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

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ABSTRACT

Shipping at low temperatures (2ºC) can reduce the risk of poor internal quality often associated with greenskins. However, at these low temperatures external chilling injury occurs, a serious problem for the export of cultivars such as 'Fuerte'. Previously an interaction between post-harvest water loss and skin damage has been reported. Furthermore, the effect of commonly occurring cold chain breaks (and subsequent water loss) on fruit quality at these low temperatures was investigated. 'Fuerte' avocado fruit were stored at low temperatures (2ºC and 5.5ºC), treated with 1-MCP and / or waxed. Additionally, commonly occurring cold chain breaks (24 hour cooling delay, break for 8 hours at 5, 10 or 20 days) were simulated. Fruit were analysed with respect to fruit softening, mass loss, CO_2 evolution, days-to-ripening, as well as external and internal quality. The storage temperature of 2ºC provided good internal quality, reduced mass loss and fruit softening, as well as an extended shelf life, compared with the 5.5ºC fruit. The 2ºC storage temperature caused a notably higher occurrence of external chilling injury than 5.5ºC, however, waxing reduced the amount of external chilling injury significantly. Cold chain breaks caused fruit softening and water loss with the most harmful break being a 24 hour delay in cooling, which resulted in a high water loss and fruit softening and, thus, the highest external chilling injury. Overall, ultra-low temperature storage shows promise, and if the external chilling injury can be successfully reduced at 2ºC by use of mitigating treatments, the South African avocado industry could realise substantial savings.

INTRODUCTION

Current shipping temperatures of 5.5ºC appear to be ineffective in preventing fruit softening during shipping, and as a result other technologies such as 1-Methylcyclopropene (1-MCP) application and controlled atmosphere (CA) are used, at a large cost to the industry. While Bower and Magwaza (2004) indicated that lower temperatures (2ºC) can be used for greenskins, possibly through prevention of premature softening, fears of extensive cold injury have prevented use of such protocols. It has also been repeatedly shown that shipping at lower than standard temperatures results in improved fruit quality for various commercial cultivars (Bower & Jackson, 2003; Van Rooyen, 2009; Van Rooyen & Bower, 2002; Van Rooyen & Bower, 2006).

Part of the cause of premature softening may also be due to cold chain breaks at various stages of the shipping chain. Again, the use of alternative treatments, such as 1-MCP and CA, has been able to mitigate the effects. No information is currently available on the effects of cold chain breaks on avocado fruit quality when combined with ultra-low temperature storage. Preliminary investigations by Blakey and Bower (unpublished) on 'Hass' avocados provide valuable information, implying that low temperatures may be effective in decreasing the effects of cold chain breaks. Previous results indicated an interaction between post-harvest water loss and skin damage, making further research on the effects of cold chain breaks (and subsequent water loss) on fruit quality at these low temperatures necessary. The objectives of this study were to determine the potential for shipping 'Fuerte' avocados at 2ºC, to determine the effects of cold chain breaks on fruit quality and to identify whether a shipment at 2ºC could, in 'Fuerte', replace the use of 1-MCP as a mitigating treatment.

MATERIALS AND METHODS

'Fuerte' avocado fruit were obtained from a packhouse in Wartburg, KwaZulu-Natal. The mean moisture content of the fruit at harvest was 67.8%. Post-harvest operations such as grading and sizing, 1-MCP treatment (standard treatment for export fruit), waxing and forced-air-cooling took place at the packhouse. The fruit treated with 1-MCP were gassed for 16 hours in cold storage at a temperature of 5.5ºC, whilst the untreated fruit were stored under the same temperature for the same period. All fruit were transported to the laboratories of the Horticultural Science Department at the University of KwaZulu-Natal (UKZN) for further treatment. Fruit were immediately prepared for simulated shipping for a period of 28 days under regular atmosphere and the following treatments applied:

- Temperature (2ºC and 5.5ºC)
- 1-MCP (treated and untreated)
- Waxing (waxed and non-waxed)
- Cold chain breaks (no break, 24 hour delay, breaks for 8 hours at 5, 10 and 20 days).

