

Research on Biological Control Technologies and Mechanism Analysis of Common Pests and Diseases in *Chrysanthemum morifolium* (Hangbaiju)

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Abstract *Chrysanthemum morifolium* pest and disease control is ushering in a green transformation, and biological control technology has become a key solution due to its environmentally friendly characteristics. This study comprehensively sorted out the current mainstream biological control systems, covering multiple dimensions such as microbial antagonism, natural enemy regulation, botanical pesticides and ecological management, deeply analyzed their mechanisms of action and evaluated their application prospects. In the field of microbial control, *Bacillus subtilis* and *Trichoderma harzianum* have shown excellent disease inhibition capabilities. These beneficial microorganisms work through a dual mechanism: on the one hand, they secrete antimicrobial active substances to directly inhibit pathogens, and on the other hand, they activate the plant's own immune defense system. Natural enemy insects such as ladybugs and lacewings have built a natural pest control network, which has a significant control effect on common pests such as aphids and red spiders. In terms of botanical pesticides, natural ingredients such as matrine and tea tree essential oil have attracted much attention due to their broad-spectrum antibacterial and insect repellent properties. Field practice has confirmed that the integration of multiple biological control methods can produce a synergistic effect and achieve a win-win situation of economic benefits and ecological protection. This study not only provides a systematic solution for the green production of chrysanthemum, but also provides a practical example for promoting sustainable agricultural development.

Keywords *Chrysanthemum morifolium*; Biological control; Microbial agents; Natural enemy insects; Plant-derived pesticides

1 Introduction

Chrysanthemum morifolium is an important economic crop with medicinal, edible and ornamental value. Its cultivation process is often plagued by various diseases and pests (Sha et al., 2023; Lyu et al., 2024). Although traditional chemical control is effective, it has caused a series of environmental and ecological problems: increased pest resistance, destruction of beneficial biological communities and hidden dangers to agricultural product safety (Xu et al., 2021). More seriously, non-point source pollution caused by pesticide residues is threatening the stability of agricultural ecosystems (Chen et al., 2018), which has prompted researchers to turn to more sustainable green control strategies.

Biological control technology has shown unique advantages. *Bacillus siamensis* can effectively inhibit leaf spot caused by *Nigrospora oryzae* (Sha et al., 2023); volatile terpenes released by *Chrysanthemum morifolium* itself build an indirect defense network by attracting natural enemies (Xu et al., 2021). These control measures based on ecological interactions not only avoid the negative impact of chemical pesticides, but also maintain farmland biodiversity.

This study will systematically sort out the latest progress in biological control of *Chrysanthemum morifolium*, focusing on analyzing the synergistic mechanism of antagonistic microorganisms, natural enemy insects and plant-derived active substances. This study will also evaluate the field performance of different biological control factors to provide a scientific basis for the establishment of an efficient and environmentally friendly pest and disease management system, and help the sustainable development of the *Chrysanthemum morifolium* industry.

2 Overview of Common Pests and Diseases in Hangbaiju

2.1 Major diseases

Chrysanthemum morifolium is threatened by a variety of fungal diseases during cultivation. Powdery mildew is a typical airborne disease, and its typical symptoms are the formation of white powdery spots on leaves and stems. The disease is particularly rampant under warm and dry conditions, seriously affecting the normal growth and development of plants by interfering with photosynthesis and inducing leaf deformities. Fusarium oxysporum is caused by the soil-borne pathogen *Fusarium oxysporum*, which invades the root system and destroys the vascular system, resulting in characteristic leaf yellowing and wilting symptoms. The pathogen can be spread through soil, irrigation water and diseased residues, causing dwarfing or even death of plants in the field. Studies have shown that biochar improvement can effectively reduce the number of *Fusarium oxysporum* in the soil (Chen et al., 2018).

Leaf spot is another important disease with a complex pathogenic composition, including *Epicoccum sorghinum* and *Nigrospora oryzae*. The disease initially manifests as scattered necrotic spots, which merge into large brown-black patches as the disease progresses, eventually causing the leaves to curl and necrotize. High temperature and high humidity environments significantly increase the severity of the disease, posing a serious threat to yield (Chen et al., 2020; Sha et al., 2023).

