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Mango breeding in India - Past and future

M.R. Dinesh*, K.V. Ravishankar and Donald Sangma
Division of Fruit Crops
ICAR-Indian Institute of Horticultural Research
Hesaraghatta Lake Post, Bengaluru – 560 089, India
*E-mail: mrdinesh@iihr.res.in

ABSTRACT

The mango (*Mangifera indica* L.) is one of the most important tropical fruits of India in which improvement has been attempted since the early 20th Century. The species, *M. indica,* having originated in India, has a large diversity within the country. Extensive surveys have located several wild species of importance, many of them figuring in the IUCN Red List. Conservation and evaluation of these species, as well as the large seedling diversity, needs attention as these could be a source for important traits. Strategies of *in situ, ex situ* and 'on-farm' conservation should from a priority at this juncture. Hybridization has resulted in several hybrids. Widening of genetic base in polyembryonic varieties and identification of zygotic embryos through markers is the need of the hour for utilization in breeding programmes. Although several of these have not become popular, they can be very well used as pre-breeding lines. Use of molecular markers for selection will greatly reduce time taken for developing improved varieties. Strategies other than hybridization, viz., selection among open-pollinated progenies, should be adopted for identifying better recombinants, as, a large number of progenies are available in this method.

Key words: Mango, *Mangifera india* L., breeding, polyembryonic, monoembryonic

INTRODUCTION

The mango (*Mangifera indica* L.) originated in north-eastern India, the Indo-Myanmar border region, and in Bangladesh, where it is still found as a wild tree bearing very small fruits. It is also known to occur in the lower Himalayan tract, near Nepal, Bhutan and Sikkim. As per Mukherjee (1953), mango has been cultivated for the past 4000 years at least, with over 1000 varieties under cultivation during this time.

The genus *Mangifera* belongs to the order Sapindales in the family Anacardiaceae.

Detailed classification is as follows:

Division : Magnoliophyta
Class : Magnoliopsida
Sub-Class : Rosidae
Order : Sapindales
Family : Anacardiaceae
Genus : *Mangifera*

The five species, *M. sylvatica, M. khasiana, M. andamanica, M. indica* and *M. camptosperma* reported to be found in India, are distinctly different from each other. *M. indica* is the most important species of the genus, as a producer of the most delicious tropical fruit, the mango. It is closely related to *M. longipes* Griff. and *M. sylvatica* Roxb.

Mango (*Mangifera indica* L.) is the most important fruit crop in India with considerable socio-economic significance. It is known as the 'King of fruits' owing to the delicious quality of the fruit rich in vitamins and minerals. Its long period of domestication is evident from its mention in the ancient Indian scriptures. Ancient Indians valued mango not merely for the sentiment or religious consideration, but also they realized its importance in the economic and cultural life of their society. Mughal kings promoted the practice of planting the best varieties: Lakhi Bagh (one lakh tree) planted by Akbar the Great is well-known in history. Ain-I-Akbari, an encyclopedia written in 1590 AD gives an ample understanding of mango in that period. However, research with specific objectives started by the turn of the last Century. Mango is rich in Vit A, C, flavonoids, carotenes, glucosides, sterols, terpenes, aromatic acids, essential oils, fatty acids and phenolics. It is a powerfully nutritive fruit, containing most of the essential substances needed by the human body.

Mango is a highly heterozygous crop, and it is this high heterozygosity in cultivars that is exploited in hybridization. There are inherent difficulties in obtaining large hybrid populations, which makes accurate genetic analysis in mango very difficult (Iyer and Schnell, 2009). Despite the drawbacks ailing mango breeding (like high heterozygosity and occurrence of only a single seed per fruit), breeding is successful owing to a number of positive attributes in the species, like, the wide range of available genetic variation, and the ease with which a selected hybrid can be propagated vegetatively (Iyer and Schnell, 2009). However, in spite of the large variability, adequate headway has not been made in crop improvement.

Genetic diversity - an impediment or a strength?

Bompard (1993) listed more than 60 species worldwide, with the highest diversity found in the heart of the distribution area of the genus *Mangifera,* i.e., the Malayan Peninsula, Borneo and Sumatra. In India, more than one thousand varieties are grown (Mukherjee, 1953**),** all of which belong to *Mangifera indica* L. Field gene-bank collections made in the country, to a very great extent, represent this vast gene pool. The vast diversity in indigenous mango varieties, mainly of seedling origin, has remained unexplored. However, there are still regions within the country that have not been explored for mango wealth. This unexplored genetic diversity can be a source of very important traits. It is possible that desirable traits like disease or pest resistance are available in this gene pool. It is in this context that the concepts of 'On-farm conservation' and 'Custodians of genetic diversity' assume great importance. The UNEP-GEF TFT project successfully identified 54 farmers who were conserving genetic diversity in their own orchards for various purposes, viz., better pollination, to regularity of bearing, to fruits to be used for different purposes. One example is identification of some seedling-types in Chittoor, wherein varieties with a high carotenoid content and excellent shelf-life were noticed (Dinesh *et al*, 2015). Hence, not withstanding problems of nomenclature ambiguity there is a scope for locating genotypes with desirable traits by germplasm surveys, evaluation and characterization. Chances for improvement from germplasm survey in the heterozygous perennial mango are definitely higher than that through hybridization programmes, in our experience. Hence, if the vast diversity is adequately assessed and utilized, it can be a boon for improvement.

