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Influence of storage (time, temperature, atmosphere) on ripening, ethylene production and texture of 1-MCP treated 'Abbé Fétel' pears

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ABSTRACT

'Abbé Fétel' is the most important pear cultivar in Italy but is susceptible to superficial scald and soft scald during storage, the former effectively prevented by 1-methylcyclopropene (1-MCP) treatment at harvest and by dynamic controlled atmosphere (DCA). However, 1-MCP at −0.5 °C prevents pear ripening, and DCA can favor the appearance of soft scald, especially after long storage. The aim of this research was to study how postharvest treatments (storage atmosphere, temperature and time) can modulate the ripening ability in storage of 1-MCP treated 'Abbé Fétel' pears. To this aim, control and 1-MCP treated (SmartFresh^{TM}, 300 nL L^{-1}) pears stored in air (NA), controlled atmosphere (CA) and DCA at either −0.5 °C or 1 °C for 20 and 28 weeks were evaluated for ripening in storage by relating the spectral maturity indices I_{AD} (index of absorbance difference), bound to chlorophyll, and I_{carot} (carotenoids index), bound to carotenoids, to ethylene production, background skin color, mechanical properties of the pulp (firmness, stiffness and energy-to-rupture) and sugar (soluble solid content) and organic acid (titratable acidity) contents. The 1-MCP treatment drastically reduced ethylene production, impaired skin yellowing and fruit softening during storage of fruit kept at −0.5 °C, regardless of storage atmosphere and length of storage. The 1-MCP treatment coupled to 1 °C storage in NA succeeded in maintaining firmness and green color in storage but without blocking them, as indicated by the significant decrease in texture parameters and background skin hue achieved already in storage. 1-MCP treated samples which did not ripen in storage (DCA@−0.5 °C, DCA@1 °C, CA@−0.5 °C of both storage times and CA@1 °C at 20 weeks) were distinguished from the 1-MCP treated pears which began to ripen at different times in storage, i.e. NA@−0.5 °C, showing the least marked changes, and NA@1 °C after 28 weeks, having the highest changes in ripeness in storage. In control fruit, I_{AD} index better correlated to TA and ethylene production, while I_{carot} index better correlated to pulp mechanical properties and allowed the differentiation of control samples according to the ripeness degree reached already in storage, with NA@1 °C fruit after 28 weeks being the ripest and DCA@−0.5 °C pears after 20 weeks, the least ripe.

1. Introduction

'Abbé Fétel' pears, the most important pear cultivar in Italy in terms of production (CONERPO, 2010), can be stored in normal air (NA) not longer than four months, when fruit become sensitive to superficial scald and lose their ripening ability, remaining firm, grainy and without flavor (Murayama et al., 2002; Rizzolo et al., 2010; Vanoli et al., 2010a). Controlled atmosphere (CA) storage could preserve pears from superficial scald and allows the extension of postharvest life up to six months (Bai et al., 2009), even if the low levels of O_2 used in CA can induce soft scald (Bertolini et al., 2002; Rizzolo et al., 2010; Vanoli et al., 2010a). Treatment at harvest with 1-methylcyclopropene (1-MCP) or the storage in controlled atmospheres with low levels of oxygen, such as with dynamic controlled atmosphere (DCA), are effective in preventing superficial scald (Lurie and Watkins, 2012).

It has been shown that in pears 1-MCP inhibits superficial scald and prevents or controls soft scald and internal breakdown (Villalobos-Acuña et al., 2011a,b). However, the 1-MCP dose inhibiting scald development can impair pear fruit ripening (Ekman et al., 2004; Bai et al., 2006; Vanoli et al., 2010a,b; Villalobos-Acuña et al., 2011a,b) as a consequence of the high sensitivity to 1-MCP of pears (Cucchi and Regiroli, 2011; Sugar, 2011). Furthermore, it has been reported that at high 1-MCP doses, ethylene production is inhibited (Eccher Zerbini et al., 2003; Hiwasa et al., 2003; Bai et al., 2006) and that at doses ranging from

