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REVIEW ARTICLE

ORIGIN, DISTRIBUTION, TAXONOMY, BOTANICAL DESCRIPTION, GENETICS AND CYTOGENETICS, GENETIC DIVERSITY AND BREEDING OF DRUMSTICK

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ABSTRACT

Drumstick belongs to the Family Moringaceae, Genus Moringa, Species Moringa oleifera**.** *Moringa oleifera* is a fast-growing, drought-resistant tree of the family Moringaceae, native to the Indian subcontinent and used extensively in South and Southeast Asia. Common names include moringa, drumstick tree (from the long, slender, triangular seed-pods), horseradish tree (from the taste of the roots, which resembles horseradish), or malunggay (as known in maritime or archipelagic areas in Asia). It is widely cultivated for its young seed pods and leaves, used as vegetables and for traditional herbal medicine. It is also used for water purification. India is the largest producer of moringa, with an annual production of 1.2 million tonnes of fruit from an area of 380 km^2. Even though drumstick is cultivated in countries like Philippines, Nigeria and Kenya, the crop cultivated in India is superior in quality and quantity. India contributes to about 80 per cent of world drumstick production. The total area is estimated as 43,600 ha with a production of 22,000 tons per annum. The crop is commercially cultivated in Tamil Nadu, Andhra Pradesh, Karnataka, and Odisha and in Kerala, drumstick cultivation is limited to home gardens to meet the family requirement. Fruits, leaves and dried products are mainly exported to China, USA, Canada and South Korea. Despite their nutritious edible parts, Moringa products are sometimes classified as "famine food", consumed by humans in times of food scarcity. Moringa vegetables as a human food are often linked with low social class status. As such, *M. oleifera* is still not well exploited and hence considered as underutilized in Malawi. In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding of Drumstick are discussed.

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INTRODUCTION

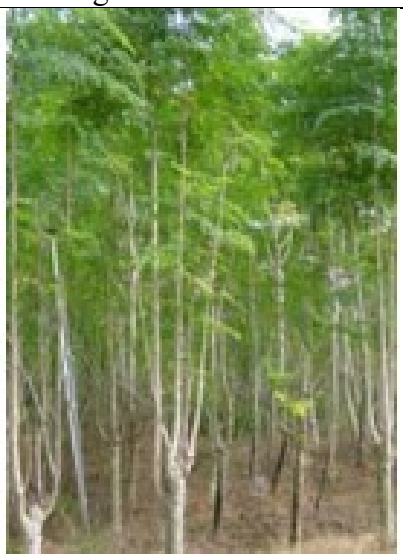
Drumstick belongs to the Family *Moringaceae,* Genus *Moringa* , Species *Moringa oleifera (*(PWO, 2024; AICRPVC, 2024; Wikipedia, 2024). The genus name *Moringa* derives from the Tamil word, *murungai*, meaning "twisted pod", alluding to the young fruit. The specific name *oleifera* is derived from the Latin words *oleum* "oil" and *ferre* "to bear" (Wikipedia, 2024). Common names in Arabic: rawag, Assamese: saijna, sohjna, Bengali: sajina, Burmese: daintha, dandalonbin, Chinese: la ken, English: drumstick tree, horseradish tree, ben tree, French: moringe à graine ailée, morungue, Gujarati: midhosaragavo, saragavo, Hindi: mungna, saijna, shajna, Kannada: nugge, Konkani: maissang, moring, moxing, Malayalam: murinna, sigru, Marathi: achajhada, shevgi, Nepali: shobhanjan, sohijan, Oriya: sajina, Portuguese: moringa, moringueiro, Punjabi: sainjna, soanjna, Sanskrit: shobhanjana, sigru, Sinhalese: murunga, Spanish: ángela, ben, moringa, Swahili: mrongo, mzunze, Tamil: moringa, murungai, Telegu: mulaga, munaga, Tellamunaga, and Urdu: sahajna (Roloff *et al.*, 2009; Mallenakuppe *et al.,* 2019; Justgo, 2024). English common names include moringa, drumstick tree, from the appearance of the long, slender, triangular seed pods, horseradish tree, from the taste of the roots which resembles horseradish, ben oil tree or benzoil tree, from the oil derived from the seeds (Gogarden, 2024). *Moringa oleifera* is a fast-growing, drought-resistant tree of the family Moringaceae, native to the Indian subcontinent and used extensively in South and Southeast Asia. Common names include moringa, drumstick tree (from the long, slender, triangular seed-pods), horseradish tree (from the taste of the roots, which resembles horseradish), or malunggay (as known in maritime or archipelagic areas in Asia) (Wikipedia, 2024). It is widely cultivated for its young seed pods and leaves, used as vegetables and for traditional herbal medicine. It is also used for water purification (Wikipedia, 2024). India is the largest

producer of moringa, with an annual production of 1.2 million tonnes of fruit from an area of 380 km^2. Moringa is grown in home gardens and as living fences in South and Southeast Asia, where it is commonly sold in local markets. In the Philippines and Indonesia, it is commonly grown for its leaves, which are used as food. Moringa is also actively cultivated by the World Vegetable Center in Taiwan, a center for vegetable research. More generally, moringa grows in the wild or is cultivated in Central America and the Caribbean, northern countries of South America, Africa, South and Southeast Asia, and various countries of Oceania (Wikipedia, 2024). Even though drumstick is cultivated in countries like Philippines, Nigeria and Kenya, the crop cultivated in India is superior in quality and quantity. India contributes to about 80 per cent of world drumstick production. The total area is estimated as 43,600 ha with a production of 22,000 tons per annum. The crop is commercially cultivated in Tamil Nadu, Andhra Pradesh, Karnataka, and Odisha and in Kerala, drumstick cultivation is limited to home gardens to meet the family requirement. Fruits, leaves and dried products are mainly exported to China, USA, Canada and South Korea (Kurian *et al*., 2020). Despite their nutritious edible parts, Moringa products are sometimes classified as "famine food", consumed by humans in times of food scarcity. Moringa vegetables as a human food are often linked with low social class status. As such, *M. oleifera* is still not well exploited and hence considered as underutilized in Malawi (Sagonaa *et al*., 2020).

In this review article on Origin, Domestication, Taxonomy, Botanical Description, Genetics and Cytogenetics, Genetic Diversity, Breeding of Drumstick are discussed.

ORIGIN AND DISTRIBUTION

In the monogeneric genus Moringa of Moringaceae family there are 13 species namely, *M. arborea*, indigenous to Kenya; *M. rivae* indigenous to Kenya and Ethiopia; *M. borziana*, indigenous to Somalia and Kenia; *M. pygmaea* indigenous to Somalia; *M. longituba* indigenous to Kenia, Ethiopia and Somalia*; M. stenopetala* indigenous to Kenya and Ethiopia; *M ruspoliana* indigenous to Ethiopia; *M. ovalifolia* indigenous to Namibia and Angola; *M. drouhardii*, *M. hildebrandi* indigenous to Madagascar; *M. peregrine* indigenous o Red sea and Horn of Africa, *M. concanensis*, *Moringa oleifera* indigenous to sub-Himalayan tracts of Northern India, among which *Moringa oleifera* (Figure 1) has so far become the most used and studied (Leone *et al.,* 2015).

		
Seeds	Seedling	Cutting
		
Young plants	Young plants	Young plants

Continue ….

		
Leaves	Leaves	Flowers
		
Flowers	Flowers	Flowers
		
Pods	Pods	Pods with seeds
		
Maured Drumsticks	Matured Seeds	Roots

Fig. 1: Botanical Description

Drumstick (*Moringa oleifera* L.) is believed to have originated from Northern India and has been distributed worldwide in the tropics and sub-tropics (Vange *et al*., 2017). M. oleifera are originated in sub-Himalayan tracts of the Indian sub-continent (Mallenakuppe *et al.,* 2019). Drumstick tree is indigenous to the Himalayan foothills of South Asia from northeastern Pakistan (33 °N, 73 °E) to northern West Bengal State in India and northeastern Bangladesh where it is commonly found from sea level to 1,400 m on recent alluvial land or near riverbeds and streams. It grows at elevations from sealevel to 1400 m (Roloff *et al.*, 2009). It is cultivated and has become naturalized in other parts of Pakistan, India, and Nepal, as well as in Afghanistan, Bangladesh, Sri Lanka, Southeast Asia, West Asia, the Arabian peninsula, East and West Africa, throughout the West Indies and southern Florida, in Central and South America from Mexico to Peru, as well as in Brazil and Paraguay (Roloff *et al*., 2009).

While Plants of the World Online describes *M. oleifera*'s native range as India, Pakistan, and Bangladesh, there are many conflicting reports on its origins. The most commonly described native range is northern India and northeast Pakistan in the sub-Himalayan areas. Some include Afghanistan while others include a much larger range including all of Asia minor, Africa, and Arabia. It grows best at elevations lower than 600 m asl but has been found growing up to 2,000 m asl (Roland, 2020). Drumstick, commonly known as 'horseradish tree', 'miracle tree' or 'tree of life', is native to the sub-Himalayan tracts of India, Pakistan, Bangladesh and Afghanistan (Kurian *et al.,* 2020). Moringa is a native of Indian subcontinent where it is commonly found from sea level to 1,400 m. Though, the tree grows widely in many tropical and subtropical countries. The importance of moringa on health issue is known dates back to 150 B.C., as ancient kings and queens used its leaves and fruits in their diet to maintain a state of mental alertness and healthy skin. Ancient Mauritanian warriors in India drank *M. oleifera* leaf extract on the war front and this drink was believed to be a kind of elixir and these brave soldiers were the ones who defeated Alexander the Great (Shankar *et al*., 2023).

Moringa oleifera Lam. belonging to the family Moringaceae is a handsome softwood tree, native of India, occurring wild in the sub-Himalayan regions of Northern India and now grown worldwide in the tropics and sub-tropics. In India it is grown all over the subcontinent for its tender pods and also for its leaves and flowers. The pod of moringa is a very popular vegetable in South Indian cuisine and valued for their distinctly inviting flavour (AICRPVC, 2024). Originated in South West India, drumstick became a popular vegetable in South Indian states. The crop is widely distributed in India, Sri Lanka, Pakistan, Singapore, Malaysia, Cuba, Jamaica and Egypt. Drumstick is a small or medium sized perennial tree of about 10 m height with fragile and corky stem (AICRPVC, 2024). Originated in South West India, drumstick became a popular vegetable in South Indian states. The crop is widely distributed in India, Sri Lanka, Pakistan, Singapore, Malaysia, Cuba, Jamaica and Egypt (Drumstick, 2024). The native range of this species is NE Pakistan to NW India. It is a tree and grows primarily in the seasonally dry tropical biome. It is used as animal food, a poison, a medicine and invertebrate food, has environmental uses and social uses and for fuel and food (PWO, 2024). Drumstick pods grow on the Drumstick or Moringa tree, a species native to Asia that has been growing wild since ancient times. The trees thrive in tropical to subtropical climates and favor warm, frost-free environments. Experts theorize that Moringa trees may have originated at the foothills of the Himalayas in India and were cultivated as early as 2000 BCE. The tree was revered throughout India for its nutritional properties, and all parts of the tree were incorporated into various medicinal remedies, often used among aristocracy and royalty. Over time, Moringa seeds were spread across trade routes, and the seeds were planted in ancient Egypt, Greece, and Rome, cultivated for health-focused practices. The Romans are credited with spreading the species throughout Europe, and the British introduced the tree to its colony in Jamaica in 1817, as well as several other port cities worldwide. Today drumstick pods are a vegetable primarily consumed in Southeast Asia, especially in India, Malaysia, Singapore, Thailand, Cambodia, and Burma. The pods are sold through local markets and are an everyday culinary ingredient favored for their nutritional properties. Outside of Southeast Asia, the pods and seeds are consumed on a smaller scale in Oceania, Africa, Central and South America, and the Caribbean. The trees are also being grown in the United States. The drumstick pods in the photograph above were sourced from Tekka Market, a local wet market in Singapore (Specialtyproduce, 2024). The moringa tree is believed to be originated in northern India but today it can be found in fresh markets and specialty grocers in Africa, Asia, Southeast Asia, Europe, Central and South America, the Caribbean, North America, and Oceania (Justgo, 2024).

