

**Recent advances in breeding of mango (*Mangifera indica*)–
A Review**

ABSTRACT

Mango is one of the most important fruit crops worldwide. It is grown mainly in tropical and subtropical areas throughout the world. Mango *Mangifera indica* L. belongs to family Anacardiaceae is a large ever green tree and bears a popular tropical fruit that is consumed locally and trade globally. Preferred mango varieties vary from country to country. In general, subcontinental Asian types are monoembryonic, while South East Asian varieties are polyembryonic. Although *M. indica* is the most common species in the genus *Mangifera*, several additional species are graft and pollination compatible with *M. indica* and can be used as rootstocks or sources of novel genes for breeders. Mango is a difficult species to raise because its seed viability declines rapidly after fruit maturity, weeks after fruit maturity. Although there is a greater variety of varieties accessible, there are certain inherent limitations, such as prolonged juvenility, high clonal heterozygosity, one seed per fruit, resistant seeds, polyembryony, early post-zygotic auto-incompatibility, and a huge area requirement for hybrid evaluation. Breeders, on the other side, benefit from the wide range of variation and simplicity of vegetative hybrid production. Dwarfness, precocity, profuse and regular bearing, attractive, good sized and quality fruit, absence of physiological problems, disease and insect resistance, and extended shelf life are some of the requirements of a successful cultivar. A thorough understanding of mango phenology, inheritance patterns, and advanced technique and methods for hybridization have existed completely advantageous to overcome the problems like abnormal bearing, susceptibility to disorders and pests, poor consuming and consistency character. The development of the genetic markers has further decreased the uncertainty in breeding mango and maintaining the hybrid populations in a better way.

Keywords: Breeding, Mango, physiological problems, disease and insect resistance.

Introduction

Mango (*Mangifera indica* L.) belongs to the family Anacardiaceae that consists of dicotyledonous trees and shrubs. Mango trees are evergreen with branched, upright to spreading dense canopies that can grow to heights of 30m. The tree is supported by one to several deep taproots and abundant surface feeder roots. Trees are long lived with many specimens living for more than 100 years. The canopy consists of dark green, simple,

alternate leaves, oval-lanceolate to roundish- oblong in shape. New leaves are produced in periodic flushes with the colour tone of expanding leaves varying between tan and red. Hundreds of hermaphrodite and male flowers are borne on branched conical panicles that grow from the terminals of branches. The fruits are fleshy drupes that vary in size, shape and colour, with the fleshy mesocarp being the most attractive edible portion of the fruit. Each fruit contains a single seed enclosed in a stony endocarp.

Mango has been considered to be a difficult plant species to improve in breeding programmes because of certain inherent characteristics including:

- (i) a long juvenile phase;
- (ii) a high level of heterozygosity resulting in unpredictable outcomes in hybridization
- (iii) only one seed per fruit;
- (iv) heavy fruit drop leading to low retention of crossed fruits
- (v) polyembryony in many cultivars
- (vi) the large area required for a meaningful assessment of hybrids.

Taxonomy:

Mango originated in the SouthEast Asian or Indo-Myanmar region as forest trees with fibrous and resinous fruits (Kostermans and Bompard, 1993). Estimates of the number of species of *Mangifera* vary widely. Wild *Mangifera indica* occurs in north eastern India. Botanically it is related to *M. sylvatica*, *M. caloneura*, *M. zeylanica* and *M. petandra*. Kostermans and Bompard (1993) have described 69 species of *Mangifera*. Out of 69 species there are no less than 12 species enumerated under *species incertae sedis* (species that cannot be placed properly), because of the insufficient confirming evidences. Majority of the *Mangifera* spp. And cultivars so far examined have $2n = 2x = 40$.

Cytology

Plooy *et al.* (2006) investigated the cytological nature of lenticels discoloration was as part of a study of affected mango fruit. Lenticels were dissected from physiologically mature fruit in predetermined groups of varying discoloration. Transmission electron microscopy and light microscopy of mesophyll cells from affected tissue indicated conservation of cellular structures and endomembranes in all variants of discoloration. It

was therefore shown that the accumulation of cell wall-bound phenolics does not result from structural damage such as vacuolar collapse or membrane disintegration. Results further suggest the apoplastic transport of the signal for phenolics deposition. Accumulation of phenolic compounds in a distinct zone of affected tissue around the lenticel creates a barrier between the atmosphere and the rest of the mesophyll. Although lenticel discoloration is an inherent self-defence mechanism supported by continued metabolic activity, it is a superficial, cosmetic defect.

Cytogenetics

Mangifera indica L., *M. sylvatica* Roxb., *M. caloneura* Kurz, *M. zeylanica* Hooker and *M. odorata* Ariff. are reported to be diploid (2x) species with chromosome number $2n=40$. One of the plants of polyembryonic variety Vellai Kolumban was found to be tetraploid (4x) with $2n=80$ chromosomes. Manjumbder and Sharma (1990) reported that Vellai Kolumban variety is diploid with $2n=40$ chromosomes. These two varying reports on the ploidy level of this variety appears to be based on the fact that earlier report was based on one of the plants of this variety, which might have alone undergone tetraploidy in nature and that particular tree might not have been available for the subsequent study. On the basis of later study, Vellai Kolumban is considered as a diploid variety.

Genetics of important traits and their inheritance pattern

The main problem in mango breeding have been the lack of information on inheritance of characters, high heterozygosity in the cultivars and few hybrid progenies realized after crossing. The upright growth habit of tree is dominant over spreading growth. Dwarfness and regularity in bearing and precocity and resistance to malformation are controlled by recessive genes and regularity in bearing appears linked with precocity. Pulp colour is controlled by additive genes. Biennial bearing habit is dominant over regular bearing.

