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Banana research and development programme in India and highlights of NRCB-INIBAP collaborative projects

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Introduction

Banana has occupied a top position in India's booming fruit industry with an annual production of 13.5 mt from an area of 4.0 lakh ha. But India has a vision for increasing the production to 25 mt by the end of 2020 AD and has been addressed systematically during the last decade. This is witnessed in the steady increase in production and productivity and presently touching 13.5 mt. But still there is a long way to go to achieve target yield potential, which is being threatened from time to time by various biotic and abiotic stresses associated with banana production.

*Research and development programmes: Objectives of **Musa** improvement programme in India*

Earliest banana improvement programme in India started in the year 1949 at Central Banana Research Station in Aduthurai in Tamil Nadu. The programme continued in Tamil Nadu Agricultural University after its formation in 1971. Improvement was also initiated in Kerala Agricultural University in Thrissur in 1982. National Research Centre on Banana (NRCB), Trichy, established by the Indian Council of Agricultural Research (ICAR) in 1993, has also initiated and pursuing banana improvement programmes, coordinating at national level. Viewing the polyclonal situation in India and the research needs, the objectives of banana improvement programme at national level are:

1. Collection, conservation and evaluation of *Musa* germplasm with complete documentation
2. Screening of germplasm for their reaction to pests and diseases
3. Identification of accessions resistant/tolerant to major production constraints like fusarium wilt (*Fusarium oxysporum* f.sp. *cubense*), leaf spot diseases and nematodes (*Radopholus similis, Meloidogyne incognita* and *Pratylenchus coffeae)*
4. Hybridization and selection to evolve potential synthetic diploids and primary tetraploids to further generate triploid hybrids having good horticultural traits coupled with resistance or tolerance to pests and diseases
5. *In vitro* approaches to create variability complementing current breeding programmes

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Explorations and germplasm collection

In explorations conducted by National Bureau of Plant Genetic Resources (NBPGR) in collaboration with IIHR, Bangalore in northeastern states of Assam, Arunachal Pradesh and Meghalaya led to the identification and collection of 60 accessions. Collection expeditions were also made in 1990 by NBPGR regional station, Thrissur and local accessions were collected. Exploration expeditions conducted in 1999 by NRCB in three northeastern states, Assam, Arunachal Pradesh and Meghalaya led to the collection of accessions including both wild and cultivated types. Though there are earlier reports about Indian variability with respect to section *Rhodochlamys* apart from *Eumusa*, the recent explorations made by NRCB have confirmed the occurrence of *Rhodochlamys* and many types of *Musa ornate*, *Musa velutina* in the forests of Arunachal Pradesh and Assam. Occurrence of *Ensete glaucum* has been reported for the first time in India by NRCB during these explorations.

NRCB has an exclusive collection of 690 accessions representing various sections, species and genomic groups. The accessions are maintained in duplicates under various agroclimatic zones in the country. The details are provided in Table 1.

Table 1. Varietal holdings of banana field genebanks in India.

Genebank	*State*	*No. of accessions*	*Zone*
NRCB, Trichy	Tamil Nadu	690	South India
TNAU, Coimbatore	Tamil Nadu	127	South India
BRS, Kannara	Kerala	212	South India
BRS, Kovvur	Andhra Pradesh	160	South India
GAU, Gandevi	Gujarat	86	West India
IIHR, Bangalore	Karnataka	320	South India
AAU, Jorhat	Assam	96	Northeastern India
AAU, Kahikuchi	Assam	87	Northeastern India

Clonal selections

At NRCB, emphasis was laid on identifying the accessions from the genepool to substitute the local commercial accessions with better traits. *Musa* genepool was evaluated for a number of characters like growth and yield parameters, tolerance to biotic and abiotic stresses, breeding behaviour, etc. to explore the possibility of utilisation in improvement programmes, either through direct selection or in conventional breeding programmes. The evaluation of germplasm led to the identification of five indigenous and three exotic accessions from ITC collections, which are promising to adapt to marginal growing conditions in India.

A high-yielding diploid accession of Sanna Chenkadali (AA), which was observed to be highly resistant to leaf diseases and field tolerant to nematodes, infectious chlorosis and shade, is also highly resistant to bacterial heart rot disease caused by *Erwinia*. However, due to poor pollen production and female fertility, it could not be utilised so far in the breeding programmes and efforts are presently underway to produce tetraploid forms of this resistant source by *in vitro* polyploidisation. Embryo abortion leading to empty seeds is a common feature in this clone. Other clonal selections have also been made in Cavendish group and two potentially high yielding selections - one each from Grande Naine and Giant Cavendish are under advanced stages of evaluation. Other selections under different stages of evaluation under All India Coordinated Research Projects (AICRP) on Tropical Fruits are mentioned below.

