

toxins include Cry and Cyt proteins. Cry proteins, such as Cry1Ac and Cry1F, are the most widely used and are known for their specificity towards lepidopteran and coleopteran pests (Jurat-Fuentes et al., 2021; Kain et al., 2022). These proteins are produced as protoxins that require activation by insect midgut proteases to become toxic (Tabashnik et al., 2015; Guo et al., 2020). Additionally, there are other classes of Bt toxins, such as Vip (vegetative insecticidal proteins), which have different modes of action and target different insect receptors (Wei et al., 2019).

2.2 Mode of action

The mode of action of Bt toxins involves multiple steps. First, the toxin binds to receptors on the epithelial cells of the insect midgut, then forms pores that lead to cell lysis and insect death (Figure 1) (Heckel et al., 2021). The active toxin then binds to specific receptors on the midgut epithelial cells, such as cadherin and ATP-binding cassette (ABC) transporters (Zhu et al., 2019). This binding facilitates the formation of pores in the cell membrane, leading to cell lysis and ultimately causing insect death (Chen et al., 2015; Heckel et al., 2021). Recent studies suggest that protoxins and active toxins may have different modes of action, with protoxins potentially being more effective against resistant insect strains (Tabashnik et al., 2015; Guo et al., 2020).

Figure 1 illustrates the hypothetical model of the mode of action of Bt toxins, including the synergistic mechanisms of trans-action and cis-action. It details how toxin monomers bind to receptors to form prepores, which ultimately lead to pore insertion into the insect gut cell membrane, revealing the multi-step action pattern of Bt toxins. This provides an important reference for studying the mode of action of Bt toxins.

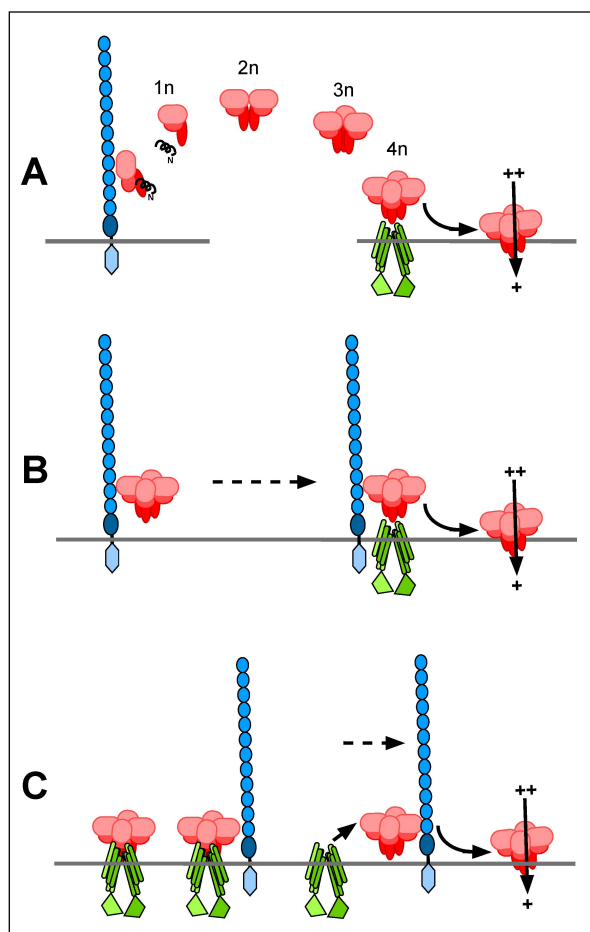


Figure 1 Hypothetical models of the mechanism of synergy between the 12-cadherin domain protein and an ABC transporter (Adopted from Heckel et al., 2021)

Image caption: (A) Trans-acting synergy, due to acceleration of oligomer formation following monomer binding to the cadherin. (B) Cis-acting synergy, due to the cadherin trapping the pre-pore and moving it to the ABC transporter. (C) Cis-acting synergy, due to the cadherin pulling the pre-pore away from the ABC transporter, freeing it to interact with another toxin pre-pore. Dotted lines represent movement of the cadherin within the membrane (Adopted from Heckel et al., 2021)