ISSN 0100-2945 http://dx.doi.org/10.1590/0100-29452017714

QUALITY PRESERVATION OF 'LAETITIA' PLUMS IN ACTIVE MODIFIED ATMOSPHERE STORAGE[1]

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ABSTRACT- Recent studies have shown that passive modified atmosphere storage (MA) delays the ripening of 'Laetitia' plums but it increases the incidence of internal browning in comparison to cold storage (CS), possibly due to high CO_2 and/or ethylene accumulation inside the package. The aim of this study was to evaluate the effect of active MA conditions [LDPE film (40 μm)] with CO_2 absorber combined with low ethylene (LE) on ripening and quality preservation of 'Laetitia' plums during storage at 0.5ºC±0.1ºC and RH of 96%±2%. The treatments evaluated were cold storage (CS; 21.0 kPa O_2 + <0.03 kPa CO_2); non-perforated MA with CO_2 absorber; non-perforated MA with CO_2 absorber and LE; perforated MA (with two perforations with diameter = 0.5 mm) with CO_2 absorber; and perforated MA with CO_2 absorber and LE. The partial pressures of O_2 + CO_2 (kPa) were 1.2 + <0.1 and 2.8 + <0.1, in non-perforated and perforated MA, respectively. Active MA, mainly non-perforated package, with CO_2 absorber and LE, delayed fruit ripening, but did not reduce the incidence of internal breakdown in 'Laetitia' plums cold stored for 60 days. Fruits in active MA, with perforated or non-perforated package, with CO_2 absorber and LE, showed lower intensity of internal breakdown than CS.

Index terms: *Prunus salicina*, internal breakdown, ethylene, postharvest, ripening.

MANUTENÇÃO DA QUALIDADE DE AMEIXAS 'LAETITIA' ARMAZENADAS EM ATMOSFETA MODIFICADA ATIVA

RESUMO – Trabalhos recentes têm demonstrado que a atmosfera modificada (AM) passiva retarda o amadurecimento de ameixas 'Laetitia', mas causa maior ocorrência de escurecimento da polpa do que o armazenamento refrigerado (AR), possivelmente devido ao acúmulo de CO_2 e/ou ao etileno no interior da embalagem. O objetivo deste trabalho foi avaliar o efeito da AM ativa, com absorção de CO_2, combinada com baixo etileno (BE) sobre o amadurecimento e a manutenção da qualidade de ameixas 'Laetitia' durante o armazenamento a 0,5ºC±0,1ºC e UR de 96%±2%. Os tratamentos avaliados foram: AR (21 kPa de O_2 + 0,03 kPa de CO_2); AM + absorvedor de CO_2; AM + absorvedor de CO_2 e BE; AM com perfuração (duas perfurações de 0,5 mm de diâmetro) + absorvedor de CO_2; AM com perfuração + absorvedor de CO_2 e BE. Nos tratamentos com AM, foi utilizado o filme de polietileno de baixa densidade de 40 μm. As pressões parciais médias de O_2 + CO_2 (kPa) foram 2,8 + <0,1 e 1,2 + <0,1, em AM com perfuração e AM sem perfuração, respectivamente. A AM ativa, especialmente em embalagem não perfurada, com absorvedor de CO_2 e BE (<0,04 $\mu L\ L^{-1}$), retardou o amadurecimento dos frutos, mas não reduziu a incidência de escurecimento da polpa após 60 dias de armazenamento. Os frutos acondicionados em AM ativa, em embalagem com ou sem perfuração, com absorvedor de CO_2 e BE, apresentaram menor intensidade de escurecimento da polpa do que em AR.

Termos para indexação: *Prunus salicina*, escurecimento de polpa, etileno, pós-colheita, amadurecimento.

[1](Paper 235-15). Received on September 29, 2015. Accepted April 12, 2016.
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INTRODUCTION

'Laetitia' plums show rapid ripening and a reduced postharvest life, the storage period being limited by the rapid loss of flesh firmness and internal browning (SINGH; SINGH, 2013a; STEFFENS et al., 2014).

