



# **Genetic Diversity and Breeding Strategies in Major Fruit Crops**

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## **Abstract**

Crop improvement is based on genetic diversity which has a key role in sustainable production of the major fruit crops. Fruits are mostly perennial, highly heterozygous and in most cases cross-pollinated leading to high degree of genetic variability that makes systematic breeding quite difficult. As pressure mounts with an increase in population, climate change, new pests and diseases and a shift in consumer preferences, the ability to efficiently exploit genetic diversity by clearly defined breeding strategies has never been more important than it is today. The morphological, physiological and biochemical variation is large in major fruit crops, including mango, banana, citrus, apple, grape, and papaya, much of which is based on wild relatives, landraces, indigenous cultivars, and the imported germplasm. Such genetic assets are good sources of genes to enhance yield, fruit quality, stress resistance and adaptation to a variety of agro-climatic environments. Nevertheless, genetic bases have become narrower as a result of extensive breeding of a few elite varieties thus contributing to vulnerability to biotic and abiotic stresses, hence the need to conserve and exploit genetic resources. Traditional methods of breeding, such as introduction, selection, hybridization and mutation breeding have also been effective in improving the varietal of the fruit crop. In vegetatively propagated fruits, clonal selection has been especially effective whereas interspecies hybridization has facilitated the transfer of desirable genes like disease resistance and abiotic stress resistance. However, the extensive juvenile stage, complicated reproductive physiology, polyploidy and self-incompatibility of most of the fruit crops tend to slow down the breeding process and hinder genetic gains. The recent development in biotechnology and molecular genetics has transformed



breeding of fruit crops. Such methods as tissue culture, marker-assisted selection, genomic mapping, and genome editing have contributed to the accuracy and effectiveness of breeding programs. Molecular tools combined with traditional breeding have made possible early selection of desirable genotypes, decrease in breeding periods, and enhancement of knowledge of genetic regulation of significant traits. Also, the conservation measures like in situ and ex situ gene banks, cryopreservation as well as on-farm conservation are significant in protection of genetic diversity to breed in future.

### **Introduction**

Fruit crops dominate the global and Indian horticulture because they play a significant role in nutritional security, farm revenues, creation of employment, and export revenue. Fruits contain a high level of vitamins, minerals, and antioxidants as well as dietary fiber and their intake is critical in the human body. The quantity of high-quality and various types of fruits demanded has been growing considerably with the growing population, the rise in the level of income, and the growing awareness as to the need to adhere to a healthy diet. A sustainable process of meeting this demand demands the sustained enhancement of fruit crop productivity, quality, and resilience which is highly reliant on the presence and successful deployment of genetic diversity. Genetic diversity is the difference in genetic composition among and within species and varieties of crop. Genetic diversity is especially abundant in fruit crops because these crops are perennial, have a long evolutionary lineage, often cross-pollinate, and are heterozygous. Mango, banana, citrus, apple, grape, papaya are major fruit crops, which vary greatly in plant structure, flowering, fruit size and shape, color, taste, ripening, and biotic and abiotic stress tolerance. Such diversity offers productive pools of genes which can be exploited to produce better varieties that can meet the diverse agro-climatic and market demands. Although there is an abundance of genetic resources, the current fruit production system tends to use a small genetic pool and a small proportion of elite cultivars is used in commercial production. This kind of genetic uniformity also contributes to susceptibility to pests, diseases and other environmental stresses as illustrated by the past crop failures and recent experiences of climate change. The new strains of



