EFFECTS OF PREPACKING HOLDING TEMPERATURES ON SHELF LIFE OF 'HASS' AVOCADOS

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ABSTRACT

The effect of holding fruit at 7°C in a high or low relative humidity (RH), just above the dew point temperature (16°C), at 20°C, or ambient conditions for 24, 48 or 96 hours prior to packing on fruit quality after subsequent storage was investigated using fruit from six orchards. Holding fruit at 7°C in a low RH, 20°C or at ambient conditions increased the potential for rots during shelf life. In contrast, holding fruit at just above the dew point (12 to 16°C) or at 7°C in a high RH resulted in minimal water loss, and decreased the potential for rots during shelf life. Irrespective of holding temperature, rot incidence was higher when fruit were held for 48 or 96 hours than 24 hours prior to packing, and with each additional days delay a 3 to 10% increase in rots can be expected. Water loss from the fruit during the holding period was related to rot incidence during shelf life.

It was concluded that an increase in water loss of 0.5% over the holding and/or storage period is likely to increase stem-end or body rots by 5 to 10% and 7 to 20%, respectively. However, the maximal effect of holding conditions on rots is likely to be two to three times less than the inherent potential of the fruit to develop rots, and therefore, future studies should focus on decreasing the inherent rot potential.

For best practice guidelines it is recommended that fruit be packed within 24 hours of harvest and held at temperatures between 7° and 16°C, or slightly above the dew point temperature in a near saturating RH. Establishing a near saturating RH as early as possible to minimise initial weight loss is required if the decrease in rot potential is to be maximised.

Keywords: holding temperatures, weight loss, ripening, fuzzy patches, stem-end rots, body rots

INTRODUCTION

The Avocado Industry Council introduced a series of best practices guidelines for postharvest handling and storage of New Zealand avocados destined for export markets (AIC USA Best Practice Manual, 2001a) in order to reduce the occurrence of rots after shipping and during shelf life. Given much of the guidelines are based on general principles rather than on specific data further improvements in quality are likely to be achieved once the effect of specific handling and shipping factors on fruit quality are quantified and more specific guidelines are developed. Currently, packhouse operators are encouraged to hold fruit after harvest for no longer than 48 hours before packing but holding conditions are not strictly defined, and in practice, vary from storage temperatures to ambient conditions.

A study in 2001-2002 that investigated the effect of four holding temperatures and two holding periods prior to packing using fruit from three orchards indicated handling conditions prior to packing had a marked effect on the quality of 'Hass' avocados during shelf life (Lallu *et al.*, 2002). This study was repeated and extended in 2003 to include fruit from six orchards, holding fruit up to 96 hours after harvest, and a 7°C low RH treatment.

MATERIALS AND METHODS

Fruit (approx. 25 count) were selected from field bins of freshly harvested fruit from 6 Bay of Plenty orchards on 12 or 13/11/02, placed into WP47 crates and transported to HortResearch (Mt Albert, Auckland). Three crates per orchard were allocated to each of five holding temperature treatments: 7°C, 7°C low RH, just above the dew point temperature (16°C), 20°C, or ambient temperature. After 24, 48 or 96 hours, fruit were passed across four rows of brushes and packed into two single layer trays per orchard per treatment. Fruit and air temperatures, RH and weight loss were recorded during the holding period. Packed fruit were stored at 5°C for four weeks, then removed to 20°C for shelf life assessment of the rate of ripening, incidence and severity of rots (stem-end rots (SER) and body rots (BR)) and weight loss using the method and 0-100% rating scales described in the NZ AIC Assessment Manual (AIC, 2001b). Fuzzy patches were not observed in any fruit in this trial. Data were analysed by ANOVA of arc sin square root transformed data in order to identify significant effects of duration, holding temperature, and/or orchard at the $p<0.05$ level. For analysis of temperature effects the 7°C low RH treatment was excluded from the ANOVA since the low RH was considered to be unrepresentative of a commercial or typical 7°C situation. The results presented are of untransformed data.

