An investigation into ultra-low temperature shipping, 1-MCP use and cold chain management of Fuerte avocados – an opportunity to reduce shipping costs

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ABSTRACT

Long distance shipping requires extended storage with potential for fruit to show softening on arrival, especially if breaks in the cold chain occur. The solution has been the use of 1-MCP, which is costly. The objectives of the research were to investigate the possibility of using lower shipping temperature. Early, mid and late season fruit were harvested and stored at 2^{o}C or 5.5^{o}C. 1-MCP and waxing were included as treatments as were cold chain breaks (24 hour delay and break at 14 days). Storage was for 28 and 56 days. Fruit softening, mass loss, days-to- ripening, and external and internal quality were determined. Storage at 2^{o}C resulted in better internal quality, reduced mass loss and softening as well as extended days-to-ripening in comparison with 5.5^{o}C storage, and similar to 1-MCP but higher external chilling injury, especially early in the season. Waxing significantly reduced, while cold chain breaks increased external damage, mass loss and fruit softening. The effects of cold chain breaks were negated by 2^{0}C, more so than 1-MCP. Waxed fruit stored at 2^{o}C for 56 days provided good external and internal quality, while 5.5^{o}C storage for 56 days is not recommended. Waxed fruit stored at 2^{o}C could eliminate the need for 1-MCP.

Key words: low temperature shipping, 1-MCP, wax, cold chain breaks, extended storage

UNA INVESTIGACION SOBRE EL USO DE ULTRA-BAJA TEMPERATURA DURANTE EL TRANSPORTE, USO DE 1-MCP Y MANEJO DE LA CADENA DE FRIO EN AVOCADOS 'FUERTE' – Una oportunidad para reducir costos de transporte

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El transporte de larga distancia requiere de almacenamiento prolongado con el potencial de afectar las características del fruto al arribo, especialmente si la cadena de frío no ha sido mantenida. La solución ha sido el uso de 1-MCP, que es costoso. El objetivo de este studio fue el de investigar la posibilidad de usar una temperatura de transporte mas baja. Frutos de cosecha temprana, media y tardía fueron almacenados a 2oC o 5.5oC. 1-MCP y encerado fueron incluidos como tratamientos así como también interrupciones en la cadena de frío (24 horas de atraso y corte a los 14 días). El almacenamiento fue por 28 y 56 días. El ablandamiento de la fruta, la perdida de peso, y la calidad interna y externa fueron determinadas. El almacenamiento a 2º C resulto en una mejor calidad interna, menor perdida de peso y ablandamiento al igual que una mejora en los días a la maduración en comparación con el almacenamiento a 5.5º C, y similar a 1-MCP pero con un mayor daño externo por enfriamiento, especialmente los de cosecha temprana. El encerado disminuyo significativamente el daño externo, la pérdida de peso y el ablandamiento de la fruta, mientras que las interrupciones en la cadena de frío tuvieron un efecto contrario en estos parámetros. El uso de refrigeración a 2º C contrarrestó el efecto de las interrupciones en la cadena de frío, más aun que el uso de 1-MCP. El encerado de la fruta almacenada a 2º C por 56 días resulto en una mejor calidad externa e interna, mientras que el almacenado a 5.5º C por 56 días no es recomendado. El encerado de fruta almacenada a 2º C podria eliminar la necesidad de usar 1-MCP

INTRODUCTION

The export of South African avocados requires that firm, high quality fruit reach the European market after a sea voyage of up to 30 days. This lengthy transport period necessitates a delay in fruit ripening, currently achieved using temperature regimes based on the industry norm of 5.5^{o}C, as well as treatments of 1-Methylcyclopropene (1-MCP) and controlled atmosphere (CA). However, some shipments still shows signs of softening, uneven ripening and physiological disorders upon arrival at overseas markets. 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 and Bower, 2009; Lutge *et al.*, 2010), with particularly damaging effects on pathological disorders (Lemmer and Kruger, 2010). Some of these effects can be negated by post-harvest treatments such as 1-MCP and CA, or alternatively by implementing lower shipping temperatures, a substantially cheaper alternative. In the last five years, various studies have shown that lower shipping temperatures (2˚C) are not only possible but also relatively successful, particularly in reducing premature fruit softening and moisture loss in greenskin avocados (Bower and Magwaza, 2004; Van Rooyen and Bower, 2007). Justifiably, fears of extensive cold injury have prevented the use of such protocols to date. Recent investigations, mainly on fruit originating from the cooler production area of South Africa, have shown that lower shipping temperatures can result in improved fruit quality for various commercial cultivars when stored for 28 days under regular atmosphere (RA). Very little information is available on the extended storage time of 56 days at 2°C. Lemmer *et al*. (2006) found that 'Fuerte' avocados could be stored for 2 months when combining 1-MCP treatment and CA, using a stepped-down temperature regime with fruit stored at 7°C for the first month and 6°C for the second month.

