Review Article

The Impact of Biotechnology on Mango Enhancement: Exploring Genetic Engineering and Molecular Markers

ABSTRACT

The impact of biotechnology on mango enhancement, particularly through genetic engineering and molecular markers, has been significant. Biotechnology has revolutionized the field of agriculture, offering innovative tools and techniques for improving crop traits. In the case of mangoes, genetic engineering involves the manipulation of the organism's DNA to introduce or modify specific genes, targeting traits such as disease resistance, fruit quality, and yield. This approach has led to the development of mango varieties with enhanced resistance to pests and diseases, improved flavor and aroma, and increased productivity. Similarly, marker-assisted selection (MAS) utilizes molecular markers to identify and select plants with desired traits, bypassing the need for time-consuming and costly phenotypic evaluations. MAS has accelerated breeding programs, enabling the development of superior mango cultivars with desired traits. By exploring the impact of genetic engineering and molecular markers in mango improvement, we gain insights into their potential to address key challenges in mango cultivation and meet consumer demands.

Keywords: Biotechnology, Mango enhancement, Genetic engineering, Molecular markers, Disease resistance and fruit quality.

Introduction

Mango (*Mangifera indica* L.) is an important fruit crop grown in tropical and subtropical regions worldwide with a global production of over 52 million metric tons (FAOSTAT, 2021). India is the largest producer of mango in the world with an annual production of 20.52 MT from an area of 2.30 M ha (Anon. 2020). India's share in the world's mango production is around 56 percent with a productivity of 8 t/ha. Mangoes are not only a source of nutrition and income but also a symbol of cultural heritage and identity The demand for mangoes is increasing due to their delicious taste, nutritional value, and potential health benefits. However, the production of mangoes is often limited by various biotic and abiotic stresses, including pests, diseases, and climatic factors. Biotechnology has played a significant role in the improvement of mango cultivars, particularly through the use of genetic engineering and molecular markers. Genetic engineering is a powerful tool that allows the introduction of new or modified genes into plants, leading to the expression of desired traits such as disease resistance, improved nutritional content, and enhanced yield. Several studies have reported successful genetic transformation of mango using various techniques, including Agrobacterium-mediated transformation, particle bombardment, and electroporation. For example, genetic engineering has been used to develop mango cultivars with improved resistance to anthracnose, a fungal disease that affects mango production in many countries.

Molecular markers are another important tool in the improvement of mango cultivars. Molecular markers are specific DNA sequences that can be used to identify genetic variations among individuals or populations (Khan *et al.* 2012). They are used for genetic mapping, marker-assisted selection (MAS), and the identification of genes associated with desirable traits. Several types of molecular markers have been developed for mango, including random amplified polymorphic DNA (RAPD), amplified fragment length polymorphism (AFLP), simple sequence repeats (SSRs), and single nucleotide polymorphisms (SNPs). These markers have been used to identify genetic diversity among mango cultivars, to develop linkage maps, and to identify quantitative trait loci (QTLs) associated with important traits such as fruit size, yield, and disease resistance (Menezes *et al*. 2017).

Despite the significant progress made in the application of biotechnology in mango improvement, there are still some challenges and limitations that need to be addressed. For example, the limited availability of molecular markers and the complex genetic architecture of mango make it difficult to identify and select specific genes for improvement. Additionally, concerns about the potential environmental and health risks associated with the use of genetic engineering in mango improvement need to be addressed (Rrododriguez-García & Cano-Medina 2018). Overall, the continued development and application of biotechnology in mango improvement have the potential to significantly contribute to the sustainable production of high-quality mangoes, improving the livelihoods of farmers and meeting the increasing demand for mangoes worldwide.

Overview of biotechnology in mango improvement

Biotechnology has revolutionized the field of agriculture by providing innovative tools and techniques for crop improvement. In the case of mangoes, biotechnology plays a significant role in enhancing various desirable traits, such as disease resistance, fruit quality, and yield. Biotechnology techniques such as genetic engineering and molecular markers have enabled the identification of genes responsible for important traits. These techniques have also enabled the transfer of genes across different mango varieties and species, leading to the development of new and improved cultivars with desirable traits (Singh *et al.* 2018). This provides an overview of the key biotechnological approaches used in mango improvement, along with their corresponding applications and outcomes.

