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Storage of 'Laetitia' plums (*Prunus salicina*) under controlled atmosphere conditions

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The optimum condition for storage of 'Laetitia' plums (*Prunus salicina*) under controlled atmosphere (CA) is not currently known. This study was aimed at assessing the effects of controlled atmospheric (CA) conditions on the postharvest quality preservation of 'Laetitia' plums. Besides regular atmosphere (RA; 21kPa O_2 + 0.03 kPa CO_2) as condition/treatment control, the following CA conditions (kPa O_2 + kPa CO_2) were assessed: 1+3; 1+5; 2+5; 2+10; and 11+10. In all cases, the fruit were stored for 60 days at 0.5°C±0.1°C and 96±2% of relative humidity (RH). Upon removal from the cold storage chamber and after four days in ambient conditions (20±2°C/60±5% RH), the fruit were assessed in terms of: respiration and ethylene production rates; flesh firmness; texture; titrable acidity; red color index and hue angle (h^o) of the skin; incidence of fruit cracking and internal breakdown (flesh browning). The fruit stored under the different CA conditions presented lower respiration and ethylene production rates, higher values of flesh firmness, texture and titrable acidity, lower development of skin red color, and lower incidence of skin cracking compared to the fruit under RA. CA conditions of 2+5, 1+5, and 1+3 resulted in a more substantial delay of ripening. CA conditions of 2+5 and 1+3 resulted in lower incidence of internal breakdown.

Key words: Ripening, physiological disorder, postharvest, *Prunus salicina.*

INTRODUCTION

The maturation of plums (*Prunus salicina*) is extremely fast, and its harvesting period usually does not last more than 20 days, providing a large amount of fruit in a short period of time. Nevertheless, the storage conditions can extend the supplying period. Storage under controlled atmosphere (CA) is the storage system that allows the maintenance of quality by reducing the fruit metabolism.

Storage of plums under CA is still little explored, and in the case of the 'Laetitia' cultivar, studies evaluating the CA conditions for maintaining quality are scarce. The studies were not able to define the ideal CA condition for storage. Nevertheless, better quality during storage under this system has been observed in plum, due to the reduction of chilling injury and the preservation of the

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physicochemical attributes (Streif, 1995; Maré et al., 2005; Manganaris et al., 2008).

Van de Geijn (1993) recommends the temperature of 0°C and CA condition of 3 kPa O_2 and 7 kPa CO_2 for European plums. Manganaris et al. (2008) observed higher flesh firmness in plums stored under CA at 1 to 2 kPa O_2 and 3-5 kPa CO_2, than in regular atmosphere (RA). According to Streif (1995), the best CA conditions for plums are partial pressures of 1 to 3 kPa O_2 and 8 to 12 kPa CO_2. The author also states that the use of partial pressures of 10 kPa CO_2 or higher inhibits the development of pathogens that cause decay. However, the benefits of CA condition in plums are cultivar-dependent (Manganaris et al., 2008).

Alves et al. (2010), in a previous study assessing the effect of CA on the quality of 'Laetitia' plums in Brazil, observed a delay in fruit ripening, where the condition which presented the best results was 2 kPa O_2 + 5 kPa CO_2. Nevertheless, the authors observed an increased incidence of internal breakdown and suggested that storage under CA conditions with lower O_2 and CO_2 levels may allow for storage without the occurrence of this disorder. CA reduces internal breakdown in plums, but fruits are very sensitive to CO_2; higher CO_2 concentration is associated with more severe anaerobic respiratory and flesh browning (Hui and Bo-Xun, 2007).

This study was aimed at assessing the effect of CA conditions on the maintenance of the physicochemical quality of 'Laetitia' plums.

MATERIAL AND METHODS

The "Laetitia" plums were harvested from a commercial orchard located in Lages, SC, southern Brazil, in 01/15/2010, and immediately transported to the laboratory, where the fruit were selected. The fruit with lesions, defects, wounds and/or mechanical damages were eliminated by visual inspection, and afterwards, the experimental units were homogenized.

