# Potassium silicate in the management of anthracnose in post-harvest bananas

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## Abstract

This study aimed to evaluate the efficacy of a potassium silicate-based product to manage anthracnose in post-harvest bananas. A randomized block design with one plate per plot, six treatments, and 10 replications were used in the *in vitro* experiment. The mycelial growth velocity index of the pathogen *Colletotrichum musae* was evaluated under the following treatments: registered fungicide (chemical group benzimidazole; 4 mL $L^{-1}$), control (no application), and four doses of potassium silicate (15, 30, 45, and 60 mL $L^{-1}$ concentrations). An *in vivo* experiment was installed in randomized blocks with three fruit per plot, three treatments, and 10 replications. The fruit were sanitized and immersed in a solution with the following treatments: fungicide (4 mL $L^{-1}$), potassium silicate (60 mL $L^{-1}$; the dose calculated in the *in vivo* experiment), and control (autoclaved distilled water). They were immersed for three minutes and allowed to dry for 12 hours. The center of the dried fruit was incised so a mycelium of the pathogen disc could be inserted. The fruit were kept in a humid chamber for 12 days at a temperature of 25 °C. Anthracnose severity was evaluated every 24 hours. In the *in vitro* experiment, increasing the tested potassium silicate dosages more greatly inhibited the pathogen. In the *in vivo* experiment, fruit treated with potassium silicate showed a reduced disease progression.

**Keywords:** Integrated management. *Colletotrichum musae*. Phytopathology.

## Introduction

The banana (*Musa* spp.), belonging to the Musaceae family, is a fruit tree that is typical of humid tropical regions. It constitutes the food base for millions of people in various economic classes around the world (Ayres, 2022). Among fruits, bananas stand out for their social and economic relevance in Brazil (being surpassed only by citrus cultivation). Brazilians consume an average of 25 kg per person per year (Araújo *et al*., 2019).

India leads the world in banana production, followed by China, Indonesia, and Brazil (Albuquerque, 2022). More than 465 thousand hectares in the latter produce bananas to supply domestic and foreign markets. The main exporting states in 2021, 2022, and 2023 were Santa Catarina (49%), Ceará (21%), Rio Grande do Sul (14%), and Rio Grande do Norte (7%) and the main export destinations were Uruguay (40%), Argentina (39%), the Netherlands (8.52%), and Poland (3%) (Conab, 2023).

After harvest, banana losses can total about 40% of production, a significant part of which is due to pre- and post-harvest fungal infections that lead to fruit spots and rot (Cordeiro, Matos, Kimati, 2016; Medeiros, 2020). A major problem in the production chain of many crops is the existence of pathogens that cause post-harvest diseases that compromise the quality of the fruit and limits their commercialization (Aguiar, 2019).

Bananas are widely marketed as one of the main fresh fruits, offering considerable economic relevance due to its high energy content and nutritional value, making it one of the most consumed foods (Lorenzetti *et al*., 2019). As a climacteric fruit, bananas have a short ripening period, resulting in reduced conservation time (Falcão *et al.*, 2017).

Several types of contamination can occur in bananas as their crop falls subject to several phytosanitary problems. Anthracnose constitutes one of the main diseases affecting banana crops. The disease, caused by the fungus *Colletotrichum musae* (Berk. & M.A. Curtis) Arx, 1957 (*Myxosporium musae*), can occur in the field, but its problems are related to the post-harvest period. Anthracnose forms depressed dark lesions that are more extensive longitudinally. The pathogen causes necrotic lesions on the skin and pulp of bananas that increase in size and can coalesce as the disease progresses, compromising crop appearance and facilitating the entry of rot-causing fungi, reducing the quality and price of the product (Coelho *et al.*, 2010).

*C. musae* spores dispersed in the air are deposited on the fruits, in which they germinate, form appressoria, and penetrate crops (Cordeiro, Matos, Kimati, 2016). Wounds on fruits facilitate the penetration of this fungus, so all cultivation and post-harvest practices must be carried out to minimize these injuries as much as possible. Thus, chemical control remains the most common method of treating this disease.

