Potassium Sorbate Residue Levels and Persistence in Citrus Fruit as Detected by a Simple Colorimetric Method

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A colorimetric method that employed extraction of the macerated fruit, followed by a reaction with 2-thiobarbituric acid, was used to quantify potassium sorbate residues in citrus fruit. A recovery of more than 90% in oranges and lemons was obtained. Potassium sorbate residues determined by this method and a standard high-performance liquid chromatography (HPLC) method were similar. Residues were proportionate to the potassium sorbate concentration in the treatment solution. In oranges stored at 15 °C, following the potassium sorbate treatments, residues declined initially rapidly and later more slowly, until residues stopped declining after 6 days. A brief double-dip rinse in tap water applied immediately after immersion of lemons in a 2% (wt/vol) potassium sorbate removed more than 90% of the potassium sorbate residue. The influence of high-pressure water washing (HPWW) on potassium sorbate residues in potassium-sorbate-treated fruit was determined. Potassium sorbate residues were more effectively reduced by rinsing oranges than lemons.

INTRODUCTION

Sorbic acid and its water-soluble salts, especially potassium sorbate, are common food preservatives. Sorbates are the best characterized of all food antimicrobials because of their broad spectrum of action. They effectively inhibit certain bacteria and food-borne yeast and mold species (*1*). Their use for the control of postharvest diseases of citrus fruit was first evaluated by Smoot and McCormack (*2*). Later, Nelson et al. (*3*) combined potassium sorbate with benzimidazoles and found some improvement in the control of resistant strains of *Penicillium digitatum*. Kitagawa and Kawada (*4*) found that potassium sorbate was as effective as sodium *o*-phenyl-phenate to control sour rot on lemons, and Wild (*5*) showed that potassium sorbate was approximately $^1/_5$ as active as sodium *o*-phenylphenate against green mold on 'Valencia' oranges. Potassium sorbate was used commercially to retard citrus postharvest decay, but its use did not become popular because its efficacy was sometimes low and it was reported to delay rather than stop green mold infections (*6, 7*). However, the rise in fungicide-resistant strains of pathogenic fungi, together with the increasing concern about environmental and health risks, has elicited interest in finding alternatives to conventional synthetic fungicides for postharvest treatment of fresh fruit. The use of potassium sorbate alone, heated and/or combined with fungicides, has been recently studied with

citrus fruit (*8, 9*). Dip treatments with potassium sorbate solutions significantly reduced sour rot incidence on lemons, and its effectiveness was improved by heat (*9*). When used against green and blue molds, the effectiveness of potassium sorbate strongly depended upon the citrus cultivar and species, being generally more effective on oranges than on mandarins (*8*). The use of potassium sorbate as an alternative to synthetic fungicides has also been studied on other fruits, such as table grapes (*10*) and cherries (*11*).

Although the performance of potassium sorbate treatments to control decay on citrus fruit has been rigorously studied, little is known about the level of potassium sorbate residues remaining in treated fruit. Potassium sorbate residues that remain after treatment may be an issue to some buyers. At one time registered as a fungicide in the U.S., potassium sorbate was more recently listed as a "minimum risk pesticide" by the United States Environmental Protection Agency (U.S. EPA) and exempt from residue tolerance requirements (*12*). However, regulations in other countries are not clear about the level of residue permitted in citrus fruit, and the use of potassium sorbate is prohibited for use under most "organic" crop production rules. Sorbates leave a persistent antimicrobial residue in food products that they protect (*13*), and it is possible that they provide a persistent residue in citrus fruit. An accurate assessment of the fungicidal activity of potassium sorbate requires the development of a method for analysis of potassium sorbate in whole fruit, so that experimental application, storage, and shipping tests can be evaluated.