***In situ, ex situ* and on-farm conservation**

The large gene-pool in mango needs to be conserved. *In situ* conservation, so far, has not been able to prevent genetic erosion due to several factors. *Ex situ* conservation has the limitation of a variety not expressing itself fully due to the environmental effect. This also needs a large area, which is a difficult proposition. Hence, the concept of 'Core collection' needs to be adopted. However, for a heterozygous population, it is to be seen very critically whether a suitable representative sample can be selected. Under these circumstances, 'On-farm conservation' is one of the strategies that can be satisfactorily adopted. Dinesh *et al* (2015) observed that several of the seedling-types being grown as heirloom varieties, are conserved in farmers' orchards. Andhra Pradesh is home to many juicy type of mangoes known as 'Rasalu' types, viz., Chinnarasam, Peddarasam, Cherukurasam, etc. Registration of these varieties with PPV&FRA can result in conservation and, further, the farmer can also receive royalty for his sustained effort.

Past approaches and present modifications

In a fruit crop like the mango which has a very wide genetic base of monoembryonic varieties, nomenclature ambiguity is one of the major impediments. Very few studies on diversity have been made. Choice of ideal parents has remained a problem (Dinesh, 2003). Lavi *et al* (1998) opined that parents should not be chosen on the basis of phenotype alone, since, offspring-performance is quite unpredictable. Several studies have shown that genetic studies can only be a pointer, as in a heterozygous crop like mango, progeny performance remains quite unpredictable (Iyer, 1991; Dinesh, 2003). However, the key to solving this problem is to raise a large number of progeny. In this context, the suggestion of Iyer (1991) to raise a large number of F2 populations is noteworthy. In the past, number of progenies obtained from a particular cross has been very low. Hence, selection of recombinants was limiting. Lack of stable morphological pre-selection indices has further not helped selection, while the time taken for improvement too is not reduced.

Exploiting heterozygosity in mango

Owing to propagation by seeds and due to cross-pollination, high heterozygosity is present in mango. In a cross between two heterozygous varieties, segregation in F_1 is similar to that obtained in F_2 population obtained from crossing homozygous lines. In mango, where a limited progeny population hampers meaningful selection, exploitation of heterozygosity to raise a large number of progenies, is required for better selection. Two approaches

that can help increase variability in a progeny population are: (i) raising half-sibs, and (ii) open-pollinated progenies. Progenies so raised are evaluated for various characters and their parentage validated.

Polyembryonic varieties as parents

The genetic base of polyembryonic varieties in mango is very narrow, unlike in monoembryonic varieties. Major mango producing countries, viz., Australia, Philippines, etc. have polyembryonic types as a commercial variety. Polyembryonic types, in India, are mainly located in Western Ghats, in the coastal and North-eastern regions of the country. Due to their propagation by nucellar seedlings, no large diversity is noticed in these types. Polyembryony in mango is genetically controlled. Leroy (1947) opined that the presence of one or more recessive genes results in adventive embryony. Sturrock (1968) also observed that when monoembryonic varieties were crossed with polyembryonic varieties, the resultant progenies indicated monoembryony as a dominant trait. However, Arnon *et al* (1998) observed that dominant genes controlled polyembryony. Brettell *et al* (2004) also opined that dominant genes controlled polyembryony. In addition, they concluded that this varied with location.

Pre-selection indices in mango breeding

Mango is perennial in nature and because of its long juvenile-phase, evaluation of progenies takes a long time which needs a large area. Pre-selection indices help overcome this problem to a great extent. Pre-selection involves selection from seedling progenies even at the juvenile stage for adult characteristics, based on well-established correlations.

Some correlations worked out in mango have shown leaf flavour to be directly correlated with fruit flavour (Majumder *et al,* 1972; Whiley *et al,* 1993). Emergence of new growth flush simultaneously with fruiting, or immediately after harvest, indicates that the tree is going to be regular in bearing (Sharma *et al,* 1972). Higher phloem to xylem ratio was found to be associated with the dwarf stature. If this ratio exceeds 1.0, the trees tend to be least vigorous; if this value is 0.6 to 1.0, the trees will have medium vigour; those with a ratio less than 0.6 will be the most vigorous (Kurian and Iyer, 1992). Higher amount of phenolics in the apical bud has also been shown to be associated with the dwarf stature (Iyer, 1991). Majumder *et al* (1981) had earlier reported that lower stomatal density was an indication of dwarf stature.