The internal browning is a disturbance that affects plums stored under refrigeration, being considered damage by cold (SINGH et al., 2009; SINGH; SINGH, 2013b). The internal browning due to an oxidative process related to the production of reactive oxygen species has been proposed, which cause lipid peroxidation and the reduction in the efficiency of antioxidant systems, with consequent damage to cell membranes (SINGH; SINGH, 2012; 2013a; 2013b). In addition, internal browning may be aggravated by the action of the ethylene (CANDAN et al., 2008; 2011), as well as by a reduction of the energy metabolism, implying a lower energy supply for the maintenance of cell membranes (SAQUET et al., 2003). Storage conditions with excessive O_2 reduction or CO_2 increase raise the incidence and severity of internal browning (SINGH; SINGH, 2013a, STEFFENS et al., 2014), as they compromise the antioxidant system (SINGH; SINGH, 2013a).

The storage in modified atmosphere (MA) associated with the temperature reduction has allowed some fruits to be stored for longer and with better quality maintenance (ALI et al., 2004) because it is a storage system that causes greater reduction in the cellular metabolism than the isolated use of the refrigeration (STEFFENS et al., 2007a).The temperature reduction, the decrease of the partial O_2 pressure and the increase of the partial CO_2 pressure through the MA are the main factors that contribute to the maintenance of the product quality and, consequently, the reduction of post-harvest losses (STEFFENS et al., 2007a). Thus, the MA could increase the supply period of the 'Laetitia' plum, as well as enable the commercialization of better quality fruits during the off season.

Although MA contributes to the maintenance of fruit quality, it may in some cases induce fermentation and the development of physiological disturbances in fruits, due to the intense reduction in O_2 levels and increase of CO_2 (STEFFENS et al., 2007b). 'Laetitia' plums stored for 60 days in MA, where CO_2 accumulation occurred between 9.6 and 16 kPa, although this condition delayed fruit maturation, there was an increase in the incidence of internal browning (STEFFENS et al., 2009). However, MA conditions without CO_2 accumulation can be promising because controlled atmosphere conditions with low O_2 and CO_2 levels (up to 1 kPa) provided the best results for maintaining the quality of 'Laetitia' plums (STEFFENS et al., 2014). In this way, the use of CO_2 absorber inside the MA storage would be an alternative to reduce the partial pressure of this gas in the package and could delay the ripening of 'Laetitia' plums, without increasing the incidence and/or severity of internal browning.

Several studies have demonstrated the effect of 1-methylcyclopropene (1-MCP), an ethylene action inhibitor, on ripening delay and control of plum internal browning (ARGENTA et al., 2003; CANDAN et al., 2006; 2011; CORRÊA et al., 2011). However, the 1-MCP has a high cost and a difficult application management to be implemented in MA storage. Thus, the addition of ethylene absorber within the MA package may represent an alternative to minimize the ethylene effects, and thereby delay the ripening that occurs during prolonged periods of cold storage and to prevent physiological disorders.

The aim of this study was to evaluate the effect of active MA, with CO_2 absorber and low ethylene, on ripening and maintenance of postharvest quality of 'Laetitia' plums.

MATERIALS AND METHODS

The 'Laetitia' plums were harvested in a nine-year-old commercial orchard, conducted in a "Y" system, located in the municipality of Lages-SC (27º48'58" S and 50º19'34" W), and after being transported to the laboratory of Postharvest Physiology and Technology of the Agroveterinary Sciences Center of the State University of Santa Catarina. In the laboratory, the fruits were selected; eliminating those with lesions, defects or mechanical damages, and later the homogenization of the experimental units was carried out.

The experimental design was completely randomized, with four replicates per treatment and experimental unit composed of 30 fruits. The treatments used were: cold storage (CS; 21 kPa of O_2 + 0.03 kPa of CO_2), MA + CO_2 absorber; MA + CO_2 absorber and low ethylene (LE); perforated MA + CO_2 absorber; perforated MA + CO_2 absorber and LE. In the MA treatments, the low-density polyethylene film of 40 μm was used, and a sachet containing hydrated lime (50 g kg^{-1} of fruit) was placed inside the package to absorb CO_2. In the perforated MA treatment, two perforations of 0.5 mm diameter were carried out in the middle region of the package. In the treatments with LE, the chemical absorption of this gas inside the package was carried out through the addition of sachets (a sachet of 10g for every three kilos of fruits) containing pellets with $KMnO_4$.The fruits of all treatments were stored for 60 days in a cold room at a temperature of 0.5ºC±0.1ºC and RH of 96%±2%.

