Postharvest Biology and Technology 113 (2016) 87–94

Contents lists available at ScienceDirect

Postharvest Biology and Technology

journal homepage: www.elsevier.com/locate/postharvbio

Quantifying the ethylene induced softening and low temperature breakdown of ‘Hayward’ kiwifruit in storage

Abdul Jabbar, Andrew R. East*

Centre for Postharvest and Refrigeration Research, Massey University, Palmerston North, New Zealand

ARTICLE INFO

Article history:
Received 15 July 2015
Received in revised form 30 September 2015
Accepted 4 November 2015
Available online 22 November 2015

Keywords:
Actinidia deliciosa
Climacteric
Firmness
Chilling injury
Storability

ABSTRACT

Kiwifruit are considered highly sensitive to exogenous ethylene during refrigerated storage (0 °C). This study aimed to quantifiably describe the effect of continuous application of exogenous ethylene (0.001, 0.01, 0.1 and 1 $\mu L L^{-1}$) in the storage environment (0 °C, 95% RH) on quality (softening and low temperature breakdown; LTB) of ‘Hayward’ kiwifruit when exposed either after harvest or after 10 weeks of storage. For both ethylene application times fruit exposed to 1 and 0.1 $\mu L L^{-1}$ ethylene exhibited significant loss of firmness compared to control (0.001 $\mu L L^{-1}$) after 2 weeks of application. Fruit exposed to 0.01 $\mu L L^{-1}$ ethylene also softened rapidly compared to control fruit (0.001 $\mu L L^{-1}$) when ethylene was applied at-harvest, but no substantial difference in softening was observed when applied after 10 weeks of storage. Most of the softening differentiation occurred in the first 4 weeks of exposure, after which the rates of softening returned to being relatively constant irrespective of the ethylene environment. Along with rapid softening, fruit exposed to 1 $\mu L L^{-1}$ ethylene were higher in incidence of LTB, irrespective of exposure timing. This study demonstrates that ethylene concentrations as low as 0.01 $\mu L L^{-1}$ can influence softening of ‘Hayward’ kiwifruit in a commercial cool storage environment. As the differentiation of treatments occurs solely in the initial period of ethylene exposure, more research is required to understand the impact of small exposure occasions, which are more likely to occur in real supply chain scenarios.

1. Introduction

Kiwifruit (‘Hayward’ *Actinidia deliciosa* (A. Chev.) C.F. Liang and A.R. Ferguson) produces autocatalytic ethylene during ripening and therefore is considered climacteric (Arpaia et al., 1994; Sfakiotakis et al., 1997; Antunes, 2007; Chiaramonti and Barboni, 2010). However, kiwifruit produces little ethylene (<0.01 nL kg^{-1} h^{-1}) at harvest (Burdon and Lallu, 2011). Kiwifruit are usually stored at 0 °C with relative humidity (RH) of 90–95% for up to 6 months (Arpaia et al., 1987; McDonald, 1990; Hewett et al., 1999; Burdon and Lallu, 2011). At low temperature (0 °C) kiwifruit has a unique climacteric behaviour, as they do not produce substantial ethylene until softening dramatically (<10–15 N) later in storage (Hewett et al., 1999; Kim et al., 1999; Ritenour et al., 1999; Feng et al., 2003; Atkinson et al., 2011).

Ensuring that no substantial ethylene accumulation occurs is essential for successful management of fruit quality (Atkinson et al., 2011). Kiwifruit are considered to be highly susceptible to small ethylene concentrations (i.e. 0.005–0.01 $\mu L L^{-1}$) in storage and may exhibit excessive softening, leading to fruit losses (Mitchell, 1990; Hewett et al., 1999; Kim, 1999; Antunes, 2007). A maximum threshold of 0.03 $\mu L L^{-1}$ ethylene is used in industry to minimise ethylene effects on premature softening (Beever and Hopkirk, 1990; Jeffery and Banks, 1996).

