An investigation into ultra-low temperature shipping and cold chain management of 'Fuerte' avocados – An opportunity to reduce shipping costs

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ABSTRACT

Present shipping temperature (5.5°C with slight variation depending on fruit maturity) and expensive CA and MA treatments are currently used to delay ripening during shipping. Despite this, fruit may still appear on the European market showing signs of softening and physiological disorders. Recent work by Lutge (2009) on 'Fuerte' avocados, showed that 2°C storage could be a potentially successful alternative, while cold chain breaks were shown to cause increased fruit softening, water loss and susceptibility to external cold damage, especially a break or delay early in the cold chain. However, previous work did not evaluate the effects of fruit maturity changes during the season. The objective of the study was to determine the potential for shipping 'Fuerte' avocados at temperatures of 2°C as well as determining the effects of cold chain breaks on fruit quality, throughout the growing season after storage for 28 and 56 days. 'Fuerte' avocados were harvested on three dates with moisture contents of 74%, 68% and 63%. Fruit were subjected to treatments of temperature, 1-MCP, waxing and cold chain breaks during shipping of 28 days, as well as an additional trial of 56 days. Fruit softening, mass loss, days-to-ripening, external and internal quality were recorded. The storage temperature of 2°C provided good internal quality as well as reduced mass loss and fruit softening. The 2°C storage temperature did cause a notably higher occurrence of external chilling injury than 5.5°C, but extended days-to-ripening. Waxing significantly reduced the external damage on fruit stored at 2°C, so much so that the treatment combinations of '2°C, No 1-MCP, waxed, no break' throughout the season showed no external chilling injury. Cold chain breaks were found to increase mass loss and fruit softening, reduce days to ripening and increase chilling injury, especially early in the season. Importantly, a storage temperature of 2°C was found to negate the effects of cold chain breaks with respect to fruit softening in much the same way, and in some cases more than 1-MCP. Initial results indicate that waxed fruit may be stored fairly successfully for 56 days at 2°C, while 5.5°C is not an option for this length of time. Best results were achieved for mid season fruit stored at 2°C with late season fruit showing increased body rots (anthracnose and stem-end rot). Storage at 2°C can improve the internal quality over a storage period of 28 days. Further, waxed fruit stored at 2°C could eliminate the need for 1-MCP in terms of delivering the required shelf-life and quality. However, the external damage at a storage temperature of 2°C is still a concern, suggesting that at present 1-MCP and 5.5°C storage may still be required for greenskins, particularly early in the season with an opportunity to lower temperatures as fruit maturity increases later in the season.

INTRODUCTION

Exporting South African avocados to European markets requires that firm, high quality fruit reach the oversees ports after a sea voyage of up to 30 days. Temperature regimes revolving around a storage temperature of 5.5°C as well as expensive treatments of 1-Methylcyclopropene (1-MCP) and controlled atmosphere (CA) are currently being used to delay ripening. However, fruit still appear on the European market showing signs of softening and physiological disorders. Studies have shown that lower shipping temperatures (2°C) are not only possible, but also relatively successful (Bower & Magwaza, 2004; Lutge *et al.*, 2010) as a measure to reduce premature softening and moisture loss in greenskins, however, fears of extensive cold injury have prevented the use of such protocols. Lower temperatures have also been repeatedly shown to result in improved fruit quality for various commercial cultivars when stored for 28 days (Bower & Jackson, 2003; Van Rooyen, 2009;

Van Rooyen & Bower, 2006), while very little information is available on an extended storage time of 56 days at 2°C.

Cold chain breaks can contribute further to fruit softening during storage as well as a reduced shelf life, and are detrimental to avocado fruit quality (Blakey & Bower, 2009; Lutge *et al.*, 2010), with particularly damaging effects relating to pathology (Lemmer & Kruger, 2010). Some of these effects can be negated by treatments such as 1-MCP or CA, as well as lower shipping temperatures. Recent focus on the negative effects of cold chain breaks (Blakey & Bower, 2009), the influence of 1-MCP and CA (Lemmer & Kruger, 2010), as well as the interaction of cold chain breaks with ultra-low temperatures (Blakey & Bower, 2009; Lutge *et al.*, 2010), has provided valuable and much needed information. Of great importance is the interaction between post-harvest water loss and skin damage, and further work was necessary to determine the effects of cold chain breaks on fruit quality at these ultra-low temperatures. The effects of fruit maturity (time of harvest during season) has not, however, been shown by the previous studies.

