

Protected Strawberry Cultivation Research Center

**Agricultura Measures and Soil Disinfection for
Protected Strawberry**

Author: Li Zhengxuan

Affiliation: Shijiazhuang Foreign Language School

Contact: 23054434@qq.com

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Control and Application of Soil-borne Diseases

Abstract: Strawberry is one of the more popular fruits on the market and one of the pillars of agricultural production in Baoding City. To address the current situation of soil-borne diseases in strawberry production, this project adopted agricultural measures such as the incorporation of strawberry residues and the crushing and returning of cover crops to the field. These were combined with four soil disinfection treatments: physical film mulching and greenhouse fumigation, biological reduction methods, the chemical agent dazomet, and the Zhongshu Genbao 401 disinfection combination (a mix of the chemical agents amobam, thiazophos, and humic acid). These measures effectively controlled soil-borne diseases, addressed challenges such as field sanitation and the transportation and disposal of strawberry residues, and improved the quality and yield of protected strawberries, meeting market demand while increasing farmers' income.

Keywords: Protected strawberry; Soil-borne diseases; Residue incorporation; Control efficacy

Strawberry (*Fragaria ananassa* Duch) is a perennial herbaceous plant with high economic value. At present, China has become the world's largest producer and consumer of strawberries, and strawberry cultivation has become a pillar industry in many regions. However, protected strawberry cultivation faces challenges such as low temperature, high humidity, low light, and a relatively closed greenhouse microclimate, as well as issues like year-round production and continuous cropping. These factors exacerbate the obstacles of continuous cropping and intensify soil-borne diseases, severely affecting the healthy development of the strawberry industry[1].

1. Overview of Soil-borne Disease Control in Protected Strawberry Cultivation

1.1 Protected Strawberry

Strawberry production includes two cultivation methods: conventional open-field cultivation and the newer protected cultivation. Open-field cultivation relies on natural climatic conditions, which are highly variable and limit production seasons, making it difficult to fully meet market demand. To address this, protected strawberry cultivation was developed.

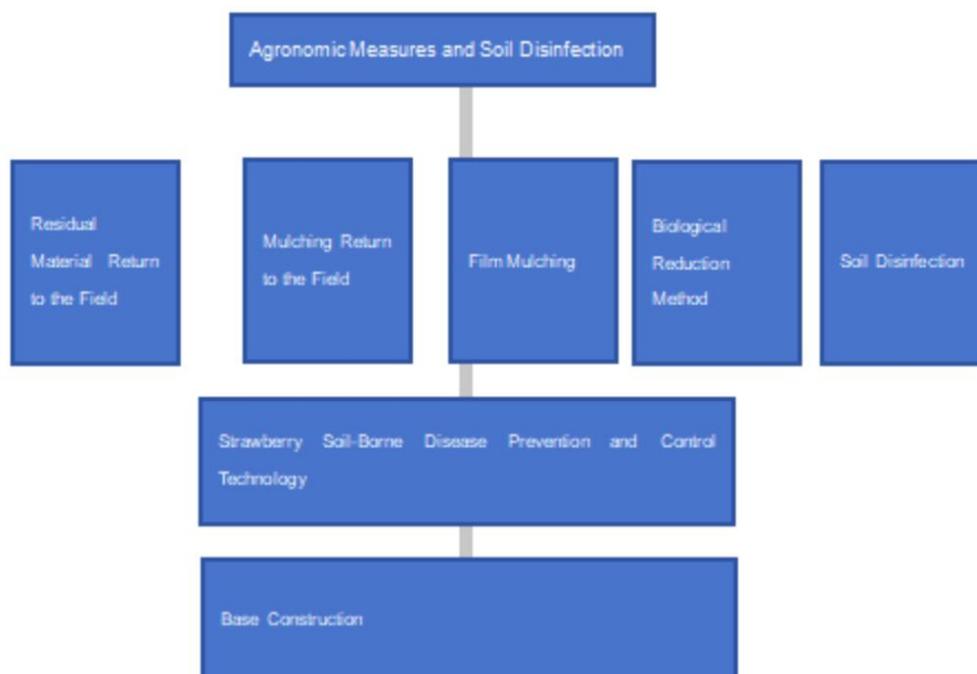
Protected strawberry cultivation uses protective facilities such as greenhouses and tunnels to regulate environmental conditions, ensuring optimal growth and even enabling production during winter. Compared to traditional open-field cultivation, protected cultivation offers more advantages, such as lower costs, ease of operation, and higher

land utilization efficiency, making it widely adopted in strawberry production.