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Article

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Methods for determination of potassium sorbate in food products traditionally included distillation and subsequent determination by ultraviolet absorption and titration techniques (*14*, *15*). The initial Association of Official Analytical Chemists (AOAC) methods (*16*) required extensive sample preparation and relatively long analysis times and did not give accurate results at low levels. Park and Nelson (*17*) described a method for determining sorbic acid in citrus fruit by reverse-phase high-performance liquid chromatography (HPLC). The method involved extraction of the peel with methanol, cleanup of the extract by solvent partitioning and column chromatography, and quantitative determination by HPLC using ultraviolet detection. Distillation or extraction with methanol is time-consuming, and HPLC methods are not adaptable for use by small processors, because they lack technical personnel and equipment costs are high. Nury and Bolin (*18*) described a simple, direct colorimetric method requiring no distillation for the determination of potassium sorbate in dried fruits. The method made use of the oxidation of sorbic acid to malonaldehyde, which reacts with thiobarbituric acid to form a red pigment that was measured photometrically. Different adaptations of this method, using the same basic reaction, have been used in the determination of sorbic acid in wines (*19*).

This study investigated a simple colorimetric method for the determination of potassium sorbate in citrus fruit based on the previously mentioned reaction with thiobarbituric acid. This method was applied in this study to (a) evaluate the influence of the potassium sorbate concentration on the residue level in treated fruit, (b) determine the effectiveness of water rinse and high-pressure water wash (HPWW) in removing potassium sorbate residues from treated fruit, and (c) assess the evolution of the potassium sorbate residue level in treated fruit during storage.

MATERIALS AND METHODS

Fruit. 'Eureka' lemons or 'Atwood' navel oranges were used in this study. Lemons were collected from field bins in a packinghouse in Tulare County, CA, 1 day after harvest. The oranges originated from a groove of the University of California, Lindcove Research and Extension Center in Exeter, CA. No postharvest treatments had been applied. Before use, fruits were stored at 15 °C for less than 2 weeks. Fruits were randomized before the experiments.

Spectrophotometric Method for the Analysis of Potassium Sorbate Residues in Citrus. A colorimetric assay for potassium sorbate in dried fruits (*18*) was adapted for its use in the analysis of potassium sorbate residues in citrus fruit.

Reagents. All reagents used were analytical-reagent-grade. Doubly deionized water (18 MΩ) was used. A potassium sorbate working solution (0.1 wt %/vol) was prepared from potassium salt of sorbic acid (min of 99%) (Sigma-Aldrich, St. Louis, MO). A 1:1 mixture of 0.01 N $K_2Cr_2O_7$ and 0.3 N H_2SO_4 was prepared from potassium dichromate (min of 99.5%) (Sigma-Aldrich) and sulfuric acid (95–97%) (ACS reagent, Sigma-Aldrich). For the preparation of 2-thiobarbituric acid, 0.5 g of 2-thiobarbituric acid (min of 98%) (Sigma-Aldrich) was dissolved in 20 mL of water and 10 mL of 1 N NaOH in a 100 mL volumetric flask. After dissolving, 11 mL of 1 N HCl was added and the solution was made to 100 mL volume. The 2-thiobarbituric acid solution was made fresh daily. The reagent remains relatively unchanged for about 6 h, but after that time, absorbance values are lower, resulting in erroneous results (*18*).

Standard Curve. The standard curve was prepared from non-treated fruit. One whole fruit was weighed, cut into pieces, and blended with 0.95 mL of water per 1 g of fruit for 1 min. A total of 10 g of the slurry was poured in each of five 250 mL volumetric flasks and fortified with 0, 0.25, 0.5, 0.75, or 1.0 mL volume of the standard

