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Post-harvest Heat Treatments with a view to Reducing Chilling Injury in Fuerte Avocado Fruit

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ABSTRACT

A number of exploratory heat treatment trials were carried out on Fuerte avocado fruit using dry heat, vapour heat and warm water baths, in an attempt to find a time-temperature relationship which would confer greater chilling resistance to Fuerte fruit. Dry heat treatments were carried out in 1993 using temperatures of 36 and 38 C for 48 h. These treatments all caused rind blackening but extended ripening time after 28 days of cold storage at 6.5, 5.5 or 3.5 °C.

In 1994, a wider range of temperatures and treatment durations were tested and ranged from 48 h at 36 °C to 10 min at 48 °C. Fruit in all of the trials was stored at 3.5 °C for 28 days after heat treatment. Warm water treatments caused severe rind blackening, even before cold storage and inhibited ripening after cold storage. Dry heat treatments did not produce fruit of quality superior to that of untreated fruit after cold storage. Vapour heat treatment for 1.5 and 3 h at 40 °C produced fruit with less external blackening and pulp spot than untreated fruit, without reducing ripening time after storage. These two treatments show promise, but need to be tested throughout an entire harvesting season to confirm the results obtained.

INTRODUCTION

The concern of the consumer that chemicals used to maintain post-harvest quality are potentially harmful to humans has placed an emphasis on research to manage post-harvest disorders by non-chemical means (Klein & Lurie, 1992). Pre-storage heat treatment has received much attention lately with the following objectives in mind: i) To slow down ripening of climacteric fruits to enhance shelf life; ii) To reduce chilling sensitivity of tropical and subtropical crops, allowing longer storage periods at temperatures which would usually cause chilling injury; iii) To reduce rots by inactivating the pathogen or increasing host resistance; and iv) To control insect pests (Klein & Lurie, 1991).

Reduction of chilling sensitivity of tropical and subtropical crops, would allow longer storage periods at temperatures which would usually cause chilling injury. Sensitivity of tomatoes (Lurie & Klein, 1991) and mangoes (McCollum *et al.,* 1993) to low temperatures has been reduced by vapour heat treatments. In the literature, two different approaches to heat treatment have been taken, viz. long term: 12 to 48 h at 38 to 46 °C or short term: up to 70 min at 45 to 55 °C (Lurie and Klein, 1991). Short term

heat treatments have been used for insect disinfestation and disease control but have also been noted to have an effect on fruit ripening (Paull, 1990). Long term heat treatments have been carried out with the aim of reducing chilling injury (e.g. McCollum *et al,* 1993). Lurie and Klein (1991) mention that heat treatment of avocados at 36 °C produces a good response and that 38 °C causes heat injury. These data however, have not been published. Heat treatment of Sharwil avocados at 37 to 38 °C for 17 to 18 h reduced external chilling injury after storage at 1.1 °C for 14 days for insect disinfestation purposes. However, the average external appearance of the heat treated fruit was only rated as "marginally acceptable" which was below a "marketable" rating (Sanxter *et al.,* 1994). Florissen *et al.* (1993) reported a reduction in chilling in Hass fruit treated for 6 and 12 h at 38 °C.

Fuerte avocados are susceptible to cold storage disorders. Reduction of susceptibility to these disorders using heat treatments would be advantageous to the export industry as improved quality fruit should fetch higher prices.

MATERIALS AND METHODS

A number of heat treatment trials were carried out during the 1993 and 1994 Fuerte harvesting seasons in the KwaZulu/Natal Midlands using dry heat, where the fruit was placed in an incubator; a warm water bath; or vapour heat, where the fruit was treated in a high humidity atmosphere (RH > 90 %), generated by a Paxton Electrotherm® heater and humidification unit, attached to a shipping container. On removal from cold storage, firmometer readings were taken (Swarts, 1981), and the fruit was allowed to ripen at ± 20 °C. When eating ripe, the fruit was rated externally on a scale of 1 to 3 (1 = mild; 2 = moderate; 3 = severe) for rind pitting and discolouration, and internally for anthracnose, stem end rot, vascular browning, pulp spot and grey pulp (Swarts, 1984). Ripening time after storage was also noted.