Drumstick was introduced into Aldabra, Andaman Is., Angola, Arizona, Assam, Bahamas, Bangladesh, Benin, Burkina, California, Cambodia, Cameroon, Cape Verde, Caroline Is., Cayman Is., Central African Repu, Chad, Chagos Archipelago, China South-Central, China Southeast, Christmas I., Costa Rica, Cuba, Djibouti, Dominican Republic, East Himalaya, El Salvador, Eritrea, Ethiopia, Fiji, Florida, Gambia, Ghana, Guatemala, Guinea, Guinea-Bissau, Haiti, Honduras, Ivory Coast, Jamaica, Jawa, Kenya, Laccadive Is., Laos, Leeward Is., Lesser Sunda Is., Libya, Madagascar, Maldives, Mali, Marianas, Mauritania, Mauritius, Mexico Northwest, Mozambique Channel I, Myanmar, Nepal, Netherlands Antilles, New Caledonia, Nicobar Is., Niger, Nigeria, Puerto Rico, Queensland, Rodrigues, Réunion, Senegal, Seychelles, Sierra Leone, Solomon Is., Somalia, Southwest Caribbean, Sri Lanka, Sudan, Taiwan, Tanzania, Thailand, Togo, Trinidad-Tobago, Uganda, Vanuatu, Venezuela, Venezuelan Antilles, Vietnam, Windward Is., Zaïre (PWO, 2024).

TAXONOMY

Drumstick belongs to the Family *Moringaceae*, Genus *Moringa* , Species *Moringa oleifera (*Wikipedia, 2024 ; PWO, 2024; AICRPVC, 2024). Moringa belongs to the family Moringaceae comprising 13 species of which *Moringa oleifera* is more widely cultivated. It is an economically important multipurpose tree with immense nutritional value and has significant potential to address malnutrition (Rajalakshmi *et al.,* 2017). The species in this genus can be categorized into three groups depending on their type of trunk. *M. stenopetala, Moringa drouhardii, Moringa ovalifolia*, and *Moringa hildebrandtii* have bloated water-storing

trunks and are known as bottle trees. Meanwhile, *M. peregrina, M. concanensis*, and *M. oleifera* have slender trunks. The remaining species are tuberous shrubs endemic to Northeast Africa. *Moringa* species are also resistant to drought, and can grow fast without needing much care (Rani *et al*., 2018). The genus *Moringa* is one of the genera found in the Moringaceae family along with *Anoma* and *Hyperanthera*. It is well-known as the "drumstick" or "horseradish" family. The *Moringa* genus comprises 13 species distributed through southwest Asia, southwest Africa, northeast Africa, and Madagascar. The species and their distributions are listed in Table1 (Rani *et al.*, 2018). List of *Moringa* species throughout the world is given in Table 1. The related species are • *Moringa arborea* • *Moringa borziana* • *Moringa concanensis* • *Moringa drouhardii* • *Moringa hildebrandtii* • *Moringa longituba* • *Moringa oleifera* • *Moringa ovalifolia* • *Moringa peregrina* • *Moringa pygmaea* • *Moringa rivae* • *Moringa ruspoliana* • *Moringa stenopetala* (Bijaya Devi and Chanchan, 2023).

Among the 13 species, current research is limited to *Moringa oleifera, Moringa stenopetala, Moringa concanensis*, and *Moringa peregrina*. As the other species are endemic to Madagascar and Northeast Africa, they are being evaluated less as there is less exploration for naturally occurring bioactive substances in these locations. In contrast, *M. oleifera*, which is native to India, is being studied widely. As a result, the species has been cultivated throughout the world, specifically in Asia, Latin America, Florida, the Caribbean, and the Pacific Islands (Rani *et al*., 2018). The *Moringa* genus of the Moringaceae family is monogeneric of the Dicotyledaneae and it contains 13 species. *Moringa* spp., are geographically distributed in several tropical countries. For example, *M. drouhardii* and *M. hildebrandtii* are found in Madagascar, *M. stenopetala* is noticed in Kenya and Ethiopia, *M. ovalifolia* is located in Namibia and Angola, *M. concanensis* is largely reported in India, Pakistan and Bangladesh, *M. oleifera* is found in India, *M. peregrina* is observed in Arabia and Red sea area. On the other hand, *M. arborea, M. longituba, M. rivae, M. pygmea, M. borziana* and *M. ruspoliana* are indigenous to Kenya, Somalia and Ethiopia. Each *Moringa* species has unique morphological features and this chapter describes the botanical descriptions of all *Moringa* spp., in detail and provides useful traits that can be used to distinguish each *Moringa* species (Boopathi and Abubakar, 2021).

The 13 species have been grouped of *Moringa* into three broad categories reflecting their form and geographic distribution (Bijaya Devi and Chanchan, 2023):

1**. Bottle trees**. Massive trees with bloated, bottle shaped trunks, and small radially symmetrical flowers. *Moringa drouhardii, M. hildebrandtii, M. ovalifolia* and *M. stenopetala* are in this group. The branches and leaves of some of these such as *M. drouhardii* and *M. hildebrandtii* may grow only at the tops of the trees giving them a palm-like appearance.

2. Slender trees. Trees with a tuberous early stage and pink to cream colored, slightly bilaterally symmetrical flowers. *Moringa concanensis, M. oleifera* and *M. peregrina* are in this group.

3. Trees, shrubs, and herbs of Northeast Africa. The eight remaining species of *Moringa* are all from northeast Africa and are highly variable in form, ranging from herbs to trees. Some are tuberous as juveniles and become fleshy-rooted in maturity, while others are tuberous as adults. The flowers are bilaterally symmetrically and colorful.

Moringa, derived from the vernacular south Indian (Tamil) name, is the sole genus in the family *Moringaceae*, with 12 deciduous tree species native to semi-arid habitats from North Africa to Southeast Asia. In addition to *M. oleifera*, which is a diploid species with 28 chromosomes, several other species of *Moringa* have proven to be useful sources of food, fiber, medicinals, and other products. These include *M. concanensis* Nimmo, *M. drouhardii* Jumelle, *M. longituba* Engl., *M. ovalifolia* Dinter et A. Berger, *M. peregrina* (Forsk.) Fiori, and *M. stenopetala* Cuford (Roloff *et al.,* 2009). The genus Moringa has more than 13 species of which two species *viz*., *M. oleifera* Lam. (syn. *M.pterygosperma* Gaertn.) and *M. concanensis* Nimmo occur in India and the former being the vegetable type (Tak and Maurya, 2015). It is one of the thirteen species belonging to the family moringaceae with only one genus, moringa. In West Africa, the family is represented by 10 species while in Nigeria, the plant is represented by the only species of *Moringa oleifera* (Vange *et al.,* 2017). Drumstick (*Moringa oleifera* Lam.), belonging to the mongeneric family Moringaceae, is a multipurpose tree vegetable cultivated widely for edible as well as medicinal purposes (Kurian *et al*., 2020). *Moringa* species have been widely spread across the tropical and subtropical regions of the world and a total of 13 species of the genus *Moringa* are known (Lakshmidevamma *et al.,* 2021). Being a monogenic family, very remote success in developing of interspecific crosses among the *Moring* sp., which resulted with very low genetic diversity in the cultivated species. It was found that wild forms were more diverse than cultivated form in moringa. Diversity pattern observed among *Moringa* species had four clusters, where all *M. oleifera* accessions grouped in cluster-1 and furthermore divided in to three sub groups (Shankar *et al.,* 2023).

French botanist François Alexandre Pierre de Garsault described the species as *Balanus myrepsica*, but his names are not accepted as valid, as he did not always give his descriptions binomial names. French naturalist Jean-Baptiste Lamarck described the species in 1785. A combined analysis of morphology and DNA shows that *M. oleifera* is most closely related to *M. concanensis*, and the common ancestor of these two diverged from the lineage of *M. peregrina* (Wikipedia, 2024). The genus *Moringa* includes 13 species distributed in sub-Himalayan, ranges of India, Sri Lanka, North Eastern and South Western Africa, Madagascar and Arabia. The best known and most widely distributed species is *Moringa pterygosperma* Gaerthn (syn. *Moringa oleifera* Lam).

Next in importance is the white or pink flowered *Moringa Peregrina*. Forsk, *Moringa optera* Gaerthn, *Moringa arabica* , *Moringa zeylanica* sieb. These are indigenous species of North Eastern tropical Africa, Syria, Palestine and all of Arabia in the driest areas. The tree of *Moringa sternopetala* grows wild at 1000-1800 metres above MSL in Ethiopia and is also native to the Northern Province of Kenya. Its leaves are eaten in dry seasons and have local medicinal uses. A small bush type *Moringa longihiba* Engl. occurs in the Wajir, Garissa, Teita and Moyale districts of Kenya. *Morniga concanensis* Nimmo, grows abundantly in the Yercaud area of the Salem district in Tamil Nadu of South India. *Moringa drouhardii* sumelle, a native of Madagascar with an immense trunk is extremely drought tolerant and able to thrive on saline soils where the seeds exhibit long dormancy but the seedling grows rapidly (AICRPVC, 2024). Moringa belongs to the family Moringaceae. The family consists of the single genus Moringa and the botanical name of the tree is *Moringa oleifera* Lam. The family is distinguished by parietal placentation, 3-valved fruit, elongated, non-dehiscent berry and winged seeds. There are two common species, *M. oleifera* and *M. concanensis*. *M. oleifera* is characterized by leaves usually tripinnate, leaflets 12-18 mm long, petioles yellow or white without red streaks and the tree is medium-sized. *M. concanensis* is characterized by bipinnate leaves, leaflets 15-30 mm long, petals with red streaks or reddish at base and the tree is large (AICRPVC, 2024).

Synonym(s) (Roloff *et al*., 2009)
Guilandina moringa Lam.;
Hyperanthera moringa Willd.;
Moringa nux-ben Perr.;
Moringa pterygosperma Gaertn.,

Synonym(s) (Roland, 2020)**:**
• *Anoma moringa* (L.) Lour.
• *Guilandina moringa* L.
• *Hyperanthera decandra* Willd.
• *Hyperanthera moringa* (L.) Vahl
• *Moringa amara* Durin
• *Moringa domestica* Buch.-Ham.
• *Moringa edulis* Medik.
• *Moringa eracta* Salisb.
• *Moringa nux-eben* Desf.
• *Moringa octogona* Stokes
• *Moringa polygona* DC.
• *Moringa robusta* Bojer
• *Moringa sylvestris* Buch.-Ham.
• *Moringa zeylanica* Pers.

Homotypic Synonyms (PWO, 2024).

- *Guilandina moringa* L.
- *Anoma moringa* (L.) Lour.
- *Hyperanthera moringa* (L.) Vahl
- *Hyperanthera pterygosperma* Oken
- *Moringa moringa* (L.) Millsp.
- *Moringa pterygosperma* Gaertn.

Heterotypic Synonyms (PWO, 2024).

- *Hyperanthera decandra* Willd.
- *Moringa amara* Durin
- *Moringa domestica* Buch.-Ham.
- *Moringa edulis* Medik.
- *Moringa erecta* Salisb.
- *Moringa nux-eben* Desf.
- *Moringa octogona* Stokes
- *Moringa parvifolia* Noronha
- *Moringa polygona* DC.
- *Moringa robusta* Bojer
- *Moringa sylvestris* Buch.-Ham.

- *Moringa zeylanica* Pers.

