

Foliar and Postharvest Application of Phosphite Promotes Postharvest Resistance of Potato Tubers to Late Blight Caused by *Phytophthora infestans*

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Abstract

Postharvest losses due to late blight, caused by *Phytophthora infestans*, remain a significant challenge for sustainable potato production. This study evaluated the effectiveness of potassium phosphite (KPhi) applications during the growing season and postharvest in enhancing tuber resistance to late blight in three potato cultivars (Cv. Xinjia No. 2, Cv. Zhongshu No. 3, and Cv. Minshu No. 3). Whole tuber assays were conducted on four-month stored tubers inoculated with ASO and 1-12-25 isolates of *P. infestans*, revealing that foliar KPhi treatments significantly reduced the disease severity in tubers. Five foliar applications during the growth season provided more protection than three applications. Cv. Xinjia No. 2 displayed higher resistance, Cv. Zhongshu No. 3 has moderate resistance, and Cv. Minshu No. 3 is moderately susceptible. Half-tuber and slice assays confirmed these findings, demonstrating markedly reduced late blight development in KPhi-treated samples compared to the controls, particularly when challenged with the more aggressive ASO isolates versus the 1-12-25 isolates of *P. infestans*. The most pronounced protection against the 1-12-25 isolates was observed in Cv. Xinjia No. 2. While KPhi did not entirely inhibit rot development at all treatments, it consistently delayed symptom progression and reduced lesion size across all three cultivars. These results support the application of KPhi as an effective, cultivar-dependent strategy for managing late blight development in potato tubers, with the degree of protection positively correlated with the application frequency. Postharvest KPhi application is a promising strategy to reduce tuber late blight, prolong storage life, and limit disease spread.

Keywords: cultivar resistance, *Phytophthora infestans*, postharvest disease control, potato tubers, potassium phosphite

Introduction

Potato late blight, caused by the oomycete *Phytophthora infestans* (Mont.) De Bary, is recognized as one of the most destructive diseases of potato cultivation globally. The pathogen attacks foliage, often resulting in premature leaf senescence and dramatic yield reduction. It also infects underground organs, where tubers show characteristic brown to purple, slightly depressed lesions on the skin, with internal tissue that hardens, dries, and later develops reddish-brown discoloration extending into deeper layers (Nowicki et al., 2012). Such infections not only reduce storage life but also compromise seed quality. When challenged by pathogens, potato plants activate a spectrum of defense responses, frequently associated with biochemical reprogramming. These metabolic shifts may restrict pathogen multiplication by creating unfavorable conditions or by directly targeting invading microbes (Mohammadi, Han, et al., 2020; Mohammadi, Karimi, et al., 2020). Phosphite (Phi, $\text{H}_2\text{PO}_3^{2-}$), a derivative of phosphorous acid (H_3PO_3), has emerged as a promising tool for disease management. Its protective action is largely attributed to the stimulation of plant defense pathways, which in turn reduce pathogen growth (McDonald et al., 2001; Mohammadi et al., 2021). Additionally, Phi can directly impair oomycetes by interfering with critical processes such as oxidative phosphorylation (Lobato et al., 2008).

Beyond disease control, Phi is also known to provide nutritional benefits in certain cropping systems, acting as a supplemental phosphorus source that can enhance growth and productivity (Han et al., 2021; Thao & Yamakawa, 2009). Synergistic effects have been documented when Phi is used together with fungicides like chlorothalonil, offering stronger protection against late blight (Borza et al., 2017; Wang-Pruski et al., 2010). Moreover, evidence suggests that Phi contributes to resilience under abiotic stresses, including heat stress, thereby improving overall crop performance (Xi et al., 2020). Importantly, several studies have confirmed that Phi also acts directly on oomycetes by disrupting metabolic processes essential for survival. For example, Lobato et al. (2008) demonstrated that phosphite interferes with oxidative phosphorylation, leading to impaired energy metabolism (Lobato et al., 2008). Fenn and Coffey (1984) reported that potassium phosphite suppressed sporangial production and zoospore release in *Phytophthora cinnamomi* (Fenn & Coffey, 1984). Similarly, Griffith et al. (1993) observed inhibition of mycelial growth in *Phytophthora* following phosphite exposure (Griffith et al., 1993). These findings highlight its dual action, combining host-mediated resistance with direct toxicity to the pathogen.