Pre-selection indices are pointers to selection prior to the main selection of a trait in question. These are extremely important as they save time, space and money. The concept of pre-selection index is not very new. Van Mons first reported it in 1835, and Mitschurin in 1969, based mainly on their practical experience. In mango, there is a need to look for morphological, molecular and biochemical markers. Campbell and Zill (2009), using leaf aroma, screened thousands of seedlings at their juvenile stage.

Need for diversity studies

Mango, being highly heterozygous, has a large diversity that has resulted from propagation by its seeds. This, in turn, has resulted in ambiguity in nomenclature as, the same variety is known by different names in different regions. Diversity studies would help choose parents, so that heterosis can be exploited for various traits. Souza *et al* (2011) evaluated genetic variability of mango (*Mangifera indica* L.) accessions, of which 35 originated from Brazil, six from USA, and one from India. These accessions were found to have considerable genetic variability, demonstrating the importance of analyzing each genotype in a collection, to efficiently maintain a germplasm collection. Start codon targeted (SCoT) markers were used to investigate genetic diversity of 73 mango accessions in-China, and, the studies resulted in these accessions being grouped into four (A, B, C, D) clusters. This corresponded well with their geographical origin and known history, indicating its importance for germplasm characterization, improvement, management and conservation (Luo *et al*, 2012). Ravishankar *et al* (2013) evaluated genetic diversity and relationship among 269 mango (*Mangifera indica* L.) cultivars of the Indian peninsula using 'Sequence Tagged Microsatellite Site (STMS)' markers. Gao *et al* (2013) studied 200 accessions of mango (*Mangifera*) from exotic and domestic sources as test material. Their result showed that the germplasm cluster developed did not completely correlate with their geographical origin and type of embryo. Through an eco-geographic survey covering three regions of the state of Andhra Pradesh, 31 accessions of 'Beneshan' (BN Acc-l to BN Acc-31) were selected, and their fruit and leaf samples collected to study intra-cultivar heterogeneity, based on morphological fruit traits and microsatellite markers, respectively, by Begum *et al* (2012). *In situ* characterization and evaluation of fruit samples revealed phenotypic variation among 'Beneshan' accessions. Of the 109 mango-specific simple sequence repeats (SSRs) validated, 23 were polymorphic. Highly polymorphic

microsatellites like SSR-80, SSR-87, SSR-28, and SSR-89 were more useful in differentiating these 'Beneshan' accessions. Dillon *et al* (2013) evaluated eleven (11) microsatellites markers for their usefulness in identifying varieties, validating progeny and parents, and to estimate genetic diversity in populations. The markers proved ideal for fingerprinting varieties, with an average of 8.36 alleles per locus, identified to distinguish all of the 105 accessions tested, used 25 EST-SSR markers to study the extent of PCR amplification, polymorphism and heterozygosity across a diverse selection of varieties of *M. indica* and related *Mangifera* spp. available at Australian National Mango Genebank (ANMG). These markers exhibited polymorphisms Xable of identifying a total of 86 alleles, with an average of 5.38 alleles per locus and distinguished all the *Mangifera* selections. The study has been utilized for identifying progeny and parents for selection, and, application of this extended panel will further improve and help design mango hybridization strategies for increased breeding efficiency. Thus, genotyping *Mangifera* accessions with microsatellite markers can quickly reveal genetic diversity among accessions. Sane *et al* (2015) studied genetic variability among 11 mango genotypes using inter-simple sequence repeat (ISSR) primers. Of the primers tested, di-nucleotide and tri-nucleotide repeats gave clear and reproducible band profiles. Highest similarity was observed among 'Dwarf Rumani' and 'Creeping'. 'Moreh' and 'Sabre' (both being polyembryony types) grouped together in Cluster 2. The high degree of polymorphism and reliable amplification confirmed utility of DNA markers for genetic diversity studies in mango.

Diversity studies and relatedness of accessions help the breeder choose parents, so that recombinants with desirable traits can be developed.

Genetic studies - as pointers

Genetic studies carried out using over a thousand hybrid progenies by Sharma and Majumder (1989) showed that dwarf stature, regular bearing and precocity are controlled by recessive genes. Regularity in bearing appeared to be linked to precocity, and, the character contributing to biennial bearing is dominant over those governing the regular-bearing habit. Sharma (1987) opined that additive genes controlled flesh color. However, Iyer (1991) observed that light-yellow colour was dominant over orange-yellow in the progenies of Alphonso X Neelum cross. Dinesh (2003), in a study carried out using half-sib analysis, found that fruit characters like fruit weight, TSS and pulp percentage were controlled by non-additive factors, and heritability was low. Lavi *et al* (1998) concluded that parents should not be chosen on the basis of phenotype, since, offspring performance is quite unpredictable. As for skin colour, it was found that when red coloured varieties were crossed with green coloured varieties, gradation of colour in the progenies indicated that fruit colour was controlled by a number of loci (Sharma, 1987; Iyer & Subramanyam, 1987). Presence of a beak on the fruit seems to be dominant, as, all of the progeny had the beak on their fruits when 'Totapuri' was used as one of the parents (Iyer and Subramanyam, 1979). Bunch-bearing was found to be dominant over single-fruiting (Sharma *et al*, 1972).

