



Induction of ripening capacity in 'Packham's Triumph' and 'Gebhard Red D'Anjou' Pears by temperature and ethylene conditioning

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ABSTRACT

Methods were tested for rapid induction of ripening capacity in 'Packham's Triumph' and 'Gebhard Red D'Anjou' pears in order to facilitate early marketing. Fruit of each cultivar were harvested at the onset of maturity and conditioned to develop ripening capacity by exposure to $100 \mu\text{L L}^{-1}$ ethylene at 20°C for 0, 24, 48, or 72 h, followed by varying durations of temperature conditioning at -0.5 or 10°C . Ripening capacity was tested by measuring fruit firmness after 7 d at 20°C after completion of conditioning treatments. Fruit firmness was also measured after conditioning but before ripening, and was designated "shipping firmness," indicative of the potential for the fruit to withstand transport conditions without physical injury. With temperature conditioning at -0.5°C only, 'Packham's Triumph' pears needed 45 d to develop ripening capacity, while 'Gebhard Red D'Anjou' pears were not capable of fully ripening after 60 d, the longest duration tested. Using ethylene only, 72 h exposure was necessary to develop full ripening capacity in both cultivars, and adequate shipping firmness was maintained. Using temperature conditioning at 10°C , ripening capacity in 'Packham's Triumph' and 'Gebhard Red D'Anjou' developed within 10 and 20 d, respectively, but shipping firmness in 'Gebhard Red D'Anjou' was compromised at 20 d. In both cultivars, 24 or 48 h in ethylene followed by 5 d at 10°C induced ripening capacity while maintaining adequate shipping firmness.

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1. Introduction

Winter pear (*Pyrus communis* L.) cultivars require exposure to low temperatures or to ethylene gas after harvest in order to develop the capacity to ripen when subsequently maintained at warm temperatures (Hansen and Mellenthin, 1979; Villalobos-Acuña and Mitcham, 2008). The duration of exposure to either low temperatures or to exogenously applied ethylene necessary to induce ripening capacity varies broadly among pear cultivars, and is also influenced by the fruit maturity status at harvest (Chen and Mellenthin, 1982; Elgar et al., 1997; Sugar and Einhorn, 2011). The pear industry in the Pacific Northwest has designated the term "conditioning" to describe the induction of ripening capacity (Pear Bureau Northwest, 2010). During conditioning, pear fruit develop the capacity to produce ethylene internally at a sufficient rate to activate and complete the ripening process, including tissue softening (Agar et al., 2000; Blankenship and Richardson, 1985; Chen and Mellenthin, 1982; Knee, 1987; Murayama et al., 1998). Villalobos-Acuña and Mitcham (2008) applied the terms "ethylene conditioning" and "temperature conditioning" to distinguish

the two approaches to induction of pear ripening capacity. Temperature and ethylene conditioning treatments of varying duration were sequentially combined to induce ripening capacity in 'Anjou' and 'Comice' pears (Sugar and Basile, 2013).

'Packham's Triumph' is a winter pear that originated as a cross between 'Bartlett' and 'Uvedale St. Germain' made in Australia and introduced into the United States in 1916 (Brooks and Olmo, 1997). It is the principal winter pear of the southern hemisphere (Palmer and Grills, 2008; Sanchez, 2008; Theron et al., 2008). The temperature conditioning period for 'Packham's Triumph' pears has been variously described as approximately 30–60 d (Antoniolli and Czermainski, 2012; Dinamarca and Gil, 1987; Maage and Richardson, 1997) or 60–70 d (Richardson and Gerasopoulos, 1994).