Beyond its anti-oomycete activity, Phi can provide supplementary nutritional benefits under some conditions, acting as a phosphorus source and promoting growth (Han et al., 2021; Thao & Yamakawa, 2009). Moreover, synergistic interactions have been documented between Phi and fungicides such as chlorothalonil, leading to enhanced protection against late blight (Borza et al., 2017; Wang-Pruski et al., 2010). In addition, recent evidence suggests that Phi supports tolerance to abiotic stress, including heat stress, thereby contributing to overall crop resilience (Batista et al., 2023; Xi et al., 2020).

Although KPhi has been widely reported to enhance foliar resistance against *P. infestans*, its effectiveness in improving the postharvest resistance of potato tubers remains poorly understood, particularly across cultivars with different levels of susceptibility. To address this gap, this study aimed to evaluate the impact of KPhi applications, applied both during the growing season and after harvest, on the resistance of three potato cultivars (Cv. Xinjia No. 2, Cv. Zhongshu No. 3, and Cv. Minshu No. 3) to late blight during storage.

Materials and Methods

Field experiment location

The experiment was conducted at the Fujian Agriculture and Forestry University Science and Education Base of Yangzhong Town, Youxi County, San Ming City, Fujian Province, China, from October 2016 to June 2017. The field was located at latitude 26° 10'N, longitude 118° 21'E, 550 m above sea level, average temperature 17-20 °C, average annual rainfall 1,650 mm, and a frost-free period of 295 days. It belongs to the mid-subtropical monsoon climate.

Field experimental design

The seed tubers of three potato cultivars, “Cv. Xingjia No. 2”, “Cv. Zhong Shu No. 3”, and “Cv. Minshu No. 3” were used in the field trial. The field trial was conducted using an RCBD design with four blocks (replicates); each plot was 6.3 m long, 1 m wide, and the area was 6.3 m²; in total, 24 plots. Each of the three varieties was repeated four times. Each plot contained two ridges (rows) for planting; the space between plants was 30 cm, and the space between rows was 40 cm. Each ridge contained 21 plants representing a single row. One month after emergence, the control plots were sprayed with distilled water, and the treated plots were sprayed with 1% KPhi. There were two different treatments: the first treatment included five applications of 1% KPhi, applied every 2 weeks after plant emergence; the second treatment included three applications of 1% KPhi, every 2 weeks after plant emergence. Applications were made using a 10 L backpack sprayer. Eight potato tubers were randomly collected from each plot during the harvest period and placed in separate nylon bags for subsequent experiments.

Measurement of plant growth

To monitor plant growth, plant height was measured using a steel ruler, stem diameter was determined with a digital Vernier caliper, and shoot fresh weight was recorded using a digital balance (Shanghai Yoke Instrument Co., Ltd., Shanghai, China).

Post-storage inoculation assay for late blight susceptibility of whole tubers

After four months of storage, the tubers were washed with distilled water and surface sterilized by immersing in 2.5 % sodium hypochlorite for 5 min and allowed to air dry. Six healthy tubers from each cultivar, which received KPhi as foliar application and water spray during the growing season, served as controls and were inoculated by placing them in a plastic box; each tuber was inoculated with a 2 mL (20 ×10³ sporangia /mL) suspension of *P. infestans* isolate ASO. The bag containing the tuber was then shaken gently for 5 min to distribute the inoculum on the surface of the tuber evenly. The tubers were then placed in the plastic bags overnight and stored at 15 °C and 100 % relative humidity (RH), which is reported as the optimum condition for late blight growth. Tubers were incubated for 21 days in the dark, and each tuber was evaluated visually from time to time for late blight symptoms on the surface of the tubers. All experiments were performed in triplicate. The mean index of disease severity was calculated using the method described by Mohammadi et al., (2019).

