Silicon application effects on 'Hass' avocado fruit physiology

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ABSTRACT

Silicon (Si) has been used to minimise the adverse effects of biotic and abiotic stresses on various fruit crops. Therefore, the post-harvest effect of Si on quality parameters, such as fruit firmness, as well as CO_2 and ethylene evolution of 'Hass' avocado fruit, was investigated. Different sources of silicon (potassium silicate [Ksil], Nontox-Silica® [NTS], calcium silicate, sodium metasilicate and Biosilicate) were used as post-harvest dips and pre-harvest soil drenches. Fruit were treated with Si sources at concentrations ranging from 80 ppm to 2940 ppm and subsequently stored at either -0.5, 1, 5ºC or room temperature (25ºC). With respect to net CO_2 production, there were significant differences in temperature and treatment means. Fruit stored at -0.5ºC respired at a lower rate than other storage temperatures, reaching the respiratory peak later than those stored at higher temperatures. Fruit stored at room temperature (25ºC) reached their respiration peak first. Overall treatment with Si in form of KSil 2940 ppm resulted in the lowest fruit respiration and ethylene evolution rate, while non-treated fruits (Air) had the highest respiration and the highest ethylene evolution rate. Using ultra-structural analysis (EDAX), it was found that Si passes through the exocarp into the mesocarp tissue when treated with high Si concentrations (KSil 2940), while fruit dipping into very dilute Si solutions (80 ppm and 160 ppm) resulted in very little to no Si infiltration into the mesocarp. Therefore post-harvest applications of 2940 ppm Si in the form of KSil seem to be most beneficial to maintain avocado fruit quality, probably due to a suppression of respiration and a reduction in ethylene evolution.

INTRODUCTION

Forty percent of the South African avocado crop is exported. Good phytosanitary measures are a requirement for export and are needed in ensuring high product quality. This is particularly important in avocado as the fruit is a perishable product (Wills *et al.*, 1989) with a relatively high respiration rate, resulting in a quick deterioration of fruit quality. Additionally, due to the threat of pest and disease resistance to currently used chemicals, a great need exists to diversify from their usage. Silicon (Si) has been used in a number of crop species, mainly members of the Poaceae, and has been found to infer host resistance to crops. In other horticultural crops (tomato, beans, peas and cucumber), Si has been found to offer protection against fungal infections by strengthening cell walls, thus making it more difficult for the fungi to penetrate and colonise the plant (Fawe *et al.*, 2001).

Silicon, the second most abundant element (28%) on the earth's crust and in soils, has long been associated with disease resistance in plants. Silicon is known to effectively mitigate various abiotic stresses such as manganese, aluminium and heavy metal toxicities, salinity, drought, chilling and freezing stresses (Liang *et al.*, 2007). Silicon might also play an active role in enhancing host resistance to plant diseases by stimulating defense reaction mechanisms. According to Ma and Takahashi (2002) the beneficial effects of Si are more evident under stress conditions. Datnoff and Rodrigues (2005) showed that Si increases the resistance of rice to leaf neck blast, sheath blight, brown spot, leaf scald and stem rot. Dann and Muir (2002) found that growing pea plants in a Si-amended potting mix increases the production of defense proteins.

Fauteux *et al.* (2005) proposed two mechanisms for Si-enhanced resistance to diseases: Si can act as a physical barrier as it is deposited beneath the cuticle to form a cuticle-Si double layer, while it also acts as a modulator of host resistance to pathogens. Anderson *et al.* (2005) found that injecting soluble Si into avocado trees prior to harvest significantly decreased the severity and incidence of anthracnose. However, mixing phosphorous acid and soluble silicon did not provide any control of anthracnose. Anderson *et al.* (2005) therefore proposed that foliar Si applications are likely to be ineffective. As plants vary considerably in their ability to absorb Si from the soil solution (Ma & Yamaji, 2006), avocado might not be able to take up sufficient Si from the soil to affect resistance to pathogens.

Therefore, the aims and objectives of this study were to investigate whether the application of Si as a soil drench results in increased Si levels in the fruit and if post-harvest dips have an effect on fruit qual-

ity parameters (firmness, CO_2 production and ethylene evolution and shelf life) of 'Hass' avocado fruit.

