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Review Article

Improving food security in India through non-conventional plant breeding technologies

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Abstract

Previous reviews addressed that there will be 170 crore people on the earth by 2050 the rise in the average income in emerging India. Hence, it will be the greatest challenge to meet food demand future. Aside from urbanization and land degradation, climate change also additional pressure on the food supply. These problems must be fundamentally changed because of their complexity and self-reinforcing nature. Crop improvement through breeding has been the main strategy for reducing poverty and increasing the food supply in India. New, improved crop varieties need to be developed for farmers to use to enhance food security. The biotechnological and non-conventional accelerated plant breeding methods that are not reliant on genetic engineering or gene editing are the main subject of this review. We focus particularly on the viability of short-term implementation by national agricultural research systems in underdeveloped nations. We contend that delaying the implementation of technology that can speed up reproduction is economically ineffective and supports the swift adoption of accelerated breeding techniques in the public sector. We recommend the employment of a technique called Rapid Generation Advance (RGA) as the most practical strategy for speed breeding in the public sector after taking into account a wide variety of considerations, including the economics of accelerated breeding.

Keywords biotechnology, food security, plant breeding

Introduction

Food security in India refers to the constant availability, accessibility, and affordability of food for all people. Whenever there is a problem with the production or distribution of food, impoverished households are more susceptible to food insecurity. Malnutrition causes many infectious diseases, delays in physical and mental development, and results in an unacceptable amount of premature deaths [1-2]. Major changes in Indian food systems are necessary to address these issues and achieve the Sustainable Development Goal of "Zero hunger and improved nutrition." There are currently 130 billion people on the earth and by 2050 that number will have grown to 170 billion (Figure 1). It puts more strain on India's food production, but intensified, more effective agricultural production has been able to meet these demands [3]. Only a limited number of people work in agriculture in some states that have undergone industrialization. Failure in agriculture could occasionally lead to a

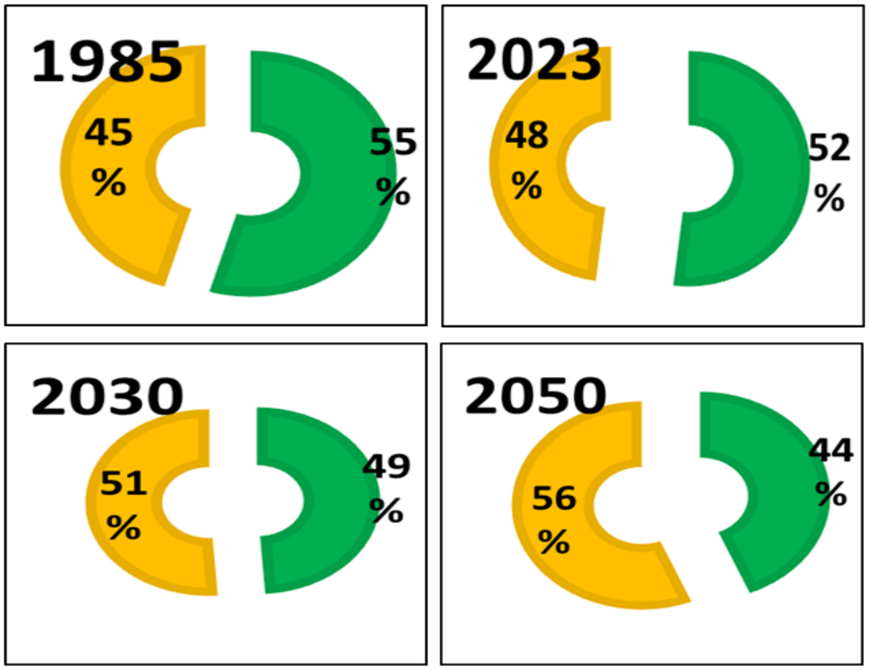

Figure 1. Comparison of food production and human population

breach in this agreement, leaving people with food insecurity. Therefore, defending agriculture involves upholding the agreement that founded civilization [4]. The primary objective of plant breeding is the selection of better kinds from variations in terms of production and the traditional use of edible components, simplicity of cultivation, harvest, and the process, tolerance to environmental obstacles, and pest resistance. Direct gene transfer between organisms that are closely or distantly related is possible through non-traditional plant breeding. Compared to traditional breeding, crop improvement can be done faster. Permits the modification of plants by turning off or eliminating specific genes [5].

The non-traditional breeding techniques demonstrate certain technologies, such as plant tissue culture, marker assisted selection, mutagenesis, and gene editing and transferring, as well as molecular crop breeding, transgenic crop breeding, and bio-control crop breeding techniques. An overview of non-traditional breeding techniques and their contribution to food security and sustainable agricultural development is given in this review article. Useful web addresses piqued readers' attention to learn more about each strategy.

