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# Field Application and Effect Evaluation of Biological Control Measures in *Chrysanthemum morifolium* (Hangbaiju)

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**Abstract** Hangbaiju (*Chrysanthemum morifolium* Ramat. cv. 'Hangbaiju') is both a traditional specialty crop and an edible, flower-based product whose market value depends on aesthetics, aroma, safety, and consumer trust. In many production bases, pest and disease pressure is increasing and is amplifying the tension between yield protection and residue-reduction goals. Chemical control often provides rapid suppression, but repeated use can destabilize greenhouse or field agroecosystems, erode beneficial microbial and arthropod communities, and raise social and regulatory concerns-especially for a flower that is harvested and directly infused as tea. This study synthesizes recent evidence on biological control technologies relevant to Hangbaiju production, with emphasis on what is practical in field deployment rather than what works only in controlled laboratory settings. The scope covers (i) microbial-based tools, including antagonistic bacteria/fungi and plant growth–promoting rhizobacteria; (ii) botanical pesticides and plant-derived insecticides; and (iii) utilization of natural enemies, with both augmentative releases (where feasible) and conservation biological control (habitat and resource management). This study then evaluates reported field/production-scale outcomes using comparable endpoints such as disease or pest suppression, stability across time, compatibility with cultivation operations, and likely economic implications, while avoiding any fabricated datasets. A case-driven synthesis is built around two documented problem windows in Hangbaiju systems: the bloom-stage contamination risk from chrysanthemum aphids (Macrosiphoniella sanborni) and the recurring soil-borne wilt complex affecting chrysanthemum production. The evidence consistently suggests that integrated approaches—especially those combining preventive microbial inputs, selective botanicals, and strategies that protect or enhance natural enemies—tend to outperform single-method interventions in robustness and practical adoptability.

**Keywords** *Chrysanthemum morifolium*; Biological control; Field application; Effect evaluation; Green agriculture

## 1 Introduction

Hangbaiju is formally recognized and standardized as a geographical-indication product in China, reflecting its strong geographic branding and the expectation of consistent quality attributes in commercial trade. Beyond branding, the production system itself shapes management choices. Hangbaiju is one of the traditional specialty and advantageous agricultural products in Tongxiang City, Zhejiang Province, with a cultivation history spanning over 300 years. The annual planting area covers approximately 3300 ha, yielding an annual output of 6,000 tons (Figure 1). A field survey summarized in a recent Frontiers dataset paper notes that Tongxiang City (Zhejiang Province)—the origin region frequently associated with Hangbaiju—tied to the flower stage linked with optimal medicinal or product properties. This concentrated harvest period magnifies the operational impact of late-season pests and quality defects: problems that would be manageable with flexible harvest scheduling become high-stakes events when harvest labor and processing capacity are already strained (Zang et al., 2023).

In practical terms, Hangbaiju's "economic value" is not only yield-per-area but also saleability: flower integrity, visual cleanliness, and consumer experience. A distinctive example is the bloom-stage aphid problem: Macrosiphoniella sanborni adults and bodies can remain with harvested flowers and become visible in the tea infusion, causing consumer rejection ("off their appetite" in the English abstract). This is a quality pathway that is unusual for many other crops, and it strongly incentivizes growers to seek control methods that work specifically during bloom without compromising harvest safety or market access (Cao et al., 2024).

Figure 1 Hangbaiju production base of Tongxiang Lvkang Chrysanthemum Industry Co., Ltd. (Photo by Weiying Gao)

The broader chrysanthemum production landscape (including ornamentals and edible/tea chrysanthemums) faces an expanding list of pathogens and pests, and recent reviews emphasize that control challenges are not only biological but also technological: improved diagnostics are identifying cryptic species complexes and mixed infections that earlier management models treated as one disease. For example, the 2015–2025 synthesis of chrysanthemum pest/disease research stresses that fungal, bacterial, viral, and insect problems remain major drivers of yield and quality losses, while new molecular and ecological tools are reshaping both detection and control strategies (Chen et al., 2025).

For Hangbaiju specifically, two pest situations stand out in the accessible Tongxiang-focused literature. First is bloom-stage aphid infestation and contamination risk from M. sanborni, which is explicitly described as feeding on or hiding within flowers and being carried through harvest and processing. Second is the soil-borne/wilt complex that can cause plant loss and reduced stand vigor, and in some studies is linked to Fusarium incarnatum rather than the historically assumed Fusarium oxysporum forma specialis. These are not marginal issues: they are framed in the reviewed studies as drivers of significant losses or high management pressure (Cao et al., 2024).

Chemical control remains a dominant tool in many chrysanthemum production systems because it is fast, familiar, and often initially effective. Yet several limitations matter more sharply in Hangbaiju than in purely ornamental markets. First, consumers ingest Hangbaiju as an infusion, so the “edible flower” identity makes residue anxiety and risk perception more central; even when legal residue limits are met, visible or sensory signs of intensive pesticide use can damage market trust. Second, repeated chemical inputs can disrupt beneficial microbes and the ecological functions that support plant health; a greenhouse study on microbial inoculants in cut chrysanthemum explicitly notes that chemical control is common but “not environmentally friendly” and can have “negative effects on beneficial microbes” (Wang et al., 2024). Third, pesticide resistance and the behavioral ecology of pests can erode chemical performance. Thrips are a classic example: the chrysanthemum–thrips study using soil-dwelling predatory mites frames chemical control as difficult partly because thrips have a short generation time, can evade sprays, and can develop pesticide resistance, motivating a shift toward IPM and biological control. Finally, chemical programs often struggle with bloom-stage constraints. In Hangbaiju, bloom is not just a biological stage but also the commercial product stage: interventions must preserve flower quality and minimize contamination. When chemical sprays are used late, they can collide with harvest scheduling, pre-harvest intervals, and the practical challenge of keeping harvested flower material “clean” in both residue and appearance. This is one reason why control methods that are physically targeted (e.g., traps) or biologically selective (e.g., compatible botanicals, microbial antagonists, or natural enemies) have become more attractive in research and extension narratives (Cao et al., 2024).

