Article

Chitosan Can Induce *Rosa roxburghii* Tratt. against *Sphaerotheca* sp. and Enhance Its Resistance, Photosynthesis, Yield, and Quality

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Abstract: Powdery mildew caused by *Sphaerotheca* sp. is the most serious disease of *Rosa roxburghii* cultivation. In this study, the foliar application of chitosan induced *Rosa roxburghii* Tratt. against *Sphaerotheca* sp. and its effects on the disease resistance, growth, yield, and quality of *R. roxburghii* were investigated. The results show that the foliar application of 1.0~1.5% chitosan could effectively control *Sphaerotheca* sp. of *R. roxburghii* with the inducing control efficacy of 69.30~72.87%. The foliar application of 1.0~1.5% chitosan significantly ($p < 0.01$) increased proline, soluble sugar, flavonoids, superoxide dismutase (SOD), and polyphenoloxidase (POD) activities of the *R. roxburghii* leaf and decreased its malonaldehyde (MDA), as well as reliably enhanced its photosynthetic rate and chlorophyll. Moreover, the foliar application of 1.0~1.5% chitosan notably improved single fruit weight, yield, vitamin C, soluble solid, soluble sugar, total acidity, soluble protein, flavonoids, and SOD activity of *R. roxburghii* fruits. This study highlights that chitosan can be used as an ideal, efficient, safe, and economical inductor for controlling powdery mildew of *R. Roxburghii* and enhancing its resistance, growth, yield, and quality.

Keywords: chitosan; *Rosa roxburghii* Tratt.; *Sphaerotheca* sp.; disease resistance; yield and quality

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1. Introduction

Rosa roxburghii Tratt., a *Rosaceae* deciduous shrub, is rich in antioxidants and nutrients, such as vitamin C, flavonoids, superoxide dismutase (SOD), and various minerals [1–3]. Due to its high nutritional and medical value, it is widely used in improving immunity, lowering blood pressure, regulating the digestive system, protecting the liver, as well as anti-oxidation, anti-cancer, antibacterial, and anti-radiation, etc. [4–8]. As a promising fruit crop and natural medicine, *R. roxburghii* is widely planted in Southwest China, especially in Guizhou Province. Recently, Guizhou's *R. roxburghii* industry has developed rapidly and made great contributions to rocky desertification control, poverty alleviation, and rural revitalization, and its planting area reached 170,000 hm² in 2020 [3,9]. However, as commercial cultivation of *R. roxburghii* expanded, many pests became increasingly serious such as *Sphaerotheca* sp., *Grapholita molesta*, and *Cercospora insulana* Sacc, which seriously affect the yield and quality of *R. roxburghii* and frequently cause great economic losses.

Powdery mildew caused by *Sphaerotheca* sp. is the most serious disease of *R. roxburghii* cultivation, which mainly damages the fresh young leaves and shoots of *R. roxburghii*, as well as flower buds, flowers, and young fruits [10]. According to the statistics, *Sphaerotheca* sp. seriously affects the growth, yield, and quality of *R. roxburghii*, as well as often causes 30~40% economic losses in Guizhou Province of Southwest China. At present, chemical fungicides such as triadimefon, myclobutanil, azoxystrobin, and tebuconazole are still the predominant measures to control *Sphaerotheca* sp. of *R. roxburghii* [11]. Nonetheless, these

chemicals easily generate resistance to pathogens, and their residuals negatively affect the environment, wildlife, and human beings [12–14]. Thus, it is of great significance to develop the green, efficient, safe, and economical control practice of *Sphaerotheca* sp. for the sustainable development of the *Rosa roxburghii* industry.