pathogens, rising temperatures, inconsistent rainfall, drought, salinity, and soil erosion are also emerging threats, which bring the urgency of the reinforcement of breeding programs based on a wide genetic base. Breeding of fruit crop has several inherent biological constraints that make the difference between breeding of a fruit crop and breeding of an annual crop. The breeding process is costly and time consuming due to long juvenile periods, complicated reproductive systems, incompatibility with self and polyploidy, apomixis and vegetative propagation. In addition, there is a high level of heterozygousness in many fruit crops and in many instances, desirable traits are regulated by a combination of multiple genes, thus making selection and inheritance studies difficult. Consequently, the traditional breeding methods might not be adequate to overcome the present and the future challenges of the fruit industry. Over the past few decades, there has been immense improvement of breeding and molecular biology and biotechnology, which have provided new prospects in the improvement of fruit crops. The combination of traditional breeding techniques and the modern tools, i.e., molecular markers, marker-assisted selection, genomic mapping, and genome editing, has been found to make breeding programs more efficient and accurate. At the same time, widespread preservation and characterization of fruit genetic resources in form of field gene banks, cryopreservation and conservation in on-farm has become a requirement in maintaining the long-term breeding.

### **Meaning and Significance of Genetic Diversity**

Genetic diversity is the sum total of variation of the genes and alleles within and between the groups of a species. As far as fruit crops are concerned it includes morphological, physiological, biochemical, and molecular variations observed among cultivars, landraces, wild relatives, and collections of germplasm. This is because of the natural evolutionary mechanisms of mutation, recombination, and selection, and the human-induced mechanisms of selection and breeding. The basis of adaptation, survival and enhancement of fruit crops is made up of genetic diversity that is essential in maintaining productivity and quality of crops in different environmental conditions. The issue of genetic diversity may be considered at different levels. Diversity at the species level indicates variation of species in a genus and this can be used to form interspecific



hybrid species, which may possess new characteristics like resistance to diseases or better quality in the fruit. Inter-varietal diversity means differences among cultivars of the same species that are frequently used in traditional breeding programs to produce superior varieties. Intra-varietal diversity, present within a population of a single cultivar, is the raw material upon which selection and improvement can be done especially in crops that are clonally propagated such as banana, grape and mango. Collectively, these breeding diversity levels guarantee a wide genetic pool to use in the breeding programs and assist in preventing the crops against the biotic and abiotic stresses.

Genetic diversity of fruits cannot be overemphasized. To begin with, it is necessary to improve crop. The genetic variability is high to enable the breeders to choose the most desirable genotypes in terms of high yield, big size, flavor, color, and texture, long shelf life, resistance to pests and diseases. As an example, the various mango germplasm offers resources of genes to enhance the fiber content, sweeten and resistance against malformation or anthracnose. In the same vein, citrus breeding depends on interspecies and intervarietal variations to make them resistant to diseases and adaptive to unfavorable climate. Secondly, genetics are associated with adaptation and resilience. Multicultural populations are less susceptible to environmental changes, weather extremities, and new strains of pathogens. Faced with the challenge of climate change, a large array of genetic material will enable breeders to come up with cultivars that are highly drought resistant, salty, heat tolerant, cold hardy, to at least guarantee the sustainability of the fruit production systems. Thirdly, food security and nutritional quality are based on genetic diversity. The differences in the nutritional characteristics of vitamins, antioxidants and taste compounds enable the breeders to produce fruit varieties, which fulfill consumer needs including health, taste and appearance. Varied genetic materials also help in addition of value and industrialization of the same that boost the processing industries and competitiveness of the market.

### **Genetic Diversity Sources of Fruit Crops**

The basic resource to the enhancement and sustainability of fruit crops is genetic diversity. It



gives the breeding programs its raw material allowing the production of better varieties with higher yield, quality, and toughness against biotic and abiotic stresses. Genetic diversity in fruit crops is normally attributed to several origins such as the wild relatives, landraces, traditional cultivars, the imported germplasm, mutations, and even hybridization. To be effective breeding and conservation strategies, proper identification, description and use of these sources is essential.

### **1. Wild Relatives:**

Wild species and subspecies can be considered as a significant source of genetic variation. These are usually characterized by resistance to pests and diseases, ability to withstand abiotic stresses and ability to survive in extreme environmental conditions that are non-existent or not common in the cultivated varieties. As an example, the wild mango (*Mangifera sylvatica*) and wild citrus species are also resistant against pathogens such as anthracnose and citrus greening and this resistance can be transferred into cultivated varieties through interspecific hybridization. Wild family members are also a source of new alleles to enhance the quality of fruits, nutritional qualities and shelf life.