2.2 Major pests

During the cultivation of *Chrysanthemum morifolium*, two typical pests often attack it. Aphids, as a representative of piercing-sucking pests, continuously suck the plant sap, causing leaf curling and growth stagnation. At the same time, as a virus transmission medium, they aggravate the degree of damage (Ji-Shuang, 2007). Its population grows exponentially under 15~25 °C conditions, with explosive damage characteristics.

Red spiders show a different damage pattern. This type of tiny mite pest destroys leaf mesophyll cells through its mouth needle, causing characteristic chlorotic spots, and in severe cases, causing leaves to scorch and fall off (Srikumar et al., 2015). It is worth noting that this pest has dual damage characteristics: in addition to damage to the aboveground part, its root infection can form typical root nodules, significantly inhibiting the absorption of water and nutrients by seedlings, causing plant development stunting. A dry environment above 28°C is particularly conducive to the rapid proliferation of its population, and the damage is particularly prominent in facility cultivation.

2.3 Damage mechanisms of pests and diseases

Various pests and diseases interfere with the normal physiological functions of *Chrysanthemum morifolium* through different pathways. After *Fusarium oxysporum* infects the plant, it selectively destroys the vascular system, blocks the transport of water and mineral nutrients, and eventually causes systemic wilting of the plant. Leaf spot disease directly damages the mesophyll tissue, significantly reducing the chlorophyll content and photosynthetic efficiency. Field observations showed that the affected plants showed typical apical wilting (Figure 1A) and leaf yellowing (Figure 1B), and the lesions showed characteristic brown necrosis (Figure 1C, Figure 1D), which directly reflected the severity of the disease.

The harm of piercing-sucking pests should not be ignored. Aphids not only cause malnutrition of plants by continuously sucking phloem sap, but also act as virus carriers to cause complex infection. Red spiders aggravate the water imbalance and metabolic disorder of plants by destroying the mesophyll cell structure. These biological stress factors work together to inhibit the growth and development of *Chrysanthemum morifolium* from multiple levels, ultimately leading to a significant decrease in yield and quality (Chen et al., 2020; Sha et al., 2023). Establishing a targeted prevention and control system is of great significance to ensuring the sustainable development of the *Chrysanthemum morifolium* industry.

3 Biological Control Technologies for Hangbaiju Pests and Diseases

3.1 Microbial control

Microbial control, as an important means of green control of *Chrysanthemum morifolium* diseases, has shown unique advantages. *Bacillus siamensis* D65 showed significant inhibitory effects on *Nigrospora oryzae*, the

pathogen of leaf spot disease (Sha et al., 2023). The strain directly inhibits the growth of pathogens by secreting antimicrobial substances, and may activate the plant defense system at the same time, with a dual control mechanism.

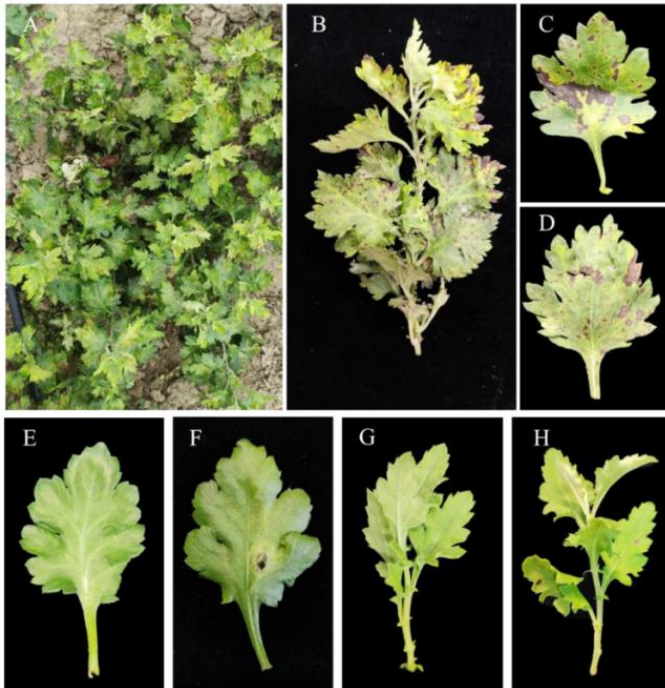


Figure 1 Symptoms of disease in *C. morifolium* and pathogenicity test (Adopted from Chen et al., 2018)

