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Minimum exposure period for dynamic controlled atmospheres to control superficial scald in 'Granny Smith' apples for long distance supply chains

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ABSTRACT

This study was conducted to investigate the potential of dynamic controlled atmospheres (DCA) to control superficial scald in pre-optimally and optimally harvested 'Granny Smith' apples over two growing seasons. The critical minimum period for DCA to control superficial scald was also investigated. Fruit were stored in DCA at 0 °C for 5 d up to 20 w followed by 6 or 10 w simulated handling temperature (−0.5 °C) for long distant supply chains plus 7 d at 20 °C. The scald potential for each storage duration in each season was assessed by storing fruit in air as the control treatment. To determine critical minimum storage period, simulated shipping of fruit in air for extended period of 10 w was used. Superficial scald incidence and fruit quality parameters such as total soluble solids (TSS), titratable acidity (TA), fruit firmness and ground colour were measured. The evolution of metabolites (α-farnesene, 6-methyl-5-hepten-2-one (MHO) and ethylene) associated with scald development were also monitored. The results showed that DCA controlled superficial scald in pre-optimally and optimally harvested fruit in both growing seasons. Results on the minimum exposure period were highly inconsistent over the two season, however, it was found that exposing DCA treated fruit to 10 w shipment period increases the risk of superficial scald development. All DCA treated fruit, regardless of the exposure period, can withstand only 6 w shipment period. For all the storage regimes, DCA stored fruit appeared to have a higher ground colour and fruit firmness compared to air stored fruit. All DCA stored fruit had lower concentrations of ethylene, α-farnesene and MHO. The Pearson's correlation showed a strong relationship among scald associated metabolites. Correlation coefficient for α-farnesene and MHO of fruit stored in air and DCA were 0.831 and 0.822, respectively, while those for scald incidence and MHO were 0.863 and 0.365 in air and DCA, respectively.

1. Introduction

Superficial scald is a major postharvest physiological disorder reducing the quality of 'Granny Smith' apples (Malus x domestic Borkh.). Susceptibility of fruit to superficial scald varies among cultivars. Cultivars such as 'White Angel', 'Idared', 'Gala', 'Émpire' and 'Golden Delicious' are scald resistant whilst superficial scald is more prevalent on 'Rome Beauty', 'Law Rome', 'Cortland', 'McIntosh' and 'Granny Smith' (Fernández-Trujillo et al., 2003; Rao et al., 1998). Despite this knowledge, biotechnology research has thus far been unsuccessful in developing scald resistant 'Granny Smith' apple which has high market value due to its desirable organoleptic properties. As a result, the apple industry heavily relies on chemical treatments for controlling scald.

Fruit maturity plays an important role in postharvest storage potential, flavour development and scald susceptibility (Echeverría

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et al., 2004). Generally, scald susceptibility declines with advancing maturity (Lurie and Watkins, 2012; Wang and Dilley, 1999). Previous experimental research has demonstrated that scald severity has inverse relationship with maturity (Meir and Bramlage, 1988). However, it is not always possible to harvest at optimal maturity due to labour shortage and poor fruit quality associated with delayed harvest. As a result, apples are normally harvested at both pre-optimal and optimal maturities. To maintain quality and control scald, chemical treatments such as diphenylamine (DPA) and 1-methylcyclopropene (1-MCP) are used (Mattheis, 2008; Jung and Watkins, 2008; Sabban-Amin et al., 2011; Lurie and Watkins, 2012). However, the use of chemical treatments at postharvest is becoming unpopular. In fact, lucrative international markets reject the use of chemical treatments on food due to health concerns.

Although a considerable amount of research has been conducted, the mechanism of scald development in apples is not completely understood. There are physiological changes preceding superficial scald development. The accumulation of ethylene and α-farnesene on apple peel (cuticle, epidermis, and hypodermis) during cold storage combined with α-farnesene oxidation to conjugated trienols (CTols) and 6-methyl-5-hepten-2-one (MHO) has been linked to scald incidence (Mir et al., 1999; Isidoro and Almeida, 2006). The relationship between ethylene synthesis and α-farnesene accumulation during cold storage is well researched (Ju and Curry, 2000a; Whitaker, 2000; Lurie and Watkins, 2012). Lower α-farnesene accumulation and reduced superficial scald development has been reported following the application of ethylene inhibitors such as 1-MCP (Zanella, 2003). Lourens and Malherbe (1997) found α-farnesene as an important biomarker for predicting superficial in 'Granny Smith' apples. In an extensive literature review, Ingle (2001) reported that apple cultivars susceptible to scald contain high α-farnesene content compared to resistant cultivars. Scald symptoms are closely linked to MHO, the end-product of α-farnesene oxidation. For instance, high MHO accumulation after removal of fruit from cold storage coincided with scald symptoms in 'Cortland' (Mir et al., 1999) and 'Granny Smith' apples (Wang and Dilley, 2000). Recently, Farneti et al. (2015) found a correlation between MHO and the on-set of superficial scald development. Using a new version of mass spectrometer based on proton transfer reaction (PTR-ToF-MS), Busatto et al. (2014) also found MHO accumulation to coincide with development of superficial scald symptoms.