The objectives of this study were to determine the potential for shipping 'Fuerte' avocados at 2°C, to determine whether 2°C could replace the use of 1-MCP as a mitigating treatment, and to determine the effects of cold chain breaks on fruit quality, using fruit harvested from early to late in the season. An additional objective was to determine the possibility of storing 'Fuerte' at 2°C for 56 days, which could increase returns fruit and provide greater flexibility in marketing.

MATERIALS AND METHODS

'Fuerte' avocado fruit were obtained from a pack house in Wartburg, KwaZulu-Natal, where post-harvest operations such as grading and sizing, 1-MCP treatment, waxing and initial cooling took place at the pack house. Harvesting occurred on 25/06/2010 ('early' season), 12/08/2010 ('mid' season) and 16/09/2010 ('late' season) in order to obtain differing maturity levels, namely moisture contents of 74%, 68% and 63% respectively. The fruit treated with 1-MCP were gassed for 16 hours in cold storage at a temperature of 5.5°C, whilst the untreated fruit were stored under the same temperature for the same period, thus constituting a conditioning treatment. The '24 hour delay' treatment entailed fruit being left in the pack house for 24 hours prior to refrigeration. Fruit were transported to the laboratories of the Horticultural Science Department at the University of KwaZulu-Natal and immediately placed into simulated shipping for a period of 28 days under regular atmosphere. Overall, the following treatments applied:

- Temperature (2°C and 5.5°C)
- 1-MCP (treated and untreated)
- Waxing (waxed and non-waxed)
- Cold chain breaks (no break, 24 hr delay, break for 8 hours at 14 days).

The above treatments, except the cold chain breaks, were also applied for a storage period of 56 days.

Both before and after the specified cold storage periods, each fruit was weighed and firmness was measured to determine fruit water loss and fruit softening during storage, respectively. A 5 mm handheld densimeter was used to measure fruit softness (ripeness) on a scale of 85-95 (hard) to 50-55 (soft) as used by Blakey and Bower (2009). The fruit were visually assessed for external chilling injury once the fruit had reached room temperature, allowing time for chilling injury symptoms to develop. After the relevant parameters were recorded, the fruit were allowed to ripen in a laboratory at room temperature (18-22°C). Ripening time was calculated as the number of days from harvest until 'eating soft' stage, which corresponded to an average densimeter reading of less than 55. On ripening, fruit were cut and assessed for anthracnose, stem-end rot, vascular browning and mesocarp discolouration. The data was statistically analysed in the form of a factorial design, where each treatment combination consisted of 10 fruit, each constituting a single replication.

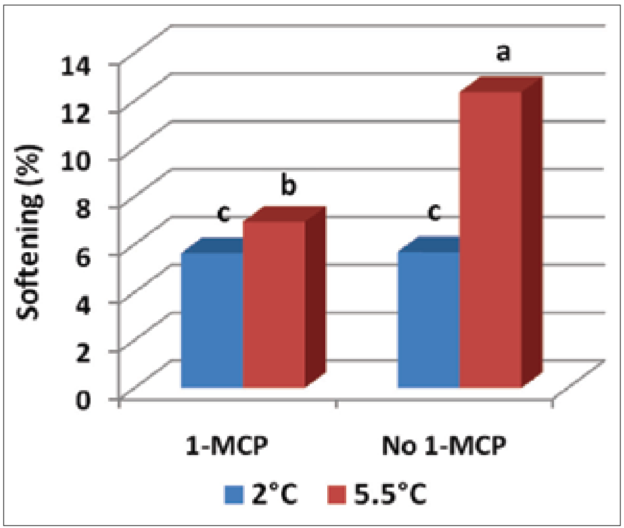

Figure 1. Percentage fruit softening after cold storage for 28 days as affected by storage temperature and 1-MCP treatment.

