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Short communication

Potassium silicate and chitosan application for gray mold management in strawberry during storage

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ABSTRACT

The objective of this study was to investigate the effect of silicon and chitosan as alternative controls for postharvest rot of strawberries (gray mold) caused by *Botrytis cinerea*. Chitosan and potassium silicate applications were performed at the preharvest stage using the following treatments: chitosan once a week; potassium silicate once a week; potassium silicate once a week + chitosan once a week; and without application. An additional variable was introduced at postharvest, with one-half of the total fruit harvested from each plot dipped in chitosan and the other half not dipped in chitosan. Potassium silicate alone was not effective for rot control. Fruits from plants that received the chitosan application showed 64% less area under the rot progress curve (AURPC) than fruits from plants that were not treated with chitosan. Harvested fruits that were chitosan dipped showed 48% less AURPC than fruits that were not treated at postharvest. Chitosan application in the field and at postharvest is a promising strategy for the management of postharvest strawberry rot.

Postharvest rot is a major problem in strawberry production. Many pathogens cause postharvest rot. One of these pathogens is *Botrytis cinerea* Pers, which causes gray mold, considered the main disease of strawberry in Brazil (Zambolim and Costa, 2006; Costa et al., 2011). To control this disease, several fungicide applications are necessary (Maas, 1998; Zambolim and Costa, 2006; Costa et al., 2011). The growing demand for fresh produce free of chemical residues has stimulated the search for alternative methods of control in this crop (Costa et al., 2011).

Mineral nutrition may be easily manipulated and used as a complement to other disease control strategies (Marschner, 1995). Among the elements that are beneficial to plants, silicon (Si) has shown promising results in the control of many diseases in several crops (Datnoff et al., 2007). The application of potassium silicate to strawberry fields was found to be effective for powdery mildew control, reducing the disease up to 85% if applied to soil (Kanto et al., 2006). This disease was completely eliminated if strawberry plants were cultivated in nutritive solution to which 50 ml L^{-1} of potassium silicate had been added (Kanto et al., 2004). The application of potassium silicate at a dose of 30 g L^{-1} to strawberry leaves reduced the severity of pestalotia spot by 61% (Carré-Missio et al., 2010). Potassium silicate applications on orange reduced the severity of green mold caused by *Penicillium digitatum* by 23% when applied in the preventive form and 40% when applied in the curative form (Moscoso-Ramírez and Palou, 2014).

Chitosan is emerging as an alternative for the management of diseases in fruits at the postharvest stage (Bautista-Baños et al., 2006; Romanazzi, 2010). A direct antifungal effect of chitosan has been observed in *B. cinerea*,. The growth of this pathogen was completely inhibited if 125 g L^{-1} of chitosan was added to the culture medium (Reglinski et al., 2010). Strawberry fruit from plants treated with chitosan in the field in doses of 0.5, 1 and 2% showed a reduced incidence of postharvest rot (Mazaro et al., 2008). The postharvest incidence of strawberry rot decreased with increased concentrations of chitosan (2, 4 and 6 g L^{-1}) applied to strawberry plants (Bhaskara Reddy et al., 2000).

Information related to the effects of silicon in the postharvest control of disease in strawberry is lacking in the literature. The postharvest use of chitosan has been studied frequently in many crops. However, studies of chitosan in combination with other compounds are lacking. Therefore, studies of the effects of applications of potassium silicate and chitosan in strawberry and the

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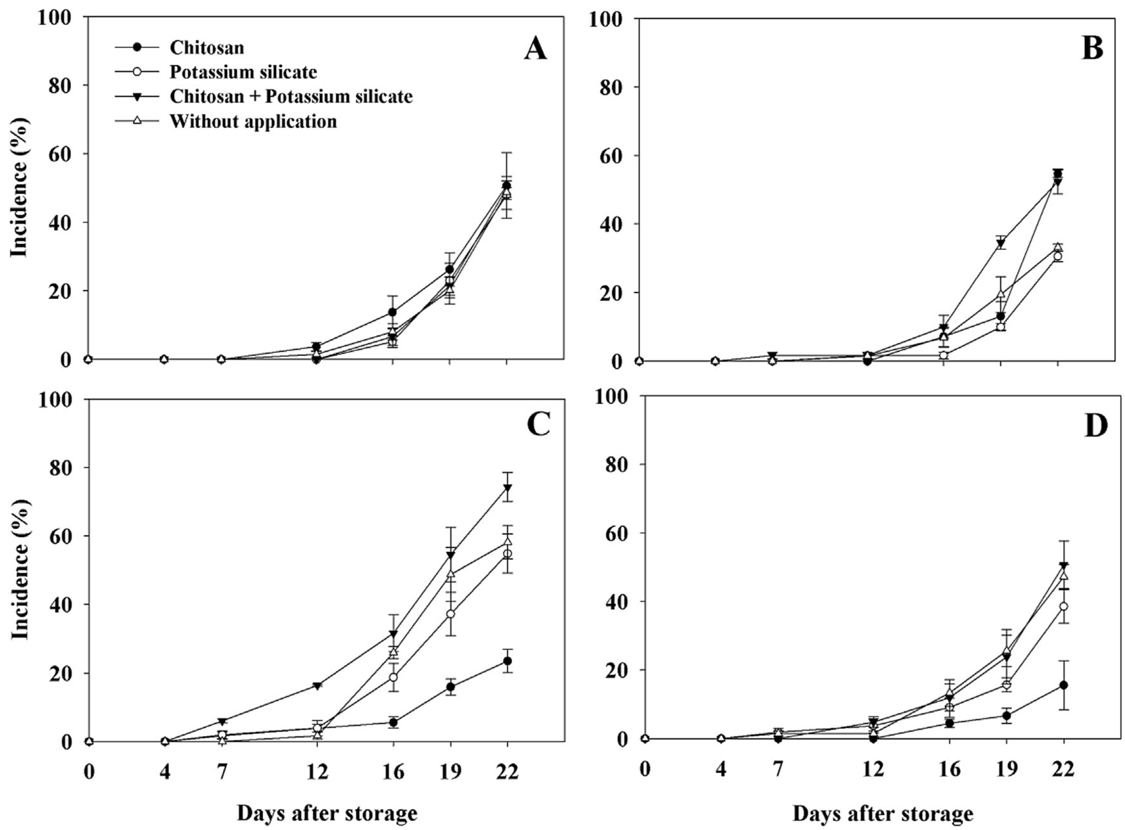