During storage, the partial pressures of O_2 and CO_2 were monitored weekly, using an Agridatalog gas analyzer.

After 60 days of storage, the samples were divided into two sub-samples of 15 fruits, one for analysis at the exit of the chamber and another for analysis after three days of shelf life (20±2ºC/60±5% of RH). The variables analyzed were flesh firmness, texture attributes (forces to peel rupture, flesh penetration and fruit compression), red color index (RCI), color of the epidermis (*hº*), intensity of internal browning (L), occurrence of cracking, rot and internal browning, respiratory and ethylene production rates, titratable acidity (TA) and soluble solids (SS), according to the methodology described in Corrêa et al. (2011) and Steffens et al. (2014).

The data were submitted to analysis of variance and the averages of the treatments were compared by the Tukey test ($p < 0.05$), with the SAS program. The percentage data, before being submitted to ANOVA, were transformed by the arcsen $[(x+0.5)/100]^{1/2}$.

RESULTS AND DISCUSSION

The average atmospheric composition was 1.2 kPa of O_2 + <0.1 kPa of CO_2 and 2.8 kPa of O_2 + <0.1 kPa of CO_2 for MA without and with perforated package, respectively. The average concentration of ethylene in the treatments during storage was 5.22 $\mu L\ L^{-1}$ in CS, 2.77 $\mu L\ L^{-1}$ in MA treatments without ethylene absorption, and <0.04 $\mu L\ L^{-1}$, in MA treatments with LE.

After three days of fruit exposure under ambient conditions, all fruits in MA had lower ethylene production rates than CS fruits (Table 1).The MAP, due to the respiratory process of the fruits and the diffusion barrier of the gases, reduced the partial pressure of O_2 during storage, reducing the oxidation of the ACC (1-aminocyclopropane-1-carboxylic acid) to ethylene (BLANKENSHIP; DOLE, 2003), and the effect of the low O_2 storage on the reduction of ethylene production may persist during the period of exposure to the ambient condition (BRACKMANN et al., 2015).

The respiratory rate, at the exit of the chamber, was lower in fruits in MA with perforated packages plus the use of CO_2 and LE absorbers and in MA without perforated package and with CO_2 absorber, independent of the ethylene absorption (Table 1).This result shows that in MA with perforated package, the modification of the atmosphere, in terms of O_2 reduction, was less intense, providing higher ethylene production in these fruits, since O_2 is required for the oxidation of ACC to ethylene by the enzyme ACC oxidase. After three days under ambient conditions, the respiratory rate was lower in fruits in MA with non-perforated package, plus CO_2 and LE absorber (Table 1), but without differing from MA treatment with non-perforated and CO_2 absorber package. Probably, the respiratory rate of the fruit was reduced by the low partial pressures of O_2 inside the non-perforated package (BRACKMANN et al., 2006), and this effect persisted during the fruit exposure period under ambient conditions.

The fruits of all MA treatments showed a lower red color index and lower intensity (higher *hº*) of red color in both evaluations than those maintained in CS. The MA treatments, on the other hand, showed differences between them only in the three days of shelf life, where the fruits in MA with package without perforation and with CO_2 absorber showed lower value of red color index and higher *hº* (Table 1). Under MA conditions, there was a reduction in the partial pressures of O_2, which should have exerted greater control in the biosynthesis and ethylene action and, consequently, on the evolution of the fruits color, especially in the fruits in MA with packages without perforation. The color maintenance of the epidermis should be related to the lower biosynthesis and ethylene action in MA (JAYAS; JEYAMKONDAN, 2002), because the color change during the ripening of plums is a process dependent on the action of this phytohormone (ARGENTA et al., 2003; CANDAN et al., 2006; CANDAN et al., 2011).