Across chrysanthemum research in the last decade, biological control is no longer treated as a niche alternative but increasingly as a main pillar of sustainability-oriented production systems. The large 2015–2025 review explicitly lists biocontrol agents-Trichoderma spp., Bacillus spp., predatory mites, and entomopathogenic fungi—as demonstrated tools and argues for future integration with microbiome management, molecular breeding, and RNA-based tools to achieve more durable control (Chen et al., 2025).

At the microbial-technology frontier, two developments are especially relevant for Hangbaiju growers and extension teams. One is the move from single strains to compatible consortia and co-inoculations. An open-access review in *Biological Control* argues that co-inoculations of Trichoderma with beneficial bacteria (often Bacillus or Pseudomonas) can produce synergistic benefits, and highlights that formulation and compatibility are central steps if such synergy is to translate outside the lab (Poveda and Eugui, 2022). The second development is the more explicit coupling of "biocontrol" with "plant growth and quality." A greenhouse study on co-inoculation of Bacillus velezensis and Pseudomonas aeruginosa in chrysanthemum reports improvements in growth and quality relative to single-strain inoculation, while also pointing to induced defense and immune activation (e.g., upregulation of defense-related transcription factors) as part of the mechanism. This matters for Hangbaiju because quality parameters—flower integrity, harvest timing, and market acceptance—are tightly linked to both stress and disease pressure (Wang et al., 2024).

This study has two practical objectives. The first is to summarize the biological control technologies most relevant to Hangbaiju cultivation, with attention to what is actually deployable under field constraints—timing, labor, weather, bloom-stage restrictions, and the economics of repeated applications. The second is to evaluate field application effects using traceable published evidence, focusing on comparative suppression of pests/diseases, yield and quality implications where reported, and practical performance compared to conventional chemical programs.

## 2 Major Pests and Diseases and Control Requirements in Hangbaiju

### 2.1 Major diseases and their characteristics

Hangbaiju disease management is best understood as a set of "risk windows" rather than a static list. Soil-borne diseases (wilt, root rots, blights under continuous cropping or soil fatigue) tend to build over time and intensify when production becomes more intensive, while foliar diseases fluctuate with weather, canopy density, and late-season management. The broad chrysanthemum review for 2015–2025 emphasizes that fungal pathogens cause leaf spot, wilt, rust, blight, and rot, affecting both yield and quality, and that improved molecular identification is changing how these diseases are classified and managed (Chen et al., 2025).

A key disease point that is directly relevant to Hangbaiju biological control is the wilt complex linked to Fusarium. The Hangbaiju-focused study in the Chinese Journal of Biological Control identifies the wilt pathogen for chrysanthemum as Fusarium incarnatum based on morphological and ITS sequence analysis, highlighting that "Fusarium wilt caused huge yield loss" and framing accurate identification as the foundation for effective control. This is important for practice: if the pathogen is misidentified, chemical or biological choices can be mismatched, leading to costly failures.

For Hangbaiju leaf and flower quality, foliar disease pressure is also significant, but accessible open literature in this query is more detailed on insect contamination than on leaf-spot epidemiology within Tongxiang fields. In such cases, a practical review approach is to focus on biological-control principles that are robust across multiple foliar pathogens—preventive microbiome support, canopy microclimate management, and the use of antagonists with broad-spectrum suppression—rather than overfitting recommendations to one pathogen that may not be uniformly dominant across production bases (Chen et al., 2025).

### 2.2 Major insect pests and their damage patterns

The insect damage profile of Hangbaiju has one unusual, market-critical feature: pests can directly contaminate the harvested flower product. The bloom-stage aphid case is the clearest example. Cao and colleagues describe M. sanborni as feeding on flowers and hiding within them, then being harvested and remaining in processed chrysanthemum-tea products; when flowers are brewed, aphid bodies can float in the tea, causing consumer disgust and product rejection. This connects entomology to quality control more directly than in many crops, and it explains why field control requirements must include “harvest cleanliness,” not only reduction of feeding damage (Cao et al., 2024).

Thrips represent another common chrysanthemum pest group, with damage patterns that complicate chemical control. In a greenhouse chrysanthemum trial, the authors describe thrips control as difficult because of thrips’ behavioral avoidance, rapid generation time, and pesticide resistance development. Importantly, thrips have a life cycle phase in the soil, creating an opportunity for soil-dwelling natural enemies that do not rely on perfect spray coverage of foliage. At the broader “chrysanthemum as a crop” level, recent reviews also emphasize aphids and thrips as key pests with virus-vector potential and highlight the role of resistance traits (trichomes, terpenoids, lignin) and biological control agents (predatory mites, entomopathogenic fungi) in sustainable management. While Hangbaiju’s production ecology differs from greenhouse ornamentals, these findings still shape technology options and selection criteria (Chen et al., 2025).

