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Influence of postharvest temperatures and the rate of fruit ripening on internal postharvest rots and disorders of New Zealand 'Hass' avocado fruit

G. HOPKIRK
A. WHITE
D. J. BEEVER
S. K. FORBES

The Horticulture and Food Research Institute of New Zealand
Mt Albert Research Centre
Private Bag 92 169
Auckland, New Zealand

Abstract Postharvest rots and internal disorders of 'Hass' avocado (*Persea americana*) fruit develop during the latter stages of fruit ripening, with symptoms first appearing when fruit are minimally ripe but often becoming quite severe before the fruit are oversoft. Fruit ripened at 20°C and assessed at the same stage of ripeness, just before the flesh becomes oversoft, had fewer postharvest rots if they had been previously stored at 4 or 6°C, than if they had been stored at either lower or higher temperatures. Postharvest disorders increased with increased length of storage. Fruit failed to ripen properly at 30°C. Even at 25°C (a temperature typically experienced by fruit exported from New Zealand), the level of postharvest disorders was greater than in fruit ripened at 20°C. Best final quality was obtained with fruit coolstored at 6°C and then ripened at 15°C. However, if fruit are to be ripened at c. 25°C, then final quality was better if the fruit were not coolstored but held at a temperature closer to the final ripening temperature. Fruit from a single orchard block, harvested, coolstored, and ripened together, individually reached minimum eating ripeness over an 8-day period. Fruit which ripened earliest had the fewest disorders, with later ripening fruit typically having high levels of postharvest rots and internal browning.

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INTRODUCTION

When harvested, avocados are mature but unripe; ripening commences only after fruit are removed from the tree. While unripe, fruit are typically free of postharvest rots or other internal disorders. However, when ripe enough for consumption, fruit can be severely affected by rots and other disorders. This increase in disorders with increased ripening has been reported by Darvas et al. (1990) and others.

Postharvest rots in avocado fruit result from latent infections in the fruit which are initiated on the tree during the growing season (Binyamini & Schiffmann-Nadel 1972). Fungi remain quiescent probably because of the presence of an inhibitory diene in the skin of the fruit which disappears as the fruit ripen (Prusky et al. 1991). Commercially, avocado fruit are frequently treated with a fungicide after harvest to reduce postharvest rots; prochloraz has been found to be the most appropriate for this purpose in Australia (Muirhead et al. 1982) and in New Zealand (Hartill et al. 1986). Despite the use of this fungicide, reports persist of New Zealand fruit with high levels of rots in export markets.

Researchers in Australia, investigating fruit losses in 'Fuerte' avocados (Fitzell & Peak 1982), observed that disease was more severe in fruit ripened in April (when ambient temperatures were 18–28°C) than in those ripened in May (ambient temperatures 14–20°C). Subsequently, Fitzell & Muirhead (1983) demonstrated that high ripening temperatures (>24°C) increased the incidence of postharvest disease in 'Fuerte' avocados, and that rot levels were decreased by ripening fruit at 17°C. Based on this type of information, the New Zealand avocado industry recommend that 'Hass' fruit be ripened at temperatures slightly below 20°C (NZ Avocado Export Council 1990). However, New

Zealand avocados are harvested and exported over the summer months (November–February), when temperatures in Australia are typically >25°C. It has been suggested that high Australian temperatures could be contributing towards the high levels of disorders in some lines of New Zealand fruit, and, to reduce these quality problems, it has been recommended that fruit should be held in coolstorage both before and after airfreight to Australia (NZ Avocado Export Council 1990).

Much postharvest avocado research has focused on extending the storage or shelf life of fruit rather than increasing ripe fruit quality, using techniques such as low temperature (e.g., Zaubermann et al. 1977; Vorster et al. 1987), or controlled atmosphere storage (e.g., Hatton & Reeder 1972; Truter & Eksteen 1987). Much of this research has used the cultivar 'Fuerte'. However, it is generally accepted that different cultivars have different postharvest characteristics and, in particular, different sensitivities to postharvest temperature (Zaubermann et al. 1973) and different susceptibilities to diseases and disorders (Darvas & Kotze 1987). Since the New Zealand avocado industry is based almost exclusively on the cultivar 'Hass', and there are reports of poor quality fruit in our overseas markets after relatively short periods of storage, we have investigated some factors affecting the quality of 'Hass' fruit after only moderate periods of storage. Fruit were allowed to ripen fully before assessment of quality.