After 60 days of storage plus three days at ambient conditions, flesh firmness and texture attributes (forces to epidermis rupture, flesh penetration and fruit compression) were higher in fruits in MA with non-perforated package and with CO_2 absorber, independent of ethylene (Table 2).The flesh firmness considered one of the attributes of greater importance in fruits quality, since it influences the fruit crunchiness and affects the resistance to the transport and the attack of microorganisms (JAYAS; JEYAMKONDAN, 2002; JERONIMO et al., 2007). The fruit softening, after color change, is the most evident transformation occurring during the plums ripening. The reduction of the partial pressure of O_2 acts inhibiting glycolysis, the cycle of tricarboxylic acids and the respiratory chain (SAQUET et al., 2003), besides reducing ethylene biosynthesis, causing less degradation of the cell wall by the action of hydrolytic enzymes that are dependent on this phytohormone (ALI et al., 2004; CIA et al., 2006).

In this study, no LE effect was observed on the maintenance of flesh firmness and forces for peeling rupture and fruit compression. However, for the force to penetrate the flesh, the LE maintained a higher value (Table 2). During the ripening of the fruits, an increase in the activity of the pectinamylesterase and polygalacturonase enzymes occurs and the middle lamella disintegration occurs, processes influenced by the ethylene action, with consequent softening of the fruits (KHAN; SINGH, 2007; CANDAN et al., 2011). Although the flesh firmness and the flesh penetration force are related variables, there was a slightly different behavior among them. This is due to the fact that in the evaluation of flesh firmness, the resistance of the epidermis and the hypodermic tissue are disregarded (GUILLERMIN et al., 2006). Steffens et al. (2013) observed similar behavior in 'Laetitia' plums stored under controlled atmosphere.

The TA was higher in fruits in MA with non-perforated package and with CO_2 and LE absorber, after 60 days of storage and three days of exposure at ambient conditions, than in fruits kept in CS (Table 3). The organic acids are substrates of the respiratory process and may be less degraded due to the reduction in respiratory rate under MA and LE conditions (CIA et al., 2006).

The incidence of cracked fruits at the exit of the chamber was lower in MA treatment in non-perforated packages with CO_2 and LE absorber than in CS and MA treatments in perforated package and with CO_2 absorber (Table 3). However, there was no difference between treatments after three days shelf life (data not shown). In the 'Laetitia' plums, stored under controlled atmosphere, the low O_2 reduced the occurrence of cracks, compared to CS (STEFFENS et al., 2014), corroborating with the results of this study, and a higher occurrence of this disorder is possibly related to excessive fruit ripening.

All treatments showed 100% incidence of internal browning after three days in ambient conditions (Table 3). However, in spite of the fact that all the treatments had a high incidence of internal browning, the fruits kept in MA with CO_2 absorber and LE, regardless of whether the package was perforated or not, showed lower internal browning intensity (*L* - pulp color), after three days of shelf life. The internal browning, although it is a cold-induced disorder, is aggravated by the action of ethylene (ARGENTA et al., 2003; CANDAN et al., 2008; CANDAN et al., 2011), corroborating with the results of this study.

The SS, after 60 days of storage and three days of fruit exposition at ambient conditions, and the incidence of rot, both at the exit of the chamber and after three days of fruits exposure at ambient conditions, showed no differences between treatments (data not shown).

The results show that the use of active MA, in package with or without perforation, with CO_2 absorber and LE, reduced the intensity, but not the incidence of internal browning, after 60 days of storage at 0.5ºC. This seems to show that, for 'Laetitia' plums, the refrigerated storage period should be less than 60 days. This justifies additional studies aiming to evaluate the potential of using active MA, with CO_2 and LE absorber, in ripening and internal browning control for periods of less than 60 days.

TABLE 1- Ethylene and respiratory rates and epidermis color of 'Laetitia' plums stored under different atmospheres for 60 days (0.5°C±0.2ºC/92±2% of relative humidity) at the exit of the chamber and after three days of shelf life (20±2ºC/ 60±5% of relative humidity).

