Low temperature shipping and cold chain management of 'Hass' avocados: An opportunity to reduce shipping costs

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ABSTRACT

Alternate treatments that could be used to possibly extend the shelf life of avocado fruit as effectively as the use of 1-MCP were evaluated, as the use of 1-MCP is costly. Previous work indicates that cold storage at 1ºC might be able to replace the use of 1-MCP in 'Hass' avocado fruit. Therefore fruit were subjected to 1ºC or 5.5ºC as well as 1-MCP, waxed and non-waxed. Additionally, cold chain breaks (24 hour delay of cooling, break at 5, 10 and 20 days) were investigated. The 40 treatment combinations were subjected to simulated shipping for 28 days. Fruit weight, softness, CO_2 as well as ethylene evolution, days to ripening, external and internal quality were determined. It was found that fruit stored at 1ºC softened more slowly and lost less mass, thereby ultimately extending the shelf life to the same extent as the 1-MCP treated fruit at 5.5ºC. It was also found that the use of 1ºC negated the effects of cold chain breaks. However, a delay of 24 hours before placing the fruit into cold storage resulted in significant water loss, which was detrimental to final fruit quality. Overall, it may indeed be possible to replace the use of 1-MCP with low temperature shipping at 1ºC for 'Hass' avocados, with respect to extending shelf life and negating effects of cold chain breaks. Further investigations are required to be assured of these findings, as well as to determine the physiological effects of cold chain breaks.

INTRODUCTION

Fruit quality is of importance for the export market. In the case of the South African avocado industry, considerable challenges are present with respect to the logistics required to export avocados to the European market (Dodd *et al.*, 2007). With a transport time of up to thirty days, there is a need to slow the natural ripening processes of the avocado fruit. The current technologies used are controlled and modified atmosphere (CA and MA) or the use of an ethylene receptor blocker 1-methylcyclopropene (1-MCP). However, problems are still associated with the use of these protocols. Examples include 1-MCP fruit having uneven ripening (Mare *et al.*, 2002), extreme CA conditions with high CO_2 levels (>5%), leading to carbon dioxide poisoning, inhibiting ripening, body rots, hypoxia and anoxia (Kader, 2003; Arpaia *et al.*, 1990; Burdon *et al.*, 2008), and the costs involved to implement these technologies. Previous work has indicated that it may be possible to achieve the same or better quality on arrival by using ultra low temperatures such as 1ºC for 'Hass'. If it is found that shipping at lower temperatures is comparable to the use of CA or 1-MCP, then costs would be reduced. There has also been indication that cold chain breaks associated with normal logistics have severe effects on the final quality of the fruit (Undurraga *et al.*, 2007). There has been little work done on this issue and the actual losses are unknown. Work conducted by Blakey and Bower (2009) indicated that shipping at 1ºC resulted in significantly better fruit quality compared to fruit shipped at 5.5ºC when incurring the same cold chain break treatments. The study aimed to ascertain whether storage at 1ºC as opposed to current industry protocol 5.5ºC is comparable to the use of 1-MCP during simulated shipping, as well as to ascertain the effects of cold chain breaks on the final fruit quality for 'Hass'.

MATERIALS AND METHODS

Fruit

'Hass' avocado fruit were obtained from a packhouse in Wartburg, KwaZulu-Natal. Post-harvest operations of waxing, 1-MCP, cooling, grading, sizing and packing to "count 16" were all conducted at the packhouse. Half the fruit samples were collected off the packline before waxing, while the other half remained on the packline to be waxed. The fruit treated with 1-MCP were subjected to standard export protocols for sixteen hours at a temperature of 5.5ºC, whilst the untreated fruit were stored under the same temperature for the same period but without 1-MCP. After the initial packhouse treatment, all fruit were transported to the laboratories of the Horticultural Science Department at the University of KwaZulu-Natal and immediately prepared for simulated shipping for a period of 28 days. Half the fruit were stored at 1ºC (±0.5ºC) and the other half at 5.5ºC (±0,5ºC). Cold chain break treatments were applied by delaying cooling for 24 hours, a break at day 5, day 10, and day 20, in each case for eight hours. To monitor the internal temperature and relative humidity of the storage containers, HOBO® H8 data loggers were used.