1993 Trials

Fuerte fruit harvested on 1993/05/19 and 1993/06/01 was heat treated in dry heat at 38°C for 48 h, and fruit harvested on 1993/06/12 and 1993/06/29 was heat treated at 36°C for 48 h. After heat treatment, the fruit was stored at either 3.5°C, 5.5°C or 6.5°C for 28 days.

Fruits which had not been heat treated were stored at each temperature and served as controls.

1994 Trials

Nine heat treatment trials using different forms of heat, temperatures and durations of treatment were carried out during the 1994 Fuerte harvesting season in the KwaZulu/Natal midlands (Table 1). Fruit for these trials was supplied by Everdon Estate. More trials were carried out than in 1993 as fruit was also obtained from the farm "Cooling" in the Wartburg area, where Fuerte fruit is harvested a few weeks later than at Everdon Estate in spite of a warmer climate. Trial numbers 6 to 9 (Table 1) were carried

out using fruit from "Cooling". Heat treated fruit was stored at 3.5°C, as this is known to cause cold storage disorders in Fuerte fruit and the aim of the heat treatments was to reduce fruit sensitivity to low temperatures. Twenty three fruit were used per treatment in trial 1 and 32 per treatment in trails 2, 3, and 4. Trial 5 had 48 fruit per treatment. In trials 6 to 8 only 8 fruit were used per treatment with the intention of testing a number of different time and temperature combinations as exploratory trials, so that any treatment which showed promise could be carried out at a later stage with sufficient replication to prove the results statistically. Thirty fruits per treatment were used in trial 9.

Table 1
Heat treatment trials carried out in the 1994 Fuerte harvesting season.

Trial	*Date*	*Treatment*	*Type of heat*
1	1994/05/17	0, 12, 24, 48 h @ 36 °C	Dry, fruit in plastic bags
2	1994/05/24	0, 4, 6, 8 h @ 40 °C	Dry
3	1994/06/02	0, 4, 6 h @ 40 °C	Water bath
4	1994/06/08	36 h @ 36 °C & 12 h @ 32 °C + 24 h @ 36 °C	Water bath
5	1994/06/24	0, 6, 12, 24, 30, 36, 42, 48 h @ 36 °C	Vapour
6	1994/07/13	0, 0.5, 1.5, 3.0, 4.0 h @ 40 °C	Vapour
7	1994/07/13	0, 10, 20, 30, 45, 60 min @ 48 °C	Vapour
8	1994/07/13	0, 2, 4, 6 h @ 36 °C	Vapour
9	1994/07/20	0, 3, 5, 12 h @ 36°C	Vapour

RESULTS AND DISCUSSION

1993 Trials

External appearance is important in the marketing of Fuerte avocados, and rind blemishes may reduce the value of the fruit. Figure 1 shows the average external rating for all treatments of the dry heat trials carried out in 1993. The higher the rating, the greater the degree of rind blackening or browning. In all four trials, there was very little external blackening in the control fruit stored at all temperatures. Heat treated fruit always displayed a greater severity of this disorder than the controls at all temperatures in all four trials. A reduction in storage temperature of heat treated fruit resulted in increased severity of external blackening in trials 1 and 4 although the control fruit of the same two trials did not show the same trend, and storage temperature of the controls seemed to have little effect on external blackening known as cold damage (Swarts, 1984). It appears therefore that heat treatment increased fruit susceptibility to cold damage. In trial 2, all heat treated fruit showed severe rind blackening as indicated by the average external ratings of 3. Varying levels of external blackening between fruit of the four different trials for the same storage temperature shows that pre- and post-harvest factors must play a role in determining fruit susceptibility to this disorder as a result of heat treatment. Especially noticeable is the difference between heats treated fruit in trials 2 and 3 where the degree of external injury was less in trial 3.