The vast majority of data demonstrating ripening responses of kiwifruit to ethylene exposure has been performed at ambient conditions (20 °C) and still lack the quantification of effect of previously unmeasurable low ethylene concentrations (e.g. 0.001 $\mu L L^{-1}$) in optimal storage environment (Sfakiotakis et al., 1997; Antunes et al., 2000; Antunes and Sfakiotakis, 2000, 2002; Sfakiotakis et al., 2001; Antunes, 2007; Albert et al., 2013). The exceptions to this is the work of Arpaia et al. (1986) who applied ethylene concentrations ranging from 0.05 to 5 $\mu L L^{-1}$ during controlled atmosphere (2% O_2 + 5% CO_2) storage (at 0 °C); Jeffery and Banks (1996) who applied ethylene at concentrations of 0.002–30 $\mu L L^{-1}$ at 1 °C; and Wills et al. (2001) who applied ethylene (<0.005–1 $\mu L L^{-1}$) during storage at 0 °C. However these studies are limited by the graduation in scale used to quantify the ethylene effect and the fact that ethylene exposure was initiated at the start of storage. Given that efforts are made to reduce ethylene concentrations in storage environments commercially, the only

---

* Corresponding author. Fax: +64 6 350 5657.
E-mail address: a.r.east@massey.ac.nz (A.R. East).

http://dx.doi.org/10.1016/j.postharvbio.2015.11.002

likely source of ethylene accumulation within a package is likely to occur from the fruit themselves when they reach a firmness of ≤20 N. At 0 °C, ‘Hayward’ requires (10–12 weeks) to reach ≤20 N firmness and hence start autocatalytic ethylene production (Chiaramonti and Barboni, 2010). Quantification of the effect of exogenous ethylene on kiwifruit quality, when applied later in storage at the stage of autocatalytic ethylene production is not addressed in previous studies.

In addition to premature softening, kiwifruit quality is impaired by a chilling injury referred to as low temperature breakdown (LTB). This physiological disorder is distinguished as a granular appearance of the outer pericarp, that develops into a water soaked appearance (Lallu, 1997; Burdon et al., 2007; Burdon and Lallu, 2011). LTB is the term used for the same injury symptoms referred to as storage breakdown disorder (SBD) in parts of the industry. Commercially, LTB results in discarded fruit, as the soft fruit are considered inedible (Bauchot et al., 1999). Storage temperature and cooling rate are known factors directly associated with the incidence of LTB in kiwifruit (Lallu, 1997; Yang et al., 2013; Zhao et al., 2015). A number of works have also associated the occurrence and induction of LTB with endogenous (Feng et al., 2003; Yin et al., 2009; Ma et al., 2014) and exogenous ethylene (Koutsoflini et al., 2013).

This study aimed to quantitatively describe in industry relevant storage conditions and ethylene concentration ranges, the impact of ethylene on Hayward kiwifruit quality (firmness and LTB incidence). Ethylene concentrations were established both after harvest and after 10 weeks (70 d) of optimal temperature storage to better quantify the ethylene effect on fruit quality in a commercial supply chain scenario. As a result this research provides guidelines on the influence of realistic cool chain ethylene conditions on storability of ‘Hayward’ kiwifruit.

2. Material and methods

2.1. Fruit sampling

‘Hayward’ kiwifruit from three growers located in the Bay of Plenty, New Zealand were commercially harvested on May 27th, 2014. After initial commercial grading and packing, 60 (20 × 3 growers) modular bulk packs (of count size 36 fruit) were transported to Massey University, Palmerston North, New Zealand. Fruit were not cooled prior or during transport. Upon arrival, 61 mesh or onion bags containing 30 fruit each were prepared randomly from the 20 packs per grower. Mesh bags were randomly labelled to allocate storage condition (ethylene concentration) and time of removal from the experiment (storage time).

2.2. Experiment setting

Two different timings were used to apply ethylene. To replicate previous work, ethylene was applied at the initiation of storage. Alternatively, to evaluate the exogenous ethylene effect on softening more likely to be experienced during commercial storage, ethylene concentrations were established after 10 weeks of optimal storage. This timing of application of ethylene after 10 weeks (70 d) was assumed to be the stage when fruit started autocatalytic ethylene production, as was informed by Chiaramonti and Barboni (2010).

