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Shrivel development in kiwifruit

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ABSTRACT

Shrivel is a potential storage quality problem for kiwifruit. 'Zesy003' (commonly called Gold9) is a newly released, yellow-fleshed *Actinidia chinensis* cultivar that tends to shrivel more than other commercialised cultivars. Water loss and shrivel in Gold9 fruit were investigated during storage at 1 °C for up to 14 weeks and shelf-life at 20 °C. In addition, the water status of ripe fruit was quantified by magnetic resonance imaging and the capacity of a crude outer pericarp cell wall extract to swell. Shrivelled Gold9 fruit had 1–6% weight loss, although 6% weight loss did not always result in shrivel. Three weeks of storage resulted in fruit taking longer to shrivel during shelf-life, with a concomitant higher weight loss by the time the fruit was shrivelled. In contrast, 14 weeks of storage resulted in fruit that shrivelled more rapidly in shelf-life at a lower weight loss. At any given time after harvest, fruit with more severe shrivel tended to be softer than less shrivelled fruit. Shrivel therefore appears associated with fruit softening. Outer pericarp tissue from ripe Gold9 fruit had lower water mobility and a greater capacity to swell than pericarp from other kiwifruit cultivars. It is concluded that shrivel is not determined simply by an absolute amount of water loss. The development and ease of expression of shrivel in Gold9, and possibly other kiwifruit, is influenced by softening and the water characteristics of the fruit outer pericarp when soft.

1. Introduction

Shrivel is a potential storage quality problem for kiwifruit, particularly when fruit are stored for several months. Generally, kiwifruit are regarded as being at risk of shrivelling when 4–5% of the weight at harvest has been lost during storage (Burdon and Lallu, 2011). Commercially, water loss is commonly managed by storing fruit in packs with polyliners or bags to create a high humidity environment around the fruit.

'Zesy003' (commonly called Gold9) is a newly released, yellow-fleshed *Actinidia chinensis* cultivar (Anon, 2010). Initial observations are that under New Zealand conditions, Gold9 are late maturing fruit with a medium capacity for storage (Lallu et al., 2011). However, the fruit has a propensity to shrivel (Boyd et al., 2011; Hernandez et al., 2012), largely during shelf-life after storage (Lallu et al., 2011).

When stored in packs with polybags, the weight loss of Gold9 fruit is similar to that of *A. chinensis* 'Hort16A' kiwifruit, although out of the pack, there is a more rapid weight loss during shelf-life (Lallu et al., 2011). The skin permeance of kiwifruit, including Gold9, decreases during fruit development (Celano et al., 2009; Boyd et al., 2011). However, at harvest, the skin permeance of Gold9 fruit is higher than for other kiwifruit cultivars, including 'Hort16A' and *A. deliciosa* 'Hayward' (Boyd et al., 2011). This at-harvest difference has led to a focus on determining the cause of higher skin permeance to explain the greater propensity for Gold9 fruit to shrivel (Hernandez et al., 2012; Minchin et al., 2013). This line of research has resulted in the conclusions that 'Gold9 fruit shrivel because their skin has a high permeance to water vapour movement' and 'Fruit show shrivel when about 5% of their fresh weight has been lost' (Minchin et al., 2013).

Observations of Gold9 fruit in 2011 suggest there is more to the development of shrivel than simply a higher skin permeance; the incidence of shrivel is not tightly associated with the degree of weight loss of fruit, as shrivel has occurred even when weight loss was well below 5% (Lallu et al., 2011).

While water loss is a necessary element in establishing the conditions under which a fruit may shrivel, it is not the only factor in determining when shrivel occurs. The loss of water only becomes a problem when the hydration state of the fruit tissue under the skin cannot be maintained by re-distribution of water within the fruit. In addition, for shrivel to develop, the fruit skin and tissues just under the skin must be capable of deforming. Hence shrivel occurs under circumstances where dehydration occurs as water lost from the surface of the fruit is not replaced and the tissue contracts.

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The objective of this study was to explain the propensity of Gold9 fruit to shrivel in physiological terms beyond skin permeance, and in so doing, to better understand the physiological basis for shrivel in kiwifruit in general. Findings for kiwifruit may also be applicable to other fresh produce where shrivel may be a commercial problem. Gold9 fruit were stored for either three or 14 weeks and the relationship between weight loss, firmness and shrivel quantified both immediately out of storage and also after periods at 20 °C. In addition, after 3–4 months of storage, the water status of ripe Gold9 fruit was compared with that of fruit of 'Hort16A' and 'Zesy002' (another newly released yellow-fleshed *A. chinensis* cultivar, commonly called Gold3) fruit through magnetic resonance imaging (MRI) quantification of tissue water mobility and an *in vitro* assay of outer pericarp cell wall swelling potential.

2. Methods and materials

2.1. Fruit

Gold9 fruit from a single orchard were harvested on 7 May 2012 at commercial maturity when flesh colour had de-greened. At this time, fruit soluble solids content (SSC) was 14.6%, flesh firmness 57.9 N, flesh colour 100.8 °h and dry matter (DM) 19.3%. All Gold9 fruit going into storage were weighed and numbered individually on the day of harvest.

Gold3 fruit from a single orchard were harvested on 26 April 2012 at commercial maturity when flesh colour had de-greened. At this time, fruit SSC was 10.0%, flesh firmness 62.8 N, flesh colour 103.1 °h and DM 17.2%.

