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Responses of ‘Rocha’ pear to delayed controlled atmosphere storage depend on oxygen partial pressure

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ABSTRACT

Internal disorders hinder long-term controlled atmosphere (CA) storage of ‘Rocha’ pear. The delayed establishment of CA regime is often recommended to reduce internal disorders in pear. This investigation evaluated the effect of delayed CA at two oxygen partial pressures (pO_2) at constant low CO_2 partial pressure (pCO_2) on internal disorders and on storage potential of ‘Rocha’ pear. Fruit were stored at −0.5 °C for 257 d under 0.6 kPa CO_2 combined with 0.5 or 3.0 kPa O_2. The pull down of pO_2 was imposed at the beginning of cold storage (immediate CA) or after 46 d (delayed CA). ‘Rocha’ pear tolerated immediate storage at 0.5 kPa O_2 without developing internal disorders for 257 d storage. However, 63.3% of fruit immediately stored at 3.0 kPa O_2 developed internal disorders. Delayed pull down of pO_2 for 46 d reduced internal disorders in fruit at 3.0 kPa O_2 to 35.5%, but increased the disorder incidence in fruit at 0.5 kPa O_2 to 27.3%. Poststorage ethylene production rate was lower in fruit stored under delayed CA at 3.0 and 0.5 kPa O_2. In conclusion, the immediate storage of ‘Rocha’ pear at 0.5 kPa O_2 prevented the development of internal disorders for 257 d, while allowing adequate poststorage ripening and maintenance of quality traits. The effect of delayed CA on internal disorders depended on pO_2. Delaying CA for 46 d did not benefit ‘Rocha’ pear during long-term storage.

1. Introduction

Long-term storage of pears extends the marketing period, improves packinghouse management, and facilitates the amortization of facilities and equipments. Several pear cultivars are suitable for long-term storage, including ‘Rocha’ that can be maintained at −1 °C under controlled atmosphere (CA) for up to 10 months (Almeida et al., 2016). However, internal disorders characterized by brown discolorations and cavities in the flesh and core can develop during CA-storage (Franck et al., 2007) leading to supply chain inefficiencies. Moreover, pear internal disorders cannot be detected by external examination causing consumer disappointment when fruit with good appearance reveal internal damage. Prevention of internal disorders remains a challenge and is the major determinant of storage life termination in ‘Rocha’ pear under CA.

Delayed CA is a storage management practice in which fruit are maintained in air at low temperature for a period at the beginning of storage, often two to eight weeks, before the CA gas regime is imposed. This technique contrasts with immediate CA storage in which the pull down of oxygen partial pressure (pO_2) starts immediately after the fruit are cooled. Delayed CA effectively reduces the incidence of internal disorders in ‘Conference’ pear (Höhn et al., 1996). This effect was first investigated by Höhn et al. (1996), who observed a reduction in the incidence of cavities in ‘Conference’ pear when the CA regime was delayed. A 21-d delayed CA reduced cavity formation by 50–90%, depending on the orchard region (Höhn et al., 1996). The beneficial effect of a 21-d delayed CA in reducing internal disorders in ‘Conference’ pear was subsequently confirmed (Roelofs and de Jager, 1997; Saquet et al., 2001, 2003a). Delayed CA is now a standard commercial practice for successful long-term CA-storage of ‘Conference’ pear and is also effective in reducing the occurrence of internal disorders in apples (Streif and Saquet, 2003; DeEll and Ehsani-Moghaddam, 2012; Neuwald et al., 2014).

The physiological and biochemical effects underlying the benefits of delayed CA in reducing internal disorders have been explored in ‘Conference’ pear. Compared with immediate CA, fruit stored under delayed CA have higher ethylene production, higher respiration rate, and higher adenylate energy charge during the first three months in storage (Saquet et al., 2001) and maintain higher levels of oleic, linoleic, and linolenic fatty acids during the initial storage period

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(Saquet et al., 2003a). Higher adenylate energy charge and better maintenance of membrane integrity are the proposed mechanisms to explain the effect of delayed CA on the reduction of internal disorders in pear and apple (Saquet et al., 2003a,b).

Together, these results and the industry practice with 'Conference' pear show that delayed CA is an effective pre-conditioning procedure to reduce internal disorder development during long-term CA storage of pears in Northern Europe. However, the few trials with 'Rocha' pear grown under warm summer conditions showed little or no benefit of delayed CA (Almeida et al., 2016).

This study evaluated the effect of delayed CA on internal disorders development and on fruit quality maintenance during long-term storage of 'Rocha' pear under 3.0 and 0.5 kPa O_2.

2. Material and methods

2.1. Fruit material

Mature-green fruit of 'Rocha' pear (*Pyrus communis* L.) were harvested in an orchard located in Cadaval, Oeste Region of Portugal. At harvest, fruit with a size of 60–65 mm had an average (n = 45) starch pattern index of 8.2 (1–10 scale), flesh firmness of 52.4 N (± 6.1), total soluble solids of 112 g kg^{-1} (± 6.3), titratable acidity, expressed as malic acid equivalents, of 2 g kg^{-1} (± 0.2), and skin hue angle (h°) of 106.4° (± 3.2).

2.2. Storage conditions

Uniform unblemished fruit were placed into plastic crates and stored in experimental CA cabinets within cold rooms previously cooled at −1 °C. Three replicated fruit batches containing of 30 kg each (total of 90 kg) were stored in each cabinet.

