Scientia Horticulturae 198 (2016) 414–423

Contents lists available at ScienceDirect

Scientia Horticulturae

journal homepage: www.elsevier.com/locate/scihorti

Review

Mass loss by low relative humidity increases gas diffusion rates in apple flesh and allows the use of high CO_2 partial pressures during ultralow O_2 storage

Rogerio de Oliveira Anese[a,*], Auri Brackmann[b], Fabio Rodrigo Thewes[b], Erani Eliseu Schultz[b], Adriano Roque De Gasperin[c]

[a] Federal Institute of Santa Catarina (IFSC), Campus Urupema, Senadinho Road, Center, Urupema, Santa Catarina, 88625-000 SC, Brazil
[b] Federal University of Santa Maria (UFSM), Postharvest Research Center, Roraima Avenue, 1000, Santa Maria, Rio Grande do Sul, 97105-900 RS, Brazil
[c] Technical and Rural Extension Company (EMATER/RS), Lopes Trovão Street, 456, Candelária, Rio Grande do Sul, 96930-000 RS, Brazil

A R T I C L E I N F O

Article history:
Received 13 October 2015
Received in revised form 7 December 2015
Accepted 11 December 2015
Available online 22 December 2015

Keywords:
Malus domestica Borkh.
Physiological disorders
Quality
Conservation
Controlled atmosphere

A B S T R A C T

Gas diffusion rate in fruit flesh (O_2 uptake and CO_2 release) is crucial to reduce physiological disorders and maintain the quality of apples during controlled atmosphere (CA) storage. The main goal of this paper was to evaluate the effect of mass loss on gas diffusion rate and sensitivity to high CO_2 partial pressure on 'Royal Gala' and 'Galaxy' apples (*Malus domestica* Borkh.) during CA storage. Thereby, two experiments (E1—'Royal Gala' and E2—'Galaxy') were carried out: in E1, two levels and periods of mass loss induced by low relative humidity (RH) were evaluated: 3 or 1% of mass loss during initial of storage period (initial) or throughout all storage period (linear). In E1, fruits were stored in CA with 1.2 kPa O_2 + 2.0 kPa CO_2. In E2, low O_2 (0.4 kPa) and high CO_2 (3 kPa) partial pressure associated with mass loss of 3% (initial or linear) were assessed. One of the main parameters evaluated was gas diffusion rate. After storage, we founded that mass loss induced by low RH, increased gas diffusion in flesh of 'Royal Gala' and 'Galaxy' apples, reduced pulp cracking, flesh breakdown and mealiness during CA storage. 3% linear or initial mass loss, maintained better 'Royal Gala' apple quality compared to 1% of mass loss. 3% initial mass loss, by low RH (90%) during two months, may allow a high CO_2 partial pressure (3.0 kPa) use during the storage of 'Galaxy' apple in CA.

Contents

* Corresponding author.
E-mail address: rogerio_anese@yahoo.com.br (R.d.O. Anese).

http://dx.doi.org/10.1016/j.scienta.2015.12.015
0304-4238/

1. Introduction

In Brazil, 'Gala' strains, such as 'Royal Gala' and 'Galaxy', represent about 60% of apple production in the country's southern states (Agapomi, 2015). Most apples are stored in controlled atmosphere (CA), however quality losses still occur (Corrent et al., 2009), which can be associated with relative humidity (RH).

RH plays an important role in fruit storage. When excessively high, it provides conditions for the development fungal diseases and physiological disorders, and when excessively low, it causes high mass loss and wilting (Schwarz, 1994; Veraverbeke et al., 2003; Brackmann et al., 2005). However, mass loss by low RH showed good results in post storage quality maintenance (Scott and Roberts, 1968; Brackmann et al., 2007; Weber et al., 2013). In the past, Scott and Roberts (1968) founded that 1% of mass loss reduced internal breakdown in 'Jonathan' apples. 'Galaxy' apples submitted to 3.5% of mass loss showed lower ethylene production and high flesh firmness, without the occurrence of wilting (Weber et al., 2013). In another work, Brackmann et al. (2007) verified low decay, internal breakdown and mealiness with 1.6 and 3.2% of mass loss in 'Royal Gala' apple stored in CA. Our hypothesis is that low RH in storage rooms induces the release of intracellular and cellular water to the atmosphere of the storage room, and this fact may increase the intercellular space and the gas diffusion rate, improving gas exchange. An increase of the CO_2 partial pressure during the CA storage may be possible to achieve with a high level of gas diffusion.