Each of the treatment combinations consisted of ten fruit replicates.

Data collection

Visual observations of fruit condition were made at start, during each break period, when removed from cold storage and during ripening. Before storage, fruit mass, CO_2 evolution, ethylene evolution and fruit softness were also measured. Fruit were visually assessed for shrivel, sunburn, netting, carapace skin and external damage, including chilling injury and lenticel damage. After ripening at room temperature (18-22ºC), fruit were cut and assessed for anthracnose, stem-end rot, vascular browning and mesocarp discolouration. Ethylene evolution was also determined during the ripening period.

CO_2 measurement

CO_2 production from each fruit was measured using an infrared gas analyser (EGM-1, PP Systems, Hitchin, Hertfordshire, UK). In order to estimate the respiration rate, fruit were sealed in 1 L jars for 15 min, after which the CO_2 of the atmosphere in the jars was determined. Net CO_2 production per gram fruit was calculated by adjusting for fruit volume (and therefore head space), fruit mass and ambient CO_2 in the jar (Van Rooyen, 2006).

Ethylene measurement

Ethylene was measured using a gas chromatograph (DANI 1000, DANI Instruments S.p.A., Monzese, Italy). To measure ethylene production, a 20 mL glass vial was placed with the fruit in a sealed 1 L jar for 30 min, thereafter sealed and transferred to the GC autosampler (HT250D, HTA S.r.L., Brescia, Italy). The GC was equipped with a flame ionization detector (FID) and a stainless steel packed column with an alumina-F1 stationary phase. The injector, column and detector temperatures were 160, 80 and 180ºC, respectively.

Fruit softness

Ripening time was calculated as the number of days from harvest until "eating soft" stage. Fruit were deemed ripe when the average reading on a densimeter fitted with a 5 mm round tip was approximately 55 on a scale of 85-90 (hard) to 55-60 (soft). Four equally spaced readings were taken around the circumference of each fruit and the average reading recorded.

Statistical analysis

The data was analysed in the form of a factorial design, where each treatment combination consisted of ten fruit, each constituting a single replication. A general analysis of variance was run using Genstat12, where the ANOVA, table of means, and LSD was computed to identify significantly different treatment combinations.

RESULTS AND DISCUSSION

Fruit softening

Fruit stored at 1ºC as well as the 1-MCP treatments (no significant difference) had substantially less softening by the end of storage than untreated fruit at 5.5ºC ($P < 0.05$) (**Figure 1**). Thus, for fruit shipped at 5.5ºC, 1-MCP was as effective in preventing softening as the lower temperature, but at the lower temperature of 1ºC 1-MCP was not required to achieve the same effect.

With respect to the cold chain breaks, it was found that all breaks resulted in significantly more fruit softening at the end of the 28 day storage period than fruit not subjected to any break (**Figure 2**). Storage at 1ºC appeared to negate the effect of cold chain breaks (**Figure 3**), similar to the findings of Blakey and Bower (2009), and was essentially similar to the effect of 1-MCP (**Figure 4**). The possible reason for this is that the core temperature of the fruit takes longer to

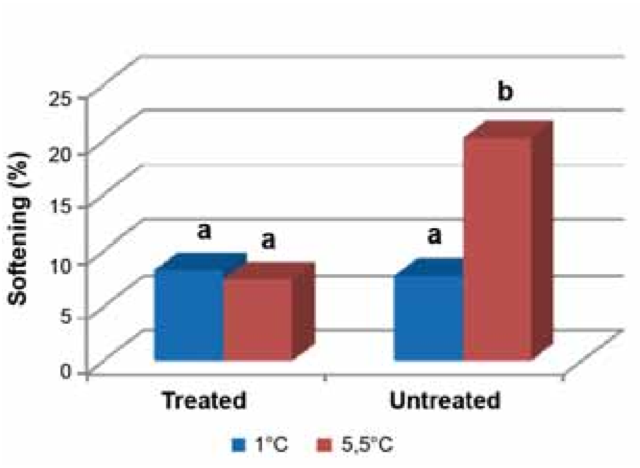

Figure 1. Percentage softening during storage for 28 days as influenced by treatment with 1-MCP and temperature.