RESULTS

Air and fruit temperatures and relative humidity

Fruit temperature was approx. 16-18°C before placing in holding treatments, and took approx. 4 hours to reach the treatment temperature (Figure 1A). Thereafter, the fruit temperatures followed or matched the air temperatures with a delay of approx. 3 hours. The diurnal fruit temperatures in the ambient treatment cycled between approx. 12 and 20°C, and ambient RH fluctuated between approx. 40 and 70% daily (Figure 1b). The highest RH (approx. 95%) was achieved in the 7°C treatment, and the lowest (approx. 30-35%) in the 7°C low RH treatment. In the 16°C treatment, the RH of the air was approx. 85% for the first 3 days and then dropped to 75% over the last day, but was cycling within a 5-8% range in response to the cycling of the air temperature between 14.5° and 17.5°C. Similarly, in the 20°C treatment, the RH was approx. 55% for the first 60 hours, but then over the next 12 hours rose to approximately 75% before dropping back to 55%, and then continuously dropped to approx. 40% over the last 24 hours.

Weight loss

Overall, weight loss was approx. 0.7, 1.3 and 2.3% after the first 24, 48 and 96 hours, respectively. After 96 hours, weight loss ranged from approx. 0.60% in the 7°C treatment to approx. 4.0% in the 20°C treatment (Figure 2). Weight loss was similar in the 7°C low RH and ambient treatments (2.3% and 2.6%) and 1.8% in the 16°C treatment. In general, the rates of weight loss were linear after the first 24 hours, and

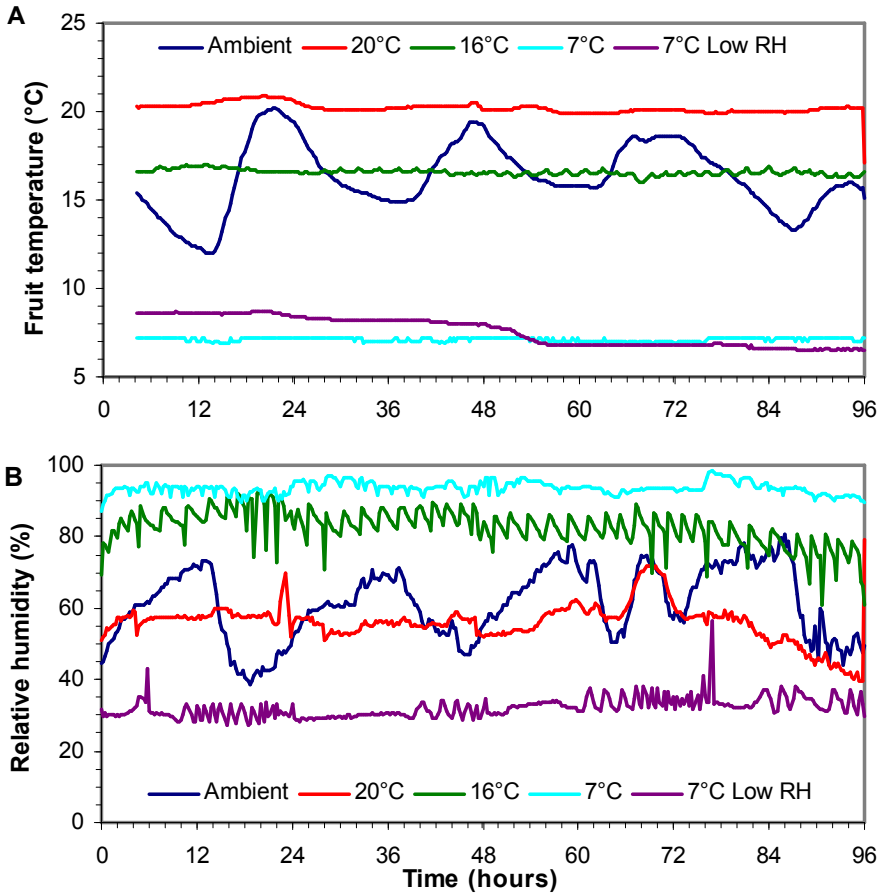

Figure 1. Fruit temperature (A), and relative humidity of the air (B) during holding of 'Hass' avocado fruit at 7°C, 7°C with low RH, 16°C, 20°C, or ambient conditions, for up to 96 hours.