Inducing resistance, a newly rising agricultural practice is often activated by various biotic and abiotic inductors and plays an important role in plant adaptation to stress [15,16]. Recently, it has gained popularity as an environmentally friendly approach for controlling crop diseases. For example, Yan et al. [17] reported that 6% ascorbic acid aqueous solutions could induce systemic resistance and enhance the ability to resist *Sphaerotheca* sp. in *R. roxburghii* with the inducing effect of 61.45%. Chitosan, a natural de-acetylated chitin derivative, is an ideal resource for sustainable agriculture due to its bioactivity, biocompatibility, biodegradability, non-toxicity, and renewability [18–20]. A wide range of studies shows that chitosan can be used as a resistance inductor and bio-fungicide for controlling plant diseases and as a growth promoter for enhancing plant development [21–26]. In the control of plant diseases, chitosan induces morphological changes and structural alterations in fungal cells that cause cell death [20,27]. When chitosan is used to improve plant defense, it induces resistant enzymes, pathogenesis-related proteins, phytoalexins, callose formation, and promotes lignification [20,28]. Up to date, however, there is no attention or documentation available about whether chitosan induces resistance of *R. roxburghii* to *Sphaerotheca* sp. and promotes its growth.

In this study, the inducing control efficacy of chitosan against *Sphaerotheca* sp. of *R. roxburghii* was firstly evaluated. Moreover, the effects of chitosan on the disease resistance, photosynthesis, yield, and quality of *R. roxburghii* were also investigated. This work provides a green, effective, safe, and economical approach for controlling *Sphaerotheca* sp., inducing disease resistance and promoting the growth, yield, and quality of *R. roxburghii*.

2. Materials and Methods

2.1. Materials

Chitosan (deacetylation $\geq 90.00\%$) was provided by Huarun Bioengineering Co., Ltd. (Zhenzhou, China). Trees of *R. roxburghii* ‘Guinong 5’ with 6-year-old were used as materials, and their planting density was 106 plants per 666.7 m².

2.2. Field Site

Field experiments were conducted in 2019 in an *R. roxburghii* orchard at Chaxiang village, Gujiao Town, Longli country, Guizhou Province, China (26°54′36″ N, 106°95′13″ E). The mean altitude, mean temperature, frostless season, annual rainfall, and annual sunshine duration of the *R. roxburghii* orchard were about 1384 m, 13.9 °C, 280 days, 1100 mm, and 1265 h, respectively. The loam soils of the *R. roxburghii* orchard had 12.78 g·kg^{−1} of organic matter, 56.02 mg·kg^{−1} of available nitrogen, 4.07 mg·kg^{−1} of available phosphorus, 25.35 mg·kg^{−1} of available potassium, 18.53 cmol·kg^{−1} of exchangeable calcium, 317.58 mg·kg^{−1} of exchangeable magnesium, 6.31 mg·kg^{−1} of available iron, 15.16 mg·kg^{−1} of available manganese, 0.43 mg·kg^{−1} of available copper, 0.56 mg·kg^{−1} of available zinc, 0.13 mg·kg^{−1} of available boron, and 6.89 of pH value.

2.3. Field-Inducing Control Experiment of *Sphaerotheca* sp. in *R. roxburghii*

The spraying chitosan method was used for conducting the field-inducing control experiment of *Sphaerotheca* sp. in *R. roxburghii*. Four treatments were designed with 0%, 0.5%, 1.0%, and 1.5% chitosan dilution liquid, respectively. A total of twelve plots were arranged randomly with four replicates, each plot had nine trees, and a 3.5 m isolation area was set among plots. Five trees on the diagonal of each plot were used for determination. Soil, plant size, and tree strength in all plots were similar. Due to *Sphaerotheca* sp. mainly damages too fresh young leaves and shoots of *R. roxburghii*, as well as flower buds, flowers, and young fruits. Thus, the experiment was carried out by spraying chitosan solution

twice, and about 1.50 L of chitosan dilution liquid was sprayed on each *R. roxburghii* plant (including flower, bud, leaf, and stem) on 1 April and 1 May, respectively.