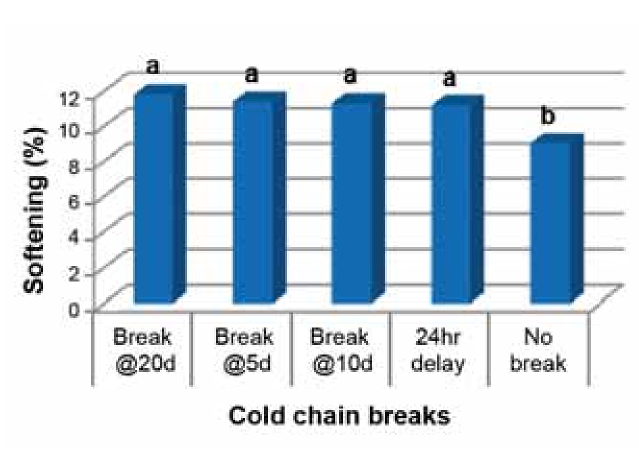

Figure 2. Percentage softening after 28 days storage as influenced by cold chain breaks.

warm up than the 5.5ºC fruit, and therefore a cold chain break of eight hours may not be long enough to reactivate the ripening enzymes.

Mass loss

The mass loss can be assumed to be predominantly due to the loss of water. It was found that storage at 5.5ºC resulted in a higher fruit mass loss than 1ºC (**Figure 5**). These findings are similar to those of Bower and Jackson (2003), as well as Blakey and Bower (2009). The 1-MCP treated fruit had a higher mass loss than the untreated fruit, but the reasons are unknown.

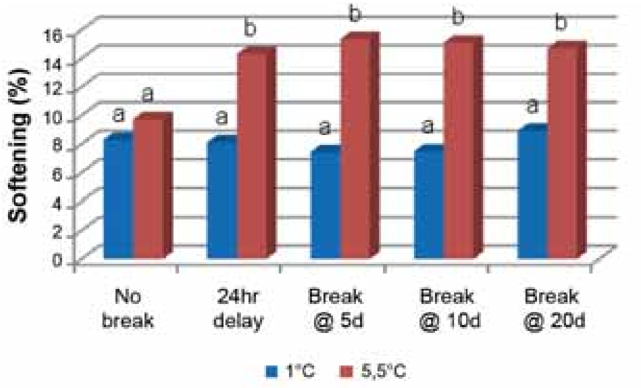

Figure 3. Percentage softening as influenced by temperature and cold chain breaks.

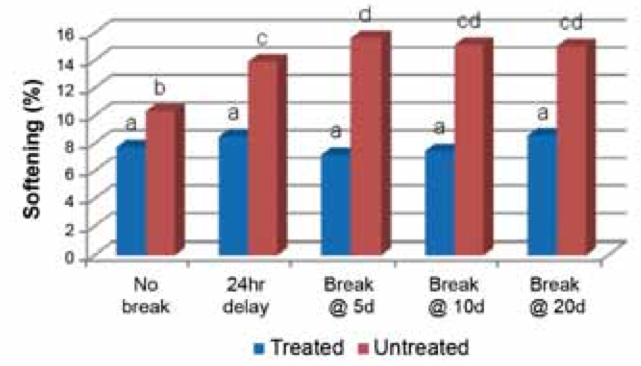

Figure 4. Percentage softening as influenced by 1-MCP and cold chain breaks.