METHODS

Export-quality avocado (*Persea americana*) fruit 'Hass', were harvested from mature trees commercially grown in the Bay of Plenty, New Zealand, dipped in prochloraz (250 ppm a.i., 1 min), size graded, and packed in pocket packs in single layer trays. Fruit were held for a period in coolstorage and then ripened at 20°C unless otherwise indicated. Temperature treatments were carried out in coolstores or temperature controlled rooms, as appropriate. During ripening, fruit was assessed daily by gentle hand-squeezing by one trained assessor, to gauge the state of ripeness. When each individual fruit was judged to be "fully ripe" (usually 1–2 days after optimum eating firmness), it was cut into quarters longitudinally, the skin peeled away, and the exposed flesh evaluated visually for rots and internal disorders. Shelf life was the mean time (at the ripening temperature) for all fruit within a treatment to reach the fully ripe stage.

Stem end rots were those which appeared to penetrate via the stem scar. Body rots were any rots developing from the skin into the body of the fruit. Isolations of fungi causing rots were occasionally made onto potato dextrose agar to aid identification. Internal browning refers to browning of the flesh, as distinct from vascular browning which was confined to browning of the vascular bundles. Uneven ripening was identified as failure of the flesh to soften normally, typically resulting in internal tissue remaining hard and attached to the stone. For each fruit, disorders were graded on a 0 (absent) –3 (severe) scale, and results for each treatment were expressed as the percentage of fruit with moderate or severe symptoms (Grades 2 and 3), except in 1990 when the percentage of fruit with slight symptoms (Grade 1) was also included. Analysis of variance was undertaken on angular transformations of these percentages; data presented in figures and tables are back-transformed means.

Storage temperature

In 1990, four replicates of 11 fruit were stored at 0, 2, 4, 6, or 10°C for each of 2, 3, 4, or 5 weeks, before ripening at 20°C. On three occasions during the 1991 season (early, mid, and late season), four replicates of 21 fruit were stored at 2, 4, or 6°C for 3 weeks, before ripening at 20°C.

Ripening temperature

In 1991, fruit were held at 6°C for 10 days before ripening at 15, 20, 25, or 30°C. Three replicates of 22 fruit were used.

Interaction between storage and ripening temperatures

In 1992, four replicates of 22 fruit were held at 6, 15, 20, or 25°C for 10 days before ripening at each of 15 (following 6 and 15°C storage only), 18 (after 6°C only), 20, or 25°C.

Rate of rot development and the time for individual fruit to ripen

On two occasions, 400 (1992) or 1000 (1994) fruit were held at 6°C for 1 week, and then transferred to 20°C to ripen. Each day, fruit judged to be just minimally ripe were selected, divided into groups, and one group evaluated on that day and each of the following 3 days in 1992 or following 5 days in 1994.

In another experiment, undertaken on two occasions during the 1992 season, eight replicates

of 20 fruit were held at 6°C for 1 week, then ripened at 20°C. For other purposes a further 160 fruit were treated with ethylene (100 ppm at 20°C for 24 h) after removal from coolstorage, before ripening at 20°C.

RESULTS

Storage temperature and length of storage

In the first season (1990), many avocado fruit stored at 0 or 2°C exhibited symptoms of chilling injury: black pitting lesions on the skin on removal from storage, and, after ripening at 20°C, grey-black flesh discoloration and blackening of the vascular bundles. The increased shelf life for fruit stored at 0 or 2°C, particularly after 5 weeks storage (Table 1), was the result of uneven flesh ripening which resulted in poor quality fruit. Fruit had significantly more stem end rots and body rots after storage at either 0 or 2°C than after storage at 4 or 6°C.