The CA cabinets were sealed, the pO_2 was lowered by N_2 flushing and the pull down monitored by gas analyzers (Isolcell Italia, Laives, Italy). Temperature inside the cabinets was maintained at −0.5 °C (± 0.3 °C oscillation) and relative humidity at 92–93%. CA pO_2 were 3.0 or 0.5 kPa O_2 with 0.6 kPa CO_2 in both conditions (balance with N_2). CO_2 above 0.6 kPa was scrubbed by an automatic system (Isolcell Italia, Laives, Italy) using a 30% KOH solution.

CA conditions were established within 48 h after harvest or, in delayed CA, the fruit maintained in air for 46 d at −0.5 °C (± 0.3) before the pO_2 was reduced to 3.0 and 0.5 kPa O_2. Pull down of pO_2 required 18 and 26 h to reach 3.0 and 0.5 kPa O_2, respectively.

The storage temperature, relative humidity, pO_2 and pCO_2 were continuously monitored and controlled automatically (Isolcell Italia, Laives, Italy).

After 257 d in storage, fruit were evaluated during 7 or 8 d of shelf life at 20 °C for quality traits or for ethylene production and respiration rates, respectively.

2.3. Assessment of fruit quality

Poststorage fruit quality was assessed by changes in flesh firmness, skin color, juice total soluble solids and titratable acidity.

Flesh firmness was measured after the skin removal with a handheld penetrometer (T.R. Turoni, Forli, Italy) equipped with an 8 mm probe. The maximum force required to insert the probe into the fruit flesh without skin was recorded. Two measurements were performed per fruit, on opposite sides of the equatorial region in 3 replicated lots of 15 fruit each.

Skin color was measured in CIE L*a*b* color space with a tristimulus CR-400 chroma meter (Konica Minolta, Tokyo, Japan) with the C illuminant. The measurements were performed on widest part of the fruit in 3 replicated blocks of 15 fruit each.

Juice extracted from pears (3 replicates of 15 fruit each) was used for total soluble solids (TSS) and titratable acidity (TA) measurements. TSS were measured with a refractometer (Hanna Instruments, Woonsocket, USA). A volume of 10 mL juice was diluted in 90 mL distilled water before titration with 0.1 M NaOH until pH 8.1 and TA expressed in malic acid equivalents.

2.4. Internal disorders

The occurrence of internal disorders was monitored immediately after removal of fruit from storage in three replicated batches of, at least, 60 fruit each, after 91, 134, 187 and 257 d of storage. Fruit were cut transversely and longitudinally in three sections to assure the detection of disorders. Symptoms of core browning and necrotic cavities (Saquet and Almeida, 2017a) were observed were combined and damage incidence is expressed as the percentage of fruit affected.

2.5. Analysis of ethylene production and CO_2 release

Ethylene production rate was measured in three replications of 4 fruit each. Fruit samples were placed inside of 2.15 L sealed glass jars and maintained at 20 °C for 2 h. A headspace volume of 0.1 mL was removed from the jars through a rubber septum and injected into a gas chromatograph (Trace 1300, Thermo Fisher Scientific Inc., Marietta, USA) fitted with a capillary column TG bond alumina (Na_2SO_4) 50 m length and 0.53 mm i.d. (Thermo Fisher Scientific Inc., Marietta, USA) as described (Saquet and Almeida, 2017b).

The respiration rate, expressed as release of CO_2, was determined in the same fruit samples used for ethylene measurements, immediately after ethylene determination. Headspace CO_2 concentration was measured with an infrared gas analyzer (Oxycarb 6, Isolcell, Laives, Italy) with a continuous flow rate of 100 mL min^{-1} and the respiration rate calculated on a fresh mass basis.

2.6. Data analysis

Data on the percentage of affected fruit were subjected to the arcsine square root transformation (McDonald, 2014) before analysis of variance (ANOVA). Data were subjected to one-way ANOVA with the storage treatment as a fixed factor according to a randomized block design with 3 replicates. Means were separated by the least significant difference (LSD) test at $\alpha = 0.05$. Statistical analysis was made with the software Action Stat (2014, São Carlos, SP, Brazil).

3. Results and discussion

3.1. Physicochemical fruit characteristics

Successful long-term storage of pear must assure firmness maintenance during storage, but allow softening during subsequent ripening in shelf life. Fruit firmness was lower after 257 d in storage at 3.0 kPa O_2 than at 0.5 kPa O_2 (Fig. 1). Fruit softened during the 7-d shelf life at 20 °C after removal from storage to final firmness values of 15.1–23.6 N, an ideal range for consumption (Kappel et al., 1995; Villalobos-Acuña et al., 2011), with no significant differences between storage conditions (Fig. 1). Delayed CA of 21 d has been reported to have no detrimental effect on firmness retention in 'Conference' pear (Höhn et al., 1996; Saquet et al., 2001), but accelerated softening in 'Elstar' apple (Streif and Saquet, 2003).

Hue angle decreased during storage when pO_2 was 3.0 kPa but not under 0.5 kPa O_2 (Fig. 2). The effect of pO_2 on color prevailed over that of the delay period. After removal from storage, pear from all storage conditions yellowed and the initial effect of storage pO_2 on hue angle did not persist after 7 d in shelf life (Fig. 2). The effect of low pO_2 in keeping green color is well documented in pear (Mattheis and Rudell, 2011; De Martin et al., 2015). No color differences were observed in 'Conference' pear subjected to a 21-d delay in CA establishment in relation to those immediately stored in CA (Saquet et al., 2003a). The