### **2. Aboriginal and Traditional Cultivars:**

The intra-species variability can be found in landraces and traditional varieties that farmers preserve over many generations. They are very often adapted to the local agro-climatic conditions, and possess desired characteristics like taste and aroma of fruits, color, and stress resistance. As an example, the common mango cultivars such as Chausa, Dasherri and Langra in India exhibit a strong variation in mango sweetness, fiber and fruiting tendency. On the same note, native grape varieties have distinct flavor characteristics and climate flexibility, which is useful in breeding programs to particular areas.

### **3. Introduced Germplasm:**

The imported germplasm of other countries/regions increases the genetic foundation of the local cultivars. Introduced varieties also introduce new alleles of certain traits such as better yield, resistances against diseases, after harvest quality and uniformity in fruit size and color.



Indicatively, with the introduction of apple cultivars like; the golden delicious and Royal Gal apples, Indian apple orchards have been diversified and breeders have the opportunity to mix these characteristics with the local varieties to come up with better cultivars.

#### **4. Mutation and Somaclonal Variation:**

Other sources of genetic variability are natural mutations, induced mutagenesis and somaclonal changes in tissue culture. Mutation breeding has been effectively employed in banana, citrus and papaya to produce new fruit characteristics, e.g. dwarf growth habit, seedlessness, changed fruit color, or resistance to disease. The in vitro culture may also lead to somaclonal variations that can be useful as breeding programs.

#### **5. Hybridization:**

Major sources of new genetic combinations include hybridization, inter-varietal and interspecific. Selective crossing between parents of different genotypes can also combine favorable characters of both parents to give a better hybrid with better qualities. As an example, the cross-breeding of various mango species or species of citrus has resulted in better cultivars with better yield, high-quality fruit and with or without resistance against environmental stresses.

#### **6. Germplasm Collections:**

Germplasm collections include frozen germplasm, isolated germline plant cells, as well as fresh and frozen plant cells. Field gene banks, seed banks and cryopreservation facilities, which offer ex situ conservation offer long-term preservation of diverse genetic material. Breeding programs, research, as well as the restoration of lost cultivars use these collections as a source of reference. The conditioned assessment and description of germplasm will guarantee that the desirable characteristics are discovered and exploited effectively to enhance crops.

#### **Procedures to measure Genetic Diversity in Fruits**

The determination of genetic diversity in fruit crop is an essential part of breeding programs, conservation and crop improvement programs. Genetic variation defines how a species can successfully adapt to changes in the environment, and also withstand pests and disease as well as offering a pool of desirable traits to be selected. A few techniques have been evolved over the



years to assess genetic variation on morphological, biochemical and molecular planes. Both methods offer valuable information about diversity and are applied to achieve the breeding goal, crop plant species, and the available resources.

### **1. Morphologic and Phenologic Characterization:**

The oldest of the methods of genetic diversity assessment is morphological evaluation. It entails the record keeping and quantification of observable characteristics like plant height, leaf form, flowering period, fruit size, form, color, taste, smell and the ripening season. Phenological characteristics are also put into consideration including flowering time, fruiting time, and juvenile stages. These are very much influenced by both the genotype and environment and they can easily be recorded in the field. An example is that mango cultivars can be distinguished by the size of the fruit, the content of the pulp, the presence of fibers and taste, and grape varieties by the size of the berries, color and the structure of the bunch. Even though the morphological characterization is economical and viable, it is in some cases constrained by environmental impacts and poor heritability of certain characteristics.

### **2. Biochemical Markers:**

Biochemical markers give the information on the underlying genetic variation through the analyses of proteins, enzymes, and secondary metabolites. Isozyme analysis that examines polymorphisms of enzymes is extensively adopted in the case of differentiating closely related cultivars and determining genetic associations. Another way to use indirect markers of diversity is through biochemical characteristics that include sugar content, acidity, levels of carotenoid, and phenolic compounds, in particular, when correlated to fruit quality characteristics. As an example, amylase/peroxidase differences in isozyme patterns can be used to distinguish apple/citrus cultivars at the biochemical level.