sorbate solution (0.1 wt %/vol). Each flask was filled at 250 mL volume of water to reach the concentration 0, 1, 2, 3, or 4 mg/L of potassium sorbate in solution, respectively. A volume of 30 mL was transferred to centrifuge tubes and centrifuged at 14500*g* for 7 min. A 2 mL volume of each of the supernatants was added to each of five test tubes containing 2 mL of potassium dichromate–sulfuric acid solution. This mixture was heated for 5 min at approximately 100 °C in a water bath. Then, 2 mL of the thiobarbituric acid solution was added to each of the tubes, and they remained in the bath for an additional 10 min time. The tubes were then removed and quickly cooled in running tap water. Absorbance was measured at 530 nm in a spectrophotometer (UV–vis spectrophotometer, UV Mini 1240, Shimadzu, China). Water was used as a blank. A standard curve was obtained by plotting absorbance versus milligrams per liter of potassium sorbate. Two standard curves, one for lemons and one for oranges, were prepared.

Sample Preparation. Potassium sorbate residues in lemons within each replicate of 27 pieces of fruit were determined by taking three lemons and following the protocol described previously. When oranges were analyzed, two pieces of fruit were used for each replicate of 20 oranges.

Calculations. Optical absorbance was applied to the regression describing the slope of the standard curve to calculate the potassium sorbate concentration of this value. This value was adjusted by multiplying it by 48.78 (conversion factor to reflect the dilution and express the final value in milligrams of potassium sorbate per kilogram of fruit).

Recovery. Residue recovery was determined in 10 replicates by spiking fresh samples of lemons and oranges with 200 mg/kg potassium sorbate in fruit before blending the fruit. They were analyzed as previously described to estimate the recovery of the colorimetric method.

Effect of a Water Rinse on Removal of Potassium Sorbate Residues in Lemons. Lemons were immersed for 1 min in 15 L volume of water at 25 °C (control) or 2% (wt/vol) potassium sorbate at 25, 40, 50, or 62 °C. The temperature of the solutions did not change more than 0.5 °C during treatment. Immediately after the immersion, lemons were rinsed by two immersions of 1 s each in tap water, left to dry in air, and stored at 15 °C for 24 h. At that time, the colorimetric analysis for the detection of potassium sorbate as previously described was used to determine the residues in fruit.

Effect of a HPWW on the Removal of Potassium Sorbate Residues in Citrus Fruit. The effectiveness of HPWW to remove potassium sorbate residues in citrus fruit treated with potassium sorbate was assessed before and after cold storage for 25 days at 15 °C. To compare the removal of residues from fruit from the two HPWW times, two sets of fruit (three replicates of 20 oranges or three replicates of 27 lemons) were immersed for 1 min in water at 25 °C (control treatment) or in aqueous solutions containing 2% (wt/vol) potassium sorbate at 25 °C. After immersion, the fruit were left to dry and then stored at 15 °C. Samples from each treatment from one of the sets were analyzed for potassium sorbate residues the same day of the treatment. The next day, one set of fruit was again analyzed for residues, and the other set was rinsed by HPWW and then analyzed. Both sets of fruit were then stored at 15 °C for 25 days. At the end of the storage period, both sets of fruit were again analyzed for potassium sorbate residues. HPWW was applied to the set of fruit that had not been rinsed, and these fruit were analyzed for potassium sorbate residues. All HPWW treatments were applied at the Fruit Evaluation Center Packline of the University of California Lindcove Research and Extension Center, in Exeter, CA. A pressure washer (Food Machinery Corporation, Lindsay, CA) delivered 2000 kPa high-pressure, room temperature water over rotating brushes. The Tufted Polycor pressure water brushes (Industrial Brush Co., Pomona, CA) were 61 cm wide and 11.43 cm in diameter. The filaments of the brush were 38 mm in diameter with 20 tufts per circumference. The brushes rotated at 80 rpm. Fruit was moved across the spraying area at a 6.35 cm/s speed, with a residence time of about 30 s inside the washer. The openings of the water delivery nozzles were 24 cm

above the top of the brushes. The water contained about 30 μL/L total chlorine (12.5% sodium hypochlorite) (Brogdex Co., Pomona, CA) with a pH of 6.5 applied over the brushes through a single 1.9 m long row of solid-cone nozzles at 9.53 cm intervals, on a 2.54 cm inside diameter pipe down the center of the brush bed. Each nozzle delivered 306 L/s of water at 2000 kPa. These tests were repeated twice with both lemons and oranges.