### 2.3 Challenges in field control

Field control in Hangbaiju is constrained by three interacting realities. First, the harvest window is narrow and often labor-limited, so any late-season pest or disease flare-up can translate into either harvest delays (missing the optimal flower stage) or quality downgrades. The Tongxiang-focused survey cited by Zang and colleagues explicitly notes a harvest period “usually lasts 25 days,” and also points to the difficulty of recruiting many trained farmers in a short time, a labor constraint that matters for repeated spray-based control programs (Zang et al., 2023).

Second, bloom-stage interventions must avoid harming the marketable organ. The aphid contamination pathway illustrates how bloom-stage spraying can be simultaneously necessary (for pest control) and risky (for product safety and market perception). Methods that physically remove or intercept pests (e.g., attractant-baited sticky traps) become attractive because they can be deployed during bloom with less direct chemical exposure to the harvested flowers (Cao et al., 2024).

Third, sustained field efficacy depends on ecological stability. Biological control is often more sensitive to microclimate and agronomic practices than “spray-and-kill” approaches, but chemical approaches can destabilize beneficial communities and create rebound pest problems. In modern chrysanthemum research, this has led to a pragmatic middle position: biological control is most robust when it is preventive and integrated, rather than used as a single replacement input (Serrão et al., 2024).

## 3 Types and Application Progress of Biological Control Technologies

### 3.1 Microbial-based control technologies

In Hangbaiju systems, microbial-based control is best seen as a spectrum of tools rather than a single category. At one end are classic antagonists that directly inhibit pathogens through antibiosis, competition, and enzymatic degradation; at the other end are plant growth–promoting rhizobacteria (PGPR) that reshape nutrient use efficiency and trigger immune activation, thereby increasing tolerance and reducing the effective damage from disease pressure. The chrysanthemum co-inoculation study by Wang et al. (2024) and colleagues explicitly frames PGPR inoculation as a sustainable strategy and reports that co-inoculation increased plant nutrient absorption/utilization and improved growth and quality relative to single inoculation; transcriptome results also indicate upregulation of defense and signaling pathways, implying that the “control effect” is partly mediated through induced resistance rather than only pathogen suppression.

For disease control at a higher evidence level across crops, a 2024 meta-analysis of Bacillus-based biocontrol reports that Bacillus agents reduced disease by about 60% compared to negative controls in the compiled literature. The same meta-analysis highlights two practice-relevant principles: higher inoculum concentrations tend to yield stronger protective effects, and protective (preventive) inoculation generally outperforms therapeutic use after disease establishment. These findings map directly onto Hangbaiju field realities: if application is delayed until symptoms surge near harvest, biological control often appears “unstable,” but when microbial tools are integrated earlier as preventive management, performance is more reliable (Serrão et al., 2024).

A Hangbaiju-specific microbial-control example is the use of Streptomyces diastatochromogenes 1628 metabolites against Fusarium-associated wilt. In the Chinese Journal of Biological Control report, metabolites of *S. diastatochromogenes* 1628 were tested against *Fusarium incarnatum* (identified as the pathogen), with pot-trial results reporting both protective and therapeutic effects after 14 and 28 days, with protective efficacy higher than therapeutic efficacy. This pattern aligns with the broader meta-analysis conclusion that preventive use tends to be stronger than “curative” use once disease is established.Technologically, the field is also moving toward multi-microbe or consortium approaches. Poveda and Eugui argue that Trichoderma–bacteria co-inoculations can produce synergistic benefits, sometimes approaching chemical-pesticide outcomes, but they emphasize formulation and compatibility as key steps for real-world adoption. For Hangbaiju, this highlights a practical boundary: the most promising microbial agents are not always the most deployable unless they are formulated for local transport, storage, and farmer-friendly application schedules (Poveda and Eugui, 2022).

### 3.2 Botanical pesticides

Botanical pesticides occupy a strategic middle ground for Hangbaiju: they can reduce reliance on broad-spectrum synthetics while maintaining the operational simplicity of spray-based programs. Yet botanical pesticides are not inherently “weak”; the best ones have distinct modes of action and can be embedded into IPM programs as selective tools.

Azadirachtin (from neem) is one of the most globally recognized botanical insecticides. In a 2021 review, it is characterized as a potent antifeedant and insect growth disruptor with low residual power and relatively low toxicity to many biocontrol agents, predators, and parasitoids, a profile that fits integrated programs where natural enemies are valued rather than collateral damage. The same review also notes practical limitations, including stability and the need for strategies (including formulation innovations such as nano-enabled delivery) to control release rate and improve field persistence (Kilani-Morakchi et al., 2021).

Evidence from chrysanthemum-focused trials shows that plant extracts can achieve meaningful suppression of aphids under protected cultivation. In a 2024 study evaluating several botanical insecticides against *Aphis gossypii* on chrysanthemum (plastic house conditions), the extract of *Chrysanthemum cinerariaefolium* at 3.0 and 3.5 g/L achieved reported average efficacy values of 76% and 72%, respectively, and was described as the most consistent treatment among those tested. This is important for Hangbaiju because it illustrates a realistic control magnitude for botanicals—strong enough to be operationally relevant, especially when combined with monitoring, sanitation, and conservation biological control (Hutapea et al., 2024).

Botanical tools also connect to the chrysanthemum plant’s own defense chemistry. Research on pyrethrum flowers shows that producing aphid alarm pheromone can repel herbivores and recruit carnivores, illustrating how plant-derived signals and compounds can function simultaneously as direct defense and as ecological regulation. While pyrethrum is not Hangbaiju, the principle is transferable: integrated programs can combine plant-derived chemistry, physical trapping, and natural enemies without relying on a single “silver bullet” insecticide (Hutapea et al., 2024).