In open-pollinated progenies, Lavi *et al* (1989) observed no maternal effect on juvenile period and fertility, but there was maternal effect on harvest season and fruit colour, and a slight effect of maternal parent on fruit size and taste. Cytoplasmic inheritance was observed for resistance to bacterial canker as all the progenies were found to be susceptible when Neelum was used as the female parent, irrespective of the male parent used (Sharma and Majumder, 1989). Iyer (1991) observed that recessive genes mediated internal breakdown (spongy tissue). Sharma and Majumder (1989) found that dominant genes controlled susceptibility to mango malformation, as, crosses with 'Bhadauran' (a resistant variety) did not yield any resistant hybrid.

Improvement in the hybridization technique, using a few flowers in a larger number of panicles for crossing, and then, covering the panicles with polythene bag instead of the muslin bag, resulted in raising a large number of hybrid progenies. In fact, one of the main reasons for success in later work on hybridization was the use of information on gene donors, and prevention of indiscriminate crossing among varieties. Work carried out extensively so far on a identifying resistance source for some of the pests and diseases has proved futile. Varieties found to be resistant resistance initially have not been found to be genetically resistant. Use of these varieties in breeding programmes resulted in progenies, which too were susceptible. Mango, as a breeding material is difficult to handle, because of its long juvenile phase, high heterozygosity with only a small number of hybrid progenies recoverable. However, information obtained on inheritance of characters, summarized as follows should be of help in planned hybridization:

1. Upright habit of the tree as dominant over spreading, and, spreading as dominant over dwarfness.

2. Dwarfness found to be governed by recessive genes
3. Strong linkage found between bearing and fruit quality
4. Biennial bearing tendency found to be dominant over regular-bearing
5. Regularity of bearing controlled by recessive genes, found to have close linkage with precocity in bearing
6. Bunch-bearing habit observed to be dominant over single-fruit bearing
7. Presence of beak, marked with sinus, dominant
8. Transgressive segregation for fruit size observed in F1 hybrids
9. Red skin-colour found to be dominant and gradations in skin colour of F1 suggestive of the role of multiple genes; also the case with flesh colour
10. Resistance to floral malformation seems to be controlled by recessive genes
11. Cytoplasmic inheritance found in the case of bacterial canker, and
12. Spongy tissue observed to be genetically controlled

Bretell *et al* (2004) observed that several important fruit-quality aspects such as fruit weight, fruit shape, ground skin-colour, fruit width and pulp depth had a high heritability and could, therefore, be readily selected in a breeding programme. For non-ordered traits scored in discrete categories (blush colour, bloom, lenticel colour, embryo type and flavour), an estimate was made of data consistency from multiple scores for individual hybrids at different times and locations. Relatively high consistency value was recorded for fruit flavour, and in combinations involving 'Kensington Pride'. Analysis of blush colour and fruit flavour in twelve families of hybrids confirmed that these characters have a strong genetic component; a high frequency of hybrids with red or burgundy blush can be recovered from crosses where one of the parents has an intense red-blush colour. Singh *et al* (2004) observed a wide magnitude of phenotypic coefficient of variation with high genetic advance for yield per plant and fruit weight in 31 chance seedlings of mango. Yadav and Dinesh (1999) evaluated genotypes of dwarf stature so that these could be used further in breeding programmes, and, progenies of dwarf stature could be isolated. Varieties 'Kerala Dwarf' and 'Janardhan Pasand' were found to be the most suitable for use as donor parents in a breeding programme. Dinesh (2003) observed that non-additive variance controlled several quantitative characters in mango. It was noticed that heritability was low, and chances of hybrid vigour manifesting for these characters in F_1 generation were bright. Selection of progenies can be made based on fruit size, i.e., medium-sized fruits have good TSS and selecting was more than the genotypic coefficient emphasizing the greater manifestation of characters and lesser influence of environment.

Outcome of research in mango improvement

With improvement in hybridization techniques, several improved varieties have been released in India from various regions (Misra *et al*, 2011). Adoption of these in different environments depends on Genotype x Environment interaction. Some of these are listed below.

Mallika

This hybrid between Neelum and Dashehari was released from IARI, New Delhi. It has a strong tendency to regular bearing. Fruits, on average, weigh about 350-400g and have a deep yellow pulp, high TSS, good odour, uniform fruit size and moderate keeping quality (Singh *et al*, 1972).

Amrapali

This is from the parentage Dashehari X Neelum. Plants are dwarf and have a regular bearing habit. Fruits weigh, on average, about 180-250g being borne on clusters, are sweet to taste and have a good keeping quality.

