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TRANSGENIC PLANTS TRANSFORMED FOR THEIR SIGNIFICANT ROLE IN PLANT PATHOLOGY: A REVIEW

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This work was carried out in collaboration among all authors. Author FUR is main author of the review. All other authors have equally contributed in literature collection and editing of the review. All these authors have read and approved the final manuscript.

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Review Article

ABSTRACT

The long-term viability of sustainable agriculture is a common concern that transcends crop processing methods. In terms of disease management, the advancements on Genetic Engineering (GE) definitely allow the rapid entry into the fields of specific and complex resistance pathways for the management of diseases and other abiotic stresses that imitate biological mechanisms if they are used accordingly. Although, acknowledging the significant advantages of GE innovations, broader concerns must be addressed, including social acceptance. When analyzing similar concerns, it is indeed significant to mention that not only various GE techniques but also that various GEs and Genetic Modification (GMs) are feasible, extending from quite small, selective genetic manipulation to the incorporation of transgenes in one species from other via cisgenics and intragenics. The applications of Transgenic Plants (TPs) transformed for disease resistance and tolerate abiotic stresses, transformed with Genes Coding (GC) for antipathogen compounds, transformed with nucleic acids that lead to resistance and to silencing of pathogen genes and production of antibodies against the pathogens have been reviewed in this review article.

Keywords: Transgenic plants; engineered genes; gene modification; genes coding; resistant genes; genetic engineering.

ABBREVIATIONS

GE - Genetic Engineering; GM - Gene Modification; TPs - Transgenic Plants; GC - Genes Coding; IDM - Integrated Disease Management; PR - Pathogenesis-Related; TB - Traditional Breeding; RGs - Resistant

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Genes; PDR - Pathogen-Derived Resistance; DAT - DNA Analysis Technique; EGs - Engineered Genes; PMIs - Plant-Microbe Interactions; TEV - Tobacco Etch Virus; CP - Coat Protein; TMV - Tobacco Mosaic Virus; TSWV - Tomato Spotted Wilt Virus;. NA - Nucleic Acid; PVY - Potato Virus Y; PVX - Potato Virus X; PLRV - Potato Leaf Roll Virus; TYLCV - Tomato Yellow Leaf Curl Virus.

1. INTRODUCTION

For ensuring agricultural productivity, minimizing losses along the supply chain, and minimizing the negative impacts of diseases [1,2], Genetic Engineering (GE) and Gene Modification (GM) can be helpful and can increase the sustainability [3]. Disease management enables farmers and consumers to achieve sustainabile targets by contributing to food protection, product safety, and sustainable development [4,5]. While chemicals have helped several millions of people throughout the world to achieve food security and autonomy [6]. The pest management by using pesticides on a routine basis would be neither beneficial nor effective on long-term bases. Pesticide usage poses serious concerns about its effects on human health as well as the population and also on the climate. Besides that, we cannot necessarily turn to natural pesticides to resolve the problems to biodiversity that are created by synthetic chemicals. By maximizing agricultural productivity, preserving and enhancing profitability for agricultural growers, minimizing cost along the supply chain, and minimizing the negative environmental impacts and their maintenance, the use of GE and GM may increase the sustainability [7]. Diseases that are caused through viruses, bacteria, fungi, and nematodes result in a massive portion of the expected harvesting output of so many crops to be reduced annually. Such issues are especially acute in developing economies, where growers lack the financial resources to purchase pesticides or introduce modern technology. Such failures end up by causing starvation in certain developing economies, putting the socioeconomic development of subsistence farmers in jeopardy. Currently, disease control is primarily achieved through the applications of protective pesticides, agronomic practices like crop rotation, and the use of improved cultivars where accessible. Even after the undeniable importance in preventing disease and their spread, pesticides are out of reach for several growers due to their high cost [8]. Furthermore, the significant negative environmental effect has prompted numerous discussions about restricting their widespread use in agricultural production. Furthermore, due to the evolutionary processes of adaptive or tolerant microbes and prolonged usage of pesticides has decreased their efficacy [9]. Therefore, preventing crops from infections due to harmful microbes is a critical concern for study in order to sustain and more importantly, improve agricultural productivity in order to satisfy the globe's rising demand for food. Crop plants tolerance, cultural practices, biocontrol agents, and chemical management are the four major types of Integrated Disease Management (IDM) that will be important to rely a little more on three remaining methodologies if pesticide applications are to be decreased [10]. Organic farming, intercropping, sowing schedule manipulation, and other cultural practices all play an important role in IDM. Regulation accomplished through cultural practices, on the other hand, is not always sufficient and are impractical or unprofitable from a business standpoint. Natural biological management of disease causing agents is a common occurrence, as it exists in all cultivated fields at a certain stage. But several devastating pathogens, on the other hand, have eluded years of effort, with no realistic, economically viable biological control choices [11]. Thus, appropriately using plant genetics would be crucial in order to mitigate the need for chemicals while still achieving reasonable yields. Growers should have viable disease-control strategies if they are to reduce pesticide applications. Crop disease control using host resistance mechanisms is also an environment friendly process. Strategies to genetic crop enhancement are increasingly diverse, ranging from basic phenotypic selection to GM strategies [12].