Image caption: (A) Field symptoms; (B) Diseased branches near the top of the chrysanthemum; (C,D) Symptoms of leaf spot disease; (E) Leaf 5 days after inoculation with sterile PDA plug; (F) Leaf 5 days after artificial inoculation; (G) Branch before inoculation; (H) Branch 7 days after inoculation (Adopted from Chen et al., 2018)

Bacillus bacteria have broad application prospects in plant disease control. Studies have shown that *B. siamensis* D65 exhibits broad-spectrum antagonistic activity against a variety of plant pathogenic fungi, which provides a scientific basis for its application in the comprehensive control of *Chrysanthemum morifolium* diseases. In addition, soil improvement measures such as biochar application can effectively reduce the population density of *Fusarium oxysporum* (Chen et al., 2018). This strategy of controlling soil-borne diseases by regulating soil microbial communities provides a new idea for the ecological control of *Chrysanthemum morifolium* wilt.

Microbial pesticides are gradually replacing traditional chemical pesticides. The discovery and application of highly effective antagonistic strains such as *B. siamensis* D65 marks a new stage in the control of *Chrysanthemum morifolium* diseases dominated by microbial regulation (Sha et al., 2023). This type of biological agent not only has significant control effects, but is also environmentally friendly and not prone to inducing drug resistance, which meets the requirements of sustainable development of modern agriculture.

3.2 Natural enemy insect control

Predatory natural enemies such as ladybugs and lacewings have shown significant effects in the control of aphids in *Chrysanthemum morifolium*. These natural enemies can effectively control the density of aphid populations and reduce the degree of plant damage through direct predation (Zhang et al., 2019). Although there are few studies on the application of predatory mites on *Chrysanthemum morifolium*, their successful practice in integrated pest management provides a reference for their application.

3.3 Plant-derived pesticides and natural product control

Botanical pesticides are widely valued for their natural insecticidal activity and are gradually becoming a sustainable alternative to synthetic chemical pesticides. Although no plant extracts specifically for *Chrysanthemum morifolium* have been clearly applied to pest control, the potential of botanical substances in

green agriculture is being explored, and the research on this topic continues to rise. When attacked by herbivorous insects such as *Spodoptera litura*, *Chrysanthemum morifolium* can release a series of bioactive volatile terpenoid compounds. This defense response is a typical indirect mechanism that relies on attracting natural enemy insects to participate in regulation (Mouden et al., 2020).

These plant volatiles mainly include monoterpenes and sesquiterpenes, and their synthesis is usually triggered by insect feeding behavior, playing an important role in resisting external biological stress. Related studies have further confirmed that this type of compound is highly specific and time-effective in the defense strategy of *Chrysanthemum morifolium* (Xu et al., 2021). This natural product-based control pathway is providing new theoretical support and practical direction for building a more eco-friendly pest and disease management system.

3.4 Trapping and exclusion techniques

Pheromone trapping technology provides a new idea for pest control of *Chrysanthemum morifolium*. Based on the specific attraction mechanism of sex pheromones, this technology can accurately trap and kill target pests (Staton and Williams, 2023). Although there are few studies specifically on *Chrysanthemum morifolium*, its successful application in other crops has laid the foundation for technology transplantation.

Physical isolation measures show multiple control benefits. Insect nets effectively reduce insect population density through mechanical barriers, while mulching has multiple functions of suppressing weeds, conserving moisture, and blocking underground pests (Wipfli et al., 2017). Such non-chemical methods significantly reduce the demand for pesticide use.

