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The Role of Modern Plant Breeding to Control Plant Disease: A Review

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ABSTRACT

Modern agriculture should be able to support the world's rising population, which is estimated to rise from 7.3 billion in 2015 to at least 9.8 billion by 2050. To feed all of these people, food production should have to increase by 60-70%. However, plant diseases remain the most challenging tasks for plant breeders to achieve these goals. To address these issues, many researchers are still investigating the mechanisms plants defend themselves against disease. Traditional and modern plant breeding practices have played a critical role in guaranteeing food security. However, isolation possibilities for resistance factors are currently limited in traditional breeding programs. Thus, modern plant breeding techniques can be used to select, or in the case of genetic modification, to insert desirable features into plants, using molecular biology techniques. Marker assisted selection, transgenic techniques, RNA interference technologies, tissue culture and CRISPR/cas9 genome editing approaches are the modern plant breeding tools that provide resistance to plant diseases. Here, we attempt to discuss the basic concepts and characteristics of modern plant breeding as well as how modern technologies might be effectively investigated to promote crop improvement in the face of increasing challenging plant production conditions.

INTRODUCTION

Modern agriculture should be able to support the world's ever-increasing population, which is estimated to be 9.8 billion by 2050. Global food production should need to rise by 60-70%, in order to meet a net demand of 1 billion tons of grain for food by 2050[1]. Many issues, such as climate change, disease and pests are making this aim more difficult to achieve. Diseases are one of the most serious crop adversaries, as they can cause the entire crop plant to failure. Some diseases, such as the Bengal famine, late blight of potatoes and coffee rust, become epidemics. Bacterial and fungal diseases diminish agricultural yields by roughly 15%, whereas viruses decrease yields by 3%. The yield loss caused by microbial pathogens is estimated to be around 30% for some crops[2]. To address these issues, breeding programs have shifted their goals to include biotic and abiotic stress tolerance[3].

Plant breeding is a deliberate human activity to modify specific aspects of plants so they can carry out new or improved functions[4]. Breeding strategies can be divided into two groups: traditional and modern plant breeding. Traditional breeding is the process of creating new plant varieties using natural process as opposed to the more recent technologies of molecular plant breeding[5]. In traditional breeding, breeders combine desirable traits from numerous but typically closely related, plants into a new cultivar using hybridization techniques[4]. Therefore, rather than introducing new genes, conventional breeding only emphasizes specific traits that already exist in the genetic potential of the species[6]. Time-consuming, labor-intensive and unfocused breeding efforts will not be able to meet the rising global food demand because it depends on diversity that can be traded within natural boundaries.

Modern plant breeding is the science of altering a plant's genetic trait to improve the plant's heredity. Modern plant breeding is based on a thorough understanding of genetic concepts and their application. It requires a considerable understanding of plant botanical traits, plant diseases and their epidemiology, physiological factors impacting plant adaptation and biochemical qualities affecting consumption and nutritional value. Knowing the level of genetic diversity and patterns of agro-morphological variation in local germplasm from a target region is critical for effective crop development[7]. Modern plant breeding has numerous advantages compared to traditional plant breeding: It allows for the selection of specific features at the seedling stage, it decreases the time it takes to determine the phenotype of a plant[8]. Plant breeders prioritize disease resistance because every successful variety must possess the complete package of high yield, disease resistance, agronomic performance and end-use quality. Marker assisted selection, transgenic techniques, RNA interference technologies, plant tissue culture and CRISPR/cas9 genome editing approaches are among the modern plant breeding tools that provide resistance to fungal, viral and bacterial diseases. The grand task of the twenty-first century will be to create sustainable society. To satisfy basic human needs, more food, feed, fiber and fuel must be produced using less land, water and nutrients[9]. The goal of this review was to examine the role of modern plant breeding in agriculture in producing disease-free plants, as well as the real impacts of modern plant breeding, with a focus on food security and long-term agricultural development.

Plant breeding: Plant breeding is the process of selecting plants with the best qualities and breeding offspring with those features. Plant breeding has had a significant impact on the advancement of agriculture and the quality of human existence. Breeding programs that are helped by well-studied genetics concepts and current techniques, as well as the breeder's knowledge and unique perspective, are critical to cultivar development success[4]. Plant breeding practices, both traditional and modern, have played a critical role in guaranteeing food security and have had a significant role in food production around the world[10]. Plant breeders are constantly under pressure to maintain and enhance food production by employing novel breeding techniques that provide a source of food as well as crops that are resistant to abiotic and biotic stress. Plant breeding has been a crucial science in enhancing agricultural output, with a contribution of roughly 50% to productivity gains[11]. The most dynamic aspect of the plant breeding process is disease resistance. Many researchers are still investigating into the mechanisms by which plants defend themselves against disease and have implemented various breeding strategies to improve pathogen resistance in crop species, speed up in the field and generate novel resistances with defense system components resistance breeding[12].

