Kodra, Kodnu • Kannada: Aaraka, Arike, Baraga • Malayalam: Varaku • Marathi: Hareek, Harik, Kodra • Sanskrit: Koddara, Kodrava, Kodravah • Tamil: Chamarutachchiivaram, cantirakikam, Chantirakikavarichi • Telugu: Allu, Alu, Arige chettu • Urdu: Kodon (Karnam, 2020; Beevi, 2021; Sharma, 2023; Vikaspedia, 2023). Kodo millet is also known as cow grass, rice grass, ditch millet, Indian cow grass. It is called as Kodo dhana in Hindi, Arikalu in Telugu, Varagu in Tamil, Kodro in Gujarati, Harka in Kannada, Kodon in Urdu (NVT, 2019; Netmeds, 2021). The plant is called Alikel in Telugu, Valag in Tamil, Valak in Malayalam, Alka in Kannada, Kodo in Hindi and Kodra in Punjabi (Academic, 2023). Some of the popular common names of the plant are Indian paspalum, Creeping paspalum, Ditch millet, Scrobic paspalum, Water couch, Scorbic, Mau'u-laiki, rice grass, rice grass paspalum, Veld paspalum and native palspalum (Sylvia, 2018; CABI, 2021). The cereal is known as kodo in Hindi, khoddi in Urdu, arugu in Telugu, and as varagu in Tamil. In southern India a small-seeded kind (karu varagu) and large-seeded kind (pern varagu) are recognized. These often grow together in the same field, with the small-seeded kind resembling the weed that grows along paths and around cultivated fields in damp habitats. The species was probably first harvested as a weed, and later became domesticated across most of its range in India. It is today grown from Kerala and Tamil Nadu, north to Rajasthan, Uttar Pradesh, Bihar and West Bengal (de Wet *et al.,* 1983).

The cultivation of kodo millets started in India about 3000 years ago. Apart from India, it is cultivated in Russia, China, Africa and Japan. In India, it is widely grown in Madhya Pradesh, Tamil Nadu, Karnataka, Gujarat and Chhattisgarh (Singh, 2023). Among all millets available, it is well known for the highest drought resistance and produces high yield in a short duration thus is of great economic value (Singh, 2023). India is the world leader in the production of kodo millets, and thus its cultivation is of great economic significance. Kodo millets are cultivated in the kharif season (monsoon season) and Kodo millets are processed into high-value foods and drinks. Apart from economic and culinary benefits, kodo millets have numerous health benefits (Singh, 2023). August-September. *Paspalum scrobiculatum*, Kodo millet is an annual grain that is grown in primarily in India, but also in the Philippines, Indonesia, Vietnam, Thailand and in West Africa where it originates. It is grown as a minor crop in most of these areas, with the exception of the Deccan plateau in India where it is grown as a major food source. It is a very hardy crop that is drought tolerant and can survive on marginal soils where other crops may not survive, and can supply 450–900 kg of grain per hectare (Mall and Tripathi, 2016). The crop is hardy and drought-resistant, and is capable of growing in marginal soils. The grain is enclosed in a hard, corneous husk, which makes debranning difficult. The grain is said to be poisonous after rain; this may be due to a fungal infection. Winnowed, clean, healthy grain seems to pose no health problem. Kodo millet is primarily cooked as rice (Gomez and Gupta, 2003).

Kodo millet is an annual grain that is grown primarily in India, but also in the Philippines, Indonesia, Vietnam, Thailand and in West Africa. It is harvested as a wild cereal in West Africa and India. It is grown as a minor food crop in most of these areas, with the exception of the Deccan plateau in India where it is grown as a major food source. Kodo millet is also grown in hot arid regions of Asia, New Zealand and USA as a pasture crop (Hariprasanna, 2015). Kodo millet is a tropical small millet indigenous to India and grown for its grain and fodder. It is a traditional, long duration, hardy and drought resistant crop (Sao *et al.,* 2016). Kodo millet grains are annual grains ranging from light red to dark grey (Singh, 2023). It is also used as fodder and forage for livestock (Hariprasanna, 2015). Kodo millet is predominantly grown as a pure crop and yields highnet returns as compared to other dry land crops owing to its high unit area productivity and market price of the produce in addition to its fodder value (Sao *et al.,* 2016). Kodo millet also has considerable production potential in marginal, low fertility soils and chronic moisture deficient areas of the country and plays an important role for the food security of the people inhabiting dry and marginal lands (Rajput *et al*., 2019). In southern India, it is called kodo or kodra and it is grown as an annual. It is a minor food crop eaten in many Asian countries, primarily in India where in some regions it is extremely important. It grows wild as a perennial in the west of Africa, where it is eaten as a famine food. Often it grows as a weed in rice fields. Many farmers do not mind it, as it can be harvested as an alternative crop if their primary crop fails. In the Southern United States and Hawaii, it is considered to be a noxious weed (Mall and Tripathi, 2016). In India, kodo millet is ground into flour and used to make pudding. In Africa it is cooked like rice. It is also a good choice for animal fodder for cattle, goats, pigs, sheep and poultry. In Hawaii, var.*scrobiculatum* is found to grow well on hillside slopes where other grasses do not flourish. It has the potential to be grown as a food source on hillside farms. It may also have potential to be used as grass ties on hillside plots to prevent soil erosion, while also providing a famine food as a secondary purpose. It has been noted that it makes a good cover crop. Kodo millet has large potential to provide nourishing food to subsistence farmers in Africa and elsewhere (Mall and Tripathi, 2016).

Kodo millet is cultivated extensively in India, Nepal, Vietnam, Philippines, Indonesia and West Africa. Kodo millet grass reaches up to four feet tall, sporting slender leaves at 20 to 40 cm in length requiring very little water to grow. When harvested the seeds are ellipsoidal in shape, tiny at 1.5mm in width and 2mm in length, colour varying between light brown to dark grey (Netmeds, 2021). Kodo millet or Arikelu is a fast growing, drought tolerant, annual grass that reaches to a height of 1-2 meters. The plant looks bushy due to their long and broad leaves. Its ability to adapt to fertility depleted soils, high herbage, huge productivity and its unique storage ability of the grains made Kodo millet a great crop among the farmers and also while famines (NVT, 2019). Its drought tolerant nature is even mentioned in several ancient texts of India like the Brihat Samhitha dating back to 6th century CE. Covered with a thick husk, seeds of this millet are small and measures about 2mm in length and 1mm in width. They vary in the color from light red to gray, round to ellipsoid in shape and germinates 5-7 days after sowing (NVT, 2019). The seeds have an excellent storage life and can be stored for several years (Nirubana *et al*., 2017). Kodo is a popular fast or upvas food in some parts of India. The millet is certainly superior to rice, gluten free and rich in fiber, vitamins and minerals. It has large potential to provide nourishing food to subsistence farmers in Africa and elsewhere (Sylvia, 2018).

It is eaten as a famine food in Africa. Kodo millet is ground into flour and used to make pudding in India. In Africa it is cooked like rice. It is economically important. Its uses include: human food (cereal), animal food (fodder, forage) and medicine (USDA-NRCS 2008). It is harvested as a wild cereal in West Africa and in India (GISD, 2023). Widely cultivated as a minor millet in Africa and Asia, especially India. Also used for forage and as a feed supplement. In India, it has been used as a substrate for mushroom production and for medicinal purposes **(**CABI, 2021**).** Millets can be cooked as we make rice and serve with dal, sambar, rasama or any curry of our choice. We can also make various dosa, idli, vada, bajjis/pakoras, murrukus/chakkli, nipatlu, pongal, mudde (dumpling), khichdi, pulav/biriyani, upma, sweets from millets, baked products such as bread and biscuits, or cooked just like boiled rice. They can also be use in baking, so we can include millets in our diet in more exciting way. Millets can be used to a whole variety of food that we consume everyday. They are ideal replacements to wheat and rice for their higher nutritional value (Mall and Tripathi, 2016). Kodo millet/Varagu Arisi has been grown and consumed in the southern part of India for centuries. The great woman and Tamil poet Avvaiyar's favourite food were Varagu Arisi Choru/Kodo Millet Rice. In her poem 'Thani Padal Thirattu'—the 32nd song goes like this—' Varagu Arisi Chorum, Vazhathunangai Vaatum, Moramoravena Pulitha Morum' (Vaaragu arisi chorum means Kodo millet Rice, Vazhathunangai Vaatum means Smoked and Smashed Brinjal (Vazhathunangai- very old Tamil name for Brinjal), Moramoravena Pulitha Morum means Frothy and Tangy Buttermilk). The poet mentions her host's name as boothan of pulvelur village and expresses gratitude for the tasty meal (Beevi, 2021). In India, Millets are not just food they are an integral part of the culture of thousands of communities all over the country. Kodo millet is one such millet. It is not just used as food but also store at the Temple tower called kalasam. Storing millet in kalasam was a very old tradition. There are two reasons for storing, the first reason is it will protect the Temple from lightning and the second reason is to ensure that in times of floods or disaster, grains could be planted using the stores in the kalasams. Once in 12 years, the grains in the Temple kalasams are refilled and changed during the festival called kumbhabhishekam (Beevi, 2021).

Kodo millet is having high nutritional value, dietary fiber, antioxidant activity as well as drought tolerance characteristics (Rajput *et al.,* 2019). Nutritional composition of Kodo millet in 100 g of grains are as follows: Moisture 11.6 g, Protein 10.6 g, Fat 4.2 g, Fiber 10.2 g, Ash 2.95 g, Calorific value 346 kcal, Carbohydrate 59.2 g, Minerals 4.4 g, Calcium 27 mg, Phosphorus 188 mg, Iron 0.5 mg, Riboflavin 0.09 mg, Niacin 2.0 mg (Bunkar *et al*., 2021). In India, millet is ground and used to make pudding. In Africa it is cooked like rice. Also suitable as animal feed for cattle, goats, pigs, sheep and poultry. In Hawaii, var. scrobiculatum has been found to grow well on hillside slopes where no other grasses grow. May be grown as a food source on hillside farms. It may also be used as weeding on hillside plots to prevent soil erosion, and may also provide starvation food as a secondary purpose. It has been noted to make an excellent cover crop (Academic, 2023). Ancient Indian medicine ayurveda classifies Kodo millet as langhana, which means bringing lightness to the body and is included under the category of Trina Dhanya Varga – (grains that are produced by grass like plants). It is termed as a wholesome food, prized for its medicinal, therapeutic and culinary properties and is recommended for diabetics, to beat fatigue, heal wounds faster. Being cold in nature, it increases vata dosha but balances issues caused due to kapha and pitta doshas (Netmeds, 2021). Kodo millet is grown throughout Asia and Africa, but is only cultivated as a minor grain crop in India, where it is of great importance in the Deccan Plateau. Its cultivation as grain crop in India is generally confined to Gujarat, Karnataka, and parts of Tamil Nadu. In other parts of the world it is grown as a forage crop (Tonapi *et al*., 2015). Kodo millet grains possess excellent storage properties and can be stored for several years without pest damage even under ordinary storage conditions. Because of this reason, kodo millet is known as the famine grain in many parts of the country. Kodo millet is indigenous to Indian subcontinent and known to be in cultivation since time immemorial, and is mentioned in *Brihad Sanhita* (Hariprasanna, 2017). The plant is used to clear the corneal opacity, to treat stiffness of lower limb, polyuria, diabetes, obesity, Epistaxis, wound, indigestion, excessive hunger, in diabetes, eye infections, dysuria, hydrocele. Typhoid and its leaf and root paste are used to relieve labour pain. The paste of the whole plant and grain flour is taken as anti-dysenteric and to cure the skin diseases. Tribal of southern Rajasthan in India boil the grains as rice and use in diabetes and dysentery. It is also used as delivery convalescence. Most interestingly, the santal tribes use the grain to prepare a country liquor (Kamam, 2020). In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding, Uses, Nutritional Value and Health Benefits of Kodo Millet are discussed.

ORIGIN AND DOMESTICATION

It is native to West Africa. It is grown as a minor crop in most of these regions, except in the Deccan Plateau of India, where it is grown as a major food source. It is a very hardy crop, drought tolerant, can survive in marginal soils where other crops cannot survive, and can provide 450-900 kg of grain per hectare (Academic, 2023). *Paspalum scrobiculatum* var. *scrobiculatum* is cultivated as an important crop in India, while *Paspalum scrobiculatum* var. *Komersonii* is a wild species endemic to Africa. Kodo millet, also known as cowgrass, ricegrass, dwarf millet, native paspalum or Indian crowngrass, is native to tropical Africa and is estimated to have been domesticated in India 3000 years ago. The domestication process is still in progress. In South India it is called Valak or Kovalak. Kodoh is probably a corruption of the Hindi name for the plant, Kodra. Cultivated as an annual herb. It is a minor food crop eaten in many Asian countries, mainly India, but very important in some regions. It grows wild in western Africa as a perennial and is eaten as a hunger food. It often grows as a weed in rice fields. Many farmers don't mind because it can be harvested as an alternative crop even if the main crop fails. In the southern United States and Hawaii, it is considered a noxious weed (Academic,. 2023). Kodo Millet is native to Africa, Tropical & Subtropical Asia to Australia (Sharma, 2023). Kodo millet, originated in Sub-Saharan Africa from Senegal east to Ethiopia and South to South Africa. It is an annual grain grown primarily in India and the Philippines, Indonesia, Vietnam, and Thailand. In India, Kodo millet is largely grown in the states of Madhya Pradesh, Chhattisgarh, Maharashtra, Tamilnadu, and Karnataka. It is also cultivated in the jhum field of Arunachal Pradesh (Beevi, 2021). Kodo millet originated in tropical Africa and it is estimated to have been domesticated in India 3000 years ago. The domestication process is still ongoing (Mall and Tripathi, 2016).

Kodo millet or Scrobic originated from Africa and is now widespread in the Old World tropics. It was first introduced to India and is now cultivated in other parts of Asia. Scrobic is common in upland rice in India, Indonesia, the Philippines, Thailand and Vietnam, and is also present in Bangladesh and Myanmar. Scrobic was introduced to Australia from Zimbabwe in 1931. Scrobic is commonly found on disturbed sites or as a weed in cropping land. It is found from sea level up to an altitude of 1500 m (Heuzé *et al*., 2015).

