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GENETIC MANIPULATION FOR PLANT RESISTANCE THROUGH TRANSGENIC APPROACH

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Introduction

Genetic manipulation through transgenic approaches has emerged as a powerful strategy to enhance plant resistance against various biotic stresses, including insects, viruses, fungi, and herbicides. By introducing specific genes into plant genomes, researchers have developed transgenic plants with enhanced resistance to pests and diseases, reduced reliance on chemical pesticides, and improved crop yields. This review discusses the key strategies and recent advancements in transgenic approaches for plant resistance.

Genetic engineering has also enabled the development of crops resistant to non-selective herbicides. This is achieved either by overexpressing target proteins to enhance tolerance or by modifying these targets to become insensitive to herbicides. Additionally, genes encoding herbicide-detoxifying enzymes have been introduced to achieve high resistance with minimal metabolic costs (Sun et al., 2025; Torra et al., 2024). Transgenic plants have been engineered for resistance against various pathogens, including bacteria, fungi, and nematodes. Strategies involve using genes that enhance the plant's own immune response or introduce resistance genes from other organisms. For example, the use of pathogen-related proteins, resistance (R) genes, and genes involved in the plant's signalling pathways have demonstrated effectiveness in combating diseases (Kameswaran et al., 2025; Zhu et al., 2024). Combining multiple resistance genes in a single transgenic plant can provide enhanced protection against a broader range of pests and pathogens. This multi-gene approach allows for the expression of different resistance mechanisms simultaneously, thereby increasing the plant's resilience and reducing the chances of resistance development in target pests (Majhi et al., 2025).

WHY GENETIC MANIPULATION?

Enhanced Resistance to Pests and Diseases

- Transgenic plants engineered with genes from *Bacillus thuringiensis* (Bt) have shown significant resistance to insect pests, reducing the need for chemical pesticides. This approach has been widely adopted in crops like cotton and maize, leading to increased yields and reduced environmental impact (Noack et al., 2024).

Reduced Dependency on Chemical Inputs

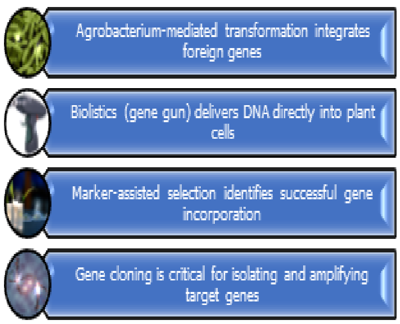
- The development of herbicide-resistant transgenic crops, such as glyphosate-resistant soybean, has allowed for more efficient weed control while reducing the overall use of herbicides (Pedroso et al., 2025).

Sustainability and Food Security

- Transgenic approaches contribute to the sustainability of agriculture by enabling crops to withstand harsh environmental conditions, thereby ensuring stable food production. (Ahmed, 2024).

Innovation in Plant Breeding

- Traditional breeding methods allows for the introduction of novel traits from different species, accelerating the development of new plant varieties with improved resistance to biotic and abiotic stresses (Sabar et al., 2024).



Transgenic Approaches for Plant Resistance

1. Agrobacterium-Mediated Transformation Integrates Foreign Genes

Agrobacterium-mediated transformation is commonly used for dicotyledonous plants (like tomatoes and soybeans) and has been optimized for some monocot species, such as rice. This method is valued for its ability to produce transgenic plants with stable gene integration and relatively fewer copies of the inserted gene, reducing the likelihood of gene silencing or unpredictable gene expression (Rahman et al., 2024).

2. Biolistics (Gene Gun) Delivers DNA Directly into Plant Cells

The biolistic method, also known as the "gene gun" technique, involves physically shooting microscopic particles coated with DNA into plant tissues. This technique is effective for a wide range of plant species, particularly those less susceptible to *Agrobacterium* transformation, such as cereals (e.g., wheat and maize) (Tripathi and Shukla, 2024).

3. Marker-Assisted Selection Identifies Successful Gene Incorporation-

Marker-assisted selection involves the use of selectable marker genes, such as those conferring antibiotic or herbicide resistance, to identify and isolate plant cells that have successfully incorporated the transgene, significantly improving the efficiency of developing transgenic plants (Abdul Aziz and Masmoudi, 2023).

4. Gene Cloning is Critical for Isolating and Amplifying Target Genes

Gene cloning involves isolating the desired gene from its natural source and amplifying it to create multiple copies for use in transformation. It is essential for precise manipulation of the gene, such as adding regulatory elements that control its expression in the target plant (Gudeta & Foley, 2024).