Before and after cold storage, each fruit was weighed to determine fruit mass loss (assumed to be equivalent to water loss). Fruit firmness was measured before and after storage to calculate the percentage fruit softening during storage. A 5 mm hand-held densimeter (Bareiss, Oberdischingen, Germany) was used to measure fruit softness (ripeness) on a scale of 85-90 (hard) to 55-60 (soft). Fruit were visually assessed before storage for shrivel, sunburn, netting, carapace skin and external damage to be able to accurately distinguish between chilling injury and these pre-storage damages.

After 28 days, the fruit were removed from cold storage and fruit mass, fruit softness and CO_2 evolution were measured. The fruit were visually assessed for external chilling injury once the fruit had reached room temperature. After the relevant parameters were recorded, the fruit were allowed to ripen in a laboratory at room temperature (18-22ºC).

Ripening time was calculated as the number of days from harvest until "eating soft" stage. Fruit were deemed ripe when the average densimeter reading was less than 55. On ripening, fruit were cut and assessed for anthracnose, stem-end rot, vascular browning and mesocarp discolouration.

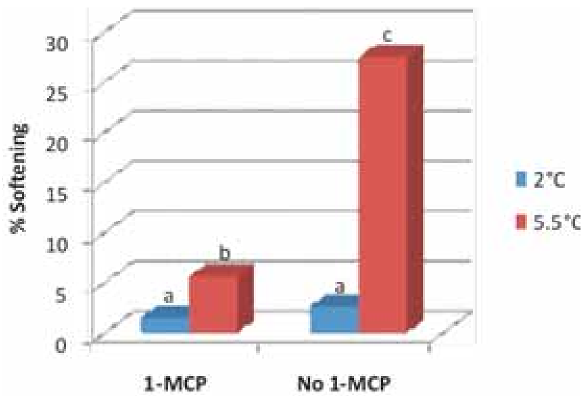

Figure 1. Percentage softening after cold storage for 28 days as affected by storage temperature and 1-MCP treatment.

Table 1. Percentage fruit softening after cold storage at 2ºC and 5.5ºC for 28 days, including four cold chain breaks and a control (no break). LSD = 1.907; (*) indicates significant differences to the relevant control ($P \leq 0.05$).

Cold chain break	Treatment	
	1-MCP	No 1-MCP
Control	2.74	13.24
24 h delay	2.62	16.14*
Break @ day 5	3.85	13.97
Break @ day 10	4.73*	15.98*
Break @ day 20	3.97	16.00*

CO_2 production from each fruit was measured using an infrared gas analyser (EGM-1, PP Systems, Hitchin, Hertfordshire, UK). Fruit were sealed in 1 L jars for 15 minutes, after which the CO_2 of the atmosphere in the jars was determined. Net CO_2 production per gram fruit was calculated with adjustment for fruit volume, fruit mass and ambient CO_2 in the jar (Van Rooyen & Bower, 2006). The day of maximal CO_2 production was used to identify the day of climacteric peak, describing the days to ripening.

RESULTS AND DISCUSSION

Fruit softening

Storage at 2ºC and 1-MCP treatment resulted in significantly less fruit softening during storage than at 5.5ºC. The combination of "2ºC and 1-MCP" resulted in the least fruit softening during storage, although this combination was not significantly different from the "2ºC and no 1-MCP" combination (**Figure 1**). For both storage temperatures, the 1-MCP treatment significantly reduced the amount of fruit softening during storage. However, at a storage temperature of 2ºC the minimal non-significant reduction in fruit softening with 1-MCP treatment indicates that this treatment may not be warranted.

All breaks in the cold chain resulted in softer fruit than the control (**Figure 2**). Although the ripening can be slowed down, the process occurs in a sequential manner (Bower, 1985) and any warm period is likely to enhance the rate of change in ripening. Assuming ethylene production is triggered by water stress, warmer temperatures which result in higher water loss from the fruit will contribute to this process (Bower & Cutting, 1986), and thus fruit softening is likely to take place. The results showed that breaks at a later stage during storage (at 10 or 20 days) tend to be more detrimental than at an early stage (at 5 days), possibly as a result of an anomaly in water loss (i.e., mass loss). The ripening enzymes and metabolic activity required for softening may have developed sufficiently by the time the break at 10 and 20 days occurs, and therefore these breaks are able to trigger the ripening process more than the break at 5 days.

