

2 Mechanisms of Bt Action

2.1 Bt toxins and their targets

Bacillus thuringiensis (Bt) produces a variety of insecticidal proteins, including Cry and Vip toxins, which target specific insect pests. These toxins are highly selective, affecting only certain insect species while being safe for humans and other non-target organisms (Gassmann and Reisig, 2022). The Cry toxins, in particular, are produced as protoxins that require activation within the insect gut to become toxic. The specificity of these toxins is due to their ability to bind to specific receptors in the insect midgut, leading to cell lysis and death (Tabashnik, 2015; Chattopadhyay and Banerjee, 2018; Heckel, 2020).

2.2 Mode of action in insect pests

The mode of action of Bt toxins involves several steps. Initially, the protoxins are ingested by the insect and activated by gut proteases, converting them into their toxic form. The activated toxins then bind to specific receptors on the midgut epithelial cells, such as cadherins and ABC transporters. This binding facilitates the formation of pores in the cell membrane, leading to cell lysis and ultimately the death of the insect (Chattopadhyay and Banerjee, 2018). Recent studies have highlighted the role of ABC transporters in the mechanism of action, suggesting that these proteins are crucial for the binding and pore formation of Cry toxins (Tabashnik, 2015; Heckel, 2020).

2.3 Specificity and safety of Bt toxins

Bt toxins are highly specific to their target pests, which makes them an attractive alternative to broad-spectrum chemical insecticides. This specificity is due to the unique receptors present in the midgut of susceptible insects, which are absent in non-target organisms (Tabashnik, 2015; Chattopadhyay and Banerjee, 2018; Gassmann and Reisig, 2022). For instance, Cry1Ac and Cry2Ab toxins are effective against lepidopteran pests but have little to no effect on other insects or mammals. The safety of Bt toxins is further supported by their long history of use in agriculture without adverse effects on human health or the environment. However, the evolution of resistance in target pests poses a significant challenge, necessitating ongoing research and the development of new strategies to manage resistance (Tabashnik, 2015; Gassmann and Reisig, 2022).

Bt toxins offer a highly specific and safe method for pest control, with their mode of action involving the activation of protoxins, binding to specific midgut receptors, and subsequent cell lysis. The specificity and safety of these toxins make them a valuable tool in integrated pest management, although the evolution of resistance remains a critical issue that requires continuous monitoring and innovation.

3 Benefits of Bt in Organic Farming

Bt crops provide numerous benefits in organic farming, including effective pest control, environmental sustainability, and alignment with organic farming principles. These advantages make Bt crops a promising option for enhancing the productivity and sustainability of organic farming systems.

3.1 Pest control efficacy

3.1.1 Spectrum of activity

Bt crops have been engineered to produce insecticidal proteins from *Bacillus thuringiensis* (Bt), which are effective against a wide range of pests, particularly lepidopteran and coleopteran species. These proteins, such as Cry1 and Cry2, target specific pests while having minimal impact on non-target organisms, including beneficial insects and humans (Tabashnik, 2015; Arends et al., 2021). The narrow and selective toxicity spectrum of Bt proteins helps in managing primary pests effectively without causing significant harm to the ecosystem (Catarino et al., 2016).

3.1.2 Field application successes

The implementation of Bt crops has led to significant successes in pest control in various regions. For instance, Bt cotton and maize have been widely adopted in the United States, India, and Australia, resulting in reduced pest populations and decreased reliance on chemical insecticides (Tabashnik, 2015; Xiao and Wu, 2019; Gassmann,