3.5 Ecological regulation and crop rotation techniques

Field ecological regulation achieves natural pest control through biodiversity enhancement. Volatile terpenes released by *Chrysanthemum morifolium* can form a "chemical ecological defense line" to attract natural enemies to control pest populations (Xu et al., 2021). This ecological network based on plant-insect interactions provides a new paradigm for sustainable control.

Crop rotation and intercropping systems effectively block the cycle of pests and diseases. Reasonable crop rotation significantly reduces the accumulation of soil-borne pathogens and pests in the field (Xiao et al., 2015). Selective intercropping enhances the control effect through allelopathic effects and improves the soil microecological environment (Wang et al., 2022). These agronomic measures organically combine pest and disease control with soil health management to promote the sustainable development of cropping systems.

4 Mechanisms of Biological Control in Hangbaiju Pests and Diseases

4.1 Mechanisms of microbial control

Rhizosphere microorganisms of *Chrysanthemum morifolium* achieve disease control through multiple mechanisms. The application of rice straw biochar significantly changed the composition of soil microbial communities, increasing the abundance of beneficial bacteria and actinomycetes, while causing a 42.4%-54.4% decrease in the population of *Fusarium oxysporum* (Chen et al., 2018). This reconstruction of the microbial flora mainly works through the following pathways:

First, nutrient and spatial competition constitute the first line of defense. Beneficial microorganisms consume the nutrient resources required for the growth of pathogens by quickly occupying ecological sites. Second, metabolite inhibition plays a key role. Antimicrobial substances secreted by antagonistic bacteria directly interfere with the physiological activities of pathogens. More importantly, biochar treatment can also activate the plant immune system and induce systemic resistance. This "microbe-plant" interaction mechanism is ultimately reflected in the significant improvement of the yield and quality of *Chrysanthemum morifolium* (Chen et al., 2018).

The ecological balance of microbial communities is crucial for disease control. When beneficial microorganisms become the dominant population, they can not only directly inhibit pathogens, but also provide dual protection by inducing plant disease resistance. This prevention and control strategy based on microecological regulation provides a new idea for the control of soil-borne diseases of *Chrysanthemum morifolium*.

4.2 Ecological control mechanisms of natural enemy insects

Chrysanthemum morifolium exhibits highly specialized ecological defense mechanisms when facing pest infestations. When the larvae of the *Spodoptera litura* feed on its leaves, they induce the plant to release a series of complex volatile terpenoids (Xu et al., 2021). These herbivore-induced plant volatiles (HIPVs) not only have significant chemical recognition functions, but can also attract predatory or parasitic natural enemies to intervene at a long distance. Through the transmission of this chemical signal, *Chrysanthemum morifolium* builds a three-trophic-level interaction network covering the plant itself, pests and their natural enemies, showing a coordinated and efficient natural defense strategy.

This chemical communication mechanism has multiple regulatory effects on the ecological balance in the field. Volatile terpenes not only directly enhance the search efficiency of natural enemies, but also indirectly affect population dynamics by changing pest behavior. The continuous predation pressure of natural enemy insects significantly reduces pest density and reduces the degree of plant damage (Xu et al., 2021). This natural pest control mechanism based on chemical ecology provides important inspiration for the green prevention and control of *Chrysanthemum morifolium* pests.

4.3 Mechanisms of plant-derived pesticides

The endophytic microbial community carried by *Chrysanthemum morifolium* can synthesize a variety of metabolites with disease resistance, showing good pathogen inhibition potential. Studies have shown that the dominant strain distributed in the leaf sphere, *Bacillus siamensis* D65, can secrete compounds with antibacterial activity, effectively inhibiting the growth and infection of the leaf spot pathogenic fungus *Nigrospora oryzae* (Sha et al., 2023). This plant-microbe interaction system provides important materials for the development of new green pesticides based on endophytes.