In the second season (1991), however, external skin damage because of chilling injury was seen in only a small proportion of fruit immediately after storage at 2°C (no fruit was stored at 0°C), and mainly in fruit harvested late in the season. Levels of internal browning, vascular browning, or uneven ripening were no higher in fruit after storage at 2°C than in fruit stored at 4 or 6°C (data not shown). No specific internal symptoms of chilling injury (e.g., grey-black flesh) were seen in any fruit. Clearly, there were large differences in chilling sensitivity between fruit in the different seasons.

Fruit which had been held at 10°C ripened significantly more quickly than fruit held at 4 or 6°C, and the shelf life of fruit after removal from storage at 10°C decreased with increasing length of storage (Table 1). There was no consistent decrease

Table 1 Shelf life and percentage of fruit with slight, moderate, or severe symptoms of stem end or body rots in 'Hass' avocados stored at reduced temperatures for various periods and then held at 20°C until individual fruit became "fully ripe". (1990 data.) (Within a column, values within each storage time, followed by the same letter do not differ significantly according to Duncan's multiple range test ($P< 0.05$); ANOVA = analysis of variance.)

Time in storage (weeks)	Storage temperature (°C)	Shelf life (days)	Stem end rot (%)	Body rot (%)
2	0	7.4a	56c	89c
	2	7.3a	30b	57b
	4	7.1a	5a	18a
	6	6.6b	12a	16a
	10	4.6c	5a	15a
	ANOVA	$P<0.001$	$P<0.001$	$P<0.001$
3	0	6.4b	58d	95d
	2	7.5a	32c	51c
	4	6.0bc	5a	11a
	6	5.7c	7a	12a
	10	4.1d	18b	32b
	ANOVA	$P<0.001$	$P<0.001$	$P<0.001$
4	0	6.4b	62c	100d
	2	7.4a	49b	80c
	4	6.7ab	30a	23a
	6	6.8ab	26a	39b
	10	3.2c	53bc	36b
	ANOVA	$P<0.001$	$P<0.01$	$P<0.001$
5	0	9.8a	61c	97c
	2	6.8b	71c	98c
	4	6.5bc	41b	39a
	6	6.0c	45b	57b
	10	0.1d	27a	33a
	ANOVA	$P<0.001$	$P<0.05$	$P<0.001$

in shelf life with increasing storage time when fruit were held at lower temperatures. In 1991, fruit harvested early in the season took longer to reach the "fully ripe" stage after a period of storage than fruit harvested in the middle or the end of the season (data not shown).

In both seasons, there were only small differences (which generally were not statistically significant) in the severity of the rots in fruit stored at 4, 6, or 10°C, although fruit held at 10°C for 3 or 4 weeks in 1990 had more rots than fruit held at 4 or 6°C for the same period of storage (Table 1). Most fruit held at 4 or 6°C, were still of a relatively high quality after 3 weeks storage (Table 1), but with increasing storage, both the percentage of avocados affected by rots and the level of severity increased. After 5 weeks storage, 30–45% of fruit had rots which we considered commercially significant (moderate or severe symptoms), c. 30% of fruit had some vascular browning, and several individual fruit also exhibited uneven ripening after this longer period of storage.

Ripening temperatures

Avocados stored at 6°C and then ripened at 30°C became rubbery in texture and failed to soften normally. Fruit ripened at 25°C softened at the same rate as fruit ripened at 20°C, but this fruit, and that ripened at 30°C, had significantly higher levels of stem end rots, body rots, and vascular browning, but had less internal browning, than fruit ripened at 20°C (Table 2). All fruit ripened at 25 and 30°C were commercially unacceptable. Fruit ripened at 15°C, on the other hand, had significantly longer shelf life than fruit ripened at 20 or 25°C, and was generally of good quality, with only 18% of the fruit exhibiting stem end and/or body rots. In 1992 also, fruit stored at 6°C and then ripened at 25°C had significantly more stem end rot, body rot, uneven ripening and vascular browning than fruit ripened at 20°C or lower (Table 3).