However, the use of post-harvest chemical fungicides has been questioned due to their risks to human health and the environment, expanding the search for healthy foods, especially with little or no application of chemical pesticides. Such search has entailed the study of new control techniques to manage these phytopathogens before and after harvests to minimally impact food and the environment and offer economically viable alternatives (Hermida, Pelaez, Da Silva, 2015).

An alternative for sustainable disease management refers to using silicon-based products as they have benefited pest and disease control and crop resistance to abiotic factors (Datnoff, Snyder, Korndörfer, 2007). Many studies are focusing on silicon as an alternative tool to manage various crops. Thus, this study aimed to evaluate the efficacy of a potassium silicate-based product to manage anthracnose in harvested bananas.

## Material and methods

This study was developed at the Phytopathology Laboratory at Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, campus Machado.

The pathogen was directly isolated from bananas of the 'BRS princesa' variety showing typical symptoms of the disease. The fruit were purchased in the local trade of Machado, Minas Gerais. Fragments of mycelial structures of the pathogen were extracted from the epicarp of the fruit with a sterile needle, transferred to a potato dextrose agar culture medium, and kept in Petri dishes in a biochemical oxygen demand chamber at a temperature of 25°C ± 2°C and a 12 h (light/dark) photoperiod (Carollo, Santos, 2016; Reis *et al*., 2024). After being placed in pure culture, the colonies and structures of the fungus were confirmed by naked-eye observation, stereoscopic microscope, and a 400-×-magnification microscope and compared to the results in the literature.

An *in vitro* experiment was carried out to evaluate the antifungal activity of the potassium silicate-based product on the development of the fungus *C. musae*. It consisted of six treatments: registered fungicide (chemical group: benzimidazole) at the dosage recommended by the manufacturer, T1 = 4 mL $L^{-1}$; T2 = control without fungicide or potassium silicate; and four concentrations of the potassium silicate-based product: T3 = 15 mL $L^{-1}$, T4 = 30 mL $L^{-1}$, T5 = 45 mL $L^{-1}$, T6 = 60 mL $L^{-1}$. A randomized block design with one plate per plot, six treatments, and 10 replications were used in this experiment.

A commercial product based on potassium silicate was used for the treatments, which this study called an alternative product due to its uncommon use in the traditional chemical control of plant diseases. The product is a formulation with $P_2O_5$ (12.0% w/w; 165.6 g $L^{-1}$) and water-soluble silicon (12.0% w/w; 165.6 g $L^{-1}$). Thus, the 15, 30, 45, and 60 mL $L^{-1}$ concentrations corresponded to 4.968, 9.936, 14.904, and 19.872 g $L^{-1}$, respectively. For comparisons, a registered systemic fungicide of the chemical group benzimidazole for the crop was used, which has thiabendazole (2-(thiazol-4-yl) benzimidazole) at a concentration of 4 mL $L^{-1}$, corresponding to 1.94 g $L^{-1}$, in its composition.

In Erlenmeyers flasks, 250 mL of a BDA medium were prepared and autoclaved. With the culture medium still fluxing, the dosages of potassium silicate and fungicide were pipetted separately. Then, 10 mL were poured into each Petri dish with 85 mm in diameter. After 24 hours, a 5-mm disk containing a mycelium of the pathogen was transferred to the center of the Petri dishes of all treatments, which were then stored in a in a BOD chamber at a temperature of 25° ± 2°C and a 12-hour (light/dark) photoperiod (Reis *et al.*, 2024).

The plates were perpendicularly measured every 24 hours with a digital caliper up to the moment in which the control mycelium reached the edges of the Petri dish to track the advance in the size of the colonies (Reis *et al*., 2024).

To evaluate the mycelial growth of the pathogen, the mycelial growth velocity index (MGVI) was calculated by daily measurements and the following equation:

$$MGVI = \sum \frac{D - p\,D}{N}$$

In which: *D* is the current average diameter of the colony (mm), p*D* is the average diameter of the colony on the previous day (mm), and *N* is the number of days after the inoculation.

