Effect of post-harvest application of silicon on 'Hass' avocado fruit

I Bertling, SZ Tesfay, JP Bower and K Kaluwa

Horticultural Science, University of KwaZulu-Natal, Pietermaritzburg,
Private Bag X01, Scottsville 3209, South Africa
E-mail: bertlingi@ukzn.ac.za

ABSTRACT

Three concentrations of potassium silicate (KSil) were investigated as post-harvest applications on 'Hass' avocado fruit to improve quality. Fruit were soaked in the Si source at 5000, 13000 and 25000 ppm silicon (Si) and subsequently stored at room temperature (25°C). The transport of Si into the mesocarp was determined as well as fruit weight, firmness and CO_2 production as ripening was approached. Electron micrographs of fruit tissues were also taken. Si was found to have been transported from the rind into the mesocarp. Si concentrations in the flesh were not dependent on the concentrations fruit were soaked in. Fruit weight was highest in the highest Si application, but no differences were found between the different treatments in fruit firmness during storage and softening. In the highest Si concentration, parts of the Si layer appeared to flake off. This could have possibly created cracks in exocarp cells, which would explain the high respiration rate and shorter shelf life of such treated fruit in comparison with the two lower Si concentrations. It therefore seems that the 5000 and 13000 ppm KSil applications are superior post-harvest treatments. Other Si formulations of similar concentrations should also be tested for their effect on post-harvest fruit quality.

INTRODUCTION

The application of Si has found wide use in agriculture. Currently Si supplements are commonly employed in hydroponic cucumber production in Europe (Moulin *et al*., 1994), in rice production in Asia (Takahasi *et al*., 1990) and in sugarcane production in South Africa (Keeping *et al*., 2009). Si has also gained importance in crop protection, as it increases resistance to insect attack (Ma and Takahashi, 2008) and enhances disease resistance in a variety of horticultural crops to Powdery Mildew (Chérif *et al*., 1992), *Colletotrichum* (Kauss *et al*., 2003), Anthracnose (Anderson, 2005) and the Damping-off complex (Heine, 2005). Although the mode of action of Si is not clearly understood (Chérif *et al*., 1994), several modes of action might be responsible for the Si-mediated resistance to pathogen attack. Firstly, the relatively hardness of silicates (Chérif *et al*., 1994) provides a physical barrier to any pathogen. Several authors have shown an increased presence of Si (amorph silica) in cell walls after Si application which results in increased mechanical cell strength and thereby affects the ability of pathogens hyphae to penetrate the cell wall – a mode of action postulated by Chérif *et al*. (1992). Furthermore, Si has been reported to generally improve plant growth, a feature linked to the ability of Si to balance nutrient uptake (Gong *et al*., 2005) or the general enhancement of nutrient transport and distribution by Si (Elawad *et al*., 1982). Apart from the physical action of Si deposits in cells, Si can also associate with cell wall proteins, where it might exert an active biochemical function, possibly through production of defence compounds (Chérif *et al*., 1994) which could reduce pathogen attacks.

Therefore, Si applications could improve the post-harvest fruit quality of avocado, not only through reducing pest and disease incidences but also by altering certain fruit parameters. The most commonly used form of Si in agricultural commodities is currently potassium silicate (KSil), although other products, such as calcium (CaSil) and sodium silicate (NaSil) as well as NonTox-silica are available. However, as these products are either less soluble than KSil or, like Na, might affect fruit quality negatively, solely post-harvest applications of various KSil concentrations were compared with respect to their efficacy to alter fruit quality parameters during and post cold storage.

MATERIALS AND METHODS

'Hass' avocado fruit from late-bearing KZN orchards were picked in November and placed into 5, 13 and 25 x 10^3 ppm Si (as potassium silicate, KSil) solutions for 20 min to allow penetration of the solution. Thereafter, fruit were allowed to air-dry on the bench and stored at 5.5°C for 16 days. Alterations in quality parameters were observed over the storage period and the following days of softening. In order to determine movement of Si into the mesocarp, Si concentrations in the flesh were measured using Energy Dispersive X-ray (EDX). Furthermore, sections of the fruit were prepared to view fruit tissues using a transmission electron microscope (TEM).

