Proceedings from Conference '97: Searching for Quality. Joint Meeting of the Australian Avocado Grower's Federation, Inc. and NZ Avocado Growers Association, Inc., 23-26 September 1997. J. G. Cutting (Ed.). Pages 38-45.

ETHYLENE RIPENING PROTOCOLS FOR LOCAL AND EXPORT MARKET AVOCADOS

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Keywords: pre-ripening, storage temperature, *Persea americana* Mill.

Abstract

Due to consumer demand there is an increasing requirement for the industry to provide a ripe to eat product. Although developed in California over a decade ago, there remain a number of issues in carrying out ethylene treatment ("pre-ripening") which need to be understood to provide a consistent, high quality product. We have examined a number of variables in the ethylene treatment and handling of avocados with the aim of optimising current industry practices for local and export market fruit. In addition we have sought to develop protocols where ethylene treatment is carried out in NZ at either 17°C or 5.5°C prior to export of fruit. Experiments have been carried out examining; fruit maturity/time of harvest, treatment duration, treatment temperature, post-treatment holding duration, and final storage temperature. From this work we have made a range of recommendations such as minimum treatment durations for two harvest times in the season for non-stored (local), and stored (export) fruit. Storage temperatures lower than 4°C are not recommended due to reduced fruit quality, particularly external chilling injury. We have questioned the need to ethylene treat fruit which have been stored/transported for 14 days since shelf life and variability of ripening was similar to non-treated fruit. We conclude that 17°C ethylene treatments prior to export, where storage is likely to be for up to 14 days, is not feasible due to reduced fruit quality. However, ethylene treatments on-shore at 5.5°C prior to shipping may be possible.

General introduction

A major focus of the Hort Research postharvest programme at Mt Albert Research Centre has been the development and refinement of ethylene ripening (or "pre-ripening") to provide ripe-to-eat product for the NZ and Australian markets.

To achieve consistently high quality produce, we must understand the response of the fruit to the large number of factors involved in both carrying out the ethylene treatment, and the subsequent handling and storage of the fruit which effect fruit quality. Variables in the treatment itself include, maturity at harvest/time of the season, delay between harvest and treatment, ethylene concentration, treatment duration and temperature,

carbon dioxide buildup, and ethylene removal (venting) of the room/fruit. After treatment a further range of variables are involved including; the delay before coolstorage ("holding" time), holding temperature, storage temperature and duration, and finally the ripening temperature. It is clear that these cannot all be examined in one season, hence, to reduce the number of variables, some factors have been held constant. These include the ethylene concentration at 100 ppm, treatment temperature at 17°C, and time after harvest at 2-3 days postharvest.

The current method of ripening New Zealand fruit for local market involves warming fruit to 17-20°C if it has been in coolstorage (~12 hours), treating with ethylene and transferring fruit to 2-6°C after 0 to 3 days. The exact method employed (ethylene concentration and treatment the fruit during this period. Export market fruit are currently treated at a number of facilities in Australia and generally involves rewarming to ~17°C, and ethylene treatment for 12 hours.

Disadvantages of the current methods include the uncertainty of operators in the capability of a given ethylene treatment to ripen fruit, a high input of time and labour, the possible unnecessary length of ethylene treatment (i.e. 2-3 day treatment), and the rewarming of coolstored fruit.

A large amount of work has been carried out over the last two seasons and it is not possible to present all these results. We have chosen to present the effect of duration of ethylene treatment in detail, and briefly summarise the effects of a range of ethylene treatment and storage scenarios on fruit quality and shelf life.

General methodology

'Hass' avocados were obtained from growers in the Whangarei area. Fruit was picked, packed, and handled in the standard commercial manner. Fruit were generally transported to Mt Albert Research Centre, Auckland by van (2.5 hour drive).

For fruit which had been stored, external appearance was examined and external chilling damage on the day of removal from storage. Fruit were ripened in commercial trays at 20°C (1995/96), or 15°C (1996/97). When fruit were "late ripe" (determined by manual assessment of fruit firmness), fruit were cut and a range of quality parameters assessed (Hopkirk *et al.,* 1994).

