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Phenolic compounds content and antioxidant activity of 'Galaxy' apples stored in dynamic controlled atmosphere and ultralow oxygen conditions

Mayara Cristiana Stanger[a], Cristiano André Steffens[a,*], Cristina Soethe[a], Marcelo Alves Moreira[a], Cassandro Vidal Talamini do Amarante[a], Vanderlei Both[b], Auri Brackmann[b]

[a] Department of Plant Science, Postharvest Research Center, University of Santa Catarina State, Centre for Agroveterinary Sciences, Luiz de Camões Avenue 2090, Conta Dinheiro, Lages, 88520-000, SC, Brazil
[b] Department of Plant Science, Postharvest Research Center, Federal University of Santa Maria, Roraima Avenue 1000, Camobi, Santa Maria 97105-900, RS, Brazil

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ABSTRACT

The effects of a dynamic controlled atmosphere, monitored by the respiratory quotient (DCA-RQ) or chlorophyll fluorescence (DCA-CF), and ultralow oxygen (ULO) conditions on the quality, individual (IPC) and total (TPC) phenolics content and total antioxidant activity (TAA) of the peel and fleshflesh tissues of 'Galaxy' apples have been evaluated. DCA, and especially DCA-RQ, resulted in higher IPC in the peel, with higher contents of chlorogenic acid and procyanidin B1. In the flesh, the IPC and TPC was higher for DCA-RQ and DCA-CF than in all ULO conditions. Highest chlorogenic acid, epicatechin and catechin contents were found in DCA-RQ stored fruit.

1. Introduction

The regular consumption of apples has been frequently associated with the promotion of human health through the prevention of chronic diseases (Condezo-Hoyos et al., 2014). Bioactive compounds in apples have shown antimicrobial (Rounds et al., 2013) and anti-inflammatory (Martinez-Micaelo et al., 2015) effects, and can aid in the prevention of cardiovascular diseases (Serra et al., 2012) and the reduction of triglyceride levels in the blood (Yao et al., 2014). These beneficial effects have been attributed to the content of phenolic compounds and their antioxidant capacity (Panzella et al., 2013).

The main groups of phenolic compounds in apples are hydroxycinnamic acid, dihydrochalcones, flavonoids, flavan-3-ols in the monomeric [(+)-catechin and (-)-epicatechin] and oligomeric (proanthocyanidins) forms and anthocyanins (Jakobek et al., 2013). The occurrence and the content of these compounds vary among cultivars (Jakobek et al., 2013; Panzella et al., 2013; Stanger et al., 2017), peel and flesh tissues (Jakobek et al., 2013; Stanger et al., 2017) and storage conditions (Hoang et al., 2011).

Most production of apples in Brazil consists of 'Gala' and 'Fuji', and their respective highly colored mutants.' Gala' apples, and its mutants, correspond to 58% of the total production (WAPA, 2011) and the harvest period lasts from January to March. Several methods have been proposed to maintain storage quality to extend the period of supply of the apples to the market. The storage of apples in a ultralow oxygen (ULO) condition (0.8 to 1.2 kPa) and high CO_2 (2.0 to 3.0 kPa) is the main technology used to complement refrigeration to preserve 'Gala' apples, and its mutants, during storage. CA, in which the partial pressures of O_2 and CO_2 are maintained fixed during storage, reduces the fruit metabolism, preserves the physical-chemical attributes (Wright et al., 2015; Saquet and Streif, 2017) and reduces and/or inhibits the occurrence of physiological disorders (Both et al., 2014; DeEll et al., 2016). In a ULO, higher CO_2 partial pressure (from 1.2 kPa to 2.0 kPa) are beneficial to reduce the metabolism and maintain fruit quality (Brackmann et al., 2015). The recommended CO_2 partial pressure is between 2.0 and 3.0 kPa for 'Gala' (Brackmann et al., 2001) and there is no difference in the postharvest behavior of the different 'Gala' apple mutants (Argenta et al., 2015).