### 3.3 Utilization of natural enemies

Natural-enemy utilization in chrysanthemum production spans augmentative release (adding commercially produced natural enemies) and conservation biological control (managing habitats, nectar resources, refuges, and pesticide selectivity to sustain resident enemies). Hangbaiju is largely field-grown, which can make repeated augmentative releases less predictable than in controlled greenhouses; nonetheless, greenhouse studies still provide valuable mechanistic guidance for timing and target life stages.

A clear example of natural-enemy utility is the greenhouse chrysanthemum trial using the soil-dwelling predatory mite *Stratiolaelaps scimitus*. The study describes thrips as difficult to control with chemicals and reports that releases of *S. scimitus* (using a farmer self-production approach) reduced thrips density substantially, with the treated greenhouse showing 74.9% suppression relative to the untreated greenhouse by late September (2018). The authors explicitly interpret this as evidence that soil-dwelling predators can suppress the thrips stage that drops to soil for pupation, an approach that complements foliage-based measures and reduces reliance on repeated sprays.

For Hangbaiju, an equally important natural-enemy concept is "making the field hospitable" to predators and parasitoids. The bloom-stage aphid paper itself highlights that visual and olfactory cues can be leveraged to attract pests into traps; by analogy, ecological regulation can be used to enhance natural-enemy foraging and persistence through habitat features and resource provisioning. In practical IPM, this typically means preserving nectar resources, avoiding broad-spectrum sprays during peak enemy activity, and ensuring that field sanitation removes pest reservoirs without eliminating beneficial refuges (Cao et al., 2024).

### 3.4 Integrated biological control strategies

In my view, the central question for Hangbaiju is not whether biological control "works," but which integration pattern makes it reliable when weather, labor, and market timing are non-negotiable. The evidence across the cited literature points toward a consistent theme: preventive, combined strategies are more stable than reactive, single-method interventions (Figure 2).

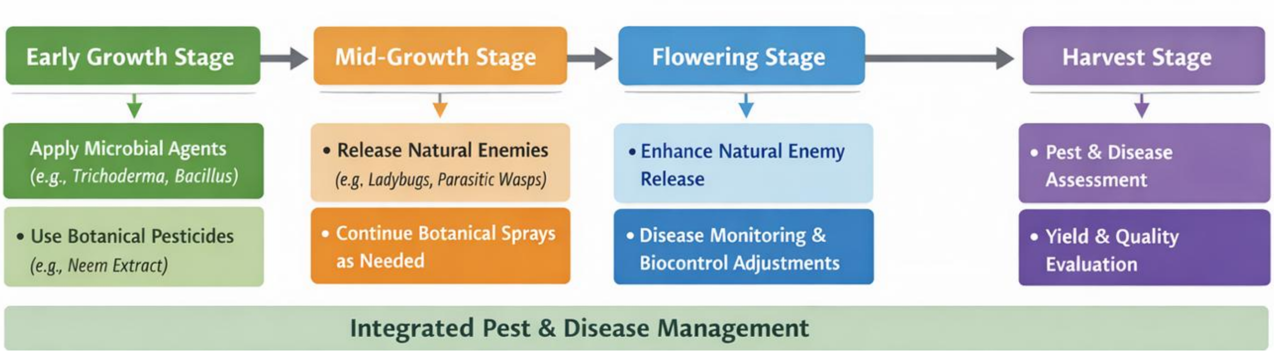

Figure 2 Integrated biological control workflow for Hangbaiju

A useful way to conceptualize this is to treat biological control as a layered system: soil health and preventive microbial inoculation reduce baseline disease pressure; selective botanicals provide flexible suppression tools for sudden pest increases; and natural enemies provide ongoing regulation, especially for pests with cryptic behavior or soil stages. This layered logic is consistent with (i) the Bacillus meta-analysis emphasizing preventive strength, (ii) the Trichoderma–bacteria synergy review emphasizing compatibility and formulation, and (iii) field/greenhouse demonstrations showing strong pest suppression when natural enemy life-history is matched to pest life-cycle vulnerabilities (Serrão et al., 2024).

## 4 Evaluation of Field Application Effect

### 4.1 Comparative effectiveness of different control measures

When comparing biological control measures, the most honest approach is to compare "effectiveness profiles" rather than pretending that each tool is measured on the same scale in the same environment. Field outcomes depend on pest species, crop stage, temperature/humidity, application timing, and sometimes the surrounding landscape.

Still, several quantitative anchors are available. In greenhouse chrysanthemum, releases of *Stratiolaelaps scimitus* achieved a reported 74.9% reduction in thrips density relative to the untreated greenhouse by late September. This level of suppression is operationally meaningful, particularly because it targets a soil stage that foliar sprays can miss.

For botanical insecticides on chrysanthemum, the 2024 evaluation under plastic house conditions reports that *Chrysanthemum cinerariaefolium* extract at 3.0–3.5 g/L achieved average efficacies of 76% and 72% against *Aphis gossypii*, and was the most consistent among tested botanicals. While *A. gossypii* is not the same as *Macrosiphoniella sanborni*, this study is still relevant for Hangbaiju because it provides a realistic magnitude of botanical suppression in chrysanthemum and supports the idea that botanicals can be more than marginal add-ons (Hutapea et al., 2024).

For microbial disease suppression, the Bacillus meta-analysis across 2000–2021 literature provides a broad benchmark: Bacillus-based biocontrol reduced disease by about 60% relative to controls, with higher efficacy in preventive contexts. This is not Hangbaiju-only, but it is a strong evidence synthesis that can guide expectations and program design (Serrão et al., 2024).