Ratna

This is a hybrid from the cross, Alphonso X Neelum, released by Fruit Research Station, Vengurla. It is regular-bearing, produces medium-sized fruits weighing, on average, about 250g. The pulp is orange in colour and is free from spongy tissue or fibre.

Sindhu

This is a hybrid progeny derived by backcrossing Ratna with Alphonso, released by Fruit Research Station, Vengurla. Fruits are borne in clusters and weigh, on average, about 150-220g. The pulp is deep yellow with good sugar: acid blend. Fruits are almost seedless, with a very thin stone, although fruits weighting above 200g have a well-developed seed.

Konkan Ruchi

This is a hybrid from the parentage, Neelum X Alphonso. It bears medium-sized fruits. Konkan Krishi Vidyapeeth, Dapoli, developed this variety, especially for pickle-making.

Konkan Raja

This is a hybrid from the parentage, Bangalora X Himayuddin, developed by Konkan Krishi Vidyapeeth, Dapoli. It has a compact growth habit and bears large-sized fruits (616g) in clusters. It is good in taste; immature fruits are useful in salad making. Pulp percentage is relatively high (83%), with good T.S.S. (16.8°Brix). It is a regular-bearing variety.

Alphonso 900

This is a selection from the variety, Alphonso. It is an early-bearer with uniform-size fruits of excellent quality, pleasing flavour, good in sugar:acid blend, attractive fruit colour and a long shelf-life, suitable for processing. Konkan Krishi Vidyapeeth, Dapoli, developed this variety.

Sai Sugandh

This is a late variety, maturing in June. It is semi-vigorous, with fruits showing prominent lenticels and a beak. Fruits are medium in size, of good quality, but susceptible to anthracnose. Konkan Krishi Vidyapeeth, Dapoli, developed this variety.

Pusa Arunima

This is from the parentage, Amrapali X Sensation, released by Indian Agricultural Research Institute, New Delhi. Fruits are medium-sized, with an attractive skin colour. The pulp is deep yellow with TSS of around 20°Brix.

Pusa Surya

This is a selection from the variety, Eldon, released by Indian Agricultural Research Institute, New Delhi. It bears medium-sized fruits, has a red peel colour (similar to that of 'Sensation').

Pusa Prathibha

This is a hybrid between the cross, Dashehari X Amrapali, developed by Indian Agricultural Research Institute, New Delhi. It is a regular-bearing variety, with an attractive fruit shape, bright-red peel and orange pulp. It has oblong, uniform-sized fruits and good sugar: acid blend. The plants are semi-vigorous.

Pusa Shresht

This is a hybrid between the cross, Amrapali X Sensation, developed by Indian Agricultural Research Institute, New Delhi. Trees are semi-vigorous, regular-bearing, with elongated fruits and an attractive red peel. The pulp is orange in colour, fibreless and firm when ripe, has a moderate sugar:acid blend, with uniform fruit-size (228g). It contains good amounts of Beta-carotene and ascorbic acid.

Pusa Pitamber

This is a hybrid between the cross, Amrapali X Lal Sundari, developed by Indian Agricultural Research Institute, New Delhi. The plants are semi-vigorous, regular-bearing, with attractive oblong fruits. Fruits turn a uniform yellow on ripening. It has a good sugar:acid blend and uniform-sized fruits.

Pusa Lalima

This is a hybrid between the cross, Dashehari X Sensation, developed by Indian Agricultural Research Institute, New Delhi. The plants are semi-vigorous, regular-bearing, with attractive oblong fruits and bright-red peel on yellowish green background, with an orange pulp and good sugar:acid blend.

Ambika

This is a hybrid between the cross, Amrapali X Janaradhan Pasand, developed by Central Institute for Subtropical Horticulture, Lucknow. The fruits of this variety are medium in size, with a slight sinus and beak, and a broadly pointed apex. Peel is smooth and tough. Fruits are bright yellow with a dark-red blush. Pulp is firm, with scanty fibre. TSS of this variety is 21°Brix. It is a late-maturing variety.

Arunika

This is a hybrid between the cross, Amrapali X Vanraj, developed by Central Institute for Subtropical Horticulture, Lucknow. Fruits of this variety are attractive, and with a red-blush, high TSS (24°Brix) and high in carotenoids. Pulp is firm. It is a regular bearer and plants are dwarf.

Pant Chandra

This is a clonal selection of 'Dashehari' from Govind Ballabh Pant University of Agriculture & Technology, Pantnagar. Plants are tall, with an erect growth habit. Fruit at maturity remains green. It is a mid-season variety. Fruits weigh upto 150g. Fruit pulp is reddish-yellow, with total soluble solids at 18%, and having a pleasant aroma.