Recent focus on the negative effects of cold chain breaks (Blakey and Bower, 2009); the influence of 1-MCP and CA on these effects (Lemmer and Kruger, 2010); and the interaction of cold chain breaks with ultra-low temperatures (Blakey and Bower, 2009; Lutge *et al.*, 2010), has provided valuable and much needed information in this field. Of great importance is the interaction between post-harvest water loss and skin damage, and further research is necessary to determine the effects of cold chain breaks on fruit quality at these ultra-low temperatures. Therefore, the objectives of this study were to determine the potential for shipping 'Fuerte' avocados at 2°C, whether 2°C could be an alternative to 1-MCP as a mitigating treatment, and the effects of cold chain breaks on fruit quality. An additional objective was to determine the possibility of storing 'Fuerte' at 2°C for 56 days, thus possibly increasing the late season export prices, providing greater flexibility in marketing and increasing the potential for South African avocados to enter new markets requiring cold disinfestation.

MATERIALS AND METHODS

In the 2009 season, a preliminary trial was conducted with a single batch of fruit (67.8% moisture content) to determine the potential for shipping 'Fuerte' avocados at 2°C, to investigate whether 2°C could be an alternative to 1-MCP, and to identify the effects of cold chain breaks on fruit quality. The cold chain breaks included five different cold chain break treatments (no break, 24hr delay and breaks at 5, 10 and 20 days) to identify which breaks were most detrimental to fruit quality.

During the 2010 season, the study was furthered by collecting three batches of fruit which were harvested on 25/06/2010 ("early" season), 12/08/2010 ("mid" season) and 16/09/2010 ("late" season) to obtain differing maturity levels, namely moisture contents of 74%, 68% and 63% respectively. The cold chain breaks were altered to focus on the areas of importance found in the preliminary trial, while the core treatments and objectives of the 2009 experiment were repeated and an extended storage period of 56 days was investigated.

'Fuerte' avocado fruit were obtained from a packhouse in Wartburg, KwaZulu-Natal, where postharvest operations such as grading and sizing, 1-MCP treatment, waxing and forced air cooling was carried out at the on-farm packhouse. 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 packhouse for 24 hours prior to refrigeration. Fruit were transported to the laboratories and immediately placed into simulated shipping for a period of 28 days under regular atmosphere and 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, 24hr delay, break for 8 hours at 14 days)

The above treatments, excepting 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 its firmness measured to determine fruit water loss and fruit softening during storage, respectively. A 5mm hand-held 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 at room temperature (18-22^{o}C). Ripening time was calculated as the number of days from harvest to the '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. Data was statistically analysed in the form of a factorial design, where each treatment combination consisted of 10 fruit, each constituting a single replication. Least significant difference (LSD) at 5% was used to indicate significantly different treatment means.

RESULTS AND DISCUSSION

Fruit Softening

Preliminary experiments indicated that the storage temperature of 2^{o}C, 1-MCP treatment and waxing result in significantly less fruit softening than storage at 5.5^{o}C, no 1-MCP and non-waxed fruit respectively. The combination of '2^{o}C and 1-MCP' resulted in the least fruit softening during storage, although this combination was not significantly different from the '2^{o}C and no 1-MCP' combination. Irrespective of the storage temperature, any break in the cold chain generally resulted in more fruit softening than the control (no break), with the greatest fruit softening occurring when breaks occurred late in the cold chain (*vis.* breaks at 10 and 20 days). The 2^{o}C storage temperature was shown to negate the softening effects of cold chain breaks as the fruit softening caused by the breaks was not significantly different from the 'control', however storage at 5.5^{o}C did not negate the softening effects of cold chain breaks. There was no significant interaction between 1-MCP and cold chain breaks (P=0.100), largely because of an anomaly of lower fruit softening in the 'break at 5 days' than the 'control' when stored at 5.5^{o}C.

