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Research paper

1-methylcyclopropene suppresses anaerobic metabolism in apples stored under dynamic controlled atmosphere monitored by respiratory quotient

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ABSTRACT

The aim of the present work was to assess the effect of 1-methylcyclopropene treatment on 'Galaxy', 'Fuji' and 'Pink Lady' apples harvested at two maturity stages (ripe and overripe) and stored under a new type of dynamic controlled atmosphere based on respiratory quotient (DCA-RQ1.5) and its effect on the anaerobic metabolism products formation (compounds related to off-flavours) and quality keeping after 9 months of storage plus 7 days of shelf life at 20 °C. The 1-methylcyclopropene (1-MCP) application suppressed the anaerobic metabolism products formation of the three apple cultivars and two maturity stages studied after 9 months of storage in DCA-RQ 1.5 plus 7 days of shelf life at 20 °C. Additionally, the anaerobic metabolism had a distinct behavior among maturity stages and apple cultivars. 1-MCP application also resulted in lower ACC oxidase enzyme activity and ethylene production. Thus, 1-MCP become an important technique to suppress the anaerobic metabolism risk of apples stored under DCA-RQ 1.5. 1-MCP treatment not result in higher flesh firmness maintenance after storage in DCA-RQ 1.5.

1. Introduction

During the last few years, there is a trend to store apples under dynamic controlled atmosphere (DCA), especially during long periods. There are three methodologies to monitor the lowest oxygen partial pressure during DCA storage: based on ethanol production by fruit (Eth) (Veltman et al., 2003), fruit chlorophyll fluorescence emission (DCA-CF) (Prange et al., 2007; Wright et al., 2012) and respiratory quotient (DCA-RQ) (Gasser et al., 2008; Wright et al., 2012; Brackmann et al., 2015; Weber et al., 2015). These three methods allow to detect the lower oxygen level tolerated by the fruit before initiating anaerobic metabolism and the necessity to vary the oxygen partial pressure during storage to avoid excessive anaerobic metabolism.

In the literature, there are some studies showing the effect of DCA on quality maintenance. Apple storage under DCA based on chlorophyll fluorescence (DCA-CF) resulted in higher flesh firmness maintenance (Zanella et al., 2008; Thewes et al., 2015a), lower ethylene production and flesh breakdown as compared to fruit stored under controlled atmosphere (Thewes et al., 2015a). On the other hand, Weber et al. (2015) found evidences that fruit stored under DCA-RQ maintained better quality as compared to DCA-CF and they attributed it to the effect of anaerobic metabolism products on ethylene production and cell wall enzyme activity. The storage under DCA-RQ with RQ values higher to 1.0 induces the anaerobic metabolism, resulting in acetaldehyde, ethanol and ethyl acetate formation (Both et al., 2017; Weber et al., 2017; Thewes et al., 2017), compounds that confers off-flavour to apple, if produced in large amount (Raffo et al., 2009; Wright et al., 2015). Thus, is important the development of a technique to mitigate the formation of these compounds in apple stored under extremely low oxygen, without reducing fruit quality maintenance due to the effect of these compounds on metabolism.

The effect of 1-MCP application on apples stored under controlled atmosphere is well known. Its application maintained higher flesh firmness (Watkins, 2006; Watkins and Nock, 2012), lower ethylene biosynthesis (Watkins, 2006; Watkins and Nock, 2012), respiration rate (Pre-Aymard et al., 2003; Steffens et al., 2008; Brackmann et al., 2010) and mealiness incidence (Steffens et al., 2008). However, there are no results in the literature evaluating its effect on the anaerobic metabolism products formation, which are related to off-flavour formation, such as ethanol and ethyl acetate in apples stored under DCA. In the literature, there are some studies evaluating the effect of 1-MCP on the volatile compounds formation of apples (Lurie et al., 2002; Kondo et al.,

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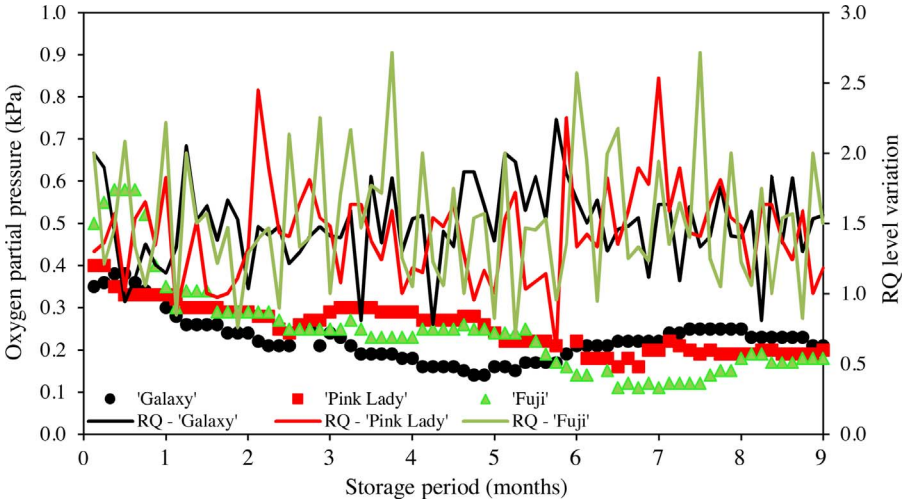

Fig. 1. Oxygen partial pressure variation (mean of the two maturity stages) according to fruit metabolism to maintain RQ 1.5 and the calculated RQ level variation in 'Galaxy', 'Fuji' and 'Pink Lady®' during 9 months of storage in DCA-RQ.