Fig. 1. Cumulative curve of incidence of gray mold in Experiment 1, showing rot incidence in fruits without additional chitosan treatment at postharvest (A) and in fruits treated with chitosan at postharvest (B). Cumulative curve of incidence of gray mold in Experiment 2, showing rot incidence in fruits without additional chitosan treatment at postharvest (C) and in fruits treated with chitosan at postharvest (D). The error bars represent the standard error of the mean. Data are from two pooled experiments ($n = 6$).

effect of these applications on rot caused by *B. cinerea* is important because these studies provide information about alternatives to chemical control. Therefore, the objective of this study was to investigate the effects of potassium silicate and chitosan alone and in combination on the progress of Botrytis rot in strawberry fruit during a storage period.

Two experiments were performed in a commercial strawberry production environment in Santa Maria de Jetibá, Espírito Santo, Brazil from March to July 2010. The strawberry cultivar 'Camarosa' was used in experiment 1 (Exp 1), and the cultivar 'Oso Grande' was used in experiment 2 (Exp 2). These strawberry cultivars are among those most frequently cultivated in Brazil. The crop was planted in beds 25 cm in height covered with black plastic mulch and equipped with drip irrigation. Each bed had two rows of plants with 35 cm spacing between rows and 25 cm spacing between plants. After 30 days of cultivation, the beds were covered with translucent plastic to a height of 70 cm (a low tunnel).

Two factorial experiments were performed in a (4 × 2) randomized complete block design. Four applications were made in the field and two at postharvest, and three replications were used. The two experiments were performed twice, and Cochran's test for homogeneity of variance (Gomez and Gomez, 1984) indicated that the data from the two experiments could be pooled for data analysis.

The chitosan and potassium silicate applications were performed at the preharvest stage during five weeks on three distinct plots according to the following treatments: chitosan once a week; potassium silicate once a week and potassium silicate + chitosan once a week (in two different applications). One additional plot without application of the product was included in this experiment. The additional variable of a chitosan dip was introduced at postharvest. The chitosan used in this study was in powdered form with 85% deacetylation. The product was purchased from Polymar Ciência e Nutrição S/A, Fortaleza, Ceará, Brazil. The chitosan was dissolved in 1% acetic acid and diluted to a concentration of 1%. Potassium silicate was obtained from PQ Silicas Brazil LTDA, Rio Claro, São Paulo, Brazil. This product contained 12.28% silicon and was dissolved in water to a final concentration of 500 mg L^{-1}.

The chitosan and potassium silicate were applied to the aerial portion of the strawberry plants with a manual backpack sprayer (Jacto PJH, JD-12P spray nozzle) gauged to apply a spray volume of 1000 L ha^{-1} from 60 to 95 days after planting. Five weeks after the initial application of the products, all of the fruits in each plot that had reached at least 70% ripening were harvested and taken to the laboratory.

The fruits from each plot were split into two groups of 50 fruits each. Half of the fruit from each plot was dipped for 5 s in 1% chitosan solution and then placed on a dry surface for 1 h for thorough drying. The fruits were placed in plastic trays with individual compartments. The second (untreated) group of fruit was placed directly on trays with sieves without application of chitosan. All fruits were maintained at a temperature of 2 °C for 22 days.

The incidence of gray mold was evaluated at 4, 7, 12, 16, 19 and 22 days after storage. Data on disease incidence were used to calculate the area under the rot progress curve (AURPC) following Shaner and Finney (1977). The AURPC data were analyzed to verify the assumptions of normality, homogeneity and independence of experimental error. An analysis of variance and a Tukey's test at a 5% significance level were performed using SAS software.