RESULTS AND DISCUSSION

Fruit softening

Both 1-MCP treatment at 5.5°C and storage at 2°C resulted in significantly less fruit softening during storage than at 5.5°C throughout the season. Importantly, storage at 2°C resulted in significantly less fruit softening than 5.5°C, even when 1-MCP was used at 5.5°C (**Figure 1**), suggesting that the use of 1-MCP may not be warranted if lower temperature shipping is used. Waxing reduced the percentage softening by approximately 1% over the three seasons, but had a larger effect on softening of fruit stored at 5.5°C as opposed to 2°C.

Both the delay in cooling and the break during storage resulted in significantly more fruit softening than the 'control'. Cold chain breaks at a storage temperature of 5.5°C resulted in significantly more softening during storage than the 'control', however, 1-MCP reduced these effects significantly (**Figure 2**). A storage temperature of 2°C was found to negate the softening effects of cold chain breaks, irrespective of whether 1-MCP was used or not, possibly because this lower storage temperature maintained pulp temperatures below critical levels for longer than fruit stored at 5.5°C. The use of 1-MCP did reduce the effects of the '24 hour delay' on fruit softening, but not as effectively as the 2°C storage temperature. The effects on softening of a 'break at 14 days', for 5.5°C storage, were negated significantly by 1-MCP, possibly nullifying the effect of any increase in ethylene production as a result of the rise in pulp temperature and metabolic activity associated with breaks in the cold chain.

Mass loss

Mass loss (assumed to be water loss) was significantly higher early in the season in comparison to the two later harvest dates. The lower storage temperature was able to significantly reduce this mass loss throughout the season, as was found by Bower and Jackson (2003). As expected, 1-MCP did not influence the amount of water loss, as this treatment is primarily used to reduce softening resulting from ethylene action during storage. Waxing was found to reduce water loss significantly. Waxing provides a hydrophobic barrier which reduces water loss and potential stress imposed on the fruit, which can lead to external chilling injury (Bower *et al*., 2003), as seen in this study (**Figure 4**) and also possibly reducing ethylene production and subsequent fruit softening during storage.

The '24 hour delay' resulted in higher mass loss than the 'control' at all three harvest dates (**Figure 3**). This is to be expected as field heat remains in the fruit after harvest and a high vapour pressure deficit is present between the warm fruit and the surrounding air, resulting in rapid water loss from the fruit. Waxing reduced this water loss in the early and mid season fruit, but not in the late season fruit. The 'break at 14 days' also resulted in a slightly higher water loss than the 'control', presumably as a result of increased pulp temperature and subsequent increase in metabolic and respiratory activity.

Internal quality

The 2°C as well as the 5.5°C storage temperatures resulted in very few internal disorders. At each storage temperature, only six fruit with mesocarp discolouration or vascular browning were recorded, whilst stem-end rot (8 fruit) and anthracnose (12 fruit) were more prevalent late in the season. Although not significant, a trend was noticeable towards increased pathological disorders as the days-to-ripening was

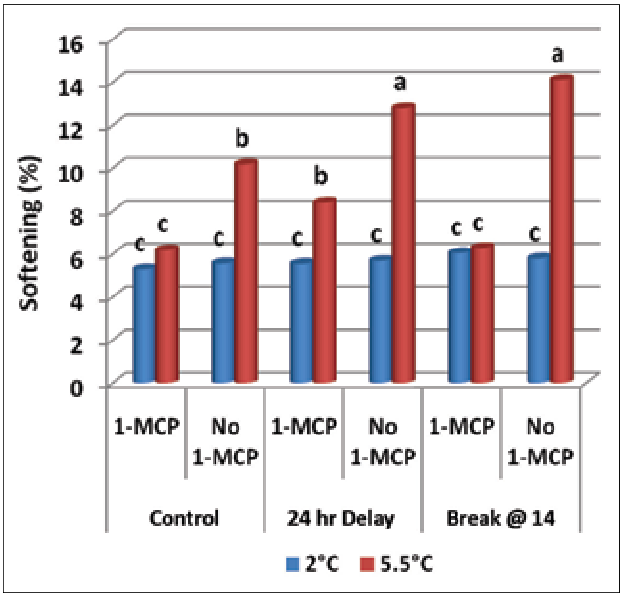

Figure 2. Effect of different cold chain breaks, storage temperatures and 1-MCP treatment on percentage softening after 28 days of cold storage.