BOTANICAL DESCRIPTION

Moringa oleifera is a small, fast-growing evergreen or deciduous tree that usually grows up to 10 or 12 m in height. It has a spreading, open crown of drooping, fragile branches, feathery foliage of tripinnate leaves, and thick, corky, whitish bark (Roloff *et al*., 2009). The leaves are bipinnate or more commonly tripinnate, up to 45 cm long, and are alternate and spirally arranged on the twigs. Pinnae and pinnules are opposite; leaflets are 1.2 to 2.0 cm long and 0.6 to 1.0 cm wide, the lateral leaflets elliptic, the terminal ones obovate; petioles of lateral leaflets are 1.5 to 2.5 mm long, those of terminal ones 3 to 6 mm long. The leaflets are finely hairy, green and almost hairless on the upper surface, paler and hairless beneath, with red-tinged midveins, with entire (not toothed) margins, and are rounded or blunt-pointed at the apex and short-pointed at the base. The twigs are finely hairy and green, becoming brown (Roloff *et al*., 2009). The fragrant, bisexual, yellowish white flowers are borne on slender, hairy stalks in spreading or drooping axillary clusters (panicles) 10–25 cm long. Individual flowers, set in a basal cup (hypanthium) ca. 3 mm long, are approximately 0.7 to 1 cm long and 2 cm broad, with five unequal yellowish-white, thinly veined, spathulate petals, five stamens with five smaller sterile stamens (staminodes), and a pistil composed of a 1-celled ovary and slender style. The fruits are pendulous, linear, three-sided pods with nine longitudinal ridges, usually 20 to 50 cm long, but occasionally up to 1 m or longer, and 2.0 to 2.5 cm broad. The pods, each usually containing up to 26 seeds, are dark green during their development, and take approximately 3 months to mature after flowering. They turn brown on maturity, and split open longitudinally along the three angles, releasing the dark brown, trigonous seeds. Seeds measure about 1 cm in diameter, with three whitish papery wings on the angles. Seed weights differ among varieties, ranging from 3,000 to 9,000 seeds per kilogram (Roloff *et al.,* 2009). The bark is whitish-gray, thick, soft, fissured and warty or corky, becoming rough. When wounded, the bark exudes a gum which is initially white in color but changes to reddish brown or brownish black on exposure. The wood is soft and light, with a density of 0.5 to 0.7 g/cm^3 (Roloff *et al*., 2009). Seedlings develop a swollen, tuberous, white taproot which has a characteristic pungent odor, and very sparse lateral roots. Trees grown from seeds develop a deep, stout taproot with a wide-spreading system of thick, tuberous lateral roots. Taproots do not develop on trees propagated from cuttings (Roloff *et al*., 2009). This is one of the fast growing, evergreen, deciduous medium sized perennial tree of about 10 m to 12 m height. The bark has whitish-grey colour and is surrounded by thick cork. Young shoots have purplish or greenish-white bark. Flowers are yellowish creamy white and sweet smelling. The matured fruit is a hanging capsule of 20-45 cm size having 15 to 20 dark brown globular seeds of 1 to 1.2 cm diameter (Mallenakuppe *et al.,* 2019). Drumstick is a small or medium sized perennial tree of about 10 m height with fragile and corky stem. The leaves are usually tripinnate with elliptic leaflets. Pods are pendulous and length ranges from 20 cm to 100 cm. Seeds are trigonous with wings on angles. Flowers are produced on current season growth on large and erect panicles or monocladial cyme. Flowers were yellowish creamy white and sweet smelling. Individual flowers are bisexual, zygomorphic and pedicellate. Calyx and corolla consist of five sepals and petals. Androecium also has five stamens alternating with five stamindodes. Gynoecium has a superior, one celled and three carpelled ovary containing many ovules on parietal placentation. Stigma is truncate. Anthesis continues throughout the day. Two anthesis peaks *i.e.,* 2.00 p.m and 4.00 a.m. are noticed at Thiruvannthapuram. In most parts of Tamil Nadu, flowering is from 4.30 a.m. to 6.30 p.m. In southern part of Kerala, stigma becomes receptive one day prior to flower opening and continues with maximum receptivity on the day of opening and a sudden decline thereafter (Drumstick, 2024). Flowering in drumstick varies from place to place and is greatly influenced by rain, temperature, humidity, wind, soil temperature, soil moisture. Under South Indian condition, one or two distinct peak periods of flowering noticed. Peak period of flowering in central parts of Kerala is December-January while in southern part it is February-March and July-August with maximum flowering in February-March. Under Coimbatore and Bangalore conditions, flowering seasons are March-May and July-September respectively (Drumstick, 2024).

Drumstick pods are long and slender, averaging 20 to 45 centimeters in length, and are generally straight to cylindrical in shape with tapered ends. Each pod has an angular, knobbed appearance with three distinct sides created from ridges extending the of the pod. The pod's surface is light to dark green and is textured, covered in a powdery coating. Young pods are favored for culinary use, and at this stage, the softer, crisp pods can often bend and be snapped using minimal force, a sign of freshness. More mature pods are fibrous and require prolonged periods of cooking. The pods can be peeled apart and split open, revealing a fleshy layer encasing round to oval seeds. Each seed is around one centimeter in diameter and is enveloped in a thin, paper-like hull that showcases three points, almost resembling tiny wings or edges of a wonton wrapper. When young, the seeds are light green, and as the pods dry out and age, the seeds will become inedible, harden, and brown. The flesh and seeds of the pods are the edible portions of the drumstick and release a mild, fresh, green aroma when opened. The exterior layer of the pod is considered too fibrous for consumption and is discarded after the flesh is removed. Once cooked, the flesh softens and can be easily scraped from the pod. The seeds retain a slightly chewy, dense consistency. Drumstick pods have a grassy and vegetal flavor combined with sweet and bitter undertones. The flesh and seeds are often likened to the taste of green beans and asparagus (Specialtyproduce, 2024). Drumstick pods, botanically classified as *Moringa oleifera*, are elongated, edible seed pods that hang from a deciduous tree belonging to the Moringaceae family. Drumstick trees are also known as Moringa trees, and the fast-growing species reaches 10 to

12 meters in height, developing seed pods in as little as two years after planting. A single Moringa tree can produce anywhere from 300 to 1,000 pods per year, and the pods were named after their similarity in shape to the musical stick used for percussion instruments (Specialtyproduce, 2024).

Drumstick leaves are small in size and oval to tear-drop in shape. It has vibrant green feathery leaflets that are nearly 1-2 centimeters in length and 0.5-1 centimeters in width. The leaves are smooth, thick, and firm, and grow in a tripinnate structure. Moringa leaves grow on trees with drooping branches and are also known for their hanging fruits with dark brown colored round seeds (Justgo, 2024). *M. oleifera* is a fast-growing, deciduous tree that can reach a height of 10–12 m and trunk diameter of 46 cm. The bark has a whitish-gray color and is surrounded by thick cork. Young shoots have purplish or greenish-white, hairy bark. The tree has an open crown of drooping, fragile branches, and the leaves build up a feathery foliage of tripinnate leaves (Wikipedia, 2024). The flowers are fragrant and hermaphroditic, surrounded by five unequal, thinly veined, yellowish-white petals. The flowers are about 1–1.5 cm long and 2 cm broad. They grow on slender, hairy stalks in spreading or drooping flower clusters, which have a length of 10–25 cm (Wikipedia, 2024). Flowering begins within the first six months of planting. In seasonally cool regions, flowering only occurs once a year in late spring and early summer (Northern Hemisphere between April and June, Southern Hemisphere between October and December). In more constant seasonal temperatures and with constant rainfall, flowering can happen twice or even all year-round. The fruit is a hanging, three-sided, brown, 20–45 cm capsule, which holds dark brown, globular seeds with a diameter around 1 cm. The seeds have three whitish, papery wings and are dispersed by wind and water (Wikipedia, 2024). In cultivation, it is often cut back annually to 1–2 m and allowed to regrow so the pods and leaves remain within arm's reach (Wikipedia, 2024).

Description of the perennial eco-types of moringa cultivated in Tamil Nadu: The cultivation of moringa in India occurs mainly in the southern states of Tamil Nadu, Karnataka, Kerala, and Andhra Pradesh. Principally perennial types have been known for cultivation for a very long time. However, perennial types are beset with many production constraints, such as a relatively long pre-fruit bearing period, non availability of planting materials (stem cuttings), requirement of a greater number of rainy days in regions where water is scarce, and vulnerability to pests and diseases. Important varieties of moringa are Moolanur moringa, Valayapatti moringa, Chavakacheri Moringa, Chemmurungai, Jaffna type, Kattumurungai, Kodikkalmurungai, Palmurungai, Punamurungai, Palamedu moringa (AICRPVC, 2024).

Annual moringa varieties released from HC&RI, Periyakulam: The Horticultural College and Research Institute of Tamil Nadu Agricultural University, Periyakulam, had an assemblage of 85 moringa accessions. The germplasm collection block contains perennial and annual moringa accessions with heavy fruit-bearing, cluster bearing, drought tolerance, dwarfing stature and pest and disease resistance. Scientists at the Horticultural College and Research Institute, Tamil Nadu Agricultural University, Periyakulam have succeeded in developing seed-propagated moringa types, which has revolutionised the moringa cultivation in the country. By judicious breeding programmes, including introduction of elite mother plants, evaluation, selection and hybridization, The Horticultural College and Research Institute of Tamil Nadu Agricultural University has released two improved annual moringa varieties (PKM-1, PKM-2) within a span of 10 years, for commercial cultivation.
These varieties *viz.*, PKM 1 Annual Moringa , PKM 2 Annual Moringa , Other annual types KM 1 and Dhanraj have developed up well in many traditional and non-traditional areas (AICRPVC, 2024). Botanical description is given in Fig. 1

Floral biology: A study was conducted on the annual drumstick plants at Vellanikkara. The observational plants comprised of a two year old annual drumstick genotype AD-4 and its five progenies of one year old viz. AD-4-1, AD-4-3, AD-4-5, AD-4-7 and AD-4-8. Observations were made on the floral morphology and floral biology of the plants under observation from 1995 August to 1996 January as per. The pollen morphology and fertility studies were made by resorting to the staining procedure postulated (Suresh Bahu and Rajan, 1996). The inflorescence was a monochasial cyme, flowers were fragrant, nectarous, hermaphrodite, oblique stalked and irregular. Calyx was deeply five partite, coupler-cyathiform, oblique and green. Corolla was comprised of five petals, white with brownish base. Stamens were five, alternating with five staminodes, the hind-most stamen being the longest. Ovary stalked, monocarpellary, bearing double row of ovules, style thin, curved white, shortly pubescent and hollowed at the apex. This observation on flower morphology was conforming to the descriptions on the perennial type of drumstick (Suresh Bahu and Rajan, 1996). The flower opening, anther dehiscence and stigma receptivity occurred in a phased manner expressing a prominent protrandrus conditions. The flower opening commenced from 2.30 p.m. and completed by next day 9 a.m. Anthers at the time of flower opening were of closed anther type and stigma introvert and non-receptive. Anthers got dehisced next day between 9 and 9.30 a.m., but the stigma still remained introvert. At this time even though the anthers got burst open, pollen did not properly disperse due to the extreme stickiness and they got clubbed together. Subsequently, the stigma got exerted outside the anther in the next day morning between 8 and 8.30 a.m. being receptive, but by that time pollen grains of that flower had mostly shrivelled and become considerably non-viable. There was little chance for the viable pollen from nearby flowers to get placed on the stigma by wind disbursement due to the pollen size and the pollen stickiness. This condition prevailed during the entire period of the early season blooms, resulting in the non-setting of fruits. In early December, the second phase of flowering commenced when, probably due to the dry span, the pollen stickiness was found to be diminished and they became more powdery. At the same time the activity

of black ants and flea beetle (Podagrionidae) were at its peak causing a fair chance for cross pollination. Assisted pollination on the exerted stigma between 8 and 9.30 a.m. resulted in fruit set (Suresh Bahu and Rajan, 1996).