In the *in vivo* experiment, 'Apple' bananas were harvested from the orchard at Instituto Federal de Educação, Ciência e Tecnologia do Sul de Minas Gerais, campus Machado, at maturation stage 2 (yellowish green, marking the beginning of fruit ripening). They were then transported to the Laboratory, selected, sanitized with neutral detergent and running water, and left to dry for 12 hours at room temperature. After drying, they underwent disinfestation in a 1% (v/v) sodium hypochlorite solution, rinsed in autoclaved distilled water, left on the bench at room temperature for 12 hours, and divided according to each treatment (Coelho *et al*., 2010; Mafra *et al*., 2020). The *in vivo* experiment was installed in randomized blocks with three fruit per plot, three treatments, and 10 replications, totaling 90 fruit.

The fruit were immersed in the solution containing the following treatments: T1 = commercial fungicide (4 mL $L^{-1}$), T2 = potassium silicate (60 mL $L^{-1}$ concentration with higher pathogen inhibition in the *in vitro* experiment), and T3 = control (autoclaved distilled water). They were immersed for three minutes and allowed to dry for 12 hours. After drying, the fruit received a wound in their central region spanning about 5 mm in diameter 3 mm deep in their epicarp by a scalpel in which a mycelium disc of the same diameter from the colony of the pathogen developed in the BDA medium was inserted (Coelho *et al*., 2010).

After treatment, the fruit were placed in plastic trays and incubated in a wet chamber and packed in a biochemical oxygen demand chamber at 25°C. After 48 hours, anthracnose severity was evaluated (size of the lesion per fruit, measured by a digital caliper) and its average for 12 successive days was calculated.

After obtaining the severity results, the area under the disease progress curve (AUDPC) was calculated by the equation in Shaner and Finney (1977):

$$AUDPC = \sum_{i=1}^{n-1} \left( \frac{y_i + y_{i+1}}{2} \right) \left( t_{i+1} - t_i \right)$$

In which $n$ is the total number of evaluations and $y_i$ and $y_{i+1}$ are two consecutive severity assessments over time ($t_{i+1} - t_i$), respectively.

All data were subjected to analysis of variance. The standard error of the mean was calculated, followed by a regression or mean comparisons by the Scott-Knott cluster test (Scott, Knott, 1974) at a 5% probability ($p \leq 0.05$) on the SISVAR software (Ferreira, 2019).

## Results and discussion

Figure 1 shows that the inhibition of the pathogen increased with dosages. The maximum used dosage (60 mL $L^{-1}$) and the commercial fungicide offered the greatest inhibitory action on the mycelial growth of *C. musae*. Comparing potassium silicate dosages showed no significance for the 15 or 30 mL $L^{-1}$ doses.

The mycelial growth velocity index under the potassium silicate-based product shows that potassium silicate significantly interfered in the development of *C. musae*, notably reducing its growth at a concentration of 60 mL $L^{-1}$ when compared to the control (Figure 2). However, the 15, 30, and 45 mL $L^{-1}$ dosages were unable to completely inhibit the growth of the pathogen.

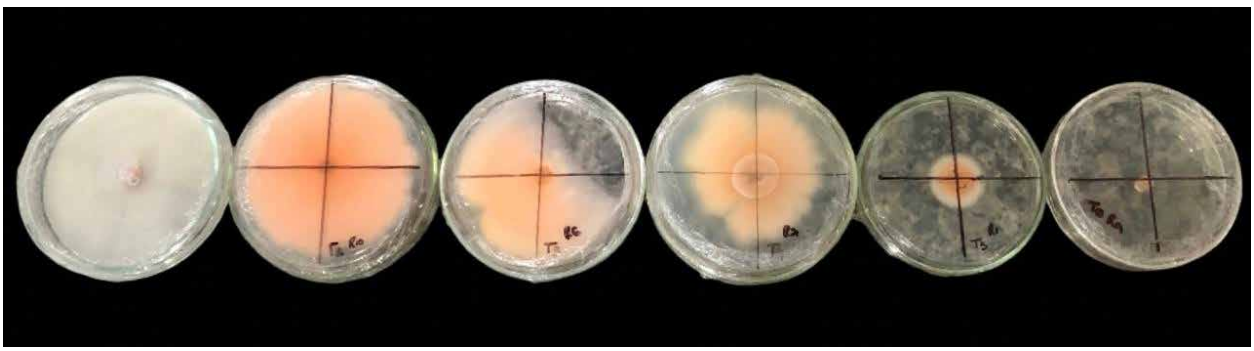
The *in vivo* experiment showed *C. musae* colonies with a smaller average size in the fungicide and potassium silicate treatments than in the control (Figure 3).

