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Storage performance of two 'Pink Lady®' clones differs, but 1-MCP treatment is beneficial, regardless of maturity at harvest

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ABSTRACT

Determining optimal apple harvest time is important for effective postharvest treatments and also for maintenance of quality along the supply chain. A non-destructive instrument, the DA meter, was used to measure changes in absorbance near the upper chlorophyll-*a* absorption peak and to segregate commercially harvested fruit into two ripeness levels. DA meter readings were made at harvest and following cold (regular air) storage removals for two 'Pink Lady®' clones, 'Cripps Pink' and 'Rosy Glow'. In addition, the destructive maturity and/or quality indicators of starch pattern index, fruit firmness, and soluble solids were determined and ethylene and CO_2 production were monitored at harvest and at each removal, i.e. every 1.5 months for 7.5 months, and during a 14 d simulated shelf life per removal. The DA meter readings were a reliable non-destructive technology for determining ripeness levels throughout storage. Ethylene production patterns were similar up to 4.5 months of cold storage for the two cultivars, 'Cripps Pink' and 'Rosy Glow', but the rate was approximately double in 'Rosy Glow'. Treatment with 1-methylcyclopropene (1-MCP) was effective at inhibiting ethylene evolution during cold storage and simulated shelf life, regardless of harvest maturity in both cultivars. However, this benefit only lasted until 4.5 months of cold storage for 'Rosy Glow', when ethylene production increased markedly after 7 d of simulated shelf life. The storage disorders, superficial scald and internal browning were more evident in 'Rosy Glow' fruit than in 'Cripps Pink', particularly after 6 months of cold storage. It is recommended that 'Cripps Pink' and its clone, 'Rosy Glow', be kept separately in storage and that 'Rosy Glow' not be stored for as long as 'Cripps Pink'. Alternatively, the efficacy of additional 1-MCP treatments after 4 months of cold storage could be explored in 'Rosy Glow' to maintain reduced ethylene production during longer storage.

1. Introduction

Determining apple maturity pre-harvest is important for the long-term storage of apples. Correct maturity at harvest results in apples that are less likely to be prone to storage disorders (Ferguson et al., 1999), ensuring better quality for the consumer. Elucidating the factors controlling storage disorders is complex because of the varied influences of, *inter alia*, temperature (pre- and post-harvest), nutrition, maturity and the storage balance of O_2 and CO_2 atmospheres. Common storage disorders include superficial scald and internal browning, both of which only become evident after some months in storage and once the apples are returned to room temperature (Watkins et al., 1995; Whitaker and Saftner, 2000). Knowledge of correct harvest maturity is also important because growers may need to know whether to continue to store a group of apples, or to prioritise their sale.

Despite several tests being used commercially to determine maturity at harvest (e.g. fruit firmness, starch-iodine test, total soluble solids), frequently there is variability of maturity within a pick and also different apple maturities within bunches of apples on the tree. This occurs, despite an apparent readiness to harvest using traditional indicators such as days after flowering, or the starch iodine conversion test devised by Smith et al. (1979). In recent years, a non-invasive indicator of harvest maturity/ripeness has been developed and tested on several apple cultivars in Europe and Canada (DeLong et al., 2014; Farneti et al., 2015; DeLong et al., 2016). The non-invasive test measures the change in absorbance of two wavelengths (670 and 720 nm) near the upper chlorophyll-*a* absorption peak (DeLong et al., 2014) in the outer mesocarp as an indicator of ripening fruit. This is known as the Index of Difference in Absorbance, I_{AD}, and is measured with a DA meter (Ziosi et al., 2008). Chlorophyll content decreases during maturity (Knee, 1972) and the DA meter readings record declining chlorophyll levels as the fruit matures (DeLong et al., 2014), showing a

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highly significant ($P < 0.001$) positive relationship ($r^2 = 0.82$) with chlorophyll concentration (DeLong et al., 2016). Nevertheless, it appears that accurate measurement and correlation of the DA meter with traditional maturity indicators is related to the particular environment in which the apples are grown because of local influences in chlorophyll catabolism and anabolism and genomic differences (DeLong et al., 2014).

As a climacteric fruit, the arrest of ethylene production in apples (and other horticultural commodities) via the use of 1-methylcyclopropene (1-MCP) has been well-documented since its first commercial trial in 2002 (AgroFresh, 2015). In addition to its ethylene receptor-binding properties, 1-MCP also delays or prevents the storage disorder, superficial scald, on apples (Fan et al., 1999; Watkins et al., 2000). This is particularly important given the recent reduced acceptance of diphenylamine (DPA) in many European Union countries. DPA has been used to control superficial scald for over 40 years (Calvo and Kupferman, 2012). However, to reduce effectively the incidence of superficial scald, and for 1-MCP to be most effective, fruit need to be at a suitable stage of maturity (Whitaker et al., 1997; Jung and Watkins, 2008). Thus, the correct harvest date, correlated with ethylene production indicators, is an important factor in the effective control of superficial scald.

The apple cultivar, 'Cripps Pink', the result of a Western Australian breeding program by J.E.L. Cripps in the 1970s, was released commercially in 1986 (Cripps et al., 1993). It is Australia's most produced and popular apple (ABS, 2014), where it is known and mostly marketed under its trademark, 'Pink Lady®'. A 'Pink Lady®' apple requires at least 40% pink colouration to be marketed as 'Pink Lady®', and > 50% pink-light red colour to be sold to one of Australia's major supermarkets (Woolworths Supermarkets, 2015).