Although there was no significant interaction between temperature and cold chain breaks (P = 0.117),

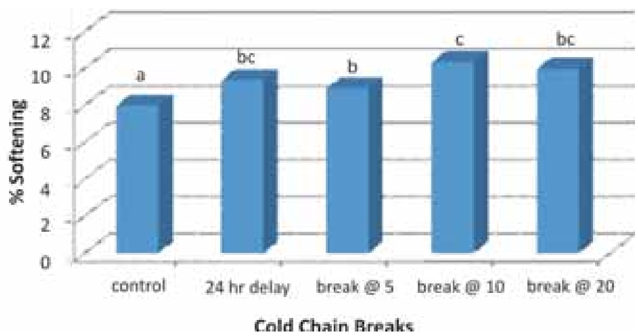

Figure 2. Effect of different timings of cold chain breaks on percentage softening after 28 days of cold storage.

the 2ºC fruit which underwent cold chain breaks did soften more during storage than the control, but to a lesser degree than the 5.5ºC stored fruit which were significantly softer than the control (**Table 1**). There was no significant interaction between 1-MCP and cold chain breaks (P = 0.100). Ultimately, a storage temperature of 2ºC resulted in less fruit softening during shipping, and the use of 1-MCP is not warranted if 2ºC is used.

Mass loss

It was found that the 2ºC storage temperature resulted in significantly less mass loss (assumed to be water loss) than 5.5ºC. These results are in accordance with work done by Bower and Jackson (2003). Results showed that 1-MCP had no significant effect on mass loss, and thus water loss. This is to be expected as the 1-MCP treatment is aimed at reducing the effect of ethylene and fruit softening, and has a minimal impact on water loss. Waxing reduced the percentage water loss over the storage period.

Waxing had been shown to reduce water loss (Durand *et al.*, 1984) which reduces a possible stress on the fruit, and thus the chance of ethylene production and fruit softening as well as the occurrence of external chilling injury (Bower *et al.*, 2003) as was seen in this study (**Figure 5**).

The break at 5 days caused significantly less mass loss than the control (**Figure 3**). This is not to be expected as cold chain breaks should result in water loss, because of the increase in temperature and increased fruit transpiration. A repeated study is suggested to identify whether the effect of the "break at 5 days" does in fact result in lower softening than the control. Overall, there are very few significant differences between the control and the other cold chain breaks, and further work is suggested in order to clarify the effects of cold chain breaks with respect to mass loss in 'Fuerte' avocados.

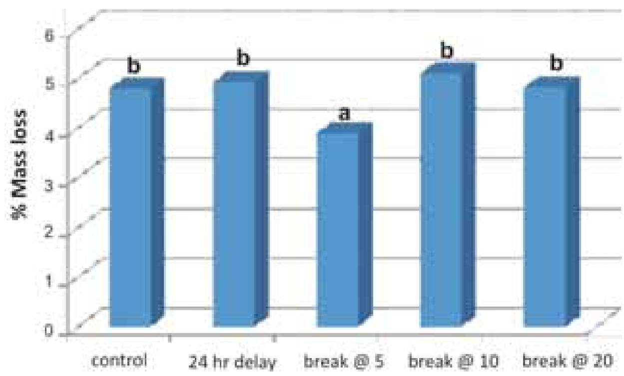

Figure 3. Effect of different timings of cold chain breaks on the percentage mass loss after 28 days of cold storage.