Incompatibility

The self-incompatibility phenomenon was unknown in mango until Singh et al. (1962) reported it in the north Indian mango cultivar 'Dushehari', which led to the development of caging technique of pollination in mango (Sharma and Singh, 1970). Embryological studies have shown that in mango pollen tubes grow down the style and effect fertilisation but the development of zygote is blocked, leading to a sporophytic type of self-incompatibility (Mukherjee et al., 1968).

The effects of self- and open-pollination on pollen germination, pollen tube growth, fruitset, ovule degeneration and growth of fruitlets were studied (Dutta *et al.*, 2013) in four mango cultivars such as 'Amrapali', 'Mallika', 'Pusa Arunima' and 'Pusa Surya'. It was observed that self-pollination resulted in rapid decline in fruit setting than open-pollination in 'Amrapali' and 'Mallika' as compared to 'Pusa Arunima' and 'Pusa Surya'. At 48 h after self-pollination, pollen tube growth in the stylar region of 'Amrapali' and 'Mallika' was considerably slower than 'Pusa Arunima' and 'Pusa Surya' and their pollen tube reached up to two-third of the stylar region. However, in case of 'Pusa Arunima' and 'Pusa Surya' pollen tube reached up to the micropylar end. Self-pollination resulted in 75% degenerated ovules in 'Amrapali' and 'Mallika', which dropped within 21 days after pollination (DAP). In contrast, open-pollination resulted in only 20% degenerated ovules in these mango cultivars. The growth of fruitlets and ovules obtained from self- and open-pollination revealed that the fruitlets weight and dimensions of fruitlets and ovules were significantly less in self-pollinated as compared to open-pollinated 'Amrapali', 'Mallika' and 'Pusa Arunima', whereas no significant differences were observed in fruitlet weight and dimension of fruitlets and ovules obtained in self- and open-pollinated 'Pusa Surya'. The present findings bring out clearly that mango cultivars 'Mallika' and 'Amrapali' are self-incompatible, whereas, cultivars 'Pusa Arunima' and 'Pusa Surya' are self-compatible.

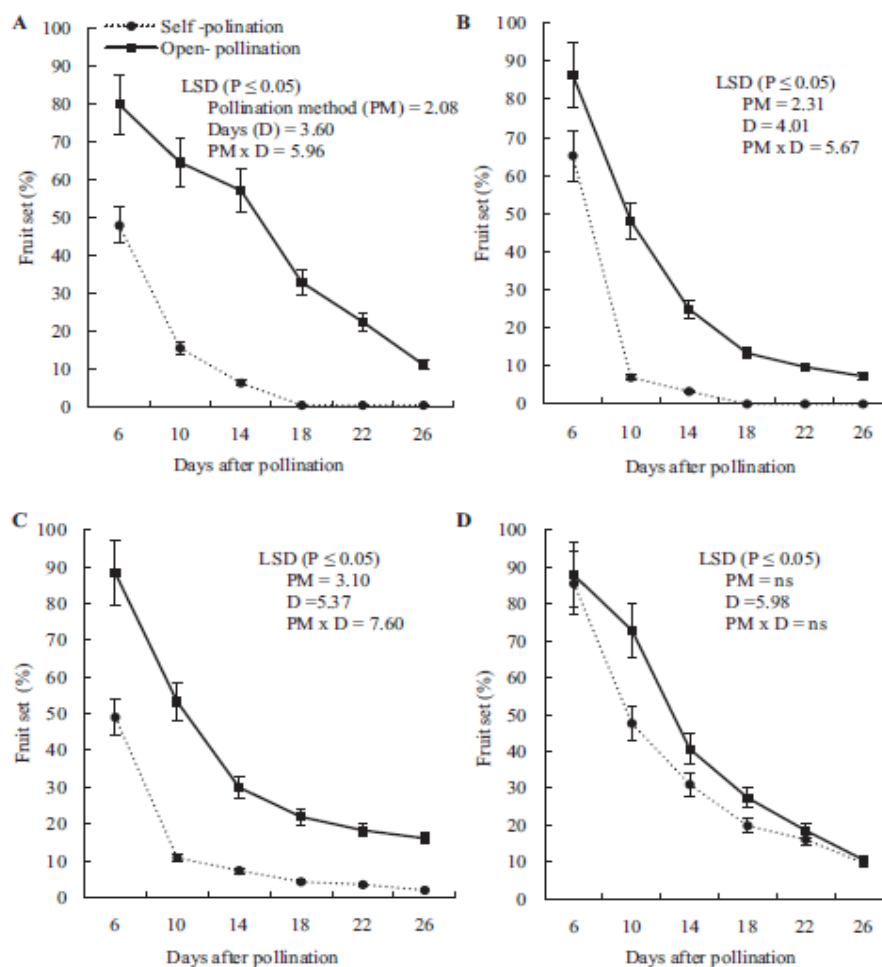


Fig. 1. Fruit set under self- and open-pollination in ‘Amrapali’ (A), ‘Mallika’ (B), ‘Pusa Arunima’ (C) and ‘Pusa Surya’ (D).

Maklad M F (2015) reported the self and cross incompatibility has been as one of the serious factor affecting fruit set in many mango cultivars. Mango (*Mangifera indica* L.) is considered one of the oldest cultivated trees in the world. Low productivity of some mango cultivars is associate with low fruit setting and/or high fruit drop of immature fruits. In this respect, five mango cultivars (Alphonse, Ewais, Hindi khassa, Keitt, and Zebda) were used as a pollinizer for Langra cultivar (as a female parent) to exanimat their cross compatibility / or incompatibility with it and its self-pollination effect. The results of the present study indicated that, microscopic examination for Langra cultivar after self-pollination revealed many deposits of callus plugs were appeared at a long of the pollen tubes after self-pollination which indicated incompatibility pollen tubes. The number of pollen tubes of Keitt and Zebdac.vs. in Langra styles were higher than other combinations and they started to reach the base of the style in 4 days after pollination, this is an indication of high cross compatible between each two cultivars and Langra c.v., while, Alphonse, Ewais and Hindi khassa

reached delayed to the base of the style and they gave the lowest percentage of pistils with pollen tubes reaching the base of the style 7 days after cross pollination with Langra styles. Cross pollination with Zebda pollens gave the higher initial number of fruits per panicle (55.93 and 73.25) compared to the other cultivars. Fruit drop % increased dramatically and it's reaching maximum at 45 days after self-pollination only and when crossed by Alphonse pollens.