Postharvest KPhi treatment of tubers

For postharvest treatment, tubers of the three cultivars from the control plants of the field trial were used for postharvest testing under laboratory conditions. Eight tubers were dipped (1-2 sec) into an 8.6% KPhi

solution and then placed on paper towels to dry for about 1 h before being stored at 8 °C and 90 % RH in the dark, as reported in a previous publication (Borza et al., 2017). To test the effectiveness of KPhi treatments against the late blight pathogen, two *P. infestans* isolates, ASO and 1-12-25, were cultured and inoculated as described in our previous publications (Mohammadi, Han, et al., 2020; Mohammadi et al., 2019).

Evaluation of the infection of tubers that received postharvest treatment

This experiment was conducted using tubers from three potato cultivars that had not received KPhi treatment during the growing season but were treated postharvest. The design included four replicates, with four tubers per replicate. After storage, tubers were surface-sterilized in 2.5% sodium hypochlorite for 10 minutes, rinsed several times with distilled water, and cut in half. One-half of each tuber was further sliced, and the slices were briefly submerged (1–2 s) in an 8.6% KPhi solution, then placed in Petri dishes lined with moist filter paper and incubated at approximately 18 °C. The unsliced half of the tuber was also submerged in 8.6% KPhi solution for 1–2 s, placed on a plate, enclosed in plastic bags with distilled water to maintain high humidity, and incubated at room temperature in complete darkness. Control samples were processed identically, except that sterile distilled water was used instead of KPhi.

After 1 hour, both slices and tuber halves were inoculated with sporangial suspensions of *P. infestans* isolates ASO and 1-12-25. Potato slices received 50 µL of sporangial suspension (2×10^3 sporangia/mL) applied to the surface of each slice, and the development of *P. infestans* and sporangiophores was monitored for 3 weeks. The unsliced tuber halves were inoculated by spraying 0.6 mL of sporangial suspension (20×10^3 sporangia/mL) onto the apical end. Three weeks post-inoculation, tuber halves were cut longitudinally from the apical end, and the extent of *P. infestans* infection was estimated as the percentage of rotted tissue, following the method of Borza et al., (2017).

Statistical calculation

The data were recorded in an Excel sheet and analyzed by one-way ANOVA, followed by Tokey's test at a significant level of $p < 0.05$. Mean values marked with the same letter were not significantly different from one another.

Results

Effect of foliar application of KPhi on postharvest resistance in whole potato tubers against P. infestans

Foliar application of KPhi during early plant growth stages led to a significant increase in tuber resistance to late blight pathogen (ASO isolates) infections during postharvest storage in all three cultivars tested. The three cultivars exhibited different levels of resistance to the ASO isolates of *P. infestans*., Cv. Xinjia No. 2 was highly resistant, Cv. Zhongshu No. 3 was moderately resistant, and Cv. Minshu No. 3 was moderately susceptible (Figure 1). Peak disease severity was observed 20 days after infection in Cv. Minshu No. 3, while the lowest severity was recorded in Cv. Xinjia No. 2. In all cultivars, five field applications of KPhi resulted in a lower tuber rot compared to three applications. The control plants exhibited the highest disease rate. These findings confirm that the effectiveness of disease prevention is directly proportional to the frequency of KPhi application.