At the molecular level, the application of genetic engineering has significantly enhanced the insect resistance of *Chrysanthemum morifolium*. Studies have shown that after the introduction and high expression of the pyrethroid synthase gene (TcCHS), the plant can stably accumulate pyrethroid alcohol and its glycoside form, thereby producing a dual inhibitory effect on the feeding behavior of aphids through a chemical interference mechanism (Hu et al., 2018). At the same time, the introduction of the TcEbFS gene enables the plant to synthesize (E)- β -farnesene (PEE), which can simulate the warning pheromone of aphids and has a significant repellent function. Further experimental observations found that PEE-8 transgenic plants showed a strong repellent effect on aphids in the S1 development stage, while this defense ability was significantly weakened in the S2 stage (Figure 2), indicating that the accumulation of this type of volatile substances has stage-specific regulatory characteristics (Li et al., 2024).

These research results not only reveal the molecular mechanism of chrysanthemum's natural defense, but also provide theoretical support for the construction of an integrated pest management strategy based on temporal regulation.

4.4 Molecular mechanisms of induced plant resistance

Chrysanthemum morifolium establishes a multi-level resistance system by finely regulating defense signaling pathways. Salicylic acid (SA) and jasmonic acid (JA) signaling pathways constitute the core defense network, which respond to different types of biological stresses. When attacked by herbivorous insects, the JA signaling pathway is rapidly activated, triggering the synthesis and release of volatile terpenoids (Xu et al., 2021). These volatile organic compounds, as chemical signals, can recruit natural enemy insects from a distance to form an indirect defense.

Chrysanthemum morifolium exhibits a complex and highly regulated defense response when responding to pathogen infection. Studies have shown that dodder parasitism can simultaneously induce the activation of two key signaling pathways, salicylic acid (SA) and ethylene (ET) (Liu et al., 2021), reflecting the ability of plants to flexibly adjust their response strategies according to different types of adversities. This synergy and interaction mechanism between signaling pathways constructs a sophisticated and dynamic defense regulatory network,

enabling *Chrysanthemum morifolium* to initiate specific immune responses in the face of diverse stresses. The elucidation of this mechanism not only expands the understanding of the plant disease resistance process, but also clarifies several molecular intervention points with potential breeding value, providing theoretical support and gene target basis for the subsequent molecular breeding of disease-resistant varieties.

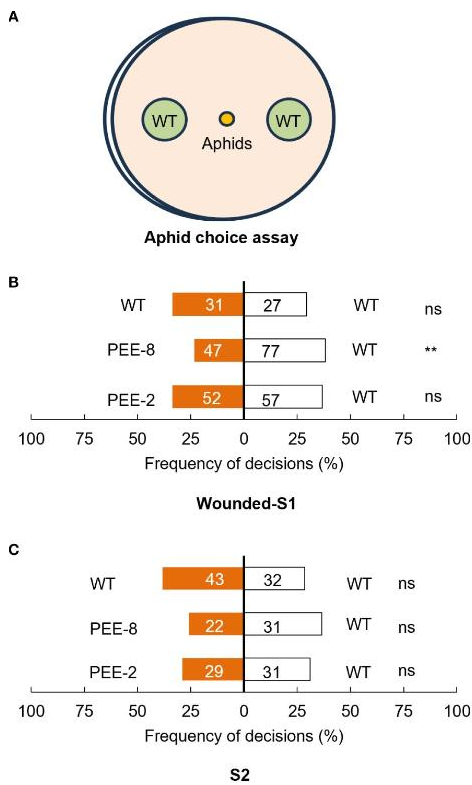


Figure 2 Choice behavior assay of aphids for wounded S1 and intact S2 flowers of transgenic and wild type chrysanthemum plants (Adopted from Li et al., 2024)

Image caption: (A) Illustration of aphid choice behavior experiment. (B) Olfactometer choices of cotton aphids in response to wounded S1 of transgenic and wild type chrysanthemum plants. (C) Olfactometer choices of cotton aphids in response to intact S2 flowers of transgenic and wild type chrysanthemum plants (paired t-test, **, $P < 0.01$; ns, not significant). Each bars represent the percentage of aphids that made a choice within 5 minutes after release. The number on the bar represent number of aphids in total (Adopted from Li et al., 2024)