The experiment followed a completely randomized design, with four repetitions of 30 fruits. Besides regular atmosphere (RA; 21 kPa O_2 + 0.03 kPa CO_2) as condition/treatment control, the following CA storage conditions were assessed (kPa O_2 + kPa CO_2): 1+3; 1+5; 2+5; 2+10; and 11+10. In all conditions, the fruit were stored during 60 days at 0.5°C±0.1°C and 96±2% RH in experimental minichambers (180 L), and the variations tolerated were of 0.1 kPa for O_2 and CO_2. The partial pressures of gases in the treatments with low O_2 and high CO_2 were obtained by means of diluting O_2 in the environment with injection of N_2 from a nitrogen generator which operates by the "Pressure Swing Adsorption" – (PSA) system, and afterwards, by injection of CO_2 from high pressure cylinders up to the level set for the treatment. The maintenance of the partial pressures determined for the gases under the different storage conditions (that varied according to the respiration of the fruit) was carried out daily. This monitoring was carried out by means of Agri-datalog electronic analyzers for CO_2 and O_2, with correction until the preset levels were reached. The O_2 consumed by respiration was replaced by means of the injection of atmospheric air in the minichambers, and the excess of CO_2 was absorbed by a solution of potassium hydroxide (40%) though which the ambient storage air was passed.

Before storage, an initial analysis of two samples of 15 fruits was carried out to determine the initial quality of plums. Fruit had flesh firmness of 42 N, soluble solids content of 9.3 ºBrix, and titratable acidity of 31.17 meq 100 mL^{-1}.

Fruit quality was assessed after 60 days of storage. Four samples of 15 fruit were analyzed after removal from the chamber, and another sample of 15 fruit were analyzed after four days of shelf life (20±2°C/60±5% RH). The variables analyzed were respiration and ethylene production rates, titratable acidity (TA), texture attributes, red color index and hue angle (h^o) of the skin and internal breakdown incidence, as described by Alves et al. (2010). Fruit were also assessed visually for the incidence (%) of skin cracks and decay (fruit affected with pathogen lesions higher than 5 mm in diameter)

Data were analyzed with SAS version 8.02 (SAS Institute, Cary, NC, USA) using analysis of variance (ANOVA) and Tukey's test to determine mean separation between treatments. The data expressed in percentage were transformed by arcsine $[(x+0.5)/100]^{1/2}$ before being submitted to ANOVA.

RESULTS AND DISCUSSION

Flesh firmness was higher in fruit stored under CA conditions than RA, after removal from the chamber as well as after four days of shelf life (Table 1). Similar results were obtained in other studies with 'Sapphire', 'Songold', 'Laetitia' and 'Stanley' plums (Maré et al., 2005; Golias et al., 2010). Among the CA conditions evaluated, the higher values obtained for flesh firmness after removal from the chamber were 2 kPa O_2 + 5 kPa CO_2, 1 kPa O_2 + 5 kPa CO_2 and 1 kPa O_2 + 3 kPa CO_2. CA conditions 11+10 and 1+10 had intermediate values of flesh firmness, but better than control treatment (Table 1). This result is partly in accordance with Streif (1995) and Manganaris et al. (2008), citing O_2 partial pressures between1 and 3 kPa as more appropriate for the storage of plums under CA. Nevertheless, Streif (1995) considers partial pressures of CO_2 between 8 and 12 kPa as ideal for storing plums under CA.