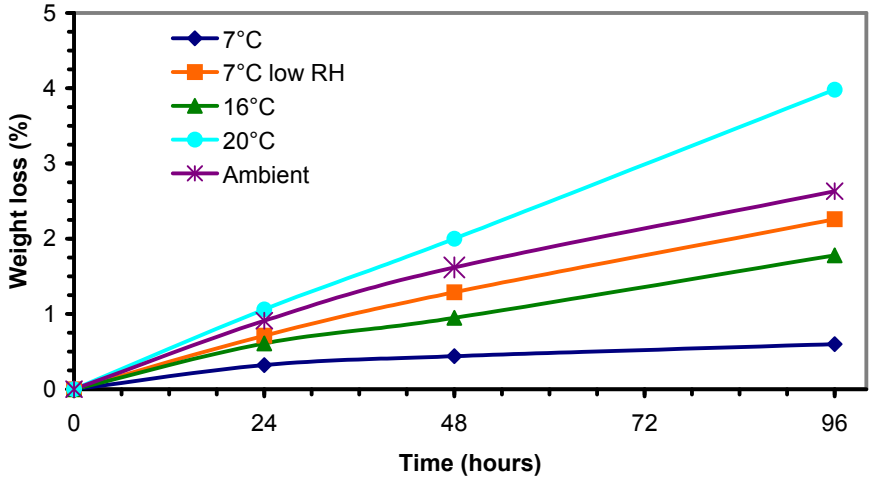

Figure 2. Weight loss from 'Hass' avocados during holding at 7°C, 7°C with low RH, 16°C, 20°C, or ambient conditions, for up to 96 hours. Values are means of 24 fruit.

differences between treatments established at the end of the holding treatment were maintained during storage (Table 1). Weight loss during storage and after 3 days shelf life was approx. 2.4% and 1.5%, respectively, resulting in an average total weight loss of approx. 4.7, 5.4 and 5.9% for the 24, 48 and 96 hour treated fruit, respectively.

Table 1. Weight loss (%), accumulative incidence (%) of ripe fruit, stem-end rots (SER; %), and body rots (BR; %) in 'Hass' avocado fruit after holding fruit in different temperatures (7°C, 7°C with low RH, 16°C, 20°C, or ambient conditions) for 24, 48 or 96 hours, then coolstorage for 4 weeks at 5°C before transfer to 20°C for shelf life. n= 24 fruit for weight loss, and n = 12 trays of fruit for ripe fruit, SER and BR.

Holding treatment	Weight loss (%)		Ripe fruit (%)		SER (%)	BR (%)
	Holding period	4 weeks storage	Shelf life day 3	Shelf life day 4	Shelf life day 5	Shelf life day 5
Duration means[1]						
24 h	0.72	3.29	31.7	94.9	20.9	41.9
48 h	1.26	3.84	54.2	97.0	20.0	47.6
96 h	2.25	4.32	60.4	99.0	21.2	45.1
Temperature means						
7°C	0.45	3.05	48.7	98.8	13.2	38.0
7°C low RH	1.42	3.82	57.3	98.8	24.1	39.0
16°C	1.11	3.50	44.0	95.7	19.7	40.6
20°C	2.35	4.66	52.8	95.1	23.8	49.0
Ambient	1.72	4.09	41.0	96.4	26.1	51.9
Statistical analysis:[2] *p values*						
Source of variation	*DF*					
Duration	*2*	*<0.001*	*<0.001*	*<0.001*	*0.003*	*0.717*	*0.282*
Temperature	*3*	*<0.001*	*<0.001*	*0.003*	*0.049*	*<0.001*	*0.002*
Dur. × temp.	*6*	*<0.001*	*<0.001*	*0.405*	*0.012*	*0.005*	*0.014*
Residuals[3]	*132*					
Total[3]	*143*					