Biotechnological Approaches in Mango Improvement:

Genetic Engineering:

Genetic engineering involves the manipulation of an organism's DNA to introduce or modify specific genes. In mango improvement, genetic engineering has been employed to enhance traits such as disease resistance, fruit quality, and yield (Pandey *et al.* 2020).

Table 1. Application and target trait an its outcome

Application	**Target Trait**	**Result/Outcome**
Insect Resistance	Enhanced pest resistance	Reduced damage from key mango pests
Disease Resistance	Enhanced disease resistance	Increased protection against fungal and viral infections
Fruit Quality Enhancement	Improved flavor and aroma	Enhanced sensory attributes and consumer

		preference
Yield	Improvement Increased fruit yield	Higher productivity and improved market competitiveness

Marker-Assisted Selection (MAS):

Marker-assisted selection involves the use of molecular markers to identify and select plants with desired traits. In mango improvement, MAS has been used to accelerate breeding programs by enabling the selection of individuals with specific traits without the need for lengthy and costly phenotypic evaluations (Kulkarni *et al.* 2018).

Table 2. **Marker-Assisted Selection**

Application	**Target Trait**	**Result/Outcome**
Disease Resistance	Enhanced disease resistance	Rapid identification of resistant cultivars
Fruit Quality Improvement	Enhanced flavor and aroma	Efficient selection of superior sensory attributes
Yield Enhancement	Increased fruit yield	Accelerated development of high-yielding varieties

Tissue Culture and Micropropagation:

Tissue culture and micropropagation techniques involve the regeneration of whole plants from small plant tissue samples, such as shoot tips or embryos. These techniques allow for the rapid multiplication of selected elite mango genotypes and the production of disease-free planting material (Roy *et al.* 2019).

Table 3. **Tissue Culture and Micropropagation**

Application	**Purpose**	**Result/Outcome**
Rapid Clonal Propagation	Mass production of selected clones	Increased availability of elite cultivars
Germplasm Conservation	Preserving genetic diversity	Long-term preservation of rare and endangered varieties
Disease Elimination	Obtaining disease-free plants	Production of healthy planting material

Genetic engineering in mango improvement

Genetic engineering is the process of modifying the genetic makeup of an organism to create new and improved traits. In mango improvement, genetic engineering has been used to enhance the genetic diversity and quality of mango cultivars. The following are the methods of genetic engineering in mango:

a. Methods of genetic engineering in mango

The two main methods of genetic engineering in mango are Agrobacterium-mediated transformation and biolistic transformation. Agrobacterium-mediated transformation involves the use of a bacterium, Agrobacterium tumefaciens, to introduce foreign DNA into the genome of the mango plant. This method is widely used in mango because it is efficient and leads to stable integration of the foreign DNA. Biolistic transformation involves the use of a gene gun to shoot DNA-coated particles into the plant cells. This method is less efficient than Agrobacterium-mediated transformation but can be used in species that are difficult to transform using the former method.

b. Genetic modifications for mango improvement

Genetic modifications in mango improvement involve the introduction of foreign genes that confer desirable traits such as disease resistance, fruit quality, and yield. The following are some of the genetic modifications that have been made in mango:

i. Disease resistance: Mango is susceptible to various diseases such as anthracnose, powdery mildew, and bacterial black spot. Genetic engineering has been used to introduce genes that confer resistance to these diseases. For instance, the gene encoding chitinase, an enzyme that degrades the cell walls of fungal pathogens, has been introduced into mango to confer resistance to anthracnose (Omar *et al.* 2016).

ii. Fruit quality: Genetic engineering has been used to improve the fruit quality of mango cultivars. For instance, the gene encoding polygalacturonase-inhibiting protein (PGIP), which prevents the breakdown of pectin in the fruit, has been introduced into mango to delay fruit ripening and improve shelf life (Rai *et al.* 2012).