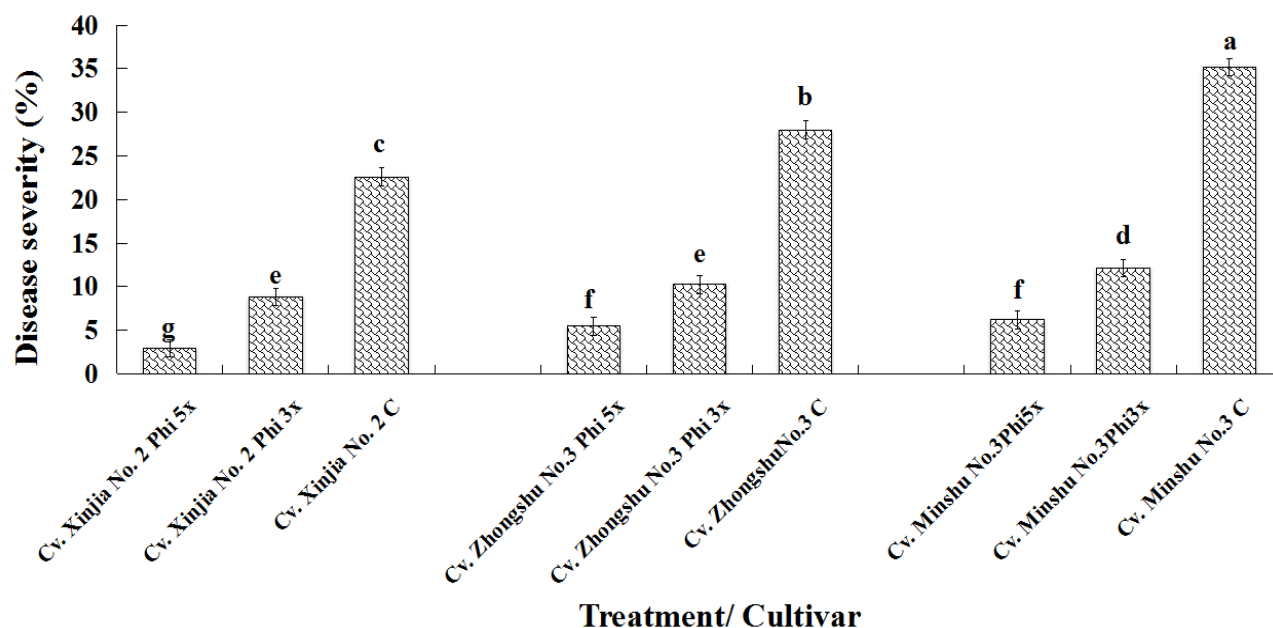


Figure 1: Effect of foliar applications of KPhi on the late blight disease severity in harvested whole tubers of three potato cultivars (Cv. Xinjia No. 2, Cv. Zhongshu No. 3, Cv. Minshu No. 3) at 21 days after inoculation with *P. infestans* isolates ASO. KPhi 3x =three applications of KPhi during the growing season; Phi 5x =five applications of KPhi during the growing season; C= control. Means followed by different letters within the same column indicate statistically significant differences at $P < 0.05$, as determined by Tukey's test.

Effect of postharvest KPhi treatment on late blight development on potato half tubers

P. infestans growth on potato tuber halves subjected to KPhi dip treatment was evaluated using two isolates, ASO and 1-12-25. The results showed that the isolates ASO was more aggressive than 1-12-25 (Figure 2A). The rot development was visible four days after inoculation on control tuber halves, while nominal growth was recorded on KPhi-treated samples during the infection experiment using the two above-mentioned isolate (Figure 2B). Similarly, tuber rot was observed on the control tuber slices in all replicates, while less *P. infestans* (using ASO and 1-12-25 isolates) development was detected in the KPhi treated samples three weeks after inoculation. In this experiment, Cv. Xinjia No. 2 showed a minor lesion diameter followed by Cv. Zhongshu No. 3, and the most susceptible variety was Cv. Minshu No. 3, as shown in (Figure 2A and 2B). In all three cultivars, the ASO showed the largest lesion size compared to 1-12-25 in all treated samples (Figure 2).