In Dias *et al.* (2009), potassium silicate inhibited the growth of the fungi *Botrytis cinerea* and *Cylindrocladium* sp. from the 40 mL $L^{-1}$ dosage upward. Such inhibition may have been due to the increase in the pH of the culture medium since this alkaline product has a buffering power. High pH more greatly inhibited *B. cinerea* that *Cylindrocladium* sp., but this difference may be related to pH and higher potassium concentrations in the culture medium. *B. cinerea* growth decreased when the pH exceeded 10, suffering total inhibition above pH 12.5 (Silva, Duarte, Coelho, 2010).

Amaral *et al*. (2008) found that potassium silicate affected the development of the fungus *Cercospora coffeicola*, indicating the fungitoxic effect of their product. The spore germination and mycelial growth of *Hemileia vastatrix* and *Phoma* sp. also directly suffered in contact with potassium silicate or phosphite (Nojosa, 2003). However, silicon, the presence of potassium, or the change in pH may have influenced these results.

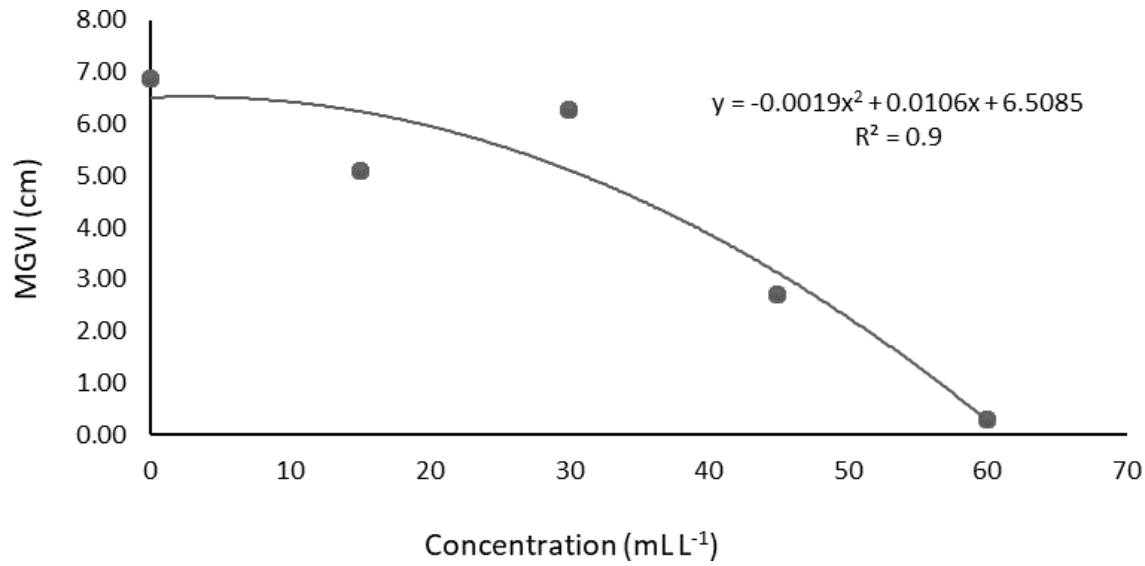
Silicon has fungicidal activity against a variety of fungi, such as *Fusarium spp*. and

**Figure 1.** Direct action of several concentrations of potassium silicate in a potato dextrose agar culture medium on the development of *Colletotrichum musae*. Treatments are represented from left to right: fungicide (4 mL $L^{-1}$), control (0 mL $L^{-1}$), and 15, 30, 45, and 60 mL $L^{-1}$ concentrations, respectively. Machado-MG, 2023.



**Source:** authors (2023).

**Figure 2.** Mycelial growth velocity index (MGVI) of *Colletotrichum musae* under a potassium silicate-based product at concentrations equal to 15, 30, 45, and 60 mL $L^{-1}$ concentrations after seven days of incubation. Machado-MG, 2023.

