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Maturity and postharvest temperature management affect rot expression in 'Hort16A' kiwifruit

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ABSTRACT

Rots that developed in 'Hort16A' kiwifruit during storage and shelf assessment were quantified and identified from fruit harvested at different maturities. Research was conducted over two seasons, with the second season's research being extended to include temperature management regimes designed to affect chilling damage. The incidence of rots in 'Hort16A' kiwifruit after storage was strongly influenced by both fruit maturity and temperature management. The higher rot incidence in less mature fruit seen in the first season was confirmed and extended in the second season to associate the prevalence of rots with fruit which had some form of physiological chilling injury. Temperature management that exacerbated the expression of chilling damage, a short delay before cooling, rapid cooling and storage at lower temperatures, resulted in a higher incidence of rots on chill damaged fruit. These findings indicate the importance of a holistic approach to understanding rot expression in storage. Not only is the inoculum source or load at harvest significant but also the physiological state of the fruit, which can influence the timing and species of fungi that ultimately grow on the fruit. That physiological state of the fruit may include the presence of physiological disorders as well as the ripeness of the fruit.

1. Introduction

The occurrence of rots during storage is a risk for all fresh produce, particularly when stored for prolonged periods. *Actinidia chinensis* Planch. var. *chinensis* 'Hort16A' kiwifruit is no exception, and the risk of ripe rots in the fruit may increase as storage time is increased and fruit are closer to full ripeness in the storage environment. The presence of rotten fruit in commercial consignments downgrades the packed fruit, reduces the amount of fruit to be sold and may necessitate repacking, discounting or dumping of the fruit. Specific rots may also cause phytosanitary problems, depending on the importing country.

The rot symptoms on 'Hort16A' fruit are frequently categorised initially by the position at which they occur on the fruit: at the stylar end of the fruit, commonly termed blossom-end rot (BER); on the main body of the fruit, termed body rot (BR, which includes a specific category of fungal pitting); and at the picking scar, termed stem-end rot (SER). Blossom-end rots may be the result of fungal contamination of remnant flower parts or the small cavity within the 'beak' at the stylar end of the fruit. The fungi that cause body rots may gain entry through lenticels or minute skin damage and they may be the result of infections on the skin established at any time during the growing season. Fungal pitting is caused by the fungal pathogen *Cryptosporiopsis actinidiae*, which results in very characteristic small, sunken lesions, usually expressing once fruit are ripe (Johnston et al., 2004). *C. actinidiae* infects fruit during flowering then survives endophytically while the fruit completes its growth (Fullerton et al., 2007). The fungi that cause stem-end rots tend to establish in the picking scar immediately after harvest. Stem-end rots in 'Hayward' fruit caused by *Botrytis cinerea* can be managed by both minimising the inoculum load in the vine canopy (Manning et al., 2010) and also through a process termed curing, in which fruit cooling is delayed prior to storage (Lallu, 1997; Pennycook and Manning, 1992). In addition to these rots, which are normally presumed to be the result of an aggressive pathogen invading the fruit tissues, there are also wound rots caused by a wide range of saprophytic fungi which can colonise fruit tissues exposed by physical damage or compromised by physiological disorder.

The main fungi commonly associated with rots on 'Hort16A' kiwifruit during storage include *Phomopsis* sp., *Cryptosporiopsis actinidiae*,*Botryosphaeria* sp., *Botrytis cinerea*, *Cylindrocarpon* sp. and *Phoma exigua*(Manning et al., 2003). While some rots tend to be present at similar incidences of severity levels irrespective of

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season (e.g. *Phomopsis* sp., *Cryptosporiopsis* sp., and *Cylindrocarpon* sp.), others vary significantly season to season. One such is *Botryosphaeria dothidea* which can cause significant numbers of pre-harvest and coolstorage rots in some years. This is indicative of the seasonal nature of this pathogen, which has been described for its interaction with 'Hayward' (Pennycook 1985) and 'Hort16A' (Manning et al., 2003) kiwifruit.

Management of rots in storage is made easier by knowing the identity of the fungus and when its symptoms become apparent. A good example is SER in 'Hayward', which can be minimised through both on-orchard and postharvest handling practices (Manning et al., 2010). Also, SER in 'Hayward' kiwifruit are largely expressed in the first 12 weeks of storage and therefore, if removed before this time, there should be no further SER expressed thereafter (Manning et al., 1995). Unfortunately, whilst being able to remove the rotten fruit, a side effect of the rots is the production of ethylene, which tends to soften the surrounding sound fruit (Pennycook 1985; Feng et al., 2003). The expression of rots during storage may also be influenced by the maturity of the fruit at harvest, as this affects the pattern of softening (MacRae and Redgwell, 1992) and thus possibly affects the incidence and timing of expression of specific rots.