The indigenous kodo millet is known to have been grown in southern Rajasthan and in Maharashtra for at least 3,000 yr. *Paspalum scrobiculatum* occurs throughout the Old World tropics. It is an aggressive colonizer of disturbed habitats and commonly invades agricultural fields. In west Africa it is a weed of rice and is harvested as a wild cereal. It is grown as a cereal only in India (de Wet *et al*., 1983). Kodo millet is also known as ditch millet. It is grown only in India, although the wild grass is a widespread tropical weed that is harvested as a wild cereal in West Africa. The species was domesticated in India some 3000 years ago. It is grown in India from Kerala and Tamil Nadu in the south, to Rajasthan and Uttar Pradesh in the north, and West Bengal in the east, as a food grain (Gomez and Gupta, 2003). Kodo millet was domesticated roughly 3000 years ago in India, the only country today where it is harvested as a grain in significant quantities, mainly on the Deccan plateau. The grain contains a diverse range of high-quality protein), and has high anti-oxidant activity (anti-cancer) even when compared to other millets. Like finger millet, kodo is rich in fiber and hence may be useful for diabetics. It is drought tolerant and can be grown in a variety of poor soil types from gravelly to clay. Most genotypes take 4 months to mature (Goron and Raizada, 2015). It was domesticated roughly 3000 years ago in India the only country today where kodo grain is harvested in significant quantities, mainly on the Deccan plateau (Rajput *et al.,* 2019). Kodo millet has been introduced to many parts of the world as an agricultural crop either as a grain crop or as a pasture species **(**CABI, 2021**).** Kodo millet is mainly grown in India. You can also find this millet in Indonesia, West Africa, the Philippines, Thailand, and Vietnam. It comes in different colors, from light red to dark grey and high in fiber content. The exception of most of the Deccan Plateau in India grow kodo millet as a staple food (Moolihai, 2023). In some parts of India, Kodo millet is the famous fast or upvas food. Especially in south India, Kodo millet is used as a staple food. Millet is superior to rice undoubtedly, gluten-free and rich in fiber, vitamins, and minerals. It has excellent potential to provide nutritious food to farmers living in Africa and elsewhere (Moolihai, 2023).

Some authors reported that kodo millet is indigenous to India, and it is believed to have been domesticated some 3000 years ago. It well adapted in the tropics and subtropics. Kodo millet is generally cultivated with its weedy species and no distinction is made between the species during harvest (Taylor and Emmambux, 2008). Kodo millet is a native of India and is in cultivation since time immemorial. Greater diversity of *Paspalum* species in the Hindustan centre. The crop was domesticated in southern Rajasthan and Maharashtra some 3000 years ago. The crop is known to be spread throughout the tropical regions of the world (Tonapi et al., 2015). Kodo millet is an indigenous cultivated cereal of India and is in cultivation since time immemorial. It is estimated to have been domesticated in southern Rajasthan and Maharashtra dating back 3000 years ago. Kodo millet is widely distributed in damp habitat across the Old World tropics. It was harvested as wild cereal in West Africa and India about 3000 years ago. Wild **P.** *scrobiculatum* grows in the western African countries as perennial grass. Kodo millet is either cultivated or picked in Africa and India as one of the psychotropic cereals. Nowadays, it is grown in Uttar Pradesh in the north, and Kerala, Karnataka, and Tamil Nadu in the south. This cereal is popular as 'kodo' in Hindi and 'varagu' in Tamil. The species is widely distributed and spread in damp habitats across the tropics and subtropics of the world**.** *Paspalum scrobiculatum* var. *scrobiculatum* is grown in India as an important crop, while *Paspalum scrobiculatum var. commersonii* is the wild variety is indigenous to Africa. *Paspalum scrobiculatum* occurs throughout the Old World tropics (Joshi *et al.,* 2021).

According to Upadhyaya *et al.* (2016) kodo millet belongs to the genus *Paspalum*, a diverse genus comprising about 400 species, most of which are native to the tropical and subtropical regions of the Americas, and the main center of origin and diversity of the genus is considered to be South American tropics and subtropics. Kodo millet was domesticated in India around 3000 years ago and cultivated by tribal people in small areas throughout India, from Kerala and Tamil Nadu in the south, to Rajasthan, Uttar Pradesh, and West Bengal in the North. It occurs in moist or shady places across the tropics and subtropics of the Old World (Upadhyaya et al., 2016). This species is found throughout the Paleotropics and in south-eastern USA. It is widely cultivated in India, which is probably its centre of origin. It is native to Africa, tropical Asia and Australia **(**CABI, 2021**).**

TAXONOMY

The millets are grouped as following (Mall and Tripathi, 2016).

A:- Major millets (the most widely cultivated species).

Tribe: Eragrostideae

- Eleusine coracana (Linn.) Gaertn.

Tribe: Paniceae

- Panicum miliaceum Linn.
- Pennisetum glaucum (Linn.) R. Br.
- Setaria italica (Linn.) P. Beauv.

Tribe: Andropogoneae

- Sorghum bicolor L. Moench
- Zea mays Linn.

B:- Minor millets

Tribe: Eragrostideae

- Eragrostis tef (Zucc.) Trotter.

Tribe: Paniceae

- Digitaria sanguinalis Linn.

- Echinochloa frumentacea (Roxb.) Link.
- Echinochloa esculenta (A. Braun) H. Scholz.
- Panicum sumatrense Roth ex Roem Schult.
- Panicum miliare Lamk.
- Paspalum scrobiculatum Linn.
- Setaria verticillata (Linn.)P. Beauv.
- Urochloa panicoides P. Beauv.

Tribe: Andropogoneae

- Coix lacryma-jobi Linn.

" Millet" is not a botanic term for a certain plant but rather an umbrella term for various small seeded grasses used for human consumption. 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* **(**TMP, 2023**).** The classification is as follows:

***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

According to Upadhyaya et al. (2016) kodo millet belongs to the genus *Paspalum*, a diverse genus comprising about 400 species. *Paspalum* genus belongs to Poaceae family which is one of the largest family of the plant kingdom. In India, it is represented by about 239 genera and 1,180 species. *Paspalum scrobiculatum var. scrobiculatum* is grown India as an important crop. While, *Paspalum scrobiculatum* var *comersonii* is a wild variety indigenous to Africa (Karnam, 2020). Kodo millet belongs to the Family: Poaceae, Subfamily: Panicoideae, Tribe: Paniceae, Genus: *Paspalum* and Species: *Paspalum scrobiculatum* (Kamam, 2020; TNAU, 2023; Sharma, 2023; Wikipedia, 2023).

Species (GBIF, 2023)

- Paspalum scrobiculatum L.
- Paspalum adelogaeum Steud.
- Paspalum akoense Hayata
- Paspalum amazonicum Trin.
- Paspalum auriculatum J.Presl
- Paspalum borbonicum Steud.
- Paspalum boscianum Flüggé
- Paspalum brunneum Bosc
- Paspalum brunneum Bosc ex Flüggé
- Paspalum cartilagineum J.Presl
- Paspalum cartilagineum subsp. biglumaceum Fosberg & Sachet
- Paspalum cartilagineum var. biglumaceum Fosberg & Sachet
- Paspalum coloratum Rich.
- Paspalum coloratum Rich. ex Döll
- Paspalum commersonii Lam.
- Paspalum commersonii subsp. hirsutum Jansen
- Paspalum commersonii subsp. polystachyum (R.Br.) Stapf
- Paspalum commersonii subsp. turgidum (Buse) Jansen
- Paspalum commersonii var. hirsutum Jansen
- Paspalum commersonii var. polystachyum (R.Br.) Stapf
- Paspalum commersonii var. turgidum (Buse) Jansen
- Paspalum commutatum Nees
- Paspalum confertum J.Le Conte
- Paspalum confertum Leconte

- Paspalum coromandelinum Lam.
- Paspalum deightonii (C.E.Hubb.) Clayton
- Paspalum dissectum subsp. grande Nees
- Paspalum dissectum var. grande Nees
- Paspalum firmum Trin.
- Paspalum frumentaceum Rottler
- Paspalum frumentaceum Rottler ex P.Beauv
- Paspalum horneri Henrard
- Paspalum jardinii Steud.
- Paspalum kora Willd.
- Paspalum ledermannii Mez
- Paspalum longifolium subsp. pseudo-orbiculare Jansen
- Paspalum mauritanicum Nees
- Paspalum mauritanicum Nees ex Steud.
- Paspalum metabolon Steud.
- Paspalum metzii Steud.
- Paspalum moratii Toutain
- Paspalum orbiculare f. villosa Däniker
- Paspalum orbiculare subsp. cartilagineum (J.Presl) Summerh. & C.E.Hubb.
- Paspalum orbiculare var. cartilagineum (J.Presl) Summerh. & C.E.Hubb.
- Paspalum palustre Vanderyst
- Paspalum polo F.M.Bailey
- Paspalum polystachyum R.Br.
- Paspalum puberulum Roem. & Schult.
- Paspalum pubescens R.Br.
- Paspalum purpurascens Elliott
- Paspalum scrobiculatum subsp. auriculatum (J.Presl & C.Presl) Merr.
- Paspalum scrobiculatum subsp. bispiculatum Hack.
- Paspalum scrobiculatum subsp. commersonii (Lam.) Stapf
- Paspalum scrobiculatum subsp. deightonii C.E.Hubb.
- Paspalum scrobiculatum subsp. frumentaceum Stapf
- Paspalum scrobiculatum subsp. gracillimum Domin
- Paspalum scrobiculatum subsp. horneri (Henrard) de Koning & Sosef
- Paspalum scrobiculatum subsp. jardinii (Steud.) Franch.
- Paspalum scrobiculatum subsp. polystachyum (R.Br.) A.Chev.
- Paspalum scrobiculatum subsp. scrobiculatum
- Paspalum scrobiculatum subsp. turgidum Buse
- Paspalum scrobiculatum subsp. velutinum Hack.
- Paspalum scrobiculatum var. auriculatum (J.Presl) Merr.
- Paspalum scrobiculatum var. bispicatum Hack. ex Merr.
- Paspalum scrobiculatum var. bispiculatum Hack.
- Paspalum scrobiculatum var. commersonii (Lam.) Stapf
- Paspalum scrobiculatum var. deightonii C.E.Hubb.
- Paspalum scrobiculatum var. frumentaceum Stapf
- Paspalum scrobiculatum var. gracillimum Domin
- Paspalum scrobiculatum var. horneri (Henrard) de Koning & Sosef
- Paspalum scrobiculatum var. jardinii (Steud.) Franch.
- Paspalum scrobiculatum var. orbiculatum Weigelt
- Paspalum scrobiculatum var. polystachyum (R.Br.) A.Chev.
- Paspalum scrobiculatum var. polystachyum (R.Br.) Stapf
- Paspalum scrobiculatum var. scrobiculatum
- Paspalum scrobiculatum var. turgidum Buse
- Paspalum scrobiculatum var. velutinum Hack.
- Paspalum serpens J.Presl
- Paspalum serpens J.Presl ex Trin.
- Paspalum thunbergii subsp. minor Makino
- Paspalum thunbergii subsp. minus
- Paspalum virgatum Walter
- Paspalum virgatum subsp. latifolium Alph.Wood
- Paspalum virgatum subsp. purpurascens (Elliott) Alph.Wood
- Paspalum virgatum var. latifolium Alph.Wood
- Paspalum virgatum var. purpurascens (Elliott) Alph.Wood
- Paspalum zollingeri Steud.

There are two forms of kodo millet or scrobic (Heuzé *et al*., 2015):

- **Kodo millet (Paspalum scrobiculatum** var. **scrobiculatum):** Is cultivated as an annual. It has been cultivated for 3000 years in India where it is considered as a minor cereal crop except in the Deccan where it is a cereal of utmost importance. It is grown as a single crop or as the

major cereal in mixed cultures. The seeds are used as human food: grains are ground into meal and used for puddings. In Africa, it is harvested as a wild cereal and is mainly considered as a famine food. Kodo millet varies considerably: light red grains are said to be sweet tasting and dark gray ones to be bitter. Yields range from 450 to 900 kilograms of grain per hectare. Kodo millet is well suited to dry conditions.

- **Wild scrobic (Paspalum scrobiculatum** var. **commersonii):** Is perennial and mostly found in damp places. Wild scrobic is used for pasture and hay or as stand-over forage. It is also sometimes used for compost or mulch. It withstands moderate grazing and requires rest periods to allow sufficient seeding for regeneration. Wild scrobic yields 3-10 t DM forage/ha. Wild scrobic often invades kodo millet fields and hybridizes with it, making it difficult to distinguish in the field the wild and cultivated scrobic complexes.

Species Description

Paspalum scrobiculatum is a tufted perennial grass; 120 to 150 cm tall; culms stout, erect, glabrous, somewhat bulbous at base, sheaths 7 to 14 cm long, glabrous or with sparse hairs at the collar, compressed, basal ones often purplish; ligule very short, but with a dense row of hairs just behind it; blades flat, 12 to 40 cm long, 3 to 12 mm wide, acute, scabrous, glaucous on upper surface; inflorescence of 4 to 6 racemes, these 2 to 4 cm long, alternate, distant, their axis 4 to 9 cm long, villous at base, sometimes pilose in the axils; rachis 1 to 1.5 mm wide, scabrous, usually reddish on the margins; spikelets paired, 2 to 2.5 mm long, broadly elliptic, imbricate, glabrous; second glume and sterile lemma 3-nerved; fertile lemma indurated, finely pitted; caryopsis 1.5 mm long, compressed-elliptic, pale (GISD, 2023). The absence of clear racial differentiation in kodo millet is surprising. The species has been grown as a cereal for at least 3,000 years. The archaeological record indicates that the species was grown from Karnataka to the Punjab at least since 600 years before the beginning of the Christian era.'Lack of raciail differentiation may indicate that the species was domesticated across the range of its cultivation. Hybridization with wild *Paspalum scrobiculatum,* which commonly invades fields of kodo millet, further restricts racial differentiation within the cultivated Complex (de Wet *et al*., 1983).