According to Golias et al. (2010), fruit softening, biochemically conditioned by spontaneous pectolysis of the contained pectin compounds, is noticeably slowed down in the atmospheres with lowered O_2 content; a higher content of CO_2 in the atmosphere (CA treatment) does not significantly slow down softening when compared to the low O_2. The authors observed that 'Stanley' plums stored for up to 55 days under CA had higher flesh firmness values in 0.5-0.6 kPa O_2 + 0.1-0.2 kPa CO_2 than in 1.2-1.4 kPa O_2 + 0.2-0.4 kPa CO_2 or 1.9-2.2 kPa O_2 + 8.7-8.9 kPa CO_2. These points out those different cultivars of plums behave differently with regard to storage conditions, and it might explain the difference between the results obtained in this study and the results obtained by other authors regarding the best partial pressures of O_2 and CO_2.

Fruit stored under CA conditions had higher values of peel break, flesh penetration and fruit compression forces than in RA upon removal from the chamber and after four days of shelf life (Table 1). The effect of CA on the texture attributes may be related to its role in reducing ethylene biosynthesis and action, therefore reducing the

Table 1. Flesh firmness, titratable acidity and texture attributes in 'Laetitia' plums stored under different atmospheres for 60 days, upon removal from storage and after four days of shelf life (20±2ºC/60±5% RH).

Atmosphere O_2+CO_2 (kPa)	Titratable acidity (meq 100 mL^{-1})	Texture attributes			
		Flesh firmness (N)	Peel break force (N)	Flesh penetration force (N)	Fruit compression force (N)
Removal from chamber					
21 + 0.03	12.4^{d}	16.9^{d}	4.42^{b}	1.11^{b}	42.8^{d}
1 + 3	19.4^{a}	35.6^{abc}	9.61^{a}	2.56^{a}	78.3^{abc}
1 + 5	18.0^{ab}	36.9^{ab}	9.41^{a}	2.47^{a}	86.3^{ab}
2 + 5	20.2^{a}	40.5^{a}	9.31^{a}	2.49^{a}	$101.^{2a}$
2 + 10	15.9^{bc}	30.2^{c}	9.95^{a}	2.23^{a}	77.3^{bc}
11 + 10	14.8^{c}	33.7^{bc}	9.15^{a}	2.02^{a}	62.5^{bcd}
CV (%)	7.8	8.7	6.2	12.4	16.4
After four days of shelf life					
21 + 0.03	10.4^{d}	12.2^{b}	3.8^{b}	0.87^{b}	32.0^{b}
1 + 3	19.6^{a}	33.8^{a}	10.1^{a}	2.04^{a}	74.3^{a}
1 + 5	18.3^{ab}	37.3^{a}	10.6^{a}	2.28^{a}	74.6^{a}
2 + 5	19.5^{a}	35.8^{a}	9.9^{a}	2.17^{a}	80.4^{a}
2 + 10	16.4^{bc}	32.4^{a}	10.5^{a}	2.00^{a}	74.5^{a}
11 + 10	13.5^{c}	34.4^{a}	9.8^{a}	2.25^{a}	67.1^{a}
CV (%)	6.2	8.7	4.3	12.0	11.5

*Averages followed by the same letters in the columns are not different by the Tukey test ($p<0.05$). CV, coefficient of variation.

Table 2. Respiration and ethylene production rates in 'Laetitia' plums stored under different atmospheres for 60 days, upon removal from storage and four days of shelf life (20±2ºC/60±5% RH).

Atmosphere O_2+CO_2 (kPa)	Respiration rate (nmol CO_2 kg^{-1} s^{-1})		Ethylene production rate (pmol C_2H_4 kg^{-1} s^{-1})	
	Removal from chamber	After four days of shelf life	Removal from chamber	After four days of shelf life
21 + 0.03	775.6^{a}	498.4^{a}	5.53^{a}	15.6^{a}
1 + 3	527.3^{b}	352.9^{a}	0.72^{cd}	5.1^{b}
1 + 5	114.1^{d}	419.4^{a}	1.16^{c}	7.0^{b}
2 + 5	529.6^{b}	362.1^{a}	0.57^{cd}	3.4^{b}
2 + 10	209.1^{d}	350.3^{a}	0.37^{d}	7.0^{b}
11 + 10	450.1^{c}	362.7^{a}	2.90^{b}	6.1^{b}
CV (%)	15.6	15.1	11.7	29.2

Averages followed by the same letters in the columns are not different by the Tukey test ($p<0.05$). CV, coefficient of variation.

activity of the hydrolytic enzymes responsible for degrading the cell wall components.

