

Research Insight

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Resistance Mechanisms to Bt Toxins in Insect Populations

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Abstract Insect resistance to *Bacillus thuringiensis* (Bt) toxins has become a significant challenge in biological control and sustainable agriculture. With the widespread use of Bt toxins in genetically modified crops and biopesticides, insect populations have gradually evolved various resistance mechanisms. This study systematically analyzes the genetic, biochemical, and behavioral resistance mechanisms of insects to Bt toxins, revealing multiple pathways such as point mutations, gene amplification, epigenetic modifications, enhanced detoxification enzyme activity, and changes in behavioral patterns. Additionally, the study explores resistance management strategies, such as refuge strategies, Bt gene pyramiding, and integrated pest management (IPM), in delaying the development of resistance. Through case studies, this research summarizes successful resistance management experiences and the challenges faced, and offers directions for future research. This study aims to provide a scientific basis for the continuous improvement of resistance management strategies to ensure the long-term effectiveness of Bt toxins in agriculture.

Keywords Bt toxin; Resistance mechanism; Gene mutation; Resistance management; Insect behavior

1 Introduction

Bacillus thuringiensis (Bt) is a bacterium known for producing insecticidal proteins, commonly referred to as Bt toxins. These toxins have been widely used in sprayable insecticides and transgenic crops as an effective alternative to synthetic pesticides (Jurat-Fuentes et al., 2021). Bt toxins, particularly Cry and Vip proteins, exhibit highly specific insecticidal activity, effectively targeting a wide range of pests while having a relatively minimal impact on non-target organisms and the environment (Cao et al., 2020; Li et al., 2022). The incorporation of Bt genes into crops has revolutionized agricultural pest management, leading to the development of transgenic plants capable of self-protection and continuous pest resistance (Lazarte et al., 2021).

However, with the widespread use of Bt toxins, target insect populations have gradually evolved resistance, posing a significant threat to the long-term efficacy of Bt toxins (Wei et al., 2019; Jurat-Fuentes et al., 2021). Resistance to Bt toxins has been observed in several insect species, particularly those exposed to transgenic Bt crops (Naik et al., 2018; Jurat-Fuentes et al., 2021). Understanding the mechanisms by which resistance develops is crucial for developing effective management strategies and ensuring the sustainability of Bt technology. These resistance mechanisms may include genetic mutations in target receptors, changes in toxin binding sites, and alterations in midgut proteases (Pinos et al., 2021). By studying these mechanisms, we can gain insights into how resistance develops and spreads, enabling the design of more effective pest management strategies and the development of new Bt toxins with novel modes of action (Wang et al., 2019).

This study aims to compile and analyze current research on the mechanisms of resistance to Bt toxins in insect populations, discuss the implications of resistance for the sustainability of Bt technology, and propose potential management strategies to delay the development and spread of resistance. Through a comprehensive analysis of existing studies, this research hopes to provide a scientific basis for improving Bt technology and ensuring its continued application in agricultural pest management.

2 Overview of Bt Toxins

2.1 Types of Bt toxins

Bacillus thuringiensis (Bt) produces a variety of insecticidal proteins, commonly referred to as Bt toxins, which are utilized in both sprayable formulations and transgenic crops to control insect pests. The primary classes of Bt