Pant Sinduri

This is a clonal selection of 'Dashehari' from Govind Ballabh Pant University of Agriculture & Technology, Pantnagar. Trees are medium in height, with a round top-

canopy. Fruit is yellow, with a pink shoulder. Average fruit weight is 200g. Fruit pulp is yellow, with a pleasant aroma. Total soluble solids vary from 16 to18%, with an average yield of upto 150kg per tree. Fruits mature from the last week of May to the first week of June.

PKM-1

This is a hybrid released from Horticultural Research Station, Periyakulam. It is of the parentage, Chinnaswarnarekha X Neelum. It is regular in bearing, produces good quality fruits in clusters.

PKM-2

This is a hybrid released from Horticultural Research Station, Periyakulam. It is from the parentage, Neelum X Alphonso. It is regular in bearing and produces good quality fruits in clusters.

Neeleshan Gujarat

This is a hybrid from the parentage, Neelum X Baneshan, developed by Agricultural Experimental Station, NAU, Paria, Gujarat. It is a mid-season variety maturing in May. It is semi-vigorous and is a poor yielder.

Neeleswari

This is from the parentage, Neelum X Dashehari, developed by Agricultural Experimental Station, NAU, Paria, Gujarat. It is a mid-season variety maturing in May. It is vigorous and a moderate yielder. Fruits are medium in size and good in quality, with high pulp content. In appearance, the fruits are similar to 'Langra'.

Neelgoa

This is a hybrid from the cross, Neelum X Mulgoa, developed at Fruit Research Station, Sangareddy, Andhra Pradesh. It has high flowering-intensity and percent perfect flowers. Shape of the fruit is similar to 'Banganapalli'. It is semi-vigorous and a moderate yielder. Fruits are medium in size, good in quality with a high pulp-content.

Neelphonso

This is from the parentage, Neelum X Alphonso, developed by Agricultural Experimental Station, Navasari, Agricultural University, Paria, Gujarat. It has low flowering-intensity. Fruits are large in size and excellent in quality, but with low pulp content.

Niranjan

This is an off-season bearing selection from the variety, 'Royal Special'. 'Niranjan' flowers thrice a year (August, October and December). Flowering intensity is highest during December. It has a low flowering intensity in general, and moderate percentage of perfect flowers. Fruits are round, with low pulp content. This varity was released by Gujarat Agricultural University.

Sonpari

This is a hybrid from the cross, Alphonso X Baneshan, developed by Agricultural Experimental Station, Navasari, Agricultural University, Paria, Gujarat. Fruits are round and weigh about 550g. The peel attains golden-yellow colour when ripe, with TSS of about 19.3°Brix.

Au-Rumani

This is a hybrid by the combination, Rumani X Mulgoa, released by Fruit Research Station, Kodur. It bears large fruits of good flavor. It is a heavy yielder, with moderately firm pulp.

KMH 1 (Kodur Mango Hybrid 1)

This is a hybrid released by Fruit Research Station, Kodur. It is from the parentage, Cherukurasam X Khader. Plants are semi-dwarf, regular in bearing; fruits are fibreless with high Brix value and low acidity.

Manjeera

This was released from Fruit Research Station, Sangareddy. It is from the parentage, Rumani X Neelum. It produces round fruits, with a firm pulp, and bears regularly. The pulp of the fruit is yellow with TSS of about 19°Brix.

Swarna Jehangir

This is a hybrid from the cross, China Suvarnarekha X Jehangir, developed at Fruit Research Station, Sangareddy. It is a late variety, maturing in June. Fruits weigh upto 450g. TSS of the fruit is 19°Brix, acidity 0.58%, and pulp content about 77%.

Neeluddin

This is from the parentage, Neelum X Himayuddin, developed at Fruit Research Station, Sangareddy, Andhra Pradesh. It is a mid-season variety maturing in May-June. It has moderate flowering-intensity, with medium percentage of perfect flowers. Fruits are large, with average weight of 435g, with TSS and acidity at 18° Brix and 0.46%, respectively.

Neeleshan

This was developed at Fruit Research Station, Sangareddy, Andhra Pradesh. It is a hybrid between the cross Neelum X Baneshan. It is a mid-season variety bearing oval-shaped fruits weighing upto 400g TSS is 18.2°Brix, and the pulp content 72%.

Sabri

This is a hybrid between the cross, Gulabkhas X Bombay Green, developed at Bihar Agricultural University, Sabour, and Bhagalpur. It is semi-vigorous with low yield potential. Fruits are small but good in quality, with TSS of 19-20°Brix.

Mahmood Bahar

This is a hybrid from the cross, Bombay Green X Kalapadi, developed by Bihar Agricultural University, Sabour, Bhagalpur. It is a mid-season variety where fruits mature in May. It is semi-vigorous and a moderate yielder. Fruits are medium in size and good to taste.

Al Fazli

This is from the parentage, Alphonso X Fazli, released by Fruit Research Station, Sabour. It is superior to Fazli and does not have spongy tissue. Fruits are sweet to taste.