Other fruit quality parameters recorded during the experimental period included fresh weight, firmness as well as shelf life and respiration rate. Electrolyte leakage of the mesocarp was also determined as a measure of cell membrane integrity, in order to determine if Si applications can counteract the breakdown of cell compartimentation, the major reason for fruit browning.

All data were analysed using GenStat® Version 9.0.

RESULTS

Soaking fruit in solutions containing various KSil concentrations resulted in increased Si concentrations in the mesocarp of all treatments in comparison to the control. All Si-treatments (5.000, 13.000 and 25.000 ppm Si) showed similarly elevated Si concentrations in fruit flesh (**Figure 1**). Fruit fresh weight declined significantly faster in control than in Si-treated fruit, with the highest Si application maintaining the highest weight (**Figure 2**). Contrary to expectation, fruit firmness was not affected by the treatment, neither within nor after storage (**Figure 3**).

During storage fruit respiration remained below 20 mL CO_2 x kg^{-1} x h^{-1}, increasing sharply in all treatments after removal from storage. Significant increases in respiration were observed in the 5.000 as well as the 13.000 ppm Si treatments compared to the control and the 25.000 ppm Si treatment (**Figure 4**).

Determination of electrolyte leakage of mesocarp tissue, in order to determine the Si effect on maintenance of cell to cell communication, revealed that the 25.000 ppm Si application had a significantly higher electrolyte leakage than the lower two Si treatments; however, no such significances were observed between the treatments and the control (**Figure 5**).

Electron-micrographs of the fruit surface of the 25.000 ppm KSil treatment demonstrated deposition of Si on the exocarp, to the extent that the deposits flaked off the fruit (**Plate 1**). The ultra-structural analysis of mesocarp tissue of Si treatment showed altera-

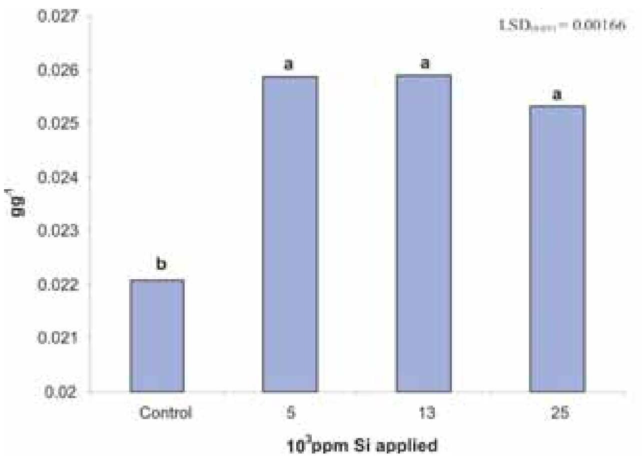

Figure 1. Mesocarp silicon concentration (g x g^{-1}) of 'Hass' avocado fruit following soaking of fruit in various KSil concentrations

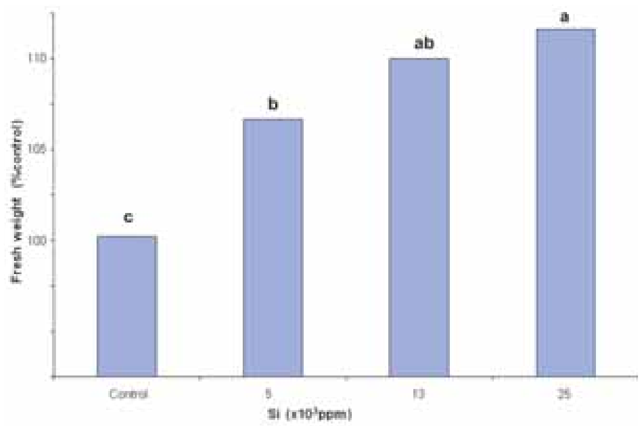

Figure 2. Fruit weight of 'Hass' avocado of soaked in various potassium silicate prior to cold storage and ripening