Assessment of the Decline in the Potassium Sorbate Residue Concentration in Oranges. To measure the concentration of potassium sorbate during storage, oranges were treated by immersion in water at 25 °C (control) or in aqueous solutions containing 0.5, 1.0, 2.0, or 3.0 g/L potassium sorbate, left to dry in air, and stored at 15 °C. Potassium sorbate residues were analyzed the day of the treatment and after 1, 2, 3, 4, 5, 6, 12, 19, and 26 days of cold storage. Only the measurements at days 1, 12, 19, and 26 were repeated in another experiment.

Statistical Analysis. All treatments to oranges or lemons were applied to three replicates of 20 or 27 fruit each, respectively. Within each replicate, three lemons or two oranges were used for each analysis of potassium sorbate residues. Experiments were repeated twice, and data shown are means of two experiments (unless otherwise stated). Results were compared using analysis of variance (ANOVA), and means were separated by Fisher's least significant difference test (LSD; $p < 0.05$). To estimate the correlation between absorbance and potassium sorbate concentration on the standard curves, Pearson's correlation index was used. Statistics were analyzed using SPSS software (SPSS, version 16, SPSS, Inc., Chicago, IL).

RESULTS AND DISCUSSION

Spectrophotometric Method for the Analysis of Potassium Sorbate Residues in Citrus. The method that we employed is based on the conversion of potassium sorbate to sorbic acid and its subsequent oxidation by potassium dichromate−sulfuric acid to malonaldehyde, which reacts with 2-thiobarbituric acid to form a reddish-pink product with a single absorption maximum at 530 nm. The amount of thiobarbituric acid lost is about 40% after 14 days and 100% after 30 days at ambient temperature (*18*). Because the reaction proceeds slowly at room temperature, it must be performed at 100 °C; however, before measuring the absorbance of the reaction mixture, it must be cooled in running tap water. The colored solution, after cooling, is stable for at least $^1/_2$ h.

Two standard curves, one for lemons and a second for oranges, were obtained from solutions prepared to equal concentrations of 0−4 mg/L potassium sorbate. Pearson's correlation coefficient for the linear standard curves for lemons and oranges was 1.000 in both cases. The correlation equations and their corresponding R^2 were $y = 0.0899x + 0.1004$ and 0.9998 for oranges and $y = 0.0717x + 0.0622$ and 0.9999 for lemons (data not shown). The relative standard deviation of 10 replicate determinations of 200 mg/kg of potassium sorbate in lemons was 3.18%. Recovery of 200 mg/kg potassium sorbate, added to the fruit in the blender before mixing with water, recovered an average of 93.45% with a standard deviation (SD) of 3.4%.

While potassium sorbate contents ($\pm$SD) determined with this spectrophotometric method in four orange samples that had been immersed in 2% (wt/vol) potassium sorbate were 25.96 $\pm$ 4.01 mg/kg, they were 16.90 $\pm$ 3.15 mg/kg in the same samples determined with a standard HPLC method, conducted by the Dried Fruit Association of California laboratory (Fresno, CA). Differences in extraction efficiency may account for these slightly different results.