1.2 Soil-borne Diseases

Soil-borne diseases are caused by pathogens (e.g., fungi, bacteria) that survive, reproduce, and spread through the soil, infecting plants. These diseases pose serious threats to agricultural production worldwide, especially in strawberry-growing regions with high replanting intensity. In long-term monoculture greenhouses, the incidence of soil-borne diseases in strawberries typically ranges from 5% to 12% in normal years and can reach 20% to 35% in severe years, with seedling mortality as high as 30%. Effectively controlling these diseases has become a major challenge for strawberry growers.

Current methods to address soil-borne diseases in protected strawberries include straw incorporation, cover crop incorporation, film mulching and greenhouse fumigation, biological reduction methods, and chemical fumigation. However, the efficacy of these measures in mitigating continuous cropping obstacles remains unclear. This project explored the incorporation of strawberry residues and cover crops combined with different soil disinfection treatments to analyze their effects on soil-borne diseases and nematodes, providing a reference for soil-borne disease control in protected strawberries.



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2. Soil-borne Disease Control Technologies and Research

2.1 Soil-borne Disease Control System

Integrating the characteristics of protected strawberry cultivation, a comprehensive soil-borne disease control system was developed, incorporating residue incorporation, cover crop incorporation, and soil disinfection technologies.

Straw is a renewable organic resource. Straw incorporation increases soil organic matter and fertility, improves soil quality, and enhances crop yield[2]. Additionally, it reduces greenhouse gas emissions and environmental pollution caused by straw burning and lowers the costs associated with straw removal.

The root exudates of cover crops inhibit soil pathogens and increase microbial diversity[3], providing a favorable environment, materials, and energy for soil microorganisms, thereby enhancing microbial activity and soil ecological functions. The long summer fallow period in strawberry fields allows for the planting of cover crops for ecological restoration[4].

Film mulching and greenhouse fumigation are also effective techniques for overcoming continuous cropping obstacles in protected vegetable cultivation, significantly reducing root-knot nematode damage and diseases such as root rot and blight caused by soil-borne pathogens[5].

The biological reduction method involves adding easily decomposable organic carbon sources to the soil, followed by irrigation and film mulching to create an anaerobic environment. Soil microorganisms utilize the carbon sources to produce toxic byproducts that suppress soil-borne pathogens while altering microbial community structures, thereby effectively controlling pests and diseases[6].

The chemical agent dazomet is an efficient, low-toxicity, and residue-free broad-spectrum soil fumigant. When applied to moist soil, dazomet decomposes into toxic methyl isothiocyanate, formaldehyde, and hydrogen sulfide, which diffuse rapidly between soil particles, effectively killing nematodes, pathogens, underground pests, and weed seeds, thereby sterilizing the soil[7].

The Zhongshu Genbao 401 disinfection combination includes the chemical agents amobam and thiazophos, commonly used fungicides and nematicides in agriculture[8-9].

Humic acid fertilizer, produced through chemical processing or blending with inorganic fertilizers, loosens soil, increases soil temperature, and provides nutrients for crops, primarily used in high-value cash crops[10].

2.2 Research

2.2.1 Test Materials

The strawberry variety tested was 'Christmas Red,' a major cultivar in Baoding City.

Six cover crops were used, with seed sowing ratios as follows: pyrethrum (36%), rye

(17%), sweet clover (10%), rapeseed (22%), buckwheat (8%), and okra (7%).

Four soil disinfection treatments were applied:

- Treatment 1: Zhongshu Genbao 401 disinfection combination.
- Treatment 2: Biological reduction method, using 75% malt syrup, 1 billion cfu/g *Trichoderma harzianum* water-dispersible granules, 10 billion cfu/g *Bacillus subtilis* wettable powder, and 5 billion cfu/g *Pseudomonas fluorescens* wettable powder, with a mass ratio of 40:8:9:20.
- Treatment 3: Dazomet, applying 98% dazomet granules.
- Treatment 4: Film mulching and greenhouse fumigation, using 0.04 mm PE film for soil fumigation.

2.2.2 Experimental Design

The experiment was conducted at Jiahe Farm Strawberry Garden in Qingyuan District, Baoding City, with a five-year planting history and medium soil fertility.

