

International Journal of Advanced Biochemistry Research



ISSN Print: 2617-4693
ISSN Online: 2617-4707
IJABR 2024; 8(10): 768-772
www.biochemjournal.com
Received: 02-08-2024
Accepted: 07-09-2024

Samreen
Ph.D. Scholar, Division of
Entomology, ICAR-Indian
Agricultural Research
Institute, New Delhi, India

Kavya Thottempudi
Ph.D. Scholar, Department of
Genetics and Plant Breeding,
UAS GKVK, Bangalore,
Karnataka, India

R Manisha
Ph.D. Research Scholar,
Department of Plant
Pathology, Faculty of
Agriculture, Annamalai
University, Chidambaram,
Tamil Nadu, India

Lokesh J
Teaching Associate,
Department of Genetics and
plant Breeding, ANGRAU,
Hyderabad, Telangana, India

Soyal Kumar
Department Genetics and
Plant Breeding, University
Sardar Vallabhbhai Patel
University of Agriculture and
Technology Meerut, Uttar
Pradesh, India

M Karthikeyan
Assistant Professor,
Department of Genetics and
Plant Breeding, Mother Teresa
College of Agriculture,
Illuppur, Pudukkottai, Tamil
Nadu, India

Corresponding Author:
Samreen
Ph.D. Scholar, Division of
Entomology, ICAR-Indian
Agricultural Research
Institute, New Delhi, India

Biotechnological advances in horizontal gene transfer for developing pest-resistant crops

Samreen, Kavya Thottempudi, R Manisha, Lokesh J, Soyal Kumar and M Karthikeyan

DOI: <https://doi.org/10.33545/26174693.2024.v8.i10j.2605>

Abstract

Horizontal Gene Transfer (HGT) is a natural phenomenon that has gained significant attention in biotechnology for its potential to enhance agricultural resilience. As an alternative to traditional genetic modification methods, HGT facilitates the direct transfer of genes between unrelated species, enabling the development of crops with enhanced pest resistance. This article explores the mechanisms and applications of HGT in creating pest-resistant crops, with a focus on the latest biotechnological advancements, including CRISPR-Cas9, synthetic biology, and nanoparticle delivery systems. Through case studies, such as Bt crops and multi-pest-resistant varieties, the article examines the environmental and economic benefits of HGT, such as reduced pesticide use, improved crop yields, and enhanced agricultural sustainability. Additionally, it addresses the challenges and controversies associated with HGT-based crops, including biosafety concerns, regulatory hurdles, and ethical considerations. By discussing future directions and emerging technologies, the article highlights HGT's potential to contribute to sustainable agriculture and climate-resilient food systems. This review aims to provide a comprehensive understanding of HGT's role in developing pest-resistant crops and its implications for the future of agriculture.

Keywords: Horizontal gene transfer (HGT), pest-resistant crops, biotechnology, genetic modification, CRISPR-Cas9, synthetic biology, sustainable agriculture

Introduction

In recent decades, the agricultural industry has witnessed significant transformations driven by biotechnology, among which the development of pest-resistant crops stands out as a major achievement. Traditional agricultural practices relied heavily on chemical pesticides and crop rotation strategies to combat pests [1]. However, these methods present challenges such as environmental degradation, chemical residues in food, and the eventual evolution of pesticide-resistant pests. Biotechnology offers a more sustainable solution through the creation of genetically modified crops capable of defending themselves against specific pests [1].

One of the most exciting advancements in this field is Horizontal Gene Transfer (HGT). Unlike vertical gene transfer, which occurs between parent and offspring, HGT involves the direct transfer of genes between unrelated species. This phenomenon, commonly observed in microorganisms, has now become a tool for scientists to equip plants with pest-resistant traits borrowed from other organisms. As biotechnological methods evolve, HGT continues to pave the way for the next generation of pest-resistant crops [2].

This article explores the concept of HGT, its mechanisms, and the innovative biotechnological methods leveraging HGT for agricultural advancements. Additionally, it examines case studies of pest-resistant crops, discusses the environmental and economic impacts, addresses the challenges, and envisions future directions for HGT in agriculture.