Traditional Breeding (TB) can still achieve sufficient disease management and we can assume that breeding methods would continue to play a crucial part in the future. When TB as well as other mitigation measures fail, or even when association restricts the utility of traditionally based characteristics, GE provides a solution. Breeding schemes, both traditional and unconventional, have resulted in an increasing number of improved breeds with beneficial resistant traits [13]. Such breeding systems, but at the other hand, are focused on time-consuming strategies that can only cope with rapid development and transmission of diseases, as well as the growingly need to increase productivity.

The emergence of GE and GM in plant genetics, as well as the plethora of knowledge acquired in the last decades about the molecular pathways of infection and infection resistance, provide a very promising option for developing new pathogen-resistant different crops. The genes used to impart disease resistance by GE come from a variety of places. Diseases have also been a significant source of Resistant Genes (RGs), due to the idea of Pathogen-

Derived Resistance (PDR) [14]. This hypothesis suggests that voicing pathogen genes in a host may disrupt the pathogen's proper functioning, thereby interacting with its development process. Plant genomes are also a good place to look for RGs. Regrettably, the RGs have still not been described or defined at the molecular scale in the majority of instances. So many labs across the world, on the other hand, are diligently working to identify complex plant pathogens RGs. There seems to be widespread consensus that these types of genomes will play a critical role in the development of disease-resistant species throughout the future. The remaining species (mammals, bacteriophages, nonphytopathogenic microorganisms, and many more) which have produced intriguing genes to impart disease resistance constitute a third source of RGs i.e. antibodies, enzymes from conserved biochemical pathways, etc. Ultimately, it's indeed easy to observe Engineered Genes (EGs) being engineered throughout the future due to its structural, metabolic, and biological data regarding to Plant-Microbe Interactions (PMIs) [15]. At first, such EGs may be a series of peptide sequences needed to perform the particular functions. This review article analyses the different approaches that are being used to develop pathogen resistant TPs. The term "resistance" refers to a continuum of defense ranging from interrupted to full infection suppression. The review concentrates mostly on selective current researches and extensively references workpapers due to the wide range of issues discussed.