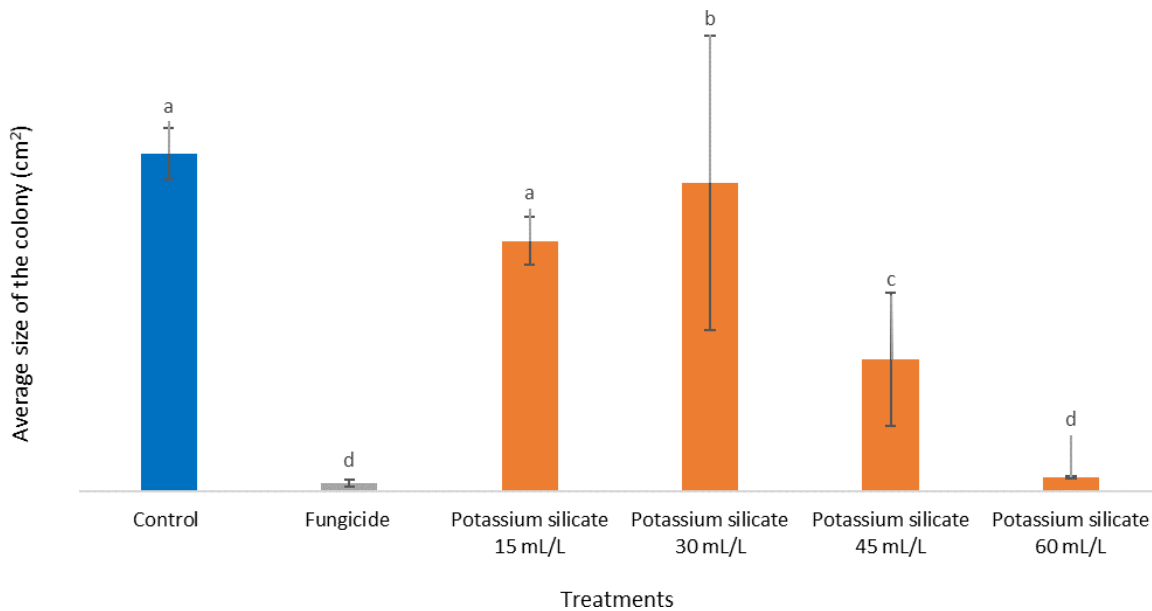



**Source:** authors (2023).

*Verticillium spp*., the growth of which significantly decreases under 5 and 10 mL of silicon. Although both pathogens belong to the same taxonomic group (Ascomycota), the observed responses differ between *Fusarium spp*. and *Verticillium spp*. (Kaiser *et al.*, 2005).

Comparing the treatments with the commercial fungicide and potassium silicate showed that bananas treated with the fungicide suffered a significant reduction in disease intensity throughout the evaluation period. However, note that the commercial fungicide was also

**Figure 3.** Average size of *Colletotrichum musae* colonies under a potassium silicate-based product in 15, 30, 45, and 60 mL $L^{-1}$ concentrations, control, and the fungicide thiabendazole (4 mL $L^{-1}$), seven days after inoculation. The bars indicate the standard error of the average, 2023. Machado-MG, 2023.




**Source:** authors (2023).

unable to completely inhibit the development of anthracnose (Figure 4).

Regarding the average severity of anthracnose in bananas, the treatments with the commercial fungicide and control failed to differ at the level of 5% of significance on the first day of evaluation. The treatment with potassium silicate obtained fruit with smaller lesions than both treatments above, corroborating its fungistatic effect. From the second to the twelfth evaluation day, a difference occurred in the three treatments since the commercial fungicide treatment stood out from the others, followed by potassium silicate (Figure 4).

