

et al., 2019). The use of Bt in agriculture not only enhances crop yields but also promotes environmentally friendly farming practices by reducing the reliance on synthetic chemicals (Jouzani et al., 2017; Dame et al., 2021). Additionally, Bt-based biopesticides are considered safe for humans and non-target organisms, making them a preferred choice for integrated pest management (Koch et al., 2015; Gutiérrez et al., 2019).

7.2 Medical and industrial uses

Beyond agriculture, Bt has shown potential in various medical and industrial applications. Recent studies have highlighted the use of Bt in bioremediation, where it helps in the detoxification of heavy metals and other pollutants (Jouzani et al., 2017). Bt has also been explored for its ability to produce polyhydroxyalkanoate biopolymers, which are valuable in the production of biodegradable plastics. In the medical field, Bt's parasporins have demonstrated anticancer properties, offering a novel approach to cancer treatment (Melo et al., 2016; Jouzani et al., 2017). Furthermore, Bt's chitinase enzyme, which degrades chitin, has industrial applications due to its abundance in nature and its role in enhancing the efficacy of Bt insecticides (Melo et al., 2016).

7.3 Regulatory and safety considerations

The widespread use of Bt in agriculture and other fields necessitates rigorous regulatory and safety evaluations. Bt proteins, particularly those expressed in transgenic crops, must undergo comprehensive biosafety assessments to ensure they do not pose ecological risks or harm non-target organisms (Li et al., 2022). These evaluations include studies on the environmental fate of Bt proteins, their impact on soil microbial diversity, and potential unintended effects on ecosystems. Additionally, the potential for gene flow from Bt crops to wild relatives is assessed to prevent ecological imbalances (Koch et al., 2015). Regulatory frameworks are in place to monitor and manage the use of Bt products, ensuring their safe and sustainable application in various industries (Koch et al., 2015; Li et al., 2022).

8 Concluding Remarks

Comparative genomics studies have revealed significant insights into the genetic diversity, insecticidal properties, and potential applications of *Bacillus thuringiensis* (Bt) and related *Bacillus* species. Bt strains exhibit a wide range of insecticidal proteins, such as Cry and Vip proteins, which are crucial for their effectiveness as biopesticides. For instance, Bt X022 contains genes for *Cry1Ac*, *Cry1Ia*, *Cry2Ab*, and *Vip3A*, while Bt GR007 harbors multiple *cry* and *vip* genes, demonstrating their genetic variability and potential for targeted pest control.

Proteomic analyses complement genomic data by identifying the expression of specific insecticidal proteins during different growth stages. For example, proteomic analysis of Bt X022 during the spore-release period detected Cry1Ca, Cry1Ac, and Cry1Da proteins, which could not be predicted solely by genomic data. Studies also identified various virulence factors and resistance genes in Bt strains, such as antibiotic and heavy metal resistance genes in Bt HM-311, which may contribute to their survival in contaminated environments.

Comparative genomic and proteomic techniques provide more accurate phylogenetic relationships among Bt strains than traditional serotyping methods, offering important insights into Bt classification and evolutionary history. Future Bt genomics research should further annotate Bt genomes functionally, particularly identifying and characterizing new insecticidal proteins and virulence factors, and exploring the regulatory mechanisms governing their expression under different environmental conditions.

In practical applications, utilizing genomic and proteomic data to develop Bt strains with specific insecticidal profiles tailored to particular pests can enhance biopesticide efficacy and reduce environmental impact. Advanced genomic tools should be used for routine monitoring of Bt biopesticide residues in food products to ensure food safety and regulatory compliance. Through these measures, future research and practical applications can maximize the benefits of Bt and related *Bacillus* species in sustainable agriculture and pest management.

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Conflict of Interest Disclosure

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