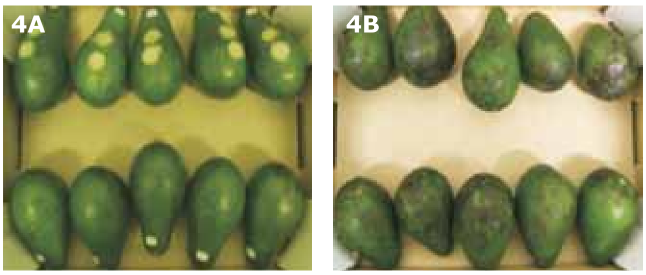

Figure 4. Effect of temperature on external chilling injury, one day after removal from cold storage of the "1-MCP, non-waxed, 24 hr delay" treatment stored at 2ºC (4A) and 5.5ºC (4B).

Internal quality

Storage at 2ºC resulted in fewer internal disorders than storage at 5.5ºC, confirming results by Bower and Magwaza (2004), although fairly insignificant given the low occurrence throughout the experiment, with only 6 out of the 400 fruit showing any signs of internal damage (two occurrences of vascular browning and four of mesocarp discolouration). Condensation is a major problem associated with cold chain breaks, as the free water on the fruit surface can increase the occurrence of fungal disorders. This was not observed in this study due to the negligible number of infected fruit throughout the study. Results confirm the reports by Bower and Magwaza (2004) of excellent internal quality of 'Fuerte' achieved by using a storage temperature of 2ºC.

External quality

Fruit stored at 2ºC (**Figure 4a**) had a significantly higher chilling injury severity than the fruit stored at 5.5ºC (**Figure 4b**). The greater chilling injury severity for the 2ºC fruit may lead to the rejection of these fruit on the export market. This is a major problem with respect to the main aim of this study and possible

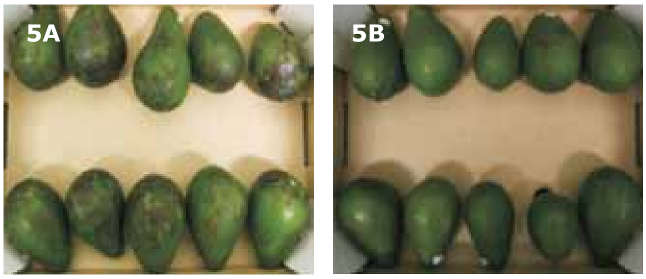

Figure 5. Effect of waxing on external chilling injury, one day after removal from cold storage of the "1-MCP, 2ºC, 24 hr delay" treatment waxed (5A) and non-waxed (5B).

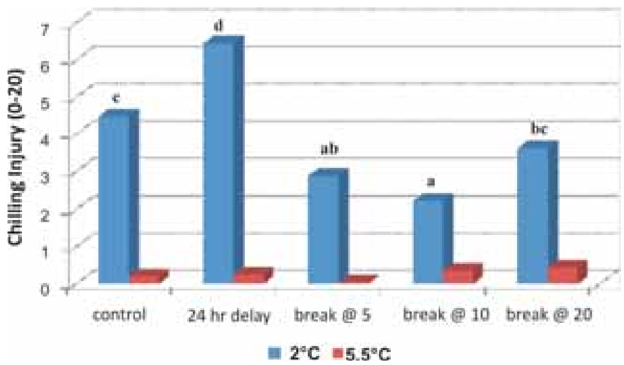

Figure 6. The effect of cold chain breaks at various storage temperatures on external chilling injury from 0 (no injury) to 20 (injury covering entire fruit). Significant differences (indicated by letters a, b, c and d) are only shown for the 2ºC storage temperature.

solutions need to be investigated. Bower and Magwaza (2004) also showed that external chilling injury occurs at 2ºC, but the use of polyethylene bags reduced this external injury.

Waxing was found to reduce chilling injury (**Figure 5**), and occurrence of chilling injury is closely related to the amount of water lost by the fruit during pre-cooling and storage. Waxing reduces water loss, and thus epidermal cells are less stressed and less likely to collapse under low temperatures (Van Rooyen & Bower, 2006). Bower (2005) noted that by minimising fruit mass loss during storage, the chance of chilling injury could potentially be reduced, which is similar to results found in this study.