Plant Genetic Resources

India is the world's richest mango germplasm centre where more than one thousand vegetatively propagated varieties/clone exist. They vary widely with respect to fruit shape, size, skin colour, time of maturity, stone (seed) size, pulp quality, yield and bearing regularity.

Singh N P *et al.* (2012) reported that in Punjab province of India, area under mango (*Mangifera indica* L.) fruit plantation in the state has declined drastically due to deforestation, population pressure, shifting to high remunerative cropping systems, reoccurrence of cold waves, developmental works, higher incidence of pests and diseases, etc. Hence, a survey was conducted for documentation about the extent of diversity found in the native landraces/strains of mango. Twenty-eight elite strains enjoying local patronage were evaluated for table and sucking purposes, preparation of pickle/canning/ beverages/amb leather on the basis of physical appearance and chemical attributes. Physico-chemical analysis of fruit samples revealed that variability found in indigenous mango population in various qualitative and quantitative attributes not only contributes to biological diversity, nutritional security and livelihood but can also be used for crop improvement. The present study highlights that it is the need and demand of Punjabi folklore to conserve and protect such biologically rich areas for the benefit of posterity.

Some interesting mango strains observed in the area are locally known as *Anda Dusehree* (flavour & taste resembled to a popular Indian table purpose mango variety 'Dashehari', but fruit shape was looked like egg), *Laddu Amb*, *Gola Ghassipur* and *Ber Ambon* the basis of fruit shape. In Punjabi folklore, native mango strains are called as '*Chhalli*' on account of their oblong shape and large fruit size (resembling a small sized corn cob). Attractive yellow fruit colour with red blush on the shoulders was observed in seven mango strains (*Anami Chhalli*, *Choe Sindhuri*, *Ghassipur di Chhalli*, *Laddu Amb*, *Mahantan di Laltain*, *Sindhuri Chusa*).

Fruit colour ranged from yellowish to light yellow, deep chrome, greenish, spinach green and dark green in rest of selected mango strains. Fully coloured fruits are locally preferred and called as *ArruAmband Pencil Amb*. These are preferred for sucking type of mangoes mostly due to thin and abundant juice content; soft flesh, coarse fibres and sell at higher price in the area. Maximum fruit weight (380.4 g) and fruit length(12.52 cm) was found in strain *JogiyaChhalli* collected from Government Orchard, Bhunga and percentage contribution of pulp, peel and stone in the fruit was 70.3, 16.0 and 13.7, respectively. The highest fruit pulp weight (267.5 g) was also recorded in *JogiyaChhalli*,

Further, strains like *Charan Achari*, *Gola Desi* and *Banta strains No.1, 2 and 3* could be conserved and exploited for further used as pickle type of mangoes on account of their higher juice acid per cent, pulp/stone ratio, sour-sweet taste, almost roundish shape and medium to abundant fibres content.

Kaur et al. (2014) recorded that tree height was maximum in Kala Gola, however, tree spread was maximum in Chausa. Amongst the evaluated germplasm Chausa showed maximum fruit weight and pulp stone ratio. Highest yield was obtained in Dashehari, that is 148.90 Kg/ tree. Local selection-1 was the earliest to mature and regular bearer. Rattaul has excellent flavour.

Table 1. Pulp percentage, pulp stone ratio, TSS, acidity and yield of different genetic resources of mango

S/N	Genetic resources	PP %	P/S ratio	TSS (°brix)	Acidity (%)	TSS/Acid ratio	Yield (kg)
T ₁	'Local Selection-I'	54.16	1.80	13.25	1.33	9.96	112.70
T ₂	Dashehari	78.56	3.36	17.40	0.30	58.00	148.90
T ₃	Gola	62.36	3.03	16.85	4.81	3.50	107.84
T ₄	Langra Banarasi	87.74	7.29	19.95	0.34	58.67	97.30
T ₅	Langra	79.23	4.54	21.68	1.57	13.81	104.56
T ₆	Kala Gola	73.66	2.52	16.95	7.86	2.16	97.35
T ₇	Dharbhanga	73.16	4.56	12.06	0.22	54.82	93.71
T ₈	Alphonso	72.1	3.11	26.84	0.33	81.33	93.33
T ₉	Hundel	41.73	2.98	15.88	0.20	79.42	113.31
T ₁₀	Malda	65.8	4.03	28.95	0.56	51.70	108.74
T ₁₁	Amarpali	63.59	5.82	23.25	0.40	58.12	44.03
T ₁₂	Rattaul	64.53	4.58	24.34	0.95	25.62	126.73
T ₁₃	Chausa	89.78	8.80	27.08	0.34	79.64	114.00
T ₁₄	'Local Selection-II'	84.34	5.43	11.35	0.34	33.82	93.60
	Mean	64.09	4.81	19.70	1.15	46.36	107.46
	C.D	2.87	.93	.94	0.77	0.59	2.64
	Range	41.7-89.78	1.80-8.80	11.35-28.95	0.20-7.86	2.16-81.33	44.03-148.90

PP- Pulp Percentage, P/S- Pulp Stone Ratio, TSS- Total Soluble Solids, RS- Reducing Sugar, TS- Total Sugar.

Table 2. Time of maturity and organoleptic ratio of different genetic recourse of mango.