Table 2. Promising accessions under evaluation for commercial exploitation.

Accession number	*Genomic group/ Subgroup*	*Utility*	*Superiority of traits*
0016	ABB-Monthan	culinary	High yielding, shorter crop cycles of both main crop and ratoon, yield stability over years
0030	ABB-Silk	dessert	High yielding and good fruit quality
0079	ABB-Pisang Awak	dual	Dwarf stature, high yielding, yield stability over years & tolerance to yellow sigatoka
0052	ABB-Ash Monthan	culinary	Highly tolerant to sodicity, yield stability over years & good quality fruits
0252	ABB-Bontha (unique)	culinary	Consistently high yielding, good quality fruits, suited to sodic soils
0626	AAAB-Pome (exotic)	dessert	Tolerance to black sigatoka, tolerance to fusarium wilt, dwarf stature, suited to windy areas without requirement of support
0634	ABB-Bluggoe (exotic)	dual	High yielding, tolerance to sodicity, yield stability
0636	ABB-Bluggoe (exotic)	dual	High yielding, highly tolerant to sodicity, yield stability and suitability to marginal conditions

Clonal selections were also made in Cavendish group and two potentially high yielding selections; one each from Grande Naine and Giant Cavendish has been made. Unfortunately, these high yielding clonal selections of Cavendish group are highly susceptible to nematodes and leaf inspite of their very high yielding potential of up to 60 kg.

Hybridisation programme

Though breeding programme in India was started as early as 1949 at CBRS, Aduthurai, it had no significant results since the programme lacked defined objectives. However, it generated a lot basic information on cytogenetical aspects, which were found useful in formulating better strategies for *Musa* improvement programmes. Systematic work was initiated on banana breeding in TNAU, KAU and later at NRCB.

Improvement in Pome (AAB) group

They are one of the elite groups favoured in southern India. Pome cultivars are generally grown in cool mid hill ranges where they develop characteristic flavour and taste. An attempt was made to improve a pome cultivar called Kallar Ladan. One of the AB hybrids from the cross Kallar Ladan (AAB) x *M. balbisiana* clone Sawai was used to cross with cv. Kadali (AA) to develop an AAB Pome hybrid. This was later released for commercial cultivation as Co-1 banana. This belongs to Pome group and closely resembles Virupakshi (AAB-Pome), another popular hill banana in Tamil Nadu. It retains the typical acid / apple flavour of Virupakshi even when grown in plains contrary to Virupakshi, which develops aroma only when grown at higher altitudes.

H-1 (Agniswar x Pisang Lilin): It is a promising hybrid owing to short cropping cycle, immunity to leaf spot, fusarium wilt and burrowing nematode (*Radopholus similis*). It is a medium tall plant, supporting 14-16 kg bunch without propping. Elongated fruits turn attractive golden yellow upon ripening. It is slightly acidic which vanishes upon full ripening with high sugar content. H-1 has a remarkable faster rate of ratooning ability completing four crop cycles in three years. Multilocational trials have shown its acceptability among growers and consumers especially in Andhra Pradesh. Immunity to leaf spot diseases, one of its unique traits, has made this hybrid highly appreciable among growers.

Improvement of Mysore (AAB) group

The hybrids produced from the crosses of Palayankodan (AAB) x Pisang Lilin (AA) were all tetraploids (AAAB) with tall stature. The ploidy level and genomic status were confirmed by chromosome counts and taxonomic scoring. All of them recorded a low incidence of leaf spot disease compared to the susceptible female parent. The hybrids resembled Palayankodan morphologically and some of them were superior to it in terms of yield and fruit quality. The majority of hybrids were found to be female fertile and are in the process of further improvement.

H-2: A hybrid of Vannan x Pisang Lilin developed at Banana Research Station (KAU) Kannara is a medium-statured plant growing up to 2-2.5 m. Crop cycle is short, only 11-12 months. The bunch weight ranges from 15-20 kg with short, stout, dark green Poovan-like fruits, which are arranged very compactly. Fruits are slightly acidic with pleasant sweet-sour aroma. Its immunity to leaf spot diseases and nematodes makes it a suitable for subsistence cultivation.

Table 3. Bunch characters and quality of hybrids and their parents.