Hangbaiju-specific microbial evidence is available for Fusarium-related wilt management where Streptomyces metabolites were tested; reported results include stronger protective than therapeutic effects, reinforcing the practical principle that microbial control is best deployed before pathogen populations and vascular symptoms surge.

### 4.2 Effects on yield and product quality

Yield in Hangbaiju is inseparable from product quality because market grading is often driven by flower appearance, cleanliness, and consumer experience. A narrow harvest window means suboptimal timing can reduce both yield (lost harvest) and quality (flowers past peak or damaged). The Tongxiang survey described in the dataset paper emphasizes that Hangbaiju is harvested within a short period for best properties, linking agronomic timing directly to product value (Zang et al., 2023).

The aphid contamination case shows a quality dimension that is almost a “binary defect”: if aphid bodies appear in tea infusion, the product may be rejected regardless of yield. In this context, control measures that remove adults during bloom—without adding new residue concerns—can protect quality even if their effect on biomass yield is indirect. The attractant-baited yellow sticky traps described by Cao et al. are explicitly positioned as an “environmental sound measure” to combat bloom-stage aphids and reduce their presence in flowers (Cao et al., 2024). Microbial inoculants may also affect quality through plant physiology and nutrient use efficiency. The co-inoculation study in cut chrysanthemum reports improved growth and quality compared with single-strain inoculation and soil conditioner application, and connects these outcomes to changes in nutrient accumulation and gene expression in metabolic and signaling pathways. Although this was conducted in a cut-flower context rather than Hangbaiju tea production, it supports a plausible mechanism by which microbial management could improve Hangbaiju flower uniformity and stress resilience—traits that contribute to usable harvest (Wang et al., 2024).

### 4.3 Comparison with chemical control methods

A fair comparison with chemical control should acknowledge that chemical programs can deliver rapid suppression, especially when pest outbreaks are acute. Yet three comparative shortcomings often push Hangbaiju systems toward integrated biological control.

First, chemical sprays can be poorly matched to pest behavior. Thrips’ cryptic behavior and life cycle phases reduce spray contact efficacy, and resistance development can further erode performance. The chrysanthemum thrips biocontrol study uses this as a rationale for shifting toward biological control and IPM approaches.

Second, chemical control can undermine biological regulation by harming beneficial microbes and disrupting soil or rhizosphere functions. The PGPR study explicitly flags negative effects of chemical control on beneficial microbes, supporting the argument that the long-run “cost” of chemical programs includes ecological degradation and potentially rising disease susceptibility (Wang et al., 2024).

Third, chemical control during bloom is constrained by product identity and consumer perception. The bloom-stage aphid case provides a direct comparison: the study reports that traps combining yellow sticky boards with a complex aphid sexual attractant had a control effect “significantly superior” to spraying imidacloprid, while also offering a non-spray alternative during the sensitive bloom period. This is one of the most concrete Hangbaiju-linked comparisons accessible in the present evidence set (Cao et al., 2024).

### 4.4 Economic benefits and application value

Without inventing cost or profit data, the most responsible way to discuss economic benefits is to focus on mechanisms by which biological control can create value and on the accounting framework growers or cooperatives can use to evaluate interventions.

In Hangbaiju, value creation can occur through (i) preventing stand loss from soil-borne diseases, (ii) stabilizing harvestable flower quantity within the narrow harvest window, and (iii) protecting marketability via reduced contamination or defect rates (such as aphid bodies in tea infusion). The available Hangbaiju aphid study is explicitly framed around consumer experience and product contamination, implying that pest suppression can translate into better product acceptance even if biomass yield changes are not reported (Cao et al., 2024). A practical field evaluation can compute the net benefit of a biological control package as:

$$\Delta \Pi=(Y_b \cdot P_b-C_b)-(Y_c \cdot P_c-C_c)$$

where $Y$ is saleable yield (not just biomass), $P$ is price (often quality-graded), and $C$ is total control cost (inputs + labor + application time). For Hangbaiju, “saleable yield” should be adjusted for contamination defects and harvest timing losses, reflecting the narrow harvest window reported for Tongxiang (Zang et al., 2023).

From a technology-adoption standpoint, biological control has application value when it reduces operational risk. The Bacillus meta-analysis suggests that preventive applications can deliver stronger control, and the Trichoderma–bacteria synergy review emphasizes that compatibility and formulation are key for performance—both points underscore that economic benefit depends on reliable, scalable delivery rather than theoretical efficacy alone (Table 1) (Serrão et al., 2024).

## 5 Case Study

### 5.1 Background of the case

This case study is organized around Tongxiang-linked Hangbaiju production constraints and two documented control problems that directly link pest pressure to product acceptance: bloom-stage aphid contamination and soil-borne wilt risk. Tongxiang, Zhejiang is repeatedly referenced in accessible Hangbaiju literature as a major production region, and a surveyed expansion to nearly 4000 $hm^2$ with a narrow ≈25-day harvest window underscores why these problems are operationally disruptive (Zang et al., 2023).

The planting and management context highlighted in the accessible studies reflects typical field constraints: dense plantings that complicate scouting and treatment precision, strong dependence on short-term labor availability during harvest, and high sensitivity of marketability to defects that are visible in the brewed tea. In this setting, “management practice” is not only a set of agronomic steps but also an implicit risk strategy: preventing late-season emergencies that cannot be safely or economically solved during the harvest rush (Figure 3) (Zang et al., 2023).