S/N	Genetic resources	Colour of fruit	OR	TM
T ₁	'Local Selection-I'	Yellowish Green 151 ^A	3.0	I st week of July
T ₂	Dashehari	Yellowish Green 144 ^A	6.6	II nd week of July
T ₃	Gola	Yellowish Green 152 ^B	0.2	IV th week of July
T ₄	Langra Banarasi	Yellowish Green 144 ^A	7.5	II nd week of July
T ₅	Langra	Yellowish Green 144 ^B	6.8	II nd week of July
T ₆	Kala Gola	Yellowish Green 144 ^C	1.5	IV th week of July
T ₇	Dharbhanga	Yellowish Green 144 ^B	0.5	II nd week of July
T ₈	Alphonso	Yellowish Green 153 ^B	8.0	II nd week of July
T ₉	Hundel	Yellowish Green 151 ^A	7.0	II nd week of July
T ₁₀	Malda	Yellowish Green 152 ^A	8.0	III rd week of July
T ₁₁	Amarpali	Yellowish Green 153 ^D	7.6	IV th week of July
T ₁₂	Rattaul	Greenish Yellowish 163 ^C	6.8	IV th week of July
T ₁₃	Chausa	Yellowish Green 151 ^A	8.8	IV th week of July
T ₁₄	'Local Selection-II'	Yellowish Green 153 ^A	6.0	III rd week of July

OR- Organoleptic Rating at 10 Point Scale, TM- Time of Maturity.

Dinesh M R *et al.* (2015) carried out evaluation of seedling diversity for morphological traits in the Chittoor area of Andhra Pradesh in India. The statistical analysis carried out for fruit characteristics showed significant differences among the varieties for various fruit characteristics. Molecular characterization was carried out using microsatellite markers. Most of the indigenous varieties from Kalepalli region are grouped in the same cluster. It is interesting to note that the morphological characterization and molecular characterization follow almost the same pattern suggesting the genetic control of these fruit characters. The study shows that the diversity observed within a geographic region is derived from the varieties that are being grown in that region. The promising seedling varieties selected with desirable traits would help the farmer in benefit sharing as and when they are registered. In addition, it would help in 'on farm conservation' and use of these varieties in crop improvement programmes.

Table 3. Characteristics of the 8 microsatellite markers with repeat motif, number of alleles, Observed Heterozygosity (Ho), Expected Heterozygosity (He) and Polymorphic Breeding Methods

Locus	Primer (5'-3')	Repeat motif	Number of alleles	Allele size range (bp)	He	Ho	PIC
M _{IIHR} 17	F: GCTTGCTTCCAAGTGAAGC R: GCAAAATGCTCGGAGAAGAC	(GT) ₁₃ GAGT(GA) ₁₀	10	230-269	0.867	0.477	0.841
M _{IIHR} 18	F: TCTGACGTCACCTCCTTTCA R: ATACTCGTGCCTCGTCTGT	(GT) ₁₂	11	148-193	0.724	0.023	0.693
M _{IIHR} 23	F: TCTGACCCAACAAGAACCA R: TCCTCCTCGTCTCATCATC	(GA) ₁₇ GG(GA) ₆	13	117-156	0.693	0.409	0.667
M _{IIHR} 26	F: GCGAAAGAGGAGAGTGCAAG R: TCTATAAGTGCCCCCTCACG	(GA) ₁₄ GGA(GAA) ₂	19	127-171	0.889	0.523	0.869
M _{IIHR} 30	F: AGCTATCGCCACAGCAAATC R: GTCTTCTTCTGGCTGCCAAC	(CT) ₁₃	11	190-213	0.857	0.674	0.831
M _{IIHR} 31	F: TTCTGTTAGTGGCGGTGTTG R: CACCTCCTCCTCCTCCTTT	(GAC) ₆	10	207-260	0.752	0.523	0.718
M _{IIHR} 34	F: CTGAGTTGGCAAGGGAGAG R: TTGATCCTTACCACCATCA	(GGT) ₉ (GAT) ₃	09	203-245	0.771	0.364	0.734
M _{IIHR} 36	F: TCTATAAGTGCCCCCTCACG R: ACTGCCACCGTGGAAAGTAG	(TC) ₁₇	14	210-250	0.834	0.545	0.805

There are two main types of mango the Indian types with monoembryonic seeds and susceptible to anthracnose while the Indo-Chinese types with polyembryonic seeds and are tolerant to anthracnose. Breeding methods involve: selection from open pollinated seedlings occurring naturally, controlled pollinations (hand pollination of limited flowers on large number of panicles), enclosing self-incompatible female and male parents and cross pollinating with houseflies, maintaining hybrid populations by grafting scions on established plants, and pre-selection of mango hybrids to discriminate undesired material.

Methods of improvement: -

The methods of mango crop improvement include introduction, selection, hybridization and mutation. The work done and future lines of work suggested for the improvement in mango through these methods are briefly mentioned below:

Exotic cv. Eldon, which performed very well in India, has been released by the Indian Agricultural Research Institute, New Delhi in the popular name of Pusa Surya through Delhi State Seed Sub-Committee for commercial cultivation. This variety has medium sized tree canopy and regular bearing habit. Fruit is medium (240 g) with thick and red peel on the fruit surface exposed to sun, firm and fibreless pulp, sweet taste (18.6% TSS and 0.22% acidity) and long-distance transportation. This is undergoing multi-location testing its performance at

the national level. Other introduced cultivars evaluated in India include Ametista, Carabao, Edward, Extrema, Florigon, Haden, Irwin, Keitt, Kensington, Kent, Sensation, Simmonds X, Tommy Atkins, etc. (Pandey, 1998 a).

Hybridization

Hybridization of mango in India was first initiated in 1911 with the objectives of breeding varieties having regular bearing habit, good fruit quality, high yield and resistance to insect pests and diseases.

