**Breeding Approaches for Genetic Improvement in Banana: A Comprehensive Review**

**Abstract**

The huge perennial monocotyledonous herb banana (Musa spp.), which comprises dessert and culinary forms, is found in over 120 countries and belongs to the Zingiberales order and the Musaceae family. Cultivated bananas evolved principally from the wild diploid species Musa acuminata (A genome) and Musa balbisiana (B genome) through intra- and inter-specific hybridization, as well as somatic variation selection. This assessment emphasized the research programs done and hybrids generated, with a focus on the work of the India Agricultural Research Institute, and presented a road map for future research programs in the banana breeding programme. During a hybridisation programme, although many crosses were made, seed set and seed germination were relatively poor in many crosses. Generation of parthenocarpic hybrids depends largely upon selection and utilisation of parents with parthenocarpic pedigree in a breeding programme. Evaluation of hybrids and parents indicated the nature of inheritance with respect to plant height and suckering habit, but no definite trend could be ascribed to the traits of bunch orientation. Triploid (AAB) X Diploid (AA) x Diploid (BB) breeding approach has led to identification of a superior triploid hybrid, CO 1 (AAB), while Triploid x Diploid approach has led to the development of a promising diploid hybrid CO 2 (Karpooravalli (ABB) x Pisang Lilin (AA)) and triploid hybrid CO 3 (AB) banana (Karpooravalli x H 201), Banana Kaveri Kanchan (Nendran x cv. Rose), ICAR- NRCB has released new varieties like Udayam, Kaveri Saba, Kaveri Kalki, Kaveri Sugantham, Kaveri Haritha and Kaveri Kanya and BRS 1 and BRS 2 from kerala to meet out various stressors. New varieties are required to boost the morale of banana farmers and other associated stakeholders.

**Keywords:** *Banana, breeding, India, hybridisation, genetic resources*

**Introduction**

“Banana (*Musa spp*.) is a perennial monocotyledonous herbaceous fruit crop originating from Indo-China and Southeast Asia about 7000 years ago, known for income generation in tropical regions of the world” (Ssebuliba et al., 2006). “Banana is one of the most important cash crops and contributes immensely to global food security” (Esan et al., 2022; Tripathi et al., 2020). “Owing to its greater socio-economic significance and multifaceted uses, the banana is popularly known as ‘Kalpataru’ (A plant with virtues)” (Arthi, L. R., & Shakila, 2023). “This fruit holds major economic value, accounting for over 16% of global production and trade in fresh produce” (Huang et al, 2023). “Botanically, bananas belong to the Musaceae family and are classified as monocotyledonous plants within the Musa genus. Species in the genus were initially divided into five sections, namely Eumusa (2n = 22), Australimusa (2n = 20), Rhodochlamys (2n = 22), Callimusa (2n = 18 or 20), and Ingentimusa (2n = 14)” (Simmonds, 1962); “later, they have been subdivided into two sections, namely Musa (Eumusa and Rhodochlamys) and Callimusa (Australimusa, Callimusa, and Ingentimusa), based on phylogenetic analyses” (Häkkinen, 2013). “Many economically important sub-groups of bananas, such as plantain (AAB), an important staple food in Africa, contain at least one B genome” (Tripathi et al., 2019). More than 70 wild species exist in the Musa genus, typically distinguished by their gravelly hard seeds and minimal pulp.

“Regarding the nutritional aspect of banana, when it is in the green phase, its main components include starch (mainly resistant starch), phenolic compounds, and antioxidants, which are excellent alternatives for processing” (Campos et al., 2024). “The evolution and selection from wild to edible bananas involved seedlessness, improved plant vigour, increased hardiness, and higher yield” (Nayar, 2010). “There are more than 1000 varieties of banana cultivated all over the world; however, the Cavendish varieties of banana are considered one of the most important commercial varieties” (Tripathi et al., 2019; Thangavelu et al., 2021). “Banana cultivation largely regulates the agri-based global bioeconomy. Hence, understanding the associated challenges in its production and developing appropriate strategies for addressing these concerns is of paramount importance. In recent years, there has been increasing interest in growing healthy and commercially important cultivars of bananas. Further, in the last few decades, banana production has been under threat due to different climatic factors and pathogenic agents such as bacteria, viruses, fungi, and nematodes” (Tripathi et al., 2019).