MATERIALS AND METHODS

Avocado (*Persea americana* Mill. cv. 'Hass') fruit were obtained from Everdon Estate in Howick (KwaZulu-Natal) and Cooling Estate in Wartburg (KwaZulu-Natal). Fruit were treated post-harvest with Si sources at concentrations ranging from 80 ppm to 2940 ppm and subsequently stored at either -0.5, 1, 5ºC or room temperature (25°C). Fruit from Everdon were treated with four different sources of Si, namely potassium silicate (K_2SiO_4) KSil, Nontox-Silica® (NTS), calcium silicate (Ca_2SiO_4) CaSil and sodium metasilicate pentahydrate ($SiO_3Na_2.5H_2O$) NaSil as dips, whereas at Cooling Estate three sources of Si (potassium silicate, Nontox-Silica® and Biosilicate) were applied as soil drenches throughout the season. Firmness measurements, ethylene evolution and CO_2 production were recorded as fruit approached ripening. The CO_2 production of fruit that were stored at room temperature was analysed daily until they had fully ripened, while fruit from cold storage were removed weekly to measure respiration.

Energy dispersive x-ray analysis (EDAX) was conducted to determine the extent of Si infiltration by the treatments into exocarp and mesocarp tissue.

Fruit firmness of each fruit was measured daily using a hand-held densimeter as soon as softening was initiated. Two measurements were taken along the equatorial region of the fruit. Fruit respiration rate, as determined by CO_2 production, was measured every second day, using an infrared gas analyser. Ethylene evolution was determined every second day until the fruit were "ripe", when softness measurements reached less than 60 (37.34 Psi) on a hand-held densimeter. Ethylene production was measured using a gas chromatograph (GC) equipped with a flame ionization detector (FID) and a stainless steel packed column with an alumina-F1 stationary phase. Fruit ethylene production was measured by placing a fruit in a 1 L jar with a 20 ml glass vial, sealing the jar and incubating for 30 minutes. The ethylene produced by the fruit during that time was retained in the glass vial and transferred to the GC where the ethylene concentration was determined. Taking into account fruit volume (head space), fruit mass and time of incubation, net ethylene values were expressed as ($\mu L kg^{-1}$ FW h^{-1}).

Statistical analysis was carried out using GenStat® version 11 (VSN International, Hemel Hempstead, UK) ANOVA. Treatment and storage temperature means were separated using least significant differences (LSD) at 5%.

RESULTS AND DISCUSSIONS

EDAX analysis revealed that Si passes through the exocarp into the mesocarp tissue in fruit treated with high concentrations of Si, i.e., KSil 2940 and 1470 ppm. Fruit dipped into very dilute Si solutions (80 ppm and 160 ppm) showed very little to no infiltration of Si into the mesocarp, similar to treatments with NTS (**Figure 1**).

Fruit firmness was significantly affected by storage temperature (**Figure 2**). Firmness of all fruit decreased following removal from storage (28 days after picking). Fruit treated with either KSil or NTS and stored at 5ºC were firmer than fruit stored at other temperatures (**Figure 3**) three days after removal from storage. Fruit firmness measurement did not show any significant differences between treatments, probably due to severe anthracnose infection of all fruit hindering fruit softening.

CO_2 production increased over time with most fruit reaching the respiratory peak four to five days after removal from the 28 day cold storage, thereafter decreasing gradually (**Figure 4**). Fruit treated with KSil 2940 produced the least amount of CO_2, while non-treated fruit (Air) had the highest respiration rate. Storage at room temperature (25ºC) resulted in significantly higher CO_2 production and an earlier CO_2 peak, compared with fruit stored at other temperatures (**Figure 5**).