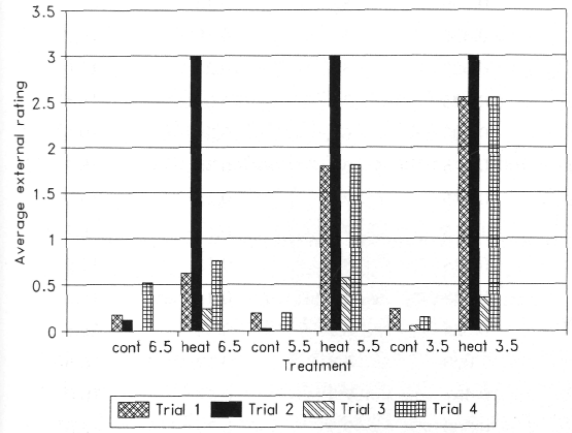

Figure 1
Average external rating of control and heat treated Fuerte fruit (1993) after storage at 3.5 °C, 5.5 °C and 6.5 °C for 28 days.

Added shelf life is advantageous in the marketing of avocados. Figure 2 shows average ripening times of heat treated and control fruit in the four trials conducted in 1993. In all four trials, heat treated fruit took longer to ripen than the control fruit stored at the corresponding temperatures. There was a trend of increasing time to ripen in control fruit as the storage temperature was reduced. Increased shelf life as a result of heat treatment is probably as a result of reduced cellulase activity (Lurie & Klein, 1990) and the failure of some fruits to ripen normally after heat treatment was probably due to the reduction of cellulase activity to a greater extent. If the problem of external blackening as a result of heat treatment can be overcome, heat treatments may be useful in extending the shelf life of Fuerte avocados. As with external blackening, there was variation in ripening time between trials, for example, trial 2 fruit took longer to ripen over all treatments than fruit in the other trials.

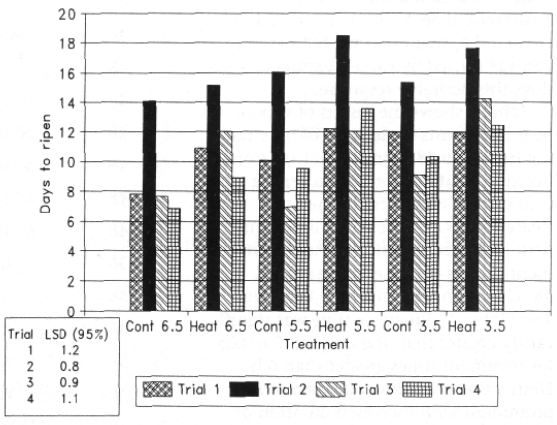

Figure 2
Average ripening times of control and heat treated Fuerte fruit (1993) after storage at 3.5 °C, 5.5 °C and 6.5 °C for 28 days

Figure 3 shows the average firmometer readings of heat treated and control fruit, which give an indication of fruit firmness on removal from cold storage. There was no trend with regards to fruit firmness and heat treatment over the four trials conducted. Heat treated fruit may have been harder (e.g. trial 3 fruit stored at 6.5°C), or softer (e.g. trial 1 fruit stored at 6.5°C) after storage than their respective controls. As with external blackening and ripening times, differences in firmness between trials were noticeable over all treatments, for example, fruit in trial 2 was firmer in all treatments than trial 4 fruit.

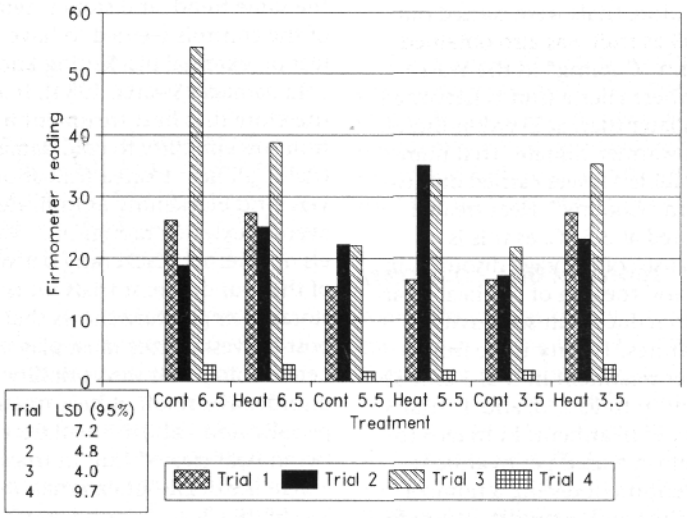

Figure 3
Average firmometer readings of control and heat treated Fuerte fruit (1993) after storage at 3.5 °C, 5.5 °C and 6.5 °C for 28 days.