Jawahar

This is a hybrid between the cross, Gulabkhas X Mahmood Bahar, developed by Bihar Agriculture University, Sabour (Bihar). It is a mid-season variety. Fruits are medium in size with average weight of 215g. The pulp is light-yellow, sweet to taste, pleasant in flavor and remains firm even after ripening. TSS, acidity and pulp percentage are 22.5°Brix, 0.14% and 79.5%, respectively.

Menaka

'Menaka' is a selection arising from 'Gulabkhas' seedling. It is a regular-bearing and late-maturing variety; fruits are attractive with deep-red basal portion. Pulp is deep-yellow, sweet and pleasant in flavour, low in fibre and firm. Fruit shape is oblong-oblique. Average fruit weight is 300g, TSS of the fruit is 20°Brix, acidity 0.14% and pulp content 75%.

Subhash

This is a selection from seedlings of 'Zardalu'. It is a mid-season variety. Ripe fruits are bright yellow as in 'Zardalu', with the shape of 'Langra' fruit. Fruits are medium in size, with an average weight of 220g. TSS and acidity of the fruits are 24°Brix and 0.29%, respectively. Pulp content is 76%.

Sundar Langra

This is from the cross, Sardar Pasand X Langra. It is regular-bearing and the fruit resembles 'Langra' in shape and size. Fruits are medium-sized and sweet to taste (Hoda and Ramkumar, 1993).

Arka Neelachal Kesari

This is a variety released from Central Horticultural Experiment Station, Bhubaneswar. It is a clonal selection from 'Gulabkhas'. Fruits are medium-sized and average fruit weight is 220g per fruit; pulp is light-yellow, sweet to taste and excellent in quality, with a good sugar-acid blend.

Arka Aruna

This was developed at Indian Institute of Horticultural Research, Bangalore. It is from the parentage, Banganapalli X Alphonso. It is regular-bearing; pulp is free from fibre or spongy tissue, pale-yellow in colour, moderately firm, good for making mango bars. Fruit size is large. Plants are dwarf in stature.

Arka Puneet

This was developed at Indian Institute of Horticultural Research, Bangalore. It is from the parentage, Alphonso X Banganapalli. It has an attractive fruit skin colour, medium-sized, fruits free from spongy tissue, with good keeping quality and sugar-acid blend.

Arka Anmol

This was developed at Indian Institute of Horticultural Research, Bangalore. It is from the parentage, Alphonso X Janardhan Pasand. It is regular-bearing, has fruits with uniform yellow skin colour. It is free from spongy tissue, has good keeping quality and a good sugar-acid blend.

Arka Neelkiran

This was developed at Indian Institute of Horticultural Research, Bangalore. It is from the parentage, Alphonso X Neelum. It is regular-bearing, with medium-sized fruits free from spongy tissue, good pulp colour, excellent skin colour, and the tree is semi-vigorous.

Arka Udaya

This is from the cross Amrapali X Arka Anmol. Fruits weigh 225 to 250g, and are oval in shape; pulp is deep-orange in colour, firm and fiberless. TSS is 21°Brix, and pulp recovery is over 70%. Fruits have an excellent shelf-

life. It is a late-season variety, with a semi-vigorous growth habit.

Breeding for biotic and abiotic stress resistance

Several insect pests, viz., hoppers, mealy bugs, stem borer, fruit fly, stone weevil, and diseases, viz., anthracnose, powdery mildew, etc. attack mango during various stages of growth. Apart from this, disorders such as spongy tissue and malformation also cause considerable damage. As mentioned elsewhere in this article, no reliable source of resistance is available so far for most of these maladies. However, large-scale screening has helped identify some varieties as tolerant, although this needs further confirmation. As for abiotic stress like salinity, rootstock breeding has been attempted in Israel. Reddy *et al* (2003), in a study spanning 21 years, observed that 'Vellaikulamban' as rootstock imparted dwarf stature to 'Alphonso'. Among polyembryonic rootstocks, the variety 'Muvandan' was found to be the most vigorous. One rootstock, 13-1, developed in Israel, is resistant / tolerant to soil stresses, viz., calcareous soils, saline irrigation-water and heavy, non-aerated soils (Gazit and Kadman, 1980).