Synonyms (GBIF, 2023a)

1) Paspalum adelogaeum Steud
2) Paspalum akoense Hayata
3) Paspalum amazonicum Trin.
4) Paspalum auriculatum J.Presl
5) Paspalum barbatum Schumach. [Illegitimate]
6) Paspalum barbatum Schumach., nom. illeg.
7) Paspalum borbonicum Steud.
8) Paspalum boscianum Flüggé
9) Paspalum cartilagineum J.Presl
10) Paspalum cartilagineum var. *biglumaceum* Fosberg & Sachet
11) Paspalum coloratum Rich. ex Döll [Invalid]
12) Paspalum coloratum Rich. ex Döll, pro syn.
13) Paspalum commersonii Lam.
14) Paspalum commersonii var. *hirsutum* Jansen
15) Paspalum commersonii var. *polystachyum* (R.Br.) Stapf
16) Paspalum commersonii var. *turgidum* (Buse) Jansen
17) Paspalum commutatum Nees
18) Paspalum confertum J.Le Conte
19) Paspalum confertum Leconte
20) Paspalum coromandelinum Lam.
21) Paspalum deightonii (C.E.Hubb.) Clayton
22) Paspalum dissectum var. *grande* Nees
23) Paspalum firmum Trin.
24) Paspalum frumentaceum Rottler ex P.Beauv [Invalid]
25) Paspalum frumentaceum Rottler ex P.Beauv, pro syn.
26) Paspalum horneri Henrard
27) Paspalum jardinii Steud.
28) Paspalum kora Willd.
29) Paspalum ledermannii Mez
30) Paspalum longifolium var. *pseudo-orbiculare* Jansen
31) Paspalum mauritanicum Nees ex Steud. [Illegitimate]
32) Paspalum mauritanicum Nees ex Steud., nom. superfl.
33) Paspalum metabolon Steud.
34) Paspalum metzii Steud.
35) Paspalum moratii Toutain
36) Paspalum orbiculare G.Forst.
37) Paspalum orbiculare var. *cartilagineum* (J.Presl) Summerh. & C.E.Hubb.
38) Paspalum palustre Vanderyst [Invalid]
39) Paspalum palustre Vanderyst, nom. provis.
40) Paspalum polo F.M.Bailey
41) Paspalum polystachyum R.Br.
42) Paspalum puberulum Roem. & Schult.
43) Paspalum pubescens R.Br. [Illegitimate]
44) Paspalum pubescens R.Br., nom. illeg.
45) Paspalum purpurascens Elliott
46) Paspalum scrobiculatum var. *auriculatum* (J.Presl & C.Presl) Merr.
47) Paspalum scrobiculatum var. *auriculatum* (J.Presl) Merr.
48) Paspalum scrobiculatum var. *bispiculatum* Hack.
49) Paspalum scrobiculatum var. *commersonii* (Lam.) Stapf
50) Paspalum scrobiculatum var. *deightonii* C.E.Hubb.
51) Paspalum scrobiculatum var. *frumentaceum* Stapf, nom. inval.

52) Paspalum scrobiculatum var. *gracillimum* Domin
53) Paspalum scrobiculatum var. *horneri* (Henrard) de Koning & Sosef
54) Paspalum scrobiculatum var. *jardinii* (Steud.) Franch.
55) Paspalum scrobiculatum var. *orbiculare* (E.Forst.) Hack.
56) Paspalum scrobiculatum var. *orbiculare* (G.Forst.) Hack.
57) Paspalum scrobiculatum var. *polystachyum* (R.Br.) A.Chev.
58) Paspalum scrobiculatum var. *scrobiculatum*
59) Paspalum scrobiculatum var. *turgidum* Buse
60) Paspalum scrobiculatum var. *velutinum* Hack.
61) Paspalum serpens J.Presl ex Trin.
62) Paspalum thunbergii var. *minus* Makino, nom. nud.
63) Paspalum virgatum var. *latifolium* Alph.Wood
64) Paspalum virgatum var. *purpurascens* (Elliott) Alph.Wood
65) Paspalum virgatum Walter [Illegitimate]
66) Paspalum virgatum Walter, nom. illeg.
67) Paspalum zollingeri Steud.

Synonyms (CABI, 2021)

Paspalum akoense Hay.
Paspalum auriculatum
Paspalum barbatum Schum.
Paspalum cartilagineum var. *horneri*
Paspalum commersonii Lam.
Paspalum horneri var. *lanceolatum*
Paspalum lamprocaryon
Paspalum orbiculare Forst.
Paspalum polystachyum R. Br.
Paspalum zollingeri var. *bispicatum*

Synonym (GISD, 2023).

Paspalum scrobiculatum, var. *bispicatum*
Paspalum scrobiculatum, var. *scrobiculatum*
Paspalum cartilagineum, J. Presl
Paspalum commersonii, Lam.
Paspalum orbiculare, G. Forst.
Paspalum polystachyum, R. Br.
Paspalum scrobiculatum, var. *commersonii* (Lam.) Stapf
Paspalum scrobiculatum, var. *polystachyum* (R. Br.) Stapf.

Kodo millet is divided into three races (*regularis, irregularis*, and *variabilis)* based on panicle morphology. In southern India, there are small (*karu varagu*) and large seeded (*peru varagu*) varieties recognized, often grown together in the same field (Goron and Raizada, 2015).

BOTANICAL DESCRIPTION

The plant height can vary from 30 to 90 cm, with 10–48 basal tillers per plant. The length of the inflorescence varies from 2 to 12 cm. It is a relatively late-maturing crop compared to other small millets. The flowers are highly cleistogamous with a maximum opening of up to 50% only, *i.e.,* this is a highly self-pollinated crop (Gomez and Gupta, 2003). Kodo millet has a 1000 kernel weight of 6.7 g. The bran and husk form a large proportion of the grain, about 37%. The starch granules are large and polygonal, but some small polygonal types can be found. The size of the granules varies from 1.2 to 9.5 µm. The amylose content expressed as a proportion of grain weight is about 20% on a dry weight basis (Taylor and Emmambux, 2008).

Kodo millet is an annual herb with adventitious root arises from lower nodes with numerous thin roots. Branched roots spread laterally and profusely, remain functional throughout the life. Stem is erect, rarely ascending with 60-90 cm height, tufted on a very short rhizome. Glabrous stem with swollen nodes and fully sheathed internodes. Nodal bands become purple at later stage. First node is hairy and the other nodes are glabrous with solid internodes. The length of internodes increases gradually from bottom to top in any tillers. The number of tillers varies from 5 to 18 according to genotypes. The Leaf is simple, alternate, bifarious, erect or sub-erect, finely acuminate, glabrous or sometimes soft hairy. Sheaths long, compressed, loose, the mouth hairy with very short membranous ligule. Inflorescence is a spike or spike like racemes. Each spikelet consists of 1 or 2 flowers and bears at the base bracts or glumes, one placed a little above and opposite the other. These two are empty while a third one called lemma is flowering i.e. it enclosed a flower in its axil. Opposite the flowering glume or Lemma, there is somewhat smaller, two nerved glumes called Palea. Spikes 2-6, sessile usually distant and spreading, rachis herbaceous, broad with ciliate margins. Spikelets usually 2 ranked, 2-3 mm diameter, sessile or shortly pedicilate, broadly elliptic or suborbicular imbricate. Androecium: Stamens 3, filamentous, anthers 3, 2 locules, open by longitudinal sutures, versatile and pendulous. Gynoecium: Monocarpellary, ovary superior, one cell with one ovule, stigma 2, feathery, style distinct. Grain: Utricle type in which pericarp is like a sac usually attached to endosperm at only one point. Grains are rotundate-elliptic, convex in front, flat on back of palea, scutellum up to half the length of the grain. The grain is enclosed in hard, corneous, persistent husks that are difficult to remove. The grain may vary in color from light red to dark grey. Compared to other small millets, it has a long-crop cycle, ranging from 105 to 120 days. The seeds can remain dormant and be stored for many years (Tonapi *et al*., 2015). Kodo millet or Scrobic is a vigorous, tufted (up to 60 cm diameter) and slender perennial grass. It grows to a height of 0.3-1 m. The roots are rather shallow and the stems are ascending, branched and somewhat succulent. Leaf blades are 15-40 cm long, 5-12 mm wide, pale green. Leaf sheaths and leaves are glabrous. The inflorescence is a panicle, generally consisting of 3-4 racemes, 4-9 cm long. The spikelets are arranged in two or three rows. Seeds are ellipsoidal, 2 mm long, 1.5 mm wide and light brown coloured (Fig.1, 2) (Heuzé *et al*., 2015).

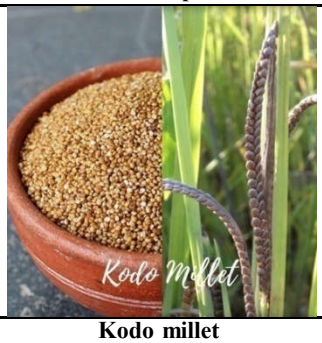
		
Kodo millet plants	Kodo millet plants	Leaf blade
		
Panicle/ Inflorescence	Panicle/ Inflorescence	Panicle/ Inflorescence
		
Closer-view-of-unripe-Kodo-Millet	Kodo millet	Kodo millet
		
Kodo millet	Kodo millet	Kodo millet
		
Earheads	Earheads tied together	Earheads tied together
		
Seeds	Seeds	Seeds

Fig. 1 : Botanical Description

Seeds with husk

Seeds with husk

Seeds cut into halves

Fig. 2. Seeds of Kodo millet

Paspalum scrobiculatum Linn. is commonly called as kodo millet, kodo, varagu rice. It is an erect or ascending, glabrous, annual grass. Leaves 10-20 x 0.3-0.8 cm linear-lanceolate, acuminate base keeled; sheath glabrous or hairy; ligule very short, membranous. Spilelets in two series, imbricate orbicular or sub oroid, plano-convex, glabrous, caryopsis biconvex, pale. It is common in paddy fields and distches (Mall and Tripathi, 2016). Kodo Millet is a monocot tufted annual or perennial grass that grows up to 150 cm tall. The plant typically occurs in seasonally flooded areas and wet depressions, often association with cultivation and settlements, such as along roadsides, ditches, and waste ground and rice fields. The plant has wide adaptability to different soil from very poor to very fertile and can tolerate a certain degree of alkalinity. Best soils are alluvial, loamy and sandy soil with good drainage. Kodo millet can be grown in gravelly and stony soil such as in the hilly region. The plant has shallow root system which may be ideal for intercropping. Stems are rather stout, not or sparingly branched, glabrous or thinly furnished with rather long hairs. Blades are 15-40 cm long, 5-12 mm wide, pale green. Leaf sheaths and leaves are glabrous. Flower is unisexual, sessile; with 5 mucronate tepals 2-3 mm long; male flowers with 5 stamens c. 1 mm long; female flowers with superior, 1-celled ovary crowned by 3 stigmas. The seeds it produces are very small and ellipsoidal, being approximately 1.5 mm in width and 2 mm in length; they vary in color from being light brown to a dark grey (Sylvia, 2018). An annual grass growing wildly as well as found cultivated in many parts of India. Culm 60 - 90 cm in height. Root-fibrous along with short rhizome. Leaves 20-30cm long, 0.5cm wide linear, distichous, stiff and erect. Inflorescence-spikes. Flower unisexual, male flowers-stamens 3, female flowers- styles 2, caryopsis- small, brown, oval- round, 4mm in length, seeds- small, ellipsoid, brown with prominent ridges (Karnam, 2020).

Kodo millet is a monocot tufted annual or perennial grass that grows up to 150 cm tall. The plant has wide availability in different soil from very poor to fertile soil and can also tolerate drought conditions. The plant has a shallow root system which may be ideal for intercropping. Plants like groundnuts and a few other millets are also grown as an intercrop. The Kodo millet plant produces very small ellipsoidal seeds, being approximately 1.5mm in width and 2mm in length; they vary in colour from light brown to dark grey (Beevi, 2021). *P. scrobiculatum* is a tufted annual or perennial grass up to 150 cm tall. Culms stout, erect, glabrous, somewhat bulbous at base, sheaths 7-14 cm long, glabrous or with sparse hairs at the collar, compressed, basal ones often purplish; ligule very short, 1 mm, membranous, but with a dense row of hairs just behind it; blades flat, 12-40 cm long, 3-12 mm wide, acute, scabrous, glaucous on upper surface. Inflorescence has four to six racemes, these are 2-4 cm long, alternate, distant, their axis 4-9 cm long, villous at base, sometimes pilose in the axils. Rachis 1-1.5 mm wide, scabrous, usually reddish on the margins; spikelets paired, 2-2.5 mm long, broadly elliptic, imbricate, glabrous. Second glume and sterile lemma 3-nerved. Fertile lemma indurated, finely pitted; caryopsis 1.5 mm long, compressed-elliptic, pale **(**CABI, 2021**)**

Kodo Millet is a perennial grass that can grow up to 150 cm tall. The plant has a shallow root system that is suitable for intercropping. Stems are very stout, or less branched, glabrous, or with long thin hairs. The blades of this plant are 15-40 cm long, 5-12 mm wide, pale green. The leaf sheaths and leaves are hairy. Flowers are unisexual, sessile, and come with 2-3 mm long with five micronate tabs; Male flowers with five pollen c. 1 mm long; Female flowers high, 1-celled uterus crowned by three spots. These millet seeds are covered with a dense husk, are small and about 2 mm long and 1 mm wide. They vary in color from pale red to gray to elliptical in shape and germinate 5-7 days after sowing (Moolihai, 2023). Kodo millet is a monocot and an annual grass that grows to heights of approximately four feet. It has an inflorescence that produces 4-6 racemes that are 4–9 cm long. Its slender, light green leaves grow to be 20 to 40 centimeters in length. The seeds it produces are very small and ellipsoidal, being approximately 1.5 mm in width and 2 mm in length; they vary in colour from being light brown to a dark grey. Kodo millet has a shallow root system which may be ideal for intercropping (Wikipedia, 2023). Millet is a monocotyledonous, annual plant that grows to about 4 feet tall. It has an inflorescence that makes 4 to 6 racemes of 4 to 9 cm in length. The elongated light green leaves grow 20-40 cm long. The seeds produced are very small and oval, about 1.5 mm wide and 2 mm long. Colors vary from light brown to dark gray. Millet has a shallow root system and is considered ideal for intercropping (Academic, 2023). Kodo Millet is an annual grass that grows to a height of approximately 4 feet. It has an inflorescence that produces 4-6 racemes that are 4-9 cm long. Its slender, light green leaves grow to be 20-40 cm long. The seeds it produces are very small and ellipsoidal, being approximately 1.5 mm in width and 2 mm in length; they vary in color from being light brown to a dark grey. Kodo millet has a shallow root system which may be ideal for intercropping (Sharma, 2023).