2.4. Determination of Chitosan Control Effect against *Sphaerotheca* sp., and Resistance Parameters, Photosynthetic Rate and Chlorophyll of *R. roxburghii* Leaves

Late May to early June is a more serious time of *Sphaerotheca* sp.; thus, the inducing control effect of chitosan against *Sphaerotheca* sp., as well as the photosynthetic rate, chlorophyll, and resistance parameters of the leaf of *R. roxburghii*, were investigated on 1 June 2019. The incidence rate, disease index, and control effect of chitosan against *Sphaerotheca* sp. of *R. roxburghii* were investigated according to Equations (1)–(3), respectively. The grading standard of the incidence degree: 0 = no incidence; 1 = 1~2 diseased lobules with thin hyphae; 2 = 3~4 diseased lobules with thick hyphae; 3 = 5~6 diseased lobules with dense hyphae; 4 = more than 7 diseased lobules with dense hyphae.

$$\text{Incidence rate (\%)} = 100 \times \text{Number of disease leaves} / \text{Total number of leaves} \quad (1)$$

$$\text{Disease index} = 100 \times \sum (\text{Disease grade value} \times \text{Number of leaves within each grade}) / (\text{Total number of leaves} \times \text{the highest grade}) \quad (2)$$

$$\text{Control effect (\%)} = 100 \times (\text{Disease index of control} - \text{Disease index of treatment}) / \text{Disease index of control} \quad (3)$$

The resistance parameters of *R. roxburghii* leaves, including proline, soluble sugar, MDA, flavonoids, SOD, and PPO activities, were determined as described by Zhang et al. [29,30]. Proline, soluble sugar, MDA, and flavonoids were analyzed by ninhydrin colorimetry, thio-barbituric acid, anthrone colorimetric, and HCl-methyl alcohol methods, respectively. SOD and PPO activities were analyzed by the nitrogen blue tetrazole and catechol methods, respectively. The photosynthetic rate (Pn) of leaves in *R. roxburghii* was determined by a portable LI-6400XT photosynthesis measurement system (LI-COR Inc., Lincoln, NE, USA) at 8:00–10:00 a.m. on 1 June 2019. Chlorophyll a and chlorophyll b content of *R. roxburghii* leaves were measured by a UV-5800PC spectrophotometer at 645 nm (OD₆₄₅) and 663 nm (OD₆₆₃) with an acetone-ethanol (v/v, 2:1) extraction, respectively [29].

2.5. Determination of Yield and Quality of *R. roxburghii*

Fruits from each plot were randomly collected on 1 September 2019, and single fruit weight, fruit yield per plant, and fruit quality of *R. roxburghii* were subsequently determined. Single fruit weight and fruit yield per plant were determined by the weighing method. Fruit quality parameters of *R. roxburghii* such as vitamin C, soluble solid, soluble sugar, total acidity, soluble protein, flavonoids, and SOD activity were also measured according to Zhang et al. [29,30].

2.6. Statistical Analyses

Data were exhibited as mean $\pm$ standard deviation (SD) of three replicates, and all analyses were carried on SPSS 18.0 (SPSS Inc., Chicago, IL, USA). A one-way analysis of variance (ANOVA) was used for determining the difference significances. Origin 10.0 was used to draw the chart.

3. Results

3.1. Field-Inducing Control Effect of Chitosan against *Sphaerotheca* sp. of *R. roxburghii*

As shown in Table 1, 0.5–1.5% chitosan significantly ($p < 0.01$) reduced the incidence rate and disease index of *Sphaerotheca* sp. of *R. roxburghii*. The inducing control effect of 1.5% chitosan against *Sphaerotheca* sp. was 72.87%, which was significantly ($p < 0.05$) higher than 69.30% of 1.0% chitosan and significantly ($p < 0.01$) higher than 48.12% of 0.5% chitosan. However, the incidence rate, disease index, and control effect were not significant between 1.0% chitosan and 1.5% chitosan treatments. The present results indicate that 1.0–1.5% chitosan had a suitable inducing control effect against *Sphaerotheca* sp. in *R. roxburghii*.

Table 1. The inducing control effects of chitosan against *Sphaerotheca* sp. of *R. roxburghii*.