A limb sport of 'Cripps Pink' was found in South Australia in 1996, noticed because of its well-coloured apples, even on the shaded side of the tree (Mason and Mason, 2002). It was patented as 'Rosy Glow' in 2002 (Mason and Mason, 2002). Despite the colour differences, both 'Cripps Pink' and its clone, 'Rosy Glow', are treated by growers as the same and are both allowed to be marketed under the 'Pink Lady®' brand. The early red colouring of 'Rosy Glow' ensures that it matures earlier than 'Cripps Pink', allowing for optimum commercial quality at harvest and therefore improved storage (Mason and Mason, 2002). These positive characteristics of 'Rosy Glow' have resulted in its production world-wide for at least 10 years, with further expansion planned (Wheat, 2015). 'Rosy Glow' and other highly-coloured sports of 'Cripps Pink' such as, for example, 'Lady in Red', 'Pink Belle' and 'Maslin', are marketed under the Pink Lady® brand because of an already-crowded cultivar marketplace and the established reputation of the Pink Lady® trademark (Warner, 2012). In 2015, the United States expanded the Pink Lady® trademark to include 'Rosy Glow', enabling the umbrella Pink Lady® product to be available up to two months earlier to consumers (Hornick, 2015).

Despite the marketing and genetic similarities between 'Cripps Pink' and 'Rosy Glow', the question is whether the two apple clones behave differently in storage. If they do, then there could be implications for how long growers store both clones. If one clone does not store as well as the other, then market repercussions and loss of consumer confidence may occur if both clones are treated as the same. A large amount of marketing has been put into the 'Pink Lady®' brand worldwide over many years, so it is important to ensure quality and consistency of the Pink Lady® product throughout storage.

By using a non-invasive maturity index meter (DA meter), we aimed to determine whether the DA meter was a good surrogate for traditional destructive maturity determination of two apple cultivars under Australian (Victorian) conditions. We tested two apple cultivars, 'Cripps Pink' and its clone, 'Rosy Glow', to determine whether ethylene production and storage quality were similar for both cultivars at two different levels of harvest maturity and 1-MCP treatment.

Table 1
Maturity/ripeness classes at harvest for 'Cripps Pink' and 'Rosy Glow' apples, based on I_{AD} readings of Farneti et al. (2015).

Cultivar	I_{AD} value range classes	
	Immature	Mature
'Cripps Pink'	1.2–0.8	0.7–0.5
'Rosy Glow'	1.4–1.0	0.9–0.6

2. Materials and methods

2.1. Plant material

In April 2015, two late-maturing apple cultivars, 'Cripps Pink' and its clone, 'Rosy Glow', were sourced from a commercial apple orchard located 77 km E of Melbourne, Australia (Three Bridges, Yarra Valley, Victoria). The cultivars were grafted onto M9 rootstocks and grown in a Güttinger V trellis system. Fruit were harvested commercially by the grower at the usual commercial harvest time. The fruit were selected from the first pick and held at ambient temperature overnight.

2.2. Maturity assessment

Within 24 h of harvest, a total of 960 fruit for each cultivar was randomly selected from bins of apples that had been commercially harvested. The fruit were sorted into two maturity/ripeness classes on the basis of the I_{AD} value (Farneti et al., 2015) (Table 1), using a DA meter (Model 53500, TR Turoni, Forli, Italy). The DA meter is a hand-held device that readily allows for repeated, non-destructive measurements of fruit chlorophyll-*a* content both in the field and in storage facilities. The I_{AD} is an index of fruit maturity that allows for the segregation of fruit based on their physiological state by correlating the I_{AD} readings with fruit ethylene production. Climacteric fruit with similar ethylene production behaviour can be pooled in similar classes of maturity (Ziosi et al., 2008). I_{AD} readings were taken on two opposite equatorial sides of the fruit, blushed and unblushed. The values of the two I_{AD} readings were averaged as a single reading (Farneti et al., 2015).

The I_{AD} maturity classes were based on similar work conducted by de Castro et al. (2007) for 'Cripps Pink'. I_{AD} values were also measured on individual fruit upon removal from cold (regular air) storage, i.e. every six weeks for 30 weeks. In addition, I_{AD} was recorded four times at regular intervals during simulated shelf life at ambient temperature (20 °C) after each removal from cold storage.

2.3. Treatment and storage conditions

Within the two I_{AD} value classes, Mature and Immature (see Table 1), half the fruit were treated with the anti-ethylene treatment, SmartFresh™ (1-methylcyclopropene, 1-MCP = Treated); the other half remained untreated (control = Untreated). 1-MCP was applied and checked by the SmartFresh™ operator under commercial conditions (6.1 g SmartFresh™ powder/100 m^3 room volume, exposed for 24 h at 1 °C; apple internal temperature 5 °C) within 4 d of fruit selection. Fruit were then transferred to cold (regular air) storage (at the grower facilities) and remained stored commercially at 1 °C for up to 30 weeks (7.5 months). No motorised forklifts were used on the premises; instead electric forklifts were used.

2.4. Atmosphere analyses

After each removal from cold storage, and at specified days during simulated shelf life, five fruit from each treatment per cultivar were selected for atmosphere analysis using a static production system (Pre-Aymard et al., 2003; Tsantili et al., 2010). Individual fruit were