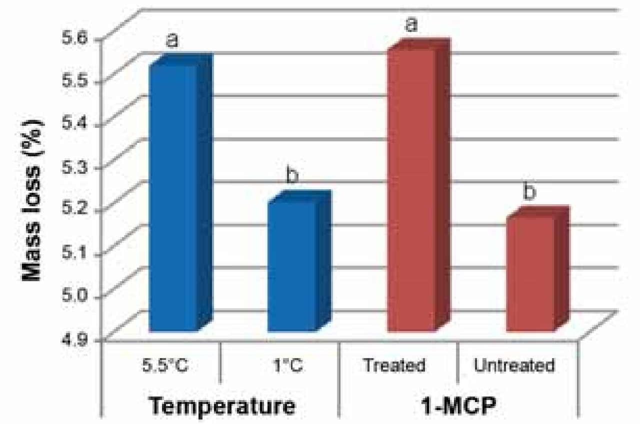

Figure 5. Effect of temperature and 1-MCP on the percentage mass loss of fruit after 28 days cold storage.

It was observed that the 24 hour delay cold chain break treatment incurred the largest mass loss (**Figure 6**). This is likely due to the effect of the vapour pressure deficit (VPD) between the fruit and the surrounding atmosphere being higher for warm than cold fruit. The importance of cooling the fruit as fast and soon as possible in order to reduce the VPD between fruit and atmosphere (and therefore water loss) is thus indicated (Mitchell, 1992).

External quality

The 1ºC treatment did cause more chilling injury than the 5.5ºC treatment (**Figure 7**). However, the results need to be placed in perspective. On a scale of 1 to 20, even the 1ºC treatment only resulted in a value of only 1.7. Chilling injury may not be a significant factor for the 'Hass' cultivar as it does change colour when ripened, so the external chilling injury (provided that it is not severe) will be masked. More chilling injury was present on the fruit which were waxed. In previous work it had been found that waxing reduced the incidence of chilling injury (Bower & Jackson, 2003; Bower & Magwaza, 2004). It is suggested that the possible cause of an increase in chilling injury for the waxed fruit was a larger water loss than the non-waxed fruit, and lower water content is known to increase the incidence and severity of chilling injury (Bower & Jackson, 2003). It is possible that the reduction in gaseous exchange for the waxed fruit was detrimental

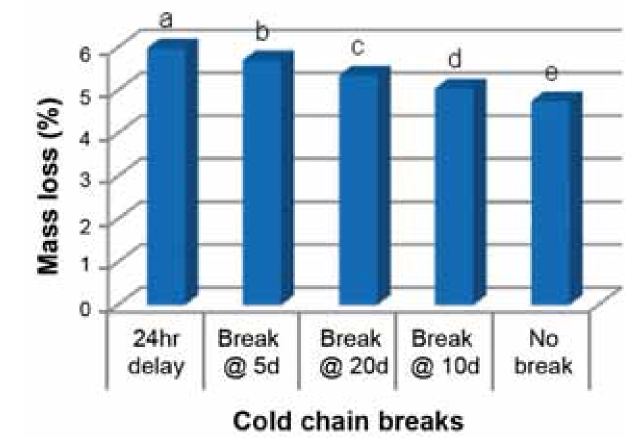

Figure 6. Effect of cold chain breaks on the percentage mass loss of fruit after 28 days cold storage.

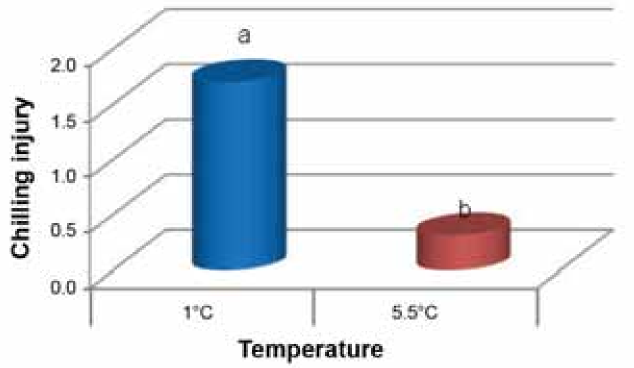

Figure 7. Effect of storage temperature on external chilling injury (scale of 1 to 20).

to the cell wall integrity in the exocarp, leading to cell wall collapse under low temperatures. It was also found that the use of 1-MCP may have an influencing effect with respect the interaction with temperature. The use of 1-MCP did reduce the severity of the chilling injury for the 1ºC treatment, but the use of 1-MCP for this reason will not be justified due to the costs involved.