Pest and disease occurrence in this case is characterized by (i) a bloom-stage aphid (*Macrosiphoniella sanborni*) that hides within flowers and can be harvested with the product, and (ii) Fusarium-associated wilt, with evidence indicating *Fusarium incarnatum* as a causal agent in chrysanthemum wilt cases, driving interest in microbial antagonists or metabolite-based control (Cao et al., 2024).

### 5.2 Implementation of biological control measures

The core implementation evidence here comes from two peer-reviewed studies that address different control windows but are complementary in an integrated Hangbaiju program.

Table 1 Traceable effect benchmarks from recent chrysanthemum/Hangbaiju-relevant biological control studies.
(Values are reported outcomes from cited sources; they are not newly generated data.)

| Control category | Target problem | Example intervention (study context) | Reported effect indicator | Practical note for Hangbaiju adoption |
|---|---|---|---|---|
| Natural enemy (predatory mite) | Thrips (soil stage contribution) | *Stratiolaelaps scimitus* releases in greenhouse chrysanthemum | 74.9% reduction vs. untreated greenhouse by late September | Strong where thrips pupate in soil; complements foliage management and reduces spray dependence during hot seasons (Jung et al., 2019). |
| Botanical insecticide | Aphids on chrysanthemum (*Aphis gossypii*) | *Chrysanthemum cinerariaefolium* extract, 3.0–3.5 g/L, plastic house | Average efficacy 76% and 72% at 3.0 and 3.5 g/L | Suggests botanicals can deliver operationally meaningful suppression, but consistency and timing are crucial (Hutapea et al., 2024). |
| Microbial biocontrol (meta-level) | Plant diseases (broad) | Bacillus-based BCAs across studies (2000–2021 synthesis) | ~60% disease reduction vs. negative controls | Highlights preventive-strength principle; informs expectation management and program design (Serrão et al., 2024). |
| Microbial metabolite (Hangbaiju-focused) | Fusarium-related wilt in chrysanthemum | *Streptomyces diastatochromogenes* 1628 metabolites vs. *Fusarium incarnatum* | Protective > therapeutic effects reported in pot trials | Supports preventive use and integration with soil management; direct Hangbaiju relevance (Cao et al., 2019). |
| Behavioral/physical control (Hangbaiju field) | Bloom-stage aphid contamination risk (*M. sanborni*) | Yellow sticky boards baited with complex aphid sexual attractant; trap spacing 7 m × 8 m | Trapping control effect superior to imidacloprid spray (qualitative superiority claim in abstract) | Especially aligned with bloom-stage “clean product” needs; reduces need for late spraying (Cao et al., 2024). |

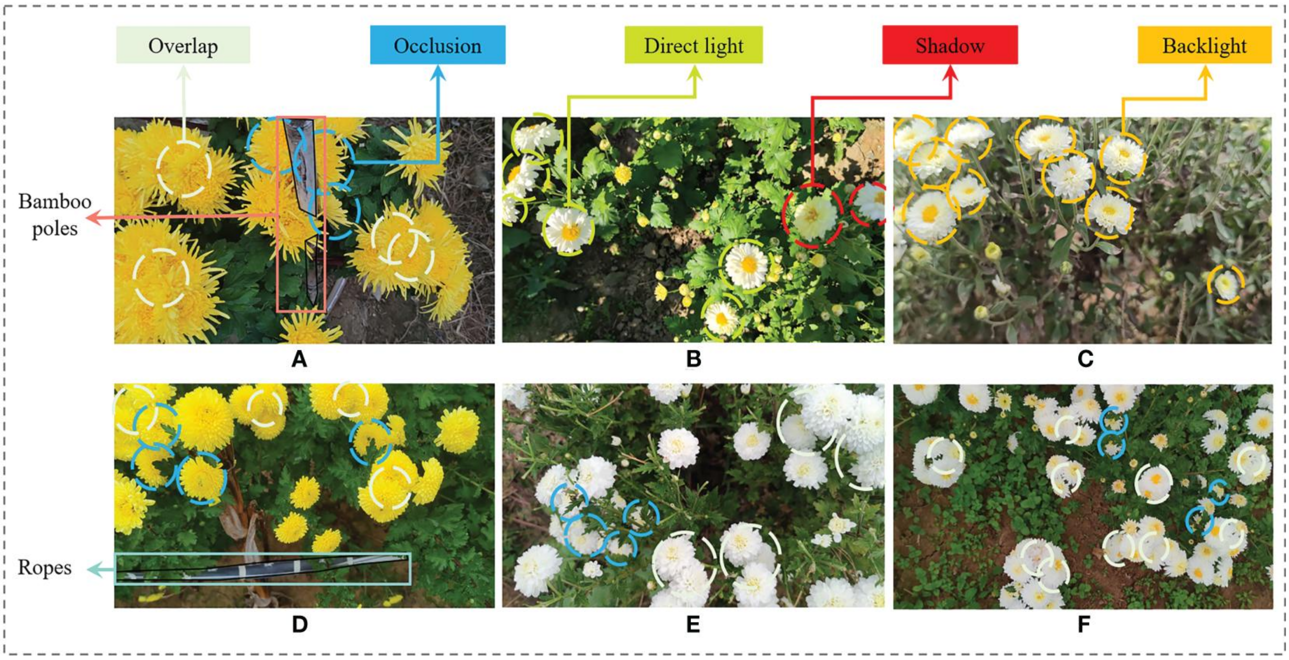

Figure 3 The category to which the sample images belong and their number in the related chrysanthemum dataset: (A) Jinsihuangju-01314, (B) Hangbaiju-00063, (C) Bo-chrysanthemum-11093, (D) Wuyuanhuangju-03285, (E) Gongju-00002, and (F) Chuju-00110 (Adopted from Zang et al., 2023)

For bloom-stage aphids, Cao et al. developed a control approach that combines olfactory and visual cues: a complex aphid sexual attractant (composed by mixing seven plant volatile components with nepetalactone at a specified volume ratio) was used to bait chrysanthemum-yellow sticky boards. Traps were deployed in Hangbaiju fields with spacing of 7 m × 8 m, and the trap bottom positioned just above plant tops (≈1 cm in the described setup) (Cao et al., 2024).