Hybrids	Days to Harvest			Bunch weight			No. of fingers			TSS	Acidity
	IC	IR	IIR	IC	IR	IIR	IC	IR	IIR		
H1	322	193	187	12.4	14.8	14.7	113	111	116	27.4	0.29
H2	329	286	252	14.4	15.0	15.5	179	182	198	25.6	0.25
Agniswar	368	220	212	6.9	6.2	6.8	105	87	90	26.7	0.28
Vannan	356	225	220	7.6	7.8	6.7	108	85	86	25.1	0.28
Pisang Lilin	242	157	146	4.7	4.9	4.0	60	65	52	27.6	0.24

IC-plant crop; IR-first ratoon; IIR-second ratoon; H1- (Agniswar x Pisang Lilin); H2- (Vannan x Pisang Lilin);

Secondary triploids were produced from the primary tetraploid hybrids by crossing with acuminata diploids like Pisang Lilin, Matti (AA), Tongat (AA) and Sanna Chenkadali (AA). The hybrids evolved were triploids with tolerance to leaf spot disease. The bunch weight varied from 5 to 15 kg in the hybrids, but the fruits were smaller in size than that of Palayankodan. The fruits developed golden yellow colour with less acidity and better keeping quality. Synthetic diploids with good bunches and resistance to leaf spot diseases were also evolved which could be used as male parents in further hybridisation programme involving commercial plantain cv. Nendran.

Diploid breeding

Diploid breeding primarily involved the use of Anaikomban, Namarai, Erachi Vazhai, Pisang Lilin and Tongat (all AA) as male parents with Matti (AA) as female parent. Matti is resistant to leaf spot diseases while Anaikomban (AA) is resistant to nematodes. Namarai was also chosen, as it was relatively free from Panama disease and tolerant to nematodes. The diploids, Pisang Lilin and Tongat were known for their resistance to nematodes and Panama disease.

The diploid hybridisation work does not always result in pure diploid progenies. Frequently, due to single and double restitution, occurrence of triploids and penta polyploids were also encountered among the generated hybrids. Many of the synthetic diploids have been found to have good resistance to burrowing nematode, sigatoka diseases and fusarium wilt. Among these, the following diploids were found to produce bunches of acceptable size with resistance to sigatoka and burrowing nematode with sufficient male and female fertility.

Table 4. Promising synthetic diploids.

Hybrid	Cross combinations	Chief traits
H.59 (AA)	Matti x Anaikomban	Acceptable bunch characters with resistance to sigatoka and burrowing nematodes
H.65 (AA)	Matti x Anaikomban	
H.109 (AA)	Matti x Tongat	

Screening of some of the synthetic banana hybrids and their parents against fusarium wilt of banana (*Fusarium oxysporum* f.sp. *cubense*, race 1) under artificial conditions was taken up during 1999-2000. The hybrids namely, H.65, H.103, H.109 and H.201 and parents viz. Anaikomban, Pisang Lilin and Robusta exhibited distinct resistant reactions.

Some of the new progenies evolved by inter diploid crosses involving diploids synthesised earlier were also evaluated. Preliminary investigations indicate that the hybrids H. 201 x Anaikomban (tetraploid) and H-59 x Ambalakadali to be highly resistant to sigatoka diseases. The newly evolved synthetic hybrids viz., H-203, H-205, H-205, H-207 and H-213, H-234 and H-237 also appear to have higher tolerance to nematodes. The hybrids H-203 and H-218 also exhibit higher resistance to sigatoka leaf diseases.

In vitro *breeding strategies*

Mutation breeding

The *in vitro* breeding strategies involve creation of variability in four commercial varieties by induction of mutations using gamma rays and increasing the ploidy level by using antimitotic agents in the culture media. From the M1V1 generation, six improved somaclonal variants cv. Robusta and two somaclonal variants of cv. Rasthali were selected. In a follow up study, from the M1V2 generation, three more superior variants of cv. Robusta have been identified. These selections are now being forwarded for intensive screening and evaluation further.

The original red colouration of the fruit skin of diploid Sanna Chenkadali (AA) was found reverted to green in few of the plants in the M1V1 generation. Such colour reverted mutants remained stable even in M1V2 generation. The pollen and female fertility status of these variants were also very low as that of the original parent. However, intensive screening is now in progress to identify possible promising variants with pollen / ovule fertility coupled with resistance to biotic stresses for future breeding programmes.

In vitro induction of tetraploidy from diploid bananas

To overcome sterility problems in some of the diploid clones of potential breeding value viz., Sanna Chenkadali (AA), Anaikomban (AA), Kunnan (AB), *in vitro* mutagenesis approach is being resorted. The shoot tips of the diploids were treated with the antimitotic agents (oryzalin 30µM or 0.1% colchicine) and then cultured *in vitro*, or were inoculated on culture medium supplemented with any one of the antimitotic agents. The cultures have been established. The verification of their ploidy status will be taken up after regeneration and *in vivo* establishment.