Objectives of plant breeding: Prior to beginning the breeding program, the breeder should clearly state his or her objectives while taking end-user needs into consideration[4]. Plant breeding's primary goal is to increase crop output, with secondary goals including quality improvement, biotic and abiotic stress tolerance, toxic chemical elimination, water and nutrient use efficiency and diverse crop maturity groups. Breeding goals are determined by the species and intended application of the cultivar in question[13].

Higher yield: The majority of breeding programs are designed to boost yields. This is accomplished by creating more effective genotypes. Depending on the crop species, conventional and modern plant breeding play a critical role in improving the yield of plant products such as grain, fodder, fiber, tuber, cane and oil yields. High yielding cultivars or hybrids can be developed to improve yield. Recent breakthroughs in plant breeding techniques have resulted in high yield products in different types of crops, including maize, wheat, rice and potato[5].

Improved quality: Another objective of plant breeding is to raise quality. The qualitative traits vary from crop to crop. Plant breeding has improved a variety of characteristics, including grain size, color, milling and baking quality in wheat, cooking quality in rice, malting quality in barley, color and size of fruit, nutritional and keeping quality in vegetables, fiber length, strength and fineness in cotton and oil quality in oil seeds[5]. One of the most important agronomical features is the type of amino acid content of food[14]. Plant breeding and transgenic initiatives are racing to increase the amount of critical amino acids and storage proteins in crops. Increasing the quantity of essential amino acids necessitates a thorough examination of their biosynthesis routes, which have already been successfully engineered into model plants[15].

Abiotic resistance: Crop plants must endure a variety of abiotic conditions, including drought, soil salinity, extreme heat, wind and cold[16]. Plants develop abiotic stress tolerance as a response to environmental changes, including physiological and biochemical adaptation processes to temperature, water availability and soil nutrients. A cascade of biochemical activities and several genes that activate under stress circumstances are involved in abiotic stress tolerance, according to molecular biology tools[17].

Change in maturity duration: The quality that is valued the most is regularity, which has several advantages. It demands different crop rotations, a shorter crop management period, fewer insecticide applications and frequently larger crop areas. Rice-wheat rotation has been made possible because to the development of wheat types that are amenable for late planting. Thus, plant breeding for early maturing crop types adaptable for various plants is critical for obtaining good quality and quantity food products[14].

Desirable agronomic characteristics: The most desirable plant growth characteristics are plant height, branching, growth habit, trailing habit and others. Dwarfness in cereals, for example, is often linked to lodging resistance and improved fertilizer response. Plant growth with these types of desirable features is critical for obtaining nullity plant products and avoiding various problems. Tallness, high tilling and abundant branching are all desirable traits in fodder crops. The breeder's goals influence the development of desired agronomic characteristics. Plants that grow erect and unbranched are developed by the breeder for use as frank furniture products[5].

Elimination of toxic substances: It is important to grow crop varieties free of dangerous chemicals in order to make some crops safe for human consumption. The nutritional value of various plant items would be increased if various harmful chemicals were removed. Dietary allergy, for example, is a major health issue that affects both children and adults. It is an immunological reaction to some food proteins that have been identified as detrimental or poisonous to the body. Various plant species, particularly wild-types, contain allergens and poisons. The breeding method focuses on producing plants that are free of allergies and poisons[18].

Wider adaptability: Adaptability relates to a variety's suitability for general culture under a number of environmental conditions, such as varied temperatures, pH levels and nutrition levels. Adaptability is a critical goal in plant breeding since it aids in crop output stability across geographies and seasons[5].

Biotic resistance: Living species such as viruses, fungus, bacteria, nematodes, insects and weeds cause damage to plants, resulting in significant output losses[19]. Genetic resistance is the inexpensive and most effective way to decrease such losses. The utilization of resistant donor parents from the gene pool is used to create resistant variants. Due to pathogens adaptation to plant species, biotic stressors resistance is frequently the most aspect of the plant breeding process, needing constant update. Different disease resistance crops and insect resistance are produced using plant breeding strategies all around the world. Insect resistance can be demonstrated through examples. Insecticidal protein-coding genes in *Bacillus thuringiensis* are transferred. *Bacillus thuringiensis* crops, which give resistance against chewing type insects to crop plants, are the most notable instances of such transgenic crops. *Bt* maize, cotton and eggplant are the most prominent examples of transgenic crops. These plants release poisonous proteins which harm the gastrointestinal region of insects, causing them to die and protect the plant from pathogens[20].