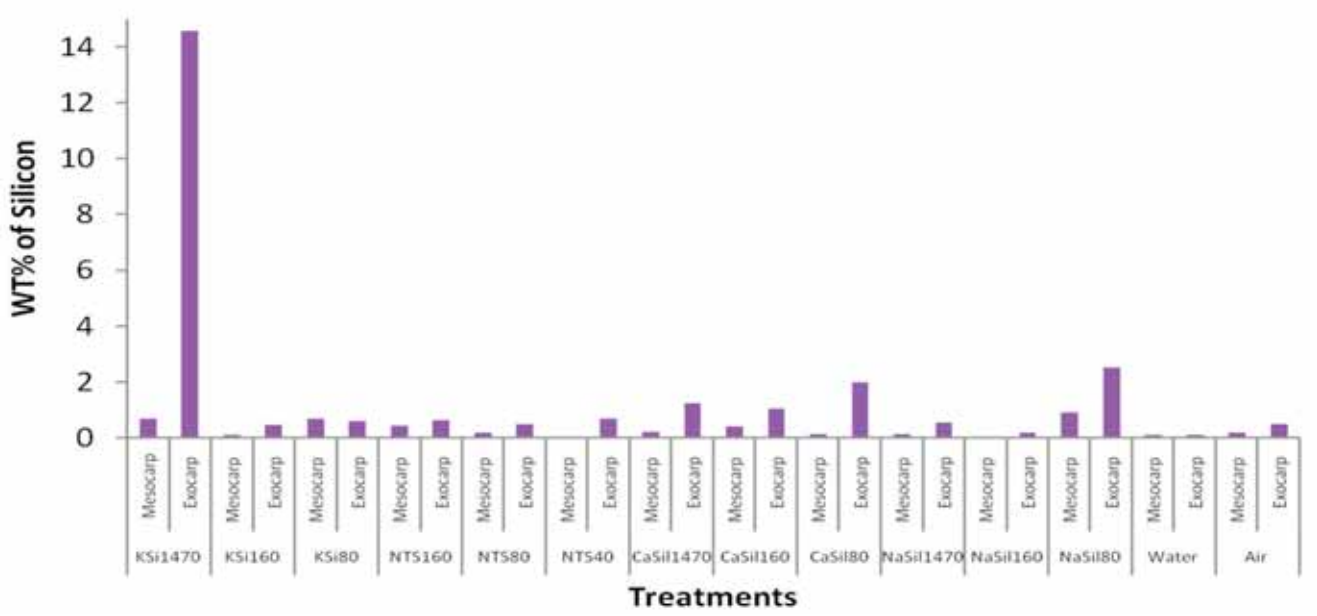

Figure 1. Percentage by weight of silicon in the exocarp and mesocarp tissue after treating with silicon compounds.

Significant differences (P <0.01) in ethylene evolution were observed, with the highest ethylene produced by fruit stored at 25ºC (**Figure 6**). There were also significant differences amongst treatment means (P <0.01), with fruits treated with KSil 2940 ppm producing the least ethylene (**Figure 7**).

In the pre-harvest trial, Si levels in exo- and mesocarp tissue of fruit from treated trees were not different from control fruit (data not presented); similarly, analysis of variance confirmed that there were no significant differences in treatment means with regards to net CO_2 production from fruit of trees treated pre-harvest with Si (**Figure 8**).

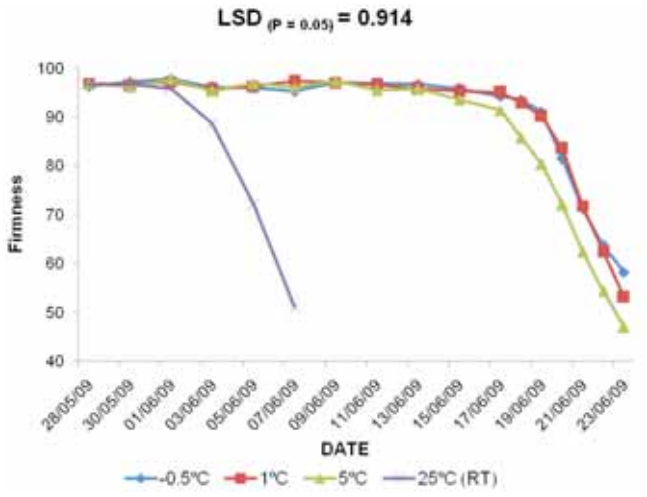

Figure 2. Firmness of 'Hass' avocado fruit stored at different temperatures over 28 days.