Musa has two genomic groups: Musa acuminata (AA) and Musa balbisiana (BB). Moreover, bananas can be classified into three classes based on ploidy levels: diploid class, which has letters AA, AB, BB; triploid class with AAA, ABB, AAB; and tetraploid class with AAAA, ABBB, AABB, AAAB (Šimoníková et al.  2020). Banana fertility depends on ploidy, an essential factor to consider during breeding (Karamura et al.  2016). Most of the cultivated bananas are triploid and do not produce seeds. Therefore, plant suckers are required for clonal propagation and multiplication, which is often unreliable because an infected sucker used for propagation might be the leading cause of disease and pest spread (Sivirihauma et al. 2017).

“To circumvent these challenges and to produce agronomically superior disease-resistant banana crop, various traditional breeding methods have been employed such as diploid breeding” (Rowe, 1984), “3x/2x strategy (pollination of susceptible triploids with male fertile diploids that are resistant), and 4x/2x strategy which involves the production of a tetraploid parent by chromosome doubling of an ancestral diploid with good agronomic trait followed by the production of triploid hybrids through hybridization of a diploid parent with the tetraploid” (Menon, 2016). However, “polyploidy in Musa is the biggest challenge in banana breeding, which ranges from diploid to tetraploidy” (Nansamba et al., 2020).

“Genetic improvement of bananas is important to create new elite hybrids possessing traits of agronomic excellence, such as high yield, combined with resistance or tolerance to biotic and abiotic stresses. Other desirable characteristics include excellent fruit quality, early flowering/maturity, short stature, photosynthetic efficiency, minimum period between successive harvests, strong roots, cylindrical bunches of fruit, and fruits of uniform size” (Bakry et al. 2009). “Initially, genetic improvement programs were conducted mainly to address some of the constraints of banana production, including the detrimental effects of pests, diseases, drought, and low yields” (Pillay & Tripathi 2007). In general, progress in banana breeding has been slow because of very limited research on this crop in the past. Other inherent problems include polyploidy, parthenocarpic fruit development, low female fertility, and the generation of asexual progeny in sufficient numbers to recombine desirable characters.

“Thus, the development of a new banana cultivar is very exhaustive via breeding because the selection of desirable characters can take more than 12 years” (Menon, 2016). “A high level of heterozygosity and the requirement of a large population for the selection of individual clones with desirable agronomic traits make it more cumbersome. Moreover, introgression of desired gene loci from diploid wild cultivars of banana also carries certain undesirable traits such as non-parthenocarpy and low yield” (Menon, 2016). This paper highlights the research programmes conducted and hybrids developed with special emphasis on the contribution of the India agricultural Research Institute and provides a roadmap for carving out future research programmes for the banana breeding programme.

1. **History of banana breeding**

The interest in banana and plantain breeding emanated from increased disease (Panama wilt) pressure that has been threatening the crop productivity and sustainability since the beginning of the century, mainly to improve the ‘Gros Michel’ dessert banana. Banana breeding started as early as 1922 in Trinidad and 1924 in Jamaica (Stover and Buddenhagen, 1986). Now the research station at Bodles in Jamaica is looking after both the programmes, funded by Banana Board of Jamaica. Another very important breeding programme in Central America is that of “*Fundación Hondurena de Investigación Agricola”* (FHIA), Honduras, which was initially established by the United Fruit Company in 1959. These programmes were primarily directed towards the needs of the export trades. The FHIA has developed various types of hybrids, some of which are currently being distributed in several countries.

The International Institute of Tropical Agriculture (IITA), Nigeria, started research on plantain and banana in 1973 and initiated a breeding programme in 1987 to develop black Sigatoka resistance in plantain genotypes. Banana breeding in Brazil was initiated in 1982 by Empresa Brasileira de Pesquisa Agropecuária (EMBRAPA) at Cuz Das Almas, Bahia. Since that time, emphasis has been shown on the improvement of Pome (AAB) and Silk (AAB), which are locally known as Prata and Maca, which are of great importance in Brazil. The French CIRAD–FLHOR Musa breeding programme began in 1983 with grants provided by the EEC (European Economic Community). The CIRAD–FLHOR research stations are located in Guadeloupe, Martinique and Nyombe in Cameroon (West Africa), with their main offices and laboratories in Montpellier, France. Other institutes pursuing banana and plantain breeding programmes are FAO / IAEA, Austria, Katholieke Universiteit Leuven, Belgium, Taiwan Banana Research Institute, and Queensland Agricultural Biotechnology Centre, Australia.