'Gebhard Red D'Anjou' is a bud mutation of 'Anjou' that was discovered in southern Oregon and patented in 1960 (Brooks and Olmo, 1997). Another red-fruited mutation of 'Anjou', 'Columbia Red Anjou', was later discovered in northern Oregon (Brooks and Olmo, 1997). Chen et al. (1993) found that in contrast to fruit of 'Anjou' and 'Columbia Red Anjou', fruit of 'Gebhard Red D'Anjou' were incapable of ripening normally even after 60 days or more of storage at -1°C , and associated this unresponsiveness with relatively low production of the ethylene precursor 1-aminocyclopropane-1-carboxylic acid during cold storage. Subsequently, Chen et al. (1997) found that fruit of

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'Gebhard Red D'Anjou' could be ripened normally following exposure to $100 \mu\text{L L}^{-1}$ exogenous ethylene at 20°C .

The typical minimum low temperature exposure duration for induction of ripening capacity in 'Anjou' pear is approximately 60 d (Chen and Mellenthin, 1982). However, Sugar and Einhorn (2011, 2012) found that temperature conditioning of 'Anjou' and 'Comice' pears could be accomplished more rapidly if fruit were held at 10°C . Ethylene conditioning of pears is effective when fruit are held in an atmosphere of approximately $100 \mu\text{L L}^{-1}$ at 20°C (Villalobos-Acuña and Mitcham, 2008).

The purposes of facilitating pear conditioning through ethylene and temperature treatments are to reduce the time needed to induce pear ripening capacity, facilitate early marketing, and enhance fruit quality for the consumer by assuring that the pears will fully ripen. However, it is important that fruit firmness at the conclusion of conditioning be sufficient to allow handling and shipment to markets without increased risk of physical injury (Thompson, 2007).

In order for early marketing and quality enhancement treatments to be useful, specific protocols must be developed for each winter pear cultivar. The objective of this study was to evaluate temperature and ethylene postharvest conditioning criteria for inducing ripening capacity in 'Packham's Triumph' and 'Gebhard Red D'Anjou' pears harvested at the onset of maturity.

2. Materials and methods

2.1. Fruit

'Packham's Triumph' and 'Gebhard Red D'Anjou' pears were harvested at the onset of maturity in 2011 and 2012 from mature trees in the orchard of the Southern Oregon Research and Extension Center (SOREC) near Medford, Oregon (42.3°N , 122.8°W , elevation 455 m). The onset of maturity was defined as when the average firmness of a 10-fruit sample, tested in two locations on opposite sides of each fruit, became $<66.7\text{ N}$ for 'Gebhard Red D'Anjou' or $<75.6\text{ N}$ for 'Packham's Triumph' (Benitez, 2001; Richardson and Gerasopoulos, 1994). Fruit firmness was measured using a Fruit Texture Analyzer (Güss Manufacturing, Strand, South Africa) fitted with an 8 mm diameter probe. Measurements were made in the widest part of the fruit after a 1–2 cm diam area of peel was removed from the area to be tested, using a kitchen peeler. For 'Gebhard Red D'Anjou', four replicate groups of trees within a 0.5 ha block were used as sources of fruit, while three replicate groups of trees were used for 'Packham's Triumph'. The field replicate identity of fruit was maintained throughout the subsequent postharvest experiments.

2.2. Ethylene conditioning

From each orchard replicate 370–440 fruit were harvested at maturity and transported to the laboratory at SOREC. Fruit firmness was measured on 10 fruit per replicate as described above as an indicator of harvest maturity, and 10 fruit per replicate were placed on a lab bench at 20°C to test ripening capacity without conditioning (0 h in ethylene, 0 d at -0.5 or 10°C). After 7 d at 20°C , fruit firmness was measured as an indicator of ripeness. Fruit were considered ripe if the average firmness after 7 d at 20°C was $<17.8\text{ N}$, a typical value for the onset of a buttery-juicy fruit texture. The remaining fruit from each replicate were treated with ethylene at 20°C for 24, 48, or 72 h. Ethylene was introduced into a sealed room from a cylinder to a concentration of approximately $100 \mu\text{L L}^{-1}$ as determined using a gas chromatograph (Model AGC Series 400, Hach Carle, Loveland, CO) operated at 70°C with an alumina column and flame ionization detector. After each 24 h period,

the room was ventilated prior to removal of samples, then re-sealed and an atmosphere of $100 \mu\text{L L}^{-1}$ ethylene was re-established.