Chitosan (%)	Incidence Rate (%)	Disease Index	Control Effect (%)
0	48.15 ± 6.42 ^{aA}	13.39 ± 1.00 ^{aA}	
0.5	29.63 ± 6.41 ^{bB}	6.88 ± 0.36 ^{bB}	48.12 ± 5.75 ^{cB}
1.0	18.52 ± 6.41 ^{cC}	4.08 ± 0.09 ^{cC}	69.30 ± 1.49 ^{bA}
1.5	14.81 ± 6.41 ^{dC}	3.60 ± 0.14 ^{cC}	72.87 ± 2.88 ^{aA}

Values indicate the mean ± SD of three replicates. Different small and capital letters indicate significant differences at 5% level ($p < 0.05$) and 1% level ($p < 0.01$), respectively.

The inducing control effect of chitosan against *Sphaerotheca* sp. increased gradually with the increase in chitosan concentration.

3.2. Effects of Chitosan on Proline, Soluble Sugar, Malonaldehyde, Flavonoids, SOD, and PPO Activity of *R. roxburghii* Leaves

The effects of chitosan on the proline, soluble sugar, MDA, flavonoids, SOD, and PPO activities of leaves in *R. roxburghii* are shown in Figure 1. A total of 1.0~1.5% chitosan significantly ($p < 0.01$) increased proline, soluble sugar, and flavonoids of *R. roxburghii* leaves compared with non-sprayed chitosan and decreased its MDA content. A total of 0.5~1.5% chitosan significantly ($p < 0.01$) enhanced SOD and PPO activities of leaves in *R. roxburghii*. Proline and soluble sugar are important substances to maintain the strong permeability of various organs. Chitosan effectively increased proline and soluble sugar of leaves in *R. roxburghii* (Figure 1a,b). MDA reflects the intensity of membrane lipid peroxidation and the damage degree of the membrane system, and flavonoids are an important disease-resistant substance. A total of 1.0~1.5% chitosan significantly ($p < 0.01$) reduced the MDA content of leaves in *R. roxburghii* and increased its flavonoids (Figure 1c,d), which promoted the healthy growth and disease resistance of the *R. roxburghii* plants. SOD and PPO are important defense enzymes associated with disease resistance in plants. Chitosan significantly ($p < 0.01$) enhanced SOD and PPO activities of leaves in *R. roxburghii* (Figure 1e,f), which improved the disease resistance of *R. roxburghii* plants. These findings here emphasize that 1.0~1.5% chitosan could effectively improve the stress resistance of *R. roxburghii* and promote its healthy growth.

3.3. Effects of Chitosan on Photosynthetic Rate and Chlorophyll Content of *R. roxburghii* Leaves

As exhibited in Figure 2, 0.5~1.5% chitosan effectively enhanced the photosynthetic rate of leaves in *R. roxburghii* compared with the control. The photosynthetic rate of leaves in *R. roxburghii* increased gradually with the increase in chitosan concentration. A total of 1.0~1.5% chitosan-treated plants possessed a superior photosynthetic rate of leaves in *R. roxburghii* with 6.63~7.46 $\mu\text{mol}\cdot\text{CO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, which was significantly ($p < 0.01$) higher than 0.5% chitosan and control. Moreover, 0.5% chitosan exhibited a relatively inferior photosynthetic rate of leaves in *R. roxburghii* with 5.46 $\mu\text{mol}\cdot\text{CO}_2\cdot\text{m}^{-2}\cdot\text{s}^{-1}$, which was significantly ($p < 0.05$) higher than non-spray chitosan. The results here indicate that 1.0~1.5% chitosan enhanced the photosynthesis of the *R. roxburghii* plant and promoted its growth.

As revealed in Table 2, 1.0~1.5% chitosan could significantly ($p < 0.05$) increase the content of chlorophyll a, chlorophyll b, and chlorophyll a + b of leaves in *R. roxburghii* compared with control. While 0.5% chitosan exhibited a relatively inferior enhancing potential for chlorophyll of leaves in *R. roxburghii*, and the difference between it and non-spray chitosan did not reach a significant level. Chlorophyll a/b value can reflect the preference of plants to light. Generally, the greater chlorophyll a/b value, the more plants like light and the stronger plants have stress resistance. A total of 1.0~1.5% chitosan could significantly ($p < 0.05$) increase chlorophyll a/b value of leaves in *R. roxburghii* compared with 0.5% chitosan and non-spray chitosan. The present findings show that 1.0~1.5% chitosan increased the chlorophyll of *R. roxburghii*, thereby enhancing its photosynthesis and stress resistance.

