Storability of 'Conference' Pear Under Various Controlled Atmospheres

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ORIGINAL ARTICLE

Storability of 'Conference' Pear Under Various Controlled Atmospheres

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Abstract

In two consecutive experimental seasons it was investigated the storage capacity of 'Conference' pear (*Pyrus communis*, L.) under regular air (RA) and various controlled atmosphere (CA) conditions during six months at 0 °C (±0.3). The occurrence flesh browning (FB), core browning (CB) and cavity formation (CF) was evaluated at each 2-months storage intervals and the ripening quality traits analyzed immediately at the end of storage period and after 7 days of shelf-life in air at 20 °C. The storage conditions were: RA; 0.5 kPa O_2 + 0.5 kPa CO_2; 1.5 kPa O_2 + 1.5 kPa CO_2, 2.0 kPa O_2 + 1.0 kPa CO_2; 3.0 kPa O_2 + 6.0 kPa CO_2 and 0.5 kPa O_2 + 6.0 kPa CO_2. After six months, 'Conference' pear was very susceptible to FB, CB and CF under CA-storage. The damages started to develop at the second month of storage, increasing continuously until end of storage period. At storage end, pear fruits kept under 0.5 kPa O_2 + 6.0 kPa CO_2 showed a dramatic high occurrence of FB, CB and CF with a severity index of 50.6, 45.3 and 27.1, respectively. The lowest incidences of FB, CB and CF were scored in fruits kept at 2.0 kPa O_2 + 1.0 kPa CO_2 with severity indexes of 1.1, 1.1 and 1.0, respectively. Flesh firmness, skin color, titratable acidity and total soluble solids were satisfactory under 2.0 kPa O_2 + 1.0 kPa CO_2. In conclusion, 'Conference' pear cannot be stored under O_2 partial pressure lower than 2.0 kPa and CO_2 higher than 0.5 kPa.

Keywords Carbon dioxide · Internal browning disorders · *Pyrus communis* L · Fruit quality traits · Ultra-low oxygen · Pear · 'Conference'

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Lagerfähigkeit der Birnensorte 'Conference' bei unterschiedlichen CA-Bedingungen

Zusammenfassung

In zwei aufeinanderfolgenden Versuchsjahren wurde die Lagerungsfähigkeit von Früchten der Birnensorte 'Conference' (*Pyrus communis*, L.) bei Kühllagerung in normaler Atmosphäre und unter verschiedenen CA-Bedingungen über einen Zeitraum von sechs Monaten bei 0 °C (±0,3) untersucht. Der Befall mit Fleischbräune, Kernhausbräune und Kavernenbildung im Fruchtfleisch wurde im Abstand von zwei Monaten während der Lagerung bonitiert. Die Reifequalitätsmerkmale wurden bei Lagerende sowohl nach der Auslagerung als auch nach 7 Tagen Nachlagerung in normaler Atmosphäre bei 20 °C gemessen. Die untersuchten Lagerungsvarianten waren: Kühllagerung; 0,5 kPa O_2 + 0,5 kPa CO_2; 1,5 kPa O_2 + 1,5 kPa CO_2, 2,0 kPa O_2 + 1,0 kPa CO_2; 3,0 kPa O_2 + 6,0 kPa CO_2 und 0,5 kPa O_2 + 6,0 kPa CO_2. Nach sechsmonatiger Lagerung verhielt sich die Birnensorte 'Conference' gegenüber dem Auftreten von Fleischbräune, Kernhausbräune und Kavernenbildung bei CA-Lagerung sehr empfindlich. Die physiologischen Frucherkrankungen traten bereits nach zwei Monaten Lagerung auf und stiegen kontinuierlich bis zum Lagerende an. Bei Lagerende zeigten die unter 0,5 kPa O_2 + 6,0 kPa CO_2 gelagerten Birnen einen dramatischen hohen Befall an Fleischbräune, Kernhausbräune und Kavernenbildung mit einem Schadindex von 50,6, 45,3 und 27,1. Der niedrigste Befall an Fleischbräune, Kernhausbräune und Kavernenbildung wurde bei Früchten beobachtet, die bei 2,0 kPa O_2 + 1,0 kPa CO_2 gelagert wurden und zwar mit einem Schadindex von 1,1; 1,1 und 1,0. Die Fruchfleischfestigkeit, die Grundfarbe der Fruchtschale, die titrierbare Säure und die lösliche Trockensubstanz waren bei der Lagerungsvariante 2,0 kPa O_2 + 1,0 kPa CO_2 ausreichend. Nach diesen Ergebnissen lässt sich die Aussage treffen, dass Früchte der Birnensorte 'Conference' nicht unter einem O_2-Partialdruck von 2,0 kPa O_2 bzw. nicht über einen CO_2-Partialdruck von 0,5 gelagert werden sollten.