In experiment 1, fruit from cv. 'Oso Grande', that were treated with chitosan at postharvest (Fig. 1A) or were not so treated (Fig. 1B) showed similar behavior. Gray mold began to appear from the seventh day of storage and reached an incidence of 50% at 22 days of storage. In experiment 2, fruit from cv. 'Camarosa' that were not chitosan treated at postharvest exhibited gray mold at the seventh day of storage, reaching an incidence of 74.0% at 22 days of storage (Fig. 1C), whereas fruits of this cultivar that were chitosan treated at postharvest achieved an incidence of 50.0% of gray mold at 22 days of storage (Fig. 1D).

No interaction was found between the products applied in preharvest and postharvest in Exp 1 ($P = 0.18$) and in Exp 2 ($P = 0.53$). In Exp 1, the AURPC did not differ ($P > 0.05$) between different products applied to the plants in the field (Table 1). No effect was found for the application of chitosan at postharvest ($P > 0.05$). In Exp 2, fruits from cv. 'Oso Grande' plants treated with chitosan in the field showed an AURPC that was 64% less ($P < 0.05$) than that of plants not so treated. Fruits treated with chitosan at postharvest showed an AURPC that was 48% less ($P < 0.05$) than that of fruits that were not chitosan treated at postharvest.

Chitosan application to plants in the field and in combination with postharvest dipping of fruits was an effective strategy for controlling gray mold in fruits in cv. 'Oso Grande' but was not effective in the cultivar 'Camarosa'. Romanazzi et al. (2000) showed that chitosan was effective in reducing the rot caused by *B. cinerea* if applied at preharvest and postharvest stages at a concentration of 1%. The application of chitosan at the preharvest stage has been shown to reduce postharvest rot in the cultivar 'Aromas' (Mazaro et al., 2008) and in the cultivar 'Seascape' (Bhaskara Reddy et al., 2000). Strawberry plants of the cultivar 'Camarosa' are larger than those of the cultivars 'Aromas', 'Seascape' and 'Oso Grande', which are considered compact plants (Duarte Filho, 2006). Chitosan has a direct effect on *B. cinerea* (Reglinski et al., 2010); however, contact of chitosan with the fungus is necessary to achieve this effect. When the products are sprayed on the larger 'Camarosa' plants, they often do not reach the surface of the fruits, which are usually located on the lower parts of the plant. Chitosan may not have been effective in this cultivar for this reason.

Potassium silicate was not effective for gray mold control in either cultivar ($P > 0.05$). In previous research, Carré-Missio et al. (2012) suggests that, foliar application of potassium silicate must have reduced the intensity of rust by creating a physical barrier on the surface following polymerization, negatively affecting the sporulation of *Hemileia vastatrix*. Other mechanisms by which Si confers resistance to certain diseases are associated with the physical barrier formed by the deposition of this element under the cuticle and on the epidermal cell wall (Kim et al., 2002) or with the enhancement of defense mechanisms (Datnoff et al., 2007). However, Carré-Missio et al. (2009) reported that the activities of glucanases, chitinases, and peroxidases increased in the presence of *Hemileia vastatrix* regardless of the presence of Si in the nutrient solution. Datnoff et al. (2007) also reported that Si is not translocated from older to newer leaves or even from one application site to another. Thus, to ensure reduced disease intensities, possibly via osmotic effects, potassium silicate should be continually applied to all organs of the plant to be protected (Rodrigues et al., 2009, 2010), but this type of application is extremely difficult to achieve in commercial plantations, as in the case of strawberry. Treatments with additional applications of potassium silicate after chitosan application had an antagonistic effect, due perhaps to increased moisture, which favored infection by *B. cinerea*.

Overall, the results of the present study showed that chitosan application in the field and at postharvest is a promising strategy for the management of gray mold in postharvest strawberry fruits.

Table 1
Values of the area under the rot progress curve (AURPC) in various treatments applied in the field and at postharvest in Exp 1 (cv. Camarosa) and Exp 2 (cv. Oso Grande).

	AURPC	
Applied in the field	Exp 1 cv. Camarosa	Exp 2 cv. Oso Grande
Chitosan[a]	233.3 a[c]	92.7 a
Potassium silicate[b]	148.0 a	222.8 b
Chitosan + Potassium silicate	254.3 a	347.0 b
No application	196.5 a	269.0 b
Application at postharvest		
Without chitosan in postharvest	229.9 A[d]	306.6 A
Chitosan in postharvest[a]	186.2 A	159.2 B
CV (%)	39.7	32.0

[a] Chitosan at 1%.
[b] Potassium silicate (500 mg L^{-1}).
[c] Means followed by the same lower-caseletter in the same column do not differ (Tukey test, 5% significance).
[d] Means followed by the same upper-case letter in the same column do not differ (Tukey test, 5% significance)..

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