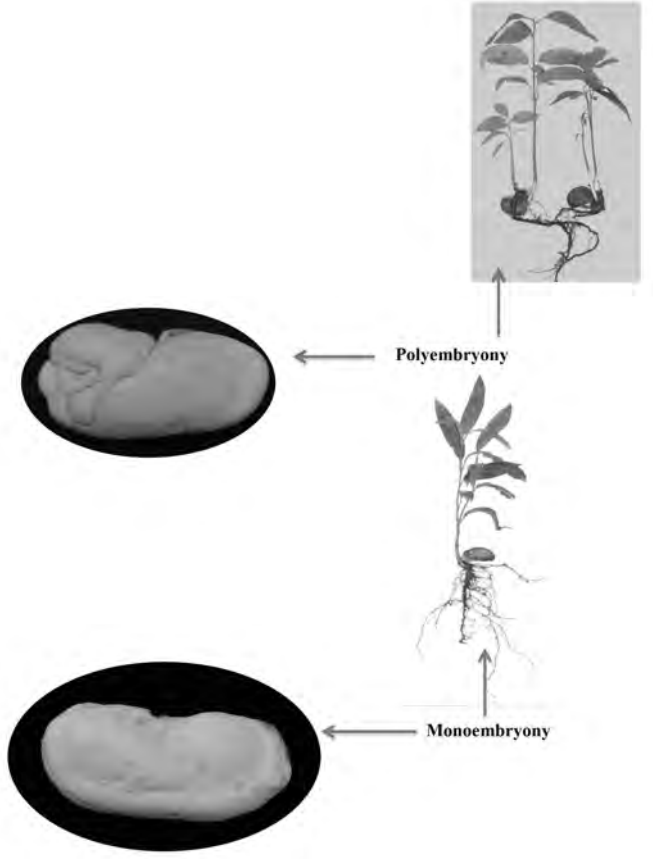
Wide hybridization

There is a need to study crossability between species, as, this would facilitate introgression of genes from wild types. A species like *M. magnifica* is completely free from fibre. *M. rufocostata and M. swintonioides* have the off-season bearing habit, *M. paiang* and *M. foetida* have good quality fruits. The variety, 'Wani', of the species, *M. caesia* from Bali & Borneo, has a distinctive taste. *M. casturi*, a newly described species occurring in South Kalimanatan, is a prolific bearer with small, black, sweet fruits. These species offer a good potential in breeding (Bompard, 1993; Kostermans & Bompard, 1993). Angeles (1991) reported *M. altissima* as not being affected by serious pests like hoppers, tip borers or seed borers. Hence, there is a need to evaluate these species.

Biotechnological approach

Use of various biotechnological methods for studying crop genetics and applying it as a tool for fruit crop improvement, is of recent origin. Use of molecular markers, *in vitro* selection and regeneration, identification of linkage for specific traits, and construction of genetic maps, gene pyramiding, allele mining, etc. are some of the recent developments. Discovery of molecular markers has led to detailed genetic analysis and use of newer approaches to improvement in crop plants. Most fruit tree breeding programmes follow the scheme of classical recurrent selection. This results in multiple breeding and production populations. In addition, trees have a long juvenile period. All these lead to a long breeding period. With the advent of

Diversity in mango fruit for shape, size and peel colour



marker assisted breeding (MAB), we can plan to reduce this period. The technique has shortened the time required for developing new cultivars. MAB has also made the process more cost-effective than selection based exclusively on the phenotype. However, basic research is needed to understand molecular and physiological mechanisms underlying the trait under study. MAB is based on identification of heritable DNA-sequence differences (polymorphisms). This combines both traditional breeding strategies and molecular tools for selecting plant material with the traits of interest, such as colour, size, or, biotic/ abiotic stress resistance. Several types of markers are used in plant breeding, like SSR (simple sequence repeats), AFLP (amplified fragment length polymorphism), SCAR (sequence characterized amplified region), etc.

With the advent of next generation sequencing (NGS), availability of genomic resources such as whole-genome sequences and high-density genotyping platforms, has increased for crops. These are helping understand important structural and regulatory genes, as well as molecular polymorphisms associated with important agronomic traits (Verde *et al*, 2012; Dirlewanger *et al*, 2012). In mango, recently, several groups have made an attempt to develop genomic resources. Using whole-genome sequence data, Ravishankar *et al* (2015) developed over eighty thousand microsatellite markers for mango. Similarly, using transcriptome data, Luo *et al* (2014) developed EST-SSR markers; Kuhn and David (2014) developed SNP markers, for mango. Shudo *et al* (2013) developed cleaved amplified polymorphic sequence (XS) markers for identifying true hybrids in the F_1 progeny in mango. However, efforts need to be made to develop high-density linkage and association maps that can help breeders identify QTLs and genes responsible for particular traits.

Future line of work

Conservation of indigenous germplasm plays role in any crop improvement programme. In the case of mango, where a large population of seedling germplasm located in the orchards, conservation and evaluation is important. This can help locate traits of interest, especially, biotic and abiotic-stress tolerance. There is a need to widen the genetic base in polyembryonic varieties. Rootstock breeding for abiotic-stress tolerance and high-density planting should be accelerated. Marker assisted selection for progenies derived from polyembryonic parents, and, extensive development and use of half-sibs for exploitation of heterozygosity, can help mango improvement programmes. Recognizing farmers who maintain diversity as 'Custodians of diversity' and linking the seedling-types with the market, can help conserve invaluable seedling-types while paving the way for registration of indigenous seedling derived mango varieties.

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