In 1995/96 ethylene treatment was carried out by placing fruit into 20 litre containers and a saturating concentration of ethylene (100 ppm) applied for one of 5 different durations (up to 10 days). In 1996/97 ethylene treatments were carried out in 360 litre chambers equipped with a fan to ensure even air mixing. The atmospheric content (ethylene, oxygen and carbon dioxide) of treatment chambers was checked twice daily, and chambers were flushed as appropriate, then re-injected with ethylene. Approximately 100g of lime was placed in each chamber to reduce the build-up of carbon dioxide.

In the 1996/97 season, the Anderson firmometer (a digital version of the South African firmometer) was employed to relate fruit firmness at various stages of the protocols to the shelf life and ripe-fruit quality.

1. Duration of ethylene treatment Introduction

The current protocol for ethylene ripening in New Zealand involves rewarming fruit to 17°C, followed by ethylene treatment at 100 ppm for between 12 and ~48 hours. For predominantly historical reasons, ethylene treatment has been carried out at 17°C. In the interests of maintaining our experience and knowledge base of the fruit response to ethylene treatment at this temperature, we see no good reason to move away from this treatment temperature.

The duration of exposure to ethylene has marked effects on the average shelf life (rate of ripening) and the variability of ripening (i.e. fruit to fruit variability). Because of the many variables involved in ethylene treatment we chose to examine the effect of treatment duration alone by ripening the fruit at the same temperature as the treatment temperature (17°C). This allowed us to determine the effect of treatment duration on the rate, and variability of ripening without the confounding effects of subsequent holding times or storage temperatures.

Aim

To examine the effect of ethylene treatment duration, and time of the season, on the rate of ripening. This would provide guidelines regarding minimum ethylene treatment times required to achieve maximum rate and synchrony of ripening at two times in the season.

Materials and methods

Fruit were harvested in November, 1996 (early season), and March, 1997 (late season). Fruit were randomised among trays, and half of the fruit placed in storage at 5.5°C for 10 days. The remaining half were placed at 17°C overnight, and ethylene treatment in 360 litre chambers the following morning (2 days postharvest). Similarly, for the stored fruit, trays were removed from storage, rewarmed to 17°C overnight, and ethylene treated the following morning.

Ethylene treatment durations were: **Early season;** for both stored and non-stored fruit; 0 (control), 6, 12, 24, 36 or 48 hours. **Late season;** non-stored fruit; 0 (control), 6, 12, 18, 24, or 36 hours, and stored fruit; 0 (control), 3, 6, 9, 12, or 24 hours. Ethylene levels ranged from 95-105 ppm in treatment chambers, carbon dioxide levels were less than 1.7% (typically 0.5-1.1%), and oxygen never less than 16%.

Three trays of 23 count fruit were used for each treatment. From two of these trays, firmometer measurements were made on 15 fruit at each evaluation time. This meant that each fruit was measured a maximum of 5 times (e.g. control treatments), but ethylene treated fruit were typically measured 3 times. Fruit in the third tray was not measured by firmometer, but, as fruit ripened, were manually assessed to determine the average shelf life (days to "late-ripe").

An analysis of variance (ANOVA) was carried for each of the 4 experimental runs. Four

one way ANOVAs were carried out using a completely randomised design.

Results

Early season: November

Ethylene treatment accelerated ripening in both stored and non-stored fruit, the extent of which was dependant on duration of exposure (Table 1).

For non-stored fruit, an ethylene treatment of 6 hours had little effect on shelf life; 10.3 days compared with 10.5 days for control fruit (Table 1). As treatment duration increased up to 36 hours, shelf life progressively reduced to 6.4 days. There was no significant difference between a 24 and 36 hour treatment.

Fruit which had been stored for 10 days before ethylene treatment (simulated export) showed a markedly faster rate of ripening than non-stored fruit, even without ethylene treatment (8.5 days cf 10.5 days; Table 1). Even a 6 hour treatment reduced shelf life by ~1 day, and a 12 hour treatment reduced shelf life to a level similar to all longer treatments (24, 36 and 48 hour).