Moringa flowers are white or ceamy-white, scented, pedicelled in larger spreading panicles with linear bracts. Calyx contains 5 sepals, lobed, linear lanceolate, refluxed and tubular outside. Corolla has 5 white petals, free narrowly spathelate and veined. Stamens are yellow and of 5 in numbers, fertile and alternate with 5-7 staminales. Filaments are villous at their base. Ovary is superior on a short gynophore, 3 carpelled and are locular with many biseriate pendulous ovules on 3 pariental placentas. Pods 30-120 cm, triangular and elongated with 13 ovules, unit locules capsules (Bose *et al.,* 2003). Anthesis has been reported to commence as early as 4.30 am and continues till 6.30 am with a peak at 5.30 am. The anther dehiscence is reported to occur from 4 am to 6.30 am. The anther of the longest stamen dehisces first followed by stamens in the descending order of filament length. At full maturity, the anthers are greenish yellow and after dehiscence, they turn to pale colour. On an average, each anther has 7,400 pollens and the diameter of each pollen measures 5-4 microns. The stigma becomes receptive a day before flower opening and continues to be receptive on the day of opening cross pollination occurs through honey bees. Pollen viability is 72% at anther dehiscence. The fertile pollen may go even upto 100% while it is only 11-15% under natural pollination. The chromosome number is 2n=28 (Bose *et al*., 2003). *Moringa oleifera* showed diurnal anthesis. Pollen ovule ratio per flower was found to be variable. Netting and bagging of flowers indicated that the external agents might be required for successful fruit setting which varied depending upon the availability of effective pollinators. At Visakkapatnam, India, *M. oleifera* flowered twice a year in February to May and in September to November. Xeno gamous pollinations gave 100% fruit set, 81% seed set and 9% fecundity, compared with 62, 64 and 6% respectively for geitonogamous pollinations. Flowers were zygomorphic and of the gullet type; they opened during 03.00 to 19.00 and visited by diurnally active insects during 6.00 to 15.00 h. Carpenter bees (*Xylocarpa latipes* and *X. pubescens*) were the most reliable pollinators (Bose *et al*., 2003). Among these *Xylocopa sp*., which carries a considerable amount of viable pollen grains on leg parts, acts as an effective pollinator. Besides *Xylocopa sp* . different types of thrips, *Apis sp*. and some members of Lepidoptera visit flowers to nourish themselves. Thus, a strong insect pollination system is present in *M. oliefera* which is eventually pollinated by geitonogamy or xenogamy, with the latter being the more significant. The pistil remains parallel with stamens just after opening but it gradually extends with time finally reaches above anther level. The separation of stamen and pistil from each other after few hours of anthesis, suggests that external agents might be required for pollination and so favour cross pollination (Bose *et al.,* 2003). Flowering phenology varies widely among varieties and with location. In its seasonally cool north Indian range, trees may flower only once between the months of April and June, while in southern India, flowering typically occurs two times each year. In locales with more constant seasonal temperatures and rainfall regimes such as the Caribbean islands, flowering may occur more or less continuously throughout the year. Flowering generally begins at an early age, usually within the first year and often within 6 months after planting. Trees generally produce good seed crops for about 12 years. Pollination is usually by bees and other insects, as well as by birds. The mature, dehiscent capsules, mature about 3 months after flowering, and remain on the tree for several months, releasing the seeds that are dispersed mainly by wind and water, but probably also by seed-eating animals (Roloff *et al*., 2009). Many aspects of drumstick's reproductive biology remain poorly understood. We investigated the floral morphology of drumstick, its stigma receptivity and the structural and cytochemical features of the stigma and style at different developmental stages. The inflorescences are panicles of hermaphroditic flowers, with a pistil consisting of one open-type stigma and a hollow stylar canal. Stigma receptivity was assayed based on pollen germination, pollen tube growth and fruit set following artificial pollination. Flowers at later developmental stages exhibited greater stigma receptivity, higher percentages of pollen germination and a higher fruit set than those in earlier stages. Enhanced stigma receptivity was associated with increased amounts of insoluble polysaccharides, lipids and proteins in the canal cells at later developmental stages. An ultrastructural study of the cells lining the canal indicated that they were secretory cells containing an enlarged endoplasmic reticulum, dictyosomes, mitochondria, plastids and ribosomes. Post-anthesis, these organelles exhibited degeneration at the end of the secretory phase. This study provides an important contribution to current knowledge of the anatomy and ultrastructure of the style and stigma in drumstick (Zhang *et al.,* 2017). Drumstick fruit production tends to be low in comparison with its abundant floral display; the reasons for its low fruit set are unclear. Previous studies have shown that drumstick flowers throughout the year, with two peaks in flower production per year, and that anthesis peaks occur within one day. The drumstick tree is a mixed mating species adapted to outcrossing, although selfing is also possible. It is insect-pollinated, with large numbers of insects required for pollination (Zhang *et al*., 2017). Fruit set via open pollination is typically 11-15%, while hand pollination yields 62-100% . Flower receptivity plays a crucial role in pollination dynamics, reproductive success and plant productivity. The stigma is the first pistil surface to intercept pollen grains; pollen adhesion to the stigma is followed by hydration and germination. The drumstick stigma is perforated and hollow and is more receptive during the third day post-anthesis; this receptivity lasts 2-3 days. However, many anatomical and ultrastructural features of the drumstick flower stigma and style are largely unexplored (Zhang *et al*., 2017).

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higher percentages of pollen germination and a higher fruit set than those in earlier stages. Enhanced stigma receptivity was associated with increased amounts of insoluble polysaccharides, lipids and proteins in the canal cells at later developmental stages (Zhang and Lin, 2018). We investigated the floral morphology of drumstick, its stigma receptivity and the structural and cytochemical features of the stigma and style at different developmental stages. The inflorescences are panicles of hermaphroditic flowers, with a pistil consisting of one open-type stigma and a hollow stylar canal. Stigma receptivity was assayed based on pollen germination, pollen tube growth and fruit set following artificial pollination. Flowers at later developmental stages exhibited greater stigma receptivity, higher percentages of pollen germination and a higher fruit set than those in earlier stages. Enhanced stigma receptivity was associated with increased amounts of insoluble polysaccharides, lipids and proteins in the canal cells at later developmental stages. An ultrastructural study of the cells lining the canal indicated that they were secretory cells containing an enlarged endoplasmic reticulum, dictyosomes, mitochondria, plastids and ribosomes. Post-anthesis, these organelles exhibited degeneration at the end of the secretory phase. This study provides an important contribution to current knowledge of the anatomy and ultrastructure of the style and stigma in drumstick (Fig. 2).(Zhang *et al.,* 2018).

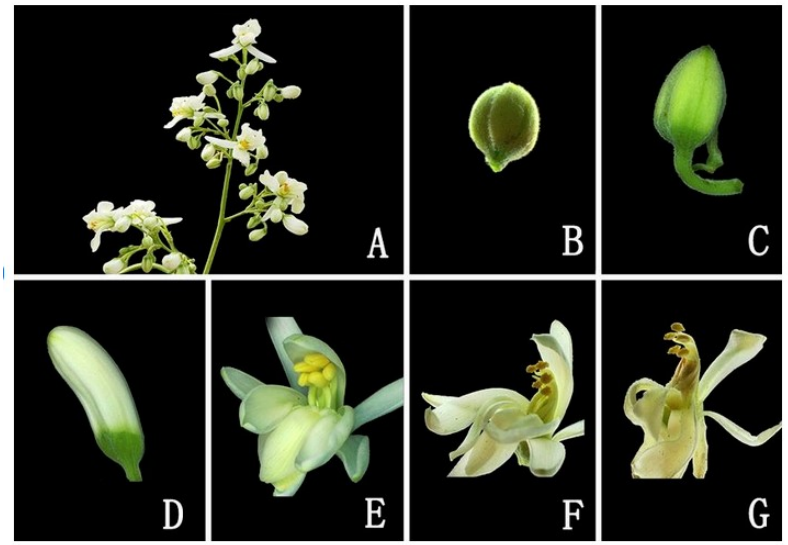

Fig.2. Structure of stigma and style of Moringa oleifera Lam. A – pollen grain germination on stigma of anthesis; B – pollen grain germination on stigma at two days post anthesis; C-D – SEM of stigma; E-J – TEM of style transverse section; E-F – two days pre anthesis; G- – two days post anthesis

It was reported that floral biology, anthesis and fruit development in drumstick under Kerala conditions using sixty bearing plants and reported that flowering occurs throughout the year except in the months of November and December with two flowering peaks *viz.,* July -August and February – March (Kurian *et al.,* 2020).

GENETICS AND CYTOGENETICS

Here we report a high-quality draft genome sequence of *M. oleifera*. This assembly represents 91.78% of the estimated genome size and contains 19,465 protein-coding genes. Comparative genomic analysis between *M. oleifera* and related woody plant genomes helps clarify the general evolution of this species, while the identification of several species-specific gene families and positively selected genes in *M. oleifera* may help identify genes related to *M. oleifera's* high protein content, fast-growth, heat and stress tolerance. This reference genome greatly extends the basic research on *M. oleifera*, and may further promote applying genomics to enhanced breeding and improvement of *M. oleifera* (Tian *et al*., 2015). Advances in cytogenetics have resulted in the development of novel strategies in chromosomal banding patterns that allow the identification of individual chromosomes within a species. Differentiating chromosomes at the basic level is essential to draw essential genetic conclusions with respect to the given plant cells and such efforts have several folds of applications in cytological studies. Recent trends in structural, comparative and functional genomics experiments that supplement, accelerate or enhance the efficiency of Moringa-genome research towards product development (Boopathi and Raveendran, 2021).

GENETIC DIVERSITY

Drumstick tree exhibits considerable phenotypic variation within its range. While wild trees usually bear small fruits, cultivated varieties grown in south India, known as “Jaffna“ and “Chavakacheri murunga“, bear fruits ranging in length from 60 to 90 cm and 90 to 120 cm, respectively. A variety with red-tipped fruits, “Chemmurunga“, is said to flower year-round and have high fruit yields. Other well-known varieties cultivated in the south Indian State of Tamilnadu include “Palmurungai“, which has a thick pulp and bitter taste’ “Punamurungai“, and “Kodaikalmurungai“, which produces very short fruits (15 to 23 cm in length). In the West Indies, several varieties are cultivated; some produce an abundance of fruit while others rarely flower and are principally

grown for their foliage (Roloff *et al.,* 2009). Genetic diversity study and analysis of genetic relationship among 20 *Moringa oleifera* were carried out with the aid of twelve primers from, random amplified polymorphic DNA marker. The seeds of twenty *M. oleifera* genotypes from various origins were collected and germinated and raised in nursery before transplanting to the field at University Agricultural Park (TPU). Genetic diversity parameter, such as Shannon's information index and expected heterozygosity, revealed the presence of high genetic divergence with value of 1.80 and 0.13 for Malaysian population and 0.30 and 0.19 for the international population, respectively. Mean of Nei's gene diversity index for the two populations was estimated to be 0.20. In addition, a dendrogram constructed, using UPGMA cluster analysis based on Nei's genetic distance, grouped the twenty *M. oleifera* into five distinct clusters. The study revealed a great extent of variation which is essential for successful breeding and improvement program (Rufai *et al*., 2013).

In India, the west and northern part has perennial types predominantly due to which the commercial cultivation of drumstick remain at poor level in this region. Hence, the main goal of the study is to identify a superior genotype for the rain fed areas among 14 genotypes. Stability analysis was assessed by yield stability statistic (yi), yield regression statistic (ri) and yield distance statistic (di). The analysis of variance revealed that the genotype were highly significant for all characters under the environment studied. However, number of flowers per plant showed nonsignificance for environments in the study. G × E (Genotypic × Environment interaction), E+ (G × E) [Environment + (Genotype × Environment)] and E [Environment (Linear)] showed significant values for all the characters. Pooled deviation exhibited significance for number of fruits per plant and yield per plant. Among the genotypes studied, PKM-2, MO-1 and PKM-1 were found stable for number of fruits per plant and yield due to bivalue around unity and non significant S2di value. Hence, PKM-2 and MO-1 were found to fit for favourable environment and PKM-1 for unfavorable environment for commercial cultivation for semi arid region of India (Tagore, 2015). Thirty-six genetically diverse genotypes of drumstick were assembled from different places of Rajasthan (Ajmer, Jhalawar, Kota, Udaipur) and subjected to a multivariate analysis regarding the content of vitamin C, protein, nitrogen, phosphorous, potassium, calcium, iron, and magnesium. All 36 genotypes could be grouped into five clusters. Genetic diversity arises due to geographical separation or due to genetic barriers to crossability. The analysis used measures the forces of differentiation at two levels, namely intra-cluster and inter-cluster levels, and thus helps in the selection of genetically divergent parents for exploitation in hybridization programmes. In any crop breeding programme, genetic diversity is an essential pre-requisite in selecting parents for hybridization and evolving high yielding genotypes. The higher the genetic diversity between the parents, the greater are the chances of achieving transgressive segregants. Diverse agro-ecological conditions, migration of genetic material due to genetic drift, gene flow, introduction/exchange of genetic stocks at national and international levels, coupled with natural and artificial selection are the possible factors responsible for such diversity in the drumstick plant. Heritability estimates were over 94% for all characters studied, except iron (64%), indicating that selection was possible (Tak and Maurya, 2017).