Internal quality

Important parameters with respect to the internal quality include mesocarp discolouration and vascular browning. These parameters were recorded on a scale of 1-5 when the fruit reached their optimal ripeness and were then cut for observation.

In general, both storage at 1ºC and the use of 1-MCP decreased the incidence of physiological disorders (**Figure 8** and **9**). It is suggested that partial softening during storage at 5.5ºC results in an imbalance in the ripening physiology, possibly resulting in a decrease in cell wall and membrane integrity, which allows for an increased probability of rupturing and solute leakage. Once this occurs in either the mesocarp or vascular bundles, PPO is released from the thylakoids, where it is latently held, and spills into the cytoplasm where browning occurs (Bower & Cutting, 1988).

Days to ripening

The effects of storage temperature on subsequent days to ripen is illustrated in **Figure 10**. Storage at 1ºC extended the days to ripening. This is expected due to the lowering of enzyme activity, respiration and ethylene production (Brady, 1987). Water loss was also lower and it is suggested that the ripening process had already become more advanced in fruit stored at 5.5ºC than 1ºC by the end of storage.

Where a shipping temperature of 1ºC was used and no cold chain break occurred, the 1-MCP had no effect on the days to ripening. However, where cold chain breaks occurred, the use of 1-MCP was advantageous (**Figure 11**).

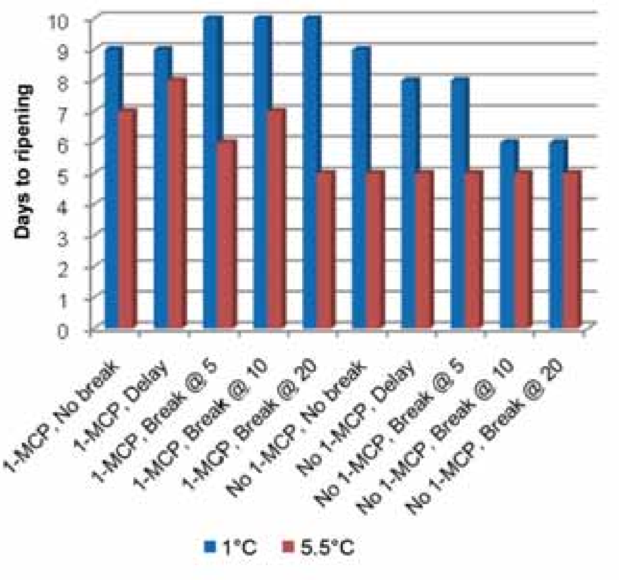

Figure 10. Effect of temperature, 1-MCP treatment and cold chain breaks on days to ripening after storage.

CONCLUSION

It was found that shipping at 1ºC in the absence of 1-MCP was comparable, and in most cases even better, than the use of the protocol temperature of 5.5ºC with the fruit being 1-MCP treated. It was also shown that if the temperature of 1ºC is used, then the use of 1-MCP

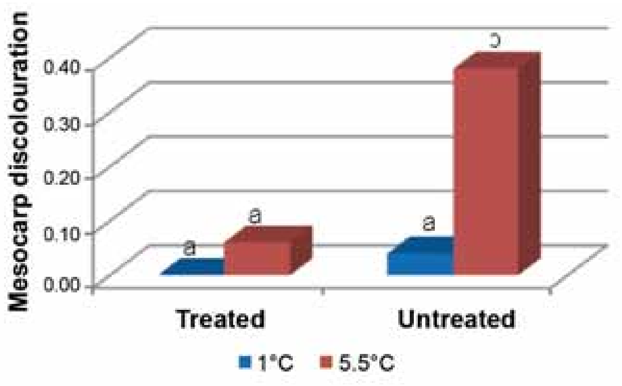

Figure 8. Mesocarp discolouration (scale 1-5) after ripening as influenced by temperature and 1-MCP treatment.