2. TRANSFORMATION OF PLANT

2.1 TPs Transformed for Disease Resistance

Despite the preventive measures, plant diseases continue to pose a major threat to agricultural sector. The applications of GM as well as GE, which expand the breeder's framework, are among the most responsible and innovative ways of treating plant diseases. These strategies must be efficient, have no unfavorable impact on plant science, and be implemented carefully in the fields. The uses of GM and GE are extremely costly for smaller scaled farmers. Pathogenic microorganisms are a great concern due to worldwide crop losses averaging 11–30 percent as well as greater on local scales [16]. By 2050, we can raise agricultural productivity for about 60% by utilizing same space [17]. The time to take action is now, and we cannot continue to neglect the emerging pathogenic microorganisms management strategies which GM and GE offer. DNA Analysis Technique (DAT) has enabled us to develop genetic variation through GC against the harmful environmental influences, for bringing resistance against the diseases [18], or for the production of enzymes like chitinases or glucanases which are targeted against pathogenic microorganisms like oomycetes, fungi, viruses, and bacteria, or nucleotide sequences which result in cell division.

2.2 TPs Totolerate Abiotic Stresses

Several species of crops are being modified through GC that help them to withstand one and sometimes more abiotic stresses even beyond their usual tolerance range [19]. For instance, *Solanum melongena*, genetically modified with the particular gene that is used for the production of mannitol phosphodehydrogenase obtained from bacteria, is resistant to osmotic stress caused through dehydration, salt, and extremely cold temperature (chilling) [20]. The modification of maize crops with a ubiquitin regulator and the rice GC for glutamine S-transferase allow the crops to withstand cooler temperatures and survive effectively when exposed to water. Besides that, when rice plants are transgenic with two different wheat genes, both genes will improve the transgenic rice plants' resistance towards stress due to dehydration and salt [21]. The yeast GC for the production of trehalose phosphate synthase can be incorporated into the genetic material of chloroplasts of tobacco cell to improve drought resistance, whereas incorporation into the target gene contributed in underdeveloped and immature crops. Ultimately, *Diospyros kaki* is usually trans-formed with a gene responsible for production of choline oxidase obtained form bacteria to make it more adaptive to stress conditions caused by salt [22].

2.3 TPs with Particular Plant Genes for Resistance

Plant genes for resistance against pathogenic strains are being identified from resistant cultivars, transferred to susceptible cultivars, and has been demonstrated in a variety of crops. Several of the previously susceptible varieties now act as resistant cultivars because all of the requisite enabling genes has been transferred in the host organisms. Plant species which are resistant to a specific disease are modified and amplified, each forming a distinct line or variety of crop which is immune to that disease. The transformation of hybrid variety of rice, by using rice gene Xa21 responsible for resistance against the the rice pathogen i.e. *Xanthomonas oryzae* pv. oryzae which causes bacterial blight of rice, is indeed an instance of a crop transformation with RGs [23]. This genetically modified rice variety containing that gene, exhibites the strong, wide resistance against *Xanthomonas oryzae* pv. oryzae races and also maintains the excellent agricultural traits. The Xa21 gene has also been introduced into transgenic elite indica rice cultivars [24]. The GM crops showed high resistance to *Xanthomonas oryzae* pv. oryzae races. When the DRR206 gene responsible for resistance in *Pisum sativum* is introduced into *Brassica napus,* the genetically modified *Brassica napus* becomes resistant to fungus *Leptosphaeria maculans* which causes blackleg disease [25]. The genetically modified plants result in lowering of seedling death induced by the root disease caused by *Rhizocotina solani.* This also help in reducing the rate of *Sclerotinia sclerotiorum* leaf lesions. Likewise, genetically modified creeping bentgrass crop is modified with gene PR5K present in thale cress, that encode for a receptor protein 'kinase' and gives resistance against Dollar Spot Disease caused by *Sclerotinia homeocarpa* [26]. The mode of action is through a delay in symptom onset. This gene PR5K is extracellular domain identical to PR proteins present in PR5 family [27]. When animal antiapoptotic genes is introduced into tobacco as well as other plants, the crops become resistant to necrotrophic pathogens and abiotic factors including salt, cold, drought, heat, while non-TPs lacking this gene are not protected against diseases.