An experiment was conducted to analyze the genetic diversity among 9 drumstick tree (*Moringa oleifera*) accessions in the Teaching and Research Farm of the University of Agriculture Makurdi. Data were recorded on growth and yield characteristics before and after pruning. The result obtained showed that at 18 weeks after transplanting, accession UAM-NI had the tallest plants (3.63m) while UAM-BE had the shortest mean plant height (2.84m) under no pruning. Other parameters that showed significant differences were number of leaves per tree and stem diameter. Although accession UAM-OY recorded highest fresh (220.22g), dry (113.42g) and leaf powder (82.60g) weights, it was not significantly different from other accessions. However, at 18 weeks after pruning, there was a significant difference among the accessions with regard to leaf length. Although accession UAM-NA recorded highest fresh leaf weight (286.60g), dry leaf weight (90.67g) and leaf powder weight (85.60g), it was not statistically different from other accessions. For the pruned accessions, significant differences were recorded in leaf length, number of flowers/tree, days to podding and fifty percent podding, pod length, pod girth, pod weight, number of seeds/pod, number of seeds/tree and 100seed weight. The result also indicated that the pruned accessions recorded higher leaf yield than the unpruned. The result of the cluster analysis grouped the accessions into two clusters and an outlier both for the pruned and unpruned accessions irrespective of area of collection (Vange *et al*., 2017).

In the present study, a total of 97 accessions collected from different districts of Tamil Nadu, Andhra Pradesh and Odisha were genotyped using 20 simple sequence repeat (SSR) markers to assess the genetic diversity and population structure. A total of 140 alleles were detected with the polymorphic information content value of 0.6832 and gene diversity 0.7292. Population structure analysis through a model-based approach divided the accessions into two subgroups. Molecular variance analysis using principal coordinate analysis (PCoA) summarized a 18.32% variation in the first 3 axes and analysis of molecular variance analysis indicates a 2% variance among the population with the remaining 98% variance attributed to variation within individuals. Cluster analysis based on unweighted neighbour-joining showed a clear separation of samples into two subgroups. Further comparison of the cluster subgroup showed high consistency with the STRUCTURE pattern and PCoA plot (Rajalakshmi *et al.,* 2017). A total of 97 accessions collected from different districts of Tamil Nadu, Andhra Pradesh and Odisha were genotyped using 20 simple sequence repeat (SSR) markers to assess the genetic diversity and population structure. A total of 140 alleles were detected with the polymorphic information content value of 0.6832 and gene diversity 0.7292. Population structure analysis through a model-based approach divided the accessions into two subgroups. Molecular variance analysis using principal coordinate analysis (PCoA) summarized a 18.32% variation in the first 3 axes and analysis of molecular variance analysis indicates a 2% variance among the population with the remaining 98% variance attributed to variation within individuals. Cluster analysis based on unweighted neighbour-joining showed a clear separation of samples into two subgroups. Further comparison of the cluster subgroup showed high consistency with the STRUCTURE pattern and PCoA plot. The findings reveal a high diversity in the analysed genotypes from which a few distinct accessions could be utilized for further exploration based on their nutritional content and for conservation of nutritionally superior germplasm (Rajalakshmi *et al.,* 2017).

Twenty-five drumstick accessions were evaluated for morphological, qualitative and quantitative characters. Considerable variation was observed among the accessions. Two peaks of flowering *viz.,* January-March and September-November, were observed in accessions VKMo 2, VKMo 7, VKMo 12, VKMo 15, VKMo 16 and VKMo 17. Three accessions *viz*., VKMo 32, VKMo 35 and VKMo 38 were categorized as leafy types. Tree shape varied from upright to spreading. Accession VKMo 3 recorded greatest tree height (7.68 m) and trunk girth (65.8 cm). Accession VKMo 10 recorded highest fruit length (89.50 cm), fruit girth (6.72 cm) and number of ridges/fruit (10.50). Highest fruit weight was recorded in VKMo 9 (160.00 g). Accession VKMo 6 recorded highest number of seeds per fruit (21.20). Highest number of fruits/tree was recorded in VKMo 2 (22.21) and total fruit yield/tree in VKMo 3 (1775.54 g/tree) (Kurian *et al*., 2020). Since drumstick is a cross-pollinated tree and also naturalized in many areas, high heterogeneity with respect to form and yield is reported. Large variability exists in drumstick with respect to flowering time (from annual type to perennial type), tree nature (from deciduous to evergreen), tree shape (from semi spreading to upright), resistance to hairy caterpillar, flowering time (*i.e*., some trees flower throughout the year while others flower in two distinct seasons). It was used morphological markers to assess variations between and within cultivated and non-cultivated species of drumstick and variations were observed with respect to bark colour such as white, grey or pale buff, along with textural differences like corky, rugose or smooth texture (Kurian *et al.,* 2020). Investigation was carried out on 34 genotypes of drumstick to study the extent of genetic variability and relationship among different morphological parameters and reported variability in plant height (3.16 to 8.09 m) and trunk girth (74.08 to 250.40 cm). It was reported variation with respect to leaflet shape *viz.*, oblong and elliptical shapes (Kurian *et al*., 2020). Popoola *et al*. (2016) reported variability in fresh pod color (pale green and green), mature pod colour (brown and golden brown) and fruit shape (straight and curved). Number of pods per peduncle/panicle ranged from 2-6, and number of pods per plant ranged from 10 to 62. Pod characters like pod length (25.45 cm to 43.87 cm) and pod weight (59.37 g to 91.34 g) also exhibited wide range of variation (Kurian *et al.,* 2020). Resmi *et al*. (2006) evaluated 28 drumstick accessions from central and southern Kerala and recorded variability in number of fruits per plant (174 to 612) and total fruit yield (8.94 to 70.46 kg per tree) (Kurian *et al*., 2020).

23 genotypes of drumstick, which were selected based on superiority of yield/tree from 120 genotypes surveyed in South India were subjected to analysis morphology, yield and quality attributes and found they are substantially varying thus necessitate further analysis. Diversity analysis based on the coefficient of variation (CV), genotypic coefficient of variation (GCV), environmental coefficient of variation (ECV), phenotypic coefficient of variation (PCV) and heritability were determined. Quantitative fruit traits such as fruit length (30.56–127.57 cm), fruit weight (72.22–163.27 g), fruit breadth (3–8 cm), number of fruits/tree (NF/T) (320–1000), and number of seeds/fruit (NS/F) (11–29) varied among the genotypes. Correlation studies revealed that the fruit yield had a significant, positive correlation with the number of fruits per tree, length of fruit and single fruit weight. The estimate of PCV was slightly higher than the GCV for all characters studied, indicating that the apparent variation is not only genetic but also influenced by the growing environment in the expression of the traits. Heritability was greater than 90% for all characters studied. The overall analysis outcome of the study emphasizes that selection of high yielding genotypes should give due weightage to the number of fruits per tree and single fruit weight (Drisya Ravi *et al.,* 2021). Moringa, being a cross-pollinated tree, high heterogeneity in many character forms is observed resulting in vast genetic diversity in the natural and cultivated accessions and substantial variation in quantitatively inherited traits has been documented which needs to be exploited for concentrated research towards its crop improvement. In-depth knowledge and understanding of the gene flow pattern and population genetic structure in moringa through molecular genetic diversity and population structure of worldwide collections is of great promise (Lakshmidevamma *et al.,* 2021). In this experiment, the genetic diversity of Moringa from several islands in Indonesia was evaluated using Sequence Related Amplified Polymorphism (SRAP) molecular markers as well as morphological characters. A total of 30 genotypes of Moringa from 10 different islands in Indonesia were planted in 10 kg of polybags for 3-7 months to observe their molecular as well as morphological characters. For molecular analysis, 10 selected primers of SRAP were used. The 70 polymorphic bands from 86 total bands (81.40%) were obtained and Polymorphic Information Content (PIC) values were 0.36 on average. The UPGMA analysis divided 10 accessions into 2 main groups which Java accession was grouped alone and separated from other accessions. The principle component analysis based on morphological characters divided them into 4 groups with Java accession consistently separated from others (Ridwan *et al.*, 2021).

Plant genetic diversity can be studied using molecular approaches. Molecular markers that have been commonly used in plant genetic diversity study include RAPD (Random Amplified Polymorphic DNA), ISSR (Inter Simple Sequence Repeat), AFLP (Amplified Fragment Length Polymorphism), SSR (Simple Sequence Repeat), and SRAP (Sequence Related Amplified Polymorphism). From those molecular markers, SRAP is a molecular marker that has never been used to study the genetic diversity of Moringa plants, in spite of some advantages over other molecular markers. The RAPD and ISSR are reported to have low levels of accuracy, reproducibility and the ability to detect polymorphism, whereas AFLP is expensive and has more complicated procedure. The SRAP requires a relatively low cost with simpler techniques but has high accuracy, reproducibility and the ability to detect polymorphism. SRAP has also been reported to be effectively successful in identifying the genetic diversity of tree plants such as bamboo, Dalbergia and Ramin (Ridwan *et al.,* 2021). We used 27 RAPD markers to resolve diversity among 23 superior drumstick genotypes mostly collected from Karnataka, Tamilnadu, and Kerala, states of India. We observed that RAPD markers are highly polymorphic, and among the 519 bands obtained, 471 (89.61%) were polymorphic. The discriminatory power of these markers was determined using various parameters like; polymorphism information content (PIC), marker index (MI), and resolving power (Rp). Primer RAPD-3 showed the highest PIC value (0.35), MI (10.28), and Rp (21.65). The dendrogram generated with UPGMA cluster analysis grouped genotypes into two main clusters with various degrees of sub clustering within the cluster. A high level of genetic diversity was observed within the genotypes. These findings can be further used for the breeding as well as conservation programs of Moringa oleifera (Drisya Ravi *et al.,* 2022a). Genetic diversity within and among accessions of *Moringa oleifera* in Northern Nigeria was evaluated to determine the level of variability its exploiting in breeding and genetic improvement programs of plant. Collection and characterisation of the crop germplasm from the major

cultivated states in Nigeria was carried. A total of 34 accessions were collected with high significant ($P < 0.05$) variability observed in seed length, days to emergence, plant height and number of branches per plant. The seed length ranged from 1.02 cm to 1.44 cm while days to emergence varied from 5.00 to 10.00 days. The highest plant height and number of branches per plant were recorded in NGR-ZFR-16 at 2 month after emergence with the value of 94.87cm and 18.00 branches per plant. These highest values recorded in the accession was maintained in subsequent months signifying the superiority of the accession. Cluster analysis grouped the accessions into three major clusters based on their morphological similarity; three major groups, with cluster I consist 55.88% of the genotypes, 38.23% in cluster II, 5.88% in cluster III. The high variability recorded in the germplasm, indicate that the accessions and traits could be explored in the crop improvement (Ndayankpa *et al*., 2022). Supriya *et al.* (2020) found that the highest GCV and PCV value were recorded for whole leaf yield/ha (44.42 and 47.93 respectively), followed by edible leaf yield/ha (42.87 and 46.80), number of shoot/ plant (27.25 and 28.15), whole leaf weight/shoot (26.32 and 31.88), and edible leaf weight/shoot (25.72 and 32.21). Edible leaf weight/shoot had a positive and highly significant correlation with whole leaf weight/shoot ($r = 0.97$) followed by shoot thickness ($r = 0.65$), number of leaf/shoot ($r = 0.62$), leaf width ($r = 0.46$), shoot length ($r = 0.45$), leaf length ($r = 0.44$), and node to flower initiation ($r = 0.38$) (Shankar *et al*., 2023).

Shankar *et al*. (2023) estimated stability index for leaf yield related traits and found highly significant differences for whole leaf yield/plant, edible leaf yield/plant and edible percent which indicated the presence of difference in phenotypic expression. The higher edible leaf yield/plant was found in IIHR-D-120, PKM-1 and PKM-2 (Xi= 4.72 kg, 4.52 kg and 3.39 kg respectively) proved its stable and adaptability to wider environments as against IIHR-D-28, IIHR-D-109, IIHR-D-4 (Xi= 8.69 kg, 7.36 kg and 6.72 kg) with suitability for favorable climate. Hence IIHR-D-28 and IIHR-D-4 can be recommended for commercial cultivation (84.5%, 55.9% and 42.3%) due to its greater edible leaf yield increment over the commercial check PKM-1 (Shankar *et al*., 2023). Genetic variability for edible leaf density, pod length and seed size and color are given in Fig. 3.

