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Letter

Enhancing Plant Disease Resistance without R Genes

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Crop plants encounter constant biotic challenges, and these challenges have historically been best managed with resistance (R) genes. However, the rapid evolution of new pathogenic strains along with the nonavailability or nonidentification of R genes in cultivated crop species against a large number of plant pathogens have led researchers to think beyond R genes. Biotechnological tools have shown promise in dealing with such challenges. Technologies such as transgenerational plant immunity, interspecies transfer of pattern recognition receptors (PRRs), pathogen-derived resistance (PDR), gene regulation, and expression of antimicrobial peptides (AMPs) in host plants from other plant species have led to enhanced disease resistance and increased food security.

Lombardo *et al.* recently reviewed new approaches to implementing R genes for insect and herbicide resistance in plants [1]. Similar approaches are also relevant for pathogen resistance in plants. Here, we summarize alternative approaches to engineer disease resistance in plants. In addition to genome editing [2] and antisense technologies [3], several other promising technologies have also emerged as potential instruments for countering the limitations of R gene-mediated resistance in plants against pathogens and insect herbivores. Technologies such as transgenerational epigenetics (TE) in plants could be employed to improve some traits in a shorter period of time. TE can be defined as an epigenetic change that persists across one or more subsequent generations. TE can also be utilized to manage plant pathogens, insect herbivores, and other abiotic stresses such as mechanical injuries. The TE blockage in the expression of some particular genes in response to environmental stimuli, due to either DNA methylation or histone modifications, may accelerate the plant's ability to restrict pest/pathogen development [4]. When outside stimuli induce such blockages in plant gene expression, loss of expression may be permanent in that generation and passed to the next generation in the same state through seeds. Plants thereby pass on the perceived environmental threats of both biotic and abiotic stresses to offspring.

Additionally, interspecies transfer of receptors has also shown promise in managing biotic stresses. Broad-spectrum resistance in plants can be developed by transferring pattern recognition receptors (PRRs) between plant species [5]. Engineering broad-spectrum disease resistance through transferring PRRs has shown promise, and the impact is expected to be long-lasting. These PRRs are either receptor kinases (RKs) or receptor-like proteins (RLPs); signals from potential pests/pathogens received by the PRR result in a conformational change in the receptor, leading to the activation of downstream defense signaling genes. Transferring PRRs from related species, or wild relatives, that can perceive a pathogen threat from one plant cultivar or species to another and thereby increasing the level of resistance in a susceptible plant cultivar or species against a specific pathogen.

Genetic engineering and biotechnology can open doors for counteracting infection; one strategy is introducing genes from various sources into plants, which could generate disease resistance with none of the species boundaries that apply to conventional methodologies. The expression of structural viral nucleic acid sequences (e.g., coat protein, movement protein, or replicase protein genes) in plants, known as pathogen-derived resistance (PDR), generally offers a broader range of resistance even to the related viruses. The technique is effective against a low level of inoculums but, as with most viral proteins, this strategy can elicit R gene-driven effector triggered immunity (ETI), causing hypersensitive response (HR), a mechanism leading to rapid cell death surrounding a pathogen infection that limits the pathogen spread [6]. Bioengineering against viral pathogens is particularly important as only around 40 R genes have been identified so far against more than 1000 identified plant viruses. Further, plantibodies have also been developed to protect plants, which could be constructed to focus on any pathogen, sequestering the antigens that are frequently required to complete the infection cycle, thus preventing diseases [7].

Similarly, regulating genes that are not considered to have direct roles in governing host resistance may also lead to enhanced disease resistance against both pathogens and insect herbivores. Downregulating cellulose synthase (*CesA*) increases Arabidopsis resistance to *Botrytis cinerea* [8]. Similarly, disruption of the main brassinosteroid receptor (*BRI1*, *brassinosteroid insensitive 1*) in both *Brachypodium distachyon* and barley enhanced disease resistance against some cereal fungal pathogens [9]. Further, when the rice *heme activator protein* (*HAP*) gene (*OsHAP2E*), which is known to regulate plant growth, development, and stress responses, was overexpressed, it not only enhanced disease resistance to a fungal and a bacterial pathogen but also conferred rice plants resistance to abiotic stresses such as drought and salinity [10].

In addition, generating antimicrobial peptides (AMPs) in plants to fight pathogens has also become an interesting tool to reduce crop losses. AMP chitin-binding capability plays a crucial role in antifungal activity. The AMP antiviral effect depends on different factors, such as the direct interaction with the viral envelope, disrupting or destabilizing it; competition with viruses for the host membrane, preventing the viral connection with particular cell receptors; and prevention of expression of viral genes in the earlier infection stages, affecting the propagation and the viral infection [11]. Interestingly, some endogenous peptides are even perceived as danger signals and a stereotypical defense response is induced in host against the invading pathogens [12]. Technological interventions may lead to greater utilization of such peptides in reducing pathogen progress in hosts.

Recent technological advancements in biological sciences have thus created the future possibility for disease resistance in crop plants to those pathogens against which neither R genes nor available chemicals have been effective. Moreover, overreliance on R genes for disease resistance has become counterproductive in several instances. Therefore, new technologies are desirable as they are proving to be viable, complementary, or supplementary to R genes, environmentally acceptable, and ecologically feasible alternatives to R gene-mediated resistance. Although, in most cases detailed work is necessary to make these technologies commercially viable, technologies such as PDR and viral antisense are already well established in certain crops and are in the marketplace. Once the newer technologies are perfected, they could be used to increase food production and reduce hunger by tackling pests and pathogens with great specificity.

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