Effect of a Water Rinse on the Removal of Potassium Sorbate Residues in Lemons. This set of experiments was designed to assess the effect of a water rinse applied right after the immersion of the fruit in potassium sorbate solutions, which is a routine that may be followed in some cases to avoid potential adverse effects on fruit quality (*8*). A brief double-dip rinse with tap water, applied immediately after treatment of lemons with 2% (wt/vol) potassium sorbate for 1 min at 25, 40, 50, or 62 °C, almost completely removed the residues of potassium sorbate in the fruit. In lemons treated at 25 °C, removal of potassium sorbate residues approached 99% compared to the amount of residue present in similarly treated, nonrinsed lemons. As treatment temperatures were increased, the amount of potassium sorbate removed from the fruit decreased to 92% in lemons treated at 62 °C (**Figure 1**). Potassium sorbate is a highly water-soluble salt that was easily removed from the surface of fruit when a simple water rinse was applied immediately after treatment. However, the effect of potassium sorbate treatments on the control of decay caused by *P. digitatum* and *Penicillium italicum* is still important even after rinsing (*7, 8*). This could be explained by the fact that these pathogens can only infect through wounds in the rind, where presumably a portion of the potassium sorbate may be trapped during treatments, not eliminated by the water rinse, and thus still active. Smilanick et al. (*20*) found that immersion treatments in sodium carbonate or bicarbonate followed by water spray onto fruit did not influence the effectiveness of the treatments to control green mold. It was discussed that, because spores survive the treatments of 1 or 2 min in duration that control green mold on fruit (*21*), it was probable that a residue of carbonate or bicarbonate remained in the fruit or at least within the wound infection courts occupied by the pathogen; therefore, the treatment inhibited the infection. This study shows that potassium sorbate residues were slightly more difficult to remove when potassium sorbate was applied at higher temperatures. Presumably, the absorption rates of potassium sorbate were higher at high temperature because of increased metabolism rates.

In studies evaluating hot water treatments to reduce postharvest decay on citrus fruit, some rind injury was observed at treatment temperatures of 53 °C or higher and
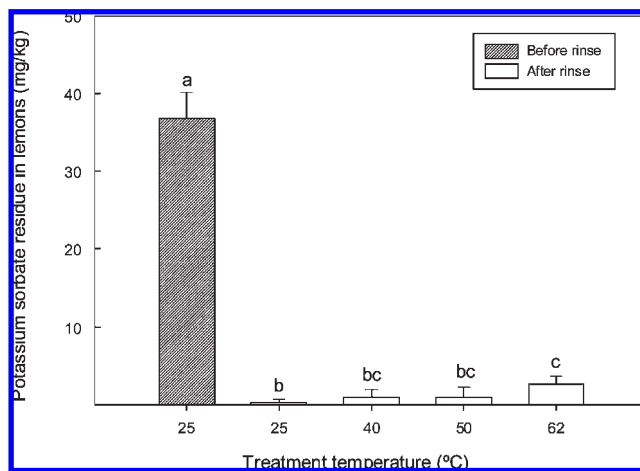

Figure 1. Effectiveness of double-dip rinse, applied immediately after treatment, on removal of potassium sorbate residues in lemons treated with 2% (wt/vol) potassium sorbate for 1 min at different temperatures. Columns with the same letter are not significantly different according to Fisher's protected LSD test ($p < 0.05$).

severe rind damage was observed at 60 °C (*22*), including melting and/or removal of epicuticular waxes (*23, 24*). The influence of the dip temperature on the residue level of fludioxonil was also studied (*24*), and it was found that there was no difference in the fludioxonil residue level between fungicide solution temperatures of 20 and 40 °C; however, residue levels proportionally increased with temperature in oranges dipped at temperatures of 50 and 60 °C. Higher depositions of imazalil at higher dip temperatures were also found in other studies (*25, 26*).