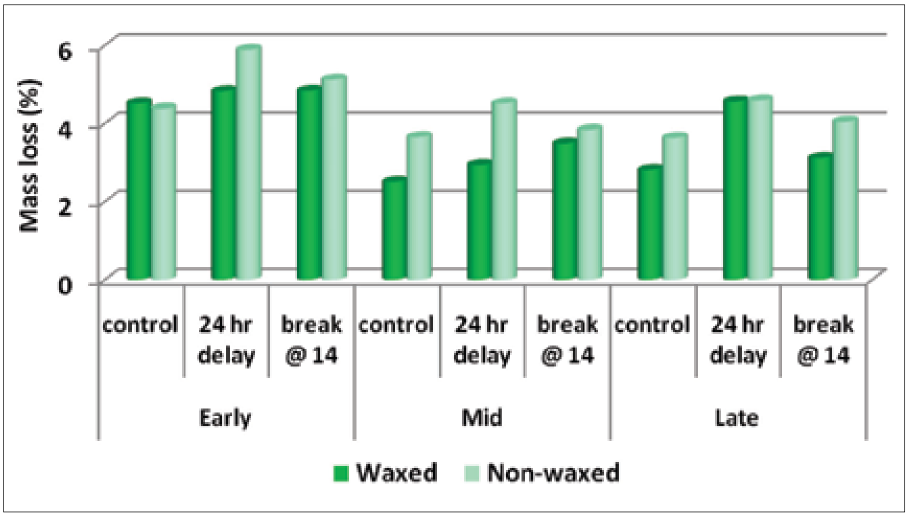

Figure 3. Effect of waxing and cold chain breaks on percentage mass loss after cold storage for 28 days.

lengthened, through the combined effects of 1-MCP and 2°C storage. This illustrated the importance of identifying a desirable days-to-ripening and applying the suitable treatments. For example, storing fruit at 2°C as well as applying 1-MCP, would result in a lengthy days-to-ripening (10-12 days), allowing time for latent infections to manifest themselves, and thus would not be desirable as avocado fruit which take longer to ripen generally have more diseases when ripe (Hopkirk *et al.*, 1994). All the fruit with anthracnose and the majority of the fruit with stem-end rot were fruit treated with 1-MCP. Use of 1-MCP has been shown to increase the incidence of anthracnose (Lemmer & Kruger, 2003), while decreasing the incidence of stem-end rots (Lemmer & Kruger, 2010) in certain instances. Ultimately, storage of 'Fuerte' avocados at 2°C resulted in very few internal problems as was found by Bower and Magwaza (2004).

External quality

External chilling injury remains a concern when implementing ultra-low temperature storage, and one of the most important parameters measured in the study. A very low incidence of notable chilling injury was recorded (4.3% of all fruit had a rating of >2/10) which was significantly less external chilling injury than in the 2009 season (15.3% with rating of >2/10)

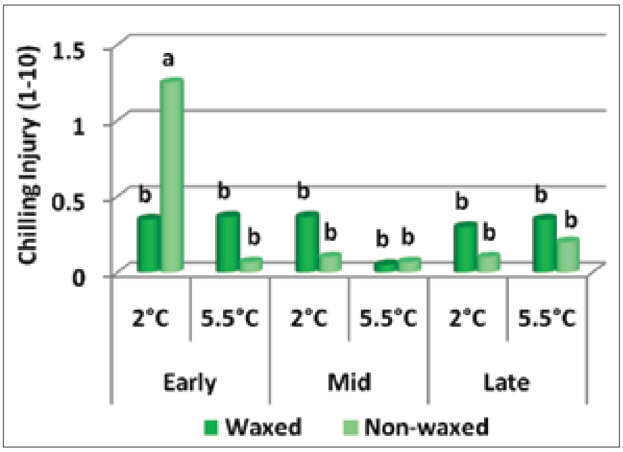

Figure 4. Effect of waxing on external chilling injury severity (rating of 1-10 based on surface area damaged with 10 being completely black) after cold storage at 2°C and 5.5°C for 28 days.