[1] Means exclude the 7°C low RH treatment.
[2] Based on arc sin square root transformed data, excluding the 7°C low RH treatment.
[3] For weight loss, Residuals = 276, and Total = 287.

Ripe fruit

Fruit began to ripen after 2 days shelf life with approx. 97% ripe on day 4 and all fruit ripe by day 5 (Table 1). The number of ripe fruit on day 3 increased significantly with an increase in holding duration, such that the number of ripe fruit doubled from approx. 32% to approx. 60% as the holding duration increased from 24 hours to 96 hours. Differences between temperature treatments were not always consistent between holding periods, but on day 3 more fruit held at 20°C or in the 7°C low RH treatment were ripe than fruit held at 16°C or 7°C (Table 1). The least number of ripe fruit were amongst fruit held at 16°C or in ambient conditions in which approx. 41% of the fruit were ripe on day 3.

Stem-end rots

Approx. 21% of all the fruit developed SER and of these fruit the average severity was low (approx. 3.4%). Holding duration had no significant effect on overall incidence (Table 1), but a longer holding time tended to result in earlier expression of SER (Figure 3A). Holding temperature significantly affected SER incidence throughout shelf life (Figure 4A). On day 5, incidences of SER in fruit held at ambient, 20°C, or 7°C with low RH were similar at approx. 25%, which was approx. twice that in fruit held at 7°C (approx. 13%, Table 1). For fruit held at 16°C the incidence was approx. 7% on day 3 and approx. 20% on day 5.