In collaboration with scientists, the breeding program generated resilience. It started productive tetraploid hybrids for use as parents and started a project to generate high-yielding, resistant triploid hybrids (Nowakunda et al. 2023). The goal of the NARO-IITA initiative remained to improve banana cultivars with resistance to various diseases and pests, high and consistent yields, better agronomic features, and acceptable fruit quality. Although progress is being made, the banana breeding program is limited by some inherent reproductive banana challenges (Šimoníková et al. 2020), including low or infertility of most grown triploid banana cultivars and difficulties in seed production (Perrier et al. 2019). The conventional breeding method involves long generation cycles, which prolong cultivar release (Sipen et al. 2011).

Although the compatibility of parents used in pollination and the production of viable seeds are among the factors considered in successful breeding, bananas develop fruit through the parthenocarpy system. Some cultivars can develop a few seeds with very low germination rates because of their hard surface structure (Batte et al.  2019). It was reported that undesirable characteristics of banana hybrids were produced during conventional and regular breeding (Khan et al. 2009). Unsuccessful results from the conventional breeding of bananas are sometimes associated with unfavourable linkage genes from diploid parents (de Carvalho Santos et al.  2019). Polyploidy and low genetic variability of cultivated bananas are a big challenge to conventional breeding (Sipen et al. 2011). Most of the time, the banana polyploidy nature is characterised by abnormal meiosis, mainly in triploid cultivars (Šimoníková et al. 2020). The presence of irregular chromosome pairing and unstable chromosome segregation during the meiosis phase is the main factor that induces low or no fertility in most cultivated bananas (de Carvalho Santos et al. 2019).

“In India, breeding work was started at the Central Banana Research Station, Aduthurai, Tamil Nadu, in 1949. During this period, due to the lack of knowledge on the cytogenetics of bananas, the wild species like *M. acuminata, M. balbisiana, M. laterita* and *M. chiliocarpa* were used as male parents. Commercial triploid cultivars of bi-specific origin are Poovan (AAB), Rasthali (AAB), Peyan (ABB), Thote (ABB), Peykunnan (ABB-Pisang Awak), Rajavazhai (ABB), Ney Vannan (ABB), *etc*., were used as female parents” (Sathiamoorthy, 1973). The progenies were mixtures of diploids, triploids, tetraploids, pentaploids and aneuploids. In the crosses of Monthan (3n) × *M. coccinia* (2n) and Monthan (3n) × *M. chiliocarpa*, the progenies were diploids and seeded.

The programme was later shifted to the Tamil Nadu Agricultural University (TNAU) at Coimbatore. Since its formation in 1997, the Banana Research Station (BRS) Agricultural University (KAU) has also been engaged in banana improvement of ‘Nendran’ (Plantain-AAB). Besides, the National Research Centre on Banana (NRCB), Trichy, established in 1994, is currently involved in crop improvement in banana.

Hamill *et al*. (1992) suggested that “the production of triploid hybrids by crossing naturally occurring or artificially synthesised autotetraploids with improved disease-resistant diploids has been identified in recent times as a promising way to increase productivity”. Vuylsteke *et al.* (1993) obtained 120 hybrids by crossing triploids with diploids, of which 92 were diploids, 6 were triploids, and 22 were tetraploids. Similarly, Ortiz (1997) also obtained 45 diploids, 3 triploids and 6 tetraploids in Bobby Tannap x Calcutta 4 and 14 diploids, 2 triploids and 13 tetraploids in a cross of Obino I Ewai x Calcutta 4. Osuji *et al.* (1997) also obtained two aneuploids, one diploid and two tetraploids from 3n x 2n crosses.

Oselebe *et al.* (2006) reported that progenies of 2n x 2n crosses were predominantly diploid (99.7%), those of 2n x 4n crosses were obtained mainly from diploid (96.2%), while the 4n x 2n crosses produced predominantly triploid progenies (94.1%).

1. **Genetics of resistance**

Rowe and Richardson (1975) reported that “nematode resistance in banana is controlled by multiple gene action (Pisang Jari Buaya group of banana accessions possessed resistance gene(s). Banana breeders have extensively used it to evolve resistant hybrids. Some banana cultivars possessed one or more dominant alleles to control resistance to burrowing nematode” (Rowe, 1984).