5 Case Studies of Biological Control in Hangbaiju

5.1 Powdery mildew control

The synergistic application of *Trichoderma* and *Bacillus subtilis* provides a new idea for the prevention and control of powdery mildew in *Chrysanthemum morifolium*. Studies have shown that *Trichoderma* strains significantly inhibit the growth of powdery mildew fungi through heavy parasitism and nutrient competition (Omomowo et al., 2018). At the same time, *Bacillus subtilis* can secrete a variety of antibacterial substances and activate the plant's system to acquire resistance (Yang et al., 2023).

The combined action of the two biocontrol strains can not only effectively block the transmission path of pathogens, but also induce the plant to activate its own defense mechanism, thereby improving the disease resistance of *Chrysanthemum morifolium*. With the help of multiple prevention and control paths, this composite microbial preparation has shown excellent prevention and control results in field applications. At the same time, this prevention and control strategy can also optimize the rhizosphere microecological environment, providing a healthier and more stable growth foundation for the plant.

5.2 Integrated biological control of aphids

A multi-pronged biological strategy is used to control aphids in *Chrysanthemum morifolium*. Extracts of neem and pyrethrum are used as botanical pesticides to selectively suppress aphid populations without affecting natural

enemy insects. When aphids feed, *Chrysanthemum morifolium* releases specific volatiles (HIPVs), forming chemical signals to attract natural enemies such as ladybugs and parasitic wasps (Xu et al., 2021). This three-level interaction network of "plant-pest-natural enemy" significantly improves the control effect.

Grafting technology provides a new way to control aphids. After chrysanthemum was grafted with *Artemisia capillaris*, the expression of defense-related genes was upregulated and insect resistance was significantly enhanced (Figure 3) (Zhang et al., 2019). The aphid density of the Cm/As grafted combination was significantly lower than that of the self-grafted control group, confirming the effectiveness of the technology. This integrated strategy of chemical ecology and genetic improvement maintains the stability of the farmland ecosystem while controlling insect pests.

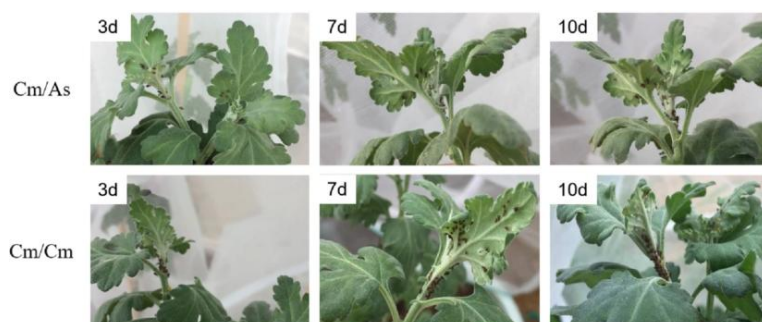


Figure 3 Representative pictures for aphid settlement at 3 d, 7d and 10d after aphid inoculation on selfrooted grafted chrysanthemum (Cm / Cm) and the grafted Artemisia-chrysanthemum (Cm / As) (Adopted from Zhang et al., 2019)

5.3 Red spider mite control

As an important natural enemy of red spider mites, predatory mites can significantly suppress pest populations after being released in the field, showing excellent biological control potential (Escudero and Ferragut, 2005). By adjusting the ecological environment of farmland, such as introducing protective plants and improving vegetation diversity, the settlement stability and diffusion efficiency of predatory mites can be effectively improved. This type of control strategy with ecological regulation as the core can help maintain the dynamic balance of farmland ecosystems while reducing dependence on pesticides (Wang et al., 2024).

