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Exploring the Versatile Tamarind: From Botanical Wonder to Genetic Advancements

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Summary
The article explores the realm of tamarind breeding, emphasizing its multifaceted utility as a tropical fruit tree. It highlights the botanical features, chemical compositions, and advancements in crop improvement techniques like selection and mutation breeding. The focal point lies in the identification of elite trees bearing desirable traits such as less acidity in pulp and larger pods. Various research endeavours on tamarind, including in vitro cultivation and micropropagation, are mentioned. Moreover, the article discusses genetic transformation and achievements in breeding superior tamarind variants, showcasing the potential for improving tamarind cultivars.

Introduction
Tamarind is not just another tropical fruit tree; it stands as a versatile marvel, treasured for its fruits, seeds, and applications beyond the culinary realm. With its tangy, sweet flavour, tamarind enriches global cuisines, from spicy seasonings to refreshing beverages. Extending its reach beyond the kitchen, its seeds and fruits find utility in various industrial sectors, making it a truly versatile multipurpose tree. Tamarind belongs to the Leguminosae family, which boasts over 19,000 species and stands out for its unique combination of flavours and uses. It is cultivated across subtropical and semiarid tropical regions, enjoys widespread distribution, and holds a revered position in numerous cultural practices.

Botanical Insights
Tamarind, scientifically known as *Tamarindus indica*, belongs to the Leguminosae family, encompassing a vast group of flowering plants. Indigenous to tropical Eastern Africa (Sookying *et al.*, 2022), this tree stands tall and resilient, a slow-growing and long-lived giant, capable of reaching heights of 30 m with a spreading, rounded crown up to 12 m under favourable conditions. It boasts a robust trunk, a wind-resistant structure, and graceful, drooping branches. The dark grey, rough bark, and bright-green, feathery foliage create a picturesque silhouette. Its inch-wide flowers, adorned with yellow petals tinged with hues of orange or red, make them visually captivating, as shown in Fig. 1 (Toungos, 2019).

Chemical Composition and Utility of Tamarind
The distinctive taste of tamarind stems from its chemical composition. Per 100 grams, the pulp contains energy (239 kcal), carbohydrates (62.5 g), sugars (57.4 g), proteins (2.8 g), fat (0.6 g), and dietary fiber (5.1 g). It is rich in vitamin A (81 µg), C (3.5 mg), B1 and B2 (0.1 mg), B3 (1.9 mg), B9 (14 µg), and minerals like potassium (628 mg), calcium (74 mg), phosphorous (11 mg), magnesium (92 mg), and sodium (28 mg) (Narina *et al.*, 2018). Its high

tartaric acid content, ranging from 8-18%, contributes to its unique sweet-sour flavour profile, making it the richest natural source of tartaric acid among sour fruits.

Tamarind finds extensive application across various industries, with its fruit pulp, seed, shell, leaf, flower, and timber all having industrial value. It is used to make tamarind juice concentrate, pulp powder, pectin, pickles, chutneys, sauces, soups, jam, syrups, candy, tartaric acid, alcohol, refreshing drinks, and tamarind kernel powder (TKP). The seeds are also ground for livestock feed. Tamarind comes in sweet and sour varieties; sweet tamarind is eaten fresh, while sour tamarind is processed into various products like juice, powder, chutney, and candies. TKP is essential for the jute and textile industries, and the seeds are valued for their protein and amino acids (Karunakaran *et al.*, 2020).

Fig. 1. Different parts of the tamarind tree (leaves, flowers, pods, pulp, seeds, etc.)

Advancements in Crop Improvement

Selection: The process of selecting elite tamarind trees involves evaluating various characteristics, including pulp acidity, tartaric acid content, sugar content, and pod traits such as broadness, brown pulp colour, high pulp recovery, and seed count. In India, farmers have traditionally identified superior mother trees for propagation based on their consistent production of large and high-quality fruits. An elite tamarind variety was identified with broad pods, good pulp colour, and high pulp recovery. The farmer selected tamarind variety "Lakshamana," which emerged from participatory breeding, exhibits significantly better traits compared to local tamarind varieties (Karunakaran *et al.*, 2020).

Selected tamarind cultivars

- ✓ **Thailand cultivars:** Muen Chong, Sri Tong, Nam Pleung, JacHom, Kun Sun, Kru Sen, Nazi Zad, Sri Chompoo, etc.
- ✓ **Philippines cultivars:** Cavite, Batangas, Bulacan, and Laguna
- ✓ **India cultivars:** Prathisthan, Periyakulam (PKM-1), Urigam, etc.

Sweet Tamarind: The identification and development of sweet tamarind varieties has gained popularity in Thailand, the Philippines, and India, sparking renewed interest in tamarind cultivation and research across Southeast Asia. These less acidic, sweet tamarinds are now grown on a limited scale in Thailand and the Philippines, with over 50 cultivars in Thailand and eight cultivars in the Philippines. This resurgence has led researchers to undertake further studies on tamarind. A point mutation causes the sweet tamarind feature, and detached branches on a few trees may produce sweet fruits while others retain sour ones. These fragrant branches, known as bud sports, have been vegetatively propagated and act as the foundation for numerous freshly developed cultivars (Van den Bilcke *et al.*, 2014).

