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Effect Evalution of Xiulijing on Fruit Rust Control of Golden Delicious Apple

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Abstract [**Objectives**] The paper was to evaluate the effectiveness of Xiulijing in the management of rust in Golden Delicious apple cultivation. [**Methods**] The Golden Delicious apple was utilized as the test material. During the young fruit stage, various dilutions of Xiulijing were applied, specifically at concentrations of 200, 400, 600, 800, 1 000, and 2 000 times. Additionally, both the application of a 3 000-fold dilution of GA_{4+7} and the practice of fruit bagging were designated as the control treatments, while a water spray was utilized as the blank control. The fruit rust index and the incidence of rust-infected fruits were evaluated to assess the effectiveness of control measures for fruit rust in Golden Delicious apple cultivation. [**Results**] The application of Xiulijing, with dilutions ranging from 200 to 2 000 times, exhibited a significant impact on reducing both the fruit rust index and the incidence of rust-infected fruits in Golden Delicious apples. The application of a 1 000-fold dilution of Xiulijing resulted in a statistically significant reduction in both the fruit rust index and the incidence of rust-infected fruits, with reduction rates of 21.1% and 31.5%, respectively. Among the various strategies for the prevention and control of apple rust, fruit bagging emerged as the most effective method. The other two technical measures demonstrated significant control effects; however, no substantial differences were observed between them. [**Conclusions**] The biological control agent Xiulijing is more deserving of promotion and application in practical production due to its significantly superior economic benefits, safety, and stability.

Key words Xiulijing; Golden Delicious; Gibberellin; Fruit rust; Prevention and control

1 Introduction

Fruit rust is a physiological disorder that frequently manifests in the peduncle pits or calyx pits of fruit. At the initial stage of fruit rust, a layer of yellow-brown material, specifically corky pericarp tissue, appears on the surface of the fruit. As the extent of fruit rust progresses, the surface roughness of the fruit intensifies, resulting in an increase in the hardness of the flesh and a concomitant decrease in palatability[1-4]. In 2023, apple orchards in certain regions of Yantai City, Shandong Province, experienced significant damage due to fruit rust, with the incidence of rust-infected fruits reaching as high as 43.2%. This outbreak led to a substantial decline in market prices, consequently resulting in considerable financial losses for fruit growers. The incidence of fruit rust is influenced by various environmental factors, including elevated temperatures, low temperatures, inadequate light, and the presence of metal ions such as mercury and copper during the young fruit stage. Additionally, factors such as wind and sand erosion, mechanical damage from branches and leaves, pathogenic microbial infections, and insect infestations also play a significant role in the development of fruit rust[2,5-9].

The 3-week interval following the fall of apple blossoms represents a critical phase for the development of fruit rust. This period is also essential for implementing effective control measures against fruit rust. Optimal results in managing apple rust can be attained by employing appropriate control strategies during this timeframe[10-12]. As a biological control agent, Xiulijing exerts a positive influence by stimulating plant growth points and enhancing cell division. The application of Xiulijing during the young apple fruit stage may contribute to the prevention of corky tissue formation and the mitigation of fruit rust disease[13-14]. The fruit rust index and the incidence of rust-infected fruits are two closely related indicators that reflect the occurrence of apple fruit rust. Additionally, these indicators are essential for assessing the severity of fruit rust and the effectiveness of its control measures. This study evaluated the fruit rust index and the incidence of rust-infected fruits in Golden Delicious apples following the application of Xiulijing. The research established control groups and various concentrations of Xiulijing to analyze its effectiveness in preventing and controlling apple fruit rust. The objective was to determine the optimal application concentration, thereby providing valuable references for practical production. Simultaneously, the study sought to contribute to the enhancement of apple quality, the improvement of competitiveness within the apple market, the reduction of pesticide and hormone application, and the increase of income for fruit growers.

2 Materials and methods

2.1 Materials The experiment was conducted from May to October 2023 in an apple orchard located in Guanshui Town, Muping District, Yantai City. The soil in this area exhibited an organic matter content of 0.82% and a pH of 7.2, and the orchard was maintained under a high level of management. The test subjects were Golden Delicious apple trees, planted with a spacing of 2.4 m × (4.3 - 4.5) m. The rootstock utilized was M26, and the trees were 6 years old, exhibiting consistent growth and yielding

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between 37 and 44 kg per plant.