In this paper, two seasons of data investigating the relationship between fruit maturity at harvest and rot expression in stored 'Hort16A' kiwifruit are presented. In the first season, fruit from five orchards harvested on four occasions were stored at a single temperature. The time course of rot expression was determined, and rot incidence was found to be associated with harvest maturity. Pathogens from the BER, BR and SER rot categories were identified. Rot incidence was strongly associated with maturity, to such an extent that it was suspected to be associated with chilling injury. Hence, in the second year, the expression of rots in fruit harvested from 20 orchards harvested on three occasions were investigated by applying temperature management treatments (delay before cooling, cooling rate and storage temperature) that would be expected to affect chilling expression.

2. Methods

2.1. Fruit

2.1.1. Season 1

Fruit were harvested from five orchards in the Bay of Plenty region between 19 April and 24 May, 2000. Each orchard was harvested on four occasions (designated H1–H4), spanning a range of development before, at and after commercial harvest. The timing of commercial harvest is largely based on fruit having degreened, with a flesh colour of ~103 °h or less. At each harvest, 92 fruit were randomly collected from each of 10 vines on each orchard (a total of 900 fruit for storage and 20 fruit for at-harvest fruit characterisation). Fruit were sampled from the same vines at each harvest date. Fruit were harvested into picking bags and placed into 30 count single-layer trays with plastic pocket packs and polythene liner in the orchard.

2.1.2. Season 2

Fruit were harvested from 20 orchards in the Bay of Plenty region between 6 May and 4 June, 2001. Each orchard was harvested on three occasions (designated H1–H3), which were equivalent to early, mid or late commercial harvests. Fruit were harvested directly into 25 count single-layer trays with plastic pocket packs and polythene liners which were left open until the packs were placed into cooling. An additional 60 fruit from each of the 20 orchards at each of the three harvests were taken for at-harvest fruit characterisation, the remaining 40 trays of fruit (1000 fruit in total) were left under cover at ambient conditions.

In both seasons, for the at-harvest characterisation, individual fruit were assessed for firmness, flesh colour and soluble solids concentration.

2.2. Treatments

2.2.1. Season 1

After approximately 24 h under cover at ambient conditions, the packed trays were transferred into storage at 0 °C for 20 weeks.

2.2.2. Season 2

The 40 trays per orchard/harvest were allocated randomly to one of two periods of delay prior to cooling, which was at one of two cooling rates. The nominal delay periods after harvest prior to cooling were: 24 h and 96 h. The delay period was at ambient conditions under cover. The fast and slow cooling rates had half-cooling times of: 2–6 h and approximately 30 h. For each cooling rate, fruit temperatures were reduced to approximately 2 °C after which the fruit were transferred to one of five storage temperatures (−1.5, −0.5, 0.0, 0.5 or 1.5 °C) for up to 24 weeks.

2.3. Assessments

Periodically during storage (6, 10, 15 and 20 weeks in Season 1 and 8, 12, 16, 20 and 24 weeks in Season 2) the incidence of rots was determined. Rotten fruit were removed from the trays for pathogen identification. Also, in Season 2, after 24 weeks of storage, all remaining fruit were moved to 20 °C and assessed for rots after 3, 7 and 10 days.

2.4. Rot assessment

At each assessment, rots were segregated into three categories by position on the fruit:

Blossom-end rots (BER): first detected by softness and collapse of the beak at the stylar end ('blossom end') of the fruit.

Stem-end rots (SER): soft rot centred on the picking scar at the stem-end.

Body rots (BR): usually soft rots on the body of the fruit, anywhere between the stylar-end and the stem-end of fruit.

As fruit with rots were removed from the trial as soon as a rot was visible, there was little opportunity for multiple rots to form on individual fruit.

In Season 2, all rots on fruit that appeared to have a physiological low-temperature disorder, either by external (skin discoloration) or internal (granularity or water soaking of the pericarp) symptoms, were recorded as a 4th category of 'rot on chill damaged'.

For the rotten fruit removed during assessments, the causal agents of each rot category were determined (the isolation method is described in Manning et al., 2003). In early assessments, this was done for all rotten fruit, but as rot numbers increased, only representative samples were taken from some categories.

2.5. Fruit assessment at harvest

Firmness was measured on two sides of the fruit at 90° to each other at the "equator" using a hand-held Effegi penetrometer (7.9 mm head) following the removal of the fruit skin and flesh to a depth of approximately 1 mm. Firmness (kgf; 1 kgf = 9.821 N) values were averaged for individual fruit.

Flesh colour was measured on two sides of the fruit at 90° to each other at the equator using a Minolta CR300Chroma Meter (D_{65} light source) following the removal of the fruit skin and flesh to a depth of approximately 2 mm. Lightness, chroma and hue angle values were averaged for individual fruit.