In the 2010 experiment, storage at 2^{o}C resulted in significantly less fruit softening during storage than at 5.5^{o}C throughout the season. Importantly, storage at 2^{o}C again resulted in significantly less fruit softening than 5.5^{o}C, even when 1-MCP was used at 5.5^{o}C (**Figure 1**), suggesting that lower shipping temperatures may be a successful alternative to 1-MCP in terms of minimising the amount the softening which occurs during shipping. Waxing reduced the amount of fruit softening significantly as opposed to non-waxed fruit, and had a larger effect on fruit stored at 5.5^{o}C than at 2^{o}C.

The most important finding with respect to cold chain breaks was that the storage temperature of 2^{o}C was found to negate the softening effects of cold chain breaks, irrespective of whether 1-MCP was used or not. The lower storage temperature is presumably able to maintain pulp temperatures below critical levels for longer than fruit stored at 5.5^{o}C. At 5.5^{o}C, both the delay in cooling and the break during storage resulted in significantly more fruit softening than the 'control', however 1-MCP reduced these effects significantly (**Figure 2**), more so the break at 14 days than the 24 hour delay. 1-MCP is likely nullifying the effect of any increase in ethylene production and respiration as a result of the rise in pulp temperature and metabolic activity associated with breaks in the cold chain at this temperature, similarly to findings by Lemmer and Kruger (2010) for 'Fuerte' fruit stored between 4^{o}C and 8^{o}C.

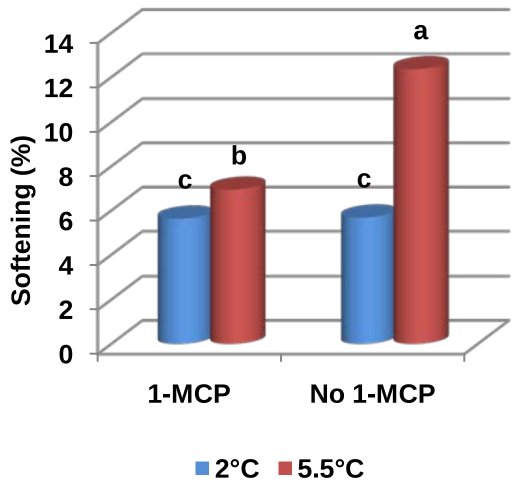

Figure 1: Effect of storage temperature and 1-MCP treatment on percentage fruit softening after cold storage for 28 days. (P < 0.001; LSD = 0.789)

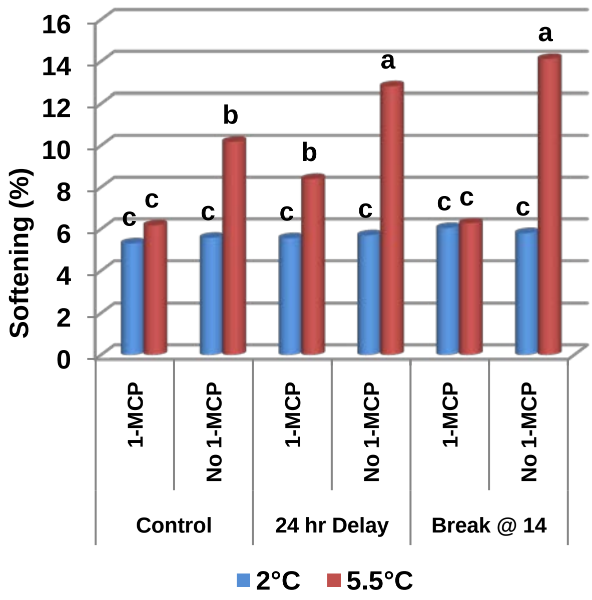

Figure 2: Effect of different cold chain breaks, storage temperatures and 1-MCP treatment on percentage softening after 28 days of storage. (P = 0.003; LSD = 1.366)

Mass Loss

Whether through reducing storage temperatures, applying a hydrophobic wax coating or ensuring a break in the cold chain does not occur, reducing water loss is of utmost importance. By reducing water loss, one ultimately reduces the potential stress imposed on the fruit, thus reducing ethylene production and subsequent fruit softening during storage - which can lead increased external chilling injury (Bower *et al*., 2003). The preliminary experiment in 2009 indicated that reducing the storage temperature from 5.5^{o}C to 2^{o}C as well as waxing of fruit reduced mass loss (assumed to be water loss) significantly; however 1-MCP treatment had no significant effect on mass loss. In general, any break in the cold chain increased mass loss compared to the control, however, there were very few significant differences between the cold chain breaks, and further work was needed in order to clarify the effects of cold chain breaks on mass loss.