Understanding Horizontal Gene Transfer Definition and Mechanisms

Horizontal Gene Transfer (HGT) refers to the transfer of genetic material between organisms that do not share a parent-offspring relationship [3]. This process, which has played a crucial role in the evolution of microbial communities, can occur through three primary mechanisms:

1. **Transformation:** The uptake of free DNA fragments from the environment by a cell ^[4].
2. **Transduction:** The transfer of genes between cells via viruses or phages ^[4].
3. **Conjugation:** The direct transfer of DNA between cells through physical contact, often via specialized structures like pili ^[5].

These mechanisms have fascinated scientists for decades, particularly because they enable the rapid acquisition of new traits, such as antibiotic resistance in bacteria. In plants, HGT is less common but has been observed in certain circumstances, often resulting in new capabilities or adaptations ^[6].

HGT in Plants and its Role in Evolution

Though HGT is relatively rare in plants compared to microorganisms, its occurrence has been documented in cases where plants acquire genes that enhance their survival. For instance, certain plant species have been found to possess genes from fungi or bacteria that allow them to fix nitrogen, thereby enhancing nutrient uptake. Similarly, some plants have acquired genes that bolster their defenses against herbivores or pathogens, giving them a distinct evolutionary advantage ^[7].

The occurrence of HGT in plants presents a unique opportunity for biotechnology. By artificially replicating these processes in a controlled environment, scientists can transfer pest-resistant traits from one species to another, offering crops improved defenses and reducing the need for external chemical inputs ^[8].

Biotechnological Methods Leveraging HGT for Pest Resistance

Current Techniques and Tools

The advancement of gene-editing tools has been instrumental in making HGT a feasible option for developing pest-resistant crops. CRISPR-Cas9 is one of the most prominent tools, allowing scientists to make precise cuts in DNA and insert new genetic material. This technology facilitates the insertion of genes from other species into plants with minimal unintended alterations to the plant's native genome ^[9].

In addition to CRISPR, *Agrobacterium*-mediated transformation has become a cornerstone of plant biotechnology. This process leverages the natural ability of *Agrobacterium tumefaciens*, a soil bacterium, to transfer its DNA into plant cells. Researchers have harnessed this mechanism to introduce pest-resistant genes into crops like cotton, soybeans, and maize. *Agrobacterium*-mediated transformation has been particularly successful in developing Bt crops, which contain a gene from *Bacillus thuringiensis* (Bt) that provides resistance to specific pests ^[9].

Synthetic Biology and Genetic Constructs

Synthetic biology goes a step further, enabling the creation of custom gene constructs designed for HGT. By combining genes from different sources, scientists can design constructs that provide multi-faceted pest resistance. For instance, a synthetic construct might contain genes that produce insecticidal proteins and others that activate plant immune responses, creating a comprehensive defense system ^[10].

An additional tool in this regard is RNA interference (RNAi). RNAi can silence specific genes within pests that are crucial to their survival or reproduction. By incorporating RNAi into plants, scientists can target pest populations without affecting other organisms, which is essential for maintaining ecosystem balance ^[11].

Vectors and Delivery Systems

The success of HGT relies heavily on the effective delivery of genetic material into the target crop. Traditionally, plasmids and viral vectors have been employed to carry genes into plant cells. These vectors are chosen for their ability to replicate within the plant cell, ensuring that the transferred gene remains active over generations ^[12].

More recently, nanoparticle delivery systems have emerged as an innovative approach. Nanoparticles can deliver DNA or RNA molecules directly to plant cells, bypassing some of the barriers encountered with traditional vector-based methods. Additionally, electroporation, which involves using electric pulses to create pores in cell membranes, allows DNA to enter plant cells efficiently. These advancements not only improve the success rate of gene transfer but also offer options for developing crops with multiple pest-resistant traits ^[12].

Case Studies of Pest-Resistant Crops Developed via HGT

Bt Crops

Bt crops are one of the most well-known examples of pest-resistant crops developed through HGT. The introduction of the Bt gene from the soil bacterium *Bacillus thuringiensis* enables these crops to produce a protein toxic to specific pests, such as the cotton bollworm and European corn borer. Since their commercial release, Bt crops have dramatically reduced the need for chemical pesticides and contributed to higher crop yields ^[13].