Method of application

Molecular crop breeding technology

This review aims to summarize some of the important developments in molecular plant breeding that have taken place recently, including marker aided selection, gene mapping, quantitative loci for traits (QTL), single nucleotide polymorphism (SNP), and plant tissue culture. This strategy helps improve food security in India while reducing the demand for food [6].

(A). Tissue culturing of plants

Tissue culture is a better method for growing plants. A plant can mature from a few plant tissues. The tissues are injected in a clean, close supervision setting. There are four steps in the entire process.

Culture initiation

Healthy plant tissues are taken from a healthy mother plant, surface sterilized, and then introduced to a nutritive solution for callus formation or organ development at this stage.

Multiplication

The tissues or explants are then added to a mixture for multiplication that contains plant hormones to promote the formation of new shoots. You can have up to 50 plants in one jar at this stage.

Rooting

To encourage the development of roots, the plant shoots that have been rejuvenated are placed in a rooting media

Acclimation

Before being transferred to the controlled greenhouse, plants are gradually acclimated to the outside environment. They are more prepared for success outside as a result of technology. Food goods including grains, fruits, and vegetables gain more nutritional value via tissue cultures, which also improves the products' quality and quantity. Combining tissue culture methods with gene editing technology can achieve this.
Examples: Wheat production: Wheat is a staple food grown all over the world and is necessary to meet human nutritional needs. New wheat cultivars with improved yields and disease resistance are being developed using tissue culture and biotechnology [7].

(B). Maker Aided Selection (MAS)

To achieve food security in India, selection-related advancements beyond traditional breeding would be increased. To achieve this, selection can be done through the discovery of molecular markers linked with trait specific loci. In particular, the enhancement of disease resistance and other relatively basic traits has made considerable use of marker assisted selection (MAS) and marker assisted backcrossing [8]. Finding major loci for complex quantitative traits that have a stable influence across environments and genetic backgrounds has proven challenging, which has limited MAB's potential to enhance yield and other complicated quantitative traits [9-10].

Procedure for marker aided selection

The following crucial processes are part of MAS for identifying and describing QTLs.

Selection and improvement of plant population

The selection of an appropriate parent is the first step in the expansion of the breeding population. Homozygous parents should be chosen, crossed, and forwarded to the second generation to produce offspring with an adequate level of segregation.

Phenotyping and genotyping

Each individual should have high-quality DNA isolated from young seedlings before being exposed to PCR and marker analysis. The next step is to use agarose gel electrophoresis to separate and score the PCR results.

Marker validation

Repeating the aforementioned steps is necessary for marker validation; the results can be utilized to enhance harvests.

Application of marker aided selection in crop improvement

Breeders' issue with conventional breeding is resolved with MAS. Since former is the phenotypic selection process, which partly depends on an individual's DNA banding patterns. Breeders can utilize MAS for gene pyramiding, marker aided recurrent selection, genomic selection, cultivars evaluation, QTL mapping, and crop improvement.

MAS in germplasm characterization

For plant genetic diversity knowledge and resources are essential for enhancing quality, boosting resistance, and establishing pest and disease resistance. MAS are employed more effectively and consistently to screen and characterize the available germplasm, including wild varieties, conventional cultivators, and landraces such that plant breeding projects can be developed and improved. The development of numerous functional markers for a given trait not only aids in the identification and evaluation of varieties and hybrids but also offers a global genetic foundation that can be successfully used to create novel cultivars with important agronomic properties and to gather novel plant genetic resources [11-13]. Detailed information is present in Figure 2.