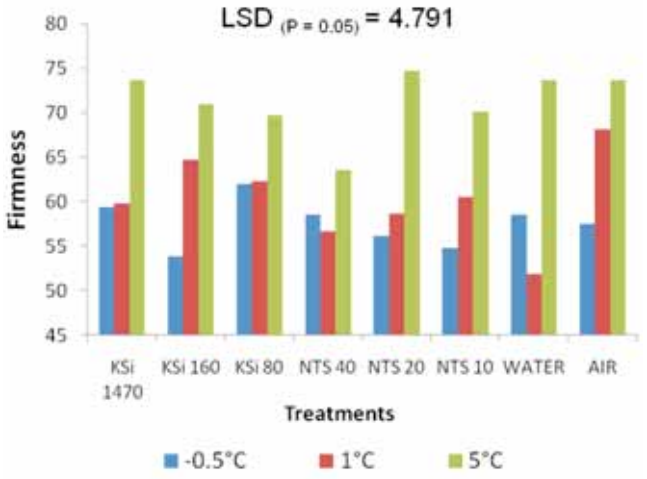

Figure 3. Firmness of fruit treated with potassium silicate (KSil) and Nontox-silica® (NTS) three days after removal from 28 days cold storage.

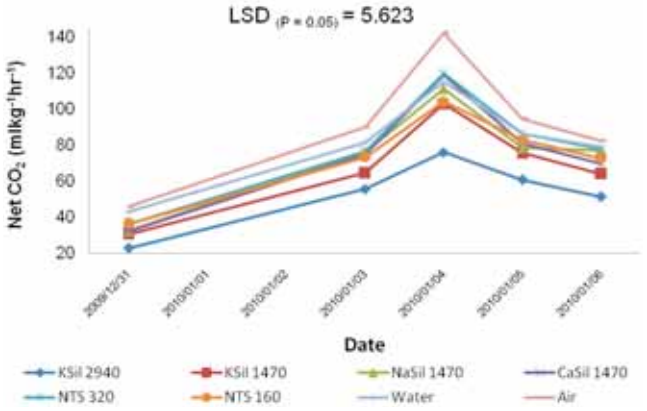

Figure 4. CO_2 production of avocado fruit after cold storage (-0.5, 1 and 5ºC) following treatment of different Si compounds.

CONCLUSION

The main effect of Si post-harvest application lies in the suppression of respiration and ethylene production. Therefore, improving Si infiltration techniques could enhance shelf life of avocado. In our experiment, however, such an enhanced shelf life could not be determined due to high occurrence of anthracnose, which was not reduced by any of the Si applications.

Post-harvest applications of 2940 ppm Si in the form of KSil seem to be most beneficial in suppressing respiration and would result in a slower decrease in the plant's carbon reserve compounds. The Si concentration applied had, however, no effect on the deposition of Si in the mesocarp tissue, but the amount of Si

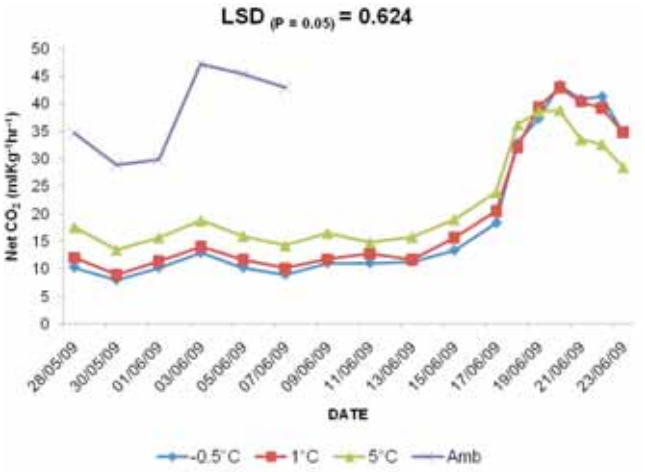

Figure 5. CO_2 (ml*Kg^{-1}*h^{-1}) production of avocado fruit stored at -0.5, 1, 5ºC and room temperature (25ºC). Fruit were removed from storage after 21 days.