Conventional plant breeding for disease control: Conventional breeding is the process of developing new plant types using more traditional methods and organic processes. It entails choosing parent plants with desirable traits and combining them in the following generation. Over the past 10,000 years, there has been a significant advancement in the process of selecting higher performing plants for food, feed and fiber products. Every year, commercial conventional breeding releases hundreds of new crop types to improve crop production, food security, nutrition and customer choice[5]. Isolation possibilities for resistance factors are currently limited, although they are gradually improving[21]. The development of disease resistance cultivars was aided by traditional plant breeding procedures. Hybridization of a plant with low disease resistance with a wild relative of a plant with high disease resistance. Several instances show how conventional breeding can result in disease resistance. Cotton resistant to leaf blight, cotton resistant to wilt, wheat stripe rust resistance in the United States, wheat stripe and leaf rust resistance, rice bacterial leaf blight resistance, wheat stem rust resistance and many more disease resistance plants have been produced[22].

The limitation of conventional plant breeding for disease control: Conventional plant breeding techniques are insufficient for developing new disease resistance verities if resistance sources are not available within the species' genetic boundaries, transfer of unwanted genes alone with resistance genes takes a long time to test and intensively record disease resistance varieties, developing disease resistance verities is expensive in terms of land and labor and the resistance mechanism is unknown[12]. To address the limitations of conventional plant breeding, plant breeders and researchers develop novel and efficient modern methodologies and technologies for plant breeding. Many current plant breeding strategies have been created for this aim as molecular genetics knowledge has advanced. To tackle the challenges associated with traditional breeding strategies, modern breeding procedures have been developed[23].

Modern plant breeding methods for disease control: In the twenty-first century, modern plant breeding was transformed, ensuing in crop development based on genomics and molecular marker selection[23]. Modern plant breeding techniques is used to select and insert desirable features into plants, using molecular biology techniques. We can introduce fungicidal, insecticidal, or bactericidal characters from outside the plant family or even outside the plant species to produce disease resistance plants. A critical task that can help modern plant breeding programs is the identification of novel genes responsible for desirable traits with the potential for commercial production of field crops like rice, wheat, maize and staple crops. To select cultivars that are resistant to disease, plant breeders have used a variety of molecular markers. Modern plant breeding techniques are based on understanding how basic endogenous defense components work together and in generating novel resistances with defense system components like pattern recognition receptors. Pattern recognition receptors are examples of these defense system components because they recognize conserved molecules in pathogens or the products of pathogen-mediated degradation of host molecules and trigger immune responses to a wide range of pathogens[25]. Many researchers and plant breeders are now successfully producing disease resistant plants such as barley, wheat, coffee, rice, potato, tomato and other staple crops around the world using modern plant breeding techniques.

Molecular marker-assisted breeding for disease control: Molecular marker-assisted breeding (MAB) is the use of molecular techniques, namely DNA markers, in conjunction with linkage maps and genomics to improve and alter plant properties using genotypic assays[25]. A DNA marker is a genetic marker that inherits with the trait of interest from generation to generation and is used to choose the desired phenotype[26]. Plant breeders employ DNA-based markers widely in MAB for numerous qualities such as disease resistance, drought tolerance and insect resistance[27]. DNA markers like RFLP, SSR, RAPD, AFLP, SCAR, STS and SNP are the most often employed markers in plant breeding[28]. Plant breeders have used a variety of molecular markers associated to disease resistance to select disease resistance cultivars[29]. Plant breeders have used markers associated to disease resistance discovered by different researchers over the last 20 years to select disease resistance cultivars. In wheat[30] employed the csLVLr34 DNA marker to find *LR34* genes conferring resistance to leaf rust disease and Hiebert[31] used the FSD-RSA marker to identify *SCAR* genes conferring stem rust resistance. Galiano-Carneiro and Miedaner[32] also reported that in maize, SSR markers were used to identify the *qMrdd* gene conferring resistance to rough dwarf disease and other markers such as RFLP markers were used to identify two genes, *Ht1*, *Ht2*, conferring resistance to leaf blight, SSR markers were used to identify *Pi9*, *Pi2* genes containing resistance to blast resistance disease, SSR markers were used to identify *Pi9*, *Xa23* genes conferring resistance to blight In tomato, RFLP was used to find the gene *Xa21*, which brings resistance to Bacterial blight, while AFLP was used to identify the genes *Ve1* and *Ve2*, which confer mosaic virus resistance (Table 1).