Buddenhagen (1987) reported that “the knowledge on the genetics of resistance in banana to *Fusarium* wilt is limited. A major problem in banana breeding is understanding the genetics of resistance or susceptibility to *Fusarium* wilt, which is the result of complex interactions operating over time and involving inoculum dose, inoculum genotype and environmental conditions. What is really needed is to develop selection procedures, disease assessment methods, and scaling techniques that would reveal the true range of genetic interactions, rather than grouping into two categories, “resistant” and “susceptible”, as wilt disease resistance is largely due to major vertical genes. However, analysis of both seeded diploid sub-species of *Musa acuminata* and the diploid parents used in breeding is required to determine more precisely how many major genes are operating for resistance”.

 Rowe (1984) reported that the genetic resistance of the burrowing nematode was controlled by one or more dominant alleles. Baker *et al*. (1997) indicated that R genes are involved in signal transduction, and five different crosses were now recognised based on the predicted protein domain of the gene.

“Calcutta-4 (*Musa acuminata* ssp. *burmaniccoides*) is highly polleniferous and a female-fertile parent is an important potential gene source for improving commercial cultivars for resistance to the *Mycosphaerella* leaf spot complex and *Fusarium* wilt” (Uma *et al.,* 2011).

1. **Breeding Objectives**

“Since the 1920s, priority in all genetic improvement programmes has been given to the development of varieties resistant to diseases and pests. The secondary objectives are more specifically linked with socio-economic aspects of production and natural susceptibilities of varieties. For export bananas, studies have been oriented towards early flowering, highly productive varieties, with perfectly cylindrical fruit bunches and uniform-sized fruit, as this facilitates their packaging and marketing. For domestic markets, varieties need to have high tolerance to biotic and abiotic stresses. They must have strong root systems to enable good soil anchorage and effective uptake of water and mineral resources. Finally, they should be able to withstand primitive transportation and preservation conditions. Preference should be given to small-sized varieties that are less sensitive to gusts of wind that can break the pseudostems and even uproot the plants. Concomitantly, recent advances in molecular biology and in tissue culture have opened new avenues (tissue culture techniques including protoplast somatic hybridisation and genetically modified organisms) to meet breeding objectives” (Hwang and Ko 1990; Remy et al. 1998; Ha¨ıcour et al. 2004; Smith et al. 2006). “Introduction of exogenous genes in current varieties will probably enable breeders to obtain varieties resistant to viruses in the near future. Finally, some research groups envisaged the utilisation of genetically transformed bananas for vaccinating humans in the developing countries” (Sala et al. 2003).

## Improvement of the diploid male parents

## “Improvement of the diploid male parents in many countries where bananas are grown, initial breeding efforts used wild diploid bananas (AA) as male parents. However, this approach led to the inheritance of undesirable traits in the resulting tetraploid offspring. As a result, banana breeders recognised the importance of creating a superior male parent. The ideal male parent should have strong resistance to Panama and Sigatoka diseases, as well as compact bunches with upright orientation. Additionally, it should produce large fruits within the limits of diploidy and exhibit parthenocarpy, while still providing enough pollen for use in breeding. The National Research Centre for Banana and the TNAU have successfully developed numerous monospecific and interspecific diploid hybrids. More recently, they have focused on using fertile diploid AA hybrids resulting from 3x/2x crosses as parents for creating high-quality diploid varieties. Specifically, they have produced plantain hybrids that show resistance to Panama wilt and sigatoka leaf spot diseases (SLSDs), while maintaining the desirable fruit characteristics of plantains. This approach has been particularly adopted by organisations like CARBAP and IITA to develop diploid varieties tailored to specific sub-groups, including plantains and East African highland bananas” (Ha¨ıcour et al. 2004).

## Diploid breeding

Diploids are the main source of genetic variability in breeding programmes to develop new commercial hybrids. Before any attempt is made to improve cultivated triploids, it is necessary to improve the diploids to be used as parents. The diploid breeding programme was initiated in 1943 by Dodds to develop superior diploids in Jamaica. Dodds (1943) reported that “the future of banana breeding depends on the development of superior diploid male parents and seeking commercial bananas among the primary tetraploids produced from crossing onto Gros Michel. The ideal pollen parents should possess disease resistance, good agronomic features, viable pollen, parthenocarpy and seed sterility”.