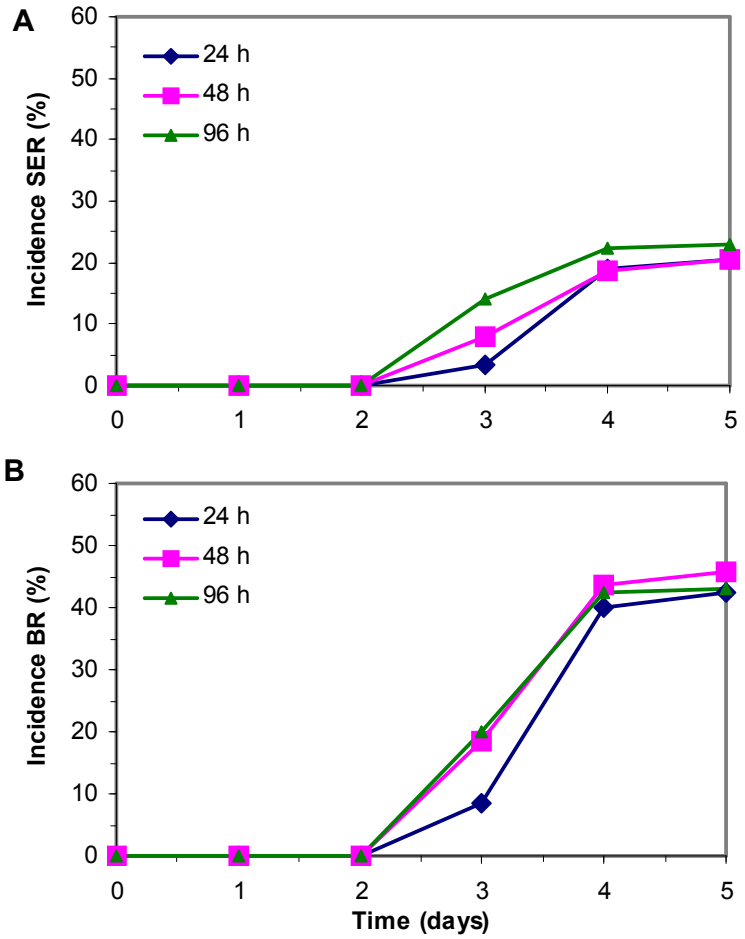

Figure 3. The effect of the duration of holding conditions on the incidence stem-end rots (SER; A), and body rots (BR; B) during shelf life at 20°C in 'Hass' avocados after holding fruit in different temperatures (7°C, 7°C low RH, 16°C, 20°C, or ambient conditions) for 24, 48 or 96 h, then coolstorage for 4 weeks at 5°C. Values for each duration are means of the 5 temperature treatment means, each of which is based on 12 trays of fruit.

Body rots

Overall, approx. 44% of the fruit developed BR, and of these fruit the average severity was approx. 5%. The highest incidence of BR was in fruit held at ambient (approx. 52%) and the lowest for fruit held at 7°C (approx. 38%, Table 1). Duration did not significantly affect overall incidence although on day 3, the incidence of BR increased significantly from approx. 7% in fruit held for 24 hours to 21% in fruit held for 96 hours (Figure 3B). As for SER, the effect of duration on BR appears to be on the rate or time of expression rather than incidence. Amongst holding temperatures, the lowest incidence of BR was for fruit held at 7°C or 16°C, and the highest incidence was for fruit held at 20°C or at ambient (Table 1, Figure 4B). The incidence of BR in fruit in 7°C low RH was only slightly more than in fruit held in a higher RH at 7°C on day 3 (approx. 14% versus 11%), but virtually the same on days 4 and 5 (approx. 38%), which suggests RH had little affect on BR incidence (Figure 4B).