(Lutge *et al.*, 2010). The 2°C storage temperature did cause a notably higher occurrence of external chilling injury than 5.5°C, which is potentially a large problem and could lead to rejection of export fruit. Early season fruit suffered more external damage than the two later harvest dates, as less mature fruit have been shown to be more susceptible to external damage (Toerien, 1986), particularly non-waxed fruit (Figure 4). Waxing significantly reduced the external damage on fruit stored at 2°C, so much so that the treatment combinations of '2°C, no 1-MCP, waxed, no break' throughout the season showed no external chilling injury (**Figure 5**).

The external chilling injury was found to be closely related to mass loss as treatments which increased water loss, such as the '24 hour delay' and non-waxed fruit, resulted in significantly higher external chilling injury. These results agree with findings of Bower and Magwaza (2004) who noted the important correlation between water loss and external chilling injury. The '24 hour delay' as well as the 'break at 14 days' resulted in more external chilling injury than the 'control' throughout the season, with significant differences indicated in **Figure 6**. The 'break at 14 days' presumably resulted in an increase in pulp temperature and thus ethylene production was triggered, causing softening during storage and subsequent external damage.

Days-to-ripening

Storage at 2°C resulted in significantly more days-to-ripening than 5.5°C, as did 1-MCP treatment and waxing. When comparing the best 2°C treatment combination with '5.5°C and 1-MCP' (**Figure 7**), the ripening period was fairly similar, barring an anomaly in the mid season fruit where several 1-MCP treated fruit did not ripen at all, which skewed the days-to-ripening upwards. A ripening time of approximately one week (6-8 days) through the season, whether fruit are stored at 2°C without using 1-MCP or at 5.5°C using 1-MCP, was found. A shelf life of only two days was recorded at all three harvest dates for fruit stored at 5.5°C, without the use of 1-MCP, indicating that at 1-MCP is required at 5.5°C to achieve an acceptable shelf life, unless these fruit are entering a ripe-and-ready program.

In terms of cold chain breaks, the '24 hour delay' resulted in the shortest days-to-ripening, significantly shorter than the 'control', while the 'break at 14

Figure 5. 'Early', 'mid' and 'late' season fruit stored at 2°C with no cold chain break for 28 days. Fruit were waxed.

days' resulted in a slightly longer days-to-ripening, but still significantly shorter than the 'control'. Storage temperature and 1-MCP had very little effect in reducing the effects of cold chain breaks with respect to days-to-ripening. Ultimately, both breaks in the cold chain resulted in a reduced shelf life and should be avoided as much as possible, with the growers needing to take responsibility in cooling their fruit as rapidly as possible after harvest.

56 days storage

Overall, the fruit stored at 5.5°C for 56 days were of poor quality and softened significantly more than at 2°C (**Table 1**) during storage, even when 1-MCP was used. Best results were achieved for mid season, waxed fruit stored at 2°C, without the use of 1-MCP (**Figure 8**). This treatment combination produced fruit of good external quality, sound internal quality (no cases of internal damage) as well as a desirable shelf life of seven days. The use of 1-MCP at 2°C had very little impact of external chilling injury but extended the days-to-ripening to 11 days, however, this may not warrant the extra cost involved. Early season fruit suffered from external chilling injury, and late season fruit were more prone to anthracnose and stem-end rot. As was the case in the 28 day trial, waxing played an important role in reducing water loss, fruit softening and external chilling injury while increasing days-to-ripening.