Intervarietal hybridization:

Pinto *et al.* (2004) conducted intervarietal mango hybridization and reported that, out of 2088 mango seedlings established in the field, 209 seedlings were selected in the first year. Out of these 209 seedlings, 42 were selected as promising materials and 4 of them have been released as cultivars:

1. Alfa - Hybrid cultivar from the cross 'Mallika' x 'Van Dyke', semi-dwarf and high yielding, regular bearing, fruit 435 g, pink/red peel, firm and medium fiber pulp with good quality (Brix 16%, acidity 0.23%, Brix/Acidity ratio 70), resistant to oidium and moderately resistance to anthracnose, without malformation or pulp soft-nose.

2. Beta - Hybrid cultivar (Selection CPAC 98/86) from the cross 'Amrapali' x 'Winter', moderately vigorous and high yielding, irregular bearing, fruit 310 g, yellow peel, firm and low fiber pulp with excellent quality for fresh consumption and processing (Brix 24.8%, acidity, 0.16%, ratio Brix/acidity 155), moderately resistant to anthracnose and oidium, without malformation.

3. Roxa - Hybrid cultivar from the cross 'Amrapali' x 'Tommy Atkins', moderately vigorous and medium yielding, regular bearing, fruit 287 g, purple reddish, very firm and fibreless pulp with excellent quality (Brix 19-21%, acidity 0.12%, ratio Brix/acidity 158-175), susceptible to cochineals, medium to low resistance to anthracnose, oidium and malformation.

4. Lita - Hybrid cultivar (Selection CPAC 136/86) from the cross 'Amrapali' x 'Tommy Atkins', vigorous and high yielding, regular bearing, fruit 414 g, very firm and low fiber pulp with excellent quality (Brix 18-20%, acidity 0.20%, ratio Brix/acidity 90-100), moderately resistant to anthracnose, oidium and malformation. The outstanding hybrid seedling selections are CPAC 165/93 and CPAC 256/94 both with red yellowish peel, firm and very sweet pulp. The hybrid progeny CPAC 256/94 has high pulp yield (82-85%) due to its thin seed.

Rajwana I A *et al.* (2010) developed a hybrid 'Faiz Kareem' by making a cross between two commercial mango cultivars i.e., Anwar Ratole X Chaunsa. These studies were carried out to compare the fruit ripening behaviour and quality of this new promising mango hybrid cultivar Faiz Kareem with its parents under ambient ($28\pm 2^{\circ}\text{C}$; 65-70% RH) conditions. During ripening, data on various physico-chemical characteristics including physiological fruit weight loss percentage, fruit softness, visual peel colour, titratable acidity, total soluble solids, sugars, vitamin C, and total carotenoids were recorded daily up to 7 days. Under ambient conditions all the cultivars took 7 days to ripe however, Faiz Kareem expressed better firmness, which indicates its potential for extended shelf life. Highest levels of total sugars (25.88%), total soluble solids (26.75°Brix) and total carotenoids ($69.99\mu\text{g g}^{-1}$) were observed in Chaunsa while lowest in Faiz Kareem (23.71%, 25.54°Brix and $24.60\mu\text{g g}^{-1}$, respectively) which can be an advantage for extended storage and for sugar conscious consumers. Taste panel studies also showed clear preference for hybrid cultivar Faiz Kareem, followed by Chaunsa and Anwar Ratole. Results of the study will help to understand the potential of Faiz Kareem for domestic and export markets.

Jana B R (2017) conducted a varietal improvement program at ICAR-RCER, Research Centre, Ranchi, India. During this study, mango cultivars Langra, Dashehai and Chausa have been used as female plant while pollen grain of Swarnarekhan, Kesar and Vanraj were used as male parent in diallel crosses. Results of study revealed that Hybrids obtained by the crossing of Langra x Vanraj (Hybrid 1) and Langra x Kesar (Hybrid -2) are superior in term of their fruit tree character, bearing habit and fruit quality. Among various obtained Hybrids, Hybrid -2 (Langra x Kesar) have highest TSS (20.50B) and total sugar content (12.37 %) with yellow color, this was followed by Hybrid -I (19.50B) and Hybrid-3 (11.50B). In terms of regular bearing, Hybrid -1 was the most promising one and it was followed by the Hybrid-3 (Chausa x Vanraj). Further, with respect to yield potential, Hybrid -2 showed superiority over the rest two Hybrids and 7-year-old plant gave 12.5 kg fruit/year.

Table 4. Physical characteristics of F1 population of mango

Cross combinations	Tree type	Inflorescence	Bearing Habit	Hermaphodite flower %
Langra x Vanraj [Hybrid-1]	Medium erect	Pink coloured	Regular	45.24
Langra x Vanraj [Off Type-1]	Medium erect	Yellow	Alternate	25.62
Langra x Kesar [Off Type-2]	Medium erect	Yellow	Alternate	23.89
Langra x Kesar [Hybrid-2]	Medium spreading	Golden Yellow	Alternate	54.65
Langra x Swarnarekha [Off Type-3]	Wild type	Yellow	Alternate	24.96
Langra x Swarnarekha [Off type-4]	Wild type	Yellow	Alternate	18.75
Chausa x Vanraj [Hybrid-3]	Medium spreading	Yellow	Alternate	19.67
Chausa x Swarnarekha [Off type-5]	Dwarf	Redish yellow	Alternate	22.82
Chausa x Swarnarekha [Off type-6]	Medium Spreading	Yellow	Alternate	16.25
Dashehari x Kesar [Off type-7]	Dwarf	Deep Yellow	Alternate	19.64
Dashehari x Swarnarekha [Hybrid -4]	Dwarf	Greenish Yellow	Alternate	35.32
[CRD] CD at 5%	--	---	----	5.86