Interaction between storage and ripening temperatures

Of fruit ripened at 15 or 20°C, fruit stored at 6°C had a longer shelf life and generally contained less postharvest rots, and uneven ripening than fruit stored at 15 or 20°C (Table 3). For fruit ripened at 25°C, storage at 6°C still resulted in increased shelf life, but the quality of the fruit was not necessarily better. For example, fruit stored at 6°C and ripened at 25°C contained more uneven ripening than fruit stored at 20°C and then ripened at 25°C. These results were confirmed in two other seasons; for fruit ripened at 25°C, there was significantly more uneven ripening when they had previously been stored at 6°C than when previously stored at temperatures closer to the final ripening temperature (data not shown).

Rate of internal disease and also disorder development and the time for individual fruit to ripen

In all our trials we observed that the incidence of disorders increased markedly as the fruit became more fully ripe. For example, in both experiments undertaken to investigate the rate of disorder development, the incidence of rots and internal disorders was low when fruit were at the minimally ripe stage (e.g., Fig. 1). As ripening progressed, both rots and disorders developed rapidly, often becoming severe by the time the fruit were fully ripe. Internal browning increased rapidly between minimally ripe and the optimum stage of ripeness, whereas both stem end rot and body rot increased in severity only later in ripening.

Fruit from a single orchard block, harvested, coolstored, and ripened together, were usually very

Table 2 Shelf life, incidence of postharvest rots, uneven ripening, internal browning, and vascular browning in 'Hass' avocado fruit stored at 6°C for 10 days and then ripened at various temperatures. (1991 data.) (Values within a column followed by the same letter do not differ significantly according to Duncan's multiple range test ($P< 0.05$); ANOVA = analysis of variance.)

Ripening temperature (°C)	Shelf life (days)	Stem end rot (%)	Body rots (%)	Uneven ripening (%)	Internal browning (%)	Vascular browning (%)
15	15.8a	1a	18a	0a	32b	2a
20	9.2bc	12b	30a	1a	32b	7ab
25	8.6c	80c	96b	77b	1a	11b
30	9.8b	66c	96b	100c	1a	51c
ANOVA	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$	$P<0.001$

variable in their rate of ripening. Typically individual fruit reached the minimally ripe stage over a period of about a week, between 5 and 12 days after removal from 7 days coolstorage. When the groups of fruit becoming minimally ripe on sequential days were considered separately (Fig. 2), the severity of internal browning remained similar, but the longer the fruit took to reach the minimally ripe stage, the more severe the stem end and body rots. This effect was even more pronounced in a further experiment, where all fruit were assessed at the same fully ripe stage. In this instance, the incidence of both stem end and body rots increased markedly as the time to ripen increased, in both early and late harvested fruit (Fig. 3). In the same experiment, fruit treated with ethylene for another purpose also showed a similar increasing severity of both stem end rot and body rot as the time to reach fully ripe increased, both early and late in the season (data not shown). This trend was first observed, but not recorded, in the earlier experiments investigating the effects of storage and ripening temperatures.

Fungi causing postharvest rots

Isolations made of fungi causing both body rots and stem end rots identified both *Botryosphaeria* spp. and *Colletotrichum* spp. as the major organisms involved. Stem end rots were caused predominantly by *Botryosphaeria* spp. These fungi have previously been shown to be responsible for most postharvest rots in avocados in New Zealand (Hartill 1991).

DISCUSSION

The present trials have shown that 'Hass' avocado fruit are similar to 'Fuerte' fruit in that they contain more rots and disorders the riper they are at the time of evaluation. In addition, we have shown that individual fruit which ripen first have fewer stem end and body rots than fruit which are slower to ripen. Loss of tissue resistance to postharvest rot has been linked to the onset of ripening (Prusky et al. 1991), but it appears that the two processes are not tightly linked throughout, since our trials show that fungal rots make greater progress in fruit which ripen more slowly. Truter & Eksteen (1987) reported that controlled atmosphere storage increased the shelf life of fruit with a concomitant increase in anthracnose rot, and Darvas et al. (1990) has reported a positive correlation between "length of ripening time" and severity of postharvest diseases. Both studies used 'Fuerte' fruit growth in South Africa.