In the 2010 experiment, the reduced storage temperature of 2^{o}C as well as waxing reduced mass loss significantly. Results showed that the mass loss was significantly higher early in the season in comparison to the two later harvest dates and that the lower storage temperature (2^{o}C) was able to significantly reduce this mass loss throughout the season, as was found by Bower and Jackson (2003). Again, 1-MCP did not influence the amount of water loss, as this treatment is primarily used to reduce softening during storage. In terms of cold chain breaks, the ‘24 hour delay’ resulted in significantly 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 significantly 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.

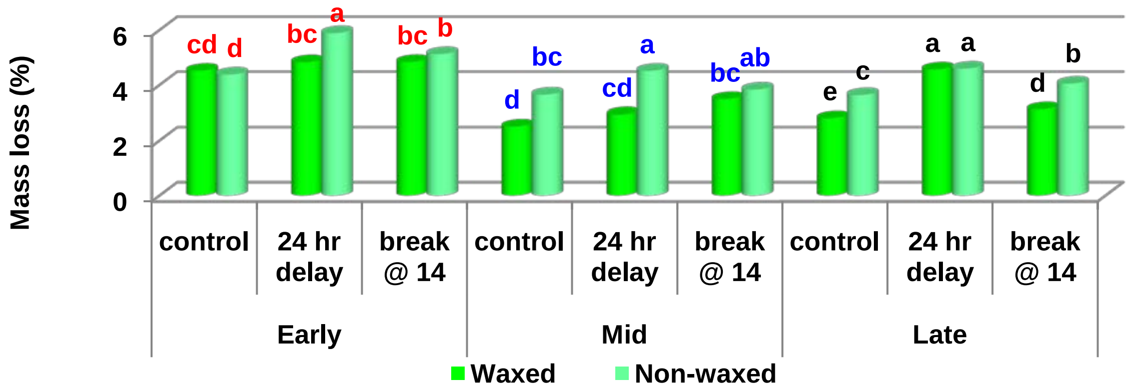

Figure 3: Effect of waxing and cold chain breaks on percentage mass loss after cold storage for 28 days at the harvest dates through the picking season. Coloured letters indicate significant differences for each of the seasons separately. (Early: P<0.001, LSD=0.4196; Mid: P=0.120, LSD=0.840); Late: P<0.001, LSD=0.2988)

Internal Quality

In both 2009 and 2010, very few internal disorders were recorded with only 1.5% of the fruit in 2009 and 4.4% of the fruit in 2010 showing any signs of internal damage. The 2°C as well as the 5.5°C storage temperatures resulted in very few internal disorders, therefore not too much can be read into these figures; however, the results confirm the reports by Bower and Magwaza (2004) of excellent internal quality of 'Fuerte' achieved by using a storage temperature of 2°C.

In 2010, the incidences of mesocarp discolouration and vascular browning were negligible, while of more importance was the occurrence of pathological disorders, namely anthracnose and stem-end rot. Stem-end rot (8 fruit) and anthracnose (12 fruit) were more prevalent late in the season. All the fruit with anthracnose and the majority of the fruit with stem-end rot were fruit treated with 1-MCP, indicating that this treatment may increase the occurrence of pathological disorders, although the low number of infected fruit means that this is merely a trend. The use of 1-MCP has been shown to increase the incidence of anthracnose (Lemmer and Kruger, 2003), while decreasing the incidence of stem-end rots (Lemmer and Kruger, 2010), in certain instances.