“In 1980, three advanced diploids from the FHIA breeding program were evaluated for reaction to race-4 from Taiwan” (Stover and Buddenhagen, 1986). “Among the hybrids developed, SH2095, SH2989 and SH3142 were chosen as potential diploid parents in resistance breeding because of their diverse pedigree. SH2095 was the first bred diploid with excellent bunch characters” (Rowe, 1984). “Diploid breeding at Tamil Nadu Agricultural University, Coimbatore, primarily involving the use of diploid varieties *viz*., Anaikomban (AA), Namarai (AA), Erachivazhai (AA), Pisang Lilin (AA) and Tongat (AA) as male parents with Matti (AA) as the female parent, led to the development of potential synthetic diploid hybrids *viz.* H 21, H 59, H 65, H 74, H 84, H 95, H 65, H 74, H 95, H 109 and H 201. Many of the synthetic diploids have been found to have good resistance to burrowing nematodes, Sigatoka leaf spot and *Fusarium* wilt” (Sathiamoorthy, 1973 and 1987). These hybrids, when tested for *Fusarium* wilt, revealed that H 65, H 103, H 109 and H-201 were found resistant (Gunavathi, 2000).

Uma *et al*. (2011) evaluated “15 diploids including nine parthenocarpic and six wild diploid accessions for various traits like resistance to nematodes, *Fusarium* wilt, drought and provided some baseline information on factors affecting seed set (like temperature and relative humidity), extent of seed set in diploid cross combinations, germination success (0 - 92 %) and regeneration capacity (2.5 - 98.3 %). Further, they reported that the percentage success of banana breeding depends mainly on the use of natural diploids and on developing superior synthetic diploids”.

## Triploid breeding

“Triploid cultivars are preferred over tetraploids for many reasons. Triploids have several advantages over tetraploids as commercial hybrids. They retain their leaves longer without the premature petiole breakage, which is common in some tetraploids” (Simmonds, 1952). Rowe and Richardson (1975) reported that “higher levels of disease resistance can be bred into the hybrids by using diploids twice in 4n × 2n crosses as opposed to the use of a single diploid in the synthesis of tetraploids. A potentially feasible method of broadening the genetic base of commercial type hybrids is to make 4n × 2n crosses and select seeded triploid progenies for further crosses.”

 “At IITA and FHIA, triploid breeding was initiated by crossing primary tetraploid hybrids (TMPx) derived from triploid x diploid crosses with either diploid hybrids selected in Honduras (SH) or plantain-derived diploid (TMP2x) from Nigeria. It resulted in the development of five triploids, *viz.*, PITA-15, PITA-16, PITA-19, PITA-20 and TM3x. Among these, TM3x triploid yielded with partial resistance to black Sigatoka leaf spot disease” (Ortiz and Vuylsteke, 1998).

“Hybridisation work was carried out at Tamil Nadu Agricultural University, Coimbatore, in banana with cultivars like Poovan (AAB), Rasthali (AAB), Peyan (ABB), Thote (ABB), Pey Kunnan (ABB), Rajavazhai (ABB) and Ney Vannan (ABB) as female parents for developing commercial triploids of bispecific origin. The cross between Kallar Ladan (AAB) x *M. balbisiana* clone Sawai resulted in one progeny with AB genomic makeup. This hybrid was again crossed with Kadali (AA) to develop a triploid hybrid H 135, which was released later as Co-1 banana from TNAU” (Azhakiamanavalan *et al.,* 1985). This belongs to the Pome group and closely resembles Virupakshi (AAB), another popular ‘Pome’ banana in the hills of Tamil Nadu. The bunch weight weight 10.5 kg on average with 7 hands and 80-85 fruits.

Rowe (1984) opined that most of the existing natural triploids of commercial importance were susceptible to many pests and diseases. Hence, new methodologies have been formulated to synthesise triploids, which include the development of primary tetraploids by crossing female triploids with male diploid parents, (3n x 2n) respectively. Tezenas *et al.* (1994) reported that triploids can also be synthesised by crossing a tetraploid with another homozygous diploid line. Triploid x diploid breeding attempted at Kerala Agricultural University, Thrissur, also led to the release of two triploid hybrids, namely BRS 1 (Agniswar × Pisang Lilin) and BRS 2 (Vannan × Pisang Lilin), with the genomic make-up of AAB. BRS1 is almost immune to Sigatoka leaf spot and resistant to nematodes, whereas BRS2 is resistant to Sigatoka leaf spot and nematodes (Menon *et al.,* 2011).