Key Genes for Insect Resistance

Key genes involved in insect resistance include Bt toxins, protease inhibitors, lectins, chitinases, RNA interference (RNAi), and gene stacking techniques, each offering unique mechanisms to combat pests effectively.

Bt Gene Selection

Cry1Ac, Cry2Ab and Cry9C: are commonly used Bt proteins known to be effective against Lepidopteran pests such as diamondback moth and cabbage white butterfly. However, these genes are widely patented, including by companies like Monsanto (now Bayer). A lesser-known Bt protein with efficacy against similar pests but with fewer IP restrictions. The Cry9C gene can serve as a good alternative for developing insect-resistant Brassicas (Guo et al., 2025).

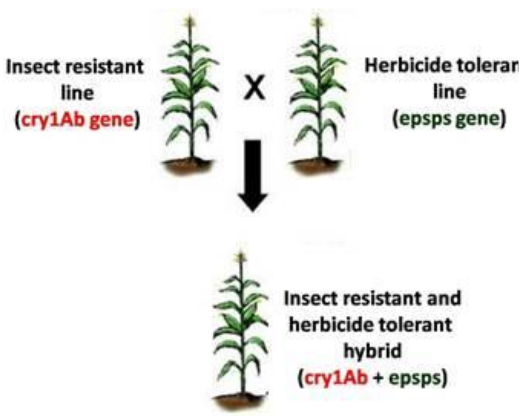
Vip3A: A vegetative insecticidal protein effective against a broad range of Lepidopteran pests, including diamondback moths. Vip3A has shown efficacy against insects resistant to Cry proteins and is a potential candidate to include in the construct. However, it is critical to ensure its use does not infringe on any specific patents in Australia (Wang et al., 2024).

Chitinase or Protease Inhibitors: Consider incorporating genes encoding chitinases or protease inhibitors that disrupt insect digestion or exoskeleton formation (Unuofin et al., 2024). These genes are typically derived from plants or microbes and may have fewer IP issues compared to Bt Cry proteins (Ayra-Pardo et al., 2025).

RNA Interference (RNAi)

- Uses dsRNA to trigger degradation of target mRNA in insects (Amiri, 2025).
- Can target vital genes, leading to pest mortality or reduced fitness.
- Highly specific, minimizing effects on non-target organisms.
- Applied in crops like corn to control rootworms.
- Challenges include efficient delivery and stability of dsRNA.
- Potential for broad application across different insect orders.

Multi-Gene Stacking



- Combines multiple resistance genes for broader protection (Rakesh and Ghosh, 2024).
- Delays resistance development in insect populations.
- Enhances control of pests with varied feeding habits.
- Examples include Bt and protease inhibitor combinations.
- Increases crop durability against pest attacks.
- Challenges involve stable expression and regulatory approval.

CRISPR/Cas9 Enables Precise Genome Editing at Specific Locations:

- Uses guide RNA (gRNA) to target specific DNA sequences (Zhu, 2022).
- High efficiency and specificity with minimal off-target effects.
- Enables gene knockouts and knock-ins for desired traits.
- Can edit multiple genes simultaneously (multiplexing).
- Applied in developing crops with enhanced resistance and yield.
- Future advancements promise even greater precision and potential.

Challenges in Transgenic Approaches

- Insect resistance can develop through genetic mutations.
- Resistance management requires strategies like gene pyramiding.
- Environmental concerns include gene flow to wild relatives.
- Non-target effects on beneficial insects needs careful study.
- Public acceptance and regulatory barriers can limit adoption.
- Continuous monitoring is essential for long-term sustainability.

Future Prospects

- CRISPR/Cas9 enables precise and targeted genome editing.
- Potential to introduce or knock out genes with high accuracy.
- Offers opportunities for multi-gene stacking and trait improvement.
- Regulatory frameworks must evolve to accommodate new technologies.
- Future crops may combine transgenic and non-transgenic approaches.
- Continued innovation is key to addressing emerging pest challenges.

References

1. Abdul Aziz M and Masmoudi K. (2023). Insights into the transcriptomics of crop wild relatives to unravel the salinity stress adaptive mechanisms. International Journal of Molecular Sciences. 24(12): 9813.