For soil-borne wilt management, the Hangbaiju Fusarium study identifies *F. incarnatum* as the pathogen and evaluates metabolites of *Streptomyces diastatochromogenes* 1628 as a biocontrol input. The study design includes in vitro inhibition endpoints and pot-trial evaluation, which is typical of microbial biocontrol development pipelines where greenhouse/pot performance is used as a bridge toward field formulation and delivery.

A practical integrated implementation, faithful to these sources, would therefore deploy microbial protection preventively (pre-plant or early growth) and rely on non-spray “clean harvest” interventions during bloom. In my experience reading the chrysanthemum biological control literature, this split design—microbes early, traps/low-residue tools late—often aligns better with on-farm logistics than trying to replace every chemical spray with a biological spray at the same timing (Serrão et al., 2024).

### 5.3 Analysis of control effectiveness

For the bloom-stage aphid problem, the published evidence emphasizes qualitative superiority of the trapping strategy relative to chemical spraying in the described field context. The Acta Ecologica Sinica paper reports that the chrysanthemum-yellow sticky boards baited with the complex sexual attractant caught “a large number” of aphid adults and that their control effect on the aphid population was “significantly superior” to spraying imidacloprid. The study also provides behavior-based evidence supporting mechanism: multiple volatile components at specified concentrations attracted adult aphids, and yellow color was slightly more attractive than bud green in field phototaxis trials (Cao et al., 2024). For wilt suppression, the Hangbaiju Fusarium/ Streptomyces study reports measurable protective and therapeutic effects in pot tests, with a consistent pattern that protective effects exceed therapeutic effects. This is a meaningful signal for implementation: the biological control input should be deployed before severe vascular symptoms, consistent with the broader Bacillus meta-analysis finding that preventive inoculation generally yields higher efficacy than therapeutic use across many plant disease contexts.

Comparison with conventional chemical control can be framed as follows. Aphid control: the trap-based approach outperformed imidacloprid spray in field effectiveness (as reported). Wilt management: microbial metabolites provide protective/therapeutic effects but are better framed as preventive tools than emergency cures, unlike some chemical fungicide programs. This difference is not a disadvantage; it is a design constraint that integrated programs exploit by shifting part of control earlier in the season, when intervention is easier and less risky for product quality (Cao et al., 2024).

### 5.4 Yield and economic benefit analysis

The accessible bloom-stage aphid study does not report yield gains in kg or yield loss avoided; it is primarily framed around control efficacy and "clean product" outcomes. For Hangbaiju, however, product acceptance is a form of economic yield. If infestation leads to aphid bodies in tea infusion and consumer rejection, then reducing adult aphids during bloom protects not only flowers but the market pathway that turns those flowers into revenue. In this sense, the economic benefit is plausibly concentrated in reduced defect rate and improved consumer acceptance, even if biomass yield is not explicitly measured (Cao et al., 2024).

For the wilt study, the phrase "huge yield loss" is used to motivate the work, but the accessible search-level summaries emphasize pathogen identification and biocontrol effect estimation rather than a complete farm-economics dataset. Without inventing numbers, the economic logic should be expressed as risk reduction: effective preventive microbial control reduces stand loss probability and stabilizes plant health, which can preserve harvestable flowers within the narrow harvest window described for Tongxiang.

A practical on-farm evaluation can combine (i) avoided spray costs during bloom due to trap deployment, (ii) reduced labor and compliance risk from late chemical applications, and (iii) avoided revenue loss from downgraded or rejected product. This can be calculated using simple farm accounting (Section 4.4), but the present review does not assign numerical values without traceable reports (Cao et al., 2024).

### 5.5 Case summary and practical insights

First, timing is not a minor detail; it is the structure of effectiveness. Trap-based control is matched to the bloom-stage contamination risk and can outperform a conventional spray in that stage, while microbial disease suppression is most credible as a preventive input rather than a last-minute cure.

Second, combination strategies succeed when they combine different mechanisms rather than duplicating the same mechanism. The aphid strategy combines visual and olfactory cues; microbial strategies combine antagonism and induced resistance; botanical tools combine feeding deterrence and growth disruption with relatively low impact on beneficials. Integrated programs that mix these mechanisms are less likely to fail from a single weak link (such as poor spray coverage or short persistence) (Cao et al., 2024).

Third, scalability depends on formulation and farmer-facing simplicity. The Trichoderma–bacteria synergy review explicitly notes compatibility and formulation as key steps. In Hangbaiju, where harvest labor and timing are already tight, a biological strategy that adds complex, frequent operations is unlikely to be adopted widely, even if biologically "promising" (Poveda and Eugui, 2022).

## 6 Existing Problems and Limitations

### 6.1 Instability of control effects

A recurrent critique of biological control is "instability," but much of this instability is predictable when the control tool is deployed in a way that contradicts its mode of action. The Bacillus meta-analysis shows that protective inoculation tends to outperform therapeutic application, implying that using microbial tools only after disease has surged will systematically produce disappointing results (Serrão et al., 2024).