The experiment included four treatments (Table 1) and a blank control, arranged in a randomized block design with three replicates per treatment, totaling 15 plots of 38 m² each. Strawberry residues were crushed and incorporated on May 8. Cover crops were sown on May 14 and crushed and incorporated on June 23. Soil disinfection treatments were applied on July 10, and planting was conducted on August 30.

Agricultural Practices	Soil Disinfection	Dosage and Usage (667m ²)
1 The strawberry residues were returned to the field. The covering crops were sown at 360kg/hm ² and crushed and returned to the field after 45 days	Zhongshu Genbao 401	6.1kg of Genbao 401 [(containing humic acid water-soluble fertilizer +45% diosinamide AS 20%+ thiazolophosphine AS in a volume ratio of 50:1:10] is mixed with 14.8kg of water as the mother liquor and evenly applied with a large amount of water until the maximum holding capacity in the field reaches 60%. After application, the ground film is tightly sealed and the greenhouse film is closed, and the greenhouse is sealed for 10 to 15 days
2	Biological method	reduction 75% malt syrup 400 kg/667m ² , 100 million cfu/g <i>Trichoderma harzianum</i> WG 80 g/667m ² , 1 million CFU/g <i>Bacillus subtilis</i> WP 90g, 500 million cfu/g <i>Pseudomonas fluorescens</i> WP 200g, diluted 300 times, drip irrigated and then covered with film and sealed in a greenhouse for 15 to 20 days
3	Mylone	After land preparation, water to maintain soil moisture. Apply 25kg of 98% cotton loner per 667 square meters by scattering. After uniform rotary tillage with a rotary tiller, cover with film and seal for more than 20 days
4	Cover with film and seal the greenhouse	After deep ploughing and land preparation on July 10th, organic fertilizers and other substances should be turned into the ground and irrigated with a large amount of water. The soil moisture content should be 60% of the maximum water holding capacity in the field. Cover with plastic film and greenhouse film to maintain airtightness and keep the greenhouse sealed for 15 to 20 days. The maximum soil temperature at 10cm below the surface can be 70°C, and at 20cm, it is above 45°C
CK		

2.2.3 Survey Methods

(1) Inhibition of Strawberry Pathogen Activity

On August 20, soil samples (1000 g) were collected from each treatment area using a five-point sampling method to isolate and detect *Fusarium*, *Pythium*, *Phytophthora*,

and nematodes[11-14]. Pathogen inhibition rate (%) = [(Pathogen count in control - Pathogen count in treatment) / Pathogen count in control] × 100.

(2) Control Efficacy Against Strawberry Diseases

The control efficacy of different treatments against strawberry root rot and blight was investigated. Disease incidence was surveyed three times, starting from the first harvest, at 30-day intervals. The first survey was conducted on October 8. Five points per plot were surveyed, with 20 plants per point, and the number of infected plants was recorded. Disease incidence (%) = (Number of infected plants / Total plants surveyed) × 100. Control efficacy (%) = [(Disease incidence in control - Disease incidence in treatment) / Disease incidence in control] × 100.

2.2.4 Results and Analysis

(1) Inhibition of Soil Pathogens by Different Treatments

The combination of strawberry residue and cover crop incorporation with different soil disinfection treatments showed varying effects on pathogen inhibition. As shown in Table 2, the inhibition rates for the four soil pathogens, in descending order, were: dazomet > Zhongshu Genbao 401 > biological reduction method > film mulching and greenhouse fumigation. Significant differences were observed in the inhibition of Pythium. Dazomet showed significantly higher inhibition rates for Fusarium, Phytophthora, Pythium, and nematodes compared to Zhongshu Genbao 401 and the biological reduction method. Zhongshu Genbao 401 and the biological reduction method showed no significant differences in inhibiting Fusarium, Phytophthora, and nematodes, but Zhongshu Genbao 401 was significantly more effective against Pythium. Film mulching and greenhouse fumigation had significantly lower inhibition rates for the three pathogens and nematodes compared to the other treatments.

Management	Inhibitory effect (%)			
	Fusarium solani	phytophthora	Pythium	nematode
Zhongshu Genbao 401	(80.77±2.24)b	(82.57±3.29)b	(75.62±3.54)b	(65.77±5.56)ab
Biological reduction method	(78.59±23.99)b	(80.88±1.01)b	(68.60±3.53)c	(70.22±8.59)ab
dazomet	(92.29±3.71)a	(95.87±2.904)a	(94.63±1.82)a	(74.51±8.09)a
Cover with film and seal the greenhouse	(59.41±3.92)c	(63.73±3.53)c	(59.61±1.07)d	(56.98±6.88)b

Note: Values are mean \pm standard deviation; different lowercase letters in the same column indicate significant differences ($p < 0.05$).