Table 5. Fruit characteristics

Cross combinations	Fruit weight (g)	TSS (°B)	Total Sugar (%)	Plant yield (Kg/plant)
Langra x Vanraj [Hybrid-1]	230.56	19.5	11.42	10.07
Langra x Vanraj [Off Type-1]	200.45	16.3	9.87	4.25
Langra x Kesar [Off Type-2]	212.85	15.7	8.88	5.63
Langra x Kesar [Hybrid-2]	250.12	20.5	12.37	12.50
Langra x Swarnarekha [Off Type-3]	152.00	14.8	8.24	5.97
Langra x Swarnarekha [Off type-4]	174.64	12.8	7.99	3.89
Chausa x Vanraj [Hybrid-3]	140.67	11.5	8.88	4.05
Chausa x Swarnarekha [Off type-5]	262.75	11.5	7.45	8.72
Chausa x Swarnarekha [Off type-6]	128.45	11.5	7.41	8.42
Dashehari x Kesar [Off type -7]	205.86	10.31	6.65	7.69
Dashehari x Swarnarekha [Hybrid -4]	188.52	12.25	7.58	6.83
[CRD] CD at 5%	34.08	2.49	1.82	2.61

Interspecific hybridization

Resistance breeding

Several diseases are of economic importance to the production and marketing of mangoes. The most important one is anthracnose caused by *Colletotrichum gloeosporioides* Penz. This disease appears on mango flushes and leaves as leaf blight, on flower panicles as blossom blight, on mature trees as tree dieback and on ripened fruits as postharvest rots. Postharvest anthracnose on fruits is responsible for significant losses in fruit quality during storage and transport. Current management of the disease involves a combination of cultural and chemical practices in the field and postharvest. These control measures, however, do not provide complete control, resulting in significant reductions in fruit quality and shelf life. Although there is variation in resistance to anthracnose among commercial mango cultivars, the level of resistance is generally weak and tends to fail under certain environmental, storage

and transport conditions. A strong genetics-based resistance to anthracnose in mango would significantly reduce the current costs of production by reducing the chemical and cultural management inputs and greatly improve postharvest shelf life and fruit quality presented to the consumers.

Bally *et al.* (2013) conducted an experiment on screening and breeding for genetic resistance to anthracnose in mango. The germplasm screened for reaction to anthracnose demonstrated a wide range of responses to *C. gloeosporioides* in both natural and artificial assessments. The *M. laurina* accession 'Lomboc' has shown good resistance to artificial inoculation over 3 seasons with two virulent isolates of *C. gloeosporioides*. It has also been used as a male parent in hybridisation with *M. indica*.

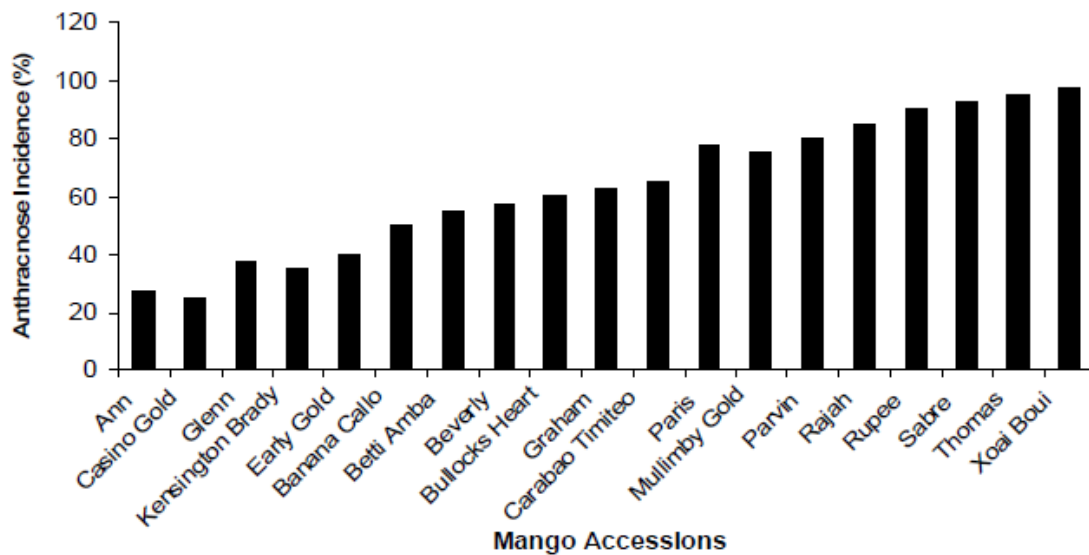


Fig. 2. Disease incidence of anthracnose from natural fruit infections on mango accessions screened during 2008.