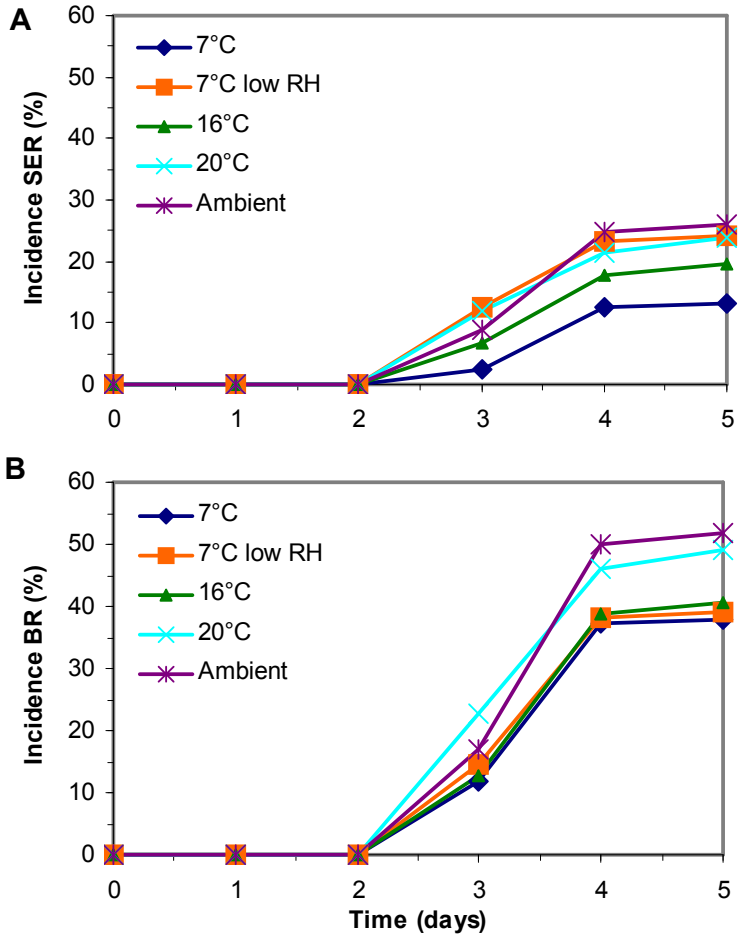

Figure 4. The effect of holding temperatures on the incidence stem-end rots (SER; A), and body rots (BR; B) during shelf life at 20°C in 'Hass' avocados after holding fruit in different temperatures (7°C, 7°C low RH, 16°C, 20°C, or ambient conditions) for 24, 48 or 96 h, then coolstorage for 4 weeks at 5°C. Values for each temperature treatment is the mean of the 3 duration means, each of which is based on 12 trays of fruit.

Orchard differences

Despite significant differences between the orchards, the fruit from each orchard responded in a similar manner to each of the duration and temperature treatments (data not shown). For example, fruit from orchard 1 had the highest weight loss, and more ripe fruit on days 3 and 4 resulting in the highest incidence of SER or BR and amongst the duration and temperature treatments, respectively. By contrast, fruit from orchard 4 tended to have the lowest weight loss, ripe fruit on days 3 and 4 and lowest incidence of SER or BR.

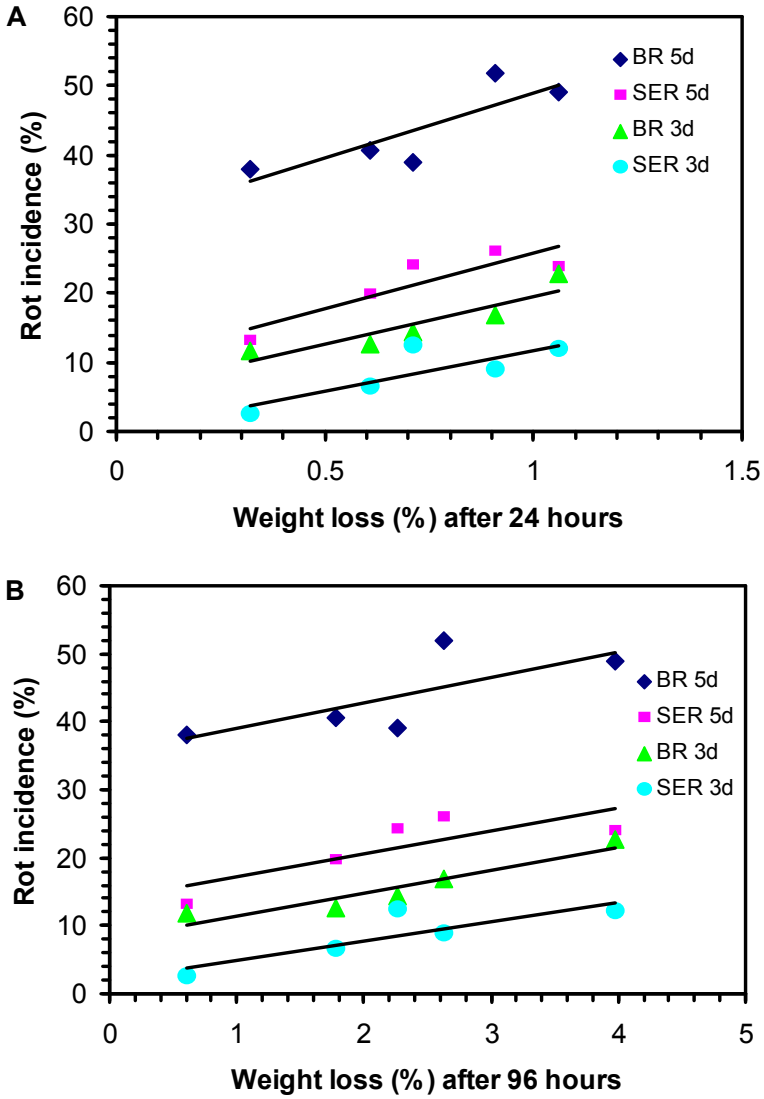

Figure 5. Linear regressions of weight loss incurred after 24 hours (A) or 96 hours (B) in the holding treatments on stem-end rot (SER), or body rot (BR) incidence after 3 days (3d) or 5 days (5d) shelf life. Fruit were held at different holding temperatures (7°C, 7°C low RH, 16°C, 20°C, or ambient) for 24 or 96 h, then coolstored for 4 weeks at 5°C before transfer to 20°C for shelf life assessment.