iii. Yield: Genetic engineering has been used to increase the yield of mango cultivars. For instance, the gene encoding cytokinin oxidase, which regulates the level of cytokinins, has been introduced into mango to increase the number of flowers and fruits (Purwar *et al.* 2011).

c. Applications of genetic engineering in mango improvement

The application of genetic engineering in mango improvement has opened up new opportunities to improve the crop's productivity and quality. Genetic engineering techniques have been used to modify several traits in mango, including disease resistance, fruit quality, and nutritional content.

One of the most significant applications of genetic engineering in mango improvement is the development of disease-resistant varieties. The use of genetic engineering techniques to develop disease-resistant varieties has been successful in several crops, including mango. For instance, the insertion of a bacterial gene that produces a protein that enhances disease resistance in mango has been successful in developing resistance to bacterial black spot disease (*Xanthomonas campestris* pv. *Mangiferae indicae*) (Manoharan *et al.* 2015).

Another application of genetic engineering in mango improvement is the enhancement of fruit quality. Genetic engineering techniques have been used to modify the genes responsible for the production of specific compounds that affect fruit quality, such as flavor, aroma, and texture. For example, the overexpression of the ACC synthase gene, which regulates ethylene biosynthesis, has been used to enhance mango fruit ripening and improve fruit quality (Palmer *et al.* 2018).

Genetic engineering has also been used to improve the nutritional content of mango. For instance, the overexpression of genes involved in carotenoid biosynthesis has been used to increase the levels of β-carotene, a precursor of vitamin A, in mango fruit (Daryanto *et al.* 2018). Additionally, genetic engineering techniques have been used to modify the genes responsible for the production of secondary metabolites, such as phenolic compounds, which have antioxidant properties (Hossain *et al.* 2021). Overall, genetic engineering has the potential to improve the productivity and quality of mango crops. However, the application of genetic engineering techniques in mango improvement is still in its early stages, and further research is required to optimize the technology and ensure its safety and efficacy.

Molecular markers in mango improvement

Molecular markers are DNA sequences that can be used to identify and track specific traits in a population. The use of molecular markers in mango improvement has become increasingly important in recent years, as it allows for the identification and selection of desirable traits more efficiently and accurately than traditional breeding methods.

a. Types of molecular markers used in mango improvement

Molecular markers are powerful tools for the genetic improvement of mango. There are various types of molecular markers that have been used for mango improvement. The most commonly used molecular markers in mango breeding include SSRs, RAPDs, AFLPs, and SNPs.

Simple sequence repeats (SSRs), also known as microsatellites, are widely used for the analysis of genetic diversity, cultivar identification, and gene mapping in mango (Mekbib *et al.* 2016a). SSR markers have been used to assess the genetic diversity of mango cultivars from different regions (Amusa *et al.* 2007).

Random amplified polymorphic DNA (RAPD) markers are PCR-based markers that detect random DNA fragments amplified by short arbitrary primers. RAPDs have been used to identify different mango cultivars (Jha *et al.* 2008a).

Amplified fragment length polymorphism (AFLP) markers are PCR-based markers that detect restriction fragment length polymorphisms. AFLPs have also been used to identify different mango cultivars.

Single nucleotide polymorphism (SNP) markers are the most abundant and stable genetic variations that occur within the genome. They have been used for genetic mapping and identification of QTLs related to important traits such as fruit quality and disease resistance (Gonzalez *et al.* 2015a; Upadhyay *et al*. 2017). Overall, the use of molecular markers has revolutionized mango breeding and has the potential to significantly accelerate the development of new and improved mango varieties. The choice of marker type depends on the specific application and research objectives.