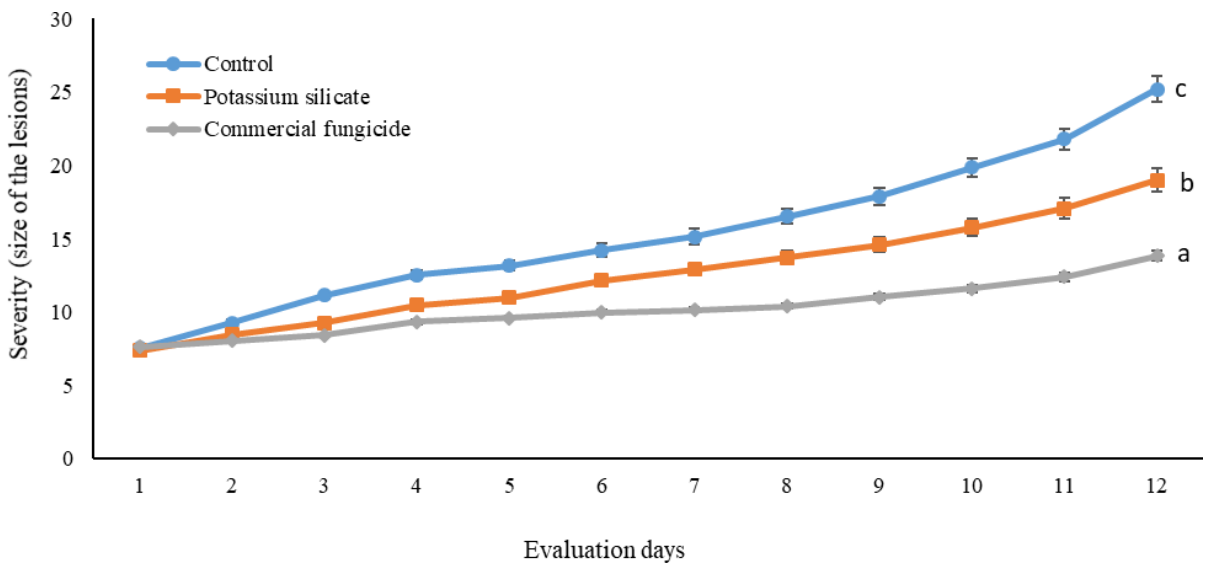
The area under the disease progress curve decreased in the treatment with the commercial fungicide, followed by that with potassium silicate, when compared to the control (Figure 5).

Figure 6 shows the triads representing each treatment, evincing the lesions under a homogeneous pattern of development. The control showed that the mycelial discs of *C. musae* that had been inoculated into the fruit had considerably grown and were surrounded by more aggressive necrotic lesions. The treatment with potassium silicate shows more harmonious concentric circles, and the mycelial disc is surrounded by a poorly developed necrotic halo, whereas the treatment with the application of the commercial fungicide shows the lesser development of the pathogen. Potassium silicate reduced the progression of the disease (Figure 6), offering an alternative for the postharvest management of anthracnose in 'Apple' bananas.

Results showed how potassium silicate suppressed the harmful effects of *C. musae* in bananas by promoting the viability and quality of postharvest agronomic attributes) despite the greater pathogen control of the fungicide treatment).

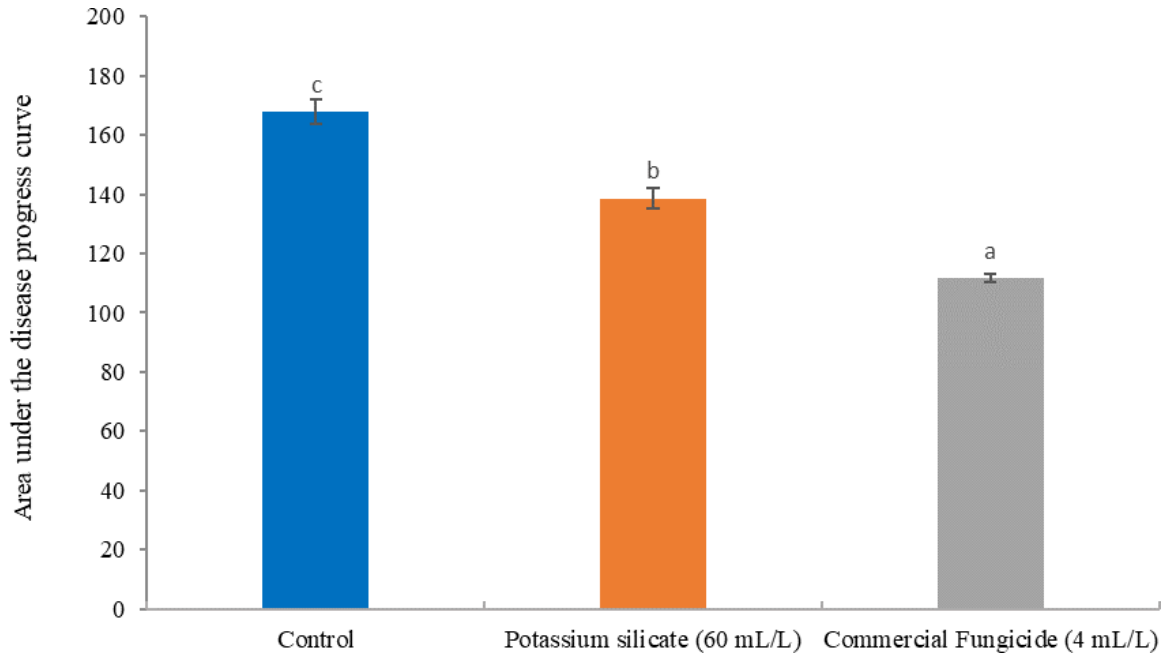
Thus, potassium silicate may serve as a tool to manage anthracnose in bananas and as a vehicle for the commercial availability of the fruit with fewer chemical residues.