CONCLUSION

Storage at 2°C resulted in better internal quality, reduced mass loss and softening as well as extended days-to-ripening in comparison with conventional 5.5°C storage, and similar to 1-MCP treatment, but having higher external chilling injury, especially early in the season. The '24 hour delay' in cooling has the greatest impact on water loss, causing a stress which may have knock-on effects on fruit softening and external chilling injury, and should thus be avoided as

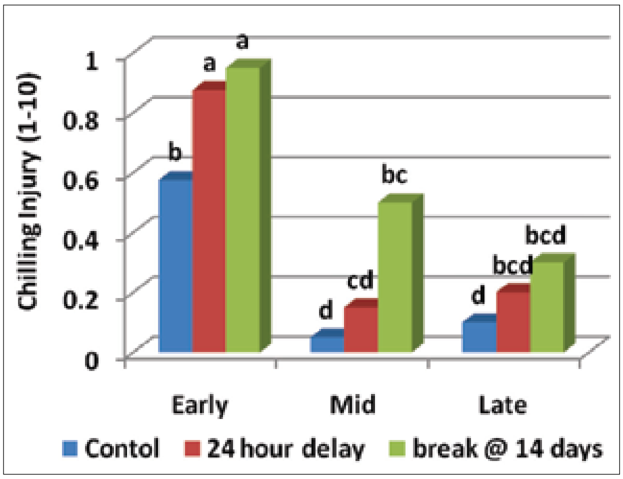

Figure 6. Effect of cold chain breaks on external chilling injury after storage at 2°C for 28 days.

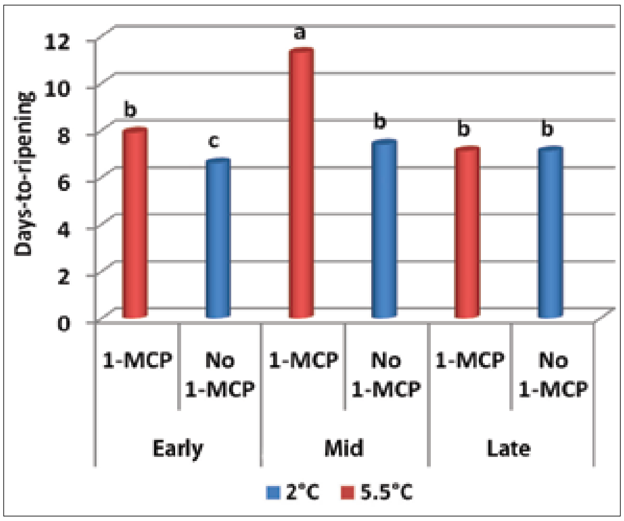

Figure 7. Effect of storage temperature and 1-MCP on waxed fruit, comparing combinations of '2°C + no 1-MCP' and '5.5°C + 1-MCP' (approx. current protocol) throughout the season.

Table 1. Effect of storage temperature, waxing and 1-MCP use on the percentage fruit softening after 56 days of cold storage. LSD = 5.102.

		Early		Mid		Late	
1-MCP	**Wax**	**2°C**	**5.5°C**	**2°C**	**5.5°C**	**2°C**	**5.5°C**
1-MCP	Waxed	8.7	15.9	8.78	19.51	6.32	30.36
	Non-waxed	9.62	21.36	8.09	33.72	7.54	28.38
No 1-MCP	Waxed	11.42	34.32	8.85	40.92	8.31	41.08
	Non-waxed	10.08	31.92	11.15	42.68	9.24	43.28

Figure 8. External chilling injury of mid season, waxed fruit with (left) and without 1-MCP (right) after storage at 2°C for 28 days.

much as possible. The break during storage results in significantly more softening and also leads to a reduction in external and internal quality, with a generally underestimated effect on pathology.

Waxing appears to be an invaluable treatment for a thin skinned avocado such as 'Fuerte', resulting in reduced water loss and subsequent softening, with reduced severity of external chilling injury. Waxed fruit stored at 2°C for 56 days provided good external and internal quality, while 5.5°C storage for 56 days is not recommended. Best results were achieved for mid season fruit stored at 2°C. 'Late' season fruit would potentially be the most profitable; however body rots (anthracnose and stem-end rot) were more of a concern late in the season.

Further research and commercial trials are required before changes to export protocol. However, successful cold storage treatment of 2°C for 'Fuerte' may satisfy phytosanitary certification requirements, and could allow South African avocados to reach new markets. Cold treatment will most likely be part of these requirements. In addition, there does appear to be the potential to ship at 2°C without the cost of CA or 1-MCP, provided fruit is of the correct maturity.

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