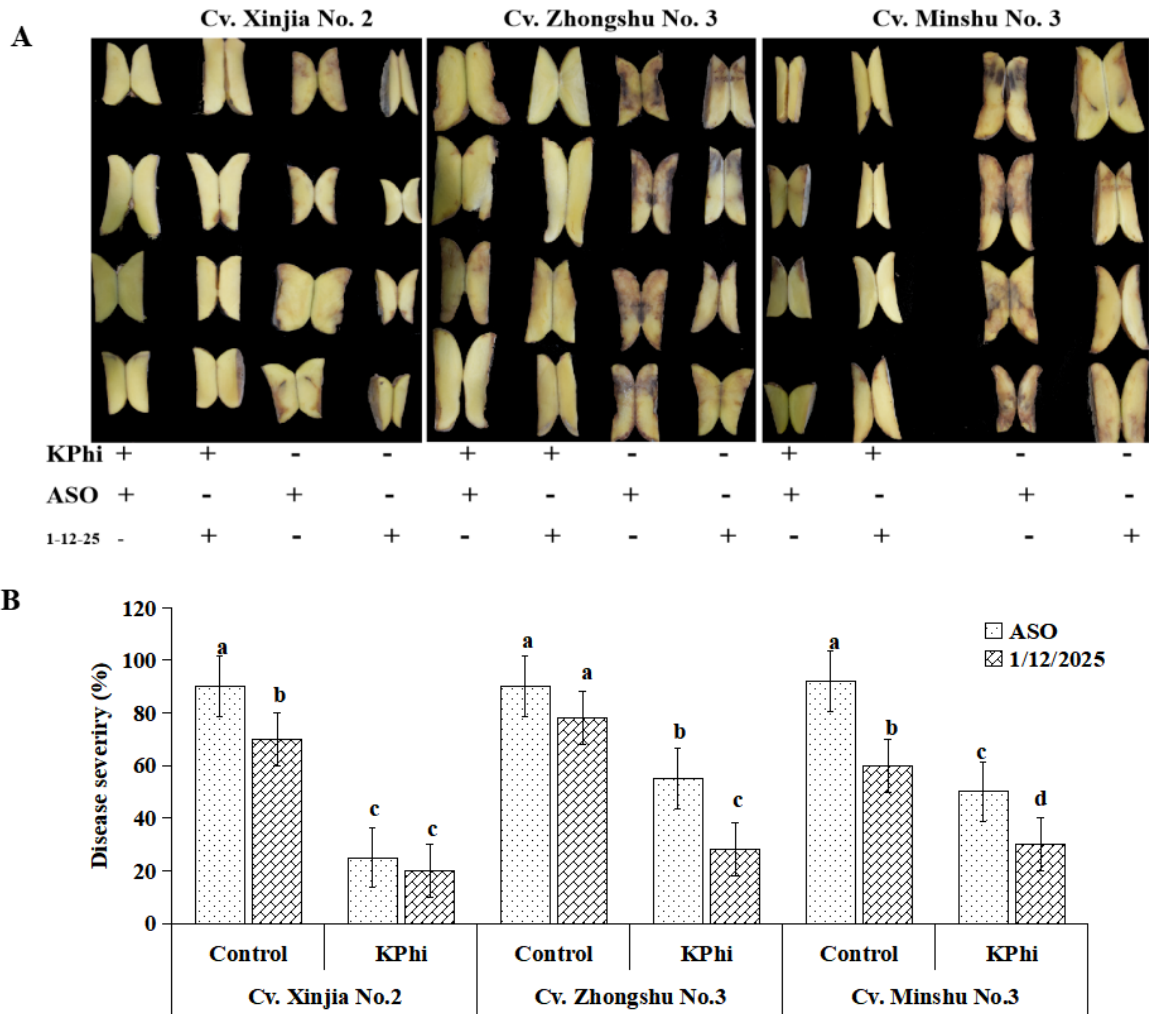


Figure 2: Effect of postharvest application of KPhi on late blight severity in half potato tubers of three potato cultivars (Cv. Xinjia No. 2, Cv. Zhongshu No. 3, and Cv. Minshu No. 3) after 21 days of inoculation by two *P. infestans* isolates ASO and 1-12-25. A Symptom at 21 days after the tubers infection with *P. infestans* isolates “+” indicates KPhi treated or inoculated; “-” indicates without KPhi treatment or inoculation. B Disease severity index. Means followed by different letters within the same column indicate statistically significant differences at $P < 0.05$, as determined by Tukey’s test.

Effect of postharvest KPhi treatment on late blight development in potato tuber slices

Potato slices exposed to postharvest KPhi treatment were inoculated with *P. infestans* isolates ASO and 1-12-25, and the late blight symptoms were recorded three weeks after incubation. The highest degree of rotten area was recorded in Cv. Minshu No. 3 control tubers, followed by Cv. Zhongshu No. 3 and then in Cv. Xinjia No. 2 (Figure 3). KPhi treatment protected tubers from late blight with the highest protection recorded in Cv. Xinjia No. 2, medium protection in Cv. Zhongshu No. 3 and less protection in Cv. Minshu No. 3. Our results demonstrated that, across all experiments, the ASO isolates exhibited greater aggressiveness (Figure 3).