Floral morphology and Floral biology: The inflorescence has two to six racemes that spread widely on a sub-digitate or a short axis. Sessile spikelets are present. On a flattened rachis, the spikelets are arranged in two rows. Occasionally, some spikelets are paired in the middle of the raceme. Kodo millet has two types of spikelet arrangement, *i.e.,* regular and irregular types. An alternative arrangement of spikelets in two series, *i.e*., long and short pedicelled, is observed. One glume is missing, and the other glume is as much as that of the length of the spikelet. One lemma is similar to that of the glume whereas, the other lemma embodies two florets. The lower floret is sterile and reduced to half. The upper floret is a hermaphrodite. Hard, horny, and persistent husk encloses the grain (Fig.3, 4) (Nagaraja *et al.,* 2023).

Flowers of kodo millet are cleistogamous in nature and thus remained closed. Protogynous flowers occurs rarely in few genotypes. The opening of the flowers occurs between 7.30 to 8.00 AM in Nagpur conditions. Only 5% flowers open and remaining being cleistogamous. The glumes begin to open at 2.30 AM. The anthers become visible through opening at 2.40 AM, emerge at 3.15 AM and comes completely out at 3.30 AM. Anthers dehisce at 3.35 AM and glumes close completely at 3.45 AM. The dehiscence of anther occurs by a slit at one end and speed up gradually. Mostly the dehiscence of anther begins from the middle and proceed to both ends. The feathery stigma dry up in the evening. The anthers remains fresh and do not wither till next morning. The lodicules are fleshy and do not shrink immediately after the anthesis of flowers. They remain fleshy for 6 to 8 hour after opening the glume and then dried up. The grains mature in 30¬40 days after flowering and remain tightly enclosed by the hardened fourth glume and its palea and have various shades of brown colour. The best time of anthesis is between 5.45 and 7.30 AM. In this period a single floret of panicle is open for 20 to 30 minutes. The stigma comes first during anthesis of flowers and anthers arise just after the emergence of stigma (Tonapi *et al*., 2015). The flower opening in kodo millet is cleistogamous. About 15% to 20% of flower opening is noticed, making it a self-pollinated crop. Spikelet opening initiates between 2:30 and 6:00 a.m.

Fig. 3. Kodo millet panicles: A. Regular type. B. Irregular type

The presence of a very intact lemma makes it more difficult to artificially open the flower, which results in damaging it. Due to the cleistogamous flowering pattern, recombination breeding is limited. Nevertheless, quite a few improved varieties have been released for commercial cultivation purposes. These are majorly developed as selections from landraces or superior germplasm accessions (Nagaraja *et al*., 2023).

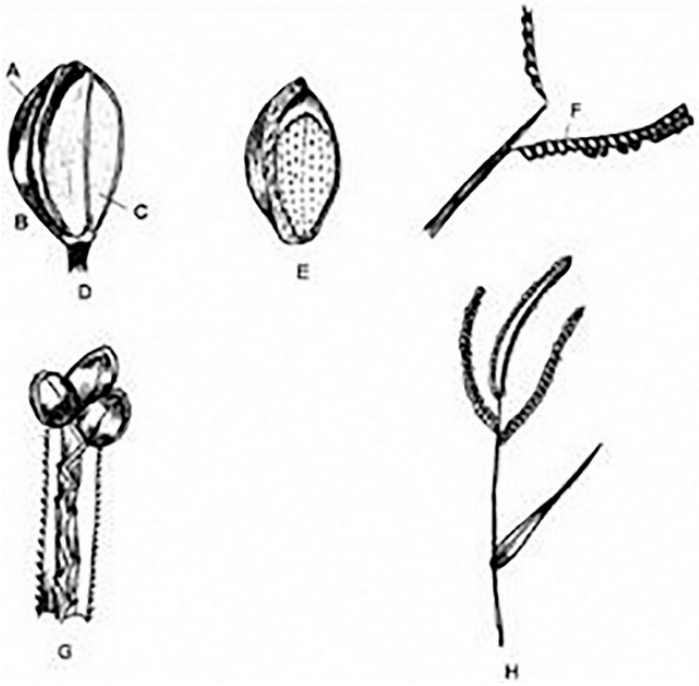


Fig. 4: Kodo millet inflorescence and its parts:
A. Upper floret, B. Second glume, C. Lemma of lower floret, D. Spikelet, E. Floret, F. Rachis, G. Arrangement of rachis in a spikelet, H. Inflorescence

Since kodo millet is a self-pollinated plant, it is essential to understand the factors that influence the length of the flowering period, pollination behaviour, and seed set in order to improve breeding programme effectiveness and yield stability while also boosting productivity. Kodo millet flowers remain closed because they are cleistogamous in nature. They have tiny florets. Emasculation and artificial hybridization are challenging because pollen is less readily available. There are also only a few sources of information. To get around this, the current inquiry was started. It aims to gather fundamental data from a variety of sources of literature, and then, with the use of fieldwork this text was prepared (Selvi and Nirmalakumari, 2023).

GENETICS AND CYTOGENETICS

Kodo millet is cultivated by tribal poor in small areas throughout India. Among all the millets it takes more duration (4-6 months) to mature and the grains are coarse. However, this millet can grow well on rough, stony and gravel soils with little moisture. *Paspalum* L. is a large diverse genus with more than 400 species. Apart from cultivated Kodo millet several species (*e.g., P. notatum, P. dilatatum*) are important forage grasses. The basic chromosome number in this genus is x=10 and polyploidy is fairly common. Genome relations among several forage and pasture species of *Paspalum* have been extensively investigated. In Kodo millet somatic chromosome number is 2n=4x=40 and the chromosomes are medium sized. There is not much size variation in chromosomes. Karyotype consists of a single pair of satellite chromosome with submedian centromere and with satellite on the long arm, eight pairs of metacentric chromosomes having submedian centromeres. Chromosome length varies from 1.9 to 3.5 µm, with an absolute length of 103.2 µm. Meiotic behaviour in Kodo millet is normal and 20 bivalents are normally formed. About 10% of the PMCs showed a single quadrivalent. This pairing behaviour suggests that Kodo millet is probably a segmental allotetraploid.

The progenitor of this millet is not known, although it is probably *Paspalum scarbiculatum* Var. *commersonii* (Chennaveeraiah and Hiremath, 1991). Cytological studies have revealed the chromosome number as 2**n** = 40 (Gomez and Gupta, 2003). The chromosome number of the kodo millet is reported to be 2n = 4x = 40 (Upadhyaya *et al*., 2016).

GENETIC DIVERSITY

Genetic improvement through conventional breeding approaches depends mainly on the availability of the diverse germplasm and the amount of genetic variability present in the population. The knowledge of characters influencing divergence is an important aspect for a breeder. Information on the nature and degree of genetic divergence would help the plant breeder to choose right parents for breeding programmes (Sao *et al*., 2016). Genetic diversity is a tool for effective plant breeding in a crop because the selection procedure of parental genotype in any plant breeding programme fundamentally depends on the nature and extent of genetic variability present in the gene pool. Genetic diversity in a crop gene pool can be estimated with morphological, biochemical, or DNA markers, among which DNA based molecular markers, are most preferred owing to their rapid and authentic results (Rajput *et al.,* 2019). The grain of kodo millet varies in colour from light red to dark grey and is enclosed in a tough husk that is difficult to remove. The seed coat is multiple layered (Hariprasanna, 2015). Seed with husk and seed without husk and variability of seed color, shape and size are given in Fig. 5 and 6.

Fig. 5 : Kodo millet seeds with husk **Kodo millet seeds without husk**

Fpg. 6 . Variabilty for seed color, shape and size in Kodo millet

Most genotypes studied require at least 4 months to mature. The cereal is morphologically variable. The most common kinds observed in farmers' fields were robust plants (over 60 cm tall) that frequently lodge at maturity, and smaller plants (less than 50 cm tall) with decumbent culms even before flowering. No other characters studied are correlated with growth habit. Raceme morphology allows for the recognition of 3 complexes. The most common kodo millet is characterized by racemes with the spikelets arranged in 2 rows on one side of a flattened rachis. In most fields of kodo millet, plants with irregularly arranged spikelets also occur. Rarely are these aberrant kinds grown as pure stands. Two kinds of aberrations occur. In one kind, the spikelets are arranged along the rachis in 2-4 irregular rows. In the other aberrant kind, the lower part of each raceme is characterized by irregularly arranged spikelets, while spikelet arrangement becomes more regularly 2-rowed in the upper part of the raceme. Increase in spikelet number at a rachis node is associated with elongation and branching of the pedicel. Terminal inflorescences are composed of 3-7 racemes that are more or less alternately arranged along a 20-120 mm long primary axis. Racemes are peduncled and up to 130 mm long. The inflorescence may, or may not be subtended by a well developed leaf or leaf sheath. One internode below this terminal inflorescence is a second inflorescence, usually composed of a single raceme that is always subtended by a well developed leaf. Plants are 30-90 cm tall, with the culms often decumbent at flowering time. Robust, erect plants tiller less than smaller, decumbent plants (de Wet *et al*., 1983).

General morphological variability is high, with large variance reported in many phenotypic parameters such as time before flowering, tiller number, and yield (Goron and Raizada, 2015). Kodo millet is known for its high nutritive value, dietary fiber, antioxidant activity, as well as for drought tolerance. It is primarily grown as a grain in India and in Africa it is either cultivated or harvested in wild. Neutral—ISSR (inter simple sequence repeat) as well as functional—SCoT (start codon targeted) and SRAP (sequence-related amplified polymorphism) markers were employed for genetic diversity studies in 96 accessions of kodo millet collected from diverse regions of India. The genetic diversity parameters like average bands per primer, Polymorphic information content, Nei's gene diversity and Shannon's information index of 11.22, 9.69; 0.12, 0.11; 0.15 ± 0.14, 0.13 ± 0.13 and 0.26 ± 0.21, 0.22 ± 0.19 was observed with neutral and functional markers respectively. Neutral markers were showing higher values as compared to functional markers for the genetic diversity parameters as discussed. Structure based analysis placed all the accessions into four sub-groups not strictly according to their geographical locations. The accessions from Bihar followed by Karnataka were showing high diversity based on both the marker systems useful for designing exploration, conservation and germplasm enrichment strategies. Further, the set of diverse accessions selected based on these markers would serve as potential sources of unique alleles and may be exploited in future for enhancement and utilization of kodo millet germplasm. Usage of African gene pool and wild species for broadening the genetic base of Indian kodo millet was also suggested based on the present studies (Yadav *et al*., 2016). Divergence analysis was conducted in twenty seven diverse advance breeding lines of Indian kodo millet. Cluster analysis grouped twenty seven kodo millet entries into 4 different clusters through Euclidian clustering. The clustering pattern could be utilized in choosing the diverse genotypes which were likely to generate the highest possible variability for various economic characters. Cluster I was the largest comprising of 13 genotypes followed by cluster II with 8 genotypes, cluster IV with 3 genotypes and cluster III with 2 genotypes. Cluster I formed solitary clusters which revealed the presence of wide diversity for various characters among different diverse breeding lines of kodo millet. The existing variability in the kodo millet lines provides opportunities for breeders to select specific donors for genetic improvement (Sao *et al*., 2016).

An attempt was made to assess the genetic divergence among the 103 kodo millet germplasm accessions using Mahalanobis D^2 statistic collected from Millet Breeding Station, Coimbatore. The observations were recorded on yield components and nutritional quality traits. The 103 germplasm lines were grouped into 11 different clusters based on D^2 analysis. Cluster I had a maximum of 63 genotypes, followed by clusters II and III with 14 each, cluster X with four genotypes and cluster VIII with two genotypes. Remaining clusters IV, V, VI, VII, IX and XI were mono-genotypic indicating wide divergence from other clusters. The highest intra cluster distance was observed in cluster X indicating differences in genotypes within cluster. The highest inter-cluster distance was observed between clusters III and X followed by clusters IV and VII suggesting the use of genotypes from these clusters to serve as potential parents for hybridization. The characters days to 50 per cent flowering contributed maximum towards divergence followed by Fe content, Zn content and grain yield per plant (Nirubana *et al*., 2017).

Study was conducted for assessing genetic diversity using ISSR (Inter Simple Sequence Repeat) markers among a total of 42 landraces of kodo millet collected from five districts of Madhya Pradesh (India) *viz.* Rewa, Betul, Chhindwara, Dindori, and Jabalpur. Ten ISSR markers amplified a total of 63 loci while 56 loci showed 88.88% polymorphism. Average number of bands per primer was found to be 6.3 whereas, average number of polymorphic bands per primer was 5.6. Maximum number of alleles (09) was scored by the primer UBC-886 followed by 08 by UBC-807 whereas; minimum number of alleles (04) was scored by the primers UBC-812 and UBC-816. Cluster analysis was done and a dendrogram was generated using UPGMA (Weighted Pair Group Method with Arithmetic Mean). The highest PIC (Polymorphism Information Content) value of 0.58 was observed by primer UBC-884 revealing 07 alleles among 42 accessions. Percentage of the number of polymorphic loci within population among the three regions, the highest frequency of polymorphism was found in the Dindori region (69.84 ± 22.22). The highest genetic diversity was observed in Dindori region three other in region. These findings not only highlighted the capacity of the ISSR technique for genetic diversity assessment but also help in the selection of diverse kodo millet landraces and further genetic improvement by tagging the desirable traits or for broadening the genetic base of Indian kodo millet (Rajput *et al*., 2019). Kodo millet is tetraplod ($2n = 4x = 40$) with a genome size of ca. 1900 Mbp. Wild and cultivated types of Kodo millet grow together, and the species is widely distributed across the tropics and subtropics of Asia and Africa. These authors state that Kodo millet is morphologically variable. However, a recent DNA study of accessions of cultivated Indian Kodo millet did not show great genetic diversity. A Random Amplified Polymorphic DNA comparison of African and Indian kodo millet accessions, however, revealed that there were distinct differences between them (Taylor, 2019).