2.3. Post-ethylene temperature conditioning

Immediately following each ethylene treatment, 10 fruit per replicate were measured for fruit firmness, and 10 fruit per replicate were placed on a lab bench at 20°C to test ripening capacity without additional temperature conditioning. Fruit firmness was measured on those fruit after 7 d at 20°C . The remaining fruit were transferred to regular air storage rooms maintained at either -0.5 or 10°C . After varying durations of temperature conditioning following each duration of ethylene conditioning, 20 fruit per replicate were removed. Fruit firmness was measured on 10 fruit per replicate per treatment at the end of conditioning. The remaining 10 fruit were placed at 20°C for 7 d, after which fruit firmness was measured on each fruit to determine ripeness.

Fruit firmness after conditioning but before ripening was considered the "shipping firmness," reflecting fruit vulnerability to physical injury during shipment. Based on personal inquiries of pear producers in the Pacific Northwest, fruit firmness values $>44.5\text{ N}$ were considered suitable for shipping to all destinations within the continental United States by normal means. Fruit with firmness values $<44.5\text{ N}$ but $>35.6\text{ N}$ were considered not suitable for long-distance shipping, but likely to be suitable for moderate and short-distance shipping. Fruit with firmness values $<35.6\text{ N}$ were considered unsuitable for any but local shipping.

For 'Gebhard Red D'Anjou' pear, the duration of temperature conditioning at -0.5°C in each year was 0, 40, 50, or 60 d following 0 h in ethylene; 0, 20, 30, or 40 d following 24 h in ethylene; 0, 10, or 20 d following 48 h in ethylene; and 0, 5, or 10 d following 72 h in ethylene. At 10°C , the duration of temperature conditioning was 0, 10, or 20 d following 0 h in ethylene, and 0, 5, or 10 d following 24, 48, or 72 h in ethylene.

For 'Packham's Triumph' pear, the duration of temperature conditioning at -0.5°C in both years was 0, 30, and 45 d following 0 h in ethylene; 0, 20, or 30 d following 24 h in ethylene; 0, 5, and 10 d following 48 h in ethylene; and 0 and 5 d following 72 h in ethylene. At 10°C , the duration of temperature conditioning was 0, 10, or 15 d following 0 h in ethylene; 0, 5, or 10 d following 24 or 48 h in ethylene; and 0 or 5 d following 72 h in ethylene.

2.4. Statistical analysis

Values for fruit firmness after 7 d at 20°C following all combinations of ethylene treatment and post-ethylene temperature conditioning for the two years of study for each pear cultivar were subjected to ANOVA based on a factorial design using Statistix software v. 9 (Analytical Software, Tallahassee, FL). Year of treatment was not a significant factor; accordingly, data for the two years were pooled. Post-conditioning fruit firmness was analyzed for each cultivar and conditioning temperature using ANOVA and firmness means were separated using Fisher's protected LSD test.

3. Results

3.1. Induction of ripening capacity

Ethylene treatment, post-ethylene temperature conditioning, and the ethylene $\times$ temperature conditioning interaction affected the extent of softening of both 'Packham's Triumph' and 'Gebhard Red D'Anjou' pears within 7 d at 20°C (Table 1).

3.1.1. 'Packham's Triumph'

Without ethylene treatment, 'Packham's Triumph' pears harvested at 75.6 N average firmness needed approximately 45 d conditioning duration at -0.5°C to develop ripening capacity, while at 10°C , the fruit were capable of ripening following 10 d of conditioning (Fig. 1A). Following exposure to ethylene for 24 h, 30 d of temperature conditioning at -0.5°C was necessary to induce ripening capacity

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