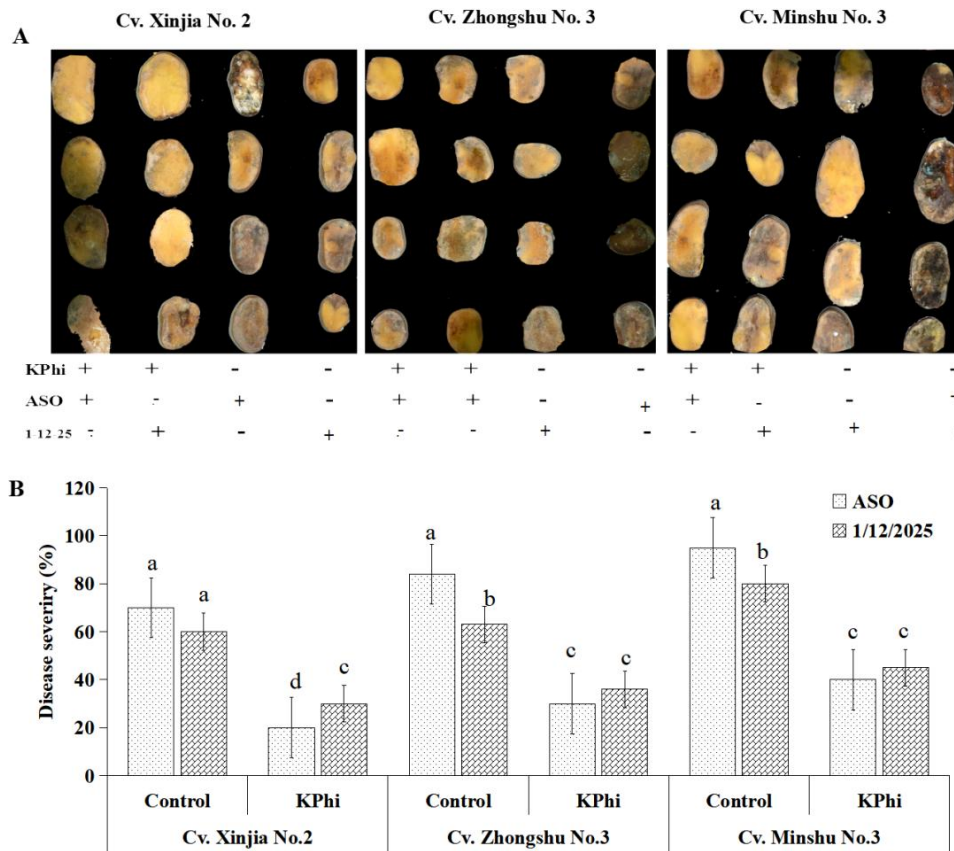


Figure 3: Effect of post-treatment application of KPhi on tuber slices of three potato cultivars (Cv. Xinjia No. 2, Cv. Zhongshu No. 3, and Cv. Minshu No. 3) after 21 days of inoculation by two *P. infestans* isolates, ASO and 1-12-25. A Symptom at 21 days after half tubers infection with *P. infestans* isolates “+” indicates KPhi treated or inoculated; “-” indicates without KPhi treatment or inoculation. B Disease severity index. Means followed by different letters within the same column indicate statistically significant differences at $P < 0.05$, as determined by Tukey’s test.

Discussion

The potato cultivars Cv. Xinjia No. 2, Cv. Zhongshu No. 3 and Cv. Minshu No. 3 were grown at San Ming City, Fujian Agriculture and Forestry University Research Base. In this study, plants were subjected to foliar applications of potassium phosphite (KPhi) or postharvest treatment of KPhi. Both modes of KPhi treatments significantly reduced the susceptibility of tubers to late blight. The amount of 1% KPhi applied 3 or 5 times during the growing season effectively protected the whole tubers and tuber slices from the pathogen attack. These findings are in agreement with previous research. For instance, (Lobato et al., 2011) reported that multiple foliar applications of 1% KPhi (equivalent to 3 L/ha) reduced the sensitivity to *P. infestans* of cultivar Shepody tubers by about 50%. Similarly, (Cooke & Little, 2002; Johnson et al., 2004) observed a reduced susceptibility to tuber rot after KPhi treatment. (Cooke & Little, 2002) also showed that five to six sprays of various phosphite formulations at a rate of 2 kg/ha minimized tuber infection across all cultivars, with more than 80% reduction of tuber susceptibility to *P. infestans*. However, the authors pointed out that too much application of Phi may not be economical. Therefore, multiple foliar applications

are sufficient to provide significant protection against tuber decay during the growing season and subsequent tuber protection in storage.