Schlüsselwörter Kohlendioxid · Physiologische Fruchterkrankungen · *Pyrus communis* L · Fruchtqualitätsmerkmale · Sehr niedriger O_2-Partialdruck · Birne · 'Conference'

Introduction

'Conference' pear is very attractive in flavor, juiciness and aroma allowing being the most cultivated pear variety in Europe. Pears, in general, can be stored for up to 3–5 months under regular air (RA) storage at temperature around –0.5 °C (Kupferman 2001; Streif et al. 2001; Thompson 2010; Saquet and Almeida 2017a). In the case specific of 'Conference' pear, the RA-storage at –1 to 0 °C allows to keep high quality up to 4 months without significant fruit quality losses (Streif et al. 2001; Saquet and Streif 2006). However, to prolong the storage duration of 'Conference' pear, without using of post-harvest chemicals, despite the decrease in the storage temperature and the relative humidity (RH) management, it is necessary to reduce the oxygen and slightly increase the carbon dioxide partial pressures (pO_2; pCO_2) in CA-storage rooms (Streif et al. 2003; Streif 2008). The range of gas partial pressures during CA-storage for 'Conference' pear varies according pre- and post-harvest factors, but in Europe it is frequently recommended oxygen of 2.0–2.5 kPa and carbon dioxide below 0.7 kPa to avoid the development of internal disorders during long-term CA-storage (Saquet et al. 2003; Streif 2008; Pedreschi et al. 2009; Rizzolo et al. 2014).

The basic principle of CA-storage, in reducing the pO_2 and increasing the pCO_2 allows prolonging significantly the storage period of pears by reducing the respiration rate and various other metabolic pathways in fruit cell metabolism (Saquet et al. 2000; Streif 2008; Pedreschi et al. 2009; Rizzolo et al. 2014). Because of pears, in general, are less tolerant to low pO_2 and/or high pCO_2, be careful in changing the gas composition during CA-storage is necessary. If the pO_2 is lowered, below the fruit tolerance limit and/or the pCO_2 is increased above the fruit tolerance, fruit metabolism is changed and various undesirable biochemical processes occur leading to the development of flesh browning (FB), core browning (CB) and cavity formation (CF) (Kupferman 2001; Saquet and Streif 2002; Pedreschi et al. 2009). Unfortunately, the occurrence of these physiological disorders cannot be externally detected and, depending on the cultivar, season, pre- and post-harvest factors the damages can lead to significant quality and economic losses (Franck et al. 2007; Lum et al. 2016).

Therefore, the aim of this research was to investigate the tolerance of 'Conference' pear to the lowering of pO_2 from 2.0 to 0.5 kPa combined with the increase in the pCO_2 of 0.5 to 6.0 kPa during six months storage at 0 °C. Specifically will be investigate the occurrence of internal storage disorders and the maintenance of fruit quality traits.

Material and Methods

Fruit Material and Storage Procedures

Pre-climacteric 'Conference' pear was used during the storage trials. The fruit maturity at harvest showed an iodine-starch test of 6.5 in a scale from 1–10; flesh firmness of 57.6 N; skin color (L a + b) of 21.6; titratable acidity of 2.3 mval/100 mL; and the total soluble solids of 13.3%.

Immediately after harvest, pear fruits were selected for size, defects and physical damages, and samples carefully homogenized. Immediately after, fruits were cooled to 0 °C (±0.3) and the storage gas combinations established: regular air (RA); 0.5 kPa O_2 + 0.5 kPa CO_2; 1.5 kPa O_2 + 1.5 kPa CO_2; 2.0 kPa O_2 + 1.0 kPa CO_2; 3.0 kPa O_2 + 6.0 kPa CO_2 and 0.5 kPa O_2 + 6.0 kPa CO_2. The storage procedures and gas management during the storage period were carried out according to Saquet et al. (2000). Three individual CA-rooms with the same storage condition were used as replicates for fruit quality evaluations during storage period.