Somatic embryogenesis

Attempts have been made to induce somatic embyogenesis involving the induction of embryogenic pathway in the competant cells of male floral buds. Three commercial cultivars were tried with the procedure involving the axenic isolation of the immature male floral buds and culturing in a mixture of auxins like 2,4-D, 2,4,5-T, Dicampa and piclogram either alone or in combinations (Anon 1999).

Banana production and management

Production of organic bananas

India has polyclonal situation with multiple production systems based on resource availability, cultivars, traditions and marketing which have its own merits under the situation. In Maharashtra and Gujarat (W. India), banana is grown in rotation with one plant crop while a tall cultivar is maintained for 4-5 years in other parts of the country. Wetland banana, having deep trenches after every two rows is common in Tamil Nadu, Kerala and parts of Karnataka. Gardenland is widely adopted system of production while planting on hill slope is common in Tamil Nadu, Karnataka and northeastern regions and normally, cultivars adopted in this system need low inputs.

Banana is also grown as subsistence crop in homestead garden or as shade or nurse crop. Mixed cropping with arecanut and coconut is practiced in Kerala, coastal Karnataka, Tamil Nadu, West Bengal and Andhra Pradesh. In commercial planting, banana is invariably managed with high inputs. In reviewing the production system in the country, it is apparent that these systems have their own merits in a given situation and would need improvement through development of production technologies.

In cropping systems research, banana-based cropping system is gaining popularity with an increasing awareness to organically grown crops. The sudden shift from chemical based intensive farming to organic farming has resulted in fall in production to a tune of 30%. But with modified cropping systems the yield gap is being reduced systematically and this is favoured by the changes taking place in the soil ecosystem owing to organic cultivation. Favourable attention with awareness and better prices offered for organically grown bananas help to compensate the initial decline in yields. With increased awareness, there is a slow shift to biofertilizers, biopesticides, lesser-known organic composts like coir pith compost, vermi compost, etc. among the peasantry nature of banana growers in India.

In a unique production system, wetland system of cultivation in the delta regions, organic production of bananas is already in vogue. Trenches of 60 cm deep are dug after every 4-5 plants along rows and columns. These trenches are useful for irrigation and drainage. In this system after the harvest the mother plant and unwanted suckers are chopped and dumped in the trenches. This biomass is allowed to rot and the decomposition is hastened by creating anaerobic conditions and use of *Pleurotus* fungus (oyster mushroom). Trials are underway in optimizing the suitable conditions for effective and faster decomposition.

Integrated production and management

Banana cultivation has been facing severe cost constraints due to labour intensive operations, such as annual planting system, manuring, weeding, irrigation practices and removal of older clumps after harvesting. Efforts to develop suitable technology package to extend the crop cycles through better clump management, adopting integrated production practices in order to reduce cost of production are under way. High density planting offers scope for increasing the productivity and reducing the cost of production.

Drip irrigation and fertigation systems have proved to be of great success in terms of water saving (40-70%) and maximizing fertilizer use efficiency. Hence, high density planting with application of fertilizers through drip irrigation system would be more purposeful for enhancing and sustaining productivity.

With the ever-increasing cost of production due to high cost of labour, it becomes necessary to evolve production strategies that could reduce labour intensiveness by way of extending the crop cycles for more than 2-3 seasons (ratooning). Presently, the popular cultivars Robusta (AAA-Cavendish) and Nendran (AAB-Plantain) are annually replanted. In the context of developing a new production system adopting high planting density and fertigation practices, ratooning has become necessary to reduce the cost of production.

Pest and diseases

Over a period of time, along with *Musa* evolution, many pests and diseases have also become serious threats for banana cultivation. Among pests, weevils and nematodes, while among diseases, leaf spot diseases, fusarium wilt and viral diseases cause problem in the order of priority. Owing to polyclonal system of cultivation, production constraints as biotic stresses vary with regional level, like scarring beetle menace, a serious threat in northeastern India over any other pests and diseases.

- IMTP phase II

IMTP sigatoka trial conducted at NRCB revealed that PA-03-22, FHIA-03, cultivar Rose, Yangambi Km5, Pisang Jari Buaya and Pisang Lilin did not show any sigatoka leaf spot symptoms. FHIA-01, FHIA-23, EMB-402, GCTCV-119, GCTCV-215, Burro Cemsa, Saba, Bluggoe and Williams were found susceptible. Pisang Nangka and Pisang Mas had more YLS and less disease severity and were considered tolerant. The sigatoka leaf spot incidence was recorded at 7th month after planting. Accessions, cultivar Rose, Yangambi, PA-03-22 and FHIA-3 did not show leaf spot symptoms. The other accessions had various level of infection index. PV-03-44 had some other leaf spot disease not typical of sigatoka. Pisang Mas, FHIA-01 and Pisang Nangka had 15.84, 9.0 and 12.11 infection indices, respectively. All other accessions had infection index above 21.0.