The TA was higher in the fruit stored under CA conditions than in RA upon removal from the chamber as well as after four days of shelf life (Table 1). This result is in accordance with the data presented by Hui and Bo-Xun (2007).. Among the CA conditions, 1 kPa O_2 + 3 kPa CO_2 and 2 kPa O_2 + 5 kPa CO_2 resulted in the highest TA values. However, these CA conditions did not differ from 1 kPa O_2 + 5 kPa CO_2 condition (Table 1). The higher values of TA under CA might reflect the lower respiration rates under these storage conditions (Table 2). The low partial pressure of O_2 and/or high partial pressure of CO_2 reduce the consumption of organic acids as a source of energy for the respiration process (Steffens et al., 2007). After four days of shelf life, no difference was observed between treatments in terms of respiration rate (Table 2). The reduction of the respiration activity under low O_2 is due to the decrease in the activity of several oxidases, such as cytochrome oxidase, polyphenol oxidase, ascorbic acid oxidase and glycolic acid oxidase (Kader, 1986). The high CO_2 might reduce respiration by inhibiting enzymes in the glycolytic pathway (phosphofructo kinase), and tricarboxylic acids cycle (succinate oxidase and isocitrate dehydrogenase), as well as by reducing the activation by ethylene of enzymes involved in the respiration

Table 3. Red color index (RCI) and hue angle (h^o) of the skin, decay and internal breakdown in 'Laetitia' plums stored under different atmospheres for 60 days, upon removal from storage and after four days of shelf life (20±2ºC/60±5% RH).

Atmosphere O_2+CO_2 (kPa)	RCI* (1-4)	Hue angle (hº)		Decay (%)	Internal breakdown (%)
		Fruit side with more intense red color	Fruit side with less intense red color		
Removal from chamber					
21 + 0.03	3.51a	29.0b	66.1b	19.1a	69.7c
1 + 3	2.84b	35.6a	91.2a	4.1b	53.9c
1 + 5	2.51b	39.7a	94.1a	13.3ab	79.0bc
2 + 5	2.71b	38.1a	87.7a	3.3b	56.6c
2 + 10	2.57b	39.4a	91.6a	5.8b	95.1ab
11 + 10	2.45b	38.3a	82.8a	6.7b	98.3a
CV (%)	6.5	7.2	7.4	15.1	15.7
Four days of shelf life					
21 + 0.03	3.91a	23.1b	35.3b	12.1a	84.7a
1 + 3	3.39a	30.6a	61.4a	12.8a	48.8c
1 + 5	3.36a	30.3a	67.3a	20.3a	63.1ab
2 + 5	3.49a	32.1a	62.3a	7.26a	52.6bc
2 + 10	3.49a	33.0a	68.4a	7.74a	87.4a
11 + 10	3.40a	33.1a	66.7a	10.4a	93.3a
CV (%)	16.4	7.7	9.5	57.4	26.8

Averages followed by the same letters in the columns are not different by the Tukey test (p<0.05). CV, coefficient of variation. *, Scores 1, 2, 3, and 4: 0 to 25%, 26 to 50%, 51 to 75%, and >74% of fruit red color surface, respectively.

process (Fonseca et al., 2002).

Fruit stored under CA conditions had lower ethylene production rates than in RA, after removal from the chamber as well as after four days of shelf life (Table 2). The reduced ethylene production under CA is caused by low O_2 and/or high CO_2, as reported by other authorss (Fonseca et al., 2002; Steffens et al., 2007). The suppressed ethylene production rate under CA results of reduced oxidation of 1-carboxilic-1-aminocyclopropane (ACC) by low O_2 and/or inhibition of the ethylene action in inducing autocatalysis by high CO_2 (Kader, 1986). As for the contents of soluble solids, no differences were observed among treatments (data not shown).