Figure 1. The effects of chitosan on the proline (a), soluble sugar (b), malonaldehyde (c), flavonoids (d), SOD activity (e), and PPO activity (f) of leaves in *R. roxburghii*. Values and error bars indicate the mean and SD of three replicates, respectively. Different small and capital letters indicate significant differences at 5% level ($p < 0.05$) and 1% level ($p < 0.01$), respectively.

Figure 2. The effects of chitosan on the photosynthetic rate of leaves in *R. roxburghii*. Values and error bars indicate the mean and SD of three replicates, respectively. Different small and capital letters indicate significant differences at 5% level ($p < 0.05$) and 1% level ($p < 0.01$), respectively.

Table 2. The effects of chitosan on the chlorophyll content of leaves in *R. roxburghii*.

Chitosan (%)	Chlorophyll a	Chlorophyll b	Chlorophyll a + b	Chlorophyll a/b
0	2.87 ± 0.29 ^{bB}	2.07 ± 0.06 ^{bA}	1.38 ± 0.10 ^{bA}	4.94 ± 0.35 ^{bcA}
0.5	3.03 ± 0.10 ^{bB}	2.15 ± 0.05 ^{bA}	1.41 ± 0.08 ^{abA}	5.18 ± 0.06 ^{bA}
1.0	3.35 ± 0.20 ^{aA}	2.32 ± 0.03 ^{aA}	1.45 ± 0.08 ^{aA}	5.66 ± 0.21 ^{aA}
1.5	3.49 ± 0.18 ^{aA}	2.38 ± 0.05 ^{aA}	1.46 ± 0.10 ^{aA}	5.87 ± 0.16 ^{aA}

Values indicate the mean ± SD of three replicates. Different small and capital letters indicate significant differences at 5% level ($p < 0.05$) and 1% level ($p < 0.01$), respectively.

3.4. Effects of Chitosan on Yield and Quality of *R. roxburghii*

The effects of chitosan on the single fruit weight and fruit yield of *R. roxburghii* are shown in Figure 3. Chitosan significantly ($p < 0.01$) increased the single fruit weight and fruit yield of *R. roxburghii*. The single fruit weight and fruit yield per plant of *R. roxburghii* treated by 0.5~1.5% chitosan were 17.38~20.68 g and 5.87~7.38 kg, which significantly ($p < 0.01$) increased by 1.20~1.43 folds and 1.31~1.64 folds compared to control, respectively. The results presented here reveal that the suitable concentration of chitosan significantly enhanced fruit growth and yield formation.

Figure 3. The effects of chitosan on single fruit weight (a) and fruit yield (b) of *R. roxburghii*. Values and error bars indicate the mean and SD of three replicates, respectively. Different small and capital letters indicate significant differences at 5% level ($p < 0.05$) and 1% level ($p < 0.01$), respectively.

The effects of chitosan on the quality of *R. roxburghii* fruits are shown in Table 3. The vitamin C, soluble solid, soluble sugar, total acidity, soluble protein, flavonoids, and SOD activity of *R. roxburghii* fruits increased gradually with the increase in chitosan concentration. A total of 0.5~1.5% chitosan significantly ($p < 0.05$) improved vitamin C, soluble solid, soluble sugar, total acidity, soluble protein, flavonoids, and SOD activity of *R. roxburghii*, which effectively increased by 9.82~34.97%, 9.96~21.58%, 11.55~37.62%, 17.07~52.44%, 6.32~20.59%, 12.12~31.19%, and 9.99~20.86% compared to non-spray chitosan, respectively. The abovementioned findings indicate that the foliar application of the appropriate chitosan concentration could effectively improve the fruit quality of *R. roxburghii*.

Table 3. The effects of chitosan on quality of *R. roxburghii* fruits.