Although not significant, a trend was noticeable towards increased pathological disorders as the DTR was excessively lengthened, through the combined effects of 1-MCP and 2°C storage. This illustrated the importance of identifying a desirable DTR and applying the suitable treatments. For example, storing fruit at 2°C as well as applying 1-MCP would result in a lengthy DTR (10-12 days), allowing time for latent infections to manifest themselves, and thus would not be a desirable as avocado fruit which take longer to ripen generally have more diseases when ripe (Hopkirk *et al.*, 1994). The effect of cold chain breaks on pathological infections is extremely important and often overlooked. Although not found to be significant in this study, cold chain breaks and the associated condensation which occurs, can increase the occurrence of anthracnose and stem-end rot as found by (Lemmer and Kruger, 2010), as the free water on the fruit surface is a favourable environment for fungal growth.

External Quality

External chilling injury is the primary concern when implementing ultra-low temperature storage, and one of the most important parameters measured in the study. The preliminary experiment in 2009 showed that fruit stored at 2°C had a significantly higher chilling injury severity than fruit stored at 5.5°C. This increase in chilling injury severity for the 2°C fruit could lead to the rejection of these fruit on the export market. However, waxing was found to reduce chilling injury significantly and was closely related to the amount of water lost by the fruit during pre-cooling and storage. With respect to cold chain breaks, the fruit stored at 2°C showed that the '24 hr delay' caused significantly higher chilling injury damage than the other cold chain breaks. The fruit which showed the least mass loss (break at 5 days), also showed the least external chilling injury, which highlighted the importance of water loss on chilling injury sensitivity. The use of 1-MCP had no significant effect on the 'control' fruit, however it significantly reduced the damage occurring as a result of breaks late in the cold chain.

In the 2010 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% of all fruit had a rating of >2/10). The 2°C storage temperature did cause a significantly higher occurrence of external chilling injury than 5.5°C. 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 has been shown to reduce water loss, making the epidermal cells less stressed and thus less likely to collapse under low temperatures (Van Rooyen and Bower, 2007). As was the case in 2009, 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. 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 and no break' throughout the season showed no external chilling injury (**Figure 5**), which is extremely promising. These results agree with findings of Bower and Magwaza (2004) who noted the important correlation between water loss and external chilling injury.

The cold chain breaks were statistically significant (P=0.041) and resulted in more external chilling injury than the 'control' in all three harvests. Both breaks caused significantly higher external damage in the 'early' season, however, only the 'break at 14 days' caused significantly more external damage than the control in the 'mid' season, with neither of the breaks causing significantly more damage than the control in the 'late' season. The 'break at 14 days' presumably resulted in an increase in pulp temperature and thus ethylene production was triggered, causing measurable softening during storage and subsequent external damage. These results suggest that a delay in cooling or break in the cold chain is especially damaging to the external appearance of the fruit early in the season, when moisture loss from less mature fruit is high, while breaks in the cold chain have less of an effect on external quality later in the season when fruit are more mature and likely to lose less moisture.

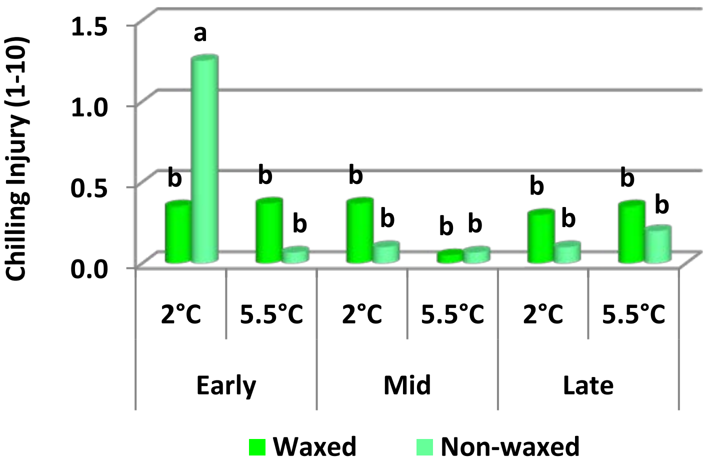

Figure 4: Effect of waxing on external chilling injury severity (rating of 1-10 based on surface area damaged with 10 being completely black) after cold storage at 2°C and 5.5°C for 28 days. (P < 0.001; LSD = 0.310)

Figure 5: 'Early', 'mid' and 'late' season fruit stored at 2°C for 28 days with 'no 1-MCP, waxed, control' treatment combinations.

Days-to-ripening (DTR)

The eventual realization of a successful storage treatment combination depends 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 post-storage quality.