In some cases, heat treated fruit was softer than control fruit on removal from cold storage, although it took longer to ripen, e.g. in trial 1, fruit stored at 6.5°C (Figure 3). This was probably due to moisture loss from the heat treated fruit and not due to a more advanced stage of ripening.

1994 Trials

Vapour heat

Table 2 shows the results of pre-storage vapour heat treated fruit obtained from the Wartburg area. Each of the following three paragraphs contains a discussion of the three temperatures tested viz. 40, 48 and 36°C. At 40 °C, treatment for 4 h produced fruit with the most severe external blackening, with an average rating of 0.875. The average number of days to ripening was similar for all treatments at 40°C and no treatment extended the ripening time appreciably compared to the control (0 h). Firmometer readings were very similar with the exception of fruit treated for 4 h which was softer than the other treatments.

A temperature of 48°C was used to determine whether a higher temperature for a

shorter period of time would elicit the desired tolerance of the fruit to low storage temperatures and this was the highest air temperature which the heating equipment could deliver. Treatment times of 10, 20, 30 and 60 min at 48°C all decreased the average ripening time (Table 2), which is not desirable. All the abovementioned durations of treatment reduced fruit firmness after cold storage, as indicated by higher firmometer readings than the control fruit. The incidence of grey pulp did not show a trend with increasing or decreasing duration of treatment. A trial with greater replication would be necessary to determine whether or not heat treatment at 48°C has an influence on this disorder as some fruit seem to be pre-disposed to it as mesocarp discolouration may occur in fruits which have not been cold stored (Vakis, 1982).

Table 2
Quality parameters of Fuerte fruit from Wartburg heat treated at different temperatures for different lengths of time prior to cold storage at 3.5 °C for 28 days.

Temp (°C)	*Duration (h)*	*External rating when ripe*	*Days to ripen*	*Grey pulp (proportion of fruit affected)*	*Firmometer reading*
40	0	0.625	8.3	0.25	15,0
40	0.5	0.625	7.8	0.50	15,3
40	1.5	0.125	8.4	0.00	15,4
40	3.0	0.250	8.4	0.13	15,4
40	4.0	0.875	7.1	0.38	16,7
48	0	0.625	8.3	0.25	15,0
48	10 min	0.125	7.1	0.00	16,1
48	20 min	0.500	6.4	0.38	19,5
48	30 min	0.375	6.4	0.38	18,9
48	45 min	0.875	7.0	0.25	19,3
48	60 min	1.625	7.1	0.13	16,7
36	0	0.625	8.3	0.25	15,0
36	2	0.438	8.3	0.44	16,4
36	4	0.625	8.1	0.32	16,5
36	6	1.000	8.8	0.19	16,6
36	0	0.467	7.3	0.47	16,0
36	3	0.800	9.9	0.33	14,8
36	5	0.800	8.7	0.60	15,4
36	12	1.237	10.3	0.33	16,2

Two separate trials (a week apart [Table 1]) were carried out heat treating fruit at 36°C. Differences in external blackening, days to ripen and incidence of grey pulp between the controls of these two trials shows that differences in maturity, and other pre-harvest factors have an effect on the quality of cold stored avocado fruit. Treatment for 4 h at 36°C in the first trial resulted in less external blackening than 3 h at 36°C in the second trial (Table 2), which highlights the variable response to heat treatment from week to

week. With the exception of 2 h at 36°C, where external blackening was more severe than in the control fruit and increased in severity with increased duration of treatment. Treatment at 36°C for 3, 5 and 12 h increased the ripening time, but external damage caused by these treatments overrides this desirable response.