Late season: March

For non-stored fruit, a 6 hour treatment reduced shelf life by over a day, and a 12 hour treatment by 4 days compared to non-treated fruit which had an average shelf life of 11.7 days (Table 1). A treatment duration of 12 hours or longer resulted in the fastest ripening rate of ~7 days. The firmometer softening curve demonstrates this since there is little difference between a 6 hour treatment and non-treated fruit, while the 12 hour treatment is only slightly slower than the longer durations (Figure 1).

Storing fruit for 10 days prior to ethylene treatment resulted in fruit with a significantly shorter shelf life than non-stored fruit. All ethylene treatment durations increased ripening rate, even a treatment as short as 3 hours (Table 1).

Table 1 **Shelf life (mean days to late-ripe) of non-stored fruit, or fruit stored for 10 Days at 5.5°C (simulated export). Ethylene treatment was carried out at 17°C, and fruit also ripened at 17°C. Values represent mean ± SEM, n = 23. Different letters indicate significantly different means for comparisons within each column**

Ethylene treatment duration	Early harvest (November) Non-stored	Stored	Late harvest (March) Non-stored	Stored
0 hour (control)	10.5 ± 0.3 c	8.5 ± 0.3 b	11.7 ± 0.4 b	8.4 ± 0.3 b
3 hour	-	-	-	7.4 ± 0.3 a
6 hour	10.3 ± 0.5 c	7.3 ± 0.3 a	10.3 ± 0.5 b	7.0 ± 0.2 a
9 hour	-	-	-	6.7 ± 0.2 a
12 hour	8.1 ± 0.4 b	6.8 ± 0.2 a	7.6 ± 0.3 a	7.2 ± 0.2 a
18 hour	-	-	7.1 ± 0.2 a	-
24 hour	7.1 ± 0.3 ab	7.0 ± 0.2 a	7.1 ± 0.2 a	7.6 ± 0.2 a
36 hour	6.4 ± 0.1 a	6.6 ± 0.1 a	7.3 ± 0.2 a	-
48 hour	6.3 ± 0.1 a	6.6 ± 0.1 a	-	-

- Not examined

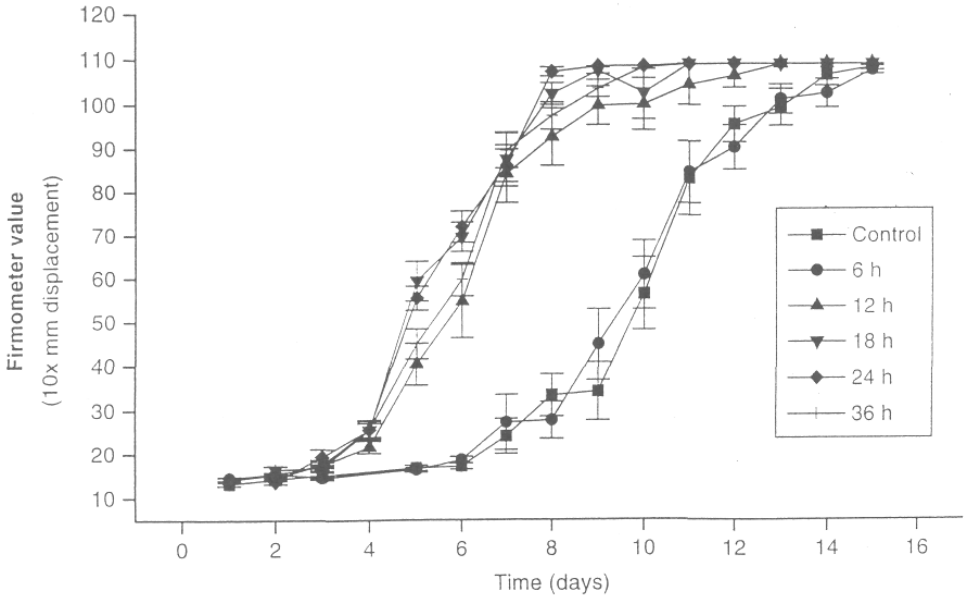

Figure 1 **Softening curve (average firmometer value) for late harvest fruit (March) not stored prior to treatment with 100ppm ethylene at 17°C for a range of durations. Fruit were then ripened at 17°C. Vertical bars represent standard error of the mean (SEM)**