Genetic variability for edible leaf density

Genetic variability for pod length

Genetic variability for seed size and seed color

Fig. 3. Genetic variability for edible leaf density, pod length and seed size and color

BREEDING

Germplasm: This species is not known to be represented in *ex situ* conservation in botanical gardens. There are 20 germplasm accessions from Brazil, Tanzania, Kenya, and India. They are held in Brazil, Kenya, and Taiwan. Multiple protected areas exist across its range, so passive conservation is assumed in these localities (Roland, 2020). Germplasm is a treasure of genes conserved in a wide array of crop varieties, landraces, and related wild species of a crop to search for specific genetic traits for identifying elite accessions for developing desirable horticultural traits. Worldwide, Moringa germplasm have been collected and conserved by national (ICAR- National Bureau of Plant Genetic Resources New Delhi, ICAR- Indian Institute of Horticultural Research, Bengaluru, ICAR-Indian Institute of Vegetable Research, Varanasi, ICAR- Central Institute for Arid Horticulture, Bikaner, Tamil Nadu Agricultural University, Coimbatore, University of Horticultural Sciences, Bagalkote, University of Agricultural Sciences, Bengaluru, Mahatma Phule Krishi Vidyapeeth (MPKV), Rahuri, Keral Agricultural University, Vellanikara) and International (World Vegetable Centre, Taiwan, National Institute of Horticultural and Herbal Science (NIHHS), Korea, Kasetsart University's Kamphaeng Saen Campus at Nakhon Pathom in Thailand, International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) Campus at Patancheru in India, Samanko Research Station at Bamako in Mali and International Institute of Tropical Agriculture (IITA) at Cotonou in Benin) etc. (Shankar *et al*., 2023). In India, germplasm exploration started during 1980s and improved varieties have been released for commercial cultivation (KM-1, PKM-1 and PKM-2) during 1990s by TNAU, Coimbatore. In late 20s, ICAR-IIHR intensified germplasm collection and the genetic diversity and distribution map prepared using 155 germplasm collected across the country showed wider genetic variations for morphological traits and less diversity in cooler regions (Shankar *et al.,* 2023). During 2001, the World Vegetable Centre, Taiwan initiated germplam collection from Africa, Asia, and the USA, and has distributed the germplasm to several countries in Africa (Egypt), Asia (Malaysia, Pakistan, Philippines, Thailand, and Vietnam), and Europe. In China, conserving about 356 accessions covering 13 moringa species. The Instituto de Biología, Universidad Nacional Autónoma de México (UNAM), Jalisco, Mexico maintains the germplasm of moringa for both basic and applied scientific research. In USA, efforts are underway at the University of Hawaii, USA to optimize the production of the leaf, pod, and oil. China in collaboration with Cuba initiated work for developing improved varieties of moringa (Xishuangbanna in China's southwestern Yunnan province) and identifying functionally diverse genes associated with important agronomical traits (South China Agricultural University, Guandong). Moringa Philippines Foundation (Philippines), AVDRC (Taiwan), Rural Development Initiative, and Moringa Community (Zambia) are other research centers across the world focused on the improvement of drum stick (Shankar *et al*., 2023).

Genetic resources where collections exist (AICRPVC, 2024).

- The World Vegetable Research and Development Center, Taiwan
- Tamil Nadu Agricultural University, India
- ECHO, North Fort Meyers, Florida

Breeding objectives (AICRPVC, 2024).

- Breeding varieties with dwarf statured plant
- Varieties suitable for leaf purpose
- Development of high yielding types
- Breeding varieties with more seed and oil content
- Development of types resistant to pest and diseases

Moringa varieties may be broadly classified into two groups (Bijaya Devi and Chanchan, 2023)

Perennial types: In India perennial types are typically propagated from cuttings. These types have several characteristics that have constrained their use for in commercial production, and favored development and cultivation of annual varieties: long growing time before reaching maturity for production of pods, limited availability of suitable planting materials (stem cuttings), less resistance to pests and diseases and greater rainfall requirements. They may be unsuited for areas with short growing seasons or shortages of water.

Annual types: Periya-kulam-1 and Periyakulam-2 (PKM1 & 2), are largely the products of recent plant breeding research and have now replaced most the perennial varieties that previously dominated commercial production in India. They are seed propagated, offer rapid maturation, higher yields and greater adaptability to varied soil and climatic conditions. Disadvantages of annual types compared with perennial types may include shorter lifespans, requirements for more frequent replanting and reduced genetic diversity varieties from India

Classification Terminology (Vange *et al.*, 2017)

The terminology used to classify the various types of moringa is often confusing, with overlapping definitions and inconsistent usage among the many sources of information. Here we define the terms as used on this section of our website.

- ***Species and Varieties.*** In some of the popular literature about moringa, species of moringa are confused with varieties. These terms are not interchangeable. Varieties and cultivars are not species; they are of a taxonomic (classification) rank below that of species and subspecies. Varieties have characteristics that distinguish them from other varieties of a species or subspecies. They may be naturally occurring, or developed by plant breeding programs.
- ***Varieties and Cultivars*** are terms often used interchangeably. In other sections of this website we usually refer to varieties deliberately developed in cultivation as "cultivars". However, most authors refer to cultivars of moringa as "varieties" so we will use that term here.
- ***Ecotypes*** are distinct varieties, forms or races of one species *occupying a specific habitat.* This habitat may not be in isolation from other populations of the species. Some of the seeds in our bank are from trees grown in multiple generations at specific geographical locations such as Tamil Nadu, India and adapted to these areas. These may be considered ecotypes. Seeds with sources identified from large, non-specific regions such as "Hawaii" or "India" that have many diverse growing environments are not considered ecotypes.
- ***Landraces*** are domesticated, locally adapted, traditional varieties that have developed over time, through adaptation to the plant's natural and cultural environment of agriculture and pastoralism, *and in isolation from other populations of the species*.
- ***Pure lines*** are varieties in which certain characteristics appear in successive generations as a result of inbreeding or self-fertilization. The term "pure line" may also refer to a self-pollinated descendant of a self-pollinated plant.
- ***Pure line selection*** is a plant breeding method used to develop a new variety by selection of the single best progeny among established varieties or landraces.

Terminology Relating to Size and Form of Species (Vange *et al*., 2017): The terms used by various authors to describe and classify the various forms and sizes of moringa are not well developed and lack clear definitions. The size and form of the trees may also be variable within a species or variety. Mark Olsen (Olsen 2014) grouped the 13 species of *Moringa* into three broad categories reflecting their form and geographic distribution:

Bottle trees. Massive trees with bloated, bottle shaped trunks, and small radially symmetrical flowers. *Moringa drouhardii*, *M. hildebrandtii*, *M. ovalifolia* and *M. stenopetala* are in this group. The branches and leaves of some of these such as *M. drouhardii* and *M. hildebrandtii* may grow only at the tops of the trees giving them a palm-like appearance.

Slender trees. Trees with a tuberous early stage and pink to cream colored, slightly bilaterally symmetrical flowers. *Moringa concanensis, M. oleifera* and *M. peregrina* are in this group.

Trees, shrubs, and herbs of Northeast Africa. The eight remaining species of *Moringa* are all from northeast Africa and are highly variable in form, ranging from herbs to trees. Some are tuberous as juveniles and become fleshy-rooted in maturity, while others are tuberous as adults. The flowers are bilaterally symmetrically and colorful.

Terminology Relating to Size and Form of Varieties (Vange *et al*., 2017) Olsen's species classification scheme is not usable to describe the form and size of the varieties because the differences between varieties are not as distinctive as those of the species. All of the named varieties moringa are also of one species, *Moringa oleifera*, and it has a single geographic origin. No uniform scheme has been developed to describe the form and shape of the many varieties of moringa and such a scheme is needed to simplify descriptions and categorize varieties in our seed bank. To meet this need we have adopted the terms listed below and will begin the task of classifying the many varieties listed on this website. In most cases there is still insufficient information to classify varieties according to these terms.

Indeterminate or Standard Forms: These are the tallest trees with a form that is probably most similar to that of the natural or wild type. The young trees rapidly grow upward attaining a maximum height of about 12 meters (40 feet). These varieties typically have a single trunk and few lateral branches making it difficult to reach the leaves and pods for harvesting. They require frequent topping and severe trimming to maintain a suitable height, force lateral branching and improve productivity.

Determinate Forms: These varieties have been developed by plant breeding programs in India to have a bushier shape with more side branches, and not exceed a height of 2 – 4 meters, suitable for harvesting. They generally do not require topping and need less trimming than the indeterminate forms. Examples of widely grown determinant varieties are Periyakulam 1 and 2 (PKM1 & 2), and Oddanchathiran 3.

Dwarfs: These are determinant varieties developed to grow to shorter maximum heights than the common determinate varieties, usually from 2 – 3 meters. The height ranges defining the different dwarf designations (extra dwarf, dwarf and semi-dwarf) have no consistent usage. There does not appear to be any significant size differences between trees advertised as "extra dwarf" and "dwarf". Here, semi-dwarfs are assumed to be those attaining a maximum height of about 3 meters; dwarfs, about 2 meters. The dwarf varieties of Periyakulam 1 and 2 are most commonly grown.

Moringa are referenced in Ayurvedic text books (Agarwal, 2017)

- *Shyama*– black variety (most common),
- *Shveta*– white variety and
- *Rakta*– red variety. It is also called as Madhu shigru.

Crop Improvement Methods (AICRPVC, 2024)

Mass Selection: Selection of types starts with open pollination. Select one line with the highest potential and test it in various conditions and various sites. Then, go for controlled pollination. PKM 1 annual moringa was released through this method.

Hybridization: Annual moringa PKM 2 is a hybrid derivative from the cross between MP31 and MP28. PKM 2 exhibits 48% increase in yield over PKM1.

Mutation Breeding: Very little work has been carried out in annual moringa through mutation breeding.

Biotechnology: Limited information is available on biotechnology of moringa. Recently, due importance has been stressed on micropropagation and characterization of germplasm through molecular markers for its improvement.

Breeding of Drumstick: Drumstick (*Moringa oleifera*) is one of the important perennial vegetables indigenous to northwest India. It is widely grown in the backyards of many households in the southern states. To initiate research efforts on this crop, the Indian Institute of Horticultural Research (IIHR) started with a germplasm collection and characterization. Based on fruit characters, some promising accessions were identified, which could be used for commercial cultivation or utilized in the breeding program (Varalakshmi and Devaraju, 2007). AVRDC initiated a small project in 2001 to introduce and evaluate number of *Moringa* accessions collected from countries including India, the Philippines, Taiwan, Tanzania, Thailand, and USA. A total of 50 accessions were collected and from this collection, 42 accessions representing four species (*Moringa oleifera, M. stenopetala, M.*

drouhardii and *M. peregrine*) were germinated and transplanted in the field for seed multiplication, observation and characterization. Twenty-two accessions produced sufficient seeds for replicated evaluation trials and seed distribution. Ten promising accessions were selected and evaluated in replicated trials over a two-year period. Results showed that only three accessions mostly from *M. oleifera* have fresh young shoot yield averaging 20 t/ha in 2004. In the second year (2005) young shoot yield of all ten accessions increased ranging from 29.1 to 41.8 t/ha. Three accessions produced shoot yield of 40+ t/ha. Shoot yield of new planting in 2005 was almost similar to previous planting in 2004 suggesting that maximum shoot production was attained during the second season production. The initial study indicated that *Moringa* is well-adapted to the climatic and environmental conditions of Southern Taiwan and promising accessions are available for commercial cultivation (Palada *et al*., 2007). The main goal of the study is to identify a superior genotype for the rain fed areas among 14 genotypes. Stability analysis was assessed by yield stability statistic (yi), yield regression statistic (ri) and yield distance statistic (di). The analysis of variance revealed that the genotype were highly significant for all characters under the environment studied. However, number of flowers per plant showed nonsignificance for environments in the study. G × E (Genotypic × Environment interaction), E+ (G × E) [Environment + (Genotype × Environment)] and E [Environment (Linear)] showed significant values for all the characters. Pooled deviation exhibited significance for number of fruits per plant and yield per plant. Among the genotypes studied, PKM-2, MO-1 and PKM-1 were found stable for number of fruits per plant and yield due to bi value around unity and non significant S2 di value. Hence, PKM-2 and MO-1 were found to fit for favorable environment and PKM-1 for unfavorable environment for commercial cultivation for semi arid region of India (Raja *et al*., 2013). In experiment 36 genotypes were evaluated. The results revealed a significant difference in all the characters like pod weight (26.37-66.43 g), pod length (24.43 to 59.47 cm), pod girth (7.33 to 23.67 mm), number of leaflets/leaf (8.00 to 13.33), and leaf length (28.63 to 66.37 cm). Similarly, a wide variation was recorded for nutrients in drumstick leaves. It was 22.07 to 37.47 % for dry matter; 5.33 to 7.87 % for TSS; 0.72 to 1.43 mg/g for chlorophyll. The GCV was greater than PCV for all the characters but the differences were low. High GCV and heritability estimates coupled with greater genetic advance was recorded for pod weight and indicated that these characters had additive gene effects and therefore, they are more reliable for effective selection (Tak and Maurya, 2015).