Relationships between water loss and rot incidence
There were some strong linear relationships between weight loss incurred during the holding treatments and rot incidence (Figure 5). Overall, the incidence of SER or BR increased with an increase in weight loss, and depending on which phase of weight loss is included in the analysis, for each 1% increase in weight loss there is an increase in SER and BR incidence of approx. 5 to 15%. For both SER and BR incidence, the most sensitive relationship was with weight loss after 24 hours in that for every 0.5% increase in weight loss there was approx. 5 to 10% increase in rots (Figure 5A), whereas for relationships with weight loss after 24 hours rot increases were approx. half these values (Figure 5B).

DISCUSSION

The results of the present study confirm the finding of the 2002 study that the expression of rots and ripening rate of fruit at harvest can be influenced by holding conditions prior to packing (Lallu *et al*., 2002). However, the effect on fuzzy patches cannot be confirmed due to the lack of fuzzy patches in the present study. Extending the holding time to 96 hours helped quantify the effect of holding time on rot incidence, and increasing the number of orchards in the study from three to six has also been useful. In general, interactions between treatment and orchards were statistically non-significant, which indicates that the effect of treatment was consistent across the orchards and a more robust interpretation of the main effects is possible than in the 2002 study. Nevertheless, as in 2002, some differences between treatments were less than differences between orchards, and therefore, orchards factors and in particular the inherent rot potential may have overridden the treatment effects, especially where the rot potential and hence incidence was very high.

Holding duration had less effect than holding condition in that holding fruit beyond 24 hours did not markedly affect the total rot incidence, but did affect the timing or expression of the rots. In general, fruit held for longer than 24 hours tended to ripen earlier and have more rots than fruit held for 24 hours. In contrast, holding conditions significantly affected both total rot incidence and timing of expression. These effects of holding duration and conditions may be explained by the effects on water (weight) loss, and although, there was a trend for more rots to be associated with the highest rates of water loss during the holding period, water loss during the first 24 hours of the holding duration appear to be critical. Although there was greater water loss associated with a longer holding period, the effect on rots was similar between the holding durations because the initial rates of water loss were the same. In contrast, the initial rates of water loss amongst different holding conditions were different and these resulted in different incidences of rots.

In general, it appears that the lower the initial RH after harvest the greater the rate of ripening and incidence of rots. Hence, warming fruit above its harvest temperature (20°C treatment), and /or holding fruit in a low or fluctuating RH (ambient treatment) increases water loss and rots relative to holding fruit at 7°C or 16°C where the RH is higher. Holding fruit at low temperatures appears to reduce the incidence of SER and BR. RH appears to affect total SER incidence but not total BR incidence. However, the effect of RH was only compared at one temperature (7°C), and it may be that the effect of RH on BR was confounded by the occurrence of condensation on the fruit during brushing and packing, especially if condensation promoted the development

of BR. In addition, in the 2002 study, rots were worse when fruit were held at 7°C than 16°C, even though RH in the 7°C treatment was only slightly lower than the RH at 16°C. Therefore, there is still some uncertainty whether holding fruit at low temperatures (7°C) in a high RH will always result in a low rot incidence. Establishing or maintaining a high RH as soon as soon as possible may be needed when holding fruit at low temperatures if the rot incidence is to be minimised or reduced.