"24 hr delay" caused significantly higher chilling injury in 2ºC fruit than the other cold chain breaks (**Figure 6**). Bower and Magwaza (2004) confirmed the important correlation between water content and chilling injury and showed that early water loss increased fruit sensitivity to chilling injury. The fruit which showed the least mass loss (break at 5 days), also showed the least external chilling injury, highlighting the correlation of water loss and chilling injury.

Days-to-ripening

A successful storage treatment combination will depend on whether the important effects shown in the storage of the fruit are carried through to the ripening period and provide sufficient shelf life and good post-storage quality.

The 2ºC treatment showed a significant reduction in softening and water loss, and ultimately a longer shelf life in comparison to the 5.5ºC fruit. 1-MCP treatment

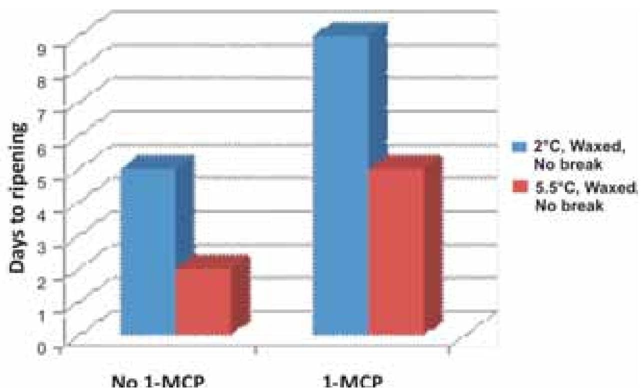

Figure 7. Days-to-ripening of waxed control (no cold chain break) fruit comparing the use of 1-MCP at 2ºC and 5.5ºC after 28 days of cold storage.

Table 2. Percentage fruit softening after cold storage at 2ºC and 5.5ºC for 28 days of four cold chain breaks and a control (no break). LSD = 1.907; (*) indicates significant differences at $P \leq 0.05$.

Cold chain break	Storage temperature (ºC)	
	2	5.5
Control	1.84	14.14
24 h delay	1.95	16.81*
Break @ day 5	1.76	16.05*
Break @ day 10	2.58	18.12*
Break @ day 20	2.26	17.71*

extended the days to ripening in all treatment combinations by between 3 and 5 days, compared to untreated fruit. Importantly, the 5.5ºC stored fruit require 1-MCP treatment if a substantial shelf life is required, while fruit stored at 2ºC can achieve similar days to ripening (as 1-MCP treated fruit stored at 5.5ºC) without the use of 1-MCP if the fruit are waxed (**Figure 7**).

CO_2 is a product of respiration, and thus the respiratory peak indicates where the respiration of the fruit has been successfully reduced. The 2ºC storage temperature delayed the peak of CO_2 evolution, compared to the 5.5ºC storage temperature. Waxing seemed to delay the respiratory peak slightly compared to non-waxed fruit, probably because of the limitation on gaseous exchange imposed on the fruit by the waxing, and thus reducing the level of O_2 present for respiration (Durand *et al.*, 1984). The CO_2 results confirm various trends seen in fruit softness and fruit mass, as well as reinforcing the reason for days-to-ripening being delayed for the various treatments.

CONCLUSION

The storage temperature of 2ºC was more effective than 5.5ºC in reducing respiration, softening and water loss during storage, as well as better internal quality. Further, the waxed fruit stored at 2ºC provided a shelf life comparable to that of fruit stored at 5.5ºC and treated with 1-MCP, which effectively negates the need for 1-MCP if lower temperatures are adopted. However, the storage temperature of 2ºC caused levels of external chilling injury which are unacceptable for export.

In general, any break in the cold chain was found to be detrimental to the quality and shelf-life of avocados. A notably higher severity of external chilling injury was visible in fruit stored at 2ºC after a 24 hour delay in cooling, which highlights the importance of reducing fruit water loss through rapid cooling. Further analysis of tissue samples is recommended in order to understand the physiological damage caused by cold chain breaks.

Until an effective and practical mitigating treatment for external chilling injury is perfected, it is recommended that 'Fuerte' avocados continue to be exported using 1-MCP and storage temperatures of 5.5ºC.

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