In the preliminary study, the 2°C treatment resulted in a longer shelf life in comparison to 5.5°C. The application of 1-MCP extended the days to ripening in all treatment combinations by between 3 and 5 days, compared to untreated fruit. Importantly, the 5.5°C required 1-MCP treatment for a substantial shelf life to be achieved, while fruit stored at 2°C achieved similar DTR (as 1-MCP treated fruit stored at 5.5°C) without the use of 1-MCP if the fruit are waxed. The 2°C storage temperature delayed the peak CO_2 evolution compared to the 5.5°C storage temperature, explaining the reduced fruit softening during storage at this temperature as well as the subsequently extended shelf life. The waxing delayed the peak evolution slightly compared to non-waxed fruit, as did the 1-MCP treatment.

In the 2010 study, storage at 2°C again resulted in a significantly longer DTR 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' through the seasons (**Figure 6**), 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, thus lengthening the DTR significantly. One could expect a ripening time of approximately one week (6-8 days) through all the seasons, whether fruit are stored at 2°C without using 1-MCP or at 5.5°C using 1-MCP. An acceptable ripening period was obtained after storage at 2°C, and a substantial saving would be realised if 1-MCP were not used. Similar to the 2009 results, a short shelf life was achieved for fruit stored at 5.5°C, without the use of 1-MCP. A DTR of only 2 days was recorded at all three harvest dates, indicating that 1-MCP is definitely needed at 5.5°C to achieve an acceptable shelf life, unless these fruit are entering a ripe-and-ready program.

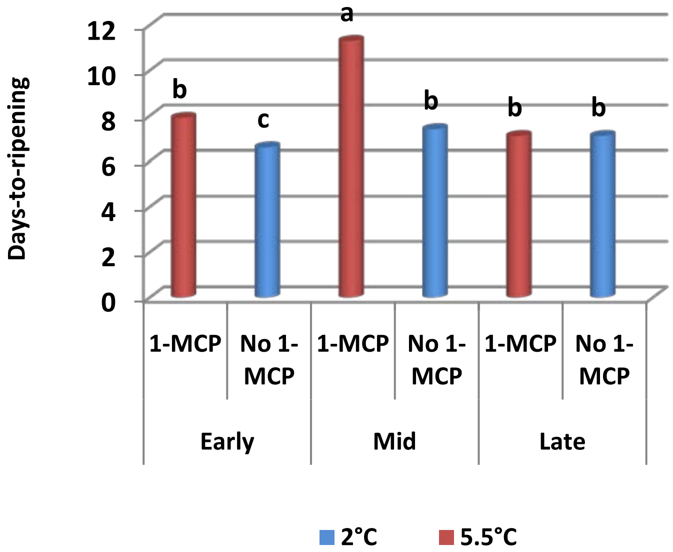

Figure 6: Effect of storage temperature and 1-MCP (waxed fruit) on days-to-ripening, comparing combinations of '2°C + no 1-MCP' and '5.5°C + 1-MCP' (approx. current protocol) throughout the season. (LSD=0.9565)

In terms of cold chain breaks, both breaks resulted in significantly fewer days-to-ripen than the 'control', at both storage temperatures. The '24 hour delay' resulted in the shortest DTR, while the 'break at 14 days' resulted in a slightly longer DTR than the '24 hour delay', but still significantly shorter than the 'control'. Unlike in the percentage fruit softening, the lower storage temperature of 2°C did not significantly negate the effects of the cold chain breaks in terms of DTR. The 1-MCP treatment had a greater negating effect on the 'break at 14 days' than the '24 hour delay' with respect to DTR, as was found for percentage fruit softening during storage, but did not negate the effects completely. 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 soon after harvest.

56 day 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 and treated with 1-MCP, followed closely by the same treatment combination but without the use of 1-MCP (**Figure 7**). The '2°C, waxed, 1-MCP' treatment combination for the mid season fruit, produced fruit of excellent external quality (rating of 0.2 out of 10), sound internal quality (no cases of internal damage) as well as a desirable mean shelf life of approximately 9 days (**Table 1 and 2**). Overall, the use of 1-MCP at 2°C had very little impact of external chilling injury during the three seasons, but extended the DTR. This extended shelf life may not warrant the extra cost involved, however, it may also be a valuable tool in providing some 'insurance' or patch-up method if this extended shipping period was to be attempted on a commercial scale. Early season fruit suffered significantly more external chilling injury than the mid and late season fruit, while late season fruit were more prone to anthracnose and stem-end rot (**Table 2**). 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 DTR.

