Breeding and Molecular Mechanisms for Pest Resistance in Plants

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Received: Jan 29, 2026; Revised: Mar 15; Accepted: Mar 18; Published: Mar 25, 2026

CITATION: Chukwu P. Breeding and Molecular Mechanisms for Pest Resistance in Plants. Recent Adv Biol Med. 2026; 12(1): 9800048. https://doi.org/10.18639/RABM.2026.9800048

KEYWORDS: Breeding; Molecular Mechanisms; Pest Resistance; Plants.

As a defense mechanism against viruses, bacteria, fungi, and nematodes, plant immunity plays a critical role. Complex molecular mechanisms play key roles in detecting pathogens, activating defense responses, and conferring resistance through this innate defense system. Through breeding approaches, it is crucial to understand these mechanisms in order to develop effective strategies to enhance crop disease resistance. PAMPs are conserved microbial molecules detected by Plant Pattern Recognition Receptors, such as bacterial flagellin or fungal chitin. A response to PAMP-Triggered Immunity (PTI) is triggered when a microbial particle is recognized, resulting in the production of antimicrobial compounds, reinforcement of cell walls, and activation of signaling pathways involving Mitogen-Activated Protein Kinases and calcium ions [1-3].

Pathogens can deliver effector proteins into plant cells to suppress PTI. In response, plants have Resistance (R) proteins that recognize specific pathogen effectors or modifications in host targets induced by effectors. These pathways include receptor-mediated phosphorylation cascades, transcriptional reprogramming mediated by transcription factors like WRKY and NAC proteins, and the synthesis of defense hormones such as Salicylic Acid (SA), Jasmonic Acid (JA), and Ethylene (ET). Besides direct pathogen recognition, plants can also induce systemic resistance against pathogens through Induced Systemic Resistance. Induced Systemic Resistance involves beneficial interactions with rhizosphere microbes that activate plant defenses against a broad range of pathogens [4,5]. This systemic resistance is mediated by signaling molecules like jasmonates and priming of defense-related genes. Traditional breeding methods aim to introduce genetic diversity from wild relatives or within cultivated species to enhance disease resistance. This approach relies on phenotypic screening for resistance traits and subsequent selection of resistant genotypes. Examples include breeding for resistance to fungal pathogens like powdery mildew and rusts in wheat and barley [6].

Marker-Assisted Selection accelerates the breeding process by utilizing molecular markers linked to known Resistance genes (R genes). These markers allow breeders to select plants with desired resistance traits more efficiently and accurately, without the need for extensive phenotypic screening. Marker-Assisted Selection has been successfully used in crops such as rice, tomato, and potato to introgress R genes for resistance against viruses, bacteria, and nematodes. Genome editing can be used to knock out susceptibility genes or engineer plants with novel resistance traits by precisely modifying specific nucleotide sequences. This approach holds promise for developing crops with durable resistance to evolving pathogens. Transgenic crops expressing R genes or antimicrobial proteins derived from other organisms have been developed to confer broad-spectrum resistance against pathogens. Examples include crops engineered with R genes from wild relatives or with genes encoding antimicrobial peptides. Transgenic approaches have shown potential in enhancing resistance to diseases like late blight in potato and bacterial wilt in tomato [7,8].

Enhanced disease resistance in crops reduces the usage of chemical pesticides and fungicides, promoting environmentally sustainable agricultural practices and reducing the ecological footprint of crop production. Farmers are less vulnerable to crop losses due to disease outbreaks, ensuring more reliable harvests. Breeding for durable resistance involves deploying multiple resistance mechanisms and genes to reduce the risk of pathogen adaptation. Understanding the molecular basis of plant immunity allows breeders to develop strategies for deploying R genes in combinations that confer long-lasting resistance. As with any genetic modification, the deployment of disease-resistant crops through breeding and biotechnological approaches raises ethical considerations related to safety, intellectual property rights, and regulatory frameworks governing Genetically Modified Organisms. Continued research and collaboration between scientists, breeders, and policymakers are essential to enhance the potential of plant immunity for sustainable agriculture [9,10].

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