Storage conditions	Ethylene production rate (pmol kg^{-1} s^{-1})	Respiratory rate (µmol CO_2 kg^{-1} s^{-1})	Epidermis color	
			RCI (1-4)****	ºh
Chamber exit				
CS*	-	403.8a	3.4a	51.9b
MA** + perforation	-	401.7a	2.9b	71.2a
MA + perforation + LE***	-	337.8b	2.9b	68.7a
MA	-	308.6b	2.5b	76.3a
MA + LE	-	339.0b	2.7b	73.9a
CV (%)	-	4.17	8.02	5.96
After three days of shelf life				
CS	4.2a	527.0a	3.8a	40.2c
MA + perforation	0.2b	501.6a	3.3ab	64.7ab
MA + perforation + LE	0.1b	493.7a	3.6a	57.6b
MA	0.5b	468.7ab	2.9b	73.3a
MA + LE	0.2b	385.4b	3.5ab	67.1ab
CV (%)	44.08	8.92	7.63	11.78

*CS: cold storage (21 kPa of O_2 + 0.03 kPa of CO_2); **MA: modified atmosphere with CO_2 absorber; ***LE: low ethylene; **** RCI: red color index (1 - 0-25%; 2 - 26-50%; 3 - 51-75% and 4 - 76-100% with red pigmented fruit surface). Averages in the columns followed by the same letter do not differ from each other by Tukey test ($p<0.05$).

TABLE 2- Flesh firmness and texture attributes (forces for peel rupture, flesh penetration and fruit compression) in 'Laetitia' plums stored under different atmospheres for 60 days (0.5°C ± 0.2°C/92±2% of relative humidity) followed by more three days of shelf life (20±2ºC/60±5% of relative humidity).

Storage conditions	Flesh firmness (N)	Force for peel rupture (N)	Force for flesh penetration (N)	Force for fruit compression (N)
CS*	19.0b	4.3c	0.8c	15.4b
MA** + perforation	17.5b	5.2b	0.8c	15.2b
MA + perforation + LE***	18.1b	5.5b	0.9c	15.7b
MA	22.4a	7.3a	1.1b	20.9a
MA + LE	24.1a	7.2a	1.3a	22.2a
CV (%)	14.2	6.3	6.2	5.7

*CS: cold storage (21 kPa of O2 + 0.03 kPa of CO2); **MA: modified atmosphere with CO_2 absorber; ***LE: low ethylene. Averages in the columns followed by the same letter do not differ from each other by Tukey test ($p<0.05$).

TABLE 3- Incidence of cracks, at the exit of the chamber, and titratable acidity, incidence and intensity of internal browning (pulp color measured by color attribute *L*), after three days shelf life (20±2ºC/60±5% of relative humidity) in 'Laetitia' plums stored under different atmospheres for 60 days (0.5°C±0.2°C/92±2% of relative humidity).

Storage conditions	Cracks (%)	Titratable acidity (meq 100 mL^{-1})	Internal browning (%)	Pulp color (*L*)
CS*	24.4a	5.9b	100	41.3bc
MA** + perforation	29.6a	6.2ab	100	39.5c
MA + perforation + LE***	13.3ab	7.3ab	100	48.7a
MA	13.4ab	6.3ab	100	45.4ab
MA + LE	4.4b	8.2a	100	48.1a
CV (%)	27.6	13.9	-	7.5

*CS: cold storage (21 kPa of O2 + 0.03 kPa of CO2); **MA: modified atmosphere with CO2 absorber; ***LE: low ethylene. Averages in the columns followed by the same letter do not differ from each other by Tukey test ($p<0.05$).

CONCLUSION

The active modified atmosphere, especially in non-perforated package with CO_2 absorber and low ethylene, delays ripening of fruits and reduces the intensity of internal browning, although it has no effect on the incidence of internal browning in 'Laetitia' plums stored for 60 days at 0.5°C.

ACKNOWLEDGEMENT

The authors thank the National Council for Scientific and Technological Development (CNPq) and the Foundation for Research and Innovation Support of the State of Santa Catarina (FAPESC) for the financial support for this project.

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