Transgenic approach for disease control: Transgenics is a type of advanced genetic engineering where foreign genes are inserted into the genome of a crop species to achieve a specific aim. It is a unique

Table 1: Some major crops disease resistant varieties developed through Marker Assisted Breeding

Crop	Gene	Marker	Disease	References
Wheat	LR34	csLVLr34	Leaf rust resistance	Lagudah *et al.*[30]
Wheat	SrCad	FSD-RSA	Stem rust resistance	Hiebert *et al.*[31]
Maize	qMrdd	SSR	Rough dwarf disease	Galiano and Miedaner[32]
Maize	Ht1, Ht2	RFLP	Leaf blight resistance	Xu[33]
Rice	Xa21	RFLP	Bacterial blight	Chen[34]
Rice	Pi9, Pi2	SSR	Blast resistance	Tian[35]
Rice	Pi9, Xa23	SSR	Blight, Blast	Nishizawa *et al.*[36]
Tomato	Ve1andVe2	AFLP	Mosaic virus	Arens *et al.*[29]

Table 2: Different disease resistant cultivars released by RNAi mediated gene silencing technology across the globe

Crop	Disease	Target region	References
Tobacco	rattle virus	Rar1, EDS	Di Stilio *et al.*[49]
Cotton	crumple virus	ChlI, PDS	Tuttle *et al.* [50].
Cassava	cassava virus	CYP79D1, CYP79D2	Fofana *et al.* [51]
Rice	Bacilliform virus	bacilliform virus	Purkayastha *et al.* [52]
Cabbage	curl virus	GUS, NtEDS1	Huang *et al.*[53]

technique for efficiently managing diseases by inserting and over expressing genes that encode proteins responsible in the manufacture of chemicals harmful to bacteria, viruses, fungi and nematodes, with a direct inhibitory effect on the proliferation of these organisms[37]. Chitinase, glucanases, thaumatin-like proteins, pathogens cell wall disintegrating enzymes and toxins are among the genes that are being introduced to confer disease resistance. Plants are given genes that boost the production of plant defense chemicals such saponins, reactive oxygen species, phytoalexins and antimicrobial peptides. Antimicrobial proteins that assault pathogen virulence factors confer resistance to pathogens. Plants with such transgenic gene invasions are resistant to a variety of illnesses[38]. Researchers have successfully inserted several disease resistance genes into many crops in recent years to prevent crop damage through transgenic techniques. The *Cre3* gene confers a substantial resistance to the cereal cyst nematode. The Cre3 gene were introduced into wheat, resulting in a cyst nematode resistant cultivar[39]. Stein[40] reported the leaf rust resistance gene *Lr10* isolated from CIMMYT germplasm and introduced other wheat cultivators to produce leaf rust resistance wheat. The *afp* gene was obtained from *Aspergillus giganteus* and transferred into rice, according to Coca[41]. When the *afp* gene is expressed in rice, it produces an antifungal chemical called *afp* protein, which makes rice resistant to rice blast disease. Researchers also create synthetic peptides like D4E1 and inject them into cotton to provide resistance to the *Thielaviopsis basicola* fungus[42].

RNAi mediated gene silencing technology for plant disease control: RNAi regulates gene expression via mRNA degradation and it a useful tool for plant gene therapy against a wide range of plant pathogens[43]. The RNAi mechanism begins with the Dicer enzyme degrading dsRNA into miRNA or siRNA of 21-24 nucleotides. The RISC complex (an effector complex) attracts these smaller RNAs to their mRNA target sequences, causing them to be degraded[44]. Plant machinery targets pathogen dsRNA generated during host machinery-based pathogen replication and converts it to pathogen siRNA when a plant pathogen infects the plant. The host RISC complex now employees these siRNA to the photogene genome, causing pathogen protein translation to be inhibited and the plant pathogen to die[45]. In recent years, a technique known as host-induced gene silencing has emerged, which uses the host plant as a delivery route to produce gene silencing in the pathogen[46]. Artificial miRNA, hairpin RNA, sense/antisense RNA and a miRNA construct targeting a disease gene are used to mark the pathogen genome in transgenic plants. When the pathogen infects the transgenic plant and begins feeding on the host, siRNA molecules are transported to the pathogen cells, activating an RNAi response in the pathogen and silencing the targeted gene[47]. Escobar[48] found that RNAi-induced technology is effective for controlling crown gall disease by targeting iaaM and ipt in *Arabidopsis thaliana* transformed plants showed resistance to lesion disease. By using RNAi silencing technology to target the pathogen proliferate mechanisms in the plants shown in Table 2, different plants such as tobacco, cassava, cotton, rice, cabbage, tomato and pea create diverse disease resistance.

