

that are activated under certain environmental conditions. The Cry proteins, for instance, are produced as protoxins that require activation to exert their insecticidal effects (Tabashnik et al., 2015). The Vip proteins, on the other hand, are secreted during the vegetative growth phase and have distinct mechanisms of action compared to Cry proteins (Jin et al., 2022).

3.2.2 Regulatory networks

The regulation of toxin production in Bt involves complex networks of genetic and environmental factors. Key regulatory genes and proteins control the expression of toxin genes in response to specific signals. For example, the expression of Cry proteins is tightly regulated by sporulation-specific sigma factors and other regulatory proteins that respond to nutrient availability and other environmental cues (Figure 1) (Li et al., 2022). Additionally, the interaction between primary and secondary metabolic pathways plays a significant role in modulating toxin production (Tabashnik et al., 2015).

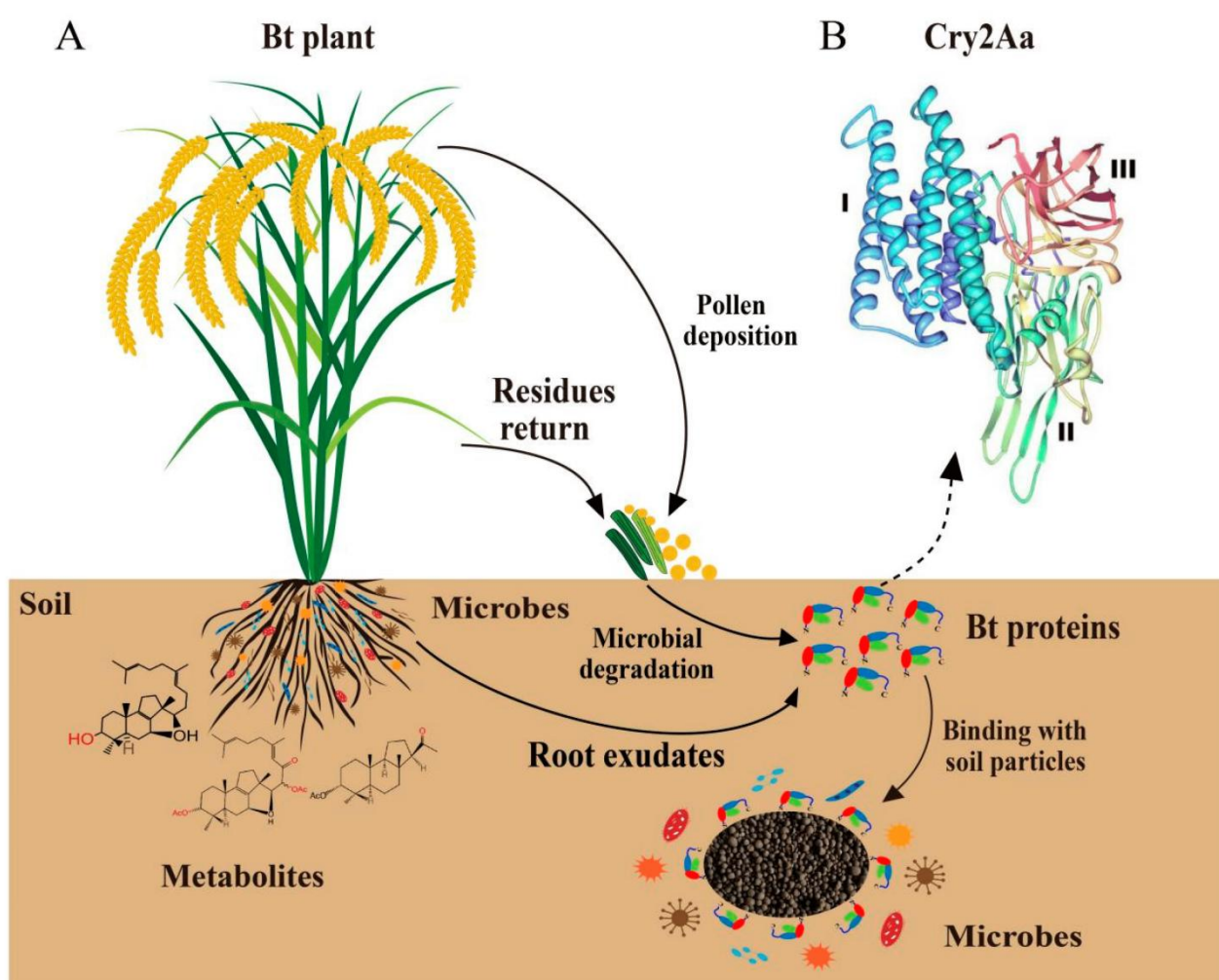


Figure 1 Environmental behaviors of Bt protein (A) and its three-dimensional structures (B). I, II, and III: domains I, II, and III (Adopted from Li et al., 2022)

The production of Bt toxin is influenced by both genetic regulation and environmental factors. At the genetic level, the expression of specific genes and regulatory networks play a key role in Bt toxin production, while environmental factors such as temperature, pH, and nutrients significantly affect the synthesis and release of the toxin. Figure 1 illustrates how high-throughput screening methods systematically assess these genetic and environmental variables to optimize Bt toxin production. This approach is crucial for improving the efficiency and stability of Bt toxin production and is an important tool in Bt metabolic engineering research.