Effect of a HPWW on the Removal of Potassium Sorbate Residues in Citrus Fruit. HPWW is another procedure that may be used in some cases to clean the fruit and remove superficial chemical residues. Washing fruit with water at high pressure significantly removed the amount of residues present on the surface of lemons and oranges. However, the amount of potassium sorbate removed depended upon the type of fruit and the time elapsed between treatment application and HPWW (**Figure 2**). The concentration of potassium sorbate residue in oranges and lemons decreased after 1 day of storage at 15 °C by 5 and 19%, respectively. When HPWW was applied 1 day after potassium sorbate treatment, on either oranges or lemons, the removal of residue was similar (75 and 73%, respectively). During the 25 days cold-storage period, potassium sorbate residues remaining in the HPWW-treated fruit continuously decreased. In oranges, residues decreased by 96% of the initial concentration, while in lemons, they decreased by 86%. In nonrinsed oranges and lemons stored at 15 °C for 25 days, potassium sorbate residues decreased by 28 and 58% during that period, respectively. When the fruit were rinsed by HPWW at the end of the 25 days storage period, 87% of the previous residue content in stored oranges was removed (to 93% less of the potassium sorbate initial content), while in lemons, this percentage was 39% (74%). The fact that the potassium sorbate content in the fruit was decreasing during storage probably is a consequence of potassium sorbate residues on the surface of the fruit progressively migrating into the rind where, apparently, some of the potassium sorbate is metabolized and transformed into other substances no longer detectable as potassium sorbate or sorbic acid by the colorimetric method. As shown in this study, a brief water rinse removes most of the potassium sorbate residues on the surface of the fruit when applied immediately after treatment, when most of potassium sorbate is supposed to be found on the surface of fruit. Smilanick et al. (*20*) washed 'Atwood' navel oranges treated with sodium carbonate with a 1380 kPa pressure water wash and found that washing significantly reduced the control of green mold by carbonate treatment compared to nonwashed oranges or those rinsed briefly with water. They suggested that salt residues were probably removed from the surface of fruit. In our study, the pressure used in the HPWW was 2000 kPa, a much rigorous and much longer procedure than a brief water rinse, which should have been able to remove the potassium sorbate residues from the fruit surface. However, when applied after storage for 1 day, some of the residues had already migrated into the rind and were no longer eliminated by the wash but remained in the fruit and could be detected when we macerated the fruit to release them before the analysis. Fruit that were HPWW-rinsed and then stored for 25 days presented a lower potassium sorbate content than they did just after the HPWW rinse, again probably because of some migration and degradation of the potassium sorbate. When the fruit were first stored and then HPWW-rinsed, only the remaining potassium sorbate residues on the skin surface were removable by washing. The proportion of potassium sorbate removed from the surface of oranges at the end of the storage period was higher than that removed from lemons. This, together with the fact that residues in lemons also decreased faster during storage, may indicate that the rind of lemons was more permeable to potassium sorbate than the rind of oranges. However, once potassium sorbate had migrated into the rind of the fruit, a higher proportion of it remains nonmetabolized and thus detectable in the case of lemons than in oranges. Moreover, whenever the HPWW is applied, either at the beginning or the end of the storage period, the amount of potassium sorbate in either oranges or lemons at the end of storage was the same. In oranges, only 4% of the initial potassium sorbate content remained after HPWW and 25 days or storage (or 25 days of storage and HPWW), while in similarly treated lemons, 20% of the initial residue content remained. If the hypothesis of potassium sorbate being metabolized is confirmed, the difference between HPWW applied at the beginning or at the end of the storage period would be that, when HPWW is applied at the beginning, a higher proportion of potassium sorbate is topical and readily washed away, while when HPWW is applied at the end of storage, a larger portion of the potassium sorbate residues had already migrated into the rind, with some portion being metabolized, and would not be removed. In other words, more potassium sorbate metabolites are probably found in fruit when it is washed at the end of the storage period. Differences between oranges and lemons in permeability,
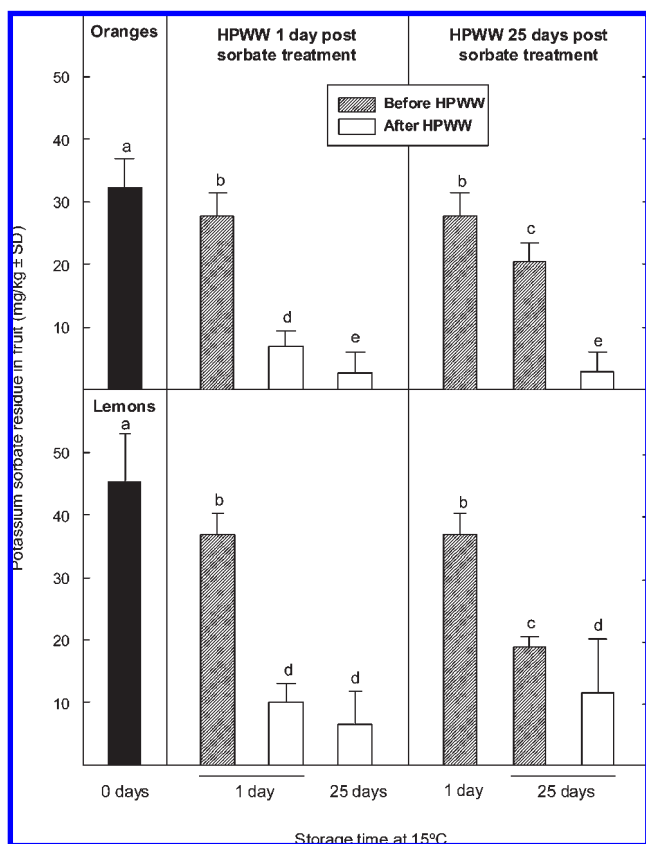
Figure 2. Influence of HPWW, applied 1 or 25 days after treatment, on potassium sorbate residues in fruit treated with 2% (wt/vol) potassium sorbate at 25 °C for 1 min. After treatment, fruit was stored at 15 °C. For each type of fruit, columns with the same letter are not significantly different according to Fisher's protected LSD test ($p < 0.05$).