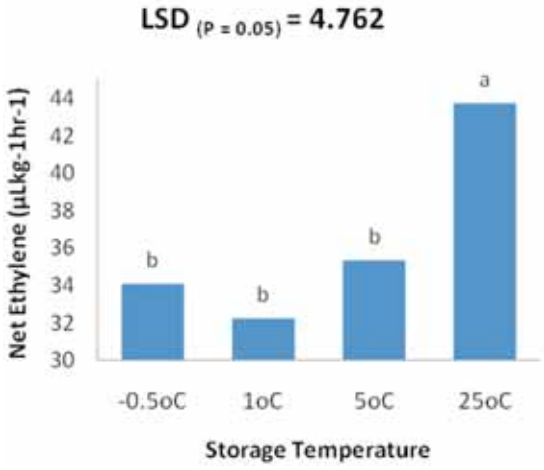

Figure 6. Ethylene (µl*Kg^{-1}*h^{-1}) production of ripe 'Hass' avocado fruit (firmness readings less than 60) stored -0.5, 1, 5ºC and room temperature (25ºC).

found in the exocarp was higher in fruit treated with high Si concentrations.

Application of Si to fruit from less anthracnose infected orchards should be recommended, as the positive effects of respiration suppression are likely to be more beneficial in such fruit. Such a recommendation is in contrast to Bekker *et al.* (2007) who suggested that the positive effect of Si on plant growth and performance is only evident when plants are under some form of stress.

It would also be beneficial to investigate if Si increases antioxidant and total phenolics accumulation in the fruit, thereby increasing the stress-relieving ability of the fruit, producing fruit with a higher ability to withstand long-term storage.

ACKNOWLEDGEMENTS

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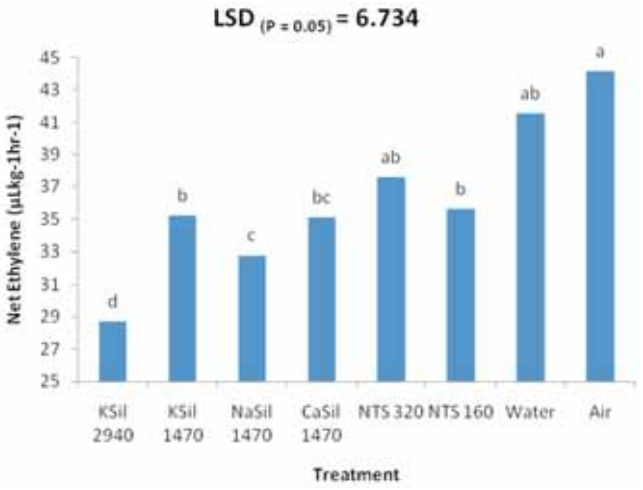

Figure 7. Ethylene (µl*Kg^{-1}*h^{-1}) production of ripe 'Hass' avocado fruit (firmness readings less than 60) treated with different concentrations of KSil (potassium silicate) and NTS (Nontox-silica).

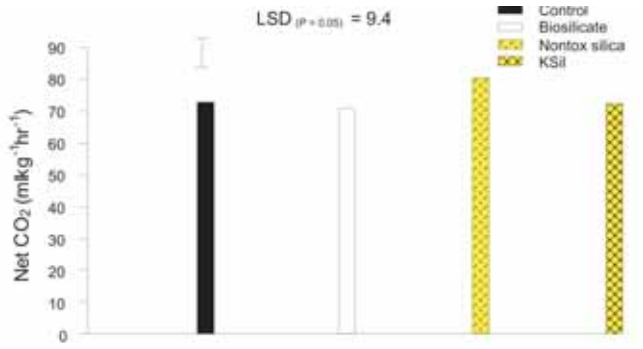

Figure 8. Net CO_2 of 'Hass' avocado fruits at the end of ripening. Fruit were treated with different sources of silicon applied as soil drench solutions.

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