Much variability has also been reported by Reshmi (2004) in drumstick with respect to morphological characters which are helpful in selection of elite tree for combination breeding programme. In a systematic breeding programme, collection, evaluation and characterization of the germplasm is the first important step for gathering the basic information about variability exists in a particular crop plant. Hence, the present study was initiated (Tak and Maurya, 2015). As Moringa is a cross-pollinated tree, high heterogeneity in form and yield is expected. Several works indeed report variability in flowering time (from annual type to perennial type), tree nature (from deciduous to evergreen), tree shape (from semi spread to upright), resistance to hairy caterpillar, flowering time (*i.e.*, some tree flowering throughout the year while others flower in two distinct season) (Leone *et al*., 2015). Many ecotypes are present in India: Jaffna (soft and taste fruits), Chavakacheri murungai (similar to Jaffna), Chemmurungai (red tipped fruits), Kadumurungai (small and inferior fruits) Palmurungai (bitter taste), Punamurungai (similar to Palmurungai), Kodikalmurungai (short fruit), Palmurungai, Puna Murungai and Kodikkal Murungai and wild Kadumurunga. Recently two varieties (PKM-1; PKM2) have been developed at Horti Nursery Networks, Tamil Nadu, India, to improve pod production: usually those varieties are grown as annual; after two harvests the tree is dragged out and new seedlings are planted. At Kerala Agricultural University (India) several varieties have been developed and available (Leone *et al.*, 2015). Outside India there are research centers focused on *Moringa oleifera* improvement across the world: AVDRC (Taiwan), Rural development initiative (Zambia), Moringa Philippines foundation (Philippines) Moringa community (Zambia) (Leone *et al.,* 2015).

Later on, a further investigation on twelve Indian populations, from northern and southern regions of India, was performed through SSR together with morphological markers. In this study too, individuals from various geographical areas were not significantly different genetically, while a large variability exist in Indian populations. Morphological analysis on fourteen quantitative and eleven qualitative characters showed correlation among some quantitative characters, *e.g.,* between tree tallness with fruit girth, trunk girth with tree branching. More SSR were identified in 2014 thanks to EST examination involving several plant species and not utilized so far in *Moringa oleifera ge*netic investigation (Leone *et al*., 2015). Even if all the reported studies are valuables and have a tremendous importance for conservation, selection and collection of *Moringa oleifera* seeds, same questions are still to be addresses in order to develop an improved *Moringa oleifera* cultivation. Considering the cultivation challenges, some research activities should be prioritized: (i) collection and characterization of world accessions both cultivated and natural in order to obtain a true understanding of the genetic diversity and structure of *Moringa oleifera*; (ii) set a collaborative network among National and International Research Centre, O.N.G, farmers that already work on *Moringa oleifera* (Leone *et al*., 2015). A study was carried out to assess the genetic variability, heritability and genetic advance of important quantitative and qualitative traits in fifty-two perennial moringa genotypes. Analysis of variance revealed a significant differences for all traits. High genotypic and phenotypic coefficients of variation were noticed for pod yield, the number of pods per tree, total carotenoids, iron and pod weight indicating maximum variability among the different genotypes. High estimates of heritability coupled with high genetic advance obtained for all the traits except crude fibre content indicating the presence of additive gene effect which showed the effectiveness of selection for these traits. Presence of high heritability coupled with moderate genetic advance for crude fibre content revealed that the straight selection has a limited scope for further improvement of the trait. Among fifty two genotypes PKM MO-55 has the highest iron content (7.20mg/100g), number of pods/tree (306.50) and pod yield (36.47 kg/tree) (Balaguru *et al*., 2020). Moringa is primarily grown for its pod but nowadays it is gaining demands for leaf production. Moringa leaves have immense medicinal and dietary value to supplement nutrients for good health. Therefore, identification and selection

of leafy type genotype(s) is imperative. Fifty-two genotypes collected from diversified areas of India were evaluated. Analysis of variance for growth and leaf yield traits indicated existence of considerable genetic variability in the gene pool. Magnitude of phenotypic coefficient of variation was higher than its genotypic level for all the traits, indicating the environmental influence on their expression. Higher genotypic and phenotypic coefficient of variation was observed for all the leaf yield traits indicating that higher variability and simple selection would be effective. High heritability was recorded for all growth and leaf yield related traits (60.74–99.89%) except number of primary rachis per leaf (35.66%), suggesting selection based on phenotypic expression is effective for improvement. The estimate of genetic advance as per cent mean value was high for all growth and leaf yield related traits except edible leaf per cent and number of primary rachis per leaf, revealing that additive gene action and selection approach is most helpful for improvement of these characters. High heritability coupled with high genetic advance was observed for stem length, whole leaf weight/shoot and edible leaf weight/shoot which revealed that these characters are under additive gene action and showed higher responses of these traits towards selection (Mandal *et al*., 2022).

The genetic improvement on moringa was initiated through selection method from perennial forms in 80s targeting annual genotypes. It was attempted to exploit the genetic variation in the seedling population and identified 20 promising plants for yield from 84 open pollinated seedlings by observing nine characters. The heritability analysis showed non-additive gene action for fruit weight and fruit length and fruit girth and involvement of additive gene action for majority of quantitative traits (Shankar *et al.,* 2023). Different crop improvements strategies have been explored to harness the available genetic diversity using both annual and perennial forms in India and across the world. The breeding approaches such as plant introduction, evaluation, selection, hybridization and use of biotechnological methods have been adopted for the development of varieties with dwarf stature, high biomass production, high seed yield and oil content, better quality, and resistance to pest and diseases (Shankar *et al*., 2023). In moringa, breeding genotypes for high leaf yield is still in budding stage. Due to which none specific varieties are recommended for commercial cultivation and the demand is substituted by superior genotypes identified for pod purpose. Breeding for leaf yield is determined by leaflets per leaf, number of leaves per shoot, node at which first flower initiation take place, leaf weight per shoot and no. of shoots per tree etc. Moringa leaves are double or triple pinnate, with 20-70 cm long. The smaller leaflets are 1-2 cm in length (Shankar *et al*., 2023). It was found that foliage density varied from sparse, medium to dense in 52 accessions evaluated and 48.07% and 23,07% gene pool had medium and dense foliage, respectively and the isolated 14 accessions were superior over comer check PKM-1. As leaf yield is concern, fresh leaf yield of a moringa plant was reported to be 1-5 kg per tree annually (Shankar *et al*., 2023).

There are several ecotypes and superior yielding genotypes have been selected from the open pollinated population of a region for its appearance, yield and quality. Perennial ecotypes are propagated by limb cuttings, as seeds take several years to fruit. Chemmurungai is selected for its red-tipped fruits, and said to produce flower year-round and have high fruit yields. Pal muraungai is identified for its thick pulp and better taste. Punamurungai and Kodaikal murungai have been selected for slender stem with tallness to use as support for betel vine crop, which is most popular in Trichy District of Tamil Nadu. It produces very short fruits of 15 to 23 cm. In addition, there are some improved genotypes selected for yield and quality with annual in nature. KM-1 (Kudumianmalai-1) is an improved type and designated as seed moringa. Pods are short (32-37 cm and 5.5-6.0 cm girth) and weighing from 65 to 82.5 g. Each tree bears 226-328 pods with high yield potential (14.69 to 26.90 kg). PKM 1 (Periyakulam-1) is improved through pureline selection from the population generated by continuous selfing. The tree comes for harvest at 8-9 months after planting and produces at least 200-350 pods. It bears twice in a year (Shankar *et al.*, 2023). Pod length is a major determinant of consumer acceptability as the pods with medium length (<60 cm) are more preferred than extra long pods (>1.0 m). The seed yield is determined by no of seeds/pod and its arrangement in pods as its is evidenced that extra long pods had poorly packed seeds as compared to short to medium length pods. There has been no exhaustive research on seed yield and oil content in India, as main focus was given to leaves and biomass production (Shankar *et al*., 2023).

In India, from where moringa most likely originated, the diversity of wild types gives a good basis for breeding programs. In countries where moringa has been introduced, the diversity is usually much smaller among the cultivar types. Locally well-adapted wild types, though, can be found in most regions. Because moringa is cultivated and used in different ways, breeding aims for an annual or a perennial plant are obviously different. The yield stability of fruits is an important breeding aim for the commercial cultivation in India, where moringa is cultivated as an annual. On less favorable locations, perennial cultivation has big advantages, such as less erosion. In Pakistan, varieties have been tested for the nutritional composition of their leaves on different locations. India selects for a higher number of pods and dwarf or semidwarf varieties. Breeders in Tanzania, though, are selecting for higher oil content (Wikipedia, 2024).

Hetertosis: An efficient *in vitro* clonal propagation methodology for *Moringa oleifera* (PKM1 Variety) was developed using nodal explants of young seedlings grown ex vitro. Nodes were cultured in Murashige and Skoog (MS) medium with different combinations of plant growth regulators. Multiple shoots were successfully achieved by culturing nodal explants in a medium containing different concentrations of 6-Benzylaminopurine (BAP) and Kinetin (Kin) in combination with naphthalene acetic acid (NAA). BAP at 2mgL-1was considered optimal for generating a maximum an average of 6.03±0.21 auxillary shoots per explants after 60 days of culture inoculation. A high rate of multiplication has been established by routine subculture on a similar shoot induction medium. Maximum numbers of individual roots were established on a medium containing indole-3-butyric acid (IBA) at 1.5mgL-1. Primary hardening was done in pots containing the potting mixture and transferred plantlets were covered with clear polythene bags. Seventy per-cent of the rooted plants survived and secondary hardening was carried out after 15 days in a shaded greenhouse (Harshitha *et al.,* 2020). Two hybrid seedlings of drumstick (*Moringa oleifera*) derived from two crosses between Jaffna and PKM1 (MF1H1) and IC632344 and PKM1 (MF1H2) were evaluated for juvenile growth and nutrient content to study

the heterosis (hybrid vigor) at College of Agriculture, Kerala agricultural University, Trissur during 2022-2023. Positive heterosis was evident in both the hybrids for seedling height, root collar girth, number of live leaves, stem volume index, dry matter of leaf and beta-carotene. Also they marked superiority over parents and check variety in case of short intermodal length. Specifically noted the positive heterosis of MF1H1 for Seedling vigour index as well as iron content and MF1H2 for protein content. Regarding the seed germination and vit. C content, both hybrids noted for inferior to the parents and check variety. The heterotic advantages emphasize the potential of harnessing hybrid vigor through hybridisation for the genetic improvement of drumstick (Manju *et al*., 2023).

Varieties of Drumstick: Moringa has three types according to Ayurveda: Shyama (black variation), Shveta (red variant), and Rakta (white variety) (Red variety) (Soni, 2020). Moringa has the varieties KM1, PKM1, PKM2, GKVK1, GKVK2, GKVK3, Dhanraj, Bhagya (KDM1), Konkan Ruchira, Anupama, and Rohit 1 created by the public sector (Soni, 2020). AMAR 32, Anupama, Bhagya KDM1, Bombay, Chemmurungai, Coimbatore 1, Coimbatore 2, Dhanraj, Durga, G.K.V.K. -1, G.K.V.K. -2 , G.K.V.K. -3 , Jaffna, Kadumurungai (Kadu) , KM 1, Kodikkal murungai, Konkan Ruchira, MOL'E, MOMAX3, Moolanur, MS01, MS02, Multiplex, MX3, Oddanchathiran (ODC), ODC3, Periyakulam 1 (PKM1) Dwarf, Periyakulam 2 (PKM2) Dwarf, Periyakulam 2 (PKM2) Extra Dwarf Hybrid, Punamurungai or Palmurungai, Rohit 1, Saragvais, Sarpan SD2, Shobhanjana, alpanamis,Valayapatti, Chavakacheri, Chemmurungai are the other varieties of drumstick.