**Figure 4.** Mean severity (size of lesions – $cm^2$) of anthracnose in bananas under the following treatments: control; potassium silicate (60 mL $L^{-1}$) and commercial fungicide (4 mL $L^{-1}$), kept at a temperature of 25°C for 12 days of evaluation. Means followed by the same letter in the column fail to differ from each other by the Scott-Knott test ($p \leq 0.05$) on the twelfth day of evaluation. The bars indicate the standard error of the average. Machado-MG, 2023.




**Source:** authors (2023).

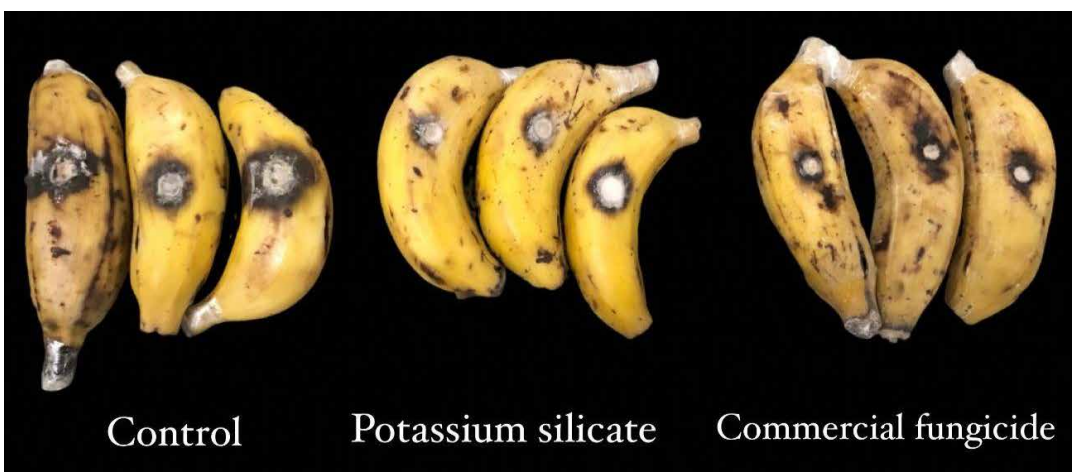
**Figure 5.** Area under the disease progress curve of anthracnose severity (lesion size) in harvested bananas: control, potassium silicate (60 mL $L^{-1}$), and commercial fungicide (4 mL $L^{-1}$ dosage indicated by the manufacturer), inoculated with *Colletotrichum musae* after their harvest, kept at a temperature of 25°C in a biochemical oxygen demand chamber, and evaluated for 12 days. The bars indicate the standard error of the average. Machado-MG, 2023.




**Source:** authors (2023).

The influence of silicon on the physiology of a range of phytopathogenic fungi, including species of the genus *Fusarium*, has undergone discussion. Conceição (2010) observed the effect of silicon sources in inducing resistance against *Fusarium oxysporum* f.sp. *lycopersici* in tomatoes, observing a reduction of around 27.3% in the severity of that fungal disease. The mitigation of disease severity in plants under silicon treatment can be attributed to

**Figure 6.** *In vivo* experiment to evaluate a potential alternative to be applied after harvests to manage anthracnose in bananas. The figure represents the twelfth day of evaluation of previously treated fruit that were inoculated with *Colletotrichum musae*. Treatments included control, potassium silicate (60 mL $L^{-1}$), and commercial fungicide (4 mL $L^{-1}$ dosage indicated by the manufacturer), respectively. Machado-MG, 2023.