5.4 Successful practices of integrated pest management (IPM)

The integrated pest management (IPM) model used in *Chrysanthemum morifolium* cultivation has shown significant advantages. The system integrates a number of biological control technologies: the rational use of natural enemy insects, the breeding of plant resistant varieties, and the optimization and regulation of field ecology. Studies have shown that the volatile terpenoids released by chrysanthemums when they are infested can effectively attract natural enemies (Xu et al., 2021); the application of grafting technology significantly improves the resistance of plants to aphids (Zhang et al., 2019).

This multi-technical integrated control strategy not only enhances the effect of pest control, but more importantly, maintains the ecological balance of farmland by reducing the input of chemical pesticides. Practice has proved that the IPM model provides a reliable guarantee for the sustainable development of the *Chrysanthemum morifolium* industry and achieves a win-win situation of economic and ecological benefits.

6 Challenges and Limitations of Biological Control Technologies

6.1 Stability issues in field applications

In actual planting environments, the effects of biological control methods are often interfered by multiple external variables and show strong uncertainty. For example, although biochar has the potential to regulate soil microecology and inhibit pathogenic fungi such as *Fusarium oxysporum*, its efficacy fluctuates due to factors such as application method, climatic conditions and soil type (Chen et al., 2018). In addition, the mechanism of *Chrysanthemum morifolium* to release herbivore-inducing plant volatiles (HIPVs) to attract natural enemies is highly dependent on the integrity of the surrounding ecosystem (Xu et al., 2021). Once the ecological chain is

unstable, the effectiveness of this defense mechanism may be weakened. This environmental sensitivity has become the main bottleneck restricting the stability of biological control effects.

6.2 Technical costs and promotion barriers

In the practice of *Chrysanthemum morifolium* cultivation, the promotion of biological control technology still faces dual challenges at the economic and technical levels. On the one hand, although biochar has significant effects in improving soil structure and enhancing soil microbial activity (Chen et al., 2018), its high production cost and application threshold make it difficult for most small and medium-sized farmers to adopt it on a large scale. On the other hand, the screening, propagation and precise field delivery of efficient strains such as *Bacillus* D65 usually rely on supporting professional equipment and technical systems. Under the condition of limited technical resources, this undoubtedly raises the threshold for farmers to adopt it, thereby restricting the popularization and implementation of such technologies.

6.3 Lack of systematic control strategies

The current practice of biological control of *Chrysanthemum morifolium* has obvious fragmentation characteristics. Although single measures such as biochar improvement and grafting technology have been proven to enhance plant resistance (Chen et al., 2018; Zhang et al., 2019), there is a lack of organic integration between the various technologies. This fragmented application mode makes it difficult to maintain a stable control effect, and it is urgent to establish a systematic integrated management plan.

6.4 Resistance and coexistence issues

In biological control practice, long-term single application of specific control measures may trigger adaptive responses. Pathogen populations can evolve to adapt to the continuous use of antagonistic strains or biochar treatments, resulting in a gradual decrease in control effectiveness (Duan et al., 2017; Barbosa et al., 2018; Sun et al., 2019). This phenomenon also exists in plant-insect interaction systems. The defense strategy of *Chrysanthemum morifolium* to attract natural enemies through volatile terpenoids may also fail due to the adaptive evolution of pests (Xu et al., 2021).

More complicated is that some pest populations can establish a dynamic balance with control measures. This "ecological adaptation" phenomenon is manifested in maintaining a certain population size under control pressure (Zhang et al., 2019). To meet these challenges, it is necessary to develop a multi-target, rotating integrated control system, and maintain long-term and stable control effects by strategically combining biological control methods with different mechanisms of action.

7 Future Directions and Prospects

7.1 Integration of multi-technologies and comprehensive control

In the future, pest and disease management of *Chrysanthemum morifolium* will tend to be an integrated prevention and control model integrating multiple technologies. Integrating biological control methods such as natural enemy insect regulation, microbial antagonism and plant-derived active substances can establish an efficient ecological prevention and control network. Studies have shown that the HIPVs released by *Chrysanthemum morifolium* when attacked by *Spodoptera litura* can specifically attract natural enemies (Xu et al., 2021). This ecological defense mechanism can be used in conjunction with biochar soil improvement technology. Biochar can not only improve the soil environment, but also significantly inhibit soil-borne pathogens such as *Fusarium oxysporum* (Chen et al., 2018), providing a new idea for building an above-ground-underground coordinated prevention and control system.