chemical composition, pH, or number of openings present in the fruit rind may cause potassium sorbate to migrate and decompose in the rind and, consequently, influence the efficiency of HPWW treatment to remove the residue.

Assessment of the Decline in Potassium Sorbate Residues in Oranges. Potassium sorbate content was analyzed in oranges treated with different concentrations of potassium sorbate for 1 min at 25 °C and stored at 15 °C. The analyses were conducted during storage to quantify the decrease in the residue content among lemons and oranges that was observed in previous experiments in this study (not shown). Results from daily and bimonthly measurements are shown in **Figures 3** and **4**, respectively. Regardless of the length of storage, a higher potassium sorbate concentration in the treatment deposited proportionately higher residues in the fruit. The amount of potassium sorbate residues consistently decreased from day 0 (measured immediately after the treatment) to day 6 (6 days after the treatment), generally with a more acute decline between day 0 and day 1. No significant differences were found between the residue contents at day 6 (**Figure 3**) and day 12 (**Figure 4**) within fruit treated with the same potassium sorbate concentration. Residue contents also remained relatively unchanged during

Figure 3. Influence of the treatment concentration on potassium sorbate (PS) residue in oranges treated for 1 min at 25 °C during the first 6 days of storage at 15 °C.

Figure 4. Influence of the treatment concentration on potassium sorbate (PS) residue in oranges treated for 1 min at 25 °C and stored at 15 °C for 26 days.

the rest of the 26 day storage period (**Figure 4**). In our work, the residue content was proportional to the amount of potassium sorbate used in the treatment; this fact has also been observed in previous studies with other fungicides, such as fludioxonil (*24*), imazalil (*25−28*), pyrimethanil (*28, 29*), or thiabendazole (*26, 30*). The level of residue declined to one-half the initial residue concentration after approximately 5 or 6 days (**Figure 3**). The decrease in the potassium sorbate residue content during the storage period could explain the loss of antifungal efficacy of potassium sorbate treatments against green and blue molds on citrus fruit observed when the incubation period of the treated fruit was prolonged (*7, 8*).