Kodo millet accessions 103 numbers were evaluated and characterized for 21 qualitative characters. The traits *viz*., leaf character, leaf blade pigmentation, panicle exertion, spikelet arrangement on rachis, panicle appearance, spike curvature, degree of culm branching, degree of lodging, shattering and grain colour showed higher variation and thus exhibits scope for selection of traits useful for breeding programmes. The traits growth habit, leaf sheath pigmentation, sheath base pigmentation, leaf juncture pigmentation, internode pigmentation, flag leaf at the second primary axis node, nerves on glumes, spike branching, spikelet density, senescence and grain shape showed no variations. Cluster analysis was carried out which grouped the 103 accessions into 13 clusters. Cluster III was the largest cluster with 39 accessions followed by cluster VII with 21, cluster IV with 13, cluster I with nine, cluster X with six, cluster IX with four, cluster V with three, cluster II and VIII with two accessions each and clusters VI, XI, XII and XIII with one accession each. The genotypes within the same cluster considered to have the similar phenotypic characters. And the genotypes between the clusters are more diverse ones. Therefore, the genotypes of most diverse cluster may be used as parents in hybridization programmes to develop high yielding varieties (Nirubana *et al.,* 2019).

Kodo millet is having high nutritional value, dietary fiber, antioxidant activity as well as drought tolerance characteristics. Present study was conducted for assessing genetic diversity using ISSR (Inter Simple Sequence Repeat) markers among a total of 42 landraces of kodo millet collected from five districts of Madhya Pradesh (India) *viz*., Rewa, Betul, Chhindwara, Dindori, and Jabalpur. Ten ISSR markers amplified a

total of 63 loci while 56 loci showed 88.88% polymorphism. Average number of bands per primer was found to be 6.3 whereas, average number of polymorphic bands per primer was 5.6. Maximum number of alleles (09) was scored by the primer UBC-886 followed by 08 by UBC-807 whereas; minimum number of alleles (04) was scored by the primers UBC-812 and UBC-816. Cluster analysis was done and a dendrogram was generated using UPGMA (Weighted Pair Group Method with Arithmetic Mean). The highest PIC (Polymorphism Information Content) value of 0.58 was observed by primer UBC-884 revealing 07 alleles among 42 accessions. Percentage of the number of polymorphic loci within population among the three regions, the highest frequency of polymorphism was found in the Dindori region (69.84 ± 22.22). The highest genetic diversity was observed in Dindori region three other in region (Rajput *et al.,* 2019).

Kodo millet genotypes were evaluated at Agricultural Research Station, Vizianagaram to assess genetic variability, heritability and genetic advance for six yield contributing traits. The ANOVA revealed significant differences among eighteen genotypes for all the characters included under study except plant height, number of productive tillers per plant and fodder yield. Moderate PCV was recorded for fodder yield followed by grain yield and plant height whereas the GCV for all the characters were low compared to PCV indicating the interaction of genotypes with the environment. High heritability was recorded for days to maturity and days to 50% flowering. The maximum genetic advance as percent of mean was observed for days to 50% flowering followed by days to maturity. High heritability coupled with moderate genetic advance as percent of mean was recorded for days to 50% flowering indicating that these traits are under influence of both additive and nonadditive gene action and selection may be effective for this trait. Grain yield per plant recorded moderate heritability with moderate genetic advance as percent mean which also indicates presence of both additive gene action and this trait was found to be significantly and positively correlated with days to 50% flowering, days to maturity and fodder yield. Indirect selection for days to 50% flowering may help in better advancement for grain yield as flowering is supposed to be controlled by fewer genes with major effect compared to grain yield. The above yield components also exhibited positive intercorrelation among themselves (Anuradha et al., 2020). The study on "Genetic Divergence Studies in Kodo Millet" was carried out at Jagdalpur, Chhattisgarh. The 33 genotypes were grouped into 6 different clusters based on D^2 analysis. Cluster V was largest with 11 genotypes followed by cluster IV with 7genotypes, cluster II with 6 genotypes cluster III and cluster I both had 4 genotypes, cluster VI with 1 genotype. The maximum intra-cluster difference was found in cluster IV indicate that the genotype present, have considerable genetic distance among them. The maximum inter cluster difference was found between cluster I and cluster VI showing high degree of genetic diversity indicating that genetic makeup of genotypes falling in this cluster may be entirely different from one another. Among the trait under studied, days to maturity contributed maximum towards diversity (Thakur *et al.*, 2020).

Kodo millet has to be extensively studied by employing advanced platforms, whereas currently only few studies are available to support the genomic approaches. Molecular diversity approach in Kodo millet with Dof (DNA binding with One Finger) primers have revealed a higher PIC value, with Kodo millet clustered with wheat, barley, little millet, and oats. This phylogeny presents its closeness with the other grass family members, suggesting the incorporation of comparative genomics in Kodo millet. Genome-wide population structure analysis by GBS among small millets identified SNP's, which are further correlated with key traits across Kodo, little, and proso millet. This also presents a valuable genomic resource information for the breeders in small millets. Recent transcriptomic profiling of Kodo millet mutants with nonlodging and higher photosynthetic efficiency identified target gene families by using foxtail primers. This also successfully presented the use of comparative genetics to target the desirable genes in Kodo millet with the help of foxtail millet sequence information. In summary, these studies illustrate the successful stories in Kodo millet research to explore this crop's inherent potential even without the availability of a complete genomic sequence. Thus, it indicates that soon after the compilation of its genomic sequence, a number of key traits for C_4, yield, biomass, and climate resilience can be exploited from this crop (Ravikesavan *et al*., 2023). The Kodo millet commonly known as rice grass, creeping paspalum, ditch millet, Indian paspalum, Kodo grass, or varagu, belongs to millets, which are the first cereal grains utilized for domestication purposes. It was initially seen as a weed in rice fields, and upon failure of the primary crop, farmers harvested it for their food and feed purposes. The genus *Paspalum* (family Poaceae) includes around 400 species and was domesticated around 3000 years ago in Maharashtra and southern Rajasthan. It is cultivated primarily in India, the Philippines, Indonesia, Vietnam, Thailand, and West Africa. Kodo millet is an important drought tolerant and hardy crop that can be grown on marginal lands. Kodo millet is a naturally biofortified crop with higher nutrients, vitamins, minerals, proteins, and fiber contents than the other major cereals. Kodo millet has a good amount of biomass, which makes it a good choice for fodder. Genetic variability is essential for any crop improvement program, which is limited in Kodo millet due to its self-pollination nature (Ravikesavan *et al*., 2023).

BREEDING

Germplasm: The major genebanks conserving kodo millet germplasm are presented in **Table 1** (Upadhyaya *et al.,* 2016).

Breeding objectives: Grain yield improvement is the prime breeding objective in kodo millet like other crops. The crop is valued for its cultivation in India and occupies significant area among the group of small millet crops. Recombination breeding in this crop is not realized due to highly cleistogamous nature of the crop although many improved varieties have been released for cultivation. The crop is prone to lodging at maturity, causing loss of grain. To prevent this, limited fertilization is recommended. However, application of fertilizer dramatically improves yields through vigorous growth. Therefore, development of nutrient efficient cultivars with lodging tolerance is another breeding objective. Identification of genotypes with special attributes such as synchronous maturity, stay green, easy threshing and dehulling, etc., are other areas requiring breeder's attention. This crop requires extensive milling and milling problems needs to be addressed to lessen the drudgery associated with the husk sticking to the endosperm tightly, which reduces the efficiency of grain recovery. Head smut is one of the important diseases of kodo millet which causes economic loss in grain yield (Viswanath and Seetharam, 1989). In Madhya Pradesh, up to 32.9% loss in grain yield was reported. The resistant sources identified for head smut like RI 1, RK65-18, RK87-9, RK162, RK106, DPS486, DPS516, DPS542, DP S672, DPS700, DPS727,1CK769 GPLM 78, GPLM 96, GPLIVI 176, GPLM 322, GPLM 364, GPLM 621, GPLM 641, GPLM 679 and GPLM 720. Similar to other small millets, shootfly (*Atherigona simplex*) can cause significant yield reduction in late-sown crops. Yield losses accounted to about 39%–49% due to shoot fly attack. Hence, development of shoot fly tolerant cultivars is one of the important objectives for yield enhancement (Ganapathy *et al*., 2021).

Breeding Methods (PBEA, 2023)

Mass selection: This is the most common type of cultivar development method being used in several African and Asian countries. In this method a group of pearl millet plants are selected from open pollinated population and the seeds from selected plants are mixed and planted to begin the next cycle of selection. Mass selection in pearl millet has helped to improve traits with high heritability.

Table 1. Major genebanks conserving germplasm of kodo millet Worldwide

Crop/country	Institute	Germplasm accessions		
		Cultivated	Wild	Total
Kodo millet				
Argentina	Banco Activo de Germoplasma de Papa, Forrajeras y Girasol Silvestre		127	127
	Instituto de Botánica del Nordeste, Universidad Nacional de Nordeste, Consejo Nacional de Investigaciones Científicas y Técnicas	390		390
Australia	Australian Tropical Crops and Forages Genetic Resources Centre	54	159	213
Brazil	Embrapa Pecuária Sudeste (CPPSE)	327		327
Colombia	Centro Internacional de Agricultura Tropical (CIAT)		155	155
Ethiopia	International Livestock Research Institute (ILRI)	3	205	208
India	AICRP on Small Millets, Bangalore	1111		1111
	International Crop Research Institute for the Semi-Arid Tropics (ICRISAT)	665		665
	National Bureau of Plant Genetic Resources (NBPGR), New Delhi	2170	10	2180
Japan	Department of Genetic Resources I, National Institute of Agrobiological Sciences (NIAS)	158		158
Kenya	National Genebank of Kenya, Crop Plant Genetic Resources Centre - Muguga	130		130
New Zealand	Margot Forde Forage Germplasm Centre, Agriculture Research Institute Ltd	281		281
Nigeria	National Centre for Genetic Resources and Biotechnology (NACGRAB)	294		294
USA	Plant Genetic Resources Conservation Unit, Southern Regional Plant Introduction Station, University of Georgia, USDA-ARS	1074	249	1323
Uruguay	Facultad de Agronomía	106	446	552

The main criteria that have been taken in to consideration to improve grain yield in pearl millet are head characteristics such as compactness, length of ear, weight of grain and uniform maturity.

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

Hybrid breeding: The hybrid breeding program at ICRISAT and West Africa includes development of inbred lines and pure line selection, and the use of cytoplasmic male sterility. Cytoplasmic male sterility in pearl millet has been used to produce hybrid for grain production in India and for forage production in USA. Several sources of male inducing cytoplasm have been discovered in pearl millet including A1, A2, A3, A4, and A5.

A1 is the most commonly used male sterile line for hybrid grain production in India. The CMS system involves the development of three line systems (A, B and R) in order to produce hybrid seeds. Line A is male sterile and serves as seed parent, line B has the recessive form of the fertility restorer gene in the nucleus and does not have the capacity to restore fertility in A system; it maintains sterility. The R line has the dominant form of the fertility restorer genes, and so reverses the effects of the CMS cytoplasm of the A line, therefore resulting in fertile hybrid seeds when used as a male parent. B and R lines should be multiplied in separate and isolated yields to maintain purity.

Crop Improvement: Crop improvement efforts were initiated as early as 1940s, resulting in the release of first improved variety PLR 1 in 1942 for the rainfed areas of Tamil Nadu. Another improved variety, T2, was released in 1949, and Co 1 variety was released during 1953. Post-independence, the genetic improvement work started at Madhya Pradesh during 1964. Niwas 1, improved variety was released in 1971 as the outcome of this program for cultivation in Madhya Pradesh. During 1978, the centre of excellence for improvement of small millets got established at Jawaharlal Nehru Krishi Vishwa Vidyalaya JNKVV, Dindori, by Indian Council of Agricultural Research with the assistance of International Development Research Centre (IDRC). Canada, is devotedly working towards the improvement of kodo millet. With the establishment of All India Coordinated Small Millets Improvement Project (AICSMIP) at UAS, Bangalore during 1986, the IDRC centre became part of AICSMIP and varietal development has gained momentum (Ganapathy *et al.,* 2021). Path analysis in kodo millet indicated that ear length, biological yield and number of tillers/plant in early-maturing genotypes, while biological yield, harvest index, peduncle length and plant height in late-maturing genotypes, are the main components of grain yield in kodo millet. An overall assessment of yield factors based on correlation and path analyses revealed that number of tillers/plant, plant height, panicle length, and biological yield are the major yield components in kodo millet. The pure-line selection is the extensively practised breeding method for improving performance, particularly grain yield in kodo millet (Hariprasanna, 2017).

Breeding Achievement: The cultivars released in kodo millet till date are mainly developed through selection from landraces or germplasm. Some of the varieties, namely GK 2, APK 1, and KMV 20, are achieved through selection from germplasm introduced in different agro-ecosystems. The pure-line selection is the extensively practiced breeding approach for improving performance particularly grain yield. Single plant selection from local collections/landraces and their evaluation for economic characters like earliness, resistance to biotic stresses and high yield resulted in development and release of many varieties in kodo millet. Breeding for high yield, earliness, resistance to head smut and shoot fly, have been achieved through pure-line selection to certain extent. Till date (1942–2015), about 33 varieties have been released. Induced Mutagenesis has been used to larger extent to generate variation in kodo and other small millets. A protogynous mutant having two rows of spikelets on rachis was identified from 5 Kr dose of gamma irradiation in variety JK 76. The identification of protogynous mutant will aid opportunities in recombination breeding. Among other mutants developed, KM 86 and KM 99 have greater yield potential coupled with early maturity. There is ample scope for kodo millet improvement through physical and chemical mutagenesis (Ganapathy *et al*., 2021).

Recommended Varieties for different States are in **Table 2** (Tonapi *et al*., 2015).

Table 2. Recommended varieties of Kodo millet in India

Name of the crop/variety	Year of release	Adaptation Zone	Special features
JK 76	1989	Madhya Pradesh	Earliness
JK 62	1989	Madhya Pradesh	Earliness and high yield
GPUK 3	1991	All states	Yield, earliness and resistance to grain smut
AKP 1	1993	Tamil Nadu	High seed yield
GK 2	1993	Gujarath	--
Vamban – 1 (KMV 20)	1996	Tamil Nadu	--
RBK 155	2000	Madhya Pradesh, Karnataka	Resistant to head smut and shootfly.
JK 48	2001	A.P., M.P., Chattisgarh, Karnataka & Gujarath.	Tolerance to head smut and high grain yield
KK 2	2002	Uttar Pradesh	Resistant to drought and lodging and suitable for saline condition

Popular kodo millet varieties GK 2, APK 1, and KMV 20 are the outcome of selections from germplasm accessions. To a great degree, pureline selection is followed to develop superior-yielding cultivars. In addition, induced mutagenesis is also practiced to a great extent to generate variability in kodo millet (Yadava, 1997). The variety JK 76 was gamma-irradiated with a 5-Kr dose to develop a protogynous mutant with two rows of spikelets on the rachis; such successful endeavors in millet breeding research shall aid in recombination breeding to identify superior varieties (Nagaraja *et al*., 2023).