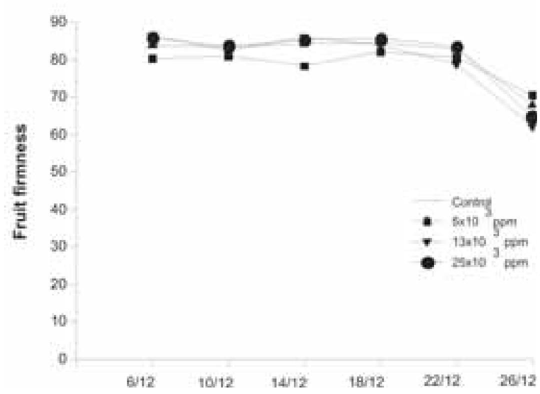

Figure 3. Fruit firmness (densimeter readings) of 'Hass' avocado fruit during cold storage and ripening at room temperature

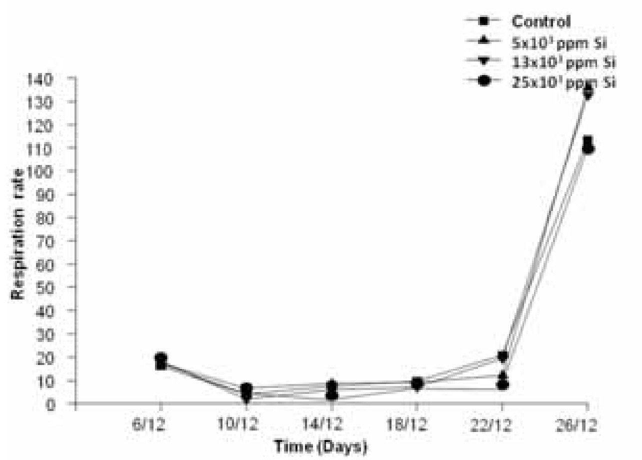

Figure 4. Fruit respiration rate (mL x g^{-1} x h^{-1}) of 'Hass' avocado fruit during cold storage and ripening at room temperature

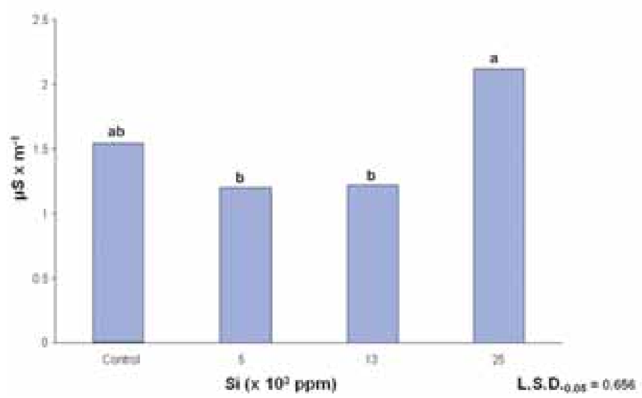

Figure 5. Electrolyte leakage of 'Hass' avocado mesocarp following cold storage and ripening at room temperature

tions in the cell membrane structure. In Si treatments the cell membrane seemed to be dislodged from the middle lamella, leaving a space which seemed to be filled out, possibly with Si or KSil between these two membranes (**Plate 2**).

The shelf life of the fruit was also affected by Si treatment; while control fruit as well as the 25.000 ppm treatment could be kept at room temperature for five days following removal from cold storage, the 5.000 and 13.000 ppm treatments lasted on average eight days after removal from storage.