Mutation Breeding: Studies in Japan have explored the safety and potential genetic mutations associated with natural food colourants, including tamarind brown. Research has shown that gamma irradiation can effectively decontaminate tamarind juice, enhancing its microbial quality and antioxidant properties without compromising taste or sensory qualities. In a study, fresh tamarind juice was prepared by dissolving 5 g of pulp in 100 ml of water and then irradiated at 0, 1, 3, and 5 kGy. Results showed improved microbial quality, maintained or increased antioxidant activity, minimal changes in glucose and fructose levels, and enhanced colour in both fresh and stored juice. Thus, gamma irradiation significantly improves the quality and safety of tamarind juice without affecting its sensory qualities (Lee *et al.*, 2009).

***In Vitro* Culture:** Studies on in vitro tamarind culture have identified optimal conditions for multiple shoot induction, aiding in the efficient propagation of superior tamarind varieties. Research highlights the impact of growth regulators on shoot multiplication in tamarind genotypes like PKM-1, Urigam, Pollachi-2, Asanoor-H-1, and Salem-144. Explants collected at different times of the year had varied success, with Urigam performing exceptionally well. It was found that PKM-1 explants, collected every 15 days and cultured on MS medium with specific supplements, had the best results, showing low contamination (7.32%) and high survival (92.68%). Urigam had the highest survival (90.50%), bud break (93.63%), shoot growth (1.40 cm), and number of shoots per bud (3.34), with the quickest bud break at 29.94 days.

Micropropagation: Micropropagation techniques have been optimized to enhance shoot multiplication and rooting, producing healthy, robust tamarind plants and meeting the growing demand for tamarind pulp sustainably. Researchers have successfully propagated tamarind using cotyledonary nodes, finding that specific combinations of growth hormones yielded the best results. Studies involving cotyledonary nodes from in vitro seedlings showed that a medium with 0.2 mg/l BAP and 0.1 mg/l NAA achieved 98.75% shoot induction and produced an average of 3.25 shoots per explant. For rooting, half-strength MS medium with 2.0 mg/l IBA was the most effective, while 2.0 mg/l NAA produced the highest number of roots per shoot. The plantlets were subsequently hardened in a greenhouse. Pattepur *et al.* (2010) found that 0.5 mg/l BAP and 0.1 mg/l NAA were optimal for shoot proliferation from tamarind cotyledonary nodes at the University of Agricultural Sciences, Dharwad. These studies have paved the way for efficient tamarind propagation techniques, ensuring the conservation and proliferation of superior tamarind cultivars.

Genetic Transformation of Tamarind: Genetic improvement of tamarind focuses on enhancing yield and quality traits by leveraging its significant genetic diversity as a highly cross-pollinated species. Recent studies aim to understand the genetic basis of desirable traits, develop elite trees suited for monoculture plantations, and address the increasing demand for tamarind pulp by identifying superior trees without causing genetic erosion. Tamarind's genetic diversity offers substantial potential for improvement through selective breeding, providing opportunities to identify diverse types. Tamarind is a valuable multipurpose tree grown on farmlands and in forests. Rising population pressures have increased the demand for tamarind pulp, necessitating the selection of superior trees. Tree improvement through genetic principles is applied to modify tree heredity, focusing on breeding systems and yield-related traits to meet farmers needs. Key aspects of tamarind improvement include species importance, distribution, ecology, clonal evaluation, variability, heritability, genetic advancement, association studies, and genetic diversity.

Achievements in Tamarind Research: Significant progress in tamarind breeding includes the collection of diverse fruit accessions for a field gene bank, exhibiting diverse pod shapes, colours, and physiochemical attributes. This genetic diversity offers opportunities for selecting high-performing tamarind trees. Studies in regions like Ashok Nagar and Lalitpur revealed variations in pod characteristics ranging from curved to straight and colours from light brown to deep brown, with pulp colour from light to reddish brown. Parameters such as pod weight (5.88–21.84 g), length (7.30–13.87 cm), and pulp weight (0.68–8.19 g). Nutritional analyses highlighted total antioxidant capacity (4.34–35.22 mg/g AEAC), total carotenoids (14.41–44.39 µg/g), phenol content (15.61–56.77 mg/g), and flavonoid content from (0.26–19.58 mg/g), indicating potential for selective breeding to enhance desirable traits.

Conclusion

The journey of the tamarind tree, marked by its rich genetic diversity and unique flavour profile, continues to fascinate researchers and farmers alike. Advances in breeding techniques, mutation methodologies, micropropagation, and cultivation practices promise to yield improved tamarind varieties, ensuring its enduring significance in tropical agriculture and beyond cuisine. From its wild origins to its cultivated multipurpose stature, it highlights its versatility and resilience, enriched by meticulous selection and advanced propagation techniques, ensuring its enduring significance in the world of agriculture and beyond.

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