## Tetraploid breeding

“Hybridisation between triploid and diploid cultivars often results in many primary tetraploids. In the hybridisation programme at Trinidad, Gross Michel, when crossed with
*M. acuminata* ssp. *malaccensis* resulted in the development of a tetraploid hybrid IC-2, which had bunch characteristics similar to Gros Michel along with Panama wilt resistance. However, the hybrid had disadvantageous features like weak leaf petioles and tall plants, which led to its failure as a cultivar” (Cheesman, 1932; Larter, 1934; and Dodds, 1943a). “These primary tetraploids in their subsequent crosses with other tetraploids and diploids resulted in inferior tetraploid and triploid progenies” (Dodds, 1943b).

“The tetraploid hybrid SH-927 obtained from a cross between diploid Lidi onto Cocos was reported to be resistant to race 1 of Panama disease, and it had desirable agronomic qualities” (Larter, 1934; Rowe and Richardson, 1975). “Tetraploid, derived from Low gate, was found comparable to Cavendish for fruit quality. In banana, the triploid cv. High Gate (a dwarf mutant of Gros Michel) was used extensively as a female parent in crosses with synthetic diploids. These 3n x 2n crosses generated tetraploids” (Shepherd, 1990). “Hybridisation between 3n x 2n has resulted in many tetraploids, which are of economic importance. Breeding work done at FHIA had resulted in the development of two tetraploids, *viz*., SH 3444 and SH 3446, respectively, which exhibited resistance to race 1 of Panama wilt disease” (Rowe, 1984).

 “Several tetraploid hybrids, *viz*., PITA 14, BITA 1, BITA 2, BITA 3, FHIA 1, FHIA 2, FHIA 3, FHIA 17 and FHIA 21, were developed and released for commercial cultivation, which are resistant to the Black sigatoka leaf spot (*Mycosphaerella fijiensis*) at the International Institute for Tropical Agriculture (IITA), Nigeria” (Ortiz and Vuylsteke, 1998). Krishnamoorthy (2002) developed 18 tetraploid hybrids by crossing Pey Kunnan (ABB, Syn: Pisang Awak) as female parent and Red Banana, Robusta, Pisang Lilin and Erachivazhai as male parents. Damodaran (2004) developed three primary tetraploids, *viz.*, H-03-13, H-03-17 and H-03-19 by crossing triploids with diploids (AA).

The crossing of 3n x 3n strategy can be widely used to create tetraploid hybrids with resistance to diseases and for good agronomic value. Kavitha (2005) crossed a primary tetraploid hybrid H-02-32 (AABB) with Pisang Lilin (AA) and obtained tetraploid hybrids, *viz*., H-04-05 (AABB) and H-04-06 (AABB), which were resistant to *P. coffeae*. Assuming nuclear restitution, Pillay *et al*. (2008) indicated that tetraploid hybrids inherited nearly 75 per cent of their genes from the triploid landrace gene pool and 25 per cent from the diploid parent sources. With normal meiosis, progenies derived from 4n × 4n crosses could potentially have 50 per cent of their genes donated by each parent and were more likely to inherit favourable alleles from the parents.

**Figure 1.** Development of polyploid cultivars in banana

**Table 1. Details of varieties released from South India**

|  |  |  |  |
| --- | --- | --- | --- |
| S.No. | Variety/hybrid | Parentage  | Traits |
| TNAU, Coimbatore, Tamil Nadu |
| 1. | CO 1 Banana | Ladan x *Musa balbisiana* (AAB). (BB) clone 'Sawai'. F1 (AB) x Kadali (AA) | It is akin to hill banana Virupakshi (AAB). It is suitable for growing in the plains as well as in the hills up to 1220m. The crop duration is 14 to 15 months. The mean bunch weight is 10.57kg with seven hands per bunch and a total of 83 fruits per bunch. The fruits contain a TSS of 22.6° brix and an acidity of 0.58per cent. The fruits will be sweet only after full ripening, and before that, acidic in taste. |
| 2. | CO 2 Banana | Karpooravalli (ABB) x Pisang Lilin (AA) | * Average bunch weight is 12-13 kg with 12-14 hands/ bunch and 150-160 fingers/bunch.
* Fruits have a subacid taste with an acceptable blend of sugar and acid (TSS 24-26 Brix). It can be propagated by suckers
* This improved culture has tolerance to nematodes, a lesser incidence of Sigatoka leaf spot and Fusarium wilt
 |
| 3. | CO 3 Banana | Karpooravalli (ABB) x H 201 (AB) | * Yield: 70-75 tonnes/ha
* Tolerant to nematodes (Root lesion Index
* 15.74 as against 42.85 in Karpooravalli)
* All banana growing regions in Tamil Nadu
* Akin to Karpooravalli
* Devoid of ashy coating
* Lesser plant height (3.0 m)
 |
| ICAR- NRC for Banana, Trichy, Tamil Nadu |
| 4. | Udhayam  |  | * This hybrid is developed by single plant selection

