Chapter 23
Concepts of Molecular Plant Breeding and Genome Editing

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ABSTRACT

Traditional plant breeding depends on spontaneous and induced mutations available in the crop plants. Such mutations are rare and occur randomly. By contrast, molecular breeding and genome editing are advanced breeding techniques that can enhance the selection process and produce precisely targeted modifications in any crop. Identification of molecular markers, based on SSRs and SNPs, and the availability of high-throughput (HTP) genotyping platforms have accelerated the process of generating dense genetic linkage maps and thereby enhanced application of marker-assisted breeding for crop improvement. Advanced molecular biology techniques that facilitate precise, efficient, and targeted modifications at genomic loci are termed as "genome editing." The genome editing tools include "zinc-finger nucleases (ZNFs)," "transcription activator-like effector nucleases (TALENs)," oligonucleotide-directed mutagenesis (ODM), and "clustered regularly interspersed short palindromic repeats (CRISPER/Cas) system," which can be used for targeted gene editing. Concepts of molecular plant breeding and genome editing systems are presented in this chapter.

INTRODUCTION

Molecular Plant Breeding is an interdisciplinary science that combines molecular genetic tools and methodologies with conventional approaches for crop improvement. Several modern breeding strategies have been included under molecular plant breeding. These include: marker-assisted selection (MAS), marker assisted backcrossing (MABC), marker-assisted recurrent selection (MARS), Genome wide selection (GWS) or genome selection (GS). The methods of molecular plant breeding continue to evolve and generated great interest among plant breeders involved in various crop improvement projects.

Genetic markers are basically determined by allelic forms of genes (loci), which can transmit from generation to generation. Accordingly they can be used as experimental probes or tags to monitor its presence in an individual, a tissue, a cell, a nucleus, a chromosome or a gene. In plant breeding, genetic

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markers are classified into two categories: classical markers and DNA markers. The morphological markers, cytological markers and biochemical markers are classical markers. On the other hand, DNA markers have been developed into many systems based on polymorphic-detection techniques or methods. The polymorphic detecting techniques include: Southern blotting- nuclear hybridization, Polymorphic chain reaction (PCR), and DNA sequencing which are used in RFLP, AFLP, RAPD, SSR, SNP etc. (Eathington et al., 2007)

Plant breeders have used mutagenic agents to create variability for their use in crop improvement. However, application of mutagenic agents has its own drawbacks, such as non-specificity and random nature, simultaneous effect on large numbers of genes, induction of chromosomal aberrations etc. To overcome these limitations, several genome editing systems have been developed. Important among them are: zinc finger nucleases (ZNFs), transcription activator-like effector nucleases (TALENs), oligonucleotide-directed mutagenesis (ODM), and clustered regularly interspersed short palindromic repeats (CRISPER) systems. These techniques are much simpler and efficient. Therefore, plant breeders are progressively adopting these techniques for crop improvement (Mao et al., 2019).

HISTORICAL DEVELOPMENT OF MOLECULAR PLANT BREEDING

Plant breeding encompasses methods applied for the creation, identification and selection of superior plant types in the development of improved cultivars to meet the requirements of the farmers and consumers. Primary objective of any plant breeding program is to improve yield, nutritional quality, and other commercial traits. There has been enormously successful plant breeding programs on a global scale, both in the agricultural and horticultural crops. Thus many products of plant breeding have contributed sustainable supply of carbon that has been harvested as food, feed, fiber, forest, and fuel (Bliss, 2007).

Selection and harvesting of phenotypically superior plant type/products have led to increased production, which in turn motivated to domesticate the first crop, during prehistoric time. Darwin laid down the scientific principles of hybridization and selection, and Mendel enunciated the relationship between phenotype and genotype. Scientific approach to plant breeding was initiated at the beginning of 20^{th} century. Although importance of Mendelian genetics was realized by the plant breeders, full integration of genetics into plant breeding was seen, only when quantitative genetics reconciled Mendelian principles with continuous variation observed in most traits, having importance from the plant breeding point of view. Subsequently advancement in the understanding of plant biology, identification and analysis of genetic variations, cytogenetics, quantitative genetics, molecular biology, genetic engineering, and genomics have been successively applied in various crop improvement process.

The era of plant biotechnology began with the landmark achievement of producing transgenic plants using *Agrobacterium,* in the early 1980s. Thereafter, molecular marker systems for crop plants were developed, wherein high-resolution genetic maps were created and genetic linkage between DNA markers and important phenotypic traits of crop plants were established. In the late 1990s commercialization of transgenic crops has become a reality, which implied successful integration of biotechnology into plant breeding and crop improvement strategies. Over the years, application of plant biotechnological tools, molecular markers and genomics has made remarkable progress on utilization of genetic variations and development of new improved cultivars in many crop plants. Molecular breeding has now become a standard practice in many agricultural and horticultural plants (Winzel 2006, Nadeem et al., 2018).

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