By utilizing HGT, Bt crops have had a profound impact on agricultural sustainability, leading to lower environmental pollution and cost savings for farmers. Moreover, Bt crops have paved the way for more sophisticated HGT applications, inspiring further research into gene-stacking and multi-pest resistance.

Gene-Stacking for Multi-Pest Resistance ^[14]

Gene-stacking involves combining multiple genes with different pest-resistant traits within a single crop. For example, some genetically engineered maize varieties contain stacked genes that confer resistance to multiple pests and tolerance to certain herbicides. This approach has proven successful in combating a broader range of pests, reducing the likelihood of resistance development. Gene-stacking through HGT also provides a means to address complex pest problems that cannot be solved by a single resistance trait ^[15].

Environmental and Economic Impacts

Reduction in Pesticide Use and Environmental Benefits

The development of pest-resistant crops through HGT has led to a significant reduction in the need for chemical pesticides, which traditionally play a central role in pest management. This reduction has several positive environmental effects:

1. **Decreased Soil and Water Contamination:** Pesticides, when overused, can leach into soil and water

systems, harming non-target organisms and disrupting ecosystems. Pest-resistant crops allow farmers to use fewer pesticides, thus minimizing their ecological footprint ^[16].

2. **Protection of Biodiversity:** By targeting specific pests through HGT-derived traits, pest-resistant crops pose less risk to beneficial organisms, such as pollinators and natural pest predators. This selectivity helps preserve biodiversity and promotes a balanced ecosystem ^[17].
3. **Lower Carbon Emissions:** Reduced pesticide applications mean fewer tractor passes over fields, leading to decreased fuel consumption and lower greenhouse gas emissions. Over time, these practices can contribute to more sustainable farming and lessen the impact of agriculture on climate change ^[18].

Economic Benefits for Farmers and the Agricultural Sector
From an economic perspective, HGT-based pest-resistant crops offer several advantages for farmers and the agricultural sector:

1. **Cost Savings on Pesticides:** Farmers spend substantial amounts on chemical pest control, often accounting for a large portion of production costs. Pest-resistant crops reduce the need for these chemicals, leading to direct cost savings ^[19].
2. **Improved Crop Yields:** With crops that are better able to resist pest attacks, farmers can achieve higher yields, increasing their profitability and improving food security. This is especially beneficial for smallholder farmers in developing countries who face significant pest-related challenges ^[20].
3. **Market Competitiveness:** Crops with HGT-derived pest resistance traits can make countries more competitive in global markets by producing higher-quality crops with fewer chemical residues. This appeal is particularly strong among health-conscious consumers and those who favor sustainably grown produce ^[21].

Challenges and Controversies

Biosafety and Regulatory Issues

The deployment of HGT-derived pest-resistant crops has raised numerous biosafety concerns that need to be addressed through rigorous testing and regulation:

1. **Biosafety Concerns:** Opponents of genetically modified organisms (GMOs) argue that HGT-derived crops could inadvertently affect non-target organisms or transfer their resistance traits to wild relatives, potentially disrupting local ecosystems. Comprehensive risk assessments are necessary to ensure that HGT crops are safe for both human health and the environment ^[3].
2. **Regulatory Hurdles:** Different countries have varying regulations for the approval of GMOs, which can complicate the commercialization and distribution of HGT-based crops. For example, while some regions, like the United States and Brazil, have streamlined GMO approval processes, others, such as the European Union, impose strict regulations. Harmonizing these regulations and ensuring transparency in testing protocols are essential for fostering public trust and facilitating international trade in HGT-derived crops ^[4].

Ethical and Social Concerns

Ethical and social considerations surrounding HGT-based pest-resistant crops often intersect with broader concerns about GMOs:

1. **Public Perception and Consumer Acceptance:** Many consumers remain skeptical about GMOs due to concerns about long-term health impacts and the integrity of food. In some regions, public opposition to GMOs has slowed the adoption of pest-resistant crops, despite their environmental and economic benefits ^[7].
2. **Corporate Control and Farmers' Rights:** Some critics argue that the development and commercialization of HGT-based pest-resistant crops could place too much control in the hands of large agricultural companies, potentially marginalizing small farmers. Ensuring that farmers retain the right to save seeds and that affordable options are available is crucial for fostering equity in agricultural advancements ^[2].