7.2 Application of molecular biology techniques

Molecular biology technology is driving the disease-resistant breeding of *Chrysanthemum morifolium* into the era of precision. Through targeted gene regulation, researchers can accurately enhance plant resistance. Transcriptome analysis of the grafting system identified multiple differentially expressed stress response genes (Zhang et al., 2019), providing key targets for molecular marker-assisted breeding. At the same time, the analysis of key enzyme genes in the terpene volatile synthesis pathway (Xu et al., 2021) laid a molecular foundation for activating the

natural defense mechanism of plants. With the maturity of gene editing technology, *Chrysanthemum morifolium* resistance breeding is moving towards a more efficient and precise direction.

7.3 Combining biological control with precision agriculture

The integration of modern information technology and traditional biological control has created a new model for pest and disease management. The intelligent monitoring system collects environmental data in real time through a sensor network and combines AI algorithms to predict the trend of pest and disease occurrence. This technology not only optimizes the application scheme of antagonistic strains (such as *Bacillus siamensis*) (Sha et al., 2023), but also dynamically adjusts the natural enemy release strategy (Zhang et al., 2019). Data-driven precision control has greatly improved management efficiency and provided a new paradigm for sustainable agricultural production (Chen et al., 2018).

7.4 Building eco-friendly pest and disease management systems

Eco-friendly control requires multi-technical collaborative innovation. The application of biochar has shown multiple benefits: improving soil structure, enhancing microbial diversity, and inhibiting soil-borne diseases (Chen et al., 2018). Highly effective antagonistic strains such as *Bacillus siamensis* have a significant inhibitory effect on leaf spot pathogen (*Nigrospora oryzae*) (Sha et al., 2023), providing a new option for green control. Combined with intelligent monitoring technology, these measures have constructed a full-process control chain of "monitoring-early warning-intervention" (Xu et al., 2021), which not only ensures production safety but also maintains ecological balance.

8 Concluding Remarks

In recent years, *Chrysanthemum morifolium* has made many breakthroughs in biological control of diseases and insect pests. As an efficient soil conditioning material, biochar not only improves the physical and chemical properties of the soil, but also has a positive impact on the structure of the microbial community, showing a significant effect in inhibiting soil-borne pathogens such as *Fusarium oxysporum*. This type of ecological regulation method has shown unique advantages in promoting yield increase and quality improvement.

Chrysanthemum morifolium exhibits unique defensive characteristics when dealing with pest attacks. When the larvae of the *Spodoptera litura* feed on the leaves, the plants release specific volatile terpenes, which can accurately attract natural enemy insects and form a natural biological defense network. This defense mechanism based on chemical ecology provides a new idea for pest control. In terms of cultivation technology innovation, the grafting combination of *Chrysanthemum morifolium* and *Artemisia capillaris* shows significant advantages. This technology not only improves the growth potential of the plant, but also enhances its resistance to aphids, demonstrating the application potential of plant resistance induction technology.

Based on this kind of research foundation, a multi-dimensional integrated biological control system is gradually replacing the traditional management method that relies on chemical agents. By integrating plant innate immune regulation, soil microecological regulation and genetic improvement of excellent varieties, this system effectively alleviates the dependence on external inputs in agricultural production, and also plays a positive role in reducing pesticide residues and food safety risks.

Future research will focus on three key directions: in-depth analysis of defense-related gene regulatory networks, optimization of biochar application technical parameters, and development of new resistant variety breeding technology. The systematic integration of these technologies will promote the transformation of *Chrysanthemum morifolium* cultivation to an environmentally friendly model. Through the collaborative innovation of molecular biology and ecological control, it is expected to establish a more efficient and environmentally friendly *Chrysanthemum morifolium* production system, providing solid technical support for the realization of sustainable agricultural development.

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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.

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