2.2 Reagents Xiulijing is a water-soluble formulation developed and manufactured by Yantai Goodly Biological Technology Co., Ltd. Its primary components include various plant and marine extracts, chitosan oligosaccharides, with an organic matter content of ≥ 80 g/L, and a pH range of 4.5 to 6.5. GA_{4+7} is a gibberellin growth regulator obtained from Zhengzhou Chengduo Chemical Co., Ltd. The apple bags utilized in this study were commercially available flat-mouth double-layer bags, characterized by a yellow exterior and a black interior.

2.3 Experimental design and methods The spraying concentrations of Xiulijing were established at dilutions of 200, 400, 600, 800, 1 000, and 2 000 times for six experimental groups. Additionally, a control group was designated with GA_{4+7} at a dilution of 3 000 times, while fruit bagging was also utilized as a control group. Furthermore, the treatment involving clean water without bagging was designated as a blank control group, resulting in a total of nine treatment groups. Three adjacent fruit trees were selected from each treatment group and arranged randomly, culminating in a total of 27 trees across the nine treatment groups.

In the initial fruiting stage, one week following the abscission of blossoms in May 2023, nine groups of Golden Delicious apple trees were assigned to specific reagent or technical treatment groups. The application of each reagent treatment was focused on the fruiting branches, ensuring the formation of liquid droplets that dripped from the branches. Furthermore, the spraying was conducted by the same personnel utilizing identical spraying equipment to minimize operational errors. The second application of the spray was conducted 5 d after the initial treatment. The third application occurred prior to the bagging process. The group designated for bagging received the appropriate treatment, while the remaining eight groups were left unbagged. Subsequently, standard field management practices were implemented. Following the removal of the bags during the harvesting period in October, observations and statistical analyses were performed. The fruit rust index and the incidence of rust-infected fruits were recorded separately for each treatment group.

2.4 Indicator measurement During the apple harvesting period, all fruits from each group were collected, and the total number of harvested fruits, the number of fruits at all grades, and the total number of rust-affected fruits were systematically measured and documented. Additionally, the surface area of rust on each group of fruits was assessed and categorized into distinct rust grades. Subsequently, the fruit rust index and the incidence of rust-infected fruits were calculated for each treatment group.

The surface area of rust was determined through a systematic process comprising the following steps. (i) Washing and drying: the surface of the fruit was thoroughly washed with water to eliminate impurities, followed by gentle drying using paper towels or drying equipment. (ii) Photography: a high-resolution camera or smartphone was employed to capture a comprehensive image of the outer surface of the apple, ensuring clarity and accurate representation of the rust distribution. (iii) Image processing: the photographs were imported into image processing software, specifically Photoshop, where image segmentation and threshold setting functions were utilized to distinguish the rusted areas from the background. (iv) Area calculation: the area of the identified rusted regions was quantified using the area calculation function available in the image processing software.

The classification criteria and calculation formula for fruit rust are delineated as follows. The fruit rust index is categorized into five grades. Grade 1 indicates the absence of rust spots; grade 2 corresponds to a rust spot area of less than or equal to 0.5 cm^2; grade 3 pertains to a rust spot area greater than 0.5 cm^2 but less than or equal to 1.0 cm^2; grade 4 applies to a rust spot area greater than 1.0 cm^2 but less than or equal to 2.0 cm^2; and grade 5 is designated for a rust spot area exceeding 2.0 cm^2.