DISCUSSION

Our literature search on post-harvest applications of Si to any kind of horticultural crop revealed that such publications are very rare, although Si effects on disease resistance have been described for a variety of agronomical crops, particularly rice (Buck *et al*., 2008). Furthermore, Si applications to various vegetable crops have been described (Heine *et al*., 2007). The lack of positive effects of Si application to quality of horticultural crops might be related to the fact that dicotyledonous plants are unable to accumulate higher levels of Si in shoot tissue (Ma and Takahashi, 2002). In avocado fruit, however, penetration of Si was observed following soaking of the fruit in various concentrations of KSil solutions. Surprisingly, the concentration of KSil, in which fruit were soaked, did not affect the Si concentration of the mesocarp (**Figure 1**). A further extension of the soaking period in future experiments might allow for better Si penetration; alternately the lack of Si transporters in avocado tissue, as compared with monocotyledonous plants (Ma and Yamaji, 2008), might have only allowed a certain number of Si molecules to pass into the mesocarp. Soaking in higher Si concentrations could therefore not enhance the trans-

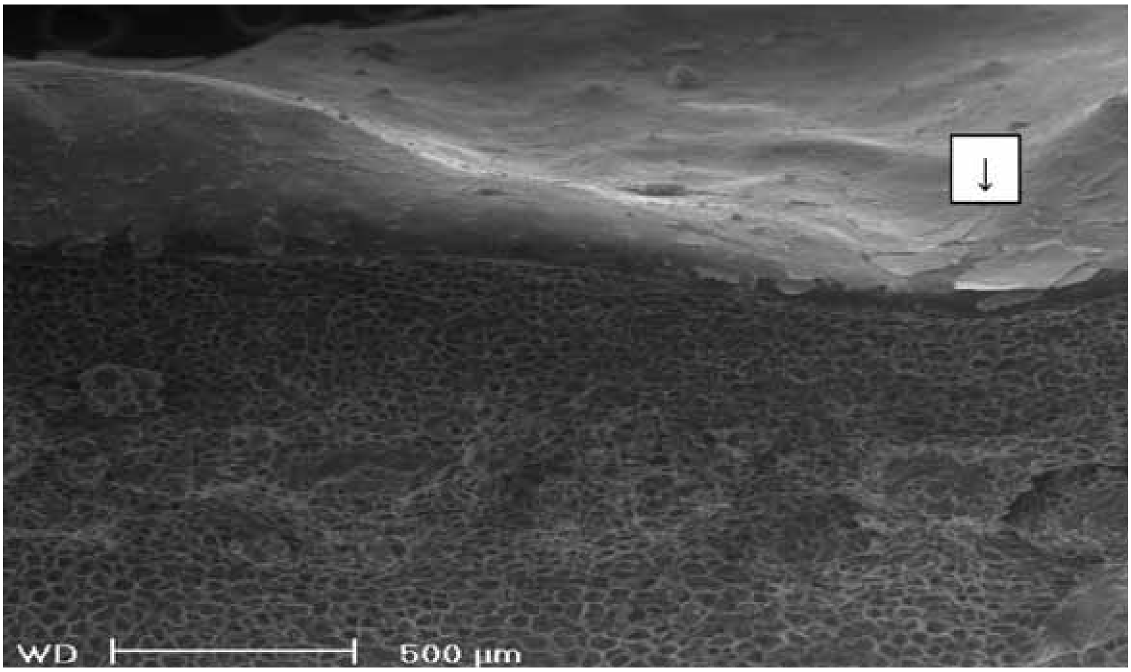

Plate 1. Electron-micrographs of fruit surface after Si application and storage. Note breaking of the Si deposit on the fruit surface (right part of picture)

