7 Optimization Strategies and Future Perspectives

7.1 Optimization of integrated control strategies

For Hangbaiju, optimization begins by matching control tools to phenological windows. Based on the narrow harvest period, the program should be designed so that heavy interventions happen before bloom and harvest, with bloom-stage emphasis on clean, non-residue measures such as trapping and selective botanicals only when necessary (Zang et al., 2023).

Microbial optimization should prioritize preventive inoculation and appropriate doses, consistent with the Bacillus meta-analysis findings. When disease suppression is the goal, protocols should explicitly define preventive timings (e.g., seedling stage, early vegetative stage, post-transplant), rather than leaving microbial products as "rescue" inputs (Serrão et al., 2024).

Where possible, multi-microbe approaches should be evaluated through the lens of compatibility and delivery. The Trichoderma–bacteria synergy review suggests that co-inoculations can exceed the sum of their parts, but it also highlights formulation challenges. For Hangbaiju, this indicates a future direction: develop locally validated consortia that can be applied through existing equipment and that tolerate local storage and transport conditions (Poveda and Eugui, 2022).

7.2 Strengthening technical guidance and training

Training programs for Hangbaiju biological control should be built around decision points that farmers already face: "When do I act?" and "What can I do during bloom without risking product quality?" The bloom-stage aphid study provides a compelling educational anchor because it translates ecological theory (olfactory + visual cues) into a concrete field practice (trap spacing, lure composition, deployment height) (Cao et al., 2024).Similarly, the thrips predatory-mite study provides a clear narrative about why chemical sprays struggle (behavior, resistance) and how biological control can exploit pest life cycle vulnerabilities (soil stage). Such case-based teaching is often more persuasive than abstract IPM slogans because it explains causality and gives farmers a mental model they can apply to new problems (Jung et al., 2019).

Extension guidance should also incorporate compatibility rules. For example, where botanicals are used, training should include selectivity and timing to protect beneficial organisms, reflecting the nuanced risk assessments described for azadirachtin and other botanicals (Kilani-Morakchi et al., 2021).

7.3 Promoting standardization and large-scale application

Standardization is crucial for scale because biological control is sensitive to product quality and operational timing. For Hangbaiju, existing standardization infrastructure is already present in production and GI frameworks. The national GI standard for Hangbaiju signals that standardization and traceability are already a market expectation, and provincial standards on production technical protocols further indicate institutional support for codifying best practices.

In the biological control domain, standardization should focus on protocol reproducibility: defined concentrations, application intervals (or monitoring triggers), and minimum quality requirements for microbial preparations or lures. The success of field trapping in the aphid study is partly due to explicit protocol details (trap color, lure composition ratio, spacing), which is a template for scalable biological control recommendations (Cao et al., 2024).For microbial products and consortia, standardization should include viability metrics, storage conditions, and application methods compatible with farmer equipment. Without this, "biological control" becomes an inconsistent category perceived as unreliable, even when the underlying biology is sound (Poveda and Eugui, 2022).

7.4 Development of sustainable and green cultivation systems

The future of Hangbaiju biological control is likely to be less about replacing one pesticide with one biopesticide and more about designing cultivation systems where pest and disease pressure is structurally reduced. This includes soil health management, crop rotation, prevention-focused microbial inoculation, ecological regulation of pests using cues and traps, and deliberate support of natural enemies.