Gas diffusion is very important to fruit metabolism, because during respiration O_2 uptake and CO_2 release happens, which needs to be diffused through the fruit pulp (Ho et al., 2013). Excessively high CO_2 or low O_2 causes physiological disorders (Saquet et al., 2000, 2001, 2003; Larrigaudiere et al., 2001; Castro et al., 2008; Herremans et al., 2013; Ho et al., 2013). Low O_2, besides producing fermentation compounds, also reduces energy production (ATP), hence cell membrane reparation is lessened, inducing the cell to collapse (Saquet et al., 2000; 2001; 2003; Ho et al., 2013), which is showed by internal breakdown (Franck et al., 2007). High CO_2 may cause oxidative stress and reactive oxygen species formation, which leads to cell damage and browning (Castro et al., 2008; Herremans et al., 2013).

If the mass loss induction, caused by low levels of RH, improves the gas diffusion rate, the CO_2 partial pressure could possibly be increased during the apple storage, without causing tissue damage by the CO_2 accumulation in the cell. Thus, certain benefits may occur, such as: a reduction in the respiration rate; low levels of ethylene production; a better quality maintenance; and, especially, a reduction in the energy consumption through the elimination of CO_2 in the chamber, considering that the higher the CO_2 partial pressure, the efficiency on gas adsorption is increased.

Thus, the aim of this work was to evaluate if the induction of mass loss by low RH improves the gas diffusion rate and enables the use of higher CO_2 partial pressure in 'Royal Gala' and 'Galaxy' apples stored in CA.

2. Materials and methods

2.1. Fruit harvest

Two experiments were carried out to test our hypothesis. 'Royal Gala' apple were used as plant material in the year of 2012 (experiment 1) and 'Galaxy' apple in 2013 (experiment 2). Both cultivars were harvested in a commercial orchard, in the city of Vacaria, RS—Brazil and stored in the Postharvest Research Center of the Federal University of Santa Maria, RS—Brazil. At harvest 'Royal Gala' apples showed flesh firmness of 83.7 N, tritatable acidity of 0.32 g malic acid L^{-1}, Soluble solids (SS) of 11.6%, ACC oxidase enzyme activity (C_2H_4) of 8.48 ng g^{-1} s^{-1}, ethylene production of 0.12 ug kg^{-1} s^{-1}, respiration rate (CO_2) of 6.31 μg kg^{-1} s^{-1} and iodine start index of 6.1 (0: unripe–10: overripe). 'Galaxy' apples showed flesh firmness of 78.6 N, tritatable acidity of 0.35 g malic acid L^{-1}, SS of 11.4%, ACC oxidase enzyme activity (C_2H_4) of 9.69 ng g^{-1} s^{-1}, ethylene production of 0.35 ug kg^{-1} s^{-1}, respiration rate (CO_2) of 17.0 μg kg^{-1} s^{-1} and iodine start index of 6.9.

2.2. Treatments evaluated on experiment 1 (E1)—cv. Royal Gala

Mass loss was induced by low relative humidity in both experiments. Treatments evaluated on E1 were: (1) control (99% RH), according to Fig. 1; (2) 3% of linear mass loss (95% RH during all storage period) (3% LML); (3) 3% of initial mass loss (90% RH during the first 2 months of storage, after this period RH was maintained at 99%) (3% IML); and (4) 1% of initial mass loss (92% RH during the first month of storage, after this period RH was maintained at 99%) (1% IML). Deviation of RH was 1%. All fruit were stored in CA with 1.2 kPa O_2 + 2.0 kPa CO_2, at temperature of 1 °C during 8 months. The control treatment (T1), without mass loss induction, showed 0.90% of mass loss.

2.3. Treatments evaluated on experiment 2 (E2)—cv. Galaxy

The following treatments were evaluated: (1) control (99% of RH); (2) 3% IML, according to T3 of experiment 1; and (3) 3% IML, according to T2 of experiment 1. The samples submitted to these treatments were stored under 1.2 kPa CO_2 and 3.0 kPa CO_2. Ultralow O_2 partial pressure was used for all treatments, in order to induce the physiological disorders. Fruits were stored at 1 °C during 9 months. The control treatment (T1), without mass loss induction, showed 0.88% of mass loss.

2.4. Mass loss induction by low RH

In order to assess the chamber's absorption humidity, a KNF Neuberger pump (model D-79112, rate of 2.8 L min^{-1}) was used to pump the chamber air into a 5 L container with silica gel (2.5 kg). Monthly fruits were weighted to accompanist the mass loss of the fruits.

The desired level of RH was kept by means of an electronic humidity controller that activated the pump whenever the RH was higher than the set point. The RH in the 180 L chambers was monitored daily with psychrometers with mercury thermometers. In the treatments with RH of 99%, the humidity was not absorbed, since it remained high (98–100%) due to the low temperature in the CA chambers.

2.5. CA achieving and maintenance during storage

Fruits of all experiments were stored in an experimental chamber (with a volume of 180 L), which was placed inside a cold storage room. Temperature was lowered down to 5 °C in the first day of storage. After that the temperature was lowered at a rate of 1 °C per