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