Chitosan (%)	Vitamin C (mg·g ⁻¹)	Soluble Solid (%)	Soluble Sugar (%)	Total Acidity (%)	Soluble Protein (%)	Flavonoids (mg·g ⁻¹)	SOD Activity (U·g ⁻¹ FW)
0	17.83 ± 1.12 ^d	10.24 ± 0.11 ^d	3.03 ± 0.12 ^d	2.46 ± 0.11 ^d	12.82 ± 0.66 ^d	0.095 ± 0.005 ^c	373.61 ± 6.91 ^d
0.5	19.59 ± 1.09 ^c	11.26 ± 0.25 ^c	3.38 ± 0.08 ^c	2.88 ± 0.10 ^c	13.63 ± 0.55 ^c	0.106 ± 0.005 ^{cb}	410.95 ± 4.42 ^c
1.0	22.31 ± 0.52 ^b	12.08 ± 0.24 ^a	3.84 ± 0.12 ^b	3.43 ± 0.13 ^{ab}	14.75 ± 0.62 ^b	0.115 ± 0.005 ^b	437.78 ± 6.25 ^b
1.5	24.07 ± 1.33 ^a	12.45 ± 0.33 ^a	4.17 ± 0.13 ^a	3.75 ± 0.11 ^a	15.46 ± 0.39 ^a	0.125 ± 0.013 ^a	451.55 ± 6.11 ^a

Values indicate the mean ± SD of three replicates. Different small letters indicate significant differences at 5% level ($p < 0.05$).

4. Discussion

Numerous findings have been documented that chitosan shows excellent efficacy in reducing disease incidence and can be used as an elicitor of plants' natural defense response [30–34]. For example, Zhang et al. [30] indicated that the foliar application of 0.2~0.4 g·L⁻¹ chitosan effectively controlled the soft rot of kiwifruit with the control effect of 71.94~82.13%. The results here exhibit that the foliar application of 0.5~1.5% chitosan significantly ($p < 0.01$) reduced the incidence rate and disease index of *Sphaerotheca* sp. in *R. roxburghii*. The inducing control effect of 1.0~1.5% chitosan against *Sphaerotheca* sp. was 69.30~72.87%. The suitable effects probably derive from its dual modes of action, that it suppresses pathogen entrance, colonization, and growth, as well as induces the *R. roxburghii* plant defense responses [29,30,35,36]. However, the incidence rate, disease index, and control effect were not significant between 1.0% chitosan and 1.5% chitosan treatments, which might be related to the dose effect of chitosan.

The previous studies have also shown that the foliar application of chitosan induces the synthesis of flavonoids, polyphenolics, and lignin in plants enhances the content of sugar and proline, boosts the defense enzyme activity of the plant [22,24]. Proline and soluble sugar are important substances in regulating cell permeability. In this study, the foliar application of 0.5~1.5% chitosan effectively increased proline and soluble sugar of leaves in *R. roxburghii*. These results show that the application of chitosan effectively adjusted osmotic pressure in the cells by increasing proline and soluble sugar of leaves in *R. roxburghii* and could improve the resistance of plants to stress such as disease and drought. MDA is an important indicator for the intensity of membrane lipid peroxidation, and flavonoids are an important disease-resistant substance. The results presented here demonstrate that the foliar application of 1.0~1.5% chitosan significantly ($p < 0.01$) reduced the MDA content of leaves in *R. roxburghii* and increased its flavonoids, indicating the chitosan application alleviated the membrane lipid peroxidation and promoted the disease resistance of *R. roxburghii* plants. PPO catalyzes phenolic substances to synthesize lignin, strengthen the cell wall structure and avoid entrance and colonization of phytopathogens toward plants [20]. SOD is responsible for eliminating reactive oxygen species to avoid plants from oxidative stress during phytopathogen invasion [20,37]. In this study, the foliar application of 0.5~1.5% chitosan significantly ($p < 0.01$) enhanced SOD and PPO activities of leaves in *R. roxburghii*, further evidencing the chitosan application enhanced the disease resistance of *R. roxburghii* plants.