2.4 TPs with Genes Coding (GC) for Antipathogen Compounds

The GC for PR proteins, such as some glucanases and chitinase, are characterized, copied, and incorporated in crops that retard the microbial growth and provide resistance to affected plants. When the peanut crops are modified with antimicrobial genes, the prevalence of Sclerotinia blight caused by *Sclerotinia minoris* reduced by 36 percent when compared to vulnerable non-TPs [28]. It has been demonstrated that TPs of rose possessing a rice chitinase transgene have 13–43% less symptoms of rose blackspot disease which is caused by *Diplocarponrosae* [29]. When the broccoli plants are genetically modified by using endochitinase gene obtained *Trichoderma harzianum,* the TPs have 14–200 times the endochitinase functioning for controls and give substantially fewer symptoms than non-TPs of broccoli [30].

When tobacco and cotton crops are genetically modified by glucose oxidase gene which is obtained from *Talaromyces flavus,* the seedlings become resistant to Rhizoctonia as well as moderate resistant to Verticillium [31]. The production of hydrogen peroxide is regulated by glucose oxidase enzyme which is not favourable for the both pathogens and plants. The *A. thaliana* plants are genetically modified plants by one or more transgenes which are responsible for the production of cysteine protein inhibitors and cowpea trypsin protein inhibitors which play a protective role against nematode, particularly the reniform nematode *Rotyenchus reniformis* [32]. When the tobacco plants are genetically modified by glutamate decarboxylase gene, the TPs become resistant to the root knot nematode [33]. The GM of potato and tobacco crops by bacterial gene ubiC results in the concentrations of toxic 4-Hydroxybenzoic acid 4-O-glucoside [34]. The GMs of canola plants makes it resistant to the blackleg disease caused by *Leptosphaeria maculans* due to the production of antimicrobial peptides [35].

2.5 TPs with Nucleic Acids which result in Resistance and Silencing of Pathogen Genes

Incorporating viruses' or some other's nucleic acid components into plant genomes frequently results in the silencing of virus or subsequent pathogen genes with homologous sequences, trying to make the plants resistant. Inserting acoat protein coding pattern obtained from the Tobacco Etch Virus (TEV) into plant, for instance, results in TPs which develop symptoms on inoculated leaf surface but not remaining [36]. Several well-known instances of effective transformation of a vulnerable plant into a resistant plant using sections of a viruses' genome have been recorded. In first case tobacco, the plant was infected with the gene of Coat Protein (CP) of the TMV which was resulted in development of resistance against it [37]. The transformation of papaya, squash, cucumber, and watermelon were also done with the gene ofCP of papaya ring spot virus, squash mosaic virus, cucumber mosaic virus, and watermelon mosaic viruses respectively. The GM of soybeans, tobacco, cantaloupe and potato with coat protein of NA of the soybean mosaic virus, tobacco vein mottling virus, cucumber mosaic virus and potato leafroll virus-2 respectively are several other vulnerable crops that have been formed resistant by trans-forming them with the NA encoding for the CP. Many forms of viral NA have been used to convert the plant in some cases.

The GM of potato plantations by inserting an antisense orientation of its P1 gene makes them highly resistant to PVY [38], while peanut plants aregenetically modified by introducing an antisense nucleocapsid gene sequence obtained from tomato spotted wilt virus to make resistant [39]. Seedlings are modified in several other instances by introducing the viral replicase gene into their genome. The TPs for resistance against viral diseases have been genetically modified by the applications of viral replicase genes, as in cases of TYLCV in tomato [40], and PLRV and PVY in potato [38]. The GC of viral inclusions in plant cells have been done by using movement protein genes of raspberry bushy dwarf virus, TMV, and cymbidium mosaic virus in raspberry, tomato, and dendrobium respectively.