Recommended Varieties for different States are given in Table 3 (Vikaspedia, 2023).

Table 3. Recommended Varieties for different States
Madhya Pradesh - RK - 65 - 18,JK 439, RBK 155, JK 13, JK 65 and JK 48, JK 137, RK 390- 25, JK 106, GPUK 3
Tamil Nadu - KMV 20 (Bamban), CO 3, TNAU 86, GPUK 3
Gujarat - GK 1 and GK 2, GPUK 3
Chattisgarh - RBK 155 and JK 43 9, Indira Kodo - 1, Indira Kodo - 48, GPUK 3
Karnataka - GPUK 3, RBK 155
Hill States -VL-124, VL-149

USES

Processing: Typically, women are responsible for harvesting and processing millets, which begins with threshing the grain with their feet. Millets are dehusked before cooking, which is done traditionally with a pestle and mortar. Improvements in mechanical grain-processing technology are needed to reduce the amount of time and energy women spend on manual processing. Because kodo millet has several layers of hard seed coats, this process proves to be quite tedious and time-consuming. Kodo millet may then be further processed to produce flour, or may be cooked like rice. Kodo millet is used to make several traditional foods. The most common examples of this are roti and mudde. Because millet protein lacks gluten, to prepare roti, millet flour must be mixed with hot water to gelatinize the starch. To prepare mudde with kodo millet flour, the dough is steamed and then made into balls. Kodo millet may also be used as a substitute for rice when preparing dishes such as idli and dosa. This is done by mixing kodo millet and black gram in a 3:1 ratio, followed by wetting, grinding, and fermenting overnight. Kodo millet may also be used to prepare ready-to-eat snack foods, prepared by popping or puffing (BDI, 2018).

Traditional Benefits and Uses: Intaking varagu every day is helpful for postmenopausal women who suffer from heart disease symptoms such as high blood pressure and high cholesterol. Kodo millet helps to hydrate your colon that maintains your system every day and is constipated. It is rich in lecithin that gives excellent strengthening to the nervous system. It can digest quickly. The regular intake of Kodo millet can help to reduce your weight. Furthermore, its anti-diabetic compounds such as quercetin, ferulic acid, B-hydroxybenzoic acid, vanillic acid, and syringic acid from the body prevent obesity so that it is great for diabetic patients. Kodo millets are gluten-free that are good for gluten intolerant people. Unprocessed or processed grains can be cooked whole and ground by traditional or industrial methods if necessary. Traditionally grains of Kodo millets have been used to manage diabetes. Cereals are also effective in treating inflammation, bleeding, and general deficiency (Moolihai, 2023).

Culinary Uses: In India, you can find the Kodo millet in several traditional and novel foods. Kodo millet can be used as a flour form in many tasty dishes. You can mix Kodo millet with other grains, cereal, and legume flour that increase the nutritional value, function, and flavor. In tribal fields, it is cooked into the rice, and various dishes are made with flour. It is essential as a gluten-free diet and is a component of multigrain gluten-free food products. You can make varagu idli, varagu dosa, varagu chapatti, varagu Upma, varagu Pongal, varagu Puttu, varagu Idiyappam, varagu Kozhukattai, varagu Vada, varagu sweet Poli, varagu biscuits, varagu soup, varagu Adai, varagu Payasam, varagu Cutlet, varagu Bread, varagu Cookie, and varagu Ladoo, etc. Grind the Kodo millet into the flour form; then, you can use it to prepare murukkus, Adirasams, Vadagam, and Pakoda. Make your breakfast more special and healthy with Kodo millet. Kodo millet is used as an alternative for rice in India and Africa. Moreover, most of the Indian people used this varagu for their breakfast. They are ground into the dough and used to make pudding and porridge. Varagu is also used in the preparation of various snacks. In Africa, Kodo millet is eaten as a famine, and also, they cooked it like rice **(Fig. 7)** (Moolihai, 2023).

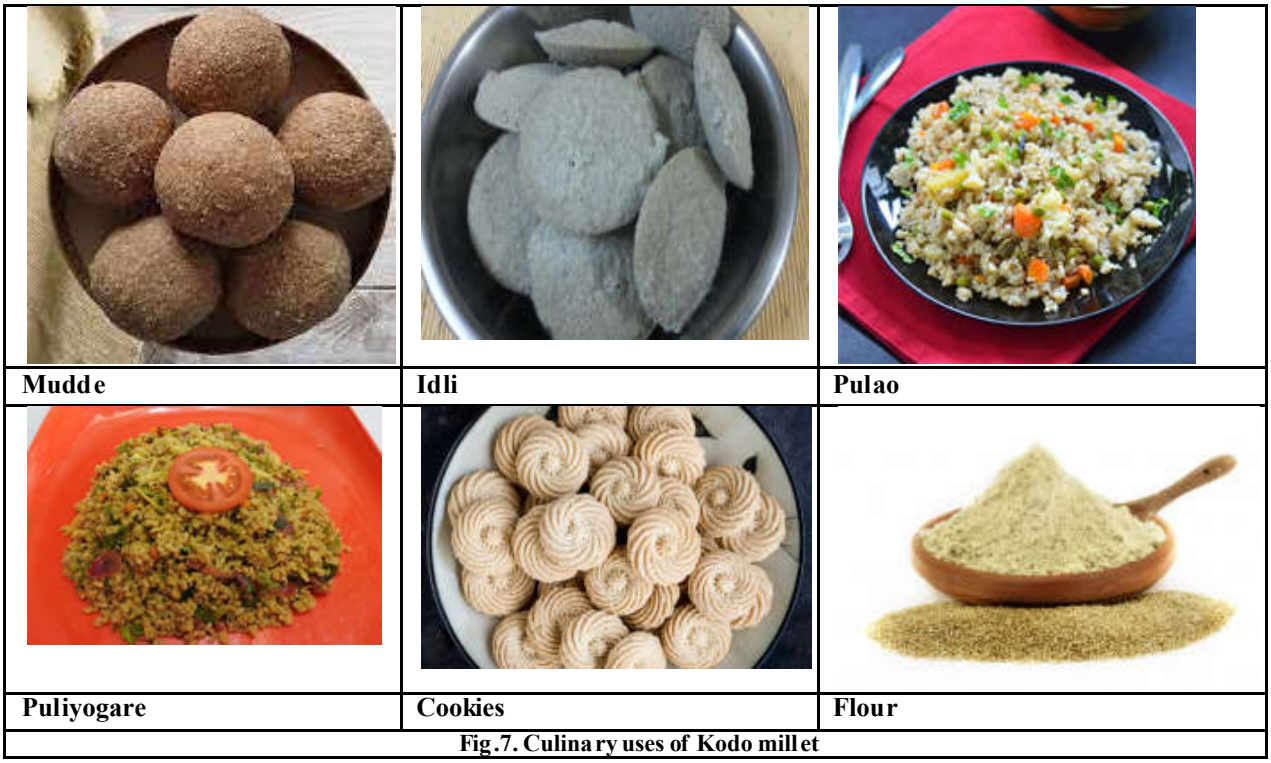


Fig.7. Culinary uses of Kodo millet

Millets can be cooked as we make rice and serve with dal, sambar, rasama or any curry of our choice. We can also make various dosa, idli, vada, bajjis/pakoras, murrukus/chakkli, nipatlu, pongal, mudde (dumpling), khichdi, pulav/biriyani, upma, sweets from millets, baked products such as bread and biscuits, or cooked just like boiled rice. They can also be use in baking, so we can include millets in our diet in more exciting way. Millets can be used to a whole variety of food that we consume every day. They are ideal replacements to wheat and rice for their higher nutritional value (Mall and Tripathi, 2016). In India and Africa, Kodo millet is used in the preparation of a wide range of dishes. They are mainly cooked and used as a substitute for rice. Breakfasts like dosa, upma, and idly are prepared in India using these millets. They are ground into flour and used to prepare puddings and porridges. They are also used in the preparation of various snack items (NVT, 2019). Kodo millet is a good substitute for Rice because it is very similar in taste. It is a combination of sweet, bitter, and astringent (Beevi, 2021). Kodo millet is widely cultivated as a minor millet in Africa and Asia, especially India. Also used for forage and as a feed supplement. In India, it has been used as a substrate for mushroom production and for medicinal purposes (CABI, 2021).

Kodo millet/Varagu Arisi has been grown and consumed in the southern part of India for centuries. The great woman and Tamil poet Avvaiyar's favourite food were Varagu Arisi Choru/Kodo Millet Rice. In her poem 'Thani Padal Thirattu'—the 32nd song goes like this—' Varagu Arisi Chorum, Vazhathunangai Vaatum, Mora moravena Pulitha Morum' (Vaaragu arisi chorum means Kodo millet Rice, Vazhathunangai Vaatum means Smoked and Smashed Brinjal (Vazhathunangai- very old Tamil name for Brinjal), Moramoravena Pulitha Morum means Frothy and Tangy Buttermilk). The poet mentions her host's name as boothan of pulvelur village and expresses gratitude for the tasty meal (Beevi, 2021). It is used just like rice grains. Even after Rice Grains were introduced village people would like to eat Kodo Millet Kanji with Paruppu Kootu. Generally, Kodo Millet/Varagu Arisi is used as a substitute for Rice. It is used as a whole grain in Pongal, a variety of rice recipes. It is ground coarsely and used in Kanji, and Puttu recipes. It is also ground into a fine powder and used in Gluten-free Chapati, Baking Dishes, and Traditional savoury recipes. The whole Kodo millet is soaked and ground into the batter and used in Dosai, Idly, and Paniyaram recipes (Beevi, 2021). Kodo millet is economically important. Its uses include: human food (cereal), animal food (fodder, forage) and medicine. It is harvested as a wild cereal in west Africa and in India (GISD, 2023). In India, millet is ground and used to make pudding. In Africa it is cooked like rice. Also suitable as animal feed for cattle, goats, pigs, sheep and poultry. In Hawaii, var. scrobiculatum has been found to grow well on hillside slopes where no other grasses grow. May be grown as a food source on hillside farms. It may also be used as weeding on hillside plots to prevent soil erosion, and may also provide starvation food as a secondary purpose. It has been noted to make an excellent cover crop (Academic,. 2023). Kodo millets are ground into flour and blended with other cereal flour to prepare bakery items like biscuits, cakes, muffins, pasta, etc. Kodo millet flour can also be used to make chapattis. Kodo millet flour is used to prepare fermented foods like dosa, idli, etc. Kodo millet is also used to prepare porridge, pulao, etc. (Singh, 2023).

Traditional use of Kodo millet: Millets are referred to as nutricereals because they are full of vitamins, minerals, phytonutrients, and sulphur-containing amino acids. Additionally, millets are suggested for people with celiac disease because they are gluten- free. Foods and beverages made from millet are particularly well- liked over the world and continue to be significant components of the diet in the majority of African nations. Porridge with milk and other liquids is typically made with millet and its flour. In many developing nations in Asia and Africa, where millet is widely farmed, it is a staple grain. Traditional dishes and drinks like idli, dosa, papad, chakli, porridges, breads, newborn formula, and snacks are made from millets (Devi *et al*., 2022).

Kodo in classics of Ayurveda: Brihattrayi provides pretty useful information on the plant. Kodrava finds its place in different contexts of Charaka samhita. Its properties and actions of are depicted in sutrasthana, while, its use as pathyadravya (wholesome diet) for the patients suffering with raktapitta (bleeding disorder), udara (ascites), trishna (thirst), visha (poison) and yonivyapat (gynaecological diseases**)** in Chikitsa sthana. Surprisingly, it is also considered as the etiology for the raktapitta (bleeding diseases) and kustha (skin diseases) in nidanasthana, if it is taken along with other food stuffs. In Sushruta samhita, it is mentioned as a virookshana ahara (food that causes dryness), a vataprakopa kaahara (food that aggrevates Vata), a pitta nashaka dravya (drug that pacifies pitta) with kashaya (astringent) madhura (sweet) and sheeta (cold) properties in sutrasthana. In Astanga hridaya, its properties and actions are described in sutrasthana, while, it is recommended as a wholesome diet in kustha (skin disease) and its kshara (alkali) is recommended for darunaka (Dandruff). Harita samhita also described its properties and actions (Karnam, 2020). Kodrava is mentioned in Mahabharata (3000 BC) where in it is prohibited for the offeringsto the ancestors. Kautalya's artha shashtra (2^{nd} - 3^{rd} century) also described Kodrava as a food grain. Interestingly, Brihat samhita (6^{th} century) explained that thriving or availability of Kodrava can be judged by the flowering of Palasha tree {*Butea monosperma* (Lam.) Taub.} (Karnam, 2020).

Precautions to take with kodo millets: Many mycotoxigenic fungi infect the food crops and affect the quality of the produce due to production of mycotoxins. Kodo millet is one of the important minor millets cultivated in India, mostly confined to marginal lands and tribal regions but has high yield potential under good management. The grains are nutritious and have anti-oxidant properties besides having many medicinal properties. However, the consumption is often hindered by the condition called 'kodo poisoning' resulting from fungal contamination producing cyclopiazonic acid, a toxic fungal secondary metabolite. By effective adoption of both pre- and post-harvest management the kodo millet grains can be made safe for human consumption and can be popularized as a nutritious grain (Deepika *et al*., 2022). A few side effects related to the consumption of kodo millets include, consumption of contaminated kodo millets can result in kodo poisoning, characterised by an increased level of liver enzymes and liver toxicity. The clinical manifestations of this poisoning include vomiting, nausea, unconsciousness, etc. Kodo millets contain goitrogens, which interfere with thyroid hormones and can result in an enlarged thyroid gland (goitre). However, if you experience any adverse reactions to kodo millet, it is advised to discontinue its intake and immediately contact a doctor or your Ayurvedic physician who has prescribed it. They will be able to guide you appropriately for your symptoms (Singh, 2023). Eating kodo millet is okay if taken in moderate amounts. However, general precautions must be followed in the following conditions: In addition to the nutritional components, kodo millets also contain anti-nutrients like phytic acid, polyphenols, etc. which reduces the availability of nutritional components. Processing methods like soaking will help reduce the level of anti-nutrients. Therefore, it is advised to soak kodo millets before use (Singh, 2023). Kodo millets are used as staple food worldwide, they change into poisonous if infected with fungal species such as Aspergillus flavus and Aspergillus tamari. These fungi produce a toxin called cyclopiazonic acid that can cause Kodua poisoning. It may lead to nausea, vomiting, depression, disturbances in mental abilities, and even dizziness (Moolihai, 2023).