Figure 7: External chilling injury of mid season, waxed fruit with 1-MCP (left) and without 1-MCP (right) treatment after storage at 2°C for 56 days.

Table 1: Effect of season, storage temperature, 1-MCP use and waxing on percentage fruit softening, percentage mass loss, days-to-ripening and external fruit quality of 'Fuerte' avocados, after 56 days of cold storage.

Season	1-MCP	Waxing	Fruit Softening (%)		Mass Loss (%)		Days-to-ripening		External Chilling Injury (1-10)	
			2°C	5.5°C	2°C	5.5°C	2°C	5.5°C	2°C	5.5°C
Early	1-MCP	waxed	8.7	15.9	6.61	8.49	10.9	6.6	1.9	0.4
		non-waxed	9.62	21.4	7.25	10.2	10.5	3.8	2.6	0.8
	No 1-MCP	waxed	11.4	34.3	6.64	8.95	6.5	1.5	2.3	1.6
		non-waxed	10.1	31.9	7.36	9.88	5.5	1.7	2.8	1.8
Mid	1-MCP	waxed	8.78	19.5	5.07	5.62	8.7	4.2	0.2	0.7
		non-waxed	8.09	33.7	6.46	8.81	6.8	1.5	1.4	0.7
	No 1-MCP	waxed	8.85	40.9	4.3	6.84	7.4	0.8	0.6	3.2
		non-waxed	11.2	42.7	7.14	9.49	3.4	0.3	2.3	4.9
Late	1-MCP	waxed	6.32	30.4	4.51	7.16	7.7	1.8	1.4	2.2
		non-waxed	7.54	28.4	5.39	9.91	6.8	2	0.4	2.4
	No 1-MCP	waxed	8.31	41.1	4.22	7.54	6.4	0.6	1	4.1
		non-waxed	9.24	43.3	4.64	9.65	3.1	0	0.9	4.2
LSD (0.05)			5.102		1.2947		1.927		1.508	

Table 2: Effect of season, storage temperature, 1-MCP use and waxing on internal fruit quality of 'Fuerte' avocados, after 56 days of cold storage.

Season	1-MCP	Waxing	Mesocarp Discolouration (1-5)		Vascular Browning (1-5)		Anthracnose (1-5)		Stem end rot (1-5)		Overal Internal Quality (% fruit damaged)	
			2°C	5.5°C	2°C	5.5°C	2°C	5.5°C	2°C	5.5°C	2°C	5.5°C
Early	1-MCP	waxed	0	0.1	0	0	0	0.4	0	0.3	0	30
		non-waxed	0.1	0.1	0.1	0.1	0.4	0	0.2	0	20	20
	No 1-MCP	waxed	0.3	0.8	0.2	0.4	0	0	0	0	30	50
		non-waxed	0	0.5	0	0.7	0	0	0	0	0	60
Mid	1-MCP	waxed	0	0	0	0	0	0	0	0	0	0
		non-waxed	0	0	0	0	0	0	0	0	0	0
	No 1-MCP	waxed	0.1	0.9	0	0.8	0	0	0	0	10	60
		non-waxed	0.1	1.4	0	0.8	0	0	0	0	10	80
Late	1-MCP	waxed	0	1	0.1	0.2	0.6	0.2	0.5	0	60	90
		non-waxed	0	1.1	0.1	0	0.2	0	0.4	0	40	70
	No 1-MCP	waxed	0.5	2.4	0.1	0.1	0.6	0.4	0.4	0	50	90
		non-waxed	0	1.8	0	0.3	0	0	0.1	0	10	80
		LSD (0.05)	0.6166		0.3847		0.4244		0.3517			

CONCLUSION

It is concluded that 'Fuerte' avocados can be successfully shipped at 2°C for 28 days, and possibly even 56 days, provided that the fruit stress is kept to minimum. The preliminary trial in 2009 as well as the 2010 trial showed that storage at 2°C resulted in better internal quality, reduced mass loss and fruit softening as well as extended DTR in comparison with conventional 5.5°C storage. Storage at 2°C resulted in similar internal fruit quality to 1-MCP treated fruit stored at 5.5°C, but having higher external chilling injury, especially early in the season. Waxing appears to be an invaluable treatment for a thin skinned avocado such as 'Fuerte'. Not only did waxing providing aesthetically appealing fruit, but also reduces water loss and fruit softening, and subsequently decreased the severity of external chilling injury after removal from cold storage. The '2°C, no 1-MCP, waxed' treatment combination provided fruit of excellent external and internal quality and is, ultimately, the best alternative method of shipping for the conventional 28 day shipping period.