Tissue culture approach: In the horticultural industry of many nations, tissue culture has played an important part in creating disease-free planting materials for vegetative propagated plants[54]. Meristem culture, or the multiplication of cells from meristem tissue, is a way of cleaning plantlets infected with viruses and other pathogenic organisms. Micro-propagation is an in vitro plant propagation approach used for growing plants quickly and accurately on artificial nutrient media in a controlled environment. Many researchers have stated that meristem tissue culture is now acknowledged as a useful method for disease control and breeding for disease-free plants. Tiwari[55] explore sugarcane free of yellow leaf virus that has been generated aseptically from

Meristem sugarcane. Ghag[56] identified and established resistance to *Fusarium oxysporium var. cubense* race from embryogenic cultures obtained from banana shoot tip. Tissue cultured sweet potatoes have been demonstrated to increase household food security in Zimbabwe, according to[57]. Farmers were able to produce up to 25 t of sweet potato per hectare using tissue culture, as compared to the 6 t per hectare national average. In Shandong, China, Fuglie[58] discovered that virus-free sweet potato planting material spread quickly, reaching 80% of the province's small growers in just four years. It was discovered that banana tissue from Kenya remained free of diseases and pests for a longer period of time than conventional suckers[59]. Other plants produced using meristem tissue culture include a strawberry and an apple that are free of the disease crown rots and the Black Spot virus, respectively[60,61].

CRISPR/Cas9 and CRISPR/Cpf1 technology used in modern plant breeding: CRISPR are DNA sequences that are approximately 25-50 nucleotides long and are divided by short sequences known as spacers[62]. This is an interesting technology for plant breeding, with the potential to bring new products to market much more quickly. The CRISPR is a revolutionary gene-editing technology that has the potential to have a significant influence on plant breeding. Plant breeding could be considerably aided by CRISPR-Cas technology, which could totally transform how plant breeding is now done. Changes to the plant genome can be made in a nucleotide-specific manner using CRISPR-Cas technology, such as altering, adding, or wiping out a gene[63]. The CRISPR/cas9 techniques have primarily been used to combat virus infection, with efforts to improve fungal and bacterial illnesses, as well as nematode resistance, following[64]. Virus disease resistance can be achieved by either targeting and eliminating host components involved in virus reproduction and destroying the viral genome itself, inhibiting replication. CRISPR/SpCas9 has been used to directly mark geminiviral genomic DNA in a number of investigations[65]. The design and construction of SpCas9 and sgRNAs that targeted the replication-associated protein gene of the beet severe curled top virus and the bean yellow dwarf virus, respectively. The plants that resulted were highly resistant to the virus in question. Type III effectors are secreted into the plant cell during the bacterial infection process[66]. For disease development, these effectors mainly disrupt the host's defense pathways and/or activate the S genes[67]. S genes and negative regulators of plant natural immunity are thus ideal targets for CRISPR/Cas9-mediated gene editing to increase disease resistance in plants. Rice resistance to bacterial disease was reported by Zhou[68], who used CRISPR/cas9 genome editing technology to target modify the SWEET13 susceptibility gene, which encodes a sucrose transporter. By using CRISPR/Cas 9 technology to target alter the elF4E susceptibility gene[69] generated cucumber plants that are resistant to potyviruses. Three types of rice were given broad-spectrum resistance to Xoo disease through genome editing of the promoter regions of OsSWEET11, OsSWEET13 and OsSWEET14, according to Oliva[70].

CONCLUSION

The use of plant breeding techniques has long improved agricultural productivity, food security and safety. Despite the fact that most crops are bred in the same manner, the selection criteria for each crop are altered to address the problems specific to that crop. Long-term agricultural development and food security have a lot of potential with modern plant breeding. Plant breeding and adoption of high-yielding cultivars were important factors in alleviating hunger and food insecurity. The introduction of scientific plant breeding has expedited varietal improvement. Plant breeding methods help boost crop output potential by improving pest and disease resistance, as well as making crops more robust to climate change. Thanks to the advancement of molecular biology and genomics, breeders can now monitor specific genes known to affect traits of interest and concern as well as characterize the genetic landscape of novel kinds more generally. Molecular markers can be used to identify minor genes and dissect origins of moderate resistance. Marker assisted breeding combined with traditional breeding programs is a promising strategy for future agricultural improvement. Despite the fact that plant breeding has contributed a lot to crop improvement, optimal diversity in crop plants is still a work in progress. Thanks to recent developments in genetic engineering techniques, plant breeders can now reshuffle genes even across organisms.

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