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Storage potential of 'SCS426 Venice' apples under different storage technologies

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Abstract- This study aimed to evaluate the storage potential of SCS426 Venice apples under different storage technologies. Fruits were harvested in an experimental orchard located in Fraiburgo, SC and stored for up to eight and ten months in 2013 and 2014, respectively. Apples were treated or not with methylcyclopropene (1-MCP) and stored under air atmosphere (AA, 0.5±0.5 °C/RH 85±5%) or controlled atmosphere (CA; 1.5 kPa of O_2 and 1.5 kPa of CO_2 at 0.7±0.5 °C/RH of 93±3%). Fruits were evaluated every two months of storage, after one and seven days of shelf life (23 ± 0.3 °C/RH 93±3%). The storage period of 'SCS426 Venice' apples under AA without 1-MCP application should not extend beyond six months. Under this storage condition, fruits had higher incidence of decay, ethylene production and respiratory rates, higher skin degreening, lower flesh firmness, titratable acidity and soluble solids content than fruits stored under CA or AA with 1-MCP. 'SCS426 Venice' apples develop flesh browning and superficial scald after long-term storage. 'SCS426 Venice' apples under AA treated with 1-MCP or under CA (regardless of 1-MCP application) can be stored for more than eight months, keeping flesh firmness above 14 lb and low incidence of physiological disorders even after ten months of storage.
Index terms: *Malus domestica* Borkh, Controlled atmosphere, 1-Methylcyclopropene, Flesh Firmness, Postharvest.

Potencial de conservação de maçãs 'SCS426 Venice' submetidas a diferentes tecnologias de armazenagem

Resumo - O objetivo deste trabalho foi avaliar o potencial de conservação de maçãs da cultivar 'SCS426 Venice' submetidas a diferentes tecnologias de armazenagem. Os frutos foram colhidos em um pomar experimental localizado no município de Fraiburgo-SC, e armazenados por até oito e dez meses, nos anos de 2013 e 2014, respectivamente. As maçãs foram tratadas ou não com 1-metilciclopropeno (1-MCP) e armazenadas em atmosfera do ar (AA; 0,5±0,5 °C/UR de 85±5%) ou em atmosfera controlada (AC; 1,5 kPa O_2 e 1,5 kPa CO_2 a 0,7±0,5 °C/UR de 93±3%). Os frutos foram analisados a cada dois meses de armazenagem, logo após a retirada da câmara e após sete dias em condição ambiente (23±0,3 °C/UR de 68±0,6%). O armazenamento de maçãs 'SCS426 Venice' sob AA e sem aplicação de 1-MCP não deve estender-se além de seis meses. Nessa condição de armazenagem, as maçãs apresentam maior incidência de podridões e maiores taxas respiratória e de produção de etileno, bem como uma coloração da epiderme mais amarelada, menor firmeza de polpa e menor acidez titulável e teor de sólidos solúveis, em comparação aos frutos armazenados em AC ou em AA tratados com 1-MCP. Maçãs 'SCS426 Venice' podem desenvolver escurecimento de polpa e escaldadura superficial depois de longos períodos de armazenagem. Maçãs 'SCS426 Venice' em AA, tratadas com 1-MCP ou em AC, independentemente da aplicação de 1-MCP, apresentam potencial de armazenagem superior a oito meses, mantendo firmeza superior a 14 lb e baixo índice de distúrbios fisiológicos, mesmo após dez meses de armazenagem.
Termos para indexação: *Malus domestica* Borkh, Atmosfera Controlada, 1-Metilciclopropeno. Firmeza de polpa, Pós-colheita.

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Introduction

Currently, the main apple cultivars (*Malus domestica* Borkh) produced in Brazil are 'Gala' and 'Fuji' clones, which represent around 60% and 30% of production, respectively (PETRI et al., 2011). However, concentrating national apple production on a few cultivars brings vulnerability in several ways. As for production, it means concentrating activities at certain crop stages, which causes greater difficulty in the management of orchards and the hiring of labor. In addition, orchards formed by a reduced number of cultivars may also be more harmed in the case of adverse climatic events or outbreaks of pests and diseases (DENARDI et al., 2013). In the postharvest period, large amounts of fruits in a short period of time make it difficult to process and store in the packing house, and occasionally fruits are harvested at inappropriate maturity stage due to the scarcity of labor during commercial maturity (FIORAVANÇO et al., 2011; SCOLARO et al., 2015). In addition, making only two types of commercially available apple restricts the purchase options, an aspect that opposes current market trends, characterized by consumers willing to innovate and seeking diversity of options (FIORAVANÇO et al., 2011).