An improved version of CA termed dynamic controlled atmosphere (DCA) has been identified as a potential method for controlling superficial scald (Zanella et al., 2005; DeLong et al., 2007). DCA technology has already been tested on different apple cultivars such as 'Gala', 'Granny Smith', 'Golden Delicious', 'Pinova', 'Idared' (Mattheis et al., 1998; Zanella et al., 2008; Gabioud et al., 2009; Tran et al., 2015; Bessemans et al., 2016). However, no DCA protocol is available for an export orientated 'Granny Smith' apple industries such as South Africa with distant markets requiring shipment period of 6 w. Currently, there is no information on whether fruit stored in DCA before shipment can be scald free. The objective of this study was to investigate the minimum exposure period for DCA to control superficial scald in 'Granny Smith' apples during an extended shipment period of 10 w. The potential of DCA to control superficial scald in pre-optimally and optimally harvested 'Granny Smith' apples was also assessed.

2. Materials and methods

2.1. Fruit source and treatments

The study was performed on pre-optimally and optimally harvested 'Granny Smith' apples during 2013 and 2014 growing seasons. Fruit free from visible external damage and blemishes were hand-picked from Valley Green Farm in Grabouw (34°12′12″S, 19°02′35″E), South Africa, at 165 and 172 days after full bloom (DAFB) (which are commonly considered in the fruit industry as pre-optimal and optimal maturity), respectively. Uniformly sized fruit with diameter of 70 ± 2 mm and mass of 160 ± 5 g were randomly divided into 3 replications of 100 fruit each. The chlorophyll fluorescence non-destructive monitoring system (HarvestWatch, Satlantic Inc, Halifax, Canada) with an ability to predict and indicate low oxygen limit (LOL) was used to determine DCA set points (Prange et al., 2003; Wright et al., 2012). In this study, the DCA was established within 48 h after harvest, using compressed air and CO_2 plus N_2 from a membrane generator (Isosep, Isolcell, Italy). Accordingly, the gas composition of the storage chamber was analysed at 90 min intervals and adjusted when necessary. Generally, the O_2 levels ranged between 0.3%–0.5% whilst CO_2 was maintained at 1% and 95% RH. The lowest O_2 set point was determined by identifying the O_2 partial pressure where an inflection in the fluorescence signal was detected, followed by increasing O_2 by 0.3% as a safety factor (Weber et al., 2015). Chlorophyll fluorescence was monitored and automatically adjusted following fluorescence signal as reported by Prange et al. (2003). Once the fluorescence signal was detected, almost 0.3% of O_2 was added to the atmosphere until fluorescence signal was reduced to its initial value (Prange et al., 2003). To simulate possible South African industry scenarios, DCA storage regimes ranged between 5 d to 20 w followed by a 6 w storage period in air (−0.5 °C, 95% RH) to simulate shipment period. Air storage was used as a control treatment.

To determine the minimum exposure period for dynamic controlled atmospheres to control superficial scald during a 10 w shipment period, another set of 3 replications of 100 fruit was used. Fruit was stored in DCA from 5 d to 20 w followed by 10 w simulated shipment period.

2.2. Assessment of fruit quality

Fruit quality was assessed at harvest and after 7 d shelf-life (20 °C and 65% RH) following each storage regime. In the 10 w trial, scald incidence was the only assessment conducted whilst all other quality, physiological and biochemical assessments were conducted on the 6 w-trial. Scald incidence was recorded as the percentage of fruit with superficial scald symptoms. Texture Analyser (Tensilon model UTM-4L, Tokyo Measuring Instruments Co., Ltd., Japan) with a 11.1 mm compression probe was used to measure fruit firmness. Operating conditions of the instrument were: pre-test speed 1.5 mm s^{-1}, 0.5 mm s^{-1} test speed, 10.0 mm s^{-1} post-test speed, and 0.20 N trigger force. On the section where the penetrometer entered, the peels were removed with a potato peeler. Two measurements on opposite sides of each fruit aligned horizontally from the stem end to the apex were taken. Fruit firmness (N) was taken as force of compression. Ground colour was assessed using Minolta Chroma Meter CR-300 (Minolta Corp, Osaka, Japan). Hue angle [°H = arctan (b*/a*)] was calculated and used to measure ground colour (Pathare et al., 2013). Total soluble solids (TSS) and titratible acidity (TA) were measured after fruit was juiced using a LiquaFresh juice extractor (Mellerware, South Africa). TA was determined using a Metrohm 862 compact titrosampler (Herisau, Switzerland), and the results were expressed as milligram per 100 mL of malic acid. TSS (°Brix) was measured using a digital refractometer (Atago, Tokyo, Japan).

2.3. Ethylene production and headspace volatile analysis

Fruit ethylene production was measured as described by Öz and Ergun (2009) with slight modifications. Individual fruit was