Similarly, botanical insecticides can show variable results when pest population stage structure and plant developmental stage shift. The botanical insecticide chrysanthemum trial describes that aphid populations and their spatial distribution changed across plant developmental stages, and different botanical treatments produced different responses. This suggests that timing and concentration are not optional details but the determinants of whether botanicals behave as reliable tools (Hutapea et al., 2024).

Natural-enemy–based control can also appear unstable when environmental conditions exceed the organism's tolerance or when pesticide programs unintentionally remove the enemies. Even in the successful thrips control study, the authors note very high summer temperatures and still report effective suppression, but this is a reminder that natural enemies have climatic and ecological requirements that must be built into the management plan (Jung et al., 2019).

### 6.2 Influence of environmental conditions

Hangbaiju is field-grown in complex outdoor scenes where light, shade, wind, and plant overlap are significant enough that even computer vision studies treat these as major confounding factors. From a biological control perspective, the same field complexity translates into microclimate variation: humidity pockets, shading effects on leaf wetness duration, and uneven coverage for sprays or microbial applications (Zang et al., 2023). Botanical pesticides' low residual power—identified as a strength for safety and selectivity—can also be a limitation under heavy rainfall or intense sunlight, where persistence may be too short to control rapidly reproducing pests. The azadirachtin review emphasizes low residual power and also discusses practical problems of application and the need for improved stability or controlled release approaches (Kilani-Morakchi et al., 2021).

Microbial agents likewise depend on environmental fit. Survival, colonization, and antagonistic activity vary with temperature, soil moisture, organic matter, and interactions with resident microbiota. This is one reason why consortium approaches and formulations are central in current research: not because single strains are uninteresting, but because field stability often requires buffering against environmental variability (Poveda and Eugui, 2022).

### 6.3 Technical promotion challenges

Promoting biological control in Hangbaiju is partly a technology-transfer challenge. Many tools require (i) quality-controlled products, (ii) correct timing, and (iii) operational discipline (monitoring, threshold decisions, record keeping). These requirements can conflict with smallholder constraints or with rapid expansion of planting area where extension services cannot keep up.

The Tongxiang survey cited in the dataset paper explicitly notes labor constraints during the short harvest window, which implies that a biological control program that demands intensive late-season operations is less likely to be adopted. In other words, technical promotion requires designing programs that reduce complexity during the most labor-constrained period, not adding new chores (Zang et al., 2023).

Compatibility across measures is another promotion challenge. For example, botanicals may be "low toxicity" to natural enemies in general, but actual compatibility depends on formulation, dose, and life stage of beneficial organisms. The azadirachtin review notes that neem-based insecticides can have slight to moderate toxicity and that pre-imaginal stages may be more susceptible in laboratory conditions, implying that real-world programs must be designed with selectivity awareness rather than assuming universal safety (Kilani-Morakchi et al., 2021).

### 6.4 Cost and farmer awareness issues

Biological control is often perceived as costly because benefits are distributed across time: preventive microbial inoculation may prevent future losses but does not always produce immediately visible "knockdown," and conservation biological control produces diffuse benefits that are harder to attribute to a single purchase.

However, cost perception also depends on what the farmer is optimizing. In Hangbaiju, where consumer rejection from contaminants can erase value quickly, investments in bloom-stage non-spray control (like trapping) may be economically rational even if they do not increase biomass yield. The bloom-stage aphid study provides an unusually direct link between pest presence and consumer experience, which can be used in extension messaging to reframe cost-benefit discussions around product acceptance, not only yield (Cao et al., 2024).Farmer awareness is also tied to clarity of protocols. The most adoptable approaches tend to have simple rules: when to apply, how often, and what success looks like. The more biological control relies on complex, multi-step mixtures or frequent monitoring without accessible decision support, the more it risks underuse or misuse—both of which produce "instability" that is actually a training and support failure (Poveda and Eugui, 2022).

## 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.

In the chrysanthemum research landscape, future directions include microbiome management and integration of molecular tools, but the near-term “green cultivation system” for Hangbaiju can be built with already-available practice: preventive microbial inoculation strategies, selective botanicals such as azadirachtin where appropriate, and bloom-stage trapping to protect product cleanliness. The 2015–2025 chrysanthemum review explicitly frames microbiome management and integrated approaches as priorities for sustainable protection (Chen et al., 2025).

In my judgment, the strongest sustainable pathway is one that respects Hangbaiju’s product identity: it is not a crop where “cosmetic damage” is acceptable, because the flower itself is consumed. Therefore, greens systems must protect both agronomic output and consumer confidence, and biological control fits best when it is implemented as a quality-protection strategy as much as a pest-suppression strategy (Cao et al., 2024).

## 8 Conclusion

Biological control in Hangbaiju cultivation is not a single technology but a portfolio of tools that can be matched to the crop’s most sensitive windows—especially the narrow harvest period and the bloom-stage quality constraints of an edible flower. Evidence from chrysanthemum and Hangbaiju-relevant studies shows that microbial-based measures can provide meaningful disease suppression when used preventively, botanical pesticides can achieve operationally relevant reductions of aphid populations under protected cultivation, and natural enemies can substantially suppress pests such as thrips when their life cycles are strategically targeted.

Integrated approaches generally outperform single methods in robustness. The strongest designs are layered: preventive microbial management for soil and early-season health, selective botanicals when rapid suppression is necessary, and bloom-stage non-spray measures such as attractant-baited trapping to protect “clean product” outcomes. The key future direction is to translate these strategies into standardized, farmer-friendly protocols that fit local labor constraints and preserve consumer trust in Hangbaiju as an edible, health-associated product.

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