In the search for solutions for these and other difficulties found by apple growers, new cultivars have been developed by genetic improvement and used in the renovation of orchards in substitution to traditional cultivars. In this context, the SCS426 Venice cultivar was developed, resulting from the cross between the 'Imperatriz' (♀) and 'Baronesa' (♂) apples (DENARDI et al., 2015). Among the main characteristics of 'SCS426 Venice' are: 1) good adaptation to the climatic conditions of the southern region of Brazil, allowing high and regular productivity over the years; 2) organoleptic characteristics well accepted by the consumer market; 3) resistance to glomerella leaf spot (GLS), which allows a significant reduction of production costs and risks of contamination of workers and environment with pesticides compared to those with 'Gala' apple trees; 4) commercial harvest period between Gala and Fuji cultivars, favoring harvest scheduling (DENARDI et al., 2015).

Proper storage is one of the critical points for the successful marketing of apples. The conservation potential of each cultivar is intrinsically related to storage conditions (air atmosphere - AA or controlled atmosphere - CA) (BRACKMANN et al., 2012) and response to treatment with 1-methylcyclopropene (1-MCP) (WATKINS, 2006; AMARANTE et al., 2010).

Because it is a recently developed cultivar, the storage potential of 'SCS426 Venice' apples under different commercially available technologies has yet to be established. Therefore, this study aimed to evaluate the storage potential of 'SCS426 Venice' apples submitted to different storage technologies.

Material and methods

'SCS426 Venice' apples were harvested in February 2013 (158 days after full bloom on February 22) and 2014 (154 days after full bloom on February 28) in an experimental orchard located in Fraiburgo, SC, Brasil (27 ° 03'32" S and 50 ° 54'21" W, and 1,050 m of altitude). The orchard was implanted in the winter 2007, on a Marubakaido rootstock with M-9 filter, spacing 0.80 m between plants and 3.80 m between lines. After harvesting, fruits with defects or low caliber were discarded and the experimental samples were homogenized.

Treatments were storage under air atmosphere (AA, 0.5 ± 0.5 ° C / 85 ± 5% RH); storage under AA with 1-MCP; storage under controlled atmosphere (CA, 1.5 kPa of O_2 and 1.5 kPa of CO_2, at 0.7 ± 0.5 ° C / 93 ± 3% RH); and storage under CA with 1-MCP. The storage duration was up to eight and ten months in years 2013 and 2014, respectively. 1-MCP application (1.0 µL L^{-1}) was carried out in hermetic chamber of 1.0 m³ for 24 hours, according to methodology described by Amarante et al. (2010).

Fruits were analyzed one day after harvesting to characterize the maturity stage of the fruits, and every two months of storage after removal from the chamber (after one day) and after seven days at ambient conditions (23 ± 0.3°C and RH of 68 ± 0.6%), simulating the shelf life period. The evaluated attributes were: fresh mass, starch index, flesh firmness, soluble solids (SS), titratable acidity (TA), respiratory and ethylene production rates and background color. After storage, flesh firmness, SS, TA, respiratory and ethylene production rates, epidermis color and incidence and severity of decay and physiological disorders were analyzed. All evaluations were carried out in both experimental years, with the exception of attributes of ethylene production, respiratory rate and background color, which were only performed for year 2014.

Determination of starch index [on a scale from 1 (high starch content) to 9 (low starch content)], flesh firmness (lb), TA (% malic acid), SS (%), background color [scores from 1 (green) to 5 (yellow-orange)], ethylene production (µmol C_2H_4 kg^{-1} h^{-1}) and respiratory rate (µmol CO_2 kg^{-1} h^{-1}) were performed according to methodology described by Scolaro et al. (2015).

Evaluations of decay and physiological disorders, after each storage period, were performed with fruits transversely sliced, and visually identified by the severity degree. The severity of decay was evaluated according to the size of externally visible lesions, as follows: 1 - absence; 2- initial, with one or two lesions with sum of diameter (s) of less than 1 cm; and 3 - severe, with one or more lesions with sum of diameter (s) greater than 1 cm.

Moldy core was evaluated using the following numerical scale: 1: absence of fungus in the carpel, without lesion in the flesh; 2: initial lesion (<1 cm of pulp diameter); 3: lesion between 1 and 3 cm of flesh diameter;

and 4: lesion> 3 cm of flesh diameter.

Flesh browning (light and diffuse flesh browning) was evaluated by the severity of symptoms as follows: 1: absence of symptoms; 2: initial: 1 to 30% of the cross section with brownish color; 3: moderate, 30% to 60% of the cross section with diffuse brownish color; and 4: severe, more than 60% of brownish cross-section.

Superficial scald was also evaluated by numerical scale varying according to the percentage of fruit surface with symptom as follows: 1: 0%; 2: 1 to 20%; 3: 21 to 60%; and 4:> 60%.

The incidence of fruits with symptoms of physiological disorders bitter pit and CO_2 damage (well defined dark brown spot in the flesh) were evaluated by assigning scores 1 and 2 for absence and presence, respectively.

The experimental design was completely randomized, with 