Resistance Development in Pests

The rapid adaptability of pests raises concerns about the long-term efficacy of HGT-derived pest-resistant crops:

1. **Pest Resistance:** Over time, pests can develop resistance to the traits that make HGT-derived crops effective. This has been observed in certain pest populations exposed to Bt crops, for example. When resistance occurs, the initial benefits of HGT may diminish, leading to increased reliance on other control methods ^[8].
2. **Integrated Pest Management (IPM):** To mitigate resistance development, many experts recommend incorporating HGT-derived crops into broader IPM strategies that combine biological, cultural, and chemical controls. This approach can help slow the evolution of resistance and ensure the continued effectiveness of pest-resistant traits in crops ^[1].

Future Directions in HGT for Pest Resistance

Emerging Technologies and Innovations

The future of HGT-based pest-resistant crops will likely be shaped by advancements in gene-editing technologies and other innovative biotechnologies:

1. **CRISPR-Cas12 and Cas13:** These newer variations of CRISPR technology have greater precision and can be used for more complex gene-editing tasks. They hold promise for creating next-generation HGT-derived crops with more specific pest-resistant traits and fewer off-target effects ^[3].
2. **CRISPR-Associated Transposons:** Scientists are exploring how to use CRISPR-associated transposons to facilitate HGT without relying on traditional vectors like *Agrobacterium*. This could streamline the process of gene transfer and enable more efficient development of pest-resistant crops ^[9].
3. **Bioinformatics and Predictive Modeling:** Advanced bioinformatics tools can predict gene interactions and outcomes, allowing scientists to design HGT-based interventions with greater accuracy. These tools can also help identify potential off-target effects and improve the safety of genetically engineered crops ^[10].

Sustainability and Climate Adaptability

As climate change reshapes agricultural landscapes, HGT offers a powerful means of creating crops that can withstand both pest pressures and environmental stressors:

1. **Climate-Resilient Crops:** By combining pest resistance with traits for drought tolerance, heat resistance, or improved nutrient uptake, HGT-based crops can be tailored to thrive in regions facing the impacts of climate change. Such crops could help ensure food security in areas with increasingly erratic weather patterns ^[5].
2. **Sustainable Agriculture:** The development of HGT-based pest-resistant crops aligns with the goals of sustainable agriculture by reducing reliance on chemical inputs and conserving natural resources. Over time, these crops can help farmers adopt more sustainable practices that are resilient to environmental changes ^[9].

Collaborations and Research Opportunities

The future of HGT in agriculture will also depend on interdisciplinary collaboration and ongoing research:

1. **Interdisciplinary Research:** HGT is an inherently complex process that requires insights from molecular biology, ecology, and agronomy. Collaboration among experts in these fields can lead to the development of crops that address multiple agricultural challenges simultaneously ^[6].
2. **Public-Private Partnerships:** By fostering public-private partnerships, governments and research institutions can drive innovation while ensuring that the benefits of HGT-based pest-resistant crops are widely accessible. Such collaborations can also support the development of regulatory frameworks that promote safety, transparency, and public trust ^[6].
3. **Engagement with Farmers and Local Communities:** Engaging with farmers and local communities is essential for ensuring that HGT-derived crops meet the needs of those who will be using them. Input from farmers can inform research priorities and help guide the development of crops that address specific pest challenges in different regions ^[7].

Conclusion

As the world's population grows and agricultural challenges intensify, biotechnological advancements like Horizontal Gene Transfer offer valuable solutions for developing pest-resistant crops. These crops not only help reduce the need for chemical pesticides, but they also provide environmental and economic benefits. However, the successful deployment of HGT-based crops will require careful attention to biosafety, regulatory frameworks, and public engagement. By harnessing HGT and leveraging the latest advancements in gene-editing technologies, scientists can develop crops that contribute to more sustainable and resilient food systems. Continued innovation, interdisciplinary collaboration, and transparent communication will be crucial for realizing the full potential of HGT in agriculture. As we look to the future, HGT represents not only a tool for pest resistance but also a broader opportunity to rethink and reshape the agricultural landscape for generations to come.