2. Ahmed I. (2024). Biotechnological Approaches in Sustainable Agriculture: Harnessing Genetic Engineering for Crop Improvement. Life Sciences Perspectives. 1(02): 117–128.
3. Amiri A. (2025). Identifying Effective Genes as Targets for RNA Interference in Sustainable Pest Control Strategies. *Journal of Epigenetics*.
4. Ayra-Pardo C, Ramaré V, Couto A, Almeida M, Martins R, Sousa JA and Santos MJ. (2025). The Proteolytic Activation, Toxic Effects, and Midgut Histopathology of the *Bacillus thuringiensis* Cry1Ia Protoxin in *Rhynchophorus ferrugineus* (Coleoptera: Curculionidae). Toxins. 17(2): 84.
5. Gudeta DD and Foley SL. (2024). Versatile allelic replacement and self-excising integrative vectors for plasmid genome mutation and complementation. Microbiology Spectrum. 12(1): e03387-23.
6. Guo Y, Huang L, Zhang H, Li J, Zhou Y, Sun Y, et al. (2025). Identification of a Snf7-domain-containing protein that exhibits high affinity and synergistic activity for Cry13Aa1 toxin in *Bursaphelenchus xylophilus.* Journal of Invertebrate Pathology. 108279.
7. Kameswaran S, Pitchika G, Ramesh B, Bangeppagari M, Swapna B, Ramakrishna M and Reddy PS. (2025). Disease-Resistant Genes and Signal Transduction Pathways and Their Applications in Disease Management. In: Molecular and Biotechnological Tools for Plant Disease Management. Springer, Singapore. pp. 427–463.
8. Majhi PK, Bhoi TK, Samal I, Mahanta DK, Behera PP, Senapati M, et al. (2025). The Exploitation of Next-Generation Breeding Strategies to Build Biotic Stress Resilience in Crops. In: Climate Change and Biotic Factors. Apple Academic Press. pp. 241–280.
9. Noack F, Engist D, Gantois J, Gaur V, Hyjazie BF, Larsen A, et al. (2024). Environmental impacts of genetically modified crops. Science. 385(6712): eado9340.
10. Pedroso RM and Moretti ML. (2025). Weed Resistance to Herbicides and Genetically Engineered, Herbicide-Resistant Soybeans as a Tool for Weed Control: Past, Present, and Future of Adoption. In: Soybean Production Technology: Crop Pests and Diseases. Springer Nature Singapore. pp. 327–351.
11. Rahman SU, Khan MO, Ullah R, Ahmad F and Raza G. (2024). *Agrobacterium*-mediated transformation for the development of transgenic crops; present and future prospects. Molecular Biotechnology. 66(8): 1836–1852.
12. Rakesh V and Ghosh A. (2024). Advancements in genetically modified insect pest-resistant crops in India. Planta. 260(4): 86.
13. Sabar M, Mustafa SE, Ijaz M, Khan RAR, Shahzadi F, Saher H, et al. (2024). Rice Breeding for Yield Improvement through Traditional and Modern Genetic Tools. European Journal of Ecology, Biology and Agriculture. 1(1): 14–19.
14. Sun H, Liu X, Yu S, Lian L, Jin T, Peng X, et al. (2025). OsGSTF1 Endows Higher Tolerance of *Oryza sativa* to 4-Hydroxyphenylpyruvivate Dioxygenase Inhibitor Tripyrasulfone than *Echinochloa crus-galli*. Journal of Agricultural and Food Chemistry. 73(14): 8609–8620.
15. Torra J, Alcántara-de la Cruz R, de Figueiredo MRA, Gaines TA, Jugulam M, Merotto A Jr, et al. (2024). Metabolism of 2,4-D in plants: comparative analysis of metabolic detoxification pathways in tolerant crops and resistant weeds. Pest Management Science. 80(12): 6041–6052.
16. Tripathi A and Shukla S. (2024). Methods of genetic transformation: major

emphasis to crop plants. Journal of Microbiology, Biotechnology and Food Sciences. 13(4): e10276-e10276.

17. Unuofin JO, Odeniyi OA, Majengbasan OS, Igwaran A, Moloantoa KM, Khetsha ZP, et al. (2024). Chitinases: expanding the boundaries of knowledge beyond routinized chitin degradation. Environmental Science and Pollution Research. 31(26): 38045–38060.
18. Wang Y, Wang M, Zhang Y, Chen F, Sun M, Li S, et al. (2024). Resistance to both aphids and nematodes in tobacco plants expressing a *Bacillus thuringiensis* crystal protein. Pest Management Science. 80(7): 3098–3106.
19. Zhu F, Cao MY, Zhang QP, Mohan R, Schar J, Mitchell M, et al. (2024). Join the green team: Inducers of plant immunity in the plant disease sustainable control toolbox. Journal of Advanced Research. 57: 15–42.
20. Zhu Y. (2022). Advances in CRISPR/Cas9. BioMed Research International. 2022(1): 9978571.