NUTRITIONAL VALUE

Millets are a group of highly variable small-seeded grasses, widely grown around the world as cereal crops/grains. Millet is tiny in size and round in shape and can be white, gray, yellow or red. Millets are very high in their nutrition content. Each millets are three to five times nutritionally superior to rice and wheat in terms of proteins, minerals and vitamins. Millets are rich in B vitamins, calcium, iron, potassium, magnesium, zinc, also gluten-free and has low-GI (Glycemic index) thus millets are suitable for people allergies/intolerance of wheat. Also for diabetic, weight loss millets are excellent. It helps to lower type 2 diabetic and reduces the risk of heart disease Millets are a great source of starch, making it a high-energy food. It is also an excellent source of protein and fiber (Mall and Tripathi, 2016). Kodo millet is a nutritious grain and a good substitute to rice or wheat. The grain is composed of 11% of protein, providing 9 grams/100 g consumed. It is an excellent source of fibre at 10 grams (3738%), as opposed to rice, which provides 0.2/100 g and wheat, which provides 1.2/100 g. An adequate fibre source helps combat the feeling of hunger. Kodo millet contains 66.6 g of carbohydrates and 353 kcal per 100 g of grain, comparable to other millets. It also contains 3.6 g of fat per 100 g. It provides minimal amounts of iron, at 0.5/100 mg and minimal amounts of calcium and 27/100 mg. Kodo millets also contain high amounts of polyphenols, an antioxidant compound (Mall and Tripathi, 2016).

The Kodo millet contains 9.8g Protein, 3.6g Fat, 3.3g Ash, 5.2g Crude fibre, 66.6g Carbohydrate, 353 k cal energy, 35 mg Calcium, 1.7 mg Iron, 0.15 mg Thiamin, 0.09 mg Riboflavin and 2.0 mg Niacin (Nirubana *et al*., 2017).

Similar to other small millets, kodo millet is a good source of phosphorus and iron. They are nutritionally comparable to rice, wheat, and other staple cereals, and even offer higher protein content, sulfur-containing amino acids Cysteine and Methionine. Kodo millet is particularly high in B vitamins, especially niacin, pyridoxine, and folic acid, in addition to minerals such as calcium, iron, potassium, magnesium, and zinc. Kodo millet contains polyphenols, tannins, and phytic acids—antinutrients which form complexes with nutrients such as carbohydrates, proteins, iron, calcium, and zinc and reduce their bioavailability. Fortunately, processing of kodo millet typically reduces the levels of tannins and phytates and increase the bioavailability of nutrients. For example, dehulling kodo millet can remove 40-50% of phytate (BDI, 2018). The grain contains a diverse range of high-quality protein and has high anti-oxidant activity (anti-cancer) even when compared to other millets. Kodo millet like other millets is rich in macro and micro nutrient contents. It has higher protein content(8.3/100 g grain). Its riboflavin content (0.10 mg/100 g grain) is also higher than rice and barnyard millet. It is also rich in magnesium (166 mg/100 g) and is considered as one of the nutritious millets (Rajput *et al.,* 2019). Kodo millets are highly nutritious and make up a very balanced diet. They are a great source of proteins, dietary fiber, vitamins like niacin and riboflavin, minerals like copper, manganese, and phosphorus. Apart from that, Kodo millets or Arikelu also have considerable amounts of calcium, magnesium, and sodium. They contain 8.3% Protein and 1.4% Fat. Essential amino acids like lysine, threonine, and valine are also present in considerable amounts in this millet (NVT, 2019).

Kodo millet is repository of nutrients, a great substitute for rice and wheat. With a whopping 11% protein for every 100 grams, it is also a rich source of fibre at 10 grams, 66.6 grams of carbohydrates, 353kcal, 3.6 grams of fat, besides impressive presence of calcium, iron, polyphenols and various other nutrients (Netmeds, 2021). Nutrient Quantity (100gm): Moisture 11.6 g, Protein 10.6 g, Fat 4.2 g, Fiber 10.2 g, Ash 2.95 g, Calorific value 346 kcal, Carbohydrate 59.2 g, Minerals 4.4 g, Calcium 27 mg, Phosphorus 188 mg, Iron 0.5 mg, Riboflavin 0.09 mg, Niacin 2.0 mg (Bunkar *et al.,* 2021).

Kodo millet contains dietary fibre, minerals like iron, and antioxidants . The nutritional value for 100 g of Kodo millet is given in **Table 4** (Devi *et al.,* 2022).

Table 4. The nutritional value for 100 g of Kodo millet

S. No	Nutrients in Kodo Millet (100 g)	Levels
1	Iron	0.5 mg
2	Phosphorus	188 mg
3	Calcium	27 mg
4	Thiamine	0.33 mg
5	Riboflavin	0.1 mg
6	Niacin	0.2 mg
7	Protein	8.3 g
8	Carbohydrate	58 g
9	Fat	1.4 g
10	Fiber	9.0 g

Millet is a nutritious grain that is a good substitute for rice and wheat. Grains contain 11% protein, providing 9 grams of protein per 100 grams. 10 g (37-38%) is an excellent source of fiber compared to 0.2/100 g of rice and 1.2/100 g of wheat. Adequate fiber sources can help fight hunger. The sugar content of Kodo cereals is 66.6g per 100g, and the calorie content is 353kcal, which is about the same as other cereals. It also contains 3.6g of fat per 100g. Provides minimal iron (0.5/100 mg) and minimal calcium (27/100 mg). Millet is also rich in polyphenols, which are antioxidants (Academic,. 2023). Kodo millet is a nutritious grain and a good substitute to rice or wheat. The grain is composed of 11% of protein, providing 9 grams/100 g consumed. It is an excellent source of fibre at 10 grams (37-38%), as opposed to rice, which provides 0.2/100 g, and wheat, which provides 1.2/100 g. An adequate fibre source helps combat the feeling of hunger. Kodo millet contains 66.6 g of carbohydrates and 353 kcal per 100 g of grain, comparable to other millets. It also contains 3.6 g of fat per 100 g. It provides minimal amounts of iron, at 0.5/100 mg, and minimal amounts of calcium, and 27/100 mg. Kodo millets also contain high amounts of polyphenols, an antioxidant compound (Wikipedia, 2023). Kodo millet offers more dietary nutritional content to you. Moreover, it can perfectly balance your diet. It is rich in protein (11 percent), has 4.2 percent low fat, carbohydrates 65 grams, fiber 5.2 g, folic acid 23.1 g. Moreover, it contains vitamins and minerals that include Vitamin B, B6, calcium, iron, potassium, magnesium, and zinc. Kodo Millet contains antioxidant polyphenols, an antioxidant compound, tannins, phosphorus, and phytic acids. When compared to the other millet and large grains, it has a high antioxidant capacity. Kodo millet has low phosphorus content compared to other millets. It is the best alternative for rice or wheat. It has more protein, fiber and minerals than staple grains like rice. You can cook like rice or ground flour. This millet contains significant amounts of essential amino acids such as lysine, threonine and valine (Moolihai, 2023).

100 grams of kodo millet contains the following nutrients **(Table** 5) (Moolihai, 2023).

Table 5. Nutrient content of 100 grams of kodo millet

Nutrient	Value
Calories	207
Total Fat	2 g
Carbohydrates	41 g
Protein	0.7 g
Dietary fiber	2 g
Manganese	0.3 mg
Calcium	3 mg
Iron	0.6 mg
Magnesium	44 mg
Copper	0.2 mg
Vitamin C	1.5 mg
Selenium	0.9 mg
Zinc	0.9 mg
Phosphorus	100 mg

Kodo millets are packed with the goodness of carbohydrates, proteins, and dietary fibres. It contains vitamins like niacin and riboflavin and minerals like calcium, iron and phosphorus. The phytochemicals found in kodo millets include antioxidants along with phenolic compounds like vanillic acid, gallic acid, tannins, ferulic acid, etc. The nutritional components of kodo millets are given in the **Table** 6 (Singh, 2023).

Table 6. Nutrient content of 100 grams of kodo millet

Nutritional components	Value per 100 g
Carbohydrate	59.2 g
Protein	10.6 g
Fibre	10.2 g
Fats	4.2 g
Phosphorus	188 mg
Potassium	107.8 mg
Calcium	27.0 mg
Sodium	3.48 mg
Vitamin B3	2.0 mg
Zinc	1.58 mg
Iron	0.5 mg
Vitamin B5	0.28 mg
Vitamin B1	0.18 mg
Vitamin B2	0.09 mg
Folate	33.06 mcg
Vitamin K	0.5 mcg

HEALTH BENEFITS

The following health benefits are reported by NVT (2019)

It may help to control Obesity: Millets were undoubtedly a healthier choice for weight management. Especially, millets like Kodo are well known to control obesity and its complications. This millet can be a great alternative source for rice and wheat. A study had found that Kodo millet is known to have a protective function against problems caused by the intake of a high-fat diet like reduced glucose intolerance, dysbiosis of intestinal beneficial bacteria and increased serum lipids saying that these millets can be incorporated as an ingredient for obesity management. Another study conducted on obese adolescent girls with metabolic syndrome had also shown that these millets have a positive effect on obesity by significantly reducing body fat, mean weight and waist to hip ratio.

A potential Anti-diabetic source: Arikalu or Kodo millets are consumed as a staple food since ancient times in India and were known to have remarkable health benefits. Recently, they had gained popularity as a food source that can help in reducing diabetes and its complications. It was found that Kodo millet extract had reduced fasting blood glucose levels and increased serum insulin levels. The millet had also significantly decreased the glycated hemoglobin levels and increased liver glycogen, a glucose polymer that helps the body by readily giving energy if glucose levels were low.

It has Anti Oxidant Properties: Studies conducted on Kodo millet had proven that they have powerful antioxidant properties. When whole grains, dehulled grains, and hulls of Kodo millet are tested to know their antioxidant activity, Kodo millet phenolic extracts had exhibited a great inhibitory activity on the oxidation of LDL cholesterol and liposomes. These grains also showed inhibition of radical induced DNA scission in a dose-dependent manner. The study also said that the antioxidant activity is high in hull than whole grain and low in dehulled grain when tested.

It has high free radical scavenging activity: Free radicals are known to cause significant damage to cells and tissues if they were not counteracted by the body. Foods such as Kodo millet are a rich source of antioxidants that can help in reducing free radicals. A study had shown Kodo millet exhibited potential free radical quenching activity on DPPH, a chemical compound widely used to evaluate free radical scavenging ability. The white variety of this millet had shown 70% DPPH quenching when compared to other millets used in the study which showed 15-53%.

Wound Healing Properties: Studies conducted to know the effect of this millet on wound healing had proven that these grains had accelerated the wound healing process. Wound healing was assessed by applying the Kodo millet flour once daily on an excision wound made on rats for 16 days. Finger millet, also known as Ragi is also tested in this study. The Kodo and Finger millet had shown 88-90% rate of contraction when compared with untreated rats which showed 75%. The days required for complete closure of the wound is 13 days for Finger Millet and 14 days for Kodo millet in comparison with 16 days in untreated rats. The leaves are antiseptic in action and their paste is applied externally in cutaneous afflictions. On the basis of ethnobotanical records this species is also used for carbuncle, diabetes, intoxication, narcotics, opthalmia, parturition and sores. The fiber content of the whole grain is very high (Hariprasanna, 2015).

The following health benefits are reported by Sylvia (2018): Kodo millet is a good substitute to rice or wheat. Protein, fiber, and mineral content are much higher than the major cereals like rice. It can be cooked just like rice or ground into flour. It provides balanced nutrition, unlike polished white rice. Listed below are some of the popular health benefits of Kodo Millet.

- **Anti-diabetic:** Kodo millet intake is found to reduce fasting blood glucose level and promotes significant increase in serum insulin level. Anti-diabetic compounds in Kodo are quercetin, ferulic acid, p-hydroxybenzoic acid, vanillic acid and syringic acid. Thus regular use is recommended for diabetic patients.
- **Antioxidant and anti-microbial activity:** Kodo millet grains consist of polyphenols and antioxidants. The polyphenols possess antimicrobial action against certain bacterias (Staphylococcus aureus, Leuconostoc mesenteroides, Bacillus cereus and Enterococcus faecalis).
- **Anti-obesity:** Kodo is high in fiber and prevents gain in weight. It also helps to prevent rise in cholesterol and triglyceride levels and is a functional food to manage weight and promotes weight loss.
- **Anti-cholesterol and anti-hypertension:** Kodo is very beneficial for post-menopausal women suffering from signs of cardiovascular disease, high blood pressure and high cholesterol levels. Hence, regular consumption of Kodo millets is recommended for all.

- **Helps in weight management:** Kodo millet consists of low fat content and fiber content is higher and makes to feel fuller after consuming less quantity itself, therefore it avoids over eating and lessens the weight, thereby controls obesity. An obese person should include this cereal in their diet and see the difference on their weight.
- **Cholesterol reduction:** Regular consumption of Kodo millet helps to lower the triglycerides and C-reactive protein, thus it lowers the bad cholesterol and ideal for your heart. Thus heart protective food too.

The following traditional uses and health benefits are reported by Sylvia (2018): Regular consumption of kodo millet is very beneficial for postmenopausal women suffering from signs of cardiovascular disease, like high blood pressure and high cholesterol levels. Kodo Millet helps hydrate your colon to keep your system regular and keep you from being constipated. Kodo Millet helps in controlling Blood sugar and Cholesterol. It is easy to digest, contains a high amount of lecithin and is excellent for strengthening the nervous system. It is rich in photo chemicals, phytate that helps in reduction of cancer risks. It helps to reduce the body weight and beneficial for postmenopausal women. It is good for those suffering from signs of cardiovascular disease, like high blood pressure and high cholesterol levels. Also, it is good for diabetics, its anti – diabetic compounds like quercetin, ferulic acid, p – hydroxybenzoic acid, vanillic acid and syringic acid from Varagu prevents obesity. Kodo millets contain no gluten and are good for people who are gluten intolerant. Kodo millets can be used for traditional as well as novel foods. Unprocessed or processed grain can be cooked whole or decorticated and if necessary ground to flour by traditional or industrial methods. In tribal sectors, it is cooked as rice also and out of flour tribal population prepares different recipes. Traditionally the grains of Paspalum scrobiculatum are used in the management of diabetes mellitus. Grains are also useful in the treatment of inflammation, hemorrhages and general debility (Sylvia, 2018).