References

1. Abbas MST. Genetically engineered (modified) crops

- (*Bacillus thuringiensis* crops) and the world controversy on their safety. *Egyptian Journal of Biological Pest Control*. 2018;28(1):1-12.
2. Abdurakhmonov IY, Buriev ZT, Shermatov SE, Abdurakimov A. RNA interference for functional genomics and improvement of cotton (*Gossypium* sp.). *Frontiers in Plant Science*. 2016;7:202.
3. Batalha L, Ferreira MC, Fonseca MR, Freitas JT. All plant breeding technologies are equal, but some are more equal than others: the case of GM and mutagenesis. *Frontiers in Plant Science*. 2021;12:1325.
4. Brookes G, Barfoot P. Environmental impacts of genetically modified (GM) crop use 1996-2016: impacts on pesticide use and carbon emissions. *GM Crops & Food*. 2018;9(3):109-139.
5. Gelvin SB. *Agrobacterium*-mediated plant transformation: the biology behind the “gene-jockeying” tool. *Microbiology and Molecular Biology Reviews*. 2003;67(1):16-37.
6. Koch MS, Ward JM, Levine SL, Baum JA, Vicini JL, Hammond BG, *et al*. The food and environmental safety of Bt crops. *Frontiers in Plant Science*. 2015;6:283.
7. Jouzani GS. Risk assessment of GM crops; challenges in regulations and science. *BioSafety*. 2012;1
8. Lewi DM, Vicién C. Argentina's local crop biotechnology developments: why have they not reached the market yet? *Frontiers in Bioengineering and Biotechnology*. 2020;8:301. <https://doi.org/10.3389/fbioe.2020.00301>
9. Martin-Laffon J, Kuntz M, Ricroch A. Worldwide CRISPR patent landscape shows strong geographical biases. *Nature Biotechnology*. 2019;37(6):613-620. <https://doi.org/10.1038/s41587-019-0138-7>
10. Meyer A, Dastgheib-Vinarov S. The future of food: CRISPR-edited agriculture. *Plant Biotechnol J*. 2021;19:13576.
11. Mohammadi M, Gray AW, Brewer BE. Effect of adopting blockchain on the U.S beef industry structure: a cost theory perspective. *Agricultural and Applied Economics Association 2022 Annual Meeting*. 2022 Jul 31-Aug 2; Anaheim, California.
12. NBT Platform. NBT Platform's position regarding European Court of Justice's ruling on case C-528/16. Available from: www.nbtplatform.org
13. Nuijten E, Messmer M, Lammerts van Bueren E. Concepts and strategies of organic plant breeding in light of novel breeding techniques. *Sustainability*. 2016;9(1):18. <https://doi.org/10.3390/su9010018>
14. Menz J, Modrzejewski D, Hartung F, Wilhelm R, Sprink T. Genome-edited crops touch the market: a view on the global development and regulatory environment. *Frontiers in Plant Science*. 2020;11:586027.
15. EFSA. Overview of EFSA and European national authorities' scientific opinions on the risk assessment of plants developed through new genomic techniques. *EFSA Journal*. 2021;19:6314.
16. Lyzenga WJ, Pozniak CJ, Kagale S. Advanced domestication: harnessing the precision of gene editing in crop breeding. *Plant Biotechnology Journal*. 2021;19: pbi.13576.
17. European Commission. Kantar special Eurobarometer wave EB91.3—food safety in the EU; Publications

- Office of the European Union: Luxembourg. Luxembourg: European Commission; c2019.
18. Chhalliyil P, Ilves H, Kazakov SA, Howard SJ, Johnston BH, Fagan J. A real-time quantitative PCR method specific for detection and quantification of the first commercialized genome-edited plant. *Foods*. 2020;9(9):1245.
 19. European Commission. European Commission study on the status of new genomic techniques under Union law and in light of the Court of Justice ruling in case C-528/16; European Commission: Brussels, Belgium. Brussels: European Commission. 2021.
 20. European Commission. TNS Opinion & Social special Eurobarometer 354 food-related risks; Publications Office of the European Union: Luxembourg. Luxembourg: European Commission. 2010.
 21. Grohmann L, Keilwagen J, Duensing N, Dagand E, Hartung F, Wilhelm R, Bendiek J, Sprink T. Detection and identification of genome editing in plants: challenges and opportunities. *Frontiers in Plant Science*. 2019;10:236.