Discussion

Non-stored fruit

To increase ripening rates and minimise fruit to fruit variability, a treatment duration of 24 to 36 hours should be employed for early season fruit, and over the season this can be reduced to as little as 12 hours. This is similar to results obtained in 1995/96 season where, for fruit treated mid-season, a treatment of 24 hours, and to a lesser extent 12 hours, was as effective as longer durations (White *et al.,* 1996).

Stored fruit

For fruit stored at 5.5°C for 10 days, the duration of ethylene treatment required to obtain the fastest rate of ripening was 6 to 12 hours for early season fruit, reducing to only 3 hours by late season. Thus for fruit ethylene treated after storage, e.g. in Australia, a treatment duration of 6 to 12 hours, which is a significantly shorter treatment duration than for non-stored fruit (24 to 36 hours), can be employed. This is in agreement with results in 1995/96 which also found that a 12 hour treatment was sufficient to maximise ripening rate (White *et al.,* 1996).

There are a number of benefits for the industry in using the correct ethylene treatment duration. Firstly, longer durations than required clearly involve a cost in terms of ethylene gas and unnecessary time in the treatment room, and also increases the risk of excessive carbon dioxide build-up. Secondly, shorter treatment times than required

will fail to achieve the main goal of maximising ripening rate. In addition, the minimising of fruit variability is important in the handling and marketing of the crop since it means fruit are at a similar stage of ripening, and hence will respond more similarly to, for example, storage temperatures. This makes maintaining fruit quality of the entire consignment more achievable.

Conclusion

For local market fruit (non-stored), early season fruit should be ethylene treated for 24 to 36 hours, and this duration should be reduced to 12 hours by the end of the season. For fruit exported to Australia (10 days storage at 5.5°C), early season fruit should be treated for 6 hours, and late season 3 hours.

2. Treatment protocols and fruit quality

Aside from the effect of duration of ethylene treatment (described above), we have examined the effect of the following variables on shelf life and fruit quality:

- Ethylene treatment temperatures (17°C and ~6°C)
- Holding time at 17°C following ethylene treatment
- Post-treatment storage temperatures (5.5, 4, and 2°C)

During the 1995/96 season we examined a wide range of possible scenarios including ethylene treatment of stored (6°C for 10 days) and non-stored fruit at 17°C and 6°C (for up to 2.5 and 12 days, respectively) followed by 14 days storage at 2°C or direct ripening at 20°C. From these 40 treatments in 8 general scenarios, we followed two main avenues in the 1996/97 season. Firstly, to determine the optimum firmometer value at which fruit should be placed into storage to achieve the best fruit quality after 14 days storage at a range of temperatures. Secondly the effect of ethylene treatment duration at 5.5°C on shelf life and fruit quality after storage was examined.

1995/96 season

Ethylene treatment at 17°C

For fruit not stored prior to ethylene treatment (as would be employed for local market fruit), we found that a 24 hour ethylene treatment increased fruit quality over non-ethylene treated fruit. Storing fruit at 2°C immediately after ethylene treatment resulted in a significant reduction in fruit quality, and no increase in the rate of ripening over that of controls.

Fruit stored for 10 days at 6°C, then ethylene treatment for 12 hours (as carried out by industry in Australia) reduced the ripening variability, thus allowing marketing fruit of more uniform ripeness and quality. There was a small increase in the rate of ripening and fruit quality was similar to that of non-treated fruit. Fruit stored at 2°C after ethylene treatment at 17°C, a scenario which would allow storage of fruit in a "ready to sell" state, reduced fruit quality.