Dynamic controlled atmosphere (DCA) is based on dynamic control of the lower limit of O_2 as a function of the storage time, based on the measurement of a biological response of the stored fruit at low partial pressure of O_2 (Zanella, 2003). Methodologies proposed to detect the lower limit of O_2 tolerated by the fruit include DCA-CF, based on chlorophyll fluorescence (Wright et al., 2012) and DCA-RQ based on the respiratory quotient (Bessemans et al., 2016). DCA-CF storage treatment reduced ethylene production (Thewes et al., 2015; Mditshwa et al., 2018), softening (Zanella et al., 2005; Thewes et al., 2015; Mditshwa et al., 2018) and flesh browning (Lafer, 2008; Thewes et al.,

* Corresponding author.
E-mail addresses: mayara.stanger@udesc.br (M.C. Stanger), cristiano.steffens@udesc.br (C.A. Steffens), crisoethe@hotmail.com (C. Soethe), marcelo.moreira@udesc.br (M.A. Moreira), cassandro.amarante@udesc.br (C.V.T. do Amarante), vanderleiboth@yahoo.com.br (V. Both), auribrackmann@gmail.com (A. Brackmann).

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2015) and superficial scald (Zanella et al., 2005; Mditshwa et al., 2018)., while 'Gala' apple mutants exhibit the same behavior during storage and DCA-CF (Thewes et al., 2015).

DCA-RQ reduced softening and superficial scald incidence compared with normal CA storage (Bessemans et al., 2016). Brackmann et al. (2015) reported that the storage of 'Galaxy' apples using the DCA-RQ treatment resulted in fruit with higher flesh firmness and lower mealiness compared with to DCA-CF. Previous studies on apples of the 'Gala' group had demonstrated that an RQ of 1.5 was the most suitable value for DCR-RQ storage treatments (Brackmann et al., 2015; Both et al., 2017).

No studies could be found in the literature regarding the total (TPC) and individual (IPC) phenolic compounds content or the total antioxidant activity (TAA) for apples of 'Gala' group, such as 'Galaxy', under DCA in comparison to ULO conditions. The objective of this study was to evaluate the effect of DCA, monitored through the respiratory quotient and chlorophyll fluorescence, and of three conditions in a ULO (1.2 kPa of O_2 + 1.2, 1.6, and 2.0 kPa of CO_2) on storage quality as well as IPC and TPC contents and the TAA of the peel and flesh of 'Galaxy' apples.

2. Materials and methods

2.1. Fruit samples and application of treatments

'Galaxy' apples were harvested from a commercial orchard located in the municipality of Vacaria, in Rio Grande do Sul State (RS), southern Brazil (28°30′44″S and, 50°56′02″W, altitude 970 m), during the 2013/2014 season. Fruit were then transported to the laboratory, in Santa Maria, RS, where the selection and the homogenization of the experimental samples were carried out. Each treatment was composed by 4 replicates of 25 fruit each. The storage treatments tested were: DCA-RQ = 1.5 (average of 0.21 kPa O_2 + 1.2 kPa CO_2); DCA-CF (average of 0.4 kPa O_2 + 1.2 kPa CO_2); and ULO with 1.2 kPa O_2 and three partial pressures of CO_2 (1.2; 1.6; and 2.0 kPa). The variation of storage conditions during the nine months is shown in Fig. 1.

The fruit were stored at a temperature of 1.0 ± 0.1 °C and relative humidity of 94 ± 1% for nine months and evaluated after seven d shelf life at20 ± 1 °C and RH of 65 ± 5%.

2.2. Control and maintenance of the storage atmosphere

Fruit were stored in experimental chambers of 0.23 m^3.Nitrogen, from a N_2 separator and purity of 996%, was applied until the pre-established level of O_2 was reached. In the ULO, the CO_2 level was obtained by the accumulation of gas in the storage rooms due to the fruit respiration. During the storage period, the levels of O_2 and CO_2 were determined and adjusted daily with the aid of an automatic control system (Valis®, Lajeado, RS, Brazil). The equipment had a gas analyzer (Siemens, Ultramat, Germany) with two case after point, it compared the oxygen and carbon dioxide measured to a set point. If the oxygen was lower than the set point, cold air was injected until the desired partial pressure was reached. When the level of CO_2 was higher than the desired partial pressure, the excess was automatically absorbed with the aid of a lime absorbent.