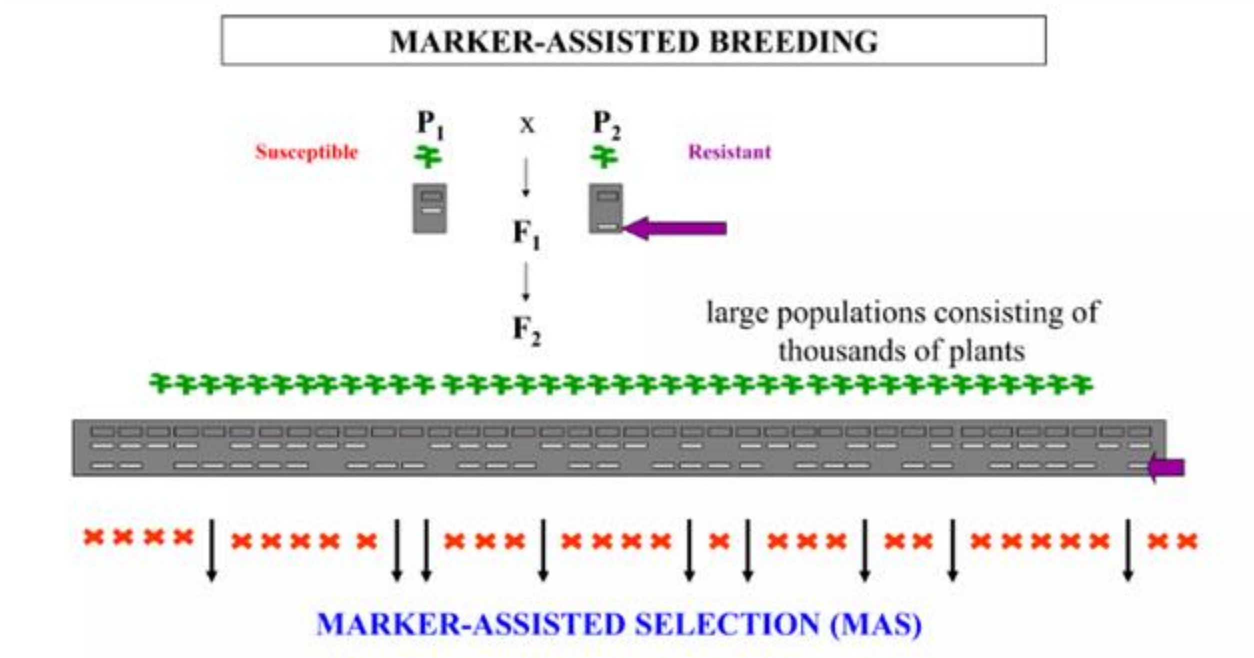

Figure 2. Representation Marker Assisted Selection (MAS)

MAS in genomic selection

Another use of MAS is the coordinated selection of thousands of markers from entire genomes that are related to at least one character. Since the invention and testing of a different set of markers are not necessary for genomic selection, high density, highly precise markers are utilized to obviate the necessity for each QTL and marker association identification. Genomic selection includes the use of phenotyping and genotyping of the training population produced by various genotypes under the assumption of genomic predicted breeding values. Wheat, maize, and brassicas are successful candidates for genomic selection [14].

MAS in gene pyramiding

The method of combining numerous genes from various donor parents into a single genotype is known as gene pyramiding. Gene pyramiding with marker assistance is a desirable option. Mostly used to delegate two or more foreign genes controlling different traits to improve crops' resistance to pests and disease. It is extremely difficult to phenotypically test a single plant with numerous genes, and the conventional gene pyramiding method is time-consuming. Pyramiding has been praised as a trustworthy technique for examining quantitative traits and nonbiotic stress in rice, wheat, maize, and barley. Pyramiding integrates many genes or QTLs with DNA-based functional markers [9-10].

Mutation

Mutation changes are the process of introducing mutagens to plant cells to breed new crops. Genetic diversity is the basis for both breeding and evolution. Mutagenesis was embraced by plant breeders in 1904 as a method for more quickly inducing mutations in plants. Gene, chromosomal, and genome-related mutations are the three most common forms that can be identified. Mutations are brought about by physical mutagens such as X-rays, neutrons, alpha and beta particles, fast and thermal neutrons, UV radiation, and particularly gamma rays. Breeders prefer X-rays and gamma rays as physical mutagens to chemical ones. Hermann J. Muller won the Nobel Prize in Physiology or Medicine in 1946 for inventing X-ray irradiation. To enhance mutant types, this radiation-based mutagenesis approach was commonly employed [15-16].

Transgenic crop breeding technology

Genes are transferred from one species to another using genetic engineering techniques to create transgenic plants. Genome editing is used in the breeding of transgenic crops. Three methods of genome editing include TALENs, CRISPR/CAS, and zinc finger nuclease based genome engineering. The editing of the human genome uses these methods [17].

GENOME EDITING

Zinc finger nuclease-based engineering

Many transcription factors have zinc finger motifs. The C-terminal portion of each finger recognizes the DNA sequence in a specific way. For the selected sequences, a large number of zinc finger nucleases are used. These artificial proteins can be used as genetic engineering tools by joining forces with a common end nuclease to edit a particular gene and cause a targeted DNA break. The two proteins can discriminate between two DNA sequences that are a few nucleotides apart from one another [18-20].

TALENs genome editing system

The revolutionary technique known as the TALEN (transcription activator-like effectors nucleases) system was created in 2011 to improve the effectiveness, security, and accessibility of genome editing. The folk domains located at the termini of chimeric protein dimers are the target of artificial nucleases when they enter the nucleus. This binding leads to a double-strand break in a spacer sequence. Numerous methods have been used to build TALE DNA-binding domains made up of 20–30 monomers or even more. One of the methods first create a dimmers library using traditional DNA cloning, followed by the application of DNA restriction endonucleases and ligation monomers. In a subsequent stage, several dimmers are simultaneously ligated in the same reaction mixture using the golden gate reaction [21-22].