Both cold chain breaks had a detrimental effect on fruit quality and should obviously be avoided where ever possible. The '24 hour delay' in cooling had the greatest impact on water loss, causing a stress which appears to have negative knock-on effects on fruit softening and external chilling injury. These results indicate the importance of cooling the fruit as soon after harvesting as possible, thus removing the 'field heat' and achieving significantly less water loss from the fruit while in the packhouse. The 'break at 14 days' generally resulted in more softening and shorter shelf-life and caused to a reduction in external and internal quality, with a generally underestimated affect on pathology. Importantly, the storage temperature of 2°C negated the fruit softening effects of cold chain breaks significantly, irrespective of whether 1-MCP was used or not, and may provide a valuable 'buffer' in the cold chain should breaks occur.

With respect to the 56 day storage period, waxed fruit stored at 2°C 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 and treated with 1-MCP, while 'early' season fruit suffered more substantial external damage over this extended storage period. 'Late' season fruit would potentially be the most profitable; however body rots (anthracnose and stem-end rot) were more prevalent later in the season. Although lower temperatures appear to be promising, storage for this extended period is risky as fruit quality is maintained only under certain treatment combinations and is assumed to be heavily reliant on good pre-storage fruit quality.

At present, more research and larger commercial trials are required before any changes will be made to export protocol. The successful implementation of a 2°C storage temperature for 'Fuerte' avocados would not only realise significant savings in the export industry, but may also satisfy future phytosanitary certification requirements, allowing South African avocados to be shipped over very long distances and reach new markets. Cold treatment will most likely be part of these requirements, and thus investigations into ultra-low temperature storage are a step in the right direction, with initial investigations providing promising results.

REFERENCES

Blakey, R. and Bower, J.P., 2009. The importance of maintaining the cold chain for avocado ripening quality. *South African Avocado Growers' Association Yearbook* 32: 48-52

Bower, J.P. and Magwaza, L.S., 2004. Effect of coatings and packaging on external and internal quality with emphasis on 'cold injury'. *South African Avocado Growers' Association Yearbook* 27:35-39

Bower, J.P., Dennison, M.T., Fowler, K., 2003. Avocado and mango cold storage damage as related to water loss control. Acta Hort. 628: 401-406.

Hopkirk, G., White, A. And Beever, D.J., 1994. The influence of postharvest temperaturesand the rate of fruit ripening on internal disorders of New Zealand 'Hass' avocado fruit. *New Zealand Journal of Crop and Horticultural Science* 22: 305-311

Lemmer, D. and Kruger, F.J., 2003. Laboratory based evaluation of 1-Methylcyclopropene (1-MCP): With five South African commercial export avocado cultivars. *Proceedings V World Avocado Congress.* Pp. 611-616

Lemmer, D., Malumane, R.T., Ntandane, J. and Kruger, F.J., 2006. Extended storage trials with South African Avocados. *South African Avocado Growers' Association Yearbook* 29: 10-13

Lemmer, D. and Kruger, F.J., 2010. Effect of cold chain breaks on the ripening and quality of 'Hass' avocados. *South African Avocado Growers' Association Yearbook* 33: 14-24

Lutge, A., Bower, J.P. and Bertling, I., 2010. Low temperature shipping and cold chain management of 'Fuerte' avocados: an opportunity to reduce shipping costs. *South African Avocado Growers' Association Yearbook* 33: 27-31

Toerien, J.C., 1986. Temperature control of avocados for sea export. *South African Avocado Growers Association Yearbook* 9: 31-32

Van Rooyen, Z. and Bower, J.P., 2007. Post-harvest treatments used to reduce chilling injury in 'Pinkerton' avocados. Proceedings VI World Avocado Congress, Chile. 12-15 Nov 2007.