Table 3 shows the results of vapour heat treatments for lengths of time ranging from 6 to 48 h on Fuerte fruit from Everdon Estate. External blackening after cold storage was worse in the heat treated fruits and increased in severity with increased duration of heat treatment, as was the case in the second 36°C trial on fruit from the Wartburg area (Table 2). Ripening time was significantly greater than the control ($P < 0.05$) for treatment times greater than 6 h. Flesh tissue breakdown became more prominent with increased duration of heat treatment in this trial. Fruit firmness on removal from cold storage did not show a trend with duration of heat treatment even though there were significant differences between treatments. There was no definite trend in grey pulp incidence with increasing duration of heat treatment. Although the incidence of grey pulp was 10% in fruit heat treated for 6, 12, 18 h as opposed to 29% the control fruit, the incidence of 23% in the 24 h treatment and 13% in the 30 and 36 h treatments tends to place doubt on whether or not heat treatment was responsible for reducing the incidence of grey pulp.

Table 3
Quality parameters of Fuerte fruit heat treated at 36 °C for different lengths of time prior to cold storage at 3.5 °C for 28 days.

Temp (°C)	*Duration (h)*	*External rating when ripe*	*Days to ripen**	*Grey pulp (% fruit affected)*	*Firmometer reading**
36	0	0.08	10.7 a	29	15,3 b
36	6	1.15	11.2 ab	10	13,5 a
36	12	1.03	11.9 bc	10	15,9 bc
36	18	1.18	12.9 d	10	15,8 b
36	24	2.00	13.7 e	23	17,3 c
36	30	2.00	13.9 ef	13	15,7 b
36	36	2.28	14.6 f	13	19,1 d
36	42	2.70	14.4 ef	28	15,2 b
36	48	3.00	12.3 cd	25	16,3 bc

* Values followed by the same letter do not differ significantly at P = 0.05.

Dry heat

Table 4 shows the results of Fuerte fruit dry heat treated at 36°C, sealed in plastic bags. Even though individual fruits were placed in plastic bags, there were significant differences in moisture loss (as measured by change in mass) between treatments of 12, 24 and 48 h duration. External blackening was more severe in heat treated fruit and increased in severity with increased duration of heat. The incidence of grey pulp was highest in the control fruit, indicating as in the vapour heat trials, that heat treatment may reduce the incidence of this disorder. The incidence of flesh tissue breakdown

increased with increased duration of treatment. Only fruit heat treated for 48 h took significantly longer to ripen than the control fruit but was significantly softer on removal from cold storage. This was probably not as a result of a more advanced stage of ripening, but due to reduced turgidity as a result of greater moisture loss during heat treatment. Anthracnose fungal infection was observed in the 24 and 48 h treatments and was probably as a result of reduced turgidity and tissue breakdown making the fruit more susceptible to pathogenic attack.

Table 4
Quality parameters of Fuerte fruit heat treated in plastic bags at 36 °C for 12 h, 24 h and 48 h prior to 28 days cold storage at 3.5 °C.

Duration (h)	*Ave. external rating*	*Mean % mass loss during heat treat.*	*Grey pulp (% fruit affected)*	*Tissue Breakdown (% fruit affected)*	*Days to ripen**	*Firmometer reading*	*Fungal infection (% fruit affected)*
0	0.43	—	26.1	0.0	12.0 ab	18,0 a	0.0
12	1.1	0.79 a	0.0	4.3	11.7 a	16,2 a	0.0
24	1.7	1.05 b	0.0	13.0	13.0 bc	17,7 a	13.0
48	2.3	1.50 c	8.6	95.7	13.9 c	20,6 b	13.0

* Values followed by the same letter do not differ significantly at P = 0.05.

Table 5 shows the results of Fuerte fruit dry heat treated for 4, 6 and 8 h at 40°C. There was a significant increase in moisture loss with each increase in duration of heat treatment. Once again, the incidence of grey pulp appears to have been reduced by heat treatment of 6 and 8 h. Ripening time was significantly greater in fruit heat treated at 40°C for 8 h. The control fruit was significantly softer than the heat treated fruit on removal from cold storage. The severity of external blackening increased with increased duration of heat treatment and was always greater than that of the control fruit.

Table 5
Quality parameters of Fuerte fruit after dry heat treatment at 40 °C for 4 h, 6 h and 8 h prior to 28 days cold storage at 3.5 °C.