The rapid development of disorders during the period of eating ripeness, and the variable ripening rate of individual fruit, make the selection of the time of fruit quality evaluation very important. Especially in the latter stages of ripening, disorder development was so rapid that selection of fruit according to ripeness only once a day is probably

Table 3 Shelf life, incidence of postharvest rots, uneven ripening, internal browning, and vascular browning in 'Hass' avocado fruit stored at various temperatures for 10 days and then ripened at various temperatures. (1992 data.) (Within a column, values within each group at the same storage temperature which are followed by the same letter do not differ significantly according to Duncan's multiple range test ($P < 0.05$); ANOVA = analysis of variance.)

Storage temperature (°C)	Ripening temperature (°C)	Shelf life (days)	Stem end rot (%)	Body rots (%)	Uneven ripening (%)	Internal browning (%)	Vascular browning (%)
6	15	11.3	2a	1a	0a	42	2a
6	18	11.8	14a	10a	13b	45	4a
6	20	10.0	15a	15ab	37c	44	1a
6	25	10.4	50b	43b	76d	41	20b
6	ANOVA		$P < 0.01$	$P < 0.001$	$P < 0.001$		$P < 0.05$
15	15	10.3a	19a	8a	14a	36	4ab
15	20	6.9b	15a	24b	28a	38	0a
15	25	9.1a	60b	50c	75b	42	14b
15	ANOVA	$P < 0.05$	$P < 0.01$	$P < 0.001$	$P < 0.001$		$P < 0.05$
20	20	5.0	37	30	39	42	2a
20	25	5.0	37	36	44	46	18b
20	ANOVA						$P < 0.05$
25	25	6.1	76	55	89	11	39
ANOVA	15		$P < 0.05$		$P < 0.001$		
ANOVA	20	$P < 0.001$		$P < 0.05$			
ANOVA	25	$P < 0.001$	$P < 0.05$		$P < 0.05$	$P < 0.001$	$P < 0.05$

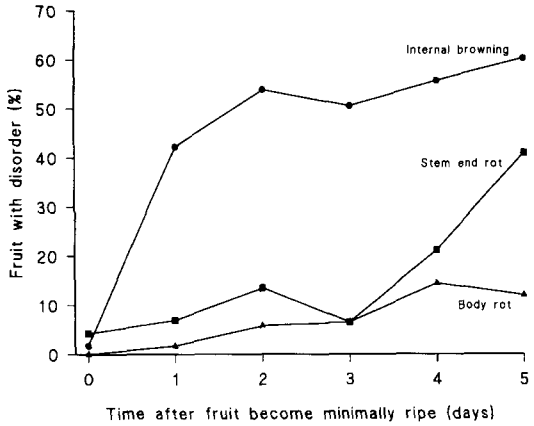

Fig. 1 Incidence of internal browning, stem end rot, and body rot in 'Hass' avocado fruit stored at 6°C for 7 days and then ripened at 20°C. Each fruit was assessed daily for ripeness by gentle hand-squeezing. One sixth of the fruit assessed as being minimally ripe was evaluated for disorders on that day (Day 0) and another sixth evaluated on each of the subsequent 5 days (Days 1–5). Data for fruit reaching the minimally ripe stage on different days have been grouped. (1994 data.)

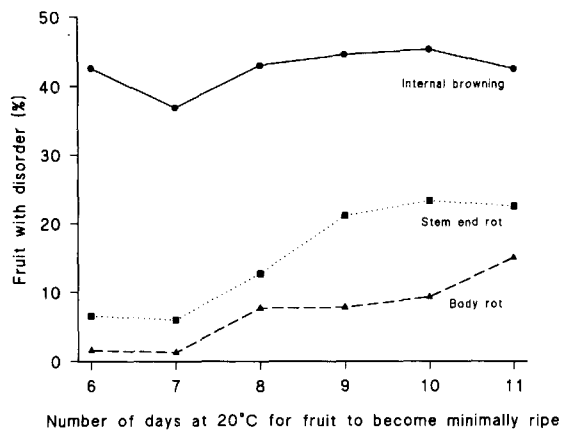

Fig. 2 Incidence of internal browning, stem end rot, and body rot in 'Hass' avocado fruit which took various times at 20°C to reach the minimally ripe stage, after storage at 6°C for 7 days. Each fruit was assessed daily for ripeness by gentle hand-squeezing. One sixth of the fruit assessed as being minimally ripe was evaluated for disorders on that day and another sixth evaluated on each of the subsequent 5 days. Data are the average incidence of disorders for fruit evaluated on all 6 days after reaching the minimally ripe stage on each of the days specified. The few fruit becoming minimally ripe outside the period 6–11 days after coolstorage have been omitted. (1994 data.)

not sufficiently frequent. This, along with variability in the inherent level of disorders in individual fruit from the same harvest, and the increase in fruit disorders the longer the fruit take to ripen, makes precise assessment of fruit disorders difficult.