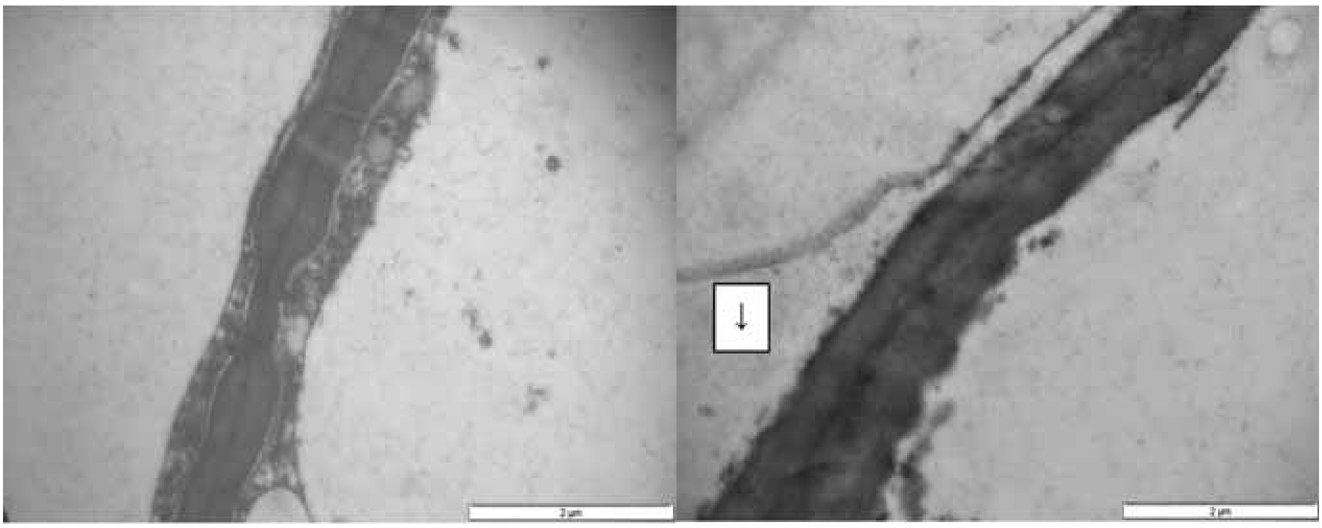

Plate 2. Electron-micrographs of mesocarp cell connections of untreated (left) and Si-treated (13.000 ppm KSil) (right). Note detachment of cell membrane from other parts of the cytoplasm in the Si-treated tissue

port of Si into the mesocarp.

Covering fruit with a silicon layer seemed to increase gas exchange (respiration) at the two lower Si concentrations, thereby potentially hastening the ripening process. However, this picture does not match with the increased shelf life of the two lower Si concentrations compared to the control and the highest Si concentration as well as the fruit weight, which was highest in the highest Si application. Therefore respiration is not clearly connected to weight loss of Si treated fruit in storage.

Fruit firmness was not affected by treatments: Although a thicker layer of Si was deposited with the higher Si concentrations applied, it failed to enhance fruit firmness, possibly because the higher Si applications are unable to form a smooth layer on the fruit surface but rather result in cracks in the exocarp, as sheets of the Si layer easily break away from the epidermis (**Plate 1**). This could have even affected the mesocarp tissue, as the highest Si concentration applied had the highest ion leakage (**Figure 5**).

Altogether results point to the two lower concentrations of Si applied (5.000 and 13.000 ppm) as the optimal concentrations to use as post-harvest treatments. Furthermore, as the highest concentration of KSil used did not give the best results, the need exists to investigate other formulations of Si which have a lower solubility, like calcium silicate (CaSil) or specialised sand solutions (NonTox-Silica).

CONCLUSIONS

It appears that intermediate KSil concentrations (5.000 and 13.000 ppm) are superior to the highest KSil solution (25.000 ppm) as post-harvest soaking solutions in 'Hass' avocado. The anticipated positive effects of Si applications on fruit firmness following treatments were not observed; however, the fruit quality improvements (weight and electrolyte leakage) following soaking in the intermediate KSil concentrations warrant further investigations.

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