Fruit rust index = ∑(Value of each grade × Number of fruits at that grade)/(Representative value of grades × total number of fruits) × 100 (1)

Incidence of rust-infected fruits (%) = Number of rust-infected fruits/Total number of fruits × 100% (2)

2.5 Data processing The statistical data were processed and analyzed utilizing SPSS version 22.0.

3 Results and analysis

3.1 Effectiveness of Xiulijing in managing apple fruit rust

The data presented in Table 1 indicate that the fruit rust index, as well as the incidence of rust-infected fruits treated with varying concentrations of Xiulijing, exhibited a reduction. Furthermore, the number of rust-infected fruits across all grades, along with the total number of rust-infected fruits, demonstrated a declining trend corresponding to the increased concentration of Xiulijing. The fruit rust index and the overall incidence of rust-infected fruits in the blank control group of the experimental orchard were recorded at 37.0% and 39.7%, respectively. The fruit rust index and the incidence of rust-infected fruits in the treatment group treated with a 2 000-fold dilution of Xiulijing did not exhibit a significant difference compared to the blank control group. In contrast, the treatment groups treated with 1 000-fold, 800-fold, 600-fold, 400-fold, and 200-fold dilutions of Xiulijing demonstrated a highly significant difference when compared to both the 2 000-fold dilution group and the blank control group. In light of the necessity to manage production costs in current agricultural practices, a 1 000-fold dilution of Xiulijing was selected as the recommended concentration for the control of apple fruit rust. This application resulted in a reduction of the rust index for Golden Delicious apples to 29.2%, as well as a decrease in the incidence of rust-infected fruits to 27.2%. These figures represent reductions of 21.1% and 31.5%, respectively, when compared to the blank control group.

Table 1 Efficacy of various Xiulijing treatments in managing apple fruit rust

Group	Total number of fruits	Total number of rust-infected fruits	No. of trees	Number of fruits at various grades					Fruit rust index		Incidence of rust-infected fruits//%	
				Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Single tree	Mean	Single tree	Mean
Water treatment	446	177	I	92	22	17	13	10	37.5	37.0 aA	40.3	39.7 aA
			II	91	23	15	14	8	36.8		39.7	
			III	86	21	14	11	9	36.7		39.0	
2 000 times dilution	451	176	I	91	21	16	10	9	36.2	36.4 aA	38.1	39.0 aA
			II	93	23	17	10	9	36.2		38.8	
			III	91	24	17	11	9	36.7		40.1	
1 000 times dilution	449	122	I	108	25	9	4	2	28.5	29.2 bB	27.0	27.2 bB
			II	108	24	7	6	4	29.7		27.5	
			III	111	23	8	7	3	29.5		27.0	
8 00 times dilution	452	106	I	115	19	10	6	2	28.6	28.2 bcB	24.3	23.5 cBC
			II	116	18	12	7	1	28.7		24.7	
			III	115	16	9	5	1	27.3		21.2	
600 times dilution	454	98	I	120	17	7	4	2	26.8	27.4 cB	20.0	21.6 dC
			II	117	16	8	6	1	27.3		20.9	
			III	119	20	9	7	1	28.1		23.7	
400 times dilution	445	94	I	114	24	5	3	0	25.9	26.1 cdB	21.9	21.1 dC
			II	119	22	7	4	1	26.8		22.2	
			III	118	18	8	2	0	25.5		19.2	
200 times dilution	450	91	I	118	18	8	2	0	25.5	25.2 dB	19.2	20.2 dC
			II	120	26	7	1	0	25.6		22.1	
			III	122	20	6	0	0	24.3		17.6	

NOTE Different lowercase letters in the same column signify statistically significant differences at the 0.05 level, while different capital letters denote highly significant differences at the 0.01 level. The same below.

3.2 Effectiveness of various technical measures for the control of fruit rust As illustrated in Table 2, the implementation of bagging techniques demonstrated the most effective results in the prevention and control of fruit rust in Golden Delicious apples. The fruit rust index and the incidence of rust-infected fruits exhibited highly significant levels when compared to the other three groups. The results of the technical measures involving the application of Xiulijing at a dilution of 1 000 times and GA_{4+7} at a dilution of 3 000 times demonstrated a highly significant difference when compared to the blank control group. Furthermore, the data from the Xiulijing (1 000 times dilution) group exhibited marginally superior outcomes compared to the GA_{4+7} (3 000 times dilution) group; however, no statistically significant difference was observed between the two treatment groups.