(2) Control Efficacy Against Strawberry Soil-borne Diseases

The combination of strawberry residue and cover crop incorporation with different soil disinfection treatments showed varying effects on disease incidence and control efficacy (Table 3). For root rot, dazomet had the lowest incidence; for blight, dazomet and Zhongshu Genbao 401 had the lowest incidence, followed by the biological reduction method and film mulching. All four treatments showed some efficacy against root rot and blight, with Zhongshu Genbao 401 and dazomet being the most effective, showing no significant differences between them but significantly outperforming the other two treatments. These results indicate that incorporating strawberry residues and cover crops, followed by dazomet or Zhongshu Genbao 401 treatment, can effectively control root rot and blight.

Table 3: Prevention Effect of Different Agricultural Measures and Soil Disinfection Treatments on Strawberry Soil-borne Diseases

Treatment	Disease Incidence (%)		Control Effect (%)	
	Root Rot	Phytophthora	Root Rot	Phytophthora
Zhongshu Genbao 401	(4.70 \pm 0.58)bc	(3.15 \pm 0.27)c	(76.23 \pm 1.61)a	(76.80 \pm 3.36)a
Bioremediation Method	(6.27 \pm 0.30)bc	(4.82 \pm 0.41)bc	(67.98 \pm 4.72)b	(64.54 \pm 4.04)b
Melon Granules	(3.53 \pm 0.32)c	(3.28 \pm 0.25)c	(82.05 \pm 2.12)a	(75.85 \pm 3.08)a
Mulching and Tunneling	(7.71 \pm 0.27)b	(6.51 \pm 0.44)b	(60.57 \pm 6.41)b	(52.04 \pm 6.54)c
CK	(19.96 \pm 3.73)a	(13.79 \pm 2.53)a	-	-

Note: Values are mean \pm standard deviation; different lowercase letters in the same column indicate significant differences ($p < 0.05$).

(3) Effects on Strawberry Growth

Different treatments had varying effects on strawberry growth (Table 4). In terms of vegetative growth (stem thickness and plant height), no significant differences were observed among treatments, but dazomet-treated plants outperformed the control. For reproductive growth, dazomet-treated plants had the highest fruit count, with all treatments significantly outperforming the control. Dazomet also produced the most fruit forks, followed by Zhongshu Genbao 401 and the biological reduction method. These results indicate that incorporating strawberry residues and cover crops, followed by dazomet, Zhongshu Genbao 401, the biological reduction method, or film mulching, can enhance strawberry fruiting potential, with dazomet also promoting vegetative growth.

Treatment	Stem Thickness (mm)	Plant Height (cm)	Fruit Number	Fruit Fork Number
Zhongshu Genbao 401	(13.17±0.35)ab	(27.37±0.45)ab	(2.73±0.12)b	(6.83±0.25)ab
Biological Reduction Method	(12.63±1.27)ab	(27.20±1.39)ab	(2.77±0.15)b	(6.80±0.26)ab
Melon	(14.03±0.75)a	(28.43±1.07)a	(3.00±0.10)a	(6.93±0.15)a
Film Mulching Greenhouse	(12.57±0.80)ab	(26.93±0.74)ab	(2.70±0.10)b	(6.40±0.20)bc
CK	(12.96±0.91)b	(26.10±0.80)b	(2.47±0.15)c	(6.17±0.31)c

Note: Values are mean ± standard deviation; different lowercase letters in the same column indicate significant differences ($p < 0.05$).

3. Application of Soil-borne Disease Control Technologies in Protected Strawberries

The strawberry industry in Baoding City has steadily developed, with planting area and yield increasing from 2017 to 2024. In 2024, the planting area reached 6,900 hectares, with a yield of 153,000 tons. The primary cultivation method was solar greenhouse forcing, representing a 26.1% increase in production area and a 51.1% increase in total yield compared to 2017. The proportion of soil-borne disease control measures increased by 55%.