Scoring the FB, CB and CF Occurrence

The occurrence of FB, CB and CF was monitored at 2-months storage intervals, immediately after the removal of fruits from storage rooms. To characterize and score these physiological disorders during storage period, pear fruits were cut transversely twice and axially also in two sections.

FB was characterized as the browned tissue between the core region and the fruit skin. The affected tissue was not soft and was absent of cavities. FB was scored in 4 severity levels and expressed by an index as follows: level 0 (absent of browned tissue); level 1 (browned tissue area smaller than 10 mm^2); level 2 (browned tissue area of 10–30 mm^2) and level 3 (browned tissue area larger than 30 mm^2). The severity index was calculated as:

$$\text{Index} = \sum \frac{\text{number of affected fruits} \times \text{severity level}}{\text{total of fruits} \times \text{maximal severity level}} \times 100$$

CB was the browning of tissue restricted to the core region with a maximal diameter of 15 mm around the core. CB was scored according to the area of the browned tissue and the severity levels calculated as: level 0 (absent of browned tissue); level 1 (browned tissue smaller than 3 mm diameter); level 2 (browned tissue of 3–6 mm diameter) and level 3 (browned tissue larger than 6 mm diameter).

CF was the development of cavities in the fruit flesh, often distributed radially around the core, but sometimes found longitudinally within the fruit. CF was quantified according to the diameter of each cavity found in fruit flesh: level 0 (absent of cavity); level 1 (cavities smaller than 5 mm diameter); level 2 (cavities of 5–15 mm diameter) and level 3 (cavities larger than 15 mm diameter). The same calculation described for FB, was used as for CB and CF occurrence.

Assessment of Fruit Quality Traits

Fruit quality characteristics of flesh firmness (FF), skin color (SC), titratable acidity (TA) and total soluble solids (TSS) were analyzed after 6 months of storage followed by 7 days of shelf-life in air at 20 °C.

For the measurement of FF, three samples of 15 fruits each were used. After skin removal at the equatorial region, FF was measured with a semi-automatic penetrometer (TR Turoni, Forlì, Italy) fitted with 8-mm tip. It were carried out two measurements each fruit on pared sides and the results given in N.

The same fruit samples of FF were used for SC measurements. In this case, one measurement each fruit was carried out with a Minolta colorimeter CR-300 (Konica Minolta Inc., Tokyo, Japan) and the results given in L (a* + b*). The greenest surface area on the skin and absent of *russeting* was used for SC measurements.

To measure TA, a disc of 10 mm thick was cut transversely on the equatorial region of pear fruits and the juice extracted. An aliquot of 10 mL fresh juice was diluted in 90 mL distilled water and titrated with a 0.1 M NaOH solution until pH 8.1. The pH changes were monitored with a WTW potentiometer (WTW GmbH, Weilheim, Germany). Results of TA were given in mval 100 mL.

TSS were measured using the same juice of TA. For this assessment maximal of 4 drops of juice were put on a hand refractometer (Atago Co. Ltd, Tokyo, Japan) and the results presented in percentage.

Data Analysis

The ANOVA was calculated using the Statistical Software Action for Excel. The standard deviations of means were calculated. For this procedure, three true replicates were used, each composed by a single CA-storage room with the same storage condition.

Results and Discussion

Occurrence of FB, CB and CF in 'Conference' Pear

The occurrence of FB, CB and CF started to develop at the second month of storage period and increased continuously until storage end (Figs. 1, 2 and 3, respectively). At the second month of storage the index of FB (Fig. 1) var-

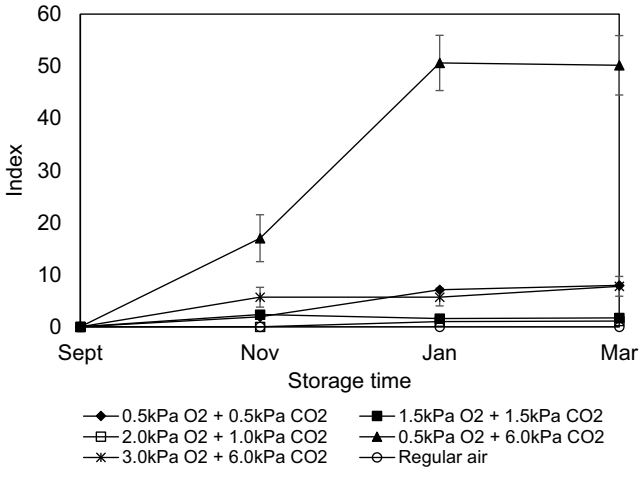

Fig. 1 Occurrence of flesh browning in 'Conference' pear during six months of storage (vertical bars are the standard deviations)