Duration (h)	*Ave. external rating*	*Mean % mass loss during heat treat.*	*Grey pulp (% fruit affected)*	*Tissue Breakdown (% fruit affected)*	*Days to ripen**	*Firmometer reading*	*Fungal infection (% fruit affected)*
0	0.3	—	28.1	0	10.8 a	17,1 c	0
4	0.6	0.19 a	31.2	0	11.5 ab	16,5 ab	0
6	1.6	0.49 b	18.8	0	11.9 ab	15,2 a	0
8	2.1	0.81 c	15.6	0	12.4 b	15,1 a	13.0

* Values followed by the same letter do not differ significantly at P = 0.05.

Water bath

Table 6 shows the results of Fuerte fruit heat treated in a water bath at 40°C for 4, 6 and 8 h. This form of heat treatment caused severe external blackening even before cold storage, and was probably due to the rate of heat transfer to the fruit being more rapid than fruit heat treated in air. Ripening was adversely affected and treatment for 6 and 8 h totally inhibited ripening. Treatment for 6 and 8 h caused flesh tissue breakdown in all

fruit.

Table 6
Quality parameters of Fuerte fruit heat treated in a water bath at 40 °C for 4 h, 6 h and 8 h prior to cold storage at 3.5 °C for 28 days.

Duration (h)	*Tissue breakdown (% fruit affected)*	*% fruit failing to ripen*	*Ave. external rating*	*Firmometer reading**
0 h	0	0	0.4	16,8 b
4 h	21.9	3.1	1.8	13,9 a
6 h	100	100	3.0	17,7 b
8 h	100	100	3.0	18,1 b

* Values followed by the same letter do not differ significantly at P = 0.05.

Table 7 shows the results of stepping up the temperature from 32°C to 36°C during heat treatment of Fuerte fruit in a water bath in an attempt to reduce the external and internal damage caused by water bath treatment at 36°C (Table 6). Stepping up the temperature was no less damaging to the fruit than holding it at 36°C for 36 h, with no reduction in tissue breakdown or external blackening.

Table 7
Quality parameters of Fuerte fruit heat treated in a water bath at 36 °C for 36 h or 32 °C for 12 h followed by 24 h at 36 °C prior to cold storage at 3.5 °C for 28 days.

Treatment	*Tissue breakdown (% fruit affected)*	*% fruit failing to ripen*	*Ave. external rating*	*Firmometer reading*
0 h (control)	0	0	0.1	16,3 a
36 h @ 36 °C	100	97	3.0	30,3 c
12 h @ 32 °C & 24 h @ 36 °C	100	100	3.0	26,7 b

* Values followed by the same letter do not differ significantly at P = 0.05.

Heat treatments in a water bath were tested as it was thought that moisture loss was causing rind browning and pitting. However, this form of heat treatment caused a greater degree of rind browning than dry heat (see Tables 5 & 6). Skin browning is therefore not as a result of moisture loss during heat treatment but is rather a symptom of heat scald. The water bath treatment probably caused greater damage due to a greater rate of heat transfer to the fruit than air. The more rapid transfer of heat to the fruit probably had a greater inhibiting effect on the enzymes involved in ripening as fruit heat treated at 40°C for 6 h and 8 h failed to ripen. A "stepped up" heat treatment where the fruit was first treated at 32°C then the temperature was increased to 36°C, was not effective in reducing heat scald and inhibition of ripening (Table 7).

CONCLUSIONS

Post-harvest heat shock treatments seem to affect the enzyme systems which control fruit softening. The extent to which these systems are affected depends on the temperature to which the fruit is exposed and its duration. Heat treatments caused heat damage in Fuerte avocados, which is characterised by exocarp browning and pitting. Vapour heat treatments were generally less damaging to the rind and the ripening process than dry heat and warm water treatments. Three treatments produced fruit with less rind damage than their controls, viz. 1.5 h and 3 h at 40°C and 10 min at 48°C. These fruits also had a lower incidence of grey pulp than their controls. Heat treatment at 48°C reduced the ripening time which is not desirable. Further trials using these treatments would have to be run for an entire harvesting season to confirm these results, as fruit of different maturity may respond differently to heat treatment. If in subsequent trials, a time temperature relationship is found which improves the quality of cold stored avocados, the cost of heat treatment relative to higher prices for better quality fruit will determine whether heat treatments are used commercially or not.

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