For DCA-CF, the partial pressure of O_2 was monitored and adjusted according to the methodology proposed by Prange et al. (2007), with the aid of a HarvestWatch™ system. The fluorescence peak was detected at 0.06 kPa of O_2 and subsequently the O_2 was injected and maintained between 0.35 and 0.45 kPa.

For DCA-RQ, the RQ was initially calculated every two days and subsequently every three days from day 40 until the end of storage. The storage rooms were kept closed for 14 h for the calculation of the RQ. RQ was calculated by the ratio between CO_2 production and O_2 uptake. The partial pressure of O_2 was adjusted (increased and decreased) so that the RQ remained close to 1.5 during the entire period of storage. The stipulated respiratory quotient was reached on day 7 d storage.

2.3. Evaluation of the fruit quality

The respiratory rate, ethylene production, flesh firmness, titratable acidity and soluble solids were determined as described by Thewes et al. (2015).

Flesh breakdown was evaluated by counting the number of apples that showed signs of internal browning. Mealiness incidence was determined by the quantification of the fruit that showed symptoms of dry flesh without juiciness. Sound fruit were quantified by counting the number of apples that did not show incidence of decay, cracks, flesh breakdown and mealiness. Incidences are expressed as percentages.

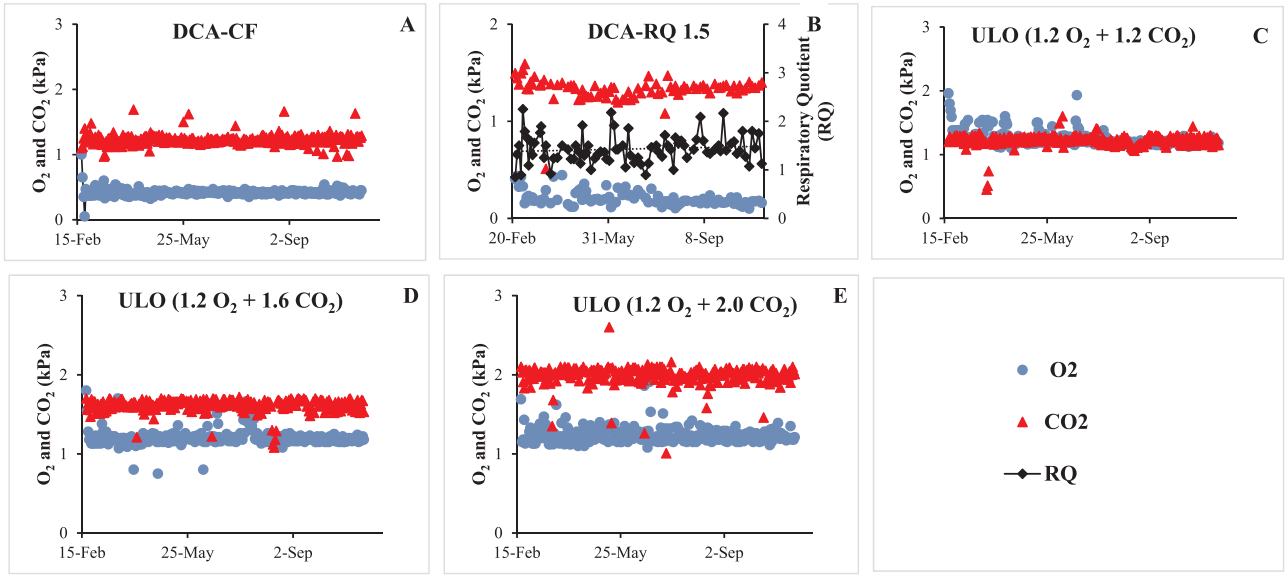

Fig. 1. Storage conditions (O_2; CO_2 and respiratory quotient-RQ) during the nine months in the treatments evaluated. A: DCA-CF (dynamic controlled atmosphere monitored by chlorophyll fluorescence); B: DCA-RQ (dynamic controlled atmosphere monitored by the respiratory quotient); C: ULO (ultralow oxygen condition) 1.2 kPa O_2 + 1.2 kPa CO_2; D: ULO 1.2 kPa O_2 + 1.6 kPa CO_2; E: ULO 1.2 kPa O_2 + 2.0 kPa CO_2.