Crops including potato, tobacco, wheat, and walnutand pea have been successfully transformed with nonviral genes, resulting in TPs that are immune to a number of pathogens. The tobacco systemic-acquired resistance gene 8.2, gene for dsRNasefrom *S. pombe*, mouse protein kinase, tobacco resistance gene N, and others are examples of non-viral genes that have evolved in virus resistance [41]. The tiny, defective interacting RNAs or DNAs which are present in nature in plant tissues or are formed during inoculation with RNA orDNA virus or gene of interest can activate virus resistance in certain instances. The silencing of virus or several other genes in infected cells, is accomplished by such small DNAs and RNAs. A gene of interest is expected to be stable. Besides that, transgenic activity may be inactivated by lack of transcription or, more possibly, by instability of the transcripts which is called as post transcriptional silencing as a consequence of the start of degradation process of RNA concerning transgene RNAs and homologous RNAs [42].

2.6 TPs with Combinations of Resistance Genes

In several host/pathogen pairs, the integration of RG of host with microbial defense genes for antimicrobial compounds results in wide and successful resistance. The combination of Sw-5 tomato gene for resistanceand nucleocapsid protein gene of Tomato Spotted Wilt Virus (TSWV) in TPs, demonstrates that high resistance is present in some cases but not in all TSWV strains [43]. The transgenic rice plants contains the promoters as well as host gene. The introduction of ubiquitin gene of maize results in the resistance against rice blast disease caused by *Magnaporthe grisea* [44]. The TPs also become tolerant to the abiotic stresses including submergence salt, and H_2O_2.

2.7 TPs Producing Antibodies against Pathogens

Plants need an antibody-making machinery, but GE has enabled the transformation of plant with added genes that allow for the development of operational recombinant antibodies [45]. The antibodies which are produced by the plants are complete antibody complexes [46]. The single chain Fv (scFv) fragments or Fab fragments are targeted against particular viral pathogens of plant [47]. They are expressed directly in certain crops' leaves, but they concentrate in intercellular spaces, chloroplasts, and lumen of Endoplasmic Reticulum [48]. The single chain Fv segments are often expressed in intracellular spaces, making them quite important in enhancing the plant's resistance to the particular virus [49]. TPs modified with genes that make it possible to produce segments of single-chain variable regions of antibodies or complete antibodies which are also used to inhibit many viral infections. TMV, PVX, PVY, and CYVV are examples of these pathogens. Until this strategy of biocontrol appears genuinely successful and commonly used, further research is necessary.

2.8 Control through Use of Transgenic Biocontrol Microorganisms

Although, the processes through which biocontrol species influence the microbes against which they are used are still unknown, it has been discovered that at only a few of them start producing antibiotics that are destructive to pathogens, several release enzymes that target physical characteristics of infectious agents, such as the cell wall, and others interact with infectious agents for space, resources, or water, among other things. GM methods are being used to introduce new genes to the biological control species or to improve its genetic structure so that it would effectively combat the pathogen [50]. Plant or microbe GC for metabolites, toxins, and some other molecules that damage the pathogen, as well as regulator genes that over-express relevant, have been demonstrated with the use of a tobacco host.

3. CONCLUSION

The long-term sustainability of sustainable agriculture is a key problem that cuts through crop processing methods. In terms of disease control, GE advances would certainly allow for the rapid entry into fields of particular, complex resistance pathways that mimic biological mechanisms if they are used properly. While recognizing the substantial benefits of developments in GE, wider considerations, such as social acceptance and whether there are any long-term environmental risks distinct from those posed by TB, must be addressed. When analyzing similar concerns, it is significant to mention that not only the GE techniques work but also the GE and GM are feasible, extending from quite small and selective genetic manipulation to incorporation of transgenes from other crops through cisgenics and intragenics. It's essential to mention that such variety of and implementations while analyzing the socio - economic and cultural implications of GE is also necessary. Due to many factors, most of the current and traditional breeding methods will remain the cornerstone of long-term sustainable agriculture. As a result, GE should always be viewed as a collection of techniques that relies mostly on expertise which scientists acquire from our extensive analysis of nature, rather than as the optimal solution to resolving sustainability issues. The GE actually contributes to the breeding "toolbox," giving farmers further choices to evaluate different strategy for developing new techniques in Integrated Disease Management.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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