The combination of agricultural measures and soil disinfection increased soil organic matter content, improved soil looseness, aeration, and water retention, and effectively killed soil pathogens. Beneficial microbial populations increased, leading to a more balanced soil microbial community and enhanced plant disease resistance. The incidence of soil-borne diseases decreased from 30% to below 10%. Seedlings grew more robustly, with well-developed root systems, improved stress resistance, shorter recovery times, and higher survival rates. Fruit quality and yield significantly improved. A comparison between fields with and without soil-borne disease control is summarized below:

Comparison of Plant Growth Conditions

Indicator	Soil-Borne Disease Control Group	Uncontrolled Group
Root Health	Well-developed roots, high proportion of white roots (>70%)	Root browning, decay (root rot rate >30%)
Leaf Status	Thick and green leaves, high leaf area index	Yellowing, spot disease (incidence rate >50%)
Plant Height and Stem Thickness	Plant height 20-25 cm, sturdy stem thickness	Plant height <15 cm, weak stem
Disease Incidence Rate	Soil-borne disease incidence rate <10%	Soil-borne disease incidence rate >50%

Comparison of Yield and Fruit Quality

Table 6 Comparison of Yield and Fruit Quality

Indicator	Soil-borne Disease Control Group	Non-Control Group
Per Plant Yield	300-400g/plant	150-200g/plant, 30%-50% yield reduction
Marketable Fruit Rate	≥80% (uniform fruit shape, no畸形)	≤50% (deformed fruit, small fruit)
Sugar Content	8%-12% (sweet taste)	6%-8% (sour and astringent taste)
Vitamin C Content	40-60mg/100g	20-30mg/100g (nutrient decline)

Economic Benefits Comparison

Table 7 Economic Benefit Comparison

Indicator	Soil-borne Disease Prevention and Control Group	Non-Prevention and Control Group
Average per-mu cost	Increased by 500-800 yuan (Biological prevention/disinfection)	Regular investment (No additional cost)
Average per-mu yield	2500-3000 kg/mu	1200-1500 kg/mu
Price difference	Premium fruit 30-50 yuan/kg	Common fruit 5-10 yuan/kg
Average per-mu net profit	15,000-25,000 yuan/mu	5,000-8,000 yuan/mu

With advancements in soil-borne disease control technologies, the protected strawberry industry has reduced seedling mortality (from 30% to 5%), increased the marketable fruit rate (premium fruits rising from 60% to 85%), and extended the harvest period by 1 – 2 months. These improvements have doubled yields, raised prices, and steadily increased farmers' income, expanding market opportunities.

4. Summary and Outlook

Comparing soil pathogens, disease incidence, control efficacy, and strawberry growth before and after treatments, the results showed that agricultural measures combined with dazomet soil disinfection provided the best inhibition of soil pathogens and control of root rot and blight, with inhibition rates exceeding 92.29% for *Fusarium*, *Pythium*, and *Phytophthora*, and control efficacy of 75.85 – 82.05%. The Zhongshu Genbao 401

disinfection combination ranked second, with control efficacy exceeding 76.23 – 76.80%. The biological reduction method achieved 67.98 – 70.22% control efficacy, while film mulching achieved 52.04 – 60.57%. Additionally, dazomet, Zhongshu Genbao 401, and the biological reduction method enhanced fruiting potential, with dazomet also promoting vegetative growth. Farmers can choose different combinations based on production needs and disease conditions.

Future prospects for soil-borne disease control in protected strawberries include:

1. Technological Innovation: Advances in biological control, efficient and low-toxicity soil disinfectants, and precision monitoring systems will improve control efficacy.
2. Green Control Demand: Growing consumer demand for green and organic products will drive the adoption of biological and physical control methods, reducing chemical pesticide use.
3. Industry Integration: The fusion of strawberry production with leisure tourism and pick-your-own experiences will promote the adoption of control technologies, emphasizing environmental aesthetics and food safety.

Recommendations:

1. Training and Guidance: Provide training and on-site support to enhance farmers' understanding and skills in soil-borne disease control.
2. Research and Promotion: Increase investment in R&D for cost-effective control technologies and expand the application of existing methods.
3. Optimized Strategies: Implement integrated control strategies combining agricultural, physical, biological, and chemical methods tailored to specific diseases.
4. Monitoring and Early Warning: Establish monitoring systems to track soil and plant health, providing timely alerts and scientific guidance.

In conclusion, soil-borne disease control technologies for protected strawberries will evolve toward efficiency, sustainability, and intelligence, supporting the industry's sustainable development and offering insights for other horticultural crops.

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