Photosynthesis is the physiological basis of plant growth and yield. Chitosan can increase the plant yield substantially by improving the photosynthetic rate by enhancing

the stomatal function and chlorophyll content [19]. Chitosan also can be used as a plant growth promoter to enhance the division of root cells by activating the plant auxin and cytokinin signal transduction, gene expression, which increases the nutrient intake and enhance the plant growth [19,38]. The present results indicate that the foliar application of 0.5~1.5% chitosan effectively enhanced the photosynthetic rate, the content of chlorophyll a, chlorophyll b, and chlorophyll a + b of *R. roxburghii* leaves compared with control plants, as well as significantly ($p < 0.01$) increased single fruit weight and fruit yield of *R. roxburghii*. Moreover, the foliar application of 0.5~1.5% chitosan significantly ($p < 0.05$) improved vitamin C, soluble solid, soluble sugar, total acidity, soluble protein, flavonoids, and SOD activity of *R. roxburghii*, which effectively increased by 9.82~34.97%, 9.96~21.58%, 11.55~37.62%, 17.07~52.44%, 6.32~20.59%, 12.12~31.19%, and 9.99~20.86% compared to non-spray chitosan, respectively. Generally, the greater the chlorophyll a/b value, the stronger plants have stress resistance. Chlorophyll a/b value of *R. roxburghii* treated by chitosan also shows that the foliar application of 0.5~1.5% chitosan effectively improved the stress resistance of *R. roxburghii*. The findings here imply that the foliar application of 0.5~1.5% chitosan could reliably decrease the occurrence of *Sphaerotheca* sp. in *R. roxburghii* and induce systemic resistance, thereby enhancing the photosynthesis, growth, yield, and quality of *R. roxburghii*.

Chitosan is a natural macromolecule compound with antibacterial, nontoxic, antioxidant, renewable, biocompatible, and biodegradable advantages. The food safety risks caused by chitosan are almost nonexistent [19,20,39]. Zhang et al. [30] indicated that the foliar application of 0.2~0.4 g·L⁻¹ chitosan effectively reduced the incidence of soft rot, and notably enhanced the yield and quality, and prolonged the shelf life of kiwifruit. Mondal et al. [40] found that the foliar application of chitosan at 100 ppm may be used at the early growth stage for getting maximum seed yield in maize. Lei et al. [41] reported that the foliar application of 100 mg·L⁻¹ chitosan improved artemisinin biosynthesis in *A. annua*. This work highlights that chitosan can be used as an ideal inductor to control *Sphaerotheca* sp. of *R. roxburghii* and enhance the photosynthesis, growth, yield, and quality of *R. roxburghii*, and 1.0~1.5% chitosan is a green, safe, efficient, and suitable concentration. In order to fully understand the inducing control mechanism of chitosan on *Sphaerotheca* sp. of *R. roxburghii*, future researches are essential about the effects of chitosan on the cell growth, cell structure, and disease resistance gene expression of *Sphaerotheca* sp., etc.

5. Conclusions

In conclusion, the present study indicates that the foliar application of 1.0~1.5% chitosan had a suitable inducing control effect against *Sphaerotheca* sp. in *R. roxburghii* and effectively increased proline, soluble sugar, flavonoids, SOD, and POD activities of leaves in *R. roxburghii* and reduced its MDA content. Moreover, the foliar application of 1.0~1.5% chitosan reliably enhanced the photosynthetic rate and chlorophyll content of *R. roxburghii* leaves, as well as improved the yield and quality of *R. roxburghii* fruits. This study highlights that chitosan can be used as an ideal inductor to control *Sphaerotheca* sp. of *R. roxburghii* and enhance the growth, yield, and quality of *R. roxburghii*.

Author Contributions: X.W. and H.A. constructed the project; X.W., H.A. and J.L. designed the experiments; J.L., Z.G. and Y.L. performed the experiments; J.L. and Z.G. analyzed the data; J.L. and X.W. wrote the paper. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: The datasets during or analyzed during the current study available from the corresponding author on reasonable request.

Conflicts of Interest: We declare that we do not have any commercial or associative interest that represents a conflict of interest in connection with the work submitted.

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