Table 2 Effectiveness of various technical measures for the control of fruit rust

Group	Total number of fruits	Total number of rust-infected fruits	No. of trees	Number of fruits at various grades					Fruit rust index		Incidence of rust-infected fruits//%	
				Grade 1	Grade 2	Grade 3	Grade 4	Grade 5	Single tree	Mean	Single tree	Mean
Water treatment	446	177	I	92	22	17	13	10	37.5	37.0 aA	40.3	39.7 aA
			II	91	23	15	14	8	36.8		39.7	
			III	86	21	14	11	9	36.7		39.0	
Bagging	451	37	I	130	8	0	0	0	21.2	21.8 cC	5.8	8.2 cC
			II	135	13	1	0	0	22.0		9.4	
			III	149	13	2	0	0	22.1		9.1	
Xiulijing 1 000 times dilution	449	122	I	108	25	9	4	2	28.5	29.2 bB	27.0	27.2 bB
			II	108	24	7	6	4	29.7		27.5	
			III	111	23	8	7	3	29.5		27.0	
GA_{4+7} 3 000 times dilution	447	126	I	109	24	11	9	4	31.3	30.3 bB	30.6	28.2 bB
			II	109	22	9	9	2	29.9		27.8	
			III	103	19	7	7	3	29.5		25.9	

4 Conclusions

This experiment was conducted to evaluate the impact of various interventions on the reduction of the fruit rust index and the incidence of rust-infected fruits at the harvesting stage. The study involved a comparative analysis of the application of different concentrations of Xiulijing and various technical measures aimed at controlling fruit rust on young apple fruits. The results indicated that the application of Xiulijing, diluted between 200 and 2 000 times, on Golden Delicious apples significantly reduced both the fruit rust index and the incidence of rust-infected fruits. Furthermore, as the dilution ratio decreased, the efficacy of the treatment in preventing and controlling fruit rust exhibited a trend of enhancement. When the spraying concentration of Xiulijing was diluted to 1 000 times, the cost of input was minimal, and the efficacy in controlling fruit rust disease was notable. Under this treatment, the fruit rust index and the incidence of rust-infected fruits were reduced to 29.2% and 27.2%, respectively, representing a decrease of 21.1% and 31.5% compared to the clean water control group, which recorded indices of 37.0% and 39.7%, respectively. The most effective among the various measures for controlling apple fruit rust was fruit bagging. The other two technical measures demonstrated significant control effects; however, they did not exhibit a statistically significant difference from one another.

Among the various technical measures available for the prevention and control of fruit rust, bagging is considered the most effective. However, this method requires significant labor and the input of additional materials, which can be time-consuming and labor-intensive. Consequently, these factors substantially increase input costs. Furthermore, the slow degradation of fruit bags contributes to environmental pollution, which is detrimental to green and sustainable development. Gibberellin application offers notable advantages, including a significant and rapid effect on plant growth. However, it also presents several disadvantages, such as a substantial susceptibility to environmental factors, inconsistent efficacy, and the potential for irreversible damage to the plant resulting from the application of inappropriate concentrations.

In a comparative analysis of various fruit rust control measures, the utilization of gibberellin demonstrated a cost-saving rate of 37.2% relative to manual bagging. Additionally, it resulted in a reduction of the fruit rust index and the incidence of rust-infected fruits by 18.1% and 29.0%, respectively, when compared to the clean water control. Similarly, the application of Xiulijing yielded a cost-saving rate of 36.7% in comparison to manual bagging, with corresponding reductions in the fruit rust index and the incidence of rust-infected fruits of 21.1% and 31.5%, respectively, also in comparison to the clean water control. Consequently, in comparison to fruit bagging, which is the most effective yet considerably more expensive technical measure for rust prevention, the application of Xiulijing can yield a more substantial control effect while offering a cost-saving rate comparable to that of gibberellin. As a biological control agent, Xiulijing can be utilized at low concentrations to effectively inhibit the fruit rust index and the incidence of rust-infected fruits. This approach demonstrates superior economic benefits, safety, and stability compared to the aforementioned technical measures, thereby making it a more advantageous option for promotion and application in practical production settings.

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