Therefore, a combination of different types of molecular markers should be used to achieve more accurate results.

b. Applications of molecular markers in mango improvement

Molecular markers have a wide range of applications in mango improvement. They can be used for genetic diversity analysis, cultivar identification, gene mapping, and marker-assisted selection (MAS). For example, SSR markers have been used to assess the genetic diversity of mango cultivars from different regions (Amusa *et al.* 2007; Mekbib *et al.* 2016b). RAPD and AFLP markers have been used to identify different mango cultivars (Jha *et al.* 2008b; Saini *et al.* 2009). In addition, SNP markers have been used for genetic mapping and identification of QTLs related to important traits such as fruit quality and disease resistance (Gonzalez *et al.* 2015b; Upadhyay *et al.* 2017).

One of the most significant applications of molecular markers in mango improvement is marker-assisted selection (MAS). MAS is a breeding approach that uses molecular markers to select plants with desirable traits at an early stage of development. This allows breeders to select individuals with desirable traits without having to wait for the phenotype to manifest itself. This approach can significantly reduce the time and cost involved in breeding programs (Nishant *et al.* 2018). MAS has been successfully used in mango breeding for the improvement of traits such as fruit quality, disease resistance, and yield (García *et al.* 2017; Upadhyay *et al.* 2018). In conclusion, molecular markers have become a valuable tool for the genetic improvement of mango. They allow for the identification of genetic diversity and cultivars, gene mapping, and the selection of plants with desirable traits. The use of molecular markers has the potential to significantly accelerate the breeding process, resulting in the development of new mango varieties with improved traits. As more genomic resources become available for mango, the use of molecular markers is likely to become even more important in the future. However, further research is needed to overcome some of the challenges associated with the use of molecular markers in mango improvements, such as the lack of genome sequence information and the limited availability of validated markers.

Challenges and limitations of biotechnology in mango improvement:

Despite the significant advancements in biotechnology, there are still some challenges and limitations that need to be addressed in the development and improvement of mango cultivars. Several types of molecular markers have been developed, but there are still gaps in the availability of suitable markers for the identification and selection of desirable traits.

Another challenge is the complex genetic architecture of mango. Mango is a highly heterozygous crop, which means that it has a high degree of genetic variability, making it difficult to identify and select specific genes for improvement. Additionally, there is a lack of understanding of the functional genomics of mango, which makes it challenging to identify and target specific genes for improvement.

Furthermore, there are concerns about the potential environmental and health risks associated with the use of genetic engineering in mango improvement. Some critics argue that the use of genetically modified organisms (GMOs) may have unintended consequences on the environment and human health, particularly if the modified genes escape into the wild or if the modified crops have unexpected effects on non-target organisms.

Future directions and opportunities:

Despite the challenges and limitations of biotechnology in mango improvement, there are several promising future directions and opportunities. One potential direction is the development of new molecular markers and technologies for the identification and selection of desirable traits. Advances in genomics, transcriptomics, and proteomics can provide new tools for understanding the genetic and molecular mechanisms of mango, which can be used to develop new markers for targeted breeding.

Another promising direction is the use of genome editing technologies such as CRISPR/Cas9 for precise modification of specific genes in mango. This technology has the potential to overcome some of the limitations associated with traditional genetic engineering approaches, as it allows for the precise targeting of specific genes without introducing foreign DNA into the plant. Furthermore, the application of bioinformatics and computational approaches can facilitate the identification of candidate genes and regulatory elements associated with specific traits, which can accelerate the development of improved mango cultivars.

Conclusion

The impact of biotechnology, specifically genetic engineering and molecular markers, on mango enhancement, has been a game-changer in the field of agriculture. Through genetic engineering, mango varieties with improved disease resistance, fruit quality, and yield have been developed, paving the way for sustainable and high-yielding cultivation practices. Marker-assisted selection has revolutionized the breeding process by enabling the selection of desirable traits with greater efficiency and accuracy. These advancements have not only benefited mango growers by providing them with improved varieties but have also addressed consumer demands for flavorful and disease-resistant mangoes. The continued exploration and application of biotechnology in mango enhancement hold immense potential for further advancements and success in the industry, ensuring a bright future for mango cultivation.

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