Genome editing method using CRISPR/Cas

CRISPR (Clustered Regularly Interspaced Short Palindromic Repeats), a revolutionary technique for genome editing, was created in 2013. Genetic components called CRISPRs gave microorganisms the ability to combat viruses [23-24]. The three essential components of the protective system are interference, transcription, and adaptation [25-27]. When foreign DNA first entered bacterial cells during the adaptation stage, a small portion was inserted into the CRISPR locus of the host genome in specialized repeat structures that were then separated from one another by short palindromic repeats. This is why they were given the name CRISPR. This technique makes use of Cas9nuclease, Ligase, CRISPR mRNA, and other widely used plasmid constructs to target, edit, change, control, and mark genomic loci of many types of cells. Species with accuracy and efficiency [28-29].

Biocontrol crop technology

Although farmers mostly utilize pesticides and genetically engineered plants to control weeds and pests, biocontrol technology has also been deployed. Biocontrol involves releasing a specific natural enemy (parasites, predators, or naturally occurring pathogens) to manage invasive weeds, insect pests, nematodes, and plant illnesses [30-31]. The United States Department of Agriculture (USDA) and various colleges run programs for biocontrol research aimed at particular pests. The improvement and use of soil bio control agents for bio-control management are being studied by the targeted research programs that are particular to the EU. In the USDA's biocontrol efforts, parasitoids are used to treat Asian citrus plant lice, fungi are used to treat rangeland grasshoppers, and gall midges are used to treat Russian knapweed. The European and Mediterranean Plant Protection Organization's members have access to a wide variety of biological control agents that are commonly used. Although biocontrol technology has been available for a while, it might become increasingly common as concerns about the use of conventional pesticides [32-33].

Farmers already employ certain aspects of IPM, as they learn more about the molecular biology of weeds and pests and see the advantages of using less pesticides and herbicides, they will probably adopt more of its components. IPM is a method of controlling a pest problem that integrates biological, cultural, physical, and chemical controls to reduce hazards to safety and to ensure the environment [34-35].

Molecular biology has been proposed by scientists from all around the world to improve the efficacy, resiliency, and success of biocontrol and biopesticides. Genetic engineering may improve the effectiveness of pest management, reduce the initial amount of biocontrol agent required, and boost the persistence of the agents. This technology is still in its very early stages of development (36). A transgenic scorpion that expresses an insect-specific neurotoxin was utilized as an example of the potential of the method by researchers from the University of Maryland and the Shanghai Institute for Biological Sciences. The genetically altered fungus increased the tobacco hornworm's susceptibility by a factor of 22. Other research has demonstrated that highly pathogenic fungi and viruses that have undergone genetic modification can be used to manage pests and weeds. Since genetically engineered biocontrol is still in its infancy, it is unlikely that by 2040 it will have a noticeable impact on agriculture [37-39].

Conclusion

In conclusion, non-traditional breeding methods hold great promise for enhancing food security throughout India. These innovative methods that provide alternatives to conventional breeding techniques enable the development of new varieties that are resilient, productive, and responsive to changing environmental conditions. Utilizing the power of cutting-edge technology like genetic engineering, genome editing, and marker-assisted selection, unconventional breeding methods can address significant concerns in agriculture, such as climate change, pests and diseases, and limited land and water resources. One of the key advantages of using unconventional breeding methods is their capacity to accelerate the breeding process. Non-traditional breeding methods can significantly shorten the time it takes to generate superior varieties compared to standard breeding methods, which sometimes take years or even decades. New features can be quickly incorporated into crops through this expedited breeding process, enhancing their production capacity, nutritional value, and resistance to biotic and abiotic stresses. Additionally, greater trait manipulation accuracy and specificity are provided by non-traditional breeding methods. Breeders can select specific genes and desirable traits since methods like genome editing, which enable precise molecular changes, are now available. This precision breeding method ensures the safety and predictability of the breeding process by reducing unwanted effects on the crop's overall genetic makeup. Unusual breeding methods can also help environmentally friendly agricultural operations. Improvement of crop varieties that are more resistant to pests and diseases. Farmers can use fewer chemical pesticides and fungicides, lowering environmental pollution and health risks. Developing crops that are more water-efficient and adaptable to a variety of agroecological environments, these approaches can also help in the efficient use of scarce resources like water and land. But it is important to act sensibly and morally and to study novel breeding methods cautiously. Safety assessments, regulatory frameworks, and public education are crucial to address any possible concerns related to new technology and to foster customer trust. An open and frank discussion of the benefits and potential downsides of unconventional breeding methods is necessary for their adoption and acceptance.

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