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10 to 300 nL L^{-1} the effects of 1-MCP on pears depends on cultivar, season, fruit maturity and dose. 'Abbé Fétel' pears and fruit in a more advanced maturity stage at harvest are less sensitive to 1-MCP than 'Conference' and less mature fruit (Eccher Zerbini et al., 2003, 2005). Ekman et al. (2004) showed for 'd'Anjou' cv that ethylene production during ripening is inhibited by exposure to 10 nL L^{-1} 1-MCP compared to untreated fruit when fruit are stored for 6 weeks at −1 °C. In contrast Argenta et al. (2003) found in 'Bartlett' cv that 500 nL L^{-1} 1-MCP delays the climacteric peak, without any ethylene production inhibition. The repetition of 25 and 50 nL L^{-1} 1-MCP treatments on 'Abbé Fétel' and 'Conference' pears every two months in NA and CA storage was not effective in both cultivars (Eccher Zerbini et al., 2005; Rizzolo et al., 2005). The time required for fruit to recover ripening ability, i.e., the sensitivity to ethylene during shelf life, is dependent on various factors such as: the 1-MCP dose applied, the length and type of storage conditions (Vanoli et al., 2008, 2010a), the cultivar (Watkins, 2006), the timing of 1-MCP treatment (DeEll and Ehsani-Maghaddam, 2011) as well as fruit maturity at the time of treatment (Calvo and Sozzi, 2004; Vanoli et al., 2008; Villalobos-Acuña et al., 2011a,b). However, sometimes 1-MCP treated pear fruit never recover their ability to ripen, remaining firm and green after shelf life.

The negative effects of 1-MCP on pear ripening can be reversed either by increasing storage temperature up to 10 °C (Cucchi and Regiroli, 2011; Villalobos-Acuña et al., 2011b; Rizzolo et al., 2013), or by applying post-storage 10–20 °C treatments for 5–21 d (Bai et al., 2006; Candan and Calvo, 2011).

The storage in controlled atmospheres with low levels of oxygen such as DCA was suggested for organic production as an alternative to ethoxyquin and to chemical treatment with 1-MCP, being effective not only in controlling scald development but also in improving overall fruit quality (Prange et al., 2011; Lurie and Watkins, 2012). However, Vanoli et al. (2008, 2010a) and Rizzolo et al. (2010) found that storing 'Abbé Fétel' pears at 0.7 kPa O_2 at −0.5 °C, even if it completely prevents superficial scald development and reduces soft scald incidence compared to 2 kPa O_2, increases internal browning and internal breakdown incidence, which can be prevented by 1-MCP treatment (Vanoli et al., 2015).

It was shown that with ripening the peel chlorophyll content declines. Blaszczyk (2012) found a significant decrease in peel chlorophyll content for 'Conference' and 'Concorde' pears with harvest date and in storage, thereby unmasking the peel yellow color due to the carotenoids contained in the chloroplasts (Gross, 1984). To better understand pigment evolution during ripening spectral maturity indices have been developed. They may consist of a single reflectance wavelength, differences or ratios between wavelengths or derivatives, or indices related to the red-edge (Vanoli and Buccheri, 2012). Among the spectral indices proposed for different horticultural products, the index of absorbance difference (I_{AD}), related to chlorophyll (Ziosi et al., 2008a), and the carotenoid index (I_{carot}), related to carotenoids (Merzlyak et al., 2003), could be useful tools to follow and differentiate the ripening evolution in storage of pear fruit kept in different atmospheres and temperatures. The I_{AD} index decreases and I_{carot} index increases as ripening proceeds (Lleó et al., 2011; Herrero-Langreo et al., 2012). Gomila et al. (2011) reported that in 'Williams' pears, I_{AD} index decreases with advanced harvest and with shelf life and has a high correlation with ethylene production. Rutkowski et al. (2012) for five pear cultivars, differing for skin color and maturity time, found a steady decrease of I_{AD} index values with storage, and the rate of changes depended on storage conditions and cultivar. For 'd'Anjou' pears Xie et al. (2014) reported that 1-MCP treatment did not affect I_{AD} index up to 8 months of storage in NA at −1.1 °C, while at 1.1 °C it maintained I_{AD} index values similar to control fruit for 5 months, and lower after 6 months. The I_{carot} index was studied in apples by Solovchenko et al. (2005), who reported that I_{carot} index value significantly increased with fruit ripening. To our knowledge, there are no studies on the relationships between I_{carot} index and ripening in pears.