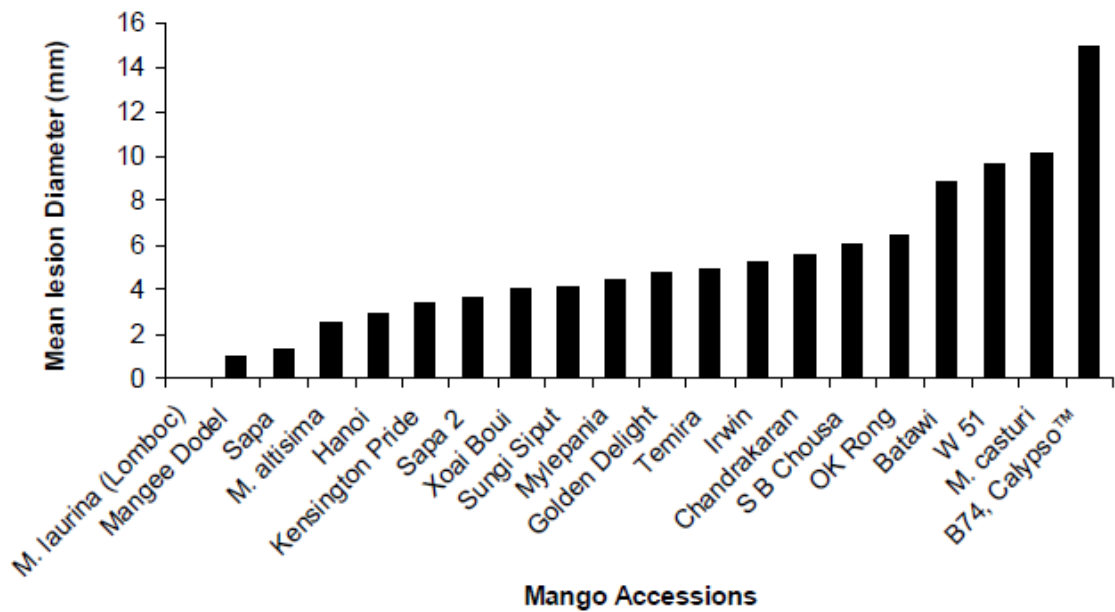


Fig. 3. Disease severity of anthracnose on fruit artificially inoculated with *Colletotrichum gloeosporioides* during 2007/2008.

Ebrahim *et al.* (2013) reported resistance gene analogues in mango against mango malformation. Mango malformation is one of the most important diseases limiting its cultivation. However, disease resistance is known in some mango cultivars and is a desirable trait that can be utilized for developing mango varieties resistant to malformation. Resistance genes cloned from different plant species have revealed several similarities in DNA sequence and structural motifs. This provides the possibility of isolating resistance genes by polymerase chain reaction (PCR) with degenerate oligonucleotide primers designed from highly conserved regions of the nucleotide binding site (NBS). In the present study, we used eight combinations of oligonucleotide primers designed on the basis of P-loop and hydrophobic domains of conserved NBS-leucine rich repeat (LRR) protein sequences for amplifying resistance gene analogues (RGAs) in eight mango cultivars and hybrids showing a variable degree of resistance to mango malformation disease. A single band of about 500 bp in all mango cultivars was obtained from the s2+as2 primer combination. RGAs isolated from mango showed 73% similarity with RGAs in databases. It confirms that RGAs were actually isolated from mango. The obtained sequence can be used for isolating full length R-genes. It is concluded that PCR amplification of resistance gene analogues based on degenerated primer combinations from conserved motifs of NBS-LRR resistance genes can be used for identification and isolation of resistance genes in mango against mango

malformation and other diseases. Further studies are needed to isolate full length resistance genes from mango cultivars resistant to malformation.

Biotechnology and mango improvement

Very few improved mango cultivars have been released during the past two decades as a result of conventional breeding. The resources necessary for a successful breeding programme, which include significant investment in land, time and genetic resources, etc., have limited the extent, success and number of mango breeding programmes. Genetic engineering, an alternative approach for improving mango production, emerged just over a decade ago, and offers a sustainable way for addressing certain key breeding objectives. The primary components of mango genetic engineering include: 1) efficient somatic embryogenesis and plant recovery from elite (i.e., nucellar) material; 2) induction of random mutations in embryogenic cultures and challenging for resistance to a specific selective agent; and 3) transformation with a gene that mediates a horticultural trait. On the basis of past and current research, it is probable that the following breeding priorities can be addressed by 1) mutation breeding: resistance to abiotic soil stress and certain diseases; and by 2) genetic transformation: control of fruit ripening, seedlessness and certain diseases.

Studies involving in vitro culture and selection, micropropagation, embryo rescue, genetic transformation, marker-assisted characterization and DNA fingerprinting, etc. are underway at different centers worldwide. In vitro culture and somatic embryogenesis of several different genotypes have been achieved. The nucellus excised from immature fruitlets is the appropriate explant for induction of embryogenic cultures. High frequency somatic embryogenesis has been achieved in some genotypes; however, some abnormalities can occur during somatic embryo germination. Embryo rescue from young and dropped fruitlets can improve the hybridization success in a limited flowering season. Protocols for protoplast culture and regeneration have also been developed. Micropropagation of mango has not met with the commercial success as obtained in other fruit crops like pineapple, banana and strawberry. This is due to many problems associated with it, viz., latent microbial infection, excessive polyphenol exudation, early explants necrosis, etc. Biotechnology could resolve some of the most serious problems of the mango industry. Moreover, molecular methods are useful for taxonomical characterization, to understand the regulation and expression of important traits/genes, etc. Today the major limitation facing the production of mango is the shortage of superior cultivars mainly because of difficulties experienced in conventional breeding of mango including the small number of seeds produced, the complex nature of flowers, excessive fruit drop, long juvenility, high level of heterozygosity and polyembryony

in some cultivars. Most of the current mango cultivars are results of selection from open-pollinated seedling populations.

Protoplast fusion and somatic hybridization techniques provide the opportunity for bypassing the conventional breeding barriers through direct transfer of cytoplasmic and nuclear genome to plant cells. Somatic hybridization could facilitate the introduction of the desirable traits like tolerance to biotic and abiotic stresses from cultivars and wild species of mango into cultivars of mango rootstocks.

In-Vitro Culture: In-vitro selection have the potential to select mango types that have positive mutation/variation through soma clonal variation. Various regeneration protocols have been developed including callus induction, somatic embryogenesis and organogenesis using different explants including cotyledons, nucellus, leaf disks and shoot tips of mango. Somatic embryos have been recovered from nucellus tissues of young mango fruit but standardization of media for maturation and germination of somatic embryos is very substantial.