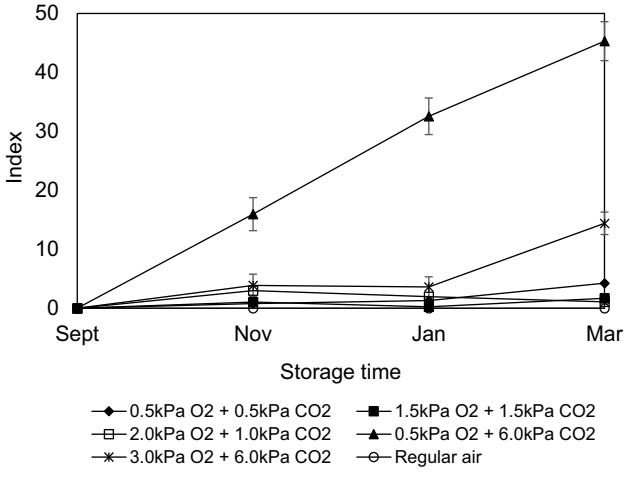

Fig. 2 Occurrence of core browning in 'Conference' pear during six months of storage (vertical bars are the standard deviations)

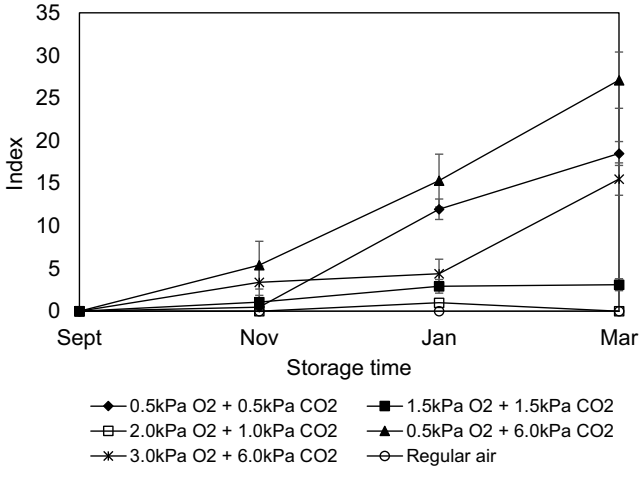

Fig. 3 Occurrence of cavities in 'Conference' pear during six months of storage (vertical bars are the standard deviations)

ied from 2.3 under the moderate CA-condition with 2.0 kPa O_2 + 1.0 kPa CO_2 to 17.1 in fruits kept at 0.5 kPa O_2 + 6.0 kPa CO_2; but increased dramatically to 50.3 after 6 months storage under 0.5 kPa O_2 + 6.0 kPa CO_2.

The occurrence of CB (Fig. 2) in 'Conference' pear followed the same trend as was observed in the FB incidence. At the second month of storage were scored indexes of 1.1–15.9 under 2.0 kPa O_2 + 1.0 kPa CO_2 and 0.5 kPa O_2 + 6.0 kPa CO_2, respectively. The CB damage also increased drastically in fruits stored at 0.5 kPa O_2 + 6.0 kPa CO_2 reaching an index of 45.3 after 6 months of storage.

The CF also begun to develop at the second month of storage (Fig. 3) and increased continuously until the end of storage period. It was here observed, that fruits stored at 0.5 kPa O_2 and keeping the CO_2 lower than 0.5 kPa also formed cavities in fruit flesh of 'Conference' pear. This suggests clearly, that the cavity formation is not only caused by high pCO_2 in CA-rooms.