Arikelu or Kodo millet was one of the ancient millets described in several traditional medicinal systems as a grain with numerous health benefits. In Ayurveda, Arikelu or Varagu arisi is used as a medicine for obesity, blood-related problems, skin problems, diarrhea and also to reduce the inflammation (NVT, 2019). The plant is used to clear the corneal opacity, to treat stiffness of lower limb, polyuria, diabetes, obesity, Epistaxis, wound, indigestion, excessive hunger, in diabetes, eye infections, dysuria, hydrocele. Typhoid and its leaf and root paste are used to relieve labour pain. The paste of the whole plant and grain flour is taken as anti-dysenteric and to cure theskin diseases. Tribal of southern Rajasthan in India boil the grains as rice and use in diabetes and dysentery. It is also used as delivery convalescence. Most interestingly, the santal tribes use the grain to prepare a country liquo. Kodrava is also one among such grains that lost its importance over a course of time in the more civilized modern life, but still a medicine and a food in some tribes. Integrating the ancient knowledge and ethno botanical knowledge with the present existing knowledge of health care system will, obviously, help in understanding the missing link of long healthy life (Karnam, 2020).

Kodrava in classics of Ayurveda Brihattrayi provides pretty useful information on the plant. Kodrava finds its place in different contexts of Charaka samhita. Its properties and actions of are depicted in sutrasthana, while, its use as pathyadravya (wholesome diet) for the patients suffering with raktapitta (bleeding disorder), udara (ascites), trishna (thirst), visha (poison) and yonivyapat (gynaecological diseases) in Chikitsa sthana. Surprisingly, it is also considered as the etiology for the raktapitta (bleeding diseases) and kustha (skin diseases) in nidanasthana, if it is taken along with other food stuffs. In Sushruta samhita, it is mentioned as a virookshana ahara (food that causes dryness), a vataprakopa kaahara (food that aggrevates Vata), a pitta nashaka dravya (drug that pacifies pitta) with kashaya (astringent) madhura (sweet) and sheeta (cold) properties in sutrasthana. In Astanga hridaya, its properties and actions are described in sutrasthana, while, it is recommended as a wholesome diet in kustha (skin disease) and its kshara (alkali) is recommended for darunaka (Dandruff). Harita samhita also described its properties and actions (Karnam, 2020).

The following health benefits are reported by Netmeds (2021):

Controls Diabetes: If you are a diabetic, it's time to switch over to millets. Bring in kodo millets in your regular diet plan for averting those sudden spikes in the levels of blood sugar and also to elevate the levels of insulin. According to studies, Kodo millet significantly reduces glycated haemoglobin levels, triggers production of liver glycogen, stimulating instant levels of energy in diabetics

Fights Chronic Ailments: Kodo millets are an impressive source of powerful antioxidants. The phenolic extracts in this tiny millet reduce LDL or bad cholesterol, keep heart healthy, bring down blood pressure levels and prevent various other chronic conditions. These antioxidants also act against free radicals causing damage to the cells, tissues thus preventing various types of cancers.

Aids in Weight Loss: . Millets of all kinds top the list of those hoping to lose those extra kilos. Kodo, a great alternative for rice and wheat serves the purpose, as it triggers metabolic activity, fights against metabolic syndrome especially in the adolescent boys and girls thus aiding in shedding that stubborn fat in and around the waist, abdomen and hips.

Heart Healthy: Cardiovascular problems are the major cause of fatalities around the world. A healthy diet, means healthy heart and it's time to bring in millets. Regular consumption of Kodo millets not only keeps this vital organ healthy but also brings down the levels of bad cholesterol, regulate blood pressure, fight anxiety and keep you happy, all thanks to the presence of protein, dietary fibre and antioxidants.

Heals Wounds: Kodo millet is a time tested home remedy for healing external wounds. Mix one spoon of fresh Kodo millet flour with water and apply it on the affected area on the skin to alleviate pain and also to accelerate the process of healing.

Ancient Indian medicine ayurveda classifies Kodo millet as langhana, which means bringing lightness to the body and is included under the category of Trina Dhanya Varga – (grains that are produced by grass like plants). It is termed as a wholesome food, prized for its medicinal, therapeutic and culinary properties and is recommended for diabetics, to beat fatigue, heal wounds faster. Being cold in nature, it increases vata dosha but balances issues caused due to kapha and pitta doshas (Netmeds, 2021).

Kodo millets are suitable for people who are gluten intolerant because they don't contain gluten. Because it has a higher level oflecithin, which is important for the health of the neurological system, kodo millet is very simple to digest. Postmenopausal women with signs of cardiovascular illness, such as high blood pressure and excessive cholesterol, can benefit greatly from regular use of Kodo millet. It contains more antioxidants, which protect against oxidative stress and keep type 2 diabetes patients' glucose levels stable. Asthma, migraines, high blood pressure, heart attacks, atherosclerosis, and diabetes can all be treated with kodo millet (Devi *et al*., 2022).

The following health benefits are reported by Devi *et al*.(2022):

Control Diabetes: If you are a diabetic, it is time to switchover to millets. Bring in Kodo millets in your regular diet plan for averting those sudden spikes in the levels of blood sugar and also to elevate the levelsof insulin. According to studies, Kodo milletsignificantly reduces glycated haemoglobin levels, triggers production of liver glycogen, stimulatinginstant levels of energy in diabetics.

Heart Healthy: Cardiovascular problems are themajor cause of fatalities around the world. A healthydiet, means healthy heart and it is time to bring in millets. Regular consumption of Kodo millets not only keeps this vital organ healthy but also brings down the levels of bad cholesterol, regulate blood pressure, fight anxiety and keepyou happy due to thepresence of protein, dietary fibre and antioxidants.

Millets and aging: The diabetes and aging is mainlyattributed due to the chemical reaction between the amino group of proteins and the aldehyde reduction group of sugars which is known as non enzymatic glycosylation. Millets including Kodo millet are rich in antioxidants and phenolics such as phytates, phenols, and tannins that may contribute to importantantioxidant activity in health, aging, and metabolic syndrome.

Millets against cancer and celiac disease: Millets are rich in phenolic acids, tannins and phytes that behave as "anti-nutrients." These anti-nutrients, however, decrease risk of colon and breast cancer inanimal. Millet contains phenolics that have beenshown to be efficient in preventing cancer initiation and in vitro development. Together with the growing amount ofindividuals suffering from celiac disease, the generalgrowing demand for novel, tasty and "healthy" foodshas provided birth to a fresh industry of cereal products produced from grains other than wheat and rye. Celiac disease is an immune-mediatedenteropathy that is caused by gluten intake in genetically prone people. Since millets are gluten-free, however, they have significant potential in foods and drinks that may be appropriate for people with celiac illness. Therefore, millet grains and their functions have the ability to be helpful in the prevention of cancer and in the production of celiac food products.

Low glycemic index: Which means that kodo millets release glucose/energy slowly, over a longer period of time and thus helps in sugar control. This makes it a great substitute for polished white rice.

Heals wounds: Kodo millet is a time tested home remedy for healing external wounds. Mix one spoonof fresh kodo millet flour with water and apply it onthe affected area on the skin to alleviate pain and alsoto accelerate the process of healing wounds

The following health benefits are reported by Moolihai (2023):

- **Has Anti-diabetic Source**: Kodo millets have been a staple food in India since ancient times, and they have significant health benefits. Recently, they have gained a reputation as a food expert to decrease diabetes and its difficulties. Consuming Kodo millet can lower the blood glucose levels fastly and supports a significant improvement in serum insulin levels. The anti-diabetic composites in Kodo are quercetin, ferulic acid, b-hydroxybenzoic acid, vanillic acid, and syringic acid. It is the most recommended millet for those who have diabetes. Millet significantly lowers the level of glycated hemoglobin and improves the glucose polymer called liver glycogen, helping the body by giving energy immediately when the glucose levels are low.
- **Antioxidant and Antimicrobial Properties**: Kodo millet comes with polyphenols and antioxidants properties. Polyphenols have an antimicrobial activity that can fight against certain bacteria (Staphylococcus aureus, Lugonostag mesenteroids, Bacillus cereus, and Enterococcus faecalis). When Kodo millet whole grains, skimmed grains, and hull were tested to know their antioxidant property, Kodo millet phenolic extracts revealed a significant inhibitory activity regarding LDL fat and liposomes oxidation. These grains have been shown to inhibit intense induced DNA cleavage in a dose-dependent manner. The study found that the antioxidant property was over the whole grains and that dehydrated grains were lower when examined.
- **Helps to Reduce Obesity**: Generally, Kodo millet is rich in fiber content, so that it can prevent you from gaining weight. In addition, this millet can prevent cholesterol and triglyceride from raising your weight and supporting weight loss. There is no doubt that millet is a healthy choice for weight management. In particular, millet like Kodo are well known for controlling obesity and its complications. This millet would be an excellent alternative source for rice and wheat. One study shows that Kodo millet has a protective function that can fight against complications caused by reduced glucose intolerance, intestinal beneficial bacterial dysbiosis, and increased serum lipids. Says that these millets can be combined as an ingredient for obesity management. In another study of obese adolescent women with metabolic syndrome, these millets showed a positive effect on obesity by significantly reducing body fat, average weight, and waist-to-hip ratio.
- **Anti-cholesterol and Anti-hypertension**: It is one of the best remedies for postmenopausal women who suffer from signs of cardiovascular disease, high blood pressure, and high cholesterol. By consuming Kodo millet every day can reduce the risk of heart-related problems. Moreover, consuming Kodo millet can decrease the triglycerides and C-reactive protein that reduce the bad cholesterol level, and it is suitable for your heart health.
- **Has High Free Radical Scavenging Property**: Free radicals can cause major damage if the body does not resist cells and tissues. Kodo millet is a rich source of antioxidants that can help decrease free radicals. One study revealed the potential free radical mitigation activity on Kodo millet DPPH, which is a widely used chemical compound, widely used to evaluate free radical scavenging potential. This white millet variety showed mitigation of 70% DPPH by 15-53% compared to other millets used in the study.
- **Wound Healing Properties**: Studies to determine the effect of Kodo millet on wound healing have shown that these grains accelerate the wound healing process. The wound was healed by applying Kodo millet dough every day on the cut wound on the rats for 16 days. Kodo millet showed a shrinkage rate of 88-90% compared to untreated mice, which showed 75%. 14 days needed for complete wound closure when using Kodo millet.

Kodo millets show numerous scientifically proven properties; some of these properties are mentioned below (Singh, 2023): It may have antioxidant properties. It may lower blood glucose levels. It may lower blood pressure. It may have anti-allergic properties. It may be able to halt the abnormal growth of cells. It may have the ability to reduce abnormally high lipid levels. It may have antibacterial properties.

The following health benefits are reported by Singh (2023):

Potential uses of kodo millets on Lipid profile: Hyperlipidemia is the elevation in lipid components like triglycerides, total cholesterol and reduced levels of high-density lipoprotein. Narra et al. conducted a study in 2013 to assess the effects of kodo millets on hyperlipidemia in rats. The results of this study showed that kodo millets helped reduce total cholesterol, triglycerides and low-density lipoprotein and caused a

significant increase in high-density lipoprotein. This indicates that kodo millets may positively impact lipid profile. However, we need more clinical studies to support these claims in humans.

Potential uses of kodo millets for bacterial infections : Literature shows that the consumption of kodo millets may have the potential to manage bacterial infections. A review conducted by Sharma et al. in 2016 stated that kodo millets could inhibit the growth of bacteria like *S.aureus, Bacillus cereus, Leuconostoc mesenteroides* and *Enterococcus faecalis* which cause urinary tract infections, diarrhoea, etc. Thus, kodo millets may help manage bacterial infections. However, we need more studies to support these claims.

Potential uses of kodo millets for type-2 diabetes: Type-2 diabetes is a metabolic disorder characterised by an increase in blood glucose due to decreased production or resistance to a hormone called insulin which regulates blood glucose. A review conducted by Han et al. in 2022 stated that kodo millets might have the potential to decrease blood glucose levels. This effect is attributed to polyphenols, which inhibit enzymes that break down carbohydrates into simpler sugars and increase blood glucose. Additionally, kodo millets have a low glycemic index. Therefore, kodo millets may have the potential to manage type-2 diabetes. However, there are not enough studies to support these claims.

Potential uses of kodo millets in cancer: Literature studies have supported the use of kodo millets and reduced risk of cancers. Chandrasekara et al. in 2010 conducted a review stating that kodo millets may potentially reduce cancer initiation and progression. This anti-cancer effect is attributed to the presence of phenolic acids, phytic acids and tannins in the grain. This indicates that kodo millets may reduce the risk of certain cancers. However, we need more scientific evidence to support these claims.

Potential uses of kodo millets in malnutrition: Malnutrition is defined as the deficiency, excess or imbalance in the intake of energy and/or nutrients. The term malnutrition addresses 3 broad groups of conditions:

1) Undernutrition , 2) Micronutrient-related malnutrition, and 3) Overweight.

Kodo millets are highly nutritious due to the presence of carbohydrates, proteins, dietary fibres, vitamins like niacin, riboflavin and minerals like calcium, iron and phosphors. Kodo millets are also rich in antioxidants and phenolic compounds like vanillic acid, gallic acid, tannins, ferulic acid. Vinoth et al. in 2017 conducted a review stating that kodo millets may help manage micronutrient-related malnutrition. Thus, the consumption of kodo millets may positively impact malnutrition. Though scientific evidence to support these claims is limited, we need more studies to ascertain these claims with better results.

Other potential uses of kodo millets; In Ayurveda, kodo millets have been used to provide relief from joint pain. Kodo millets may help in irregular menstrual cycles. High potassium content in kodo millets may help reduce abdominal cramps during the menstrual cycle. However, the exact mechanism behind these benefits has yet to be fully understood. Being a rich source of dietary fibers, kodo millets may help in managing constipation by improving bowel movements. Kodo millets also help in weight loss, by increasing satiety due to the presence of fibres and proteins, which reduces overeating. Kodo millets are rich in a protein called collagen, which increases the elasticity of the skin and may help in reducing wrinkles. Kodo millets are loaded with prebiotic fibres, which may help improve gut health (Singh, 2023).

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