

8 Concluding Remarks

Research on the resistance mechanisms of insect populations to *Bacillus thuringiensis* (Bt) toxins has revealed several key findings. The evolution of resistance to Bt toxins has become a major challenge to Bt-based pest control strategies, particularly in transgenic crops where lepidopteran and coleopteran insects have shown significant resistance. Key resistance mechanisms include mutations in ABC transporters, which play a crucial role in the mode of action of Bt toxins. Additionally, the dynamics of cross-resistance between Bt and other insecticides indicate that resistance development involves complex genetic and biochemical pathways. The continuous evolution of Bt toxins to overcome resistance underscores the need for ongoing innovation in Bt technology.

Continuous monitoring and research are essential for managing and mitigating the evolution of Bt resistance. The changes in global resistance patterns emphasize the importance of early detection and timely countermeasures. A deep understanding of the genetic and biochemical bases of resistance, particularly the role of ABC transporters, is crucial for developing effective management strategies. Moreover, research shows that spatial heterogeneity in the deployment of Bt crops can significantly influence the speed of resistance evolution, necessitating targeted management practices based on specific environmental conditions.

Future research needs to further explore how ABC transporters and other genetic factors contribute to Bt resistance, which will deepen the understanding of resistance mechanisms. Investigating the cross-resistance dynamics between Bt and other insecticides is also crucial, as it can lead to the development of pest management strategies that address multiple resistance pathways. Continuous development and testing of new Bt toxin variants will enhance their effectiveness against resistant insect populations. Expanding field studies and monitoring will provide more data to optimize resistance management strategies and ensure their effectiveness in different agricultural environments. Promoting Integrated Pest Management (IPM) practices that combine Bt crops with other control methods can effectively reduce the selection pressure for resistance.

By advancing these key research areas, future studies will not only enhance the sustainability of Bt technology but also provide innovative solutions for broader pest control. As the understanding of resistance mechanisms deepens and new Bt toxins are developed, scientists will be able to design more precise management strategies, delaying the onset of resistance and mitigating its impact on agricultural production. These efforts will ultimately ensure that Bt technology continues to serve as an effective and sustainable tool, contributing to global agricultural security and environmental protection.

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Conflict of Interest Disclosure

The author affirms that this research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest.

References

- Brewer T., and Bonsall M., 2020, Combining refuges with transgenic insect releases for the management of an insect pest with non-recessive resistance to Bt-crops in agricultural landscapes, *Journal of Theoretical Biology*, 509: 110514.
<https://doi.org/10.1016/j.jtbi.2020.110514>
- Cao B.B., Shu C.L., Geng L.L., Song F.P., and Zhang J., 2020, Cry78Ba1 one novel crystal protein from *Bacillus thuringiensis* with high insecticidal activity against rice planthopper, *Journal of agricultural and food chemistry*, 68(8): 2539-2546.
<https://doi.org/10.1021/acs.jafc.9b07429>
- Carrière Y., Crickmore N., and Tabashnik B., 2015, Optimizing pyramided transgenic Bt crops for sustainable pest management, *Nature Biotechnology*, 33: 161-168.
<https://doi.org/10.1038/nbt.3099>
- Chen Z.W., He F., Xiao Y.T., Liu C.X., Li J.H., Yang Y.B., Ai H., Peng J.X., Hong H.Z., and Liu K.Y., 2015, Endogenous expression of a Bt toxin receptor in the Cry1Ac-susceptible insect cell line and its synergistic effect with cadherin on cytotoxicity of activated Cry1Ac, *Insect Biochemistry and Molecular Biology*, 59: 1-17.
<https://doi.org/10.1016/j.ibmb.2015.01.014>
- Deans C., Behmer S., Tessnow A., Tamez-guerra P., Pusztai-Carey M., and Sword G., 2017, Nutrition affects insect susceptibility to Bt toxins, *Scientific Reports*, 7: 39705.
<https://doi.org/10.1038/srep39705>