Somatic Embryogenesis: -

Tomar R S *et al.* (2013) examined twenty mango cultivars (*Mangifera indica* Linn) collected from Gir region of Saurashtra by ISSR markers. Of the 50 primers screened, 21 primers gave reproducible, polymorphic DNA amplification patterns, and were selected to construct a DNA fingerprinting map to distinguish the genotypes of mango. According to the banding patterns obtained with 21 selected primers, all cultivars tested in this study except Jamadar and Kesar were distinguished from each other and showed ample genetic diversity, indicating that ISSR-PCR was an effective method for cultivar identification of mangoes. Based on 125 selected bands, all Gir mango landraces tested were clustered into a three big groups with 'Kaju' and 'Khodi' in first group, Dudh Pendo, Sopari, Jamadar, Kesar and Ashadhiya in second group, while the third cluster was composed of Agargato, Amir Pasand, Pethal, Gajariyo, Chhappaniyo, Alphonso, Neelum, Jamrukhiyo, Kavasji Patel, Giriraj, Amrutiyo, Dasherri and Deshi based on UPGMA analysis, indicating that some Gir landraces had a close relationship with each other, while some were drastically dissimilar from other landraces.

Shukla *et al.* (2015) conducted a study on Nucellar embryogenesis and plantlet regeneration in monoembryonic and polyembryonic mango (*Mangifera indica* L.) cultivars. Nucellar tissues from immature mango fruits of monoembryonic cultivars Alphonso,

Amrapali, Dashehari and Zafran, and polyembryonic cultivars Carabao and Turpentine were used as explants to induce somatic embryogenesis plantlets. Gamborg's B5 macronutrients, Murashige and Skoog micronutrients, iron source, vitamins and organics were used as standard basal media for all types of media used at each stage of somatic embryo development and regeneration. Induction medium 2 containing 2 mg/l 2,4-Dichlorophenoxyacetic acid and 0.5 mg/l 6-Benzylaminopurine were induced highest percentage of primary somatic embryos for Alphonso (22.08%) while induction medium 3 having 1 mg/l 2,4-Dichlorophenoxyacetic acid with sucrose 60 gm/l and induction medium 1 containing 1 mg/l 2,4-Dichlorophenoxyacetic acid and 0.25 mg/l 6-Benzylaminopurine induced highest percentage of primary somatic embryos in Carabao (29.17%) and Turpentine (42.71%) respectively. Maximum somatic embryo germination were achieved in germination medium 2 containing 0.1 mg/l Indole-3-acetic acid and 0.5 mg/l Gibberellic acid for Alphonso (7.34%) and Turpentine (3.34%) while for Carabao (18.59%) in germination medium 1 which does not contain any plant growth regulators. Germinated plantlets are surviving well in ex-vitro conditions after 4 months of transfer to greenhouse and survival rate of 66.66% for Alphonso, 26.68% for Carabao and 49.16% for Turpentine was obtained.

Table 6. Hardening and ex-vitro survival of tissue culture raised mango plants

Cultivars	Batch No.	No. of plants transferred to green house for hardening	No. of plants survived after 1 month of transfer	No. of plants survived after 3 months of transfer	% plants survived after 3 months of transfer	Mean % survival after 3 months of transfer
Alphonso	Batch 1	12	7	7	58.33	66.66
	Batch 2	6	5	4	66.66	
	Batch 3	8	6	6	75.00	
Carabao	Batch 1	28	2	2	7.14	26.68
	Batch 2	16	7	5	31.25	
	Batch 3	12	6	5	41.66	
Turpentine	Batch 1	8	5	3	37.50	49.16
	Batch 2	6	5	3	50.00	
	Batch 3	5	4	3	60.00	

Genetic Mapping

Surapaneni M *et al.* (2013) conducted Genetic analysis of 90 mango genotypes including juicy, table, dual and pickle types from different parts of Andhra Pradesh of India was carried out employing 143 mango-specific microsatellite markers. Of the 143, 34 were new mango-specific microsatellite loci isolated in the course of the present investigation by

constructing an (CA)_n and (TG)_n-enriched genomic library. Characterization of the 90 genotypes resulted in the detection of 301 alleles from 106 polymorphic loci with an average of 2.87 alleles per locus and polymorphism information content of 0.67. UPGMA cluster analysis grouped all the genotypes into two major groups with a genetic similarity range of 47–88 %. Grouping of the genotypes based on the utility type was observed only at sub-cluster level. Study of population structure by a model-based STRUCTURE analysis revealed the germplasm to exist in four gene pools. Overall *F*_{st} of 0.11 indicated genetic differentiation between the populations to be low. Analysis of molecular variance revealed that major proportion of the variation was within the individuals (62.25 %). The molecular marker-based study of genetic diversity suggests that the germplasm studied representing the kind of variability would be a valuable genetic resource for future breeding and association mapping in search for new and novel alleles.

Bajpai A *et al.* (2015) studied molecular and morphological diversity in locally grown non-commercial (heirloom) mango varieties of North India. In the present study, 37 types comprising of 27 heirloom varieties from Malihabad region and 10 commercial varieties grown in North and Eastern India were assessed for morphological attributes and molecular diversity. The employed SSR markers amplified 2-13 alleles individually, cumulatively amplifying 124 alleles. These were studied for allelic diversity and genetic dissimilarity ranged from 0.035 to 0.892 arranging the varieties in three major clusters. These results revealed that majority of unique heirloom mangoes from Malihabad were different from the eastern part of the country. It is interesting to note Dashehari, a commercial variety from Malihabad was not aligned with heirloom varieties.

Ravishankar K V *et al.* (2017) worked on development and characterization of microsatellite loci from mango. Twenty sequence tagged microsatellite site loci were characterized by employing M13 trailed PCR technique. All the twenty microsatellite loci were found to be efficient in discriminating and identifying the 20 diverse cultivars of mango used in this study. The genetic analysis for 20 microsatellite loci showed that expected heterozygosity ranged 0.350 to 0.850, with a mean of 0.505. The polymorphic information content values ranged 0.624 to 0.938, with a mean of 0.860. The probability of identity (PI) value ranged 0.012 to 0.182, with a mean of 0.050. The total PI was 1.06×10^{-28} . These novel SSR marker could be further exploited for genetic studies, cultivar identification, linkage map development and association studies.

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