Ethylene treatment at 6°C

For fruit not stored, ethylene treatment at 6°C for 60 hours resulted in better fruit quality than non-treated fruit, but there was little increase in the rate of ripening. Ethylene treatments of longer durations reduced fruit quality. Short treatment durations followed by storage at 2°C show promise as a technique for ethylene treating prior to, or during, export of fruit with subsequent storage. These results confirm that of Zauberman and Fuchs (1973) that the presence of ethylene at low temperatures can increase avocado softening.

Ethylene treatment at 6°C of stored fruit showed that a 60 hour ethylene treatment resulted in increased rate of ripening and reduction in ripening variability, but also a slight reduction in quality (10%).

1996/97 season

Ethylene treatment 17°C

This experiment sought to determine the optimum fruit firmness (firmometer value) at which fruit should be placed into storage to achieve the best fruit quality after 14 days storage at a range of temperatures. This would also show whether fruit can be ethylene ripened on-shore and then exported to Australia.

Mid-season (mid-January) fruit were ethylene treated for 24 hours in a commercial ethylene ripening room, and fruit were then held at 15°C for 5 holding times to achieve a range of firmometer values (up to ~40). Fruit were then either ripened directly at 15°C or stored at 2, 4 or 5.5°C for 14 days and then ripened at 15°C. Fruit firmness was measured using the firmometer at appropriate points during treatment and ripening, and fruit quality assessed when ripe.

Fruit not ethylene treated (control) and stored for 14 days at either 5.5°C or 4°C prior to ripening at 15°C had the best fruit quality. Storage at 2°C maintained firmness during storage but resulted in external chilling injury and reduced fruit quality. Increasing the holding period at 15°C prior to storage reduced fruit quality significantly, but had very little effect on shelf life following 14 days storage at 2-5.5°C. This emphasises the need to hold fruit at low temperatures and maintain a continuous coolchain.

Of all the ethylene treatments, only one treatment (79 hours holding at 15°C and storage at 5.5°C) increased ripening rate (the main purpose of ethylene treatment) whilst maintaining adequate fruit quality following 14 days storage. However, although this treatment had fruit quality comparable to non-treated fruit, it resulted in a very short shelf life (2.6 days).

We conclude that it is not feasible to ethylene treat fruit at 17°C and store fruit for 14 days and obtain adequate fruit quality.

Ethylene treatment at 5.5°C

Here we have examined the effect of ethylene treatment at 5.5°C on shelf life and fruit quality. The ultimate aim of this research is the development of a low-temperature ethylene ripening protocol which would allow fruit destined for export to be treated on-

shore, or even during transportation. Mid-season fruit were ethylene treated at 5.5°C for 0, 24, 48 or 72 hours, then either ripened directly at 15°C, or stored at 2, 4, or 5.5°C for 14 days, then ripened at 15°C. Firmometer values were recorded at appropriate points, and fruit quality assessed when ripe.

After 14 days storage (simulated exported to Australia), good fruit quality and rapid ripening were observed in fruit not treated with ethylene, and in fruit which had been ethylene treated at 5.5°C for 24 hours. The ethylene treatment protocol currently employed by industry (17°C following 14 days storage at 5.5°C) was found to result in no increase in ripening rate and significantly lower fruit quality than the two above treatments. This result (which confirmed the results in the 1995/96 season) suggests that fruit stored for 14 days or longer do not require ethylene treatment, and indeed may reduce fruit quality.

It was interesting to note that when fruit ripened at 15°C immediately after ethylene treatment at 5.5°C for between 48 and 72 hours ripened faster and were of good quality (~90% sound fruit). Such a treatment scenario would mean ethylene treatment for local market fruit could be carried out at storage temperatures, thus avoiding the need for fruit rewarming.

3. Conclusion/directions

The work to date demonstrates both the potential and complexity of the many possible treatment and handling regimes for ethylene ripening of avocados. Ongoing work will examine the possibility of low temperature ripening, and optimising protocols for local market fruit.

Acknowledgements

This work was funded by the NZ Avocado Industry Council. We wish to thank Dave Mandino for providing fruit, and Jonathan Cutting, Alistair Young and Tony Ponder for helpful discussions.

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