The purpose of this research was to study how post-harvest treatments (storage atmosphere, temperature and time) can modulate the ripening ability in storage of 1-MCP treated 'Abbé Fétel' pears, paying attention to the relationship between I_{AD} index and I_{carot} index and ethylene production, background skin color, mechanical properties of the pulp and sugar (soluble solid content) and organic acid (titratable acidity) contents.

2. Material and methods

2.1. Fruit and experimental plan

'Abbé Fétel' pears (*Pyrus communis* L.) were harvested in 2010 in a commercial orchard in the Modena province (Italy) at the stage of commercial maturity on 6 September (about 1500 kg). On the day of harvest, fruit were transported to CRA-IAA in Milan using a standard temperature-controlled truck. On arrival (7 September), fruit were randomized in 90 boxes (about 40 fruit per box) and put in a cold room in NA at 1 °C for 24 h. Then, 48 boxes were treated for 24 h with 300 nL L^{-1} 1-MCP (SmartFresh™, AgroFresh Inc., Rohm and Haas, Spring House, PA, USA) at 1 °C by placing four groups of 12 boxes in 1.7 m^3 gastight containers, while 42 untreated boxes were used as control. On 10 September control and 1-MCP treated boxes were put into six 1.7 m^3 gastight containers, each one dedicated to one storage atmosphere plus storage temperature combination, i.e. NA, CA (2 kPa O_2 + 0.7 kPa CO_2) and DCA at either −0.5 °C or +1 °C for 20 and 28 weeks. In order to have approximately the same storage time for all the atmospheres, the time of set up of CA and DCA with respect to NA was considered. In DCA the physiological status of fruit during storage was monitored using the HarvestWatch™ system with FIRM™ sensors (Satlantic, Canada). After reaching 2 kPa O_2, fruit were left without oxygen supplementation, with oxygen decreasing due to respiration; when an increase in fluorescence signaled O_2 at too low a level, the O_2 concentration was set to the level immediately above the stress level, keeping CO_2 as low as possible. This resulted in DCA with 0.8 kPa O_2 + 0.45 kPa CO_2. Hereafter fruit of each storage atmosphere stored at −0.5 °C are referred to as NA@−0.5 °C, CA@−0.5 °C and DCA@−0.5 °C and those stored at 1 °C as NA@1 °C, CA@1 °C and DCA@1 °C.

At harvest, a sample of 30 fruit was analyzed for mass, starch hydrolysis, titratable acidity (TA), soluble solids content (SSC), background skin color parameters and reflectance spectra, and mechanical properties of the pulp (firmness, stiffness and energy-to-rupture).

After 20 and 28 weeks of storage plus 1 day at 20 °C, 20 fruit per 1-MCP dose per storage atmosphere per storage temperature were analyzed for ethylene production (EP, on 10 fruit), background skin color and reflectance spectra, mechanical properties of the pulp (firmness, stiffness and energy-to-rupture), TA and SSC.

2.2. Spectral maturity indices and background skin color

According to Herrero-Langreo et al. (2012) spectral maturity indices were computed from spectral local measurements recorded with the Spectrophotometer CM-2600d (Minolta Co., Japan). Reflectance spectra from 360 to 740 nm at 10 nm intervals were acquired on the greener side of fruit. In order to compute the index of absorbance difference according to $I_{AD} = A_{670} - A_{720}$ (Ziosi et al., 2008a), the reflectance data at 670 and 720 nm were converted into absorbance using $A = \log(100/R)$. The carotenoid index I_{carot} (Merzlyak et al., 2003) was computed from reflectance