2005; Raffo et al., 2009; Lee et al., 2012), but little reports were found evaluating its effect on apples stored under DCA-RQ, with RQ level above 1.0, where the anaerobic metabolism of fruit become important.

In this context, the aims of the present work were to assess the effect of 1-MCP treatment on 'Galaxy', 'Fuji' and 'Pink Lady®' apples harvested at two maturity stages (ripe and overripe) and stored under DCA-RQ1.5 on the anaerobic metabolism products formation and quality keeping after 9 months of storage plus 7 days of shelf life at 20 °C.

2. Material and methods

2.1. Plant material, harvest and transportation to laboratory

Three apple cultivars were used at the present work, Galaxy, Fuji and Pink Lady®, which correspond to approximately 95% of the apples produced in Brazil and they are widely produced around world. These apples were harvested in a commercial orchard located in Vacaria-RS, Brazil.

Apples of the three cultivars were harvest at two maturity stages (ripe and overripe), according to their iodine-starch index (1–completely starch (unripe) and 10–completely hydrolyzed starch (overripe)) as proposed by Streif (1984). Apple with iodine-starch between 3.5 up to 6.5 were considered ripe and iodine-starch higher to 6.5 overripe apples. In each harvest, the iodine-starch index was determined in 4 replicates of 20 fruit each.

Immediately after harvest, the apples were transported to the Postharvest Research Center of the Federal University of Santa Maria, RS, Brazil. Thereafter the fruit were selected to remove the ones with any type of damage and homogenize its size. Afterward, 4 samples of 25 fruit per treatment, were performed. The treatments evaluated were: [1] without 1-MCP treatment and [2] with 1-MCP treatment at each maturity stage and apple cultivar.

2.2. 1-MCP application

After performing the samples, 1-MCP (SmartFresh®, 0.14% of active ingredient) was applied. Thus, fruit were stowed into a chamber with 233 Liters at a temperature of 1.5 °C. Thereafter, a solution containing 1-MCP was prepared (0.625 μL L^{-1} for 'Galaxy' apple and 1.0 μL L^{-1} for 'Fuji' and 'Pink Lady®' apples). Immediately after, the solution was put into Petry disks located inside the chamber and the chamber was immediately closed during 24 h. During this period, the air contained in the chamber was bustling with a fan. After this period, the fruit were removed from the 1-MCP application chamber and stored under DCA-RQ 1.5 during 9 months.

2.3. DCA-RQ 1.5 setup and maintenance

Fruit of the two lots, without and with 1-MCP, of the three cultivars and two maturity stages, were put into 233 Liters experimental chambers and hermetically closed, three experimental chambers were used. Afterward, the temperature was reduced down to 5.0 °C, at the first storage day, and thereafter reduced gradually to the desired storage temperature in 7 days (final temperature: 0.5 °C for 'Fuji' and 1.5 °C for 'Galaxy' and 'Pink Lady®'). After this, the DCA storage conditions were installed. Thus, the chambers were flushed with nitrogen to lowering the oxygen partial pressure down to 0.5 kPa. The targed carbon dioxide partial pressures was obtained by fruit respiration. Every time its concentration was higher to 1.2 kPa, for 'Galaxy' and 'Fuji', and 1.0 kPa for 'Pink Lady®' apples, the carbon dioxide was absorbed with a lime scrubber. The atmosphere was monitored continuously with the aid of an automatic dynamic controlled atmosphere system (Valis®, Lajeado, RS, Brazil).

In order to change the oxygen partial pressure, according to the fruit metabolism, the methodologies proposed by Weber et al. (2015) and Brackmann et al. (2015) were used. Thereby, the respiration quotient (RQ) was seated at 1.5 (DCA-RQ 1.5) and the oxygen partial pressure changed accordingly, to obtain this RQ level (Fig. 1). During the experiments, the oxygen partial pressure was changed according to fruit metabolism in order to maintain RQ 1.5 during the entirely storage time, as showed in Fig. 1. The relative humidity was maintained at 94 ± 1% during the entirely storage period by the addition of calcium chloride.

2.4. Fruit metabolism, quality and anaerobic metabolism (compounds related to off-flavours formation)

The fruit metabolism (ACC oxidase enzyme activity, ethylene production, respiration rate and pyruvic acid concentration), quality (titratable acidity and flesh firmness) and compounds related to anaerobic metabolism (acetaldehyde, ethanol and ethyl acetate) were evaluated after 9 months of storage plus 7 days of shelf life at 20 ± 1 °C, relative humidity 80 ± 2%.

2.4.1. ACC oxidase enzyme activity

The method proposed by Bufler (1986) was used to determine the ACC oxidase enzyme activity. Results expressed in ng kg^{-1} s^{-1}.

2.4.2. Ethylene production and respiration rate

A batch of approximately 1.5 kg fruit was put into a 5 Liters container and hermetically closed during about 2 h. Thereafter, two samples of 1 mL were taken of the container and injected into a Varian gas