These studies have shown that high application frequency is required, including four or more applications of Phi to inhibit *P. infestans* (Cooke & Little, 2002; Johnson et al., 2004). Moreover, (Borza et al., 2014; Lobato et al., 2011) reported that the foliar applied Phi rapidly induces defense responses in potato leaves, but these effects are transient. Phosphites are known to cause a broad range of structural and biochemical defense responses in potato plants and tubers (Mohammadi et al., 2019). Upon application, Phi does not directly serve as a phosphorus source for plant metabolism in the same way as phosphate, but instead triggers defense-related signaling pathways. Several studies have shown that Phi enhances the activity of antioxidant enzymes (superoxide dismutase, peroxidase, and catalase) and promotes the accumulation of phenolic compounds and phytoalexins, which restrict pathogen colonization (Dormatey et al., 2021; Lobato et al., 2008; Mohammadi et al., 2019).

Structural barriers also contribute to Phi-induced resistance. In potato tubers, Phi treatment has been reported to enhance cell wall fortification through lignification and suberization, thereby reducing tissue maceration and pathogen penetration (Borza et al., 2017; Lobato et al., 2024). Increased deposition of callose and cross-linking of cell wall proteins have also been observed, further limiting the spread of *P. infestans* (Wang et al., 2021).

On the chemical level, Phi can modulate the accumulation of defense-related secondary metabolites, such as flavonoids and phenolics, while also influencing hormonal signaling networks involving salicylic acid and jasmonic acid, which are crucial in the regulation of plant immune responses (Dalio et al., 2014; McDonald et al., 2001). Moreover, transcriptome analyses have shown that Phi alters the expression of genes associated with stress and defense, suggesting a role in priming plants for faster and stronger responses upon pathogen attack (Lobato et al., 2008).

Thus, further research is needed to demonstrate whether Phi's indirect mode of action would play an essential role in tubers. In any case, the direct mode of action of Phi, whose concentration plays a role in various tuber tissues, is likely to play a significant role in the resistance to oomycete pathogens of the tubers in storage. In our study, the postharvest treatment of KPhi was able to protect the outer surface of tubers. Therefore, if pathogens succeed in infecting tuber before or during harvest, postharvest treatment using KPhi can efficiently reduce the disease development on the tuber surface. The results in this study suggest that at least three applications of KPhi during the growing season are required to produce tubers with enhanced resistance to late blight in the three cultivars tested. Postharvest application of KPhi is required to enhance tubers against late blight during storage.

Conclusion

Over the past two decades, extensive research and field trials by plant protection experts have underscored the efficacy of phosphite (Phi) treatments, particularly potassium phosphite (KPhi) in managing *P. infestans* infection in potato crops. The current study, conducted using cultivars Xinjia No. 2, Zhongshu No. 3, and Minshu No. 3 at Fujian Agriculture and Forestry University, further validates the findings that both foliar and postharvest KPhi treatments significantly reduce tuber susceptibility to late blight. Foliar applications of 1% KPhi, applied three to five times during the growing season, were effective in protecting both whole tubers and slices, aligning with prior studies showing disease reduction up to 80%. Postharvest applications were also effective, particularly in safeguarding the tuber surface from infections present even

at or before harvest. However, the transient nature of Phi-induced defenses and the cost involved in multiple applications suggest the need for a balanced approach.

Collectively, the evidence points to an integrated strategy: a minimum of three foliar applications of KPhi during the growing period, combined with a postharvest treatment that offers a practical and effective method for tuber late blight management. While the phenotypical evidence showed that the direct action of Phi on the pathogen appears to have protective effects on pathogen growth, further investigation into its indirect and systemic roles in enhancing tuber resistance is warranted to optimize disease management protocols.

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