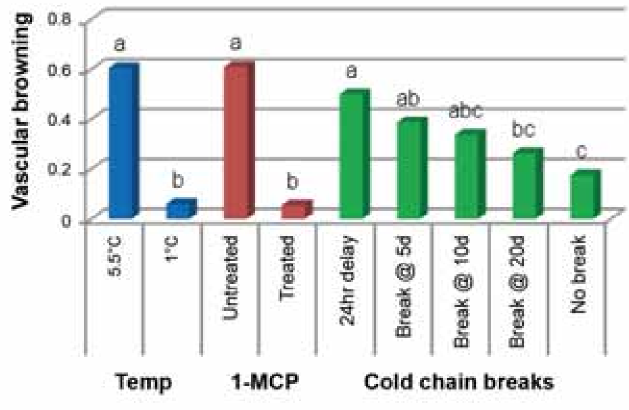

Figure 9. Rating of vascular browning (scale 1-5) after ripening as influenced by temperature, 1-MCP treatment and cold chain break.

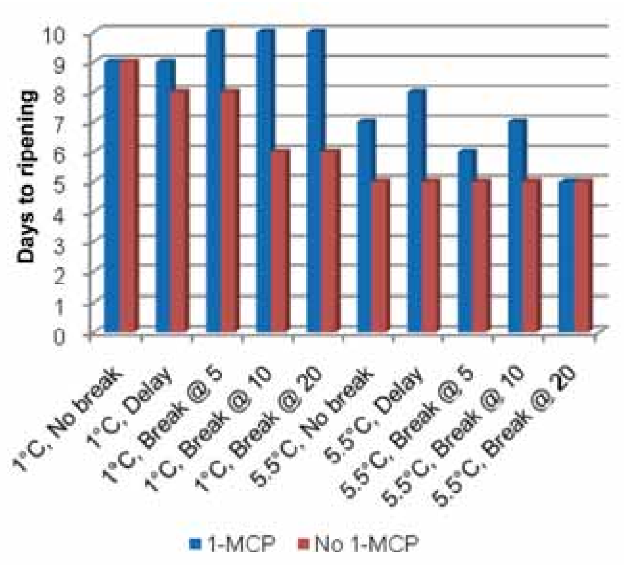

Figure 11. Effect of cold chain breaks, shipping temperature and 1-MCP on days to ripen after storage.

may be unnecessary, unless cold chain breaks occur.

Not only was it found that 1ºC can replace the use of 1-MCP for extending the shelf life of the fruit, but it also seems to substantially negate the detrimental effects of cold chain breaks. This is probably due to the core temperature of the fruit not being able to rise sufficiently within an 8 hour break to reactivate the enzymes involved with softening and break down of cell walls. When considering the effects of cold chain breaks, a delay of 24 hours before the fruit are placed into cold storage was found to cause a significant amount of water loss from the fruit, which makes them more susceptible to chilling injury as well as ripening after storage occurring at a much faster rate.

Shipping at 1ºC may cause a concern of substantial chilling injury. However, it has been found in this study, as well as previous studies, that there is a minimal amount of chilling injury present and the severity is so low that it will be insignificant for the 'Hass' cultivar due to the colour change when the fruit ripen. On the other hand, the internal quality of the 1ºC treated fruit was also significantly better than the fruit shipped at 5.5ºC.

Overall, the data resulting from this study implies that 1ºC can be used as an alternate method to extend the shelf life of avocado fruit. It also seems that if 1ºC is used, it will negate cold chain breaks as effectively as 1-MCP used at a higher shipping temperature. Therefore, it appears that shipping at low temperature may be suitable as a replacement for other technologies for ensuring hard fruit of good internal quality on export markets.

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