**Source:** authors (2023).

the formation of structural barriers that affect the ability of fungal penetration into host cells. Ultrastructural observations suggest that the silicification of cell walls acts as a physical barrier in containing the pathogen (Heath, Stumpf, 1986).

Research with potassium silicate in other species has indicated improved physicochemical properties and postharvest quality, such as increased firmness, ascorbic acid content, and soluble solids (Marodin *et al*., 2016). Moreover, spraying plants with silicate sources increased the shelf life of the fruit and decreased microbial activity (Islam *et al*., 2018).

While silicon predominantly accumulates in vacuolar spaces as crystallized structures and as precipitates in the cytoplasm and on the tonoplast (forming the vacuole walls), its final form almost immutably manifests itself as amorphous silica gel (Silva *et al*., 2009).

Marodin *et al*. (2016) highlighted that the cultivation of tomato plants fertilized with calcium, potassium, and sodium silicate as sources of silicon improved post-harvest conservation. In a study on cherry tomatoes, Islam *et al*. (2018) showed that the foliar application of silicon dioxide increased fruit firmness during harvest (which remained after storage). This extended their shelf life and increased their vitamin C content.

Resende *et al*. (2005) found that potassium silicate increased yield and better conserved harvested iceberg lettuce during summer cultivation. However, they observed that the time of application directly affected silicon in post-harvest conservation. Elsherbiny and Taher (2018) that silicon can effectively control *Sclerotinia sclerotiorum*, the pathogen that rots carrots in post-harvest storage. As in vegetables, silicates have been studied as a strategy for post-harvest conservation to maintain quality and reduce losses.

On the other hand, potassium, although absent from the molecular structure of plants, constitutes an essential nutrient for plant growth (Wang, Wu, 2017). It regulates stomatal conductance, photosynthesis, enzyme activation, cell turgidity, and tolerance to salt stress, directly influencing plant yield and quality.

According to Lu *et al*. (2015), properly applying potassium increases its concentration in leaves and fruits, improving their mass and quality. Potassium is also related to aspects such as fruit growth, skin thickness, and tissue turgidity control, and is crucial for productivity (Anjos *et al*., 2015). Potassium deficiency, according to Zhang, Liang, and Chu (2017), reduces fruit size and productivity. Lee and Kader (2000) reported increased membrane integrity and vitamin C content in silicon-treated watermelons. Other authors have evinced the potential benefits of silicate fertilization as they observed an increase in yield due to larger berries and improved postharvest quality parameters of table grapes (Zhang, Liang, Chu, 2017).

In other studies, applying potassium silicate in melons significantly reduced the post-harvest incidence and severity of *Alternaria alternata*, *Fusarium semitectum*, and *Trichothecium roseum*. This effect was attributed to the increase in the enzymes peroxidases and chitinases (Bi *et al*., 2006). Peroxidases play an important role in lignin biosynthesis and the binding of protein to cell wall tissues, strengthening the resistance of these tissues against pathogen penetration (Inbar *et al.,* 2001). In turn, chitinases can hydrolyze the cell walls of several phytopathogenic fungi (Van Loon, 1997). In addition to these potential action mechanisms of silicon in the protection of plant tissues against pathogens, chitinases can reduce the turgor pressure (dehydration) in fungal cells, resulting in the collapse and retraction of hyphae and spores and decreasing the capacity for sporulation and perpetuation of these fungi (Bi *et al.*, 2006).

## Conclusions

The *in vitro* speed of pathogen mycelial growth decreases as potassium silicate dosages increase, with greater inhibition at 60 mL $L^{-1}$ dosage.

Regarding the *in vivo* management of anthracnose, considering the diameter of the lesions on the twelfth day of evaluation, a 24% reduction in the area under the disease progress curve occurred in bananas treated with potassium silicate when compared to the control.

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