In Karnataka, GKVK-1, 2, 3 a small stemmed varieties (2-2.5 m) bearing120-200 pods/tree/year have been developed. Dhanaraj is another improved variety characterized with short fruit segments (35-40 cm) producing 150-200 pods/tree have been identified. Bhagya (KDM-1) has been developed for its medium to log pod segment (60-70 cm) bearing 350-400 pods/ tree. In Maharastra, Konkan Ruchira has been selected from Vasai local. It is a bushy type, each tree yields 275 pods with medium long size and yielding 30-35 kg per year. Rohit-1is an early bearing, dark green pods with medium long (45-60 cm) weighing 60-70 g. Each tree bears 400-600 pods per year. In Gujarat, Thar Harsha has been developed from PKM-1, though pureline selection, which is tolerant to drought, densely foliaged, and long pod (100.5 cm) with uniform parrot green colour. Each tree bears 100-125 pods and weighing 120g. Each plant bears 15-20 kg/tree in 2nd year itself and increasing every year subsequently. In addition Amar -32 (Amar seeds Pvt Ltd), Andipatty (semi dwarf type), Anupama (Kerala Agricultural University, Vellanikara), MOL'E (Advanced Biofuel Centre, India), MOMAX-3 for oil production (Advanced Biofuel Centre, India), MS01 and MS02 (Ancient Green field Pvt Ltd), MX-3 for oil production (Advanced Biofuel Centre, India) (Shankar *et al.,* 2023).

REFERENCES

AICRPVC. 2024. Crop Improvement And Varietal Status Of Moringa. In: Advances in Production of Moringa. All India Co-ordinated Research Project- Vegetable Crops

Alstine, V.A. 2024. Joshua Van Alstine's Post. https://www.linkedin.com/posts/joshuavanalstine_the-drumstick-tree-also-known-as-moringa-activity-7093561279860121600-eKEn

Balaguru, P., Sathiyamurthy, V.A., Janavi1, G.J. and Santha, S. 2020. Variability in perennial moringa (*Moringa oleifera* Lam.) genotypes for quantitative and qualitative traits. Electronic Journal of Plant Breeding, 11(2): 515-520

Bijaya Devi, A.K. and Chanchan, M. 2023. Miracle tree : Drumstick (Moringa oleifera Lam). https://www.thesangaiexpress.com/Encyc/2023/10/17/Ak- -

Bioexplorer. 2024. Drumstick. Bio Explorer. BioExplorer.net. https://www.bioexplorer.net/plants/flowers/drumstick/

Boopathi, N.M. and Abubakar, B.Y. 2021. Botanical Descriptions of *Moringa* spp. In: Boopathi, N.M., Raveendran, M., Kole, C. (eds) The Moringa Genome. Compendium of Plant Genomes. Springer, Cham. https://doi.org/10.1007/978-3-030-80956-0_2

Boopathi, N.M., Raveendran, M. and Kole, C. 2021. Moringa and Its Genome: Future Prospects. In: Boopathi, N.M., Raveendran, M., Kole, C. (eds) The Moringa Genome. Compendium of Plant Genomes. Springer, Cham. https://doi.org/10.1007/978-3-030-80956-0_15

Bose, T.K.J. Kabir, T.K. Maity, V.A. Parthasarathy and Som, M.G. 2003. Floral Biologyand Hybridization In Moringa. Vegetable crops, 3: 499 - 512.

Drisya Ravi, R.S., Bindu Nair and Siril Elenjikkal. 2022a. Fingerprinting and genetic variability in drumstick (Moringa oleifera Lam.) elite trees using RAPD markers- An underutilized and wild edible future crop. South African Journal of Botany, 145: 370-377

Drisya Ravi, R.S., Nair, B.R. and Siril, E.A. 2021. Morphological diversity, phenotypic and genotypic variance and heritability estimates in *Moringa oleifera* Lam.: a less used vegetable with substantial nutritional value. Genet Resour Crop Evol., 68**:** 3241–3256

Drumstick. 2024. Origin, Area, Production, Varieties, Package Of Practices For Drumstick, Coccinea And Curry Leaf. http://eagri.org/eagri50/HORT281/pdf/lec32.pdf

Gogarden. 2024. Munga, Drumstick, Moringa Oleifera – Seeds. https://gogarden.co.in/products/munga-drumstick-moringa-oleifera-seeds

Harshitha, J.D., Santhanakrishnan, V.P., *et al*., 2020. Micropropagation in *Moringa oleifera* Lam for high-throughput multiplication. Electronic Journal of Plant Breeding, 11(4): 1205-1210

Justgo. 2024. Drumstick leaves. https://www.justgotochef.com/ingredients/drumstick-leaves

Kashyap, P., Kumar, S., *et al*., 2022. Recent Advances in Drumstick (**Moringa oleifera**) Leaves Bioactive Compounds: Composition, Health Benefits, Bioaccessibility, and Dietary Applications. Antioxidants (Basel), 11(2): 402.

Kurian, A.J., Anitha, P. and Pradeepkumar, T. 2020. Genetic divergence studies in drumstick **(*Moringa oleifera* Lam.).** Journal of Tropical Agriculture, 58 (2): 158-167

Lakshmidevamma, T.N. *et al.* 2021. Genetic Diversity of Moringa (*Moringa Oleifera* Lam.). In: Boopathi, N.M., Raveendran, M., Kole, C. (eds) The Moringa Genome. Compendium of Plant Genomes. Springer, Cham. https://doi.org/10.1007/978-3-030-80956-0_7

Leone, A., Spada, A., *et al*., 2015. Cultivation, Genetic, Ethnopharmacology, Phytochemistry and Pharmacology of *Moringa oleifera* Leaves: An Overview. International Journal of Molecular Sciences, 16: 12791-12835

Mallenakuppe, R., Homabalegowda, H., *et al*. 2019. History, Taxonomy and Propagation of Moringa oleifera-A Review. SSR Inst. Int. J. Life Sci., 5(3): 2322-2327

Mandal, S., Shankar, R., Hanchinamani, C. N., Anjanappa, M. and Kumar, J. S. A. 2022. Morphological assessment to predict genetic variability for leaf yield and component traits in Moringa (Moringa oleifera). The Indian Journal of Agricultural Scien*ces*, 92(6): 721-725.

Manju, A., Sindhumole, P., Jiji Joseph, Pradheep, K., Sangeeta Kutty, M. and Panjikkaran, S.T. 2023. Estimation of Heterosis in Hybrid Seedlings of Drumstick (*Moringa oleifera*). Biological Forum – An International Journal, 15(9): 424-428

Ndayankpa, N.M., Falusi, A.O., Daudu, O.A.Y., Adebola, M.O. and Abubakar, A. 2022. Morphological and seeds diversity in drumstick plant (*Moringa oleifera* Lam.) Germplasm from Northern Nigeria. Proceedings of the 2nd ICAAT, Federal University of Technology, Minna, 2022, 588-595

Palada, M.C., Chang, L., Yang, R. and Engle, L.M. 2007. Introduction and varietal screening of drumstick tree (*Moringa* spp.) For horticultural traits and adaptation in taiwan. Acta Hortic, 752: 249-253
Pandey, A., Pradheep, K., Gupta, R. *et al.* 2011. 'Drumstick tree' (*Moringa oleifera* Lam.): a multipurpose potential species in India. Genet Resour Crop Evol., 58: 453–460

PWO. 2024**.** *Moringa oleifera* Lam. | Plants of the World Online | Kew Science. powo.science.kew.org/taxon/urn:lsid:ipni.org:...

Raja, S., Bagle, B. G. and More, T.A. 2013. Drumstick (*Moringa oleifera* Lamk.) improvement for semiarid and arid ecosystem: Analysis of environmental stability for yield. Glob. J. Plant Breed. Genet., 1(1): 103-109

Rajalakshmi, R., Rajalakshmi, S. and Ajay Parida. 2017. Evaluation of the genetic diversity and population structure in drumstick (Moringa oleifera L.) using SSR markers. Current Science, 112(6): 1250-1256

Rani, N.Z.A., Husain, K. and Kumolosasi, E. 2018. *Moringa* Genus: A Review of Phytochemistry and Pharmacology. Frontiers in Pharmacology, 9: 108

Ridwan, R., Hamim, H., *et al*., 2021. Molecular and Morphological Analysis of Indonesian Drumstick Tree (*Moringa oleifera* Lam.). Asian Journal of Plant Sciences, 20: 131-142

Roland, C. 2020. Moringa oleifera. The IUCN Red List of Threatened Species 2020: e.T61890232A61890241. https://dx.doi.org/10.2305/IUCN.UK.2020-3.RLTS.T61890232A61890241.en

Roloff, A., Weisgerber, H., Lang, U. and Stimm, B. 2009. Enzyklopädie der Holzgewächse, Handbuch und Atlas der Dendrologie. Copyright © 2009 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

Rufai, S., Hanafi, M.M., Rafii, M.Y., Ahmad, S., Arolu, I.W. and Ferdous, J. 2013. Genetic dissection of new genotypes of drumstick tree (*Moringa oleifera* Lam.) using random amplified polymorphic DNA marker. Biomed Res Int. 604598.

Sagonaa, W.C.J., Chirwab, P.W. and Sajiduc, S.M. 2020. The Miracle mix of Moringa: Status of Moringa Research and Development in Malawi. South African Journal of Botany, 29: 138-145

Shankar, R., Mandal, S., *et al*., .2023. Moringa breeding: International scenario. Conference: International Seminar on Exotic and Underutilized Horticultural Crops: Priorities & Emerging Trends. At: Bengaluru

Shukla, S. 2024. Why Drumstick Is Next Big Thing in Nutrition: Discover How It Revolutionizes Health, Wealth, and Sustainability. ttps://krishijagran.com/explainers/why-drumstick-is-next-big-thing-in-nutrition-discover-how-it-revolutionizes- health-wealth-and-sustainability/

Soni, S. 2020. Drumstick Cultivation: A Guidance For Beginners. https://krishijagran.com/agripedia/drumstick-cultivation

Specialtyproduce. 2024. Drumstick Moringa. https://specialtyproduce.com/produce/Drumstick_Moringa_11503.php

Suresh Bahu, K.V. and Rajan, S. 1996. Floral Biology Of Annual Drumstick. Journal of Tropical Agriculture 34: 33-135

Tagore, N.T. 2015. Drumstick (*Moringa oleifera* Lamk.) upgrading for semiarid and arid ecological unit: A study of environmental stability for yield. International Journal of Agricultural Sciences, 5 (3): 601-606

Tak, S. and Maurya, I B. 2015. Genetic Variability In Drumstick Genotypes. Annals of Plant and Soil Research, 17 (1): 67-70

Tak, S. and Maurya, I.B. 2017. Genetic diversity of *Moringa oleifera* Lam. in Rajasthan, India. ISHS Acta Horticulturae 1158: I International Symposium on Moringa

Tian, Y., Zeng, Y., Zhang, J. *et al.* 2015. High quality reference genome of drumstick tree (*Moringa oleifera* Lam.), a potential perennial crop. Sci. China Life Sci., 58: 627–638. https://doi.org/10.1007/s11427-015-4872-x

Vange, T., Jibung, G.G.1. and Odiaka, N.I. 2017. Assessment of Drumstick Tree (M. deifera) Accessions for Genetic Diversity in the Southern guinea Region of Nigeria. International Journal of Environment, Agriculture and Biotechnology (IJEAB), 2(1): 503-509

Varalakshmi, B. and Devaraju. 2007. Genetic Diversity In Drumstick (*Moringa Oleifera* Lam) Germplasm. Acta Hortic., 52: 411-412

Wikipedia. 2024. *Moringa oleifera.* From, Wikipedia,the free encyclopedia. https://en.wikipedia.org/wiki/Moringa_oleifera

Zhang, J., and Lin, M. 2018. Floral biology and pistil receptivity of the drumstick tree (*Moringa oleifera* Lam.). Arch Boil Sci., 70(2):299-305.

Zhang, J., Mengfei Lin, Hanbin Chen, Qin Zhu, Vu Ngoc Linh and Xiaoyang Chen. 2017. Floral biology and pistil receptivity of the drumstick tree (*Moringa oleifera* Lam.). Archives of Biological Sciences, 70:46-46

Zhang, J., Lin, M., Chen, H., Zhu, Q., Linh, V.N. and Chen, X. 2018. Floral biology and pistil receptivity of the drumstick tree (*Moringa oleifera* Lam.). Archives of Biological Sciences, 70: 299-305

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