### **3. Molecular Markers:**

Molecular markers have transformed the experience of measuring genetic diversity, whereby it is possible to study the variation at the DNA level, which is not affected by the environment. The most popular molecular markers are:



- RAPD (Random Amplified Polymorphic DNA): Rapid and easy way of identifying polymorphisms in DNA sequences.
- AFLP (Amplified Fragment Length Polymorphism): It is very reproducible and can identify many polymorphisms at a time.
- SSR (Simple Sequence Repeats or Microsatellites): Co-dominant and highly polymorphic, these markers have found application in cultivar identification, genetic mapping and diversity research.
- SNP (Single Nucleotide Polymorphisms): SNP is widely used in genotyping and genome-wide association studies performed in high throughput.

These are the most effective markers in estimating genetic relationships and population structure and the level of heterozygosity. Through this, a good example is SSR and SNP which has been widely applied in mango, apple and grape germplasm to detect duplicate, to study genetic diversity, and to aid in breeding programs.

#### **4. Genomic and Bioinformatics Tools:**

Nowadays, it is possible to evaluate genome-wide genetic diversity with the development of next-generation sequencing (NGS) and bioinformatics. Recent methods like the genotyping-by-sequencing (GBS) and whole-genome resequencing can identify allelic variation within the entire genome on a comprehensive scale. Bioinformatics software is then used to allow clustering, phylogenetic analysis and the calculation of diversity indices. These techniques offer high-resolution data, which are crucial in marker-assisted selection, genomic selection and selective breeding.

#### **Conclusion**

The genetic diversity forms the foundation of improving and sustainability of fruit crops. It gives the necessary variability needed to improve yield, fruit quality, stress tolerance as well as flexibility to environmental changes. The diversity of the wild relatives, indigenous cultivars,



landraces, and the introduced germplasm is the basis of the breeding programs whereby superior genotypes can be selected based on the needs of consumers and the markets. Lack of a wide genetic foundation exposes fruit crops to pests and diseases as well as environmental pressures resulting in massive crop losses and jeopardizing food and nutrition security. Evaluation and exploitation of genetic diversity play important roles in the success of contemporary fruit breeding schemes. Other established techniques like morphological and phenological characterization provide convenient and economical ways of determining variability, especially of observable characteristics like fruit size, shape, color, and ripening pattern. The biochemical indicators, such as isozyme analysis and secondary metabolite profiling, also increase the capability of differentiating cultivars and pinpointing favorable characteristics that can be associated with fruit quality. The DNA-based approaches to genetic variation that are based on molecular markers include RAPD, SSR, AFLP, and SNP, which offer very efficient, reliable and useful data about genetic variation that is used to identify genotypes, determine genetic relationships as well as heterozygosity. Developments in genomics and bioinformatics, such as genotyping-by-sequencing and whole-genome analysis, enable the global impact of genome variation, which can be used in marker-assisted selection, genomic selection, and breeding acceleration. Genetic resources conservation is also crucial in maintaining diversity and the presence of useful alleles in breeding in the future. The conservation of wild relatives and landraces in situ and ex situ conservation strategies, like field gene banks, cryopreservation and seed repositories protect the genetic material against loss through habitat degradation or overexploitation. Preservation and description of the germplasm collections will help make sure that breeders can access a wide and properly documented gene pool on which to develop climate-resistant and high quality fruit cultivars. The availability and effective use of genetic diversity is essential in breeding strategies of the major fruit crops such as hybridization, clonal selection, mutation breeding, and biotechnological breeding of the crops. By combining traditional and advanced breeding methods, it is possible to produce better breeds with higher yield, quality, resistance to diseases, and abiotic stress including drought, salinity, and extreme



temperatures.

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