from Pisang Awak (AAB) subgroup at the National Research Centre for banana, Trichi.* Plant is hardy, tall, robust, and bunch weight varies from 30-35 kg.
* Hands are well spaced with a cylindrical shape, which facilitates packing, loading and transport with minimum damage.
* Fruit quality is medium; sugar acid blend is good with maximum yellow life (7days).
 |
| 5. | Kaveri Saba |  | Drought-tolerant, suitable for marginal cultivation and saline sodic soils with a pH ranging from 8.8 to 9.0. |
| 6. | Kaveri Haritha |  | High yield of 28-30 kg (20% over local Monthan), stable over a period of 4 years (main crop + 2 ratoon crops) and good fruit quality with mealy texture |
| 7. | Kaveri Kalki (Namwa Khom) |  | Dwarf stature, short duration, suitable for high density planting under an annual cropping system and tolerant to wind damage |
| 8. | Kaveri Sugantham (Manoranjitham mutant) | Derived from a somaclonal variant of the tissue-cultured Manoranjitham | Aromatic banana. High yield potential (up to 27 kg), resistant to Sigatoka leaf spot, and sable yield up to three ratoons. |
| 9. | Kaveri Kanya |  | Resistant to wilt, good bunch weight. |
| 10. | Banana Kaveri Kanchan |  | * Pro vitamin A enriched dessert banana • Contains 30 and 40-fold higher PVA (2.4 mg/100g) than ruling cultivars Rasthali and Grand Naine, respectively.
* Weight of bunch: 23 kg (20% higher yield than Plantain type cv. Nendran). • High TSS (24.6°Brix)
* Resistant to Fusarium wilt (Foc race 1 & TR4).
 |
| Banana research station, Kannara, Kerala  |
| 11. | BRS 1 | Agniswar x Pisang Lilin | * It is a triploid hybrid of banana by crossing Agniswar x Pisang Lilin developed at the Banana Research Station, Kannara, Kerala Agricultural University.
* It is a medium-tall plant, supporting 14-16 kg bunch without propping.
* Elongated fruits turn attractive golden yellow on ripening.
* Slightly acid fruits.
 |
| 12. | BRS 2 | Vannan x Pisang Lilin | * It is a hybrid of Vannan x Pisang Lilin developed at Kannara Banana research station, Kerala Agricultural University.
* It is a medium-stature plant.
* Average weight of bunch ranges from 15-20 kg with short, stout, dark green Poovan-like fruits which are arranged compactly.
* Fruits are slightly acidic with a pleasant sweet-sour aroma.
 |

**CONCLUSIONS**

Sustainable banana production is vital to ensure a constant supply of fruit to meet world food demand. However, fruit production faces challenges from changing economic, social, and environmental conditions. The genetic improvement of the banana is one of the strategies to ensure sustained production. In India, the traditional banana breeding presents challenges of sterility and polyploidy with long generation cycles. Improving plant immunity by activating plant defence mechanisms is the most sustainable way against pathogen disease. Plant genetic modification is the best approach for developing new cultivars with desirable traits. India’s share in the World Banana trade is negligible. Newly emerging threats such as fruit scarring beetle, banana skipper, TR4 wilt disease and viral diseases need to be controlled and managed efficiently without adding additional burden to the farmers. In addition to addressing the existing lacunae in the research needs to be initiated to breeding programme to safeguard the banana industry from dwindling water resources and anticipated threats due to Climate change. High-yielding disease-resistant bananas will reduce the yield gap. In the long term, genetically improved banana cultivars could ensure sustained fruit production for food security, with the additional advantage of guaranteed income for farmers in producing countries.

**FUTURE SCOPE**

The future of banana breeding programs holds significant potential for addressing various challenges, including disease management, climate change, and nutritional needs, while also improving the overall sustainability and profitability of banana cultivation. Collaboration, innovation, and a focus on consumer and farmer needs will be crucial in shaping the future of banana breeding programs.

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**References**

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