'Hort16A' fruit from a single orchard were harvested on 18 May 2012 at commercial maturity when flesh colour had de-greened. At this time, fruit SSC was13.9%, flesh firmness 48.1 N, flesh colour 103.2 °h and DM 18.3%.

The at-harvest characteristics of each cultivar were determined on a 30-fruit sample of fruit assessed individually for flesh colour, SSC, firmness and DM. All fruit were stored in fibreboard bulk packs (about 50 fruit per pack) with polybags (18 μm HDPE bag with 8 mm × 6 mm diameter holes) in a coolstore at 1 °C.

2.2. Assessments

Storage and shelf-life. Gold9 fruit were assessed after three and 14 weeks of storage, both immediately out of storage and after holding at shelf-life (20 °C). On removal from storage, all fruit were weighed, scored for shrivel and 10 fruit per pack (four packs) were measured for firmness. The remaining 40 fruit per pack were placed into single layer trays without liners at 20 °C. These fruit were held at 20 °C until approximately 75% of the fruit had shrivelled, 10 d after 3 weeks of storage and 4 d after 14 weeks, at which time shrivel severity, fruit weight loss and firmness were assessed.

Water status. After 12–16 weeks of storage, five ripe fruit each of shrivelled Gold9 and non-shrivelled Gold9, Gold3 and 'Hort16A' were used for an MRI study. The Gold9 fruit were taken from the 'Storage and Shelf-life' study described above, with the shrivelled fruit having moderate to severe shrivel. All fruit in the MRI study were at or just below 10 N firmness (shrivelled Gold9 7.8 N, non-shrivelled Gold9 8.8 N, Gold3 10.8 N and 'Hort16A' 8.8 N). A separate sample of six fruit per cultivar was used for the *in vitro* outer pericarp cell wall swelling assay; these fruit were matched at a firmness of 7.8 N.

2.3. Assessment methods

Weight loss. Weight loss was calculated as the percentage of the initial at-harvest weight that had been lost. No attempt was made to determine components of weight loss, *i.e.*, water or carbon from respiration.

Firmness. Fruit firmness was measured using a Fruit Texture Analyser (Güss, model GS14, South Africa) fitted with a 7.9-mm Effegi™ penetrometer probe after removal of skin and flesh to a depth of approximately 1 mm. The probe was driven into the flesh at 5 mm/s to a depth of 7.9 mm, and the maximum force recorded as the firmness value. Firmness was measured twice at the equator of each fruit, with the two measurements taken at 90° to each other, and data are presented in Newtons (N).

Flesh colour. Flesh colour (°hue) was measured using a Minolta CR300 Chroma Meter after removal of skin and flesh to a depth of approximately 2 mm. Flesh colour was measured twice at the equator of each fruit, with two measurements taken at 90° to each other.

Soluble solids content. At harvest, SSC was determined separately for the stylar and stem ends of the fruit, and averaged using a hand-held refractometer (Master Series, 0–30%, Atago). After ripening, juice was measured using a digital refractometer ("Pocket" PAL-1, 0–50%, Atago).

Water content or dry matter. The DM of fruit at harvest was determined by drying a 2-mm transverse slice of the fruit at 65 °C for approximately 24 h. Water content of excised pieces of outer pericarp (OP), inner pericarp (IP) and core (C) tissue was determined by drying under the same conditions.

Magnetic resonance imaging. MRI images were taken with a Siemens 3T Magnetom Verio. T1 (spin–lattice relaxation), T2 (spin–spin relaxation) and PD (proton spin density) values were taken from transverse images from the middle of the fruit for the OP just under the skin, IP, and core of each fruit, using the Siemens software.

Cell wall swelling. *In vitro* cell wall swelling of OP tissues for Gold9, Gold3 and 'Hort16A' fruit was determined in triplicate on a bulk sample of tissue from six non-shrivelled fruit for each cultivar based on the method of Redgwell et al. (1997). As the fruit were ripe, there was no need to include a DMSO step to solubilise and remove starch. Outer pericarp tissue from six fruit, about 5 g per fruit, was combined, homogenised in 80% ethanol, centrifuged, the ethanol removed and the alcohol-insoluble solids (AIS) washed a further two times with 80% ethanol, freeze dried and held over P_2O_5. The swelling capacity of the AIS was determined by rehydrating 10 mg of AIS in 5 mL deionised water with 30 μL of 1% toluidine blue to stain the AIS. The swelling capacity was calculated as the volume of swollen tissue per mg of dry AIS.

Shrivel. Symptoms of shrivel were assessed visually with the naked eye and categorised as: None – no sign of skin deformation; Slight – <1 cm^2; Moderate – from 1 cm^2 to a quarter of the fruit surface affected, and Severe – more than quarter of the fruit surface affected.

Data analysis. Statistical significance of the differences in weight loss and firmness of fruit in different shrivel categories was quantified by analysis of variance (ANOVA), using GenStat Release 14.2 [(PC/Windows XP) Copyright 2011, VSN International Ltd].

3. Results

3.1. Storage and shelf-life

After 3 weeks of storage, the weight loss of Gold9 kiwifruit was ~0.5%, firmness 12.8 N, and there was no shrivel. Ten days at 20 °C resulted in an increased weight loss, softening and occurrence of shrivel in about 73% of the fruit (Table 1). There was no difference in weight loss between fruit that had None, Slight and Moderate shrivel symptoms (5.6–5.8%), but there was a higher weight loss (6.3%) in the fruit with Severe symptoms. Fruit with shrivel were