Sixty (60) mesh bags for each grower were stored in 8 barrels (capacity 60 L) attached to a flow through gas delivery system. Of the 8 barrels, 4 contained 7 mesh bags each for the component of the experiment where ethylene conditions were established at the introduction of storage. The remaining 4 barrels contained 8 mesh bags each, that were used for when ethylene conditions were established after 70 d of storage.

Once ethylene was applied a single pre-labelled mesh bag (30 fruit) was removed from each barrel at 2 week intervals. One (1) mesh bag (30 fruit) per grower was allocated for at-harvest quality assessments.

2.2.1. Storage conditions

Four ethylene concentrations (0.001, 0.01, 0.1 and 1 $\mu L\,L^{-1}$) were established in a flow through system to supply to the barrels. In the case where ethylene was applied after 70 days of storage, all barrels were initially supplied with air (≈0.001 $\mu L\,L^{-1}$ C_2H_4). All the barrels containing fruit were stored at 0 °C in the same cool room. Relative humidity of 95% was maintained in barrels by passing the gas mix through sealed 1000 mL jars filled with glycerol (21.1%) and water (78.9%).

2.2.2. Ethylene concentrations

For the lowest ethylene concentration (≈0.001 $\mu L\,L^{-1}$), only compressed air was used, with the measured ethylene being a result of residual contamination from the environment, despite efforts to scrub the supply (with $KMnO_4$). Ethylene concentrations of 0.01, 0.1 and 1 $\mu L\,L^{-1}$ were established by mixing air (99%) with 1% of 1, 10 and 100 $\mu L\,L^{-1}$ ethylene β-standard (BOC gases, Auckland, New Zealand) concentrations respectively. A flow controlled mixer was used to mix air and standard ethylene gas. Mixed gases were later divided into channels by using a manifold to supply gas to each barrel representing each grower. A flow of 300 mL min^{-1} for each barrel was maintained by using control valves. This flow rate was designed to ensure no significant increase in ethylene concentration accumulated within the barrels as a result of ethylene production. Out flow from each barrel was attached to room ventilation to ensure removal of ethylene from the room environment. Purafil® ($KMnO_4$) was placed in the room to minimise ethylene accumulation during storage.

Photoacoustic ethylene analysing equipment (ETD-300, Sensor Sense B.V., Nijmegen) was used to enable the project to be conducted at the accuracy necessary. Each ethylene concentration was checked and maintained every 7–10 days to ensure consistent gas concentration delivery throughout the experiment. The 1 $\mu L\,L^{-1}$, concentration remained within ±2.9% during the experiment (Fig. 1). Likewise, concentrations of 0.1 and 0.01 $\mu L\,L^{-1}$ were also maintained consistently (±8.7% and ±17.2%, respectively). For the lowest concentration of 0.001 $\mu L\,L^{-1}$, compressed air was used without added ethylene, with an average concentration of

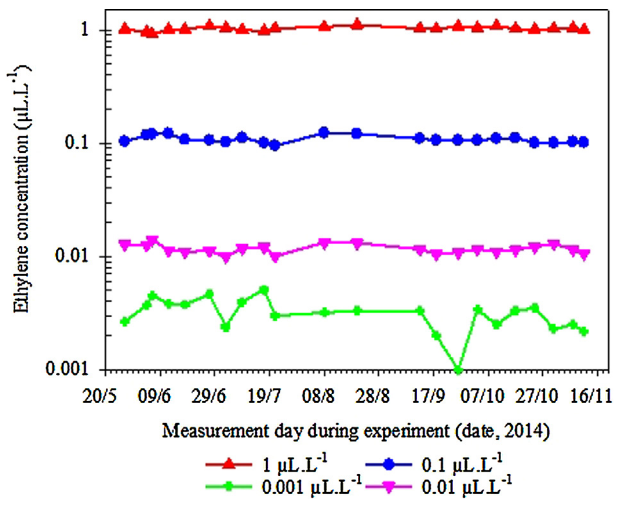

Fig. 1. Different ethylene concentrations of 1, 0.1 and 0.01 $\mu L\,L^{-1}$ were achieved throughout the experiment. All ethylene concentrations were assessed at mixers point before dividing into channels to maintain supply of gas to each barrel.