A simple, rapid, and accurate spectrophotometric method was used to determine residues of potassium sorbate in citrus fruit. The application of this method to quantify the residue level after potassium sorbate treatments of citrus fruit showed the effect of different treatment parameters and subsequent handling on residue concentrations. In comparison to a HPLC method, the spectrophotometric method is more convenient, easy, and rapid. Furthermore, knowledge of residue levels and their persistence is needed to intelligently employ the potassium sorbate treatments for disease control applications. In this work, potassium sorbate residues were analyzed on the basis of blended whole fruit. Because *Penicillium* species strictly infect fruit through rind injuries, an interesting but more complex study may consider the efficacy of postharvest potassium sorbate treatments in relation to potassium sorbate residue levels in fruit wound sites. The amount of potassium sorbate residues in the fruit increases with the temperature and concentration of the treatment solution. A brief water rinse almost completely removed the residues of potassium sorbate when applied promptly after treatment. However, potassium sorbate migrated rapidly into the rind of fruit, and the removal of residues was not complete even when a HPWW was used. Potassium sorbate residue levels in fruit decreased during storage to approximately one-half the initial residue concentration after 5 or 6 days and then remained relatively constant. This decline in residues would explain why some workers reported that potassium sorbate effectiveness declined when citrus fruit were stored for longer periods. The mechanism of decline of potassium sorbate residues on fresh fruit is not known and warrants further study. In many processed products, potassium sorbate residues decline, sometimes rapidly (*31*). Other studies (*32*) reported that pH markedly influenced the rate of decline in potassium sorbate levels in model aqueous systems designed to simulate plastic packaging; at pH 3.5, the decline was much more rapid than at pH 5. Sorbates are also metabolized by humans (*33*) and many microorganisms (*13*).
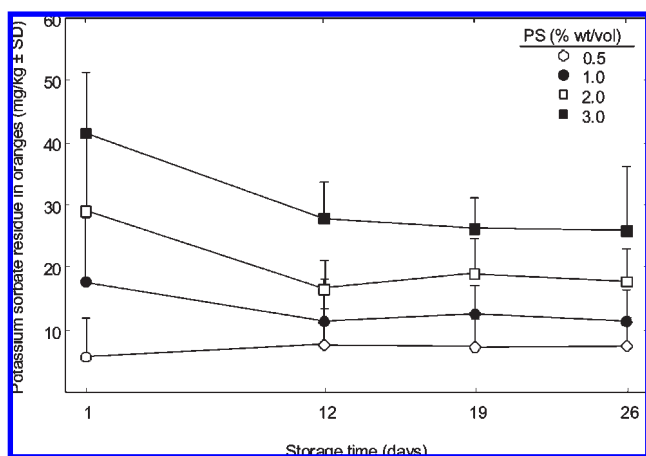
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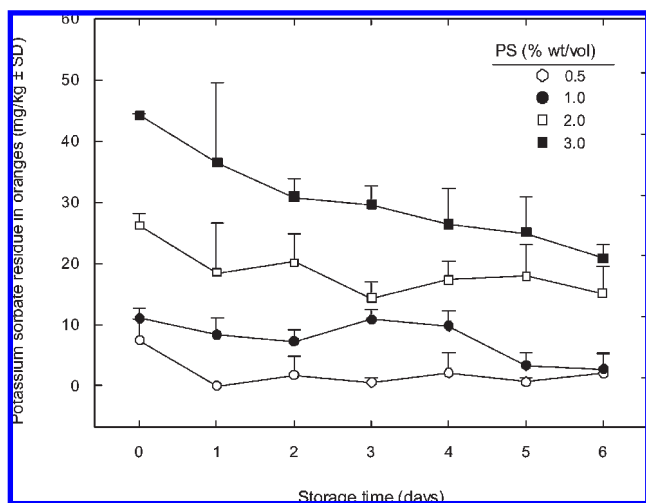
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