The fruit stored under CA conditions had lower skin red color percentage (lower values of red color index) upon removal from the chamber, as well as a less intense red color (higher h^o values in the both fruit sides, with more intense and less intense red color) upon removal from the chamber and after four days of shelf life than fruit in RA (Table 3). As observed for flesh firmness and texture, the less intense skin red color of the fruit must be related to the reduced biosynthesis and the action of ethylene in storage under CA (Alves et al., 2010).

The incidence of decay, upon removal from the chamber, was higher in the fruit stored under RA and, in general, CA conditions delayed the incidence of decay (Table 3). After four days under ambient conditions, decay was not different between treatments. The effects of the CA on decay reduction may be attributed to the low levels of O_2 combined with high levels of CO_2, which presented a fungi static effect, inhibiting spore germination and fungal growth during the storage period (Sitton and Patterson, 1997; Wszelaki and Mitcham, 2000; Vieira et al., 2006).

The incidence of internal breakdown upon removal from the chamber was higher in the CA conditions with 10 kPa CO_2 (Table 3). According to Hui and Bo-Xun (2007), plums are very sensitive to CO_2, and the increase of CO_2 partial pressure causes an increase in anaerobic respiratory and internal breakdown. Conditions with very low O_2 partial pressure or very high CO_2 partial pressure might cause damages to the integrity of the tissue (Jayas and Jeyamkondan, 2002). The CO_2 works by reducing the speed of the tricarboxylic acid cycle, and CO_2 at very high levels might leave to the accumulation of succinic acid due to inhibition of the succinate dehydrogenase enzyme, which causes physiological disorders (Monning, 1983; Kader, 1986; Matthooko, 1996; Galvis et al., 2005). The occurrence of this physiological disorder might also be the result of reduced energetic metabolism and reduced content of phospholipids, with consequent cell decompartmentalization (Saquet et al., 2003).

After four days of shelf life, CA conditions with 10 kPa CO_2 had the highest incidence of internal breakdown (Table 3). Even fruit in RA had an increase of internal breakdown after shelf life, compared to fruit assessed upon removal from storage. After shelf life, the incidence of internal breakdown was not different between fruit in RA and fruit under CA condition with 1 kPa O_2 + 5 kPa CO_2.

'Laetitia' plum develops internal breakdown, especially when stored for over 30 days in RA (Alves et al., 2010). Although the the atmospheres with 1 kPa O_2 + 3 kPa CO_2 and 2 kPa O_2 + 5 kPa CO_2 had the best results in controlling the internal breakdown, its incidence was high even under these CA conditions. Therefore the results show that 'Laetitia' plums should not be stored for more than 60 days, even under the most suitable CA conditions.

Only fruit stored in RA had skin cracking, corresponding to 20% upon removal from the chamber. No cracking was observed under CA conditions (data not shown). In 'Royal Gala' and 'Galaxy' apples, low O_2 and high CO_2 under CA condition reduced the incidence of skin cracking compared to RA due to the delay in fruit ripening (Brackmann et al., 2008).

Conclusions

The CA conditions with 2 kPa O_2 + 5 kPa CO_2 and 1 kPa O_2 + 5 kPa CO_2 provided the best results in delaying fruit ripening, while the atmospheres with 2 kPa O_2 + 5 kPa CO_2 and 1 kPa O_2 + 3 kPa CO_2 had fruit with the lowest incidence of internal breakdown. Nevertheless, the results indicate that for 'Laetitia' plums, the storage period of 60 days is excessively long, even under these CA conditions, leading to high occurrence of internal breakdown.

Conflict of Interests

The author(s) have not declared any conflict of interests.

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