- Fusarium wilt

Fusarium wilt caused by *Fusarium oxysporum* f.sp. *cubense* continues to pose threat among commercial Indian cultivars. Twenty-two percent of total banana production remains at the mercy of this pathogen which include popular cultivars like Silk (AAB), Ney Poovan (AB), Red Banana (AAA), Pome (AAB), Pisang Awak (ABB) and all cooking bananas. All these years, race 1 and 2 were reported to attack the above cultivars while recently Poovan (Mysore, AAB) has lost its immunity and sporadic reports of fusarium wilt on immune Mysore group is also being received. Widespread occurrence of nematodes in all types of soils acts as a predisposing factor for fusarium wilt occurrence. This is accentuated by perennial cultivation in hills while wetland cultivation system has a check on its rapid spread. Integrated disease management of the disease seems to be the only alternative complemented with research on development of resistant clones. Use of biocontrol agents is gaining momentum in control of the disease. NRCB strongly recommends corm injection of 3 ml of 0.2% Carbendazim through extension activities. A large project on evaluation of efficacy of biocontrol agents under various production systems is under progress.

Fusarium wilt was taken up in a farmer's field during 1999-2000. As the soil is naturally loaded with inoculum, there was no need for artificial inoculation. Artificial inoculation was also not made due to safety reasons to farmers. The results revealed that only one plant, i.e. Gros Michel (AAA), was affected with wilt.

- Nematode management

Extensive survey has indicated the presence of 71 species belonging to 33 genera of plant parastic nematodes. *Radopholus similis* is most important followed by *Pratylenchus coffeae*, *Helicotylenchus*, *Meloidogyne incognita*, *Heterodera oryzicola* and *Rotylenchus reniformis*. In evaluating varietal resistance to nematodes, the concept of Root Vigour Index is emphasised to assess comparative reaction to nematodes with respect to economic yield loss. In commercial clones, yield loss assessment is to the tune of 20-60% due to nematodes and up to 100% in places where nematode-wilt complex is well built up.

Screening of accessions at NRCB field genebank resulted in the identification of 22 accessions belonging to various genomic groups to be resistant to major nematodes in field condition. Some of them are Paka, Kunnan, Sanna Chenkadali, Vadakkan Kadali, Anaikomban, Hatidat, Yangambi Km5, etc.

Crop duration and use of repelling intercrops have found to be a component of integrated management practice for nematodes. Breeding work is being initiated using resistance diploids. Some of the synthetic acuminata diploids developed (H-59, H-65 and H-109) have exhibited resistance to nematodes and are under different stages of field evaluation.

- Weevil borers

Among the insect pests affecting banana and plantains in India corm weevil and stem borers have assumed importance lately. They are gradually spreading to other banana growing areas with increased severity.

Among the two weevils, stem weevil (*O. longicollis*) is considered more serious one causing crop losses as high as 80%. The pest has a special preference to plantains, though it also affects other commercial cultivars like Robusta, Red Banana, Rasthali, Virupakshi and Pisang Awak. Its spread is also much faster. Scanning electron microscope (SEM) studies on this pest showed that the rostrum has got special structures, which enable the pest to recognise the favourable host cultivars. The adult lives for about two years feeding on dry trash. Though injection of monocrotophos into the pseudostem appears to check the incidence, complete control of the pest appears difficult.

NRCB has already initiated studies to identify resistant lines, which can be used in breeding programmes. Many synthetic diploids (AA) and cv. Sanna Chenkadali (AA), Anaikomban and Kunnan groups (AB) have remained unaffected by the pest.

Thrust areas

Crop improvement

1. Development of durable resistance to leaf spot diseases
2. Breeding for resistance to nematode and wilt complex
3. Development of resistance to stem weevil in plantains and certain banana cultivars
4. Search for sources and alternate sources of resistance for wilt, leaf spot diseases, nematodes and weevils (stem and corm) through prospection, collection and evaluation

Production technology

1. To increase the production and productivity of banana and plantain through modified high density planting, clump management with more crop cycles

2. To formulate an integrated production system approach for export-oriented banana including standardising heat unit based maturity index and packaging
3. Production of organic bananas with better cost-benefit index

Crop protection

1. Development of integrated pest management including resistant cultivars, biocontrol agents, chemicals and production systems.