In the present investigation, 'Conference' pear was very susceptible to the low pO_2 and/or high pCO_2 during 6 months CA-storage period. The lower the pO_2 and/or the higher the pCO_2 in CA-rooms, the higher was the incidence of FB, CB and CF. Fruits stored under the moderate CA-condition with 2.0 kPa O_2 + 1.0 kPa CO_2 showed the lowest occurrence of the three kinds of internal disorders during storage period, and the obviously highest incidence of disorders was scored in fruits kept under 0.5 kPa O_2 + 6.0 kPa CO_2, that was the most extreme stress condition. Intermediary occurrence of internal disorders were scored in fruits stored at 0.5 kPa O_2 + 0.5 kPa CO_2 and 3 kPa O_2 + 6 kPa CO_2.

It is well known since much time about the beneficial effects of CA-storage in keeping quality of pears, but this is achieved only when the CA-conditions are well established, especially considering the susceptible pear cultivars such as 'Conference' pear (Poma-Treccani and Boscarello 1977; Höhn et al. 1996; Pedreschi et al. 2009).

The present results showed a synergistic effect of lowering pO_2 combined with increasing pCO_2 on the occurrence of the three kinds of internal disorders in 'Conference' pear. Long ago North et al. (1974) reported about the susceptibility of 'Conference' pear to low pO_2 and high pCO_2, but very similar synergistic effect of CA on the occurrence of FB, CB and CF was observed much later by Höhn and Jampen (1992) and Garcia and Streif (1993). Streif (2008) storing 'Conference' pear under various CA-conditions, found fruits without FB, CB and CF when kept under CA-condition with 2.0 kPa O_2 plus 0.8 kPa CO_2. These results reinforce the really need in keeping the pO_2 higher than 2.0 kPa while the pCO_2 must be lower than 0.7 kPa during CA-storage of 'Conference' pear as was early reported (Streif et al. 2001, 2003). In case of the present research, it was interesting the development of cavities in fruit flesh of 'Conference' pear under low pO_2 as low as 0.5 kPa indicating that

this damage cannot be attributed only to the high pCO_2 as has been reported in apples (Elgar et al. 1998; Clark and Burmeister 1999). These results confirms that 'Conference' pear have be stored under pO_2 higher than 2.0 kPa and pCO_2 lower than 0.5 kPa during the full storage time to prevent the development of internal disorders.

Changes in Quality Traits of 'Conference' Pear

Flesh Firmness (FF)

Storage conditions of pear affect its subsequent ripening process and further softening during shelf-life. A desired optimal storage for pear should keep fruit firm while in store and an adequate softening to a buttery and juicy texture during shelf-life after storage period (Saquet and Almeida 2017a). Kappel et al. (1995) investigating the ideal pear consumer preferences regarding sensory quality and fruit characteristics concluded, that the ideal pear FF judged by taste panelists was in the range of 18–22 N measured with an 11.1-mm penetrometer tip. In this research, 'Conference' pear firmness at harvest was of 57.6 N and decreased to 42.1 N in RA-stored fruits immediately at time of fruits were removed from storage (Table 1). The CA-storage kept higher FF than RA-storage, but among all CA-storage conditions, it was not observed significant differences and the FF varied from 49.0 to 52.9 N. Under CA, it was not possible to verify any beneficial effect of the lower pO_2 and/or higher pCO_2 in keeping higher FF of 'Conference' pear, including after 7 days of shelf-life at 20 °C. The FF after 7 days of shelf-life varied from 11.0 N in RA-stored pear fruits to 15.5 N under CA with 2.0 kPa O_2 + 1.0 kPa CO_2. Despite that in this research it was used a penetrometer tip of 8 mm to measure pear FF, the FF values after 7 days of shelf-life are within the desired range by pear consumers as was reported by Kappel et al. (1995).

Skin Color (SC)

Data on SC after storage of 'Conference' pear are given in Table 1. It is clear the effect of the CA-conditions in keeping greener the SC of 'Conference' pear immediately after storage. RA-stored pear fruits were at this time yellower than all CA-stored fruits, however, no significant differences were observed between CA-conditions. Slightly greener, but statistically not significant different, was the effect of the CA-condition with 0.5 kPa O_2 + 6.0 kPa CO_2. After 7 days of shelf-life (Table 1) the SC of 'Conference' pear was practically the same in fruits from all storage conditions. It was here perceived, that the CA-storage could not maintain the skin greener than RA-stored fruits. The effect of CA-storage in keeping greener the SC in pears is frequently reported (Nath et al. 2012; Gago et al. 2013; Almeida et al. 2016). The main enzyme involved in the chlorophyll breakdown during pear ripening, the chlorophyllase, is ethylene dependent and this explain, in part, the effect of CA-storage on retention pear fruits greener than RA-stored fruits.