These trials have confirmed that, if New Zealand 'Hass' avocado fruit are to be ripened at 20°C, 4–6°C is the appropriate temperature for storing fruit. Some specific symptoms of chilling injury—black lesions on the skin and grey-black discoloration of the flesh—were observed in fruit after storage at 0 or 2°C in one season. The increase in rot development which was observed may also have been a consequence of storage at too low a temperature. We also have confirmed that, for fruit stored at 6°C, fruit quality was improved if fruit were ripened at temperatures c. 15–18°C. However, unless dedicated commercial ripening facilities are available for this purpose, fruit are likely to be ripened at ambient temperatures in the wholesale or retail facility or in the home. Day temperatures typically exceed 25°C in mid summer in Australia, which is New Zealand's major export market. When fruit were ripened at these high temperatures, better final quality was obtained if the fruit were not coolstored at all following harvest.

It appears as though a large difference between storage and ripening temperatures results in damage to the fruit, and hence more disorders. If fruit are stored at temperatures close to the ripening temperature they may be somewhat "pre-conditioned" to the high temperatures. For this reason, Australian fruit, which are grown under higher ambient temperature conditions, are likely to be physiologically different from New Zealand fruit, allowing them to ripen normally at temperatures up to 30°C. Present recommendations are to coolstore fruit whenever possible, both to extend marketing life and to maintain quality. However, frequent access to the marketplace, and a shelf life for non-cooled fruit of c. 14 days, may mean that coolstorage for New Zealand avocado fruit is unnecessary, or even undesirable. Evaluation of this suggestion in a commercial scale trial is currently in progress.

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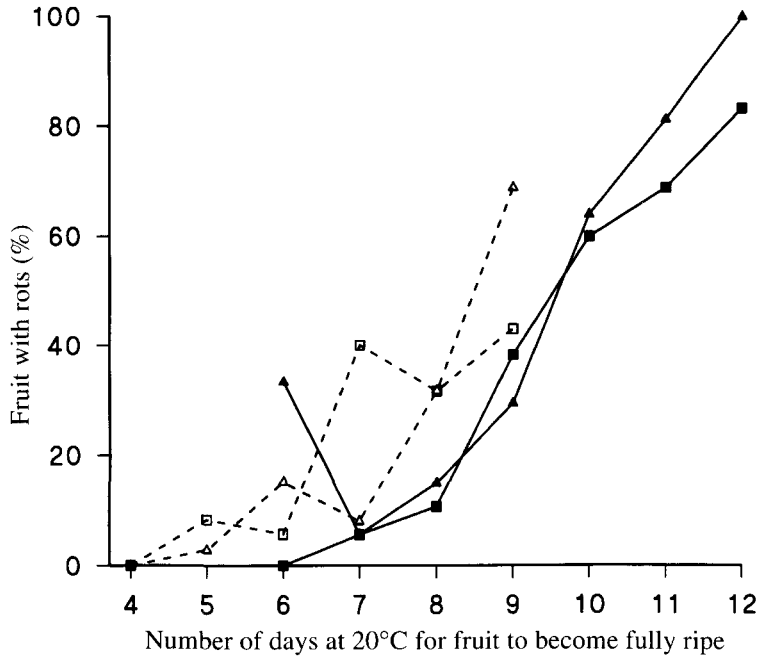

Fig. 3 Incidence of stem end rot (■, □) and body rot (▲, △) in avocado fruit harvested either early (■, ▲) or late (□, △) in the season (1992), stored at 6°C for 7 days and then ripened at 20°C. Each fruit was assessed daily for ripeness by gentle hand-squeezing and evaluated for rots when fully ripe.

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