Any differences in ripening and rot incidence established by the initial rates of water loss are likely to be maintained through storage and shelf life. However, it is not known what outcome would result should the conditions of storage accelerate water loss beyond rates during the holding period, but it can be expected that both the ripening rate and rot incidence will be increased. If so, maintaining minimum water loss during storage and shelf life should be beneficial to fruit quality. At present RH conditions during storage and transport are not specified but it may be useful to prescribe a minimum RH such as 90-94%.

Overall, water loss appears to be a common link between ripening rates and a major driver of rot expression. However, the effects of water loss on ripening and rots are not easily separated, and it is not always clear whether an effect is on ripening or on rots *per se*. Both rot and ripening occur over a few days, and any treatment effects on ripening usually differ by only a half to one day. Moreover, the extent to which water loss can influence rate of ripening and rots appears to be small relative to the inherent rot potential in the fruit, and to be fixed or maximal. Irrespective of the inherent rot potential, the level of rot that can be influenced by holding treatments is the same since the slopes of the relationship between water loss and rot incidence are the same for fruit on day 3 and day 5 yet the total rot incidence increases two to three fold. Overall, an increase in water loss of 0.5% over the holding period and/or storage period is likely to increase SER or BR by approx. 5 to 15% and 10 to 20%, respectively. This is slightly less than that found in 2002, but as in 2002, it is a smaller fraction of the total rots which were approx. 40% and 21% for SER rot and 70% and 48% for body rot in 2002 and 2003, respectively. Therefore, it appears there is a maximal proportion of the total rots that can be influenced by water loss. This maximal proportion is somewhere between 5 and 20%, whereas the natural or inherent potential to produce rots is much higher at somewhere between 40 and 70%.

Whilst holding conditions are important because of their effects on rot incidence, future work should focus on reducing the inherent potential to rot as well as the proportion that is influenced by water loss or holding conditions, and in particular the initial rate of water loss and the effect of the initial RH on this. If a standard condition is to be defined, it should be that a high or saturating RH is achieved or is present prior to placing fruit into a holding temperature in the range 7 to 16°C.

CONCLUSIONS

It is concluded that the expression of rots and ripening rate of fruit at harvest can be influenced by holding conditions prior to packing and conditions during storage. Holding temperatures in the approx. range 7 to 16°C, are likely to optimise fruit quality but only if a high RH is also present. Holding fruit at high temperatures and low RH, (e.g. 20°C or ambient summer conditions), enhances the incidence of fuzzy

patches (2002 study), SER and BR, and results in faster ripening. Holding fruit at lower temperatures (5-7°C) decreases SER and BR but increases fuzzy patches, and ripening may be slower.

Water loss from fruit during the holding period is related to rot incidence during shelf life, and in particular initial rates of water loss appear to be critical to decreasing the rate of ripening and rot incidence during shelf life. Holding fruit at just above the dew point, which can be expected to be in the range 12-16°C, will result in minimal water loss and decrease the potential for rots during shelf life. However, establishing the near saturating RH as early as possible is required if the decrease in rot incidence is to be maximised.

Irrespective of the holding condition, rot incidence is higher when fruit are held for 48 or 96 hours than 24 hours prior to packing, and with each additional days delay approx. a 3-10% increase in rots can be expected. Overall, an increase in water loss of 0.5% over the holding period and/or storage period is likely to increase SER or BR by approx. 5 to 10% and approx. 7 to 20%, respectively. Fuzzy rots although not present in this study are likely to be increased by 0 to 15%. However, the maximal effect of holding conditions on rot incidence is likely to be two to three times less than the inherent potential to develop rots. Therefore, in future studies there should be a focus on decreasing the inherent rot potential.

As best practices guidelines, it is recommended that fruit are packed within 24 hours of harvest. Fruit should be held at temperatures in the range 7 to 16°C or slightly above the dew point temperature, in a saturating RH when held prior to packing. Placing fruit at low temperatures with low RH should be avoided. If fruit are held for longer than 24 hours prior to packing, they should be held in a high RH (90-94%). After packing fruit should be maintained in a RH of 90-94%.

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