Titratable Acidity (TA) and Total Soluble Solids (TSS)

The Table 1 shows data of TA and TSS of 'Conference' pear after 6 months storage as well as after 7 days of shelf-life in air at 20 °C. TA and TSS are often evaluated in quality analyses of produce and these components are critical

Table 1 Quality attributes of 'Conference' pear after six months of storage followed by 7 days of shelf-life at 20 °C

Storage condition	Flesh firmness (N)		Skin color (a* + b*)		Acidity (mval/100 mL)		Total soluble solids (%)	
	0 day	7 days	0 day	7 days	0 day	7 days	0 day	7 days
At harvest	57.6		21.6		2.3		13.3	
Regular air	42.1 ± 3.8	11.0 ± 2.9	38.4 ± 1.9	45.5 ± 3.3	0.7 ± 0.11	0.9 ± 0.10	14.2 ± 0.5	14.2 ± 0.6
0.5 kPa O_2 + 0.5 kPa CO_2	50.1 ± 4.1	12.5 ± 2.8	24.5 ± 2.1	40.6 ± 3.1	1.3 ± 0.13	1.6 ± 0.12	14.4 ± 0.4	15.0 ± 0.4
1.5 kPa O_2 + 1.5 kPa CO_2	50.0 ± 3.9	11.5 ± 2.7	25.5 ± 1.8	40.2 ± 3.4	1.1 ± 0.12	1.6 ± 0.11	14.5 ± 0.6	15.0 ± 0.8
2.0 kPa O_2 + 1.0 kPa CO_2	52.9 ± 4.2	15.5 ± 2.9	26.2 ± 1.9	37.8 ± 3.2	1.3 ± 0.14	1.6 ± 0.13	13.8 ± 0.5	14.1 ± 0.6
3.0 kPa O_2 + 6.0 kPa CO_2	49.0 ± 4.0	12.4 ± 2.6	24.6 ± 2.2	38.3 ± 3.6	0.9 ± 0.10	1.7 ± 0.12	14.0 ± 0.7	15.1 ± 0.7
0.5 kPa O_2 + 6.0 kPa CO_2	49.1 ± 3.9	10.9 ± 2.7	23.2 ± 2.0	37.7 ± 2.9	0.9 ± 0.11	1.7 ± 0.14	14.5 ± 0.6	15.2 ± 0.5

Means ± the standard deviations ($n = 3$)

to overall sensory quality (Mattheis and Fellman 1999). It is important an acceptable balance of TSS and TA in determining fruit quality. The TSS/TA ratio is a key characteristic determining the taste and feel of fruit segments. It contributes towards giving many fruits their characteristic flavor (Kader 1999; Park 2002).

TA of 'Conference' pear decreased from 2.3 mval/100 mL, at harvest, to 0.7 immediately after storage in RA-stored fruits. The CA-conditions kept TA slightly higher than RA-stored pears with values in the range of 0.9–1.3, but not consistent among CA-conditions. The reduction in TA is observed during storage of pears (Nath et al. 2012; Almeida et al. 2016) and might be associated with the conversion of organic acids into sugars and their derivatives or their utilization by cell respiration (Zerbini 2002). After 7 days of shelf-life, a slight increase in TA was observed, mainly in CA-stored fruits which were higher than the RA-stored pears. Such behavior was also observed by Gago et al. (2013) in 'Rocha' pear.

TSS of 'Conference' pear, at harvest time, was of 13.3% and increased to 14.5% after storage. After 7 days of shelf-life was observed a further TSS increase reaching 15.2% in fruits kept at 0.5 kPa O_2 + 6.0 kPa CO_2, but with no significant differences between treatments. Increase in TSS during storage of pears is frequently reported (Nath et al. 2012) and might be associated with the transformation of pectic substances and starch hydrolysis, and also with some dehydration of fruits (Park 2002; Carrillo et al. 2003). Saquet and Almeida (2017b) investigating the ripening biochemistry of 'Rocha' pear after harvest showed, that the starch was hydrolyzed within 10 days, therefore, this increase in TSS measured during storage of 'Conference' pear may have other reasons.

Conflict of interest A.A. Saquet declares that he has no competing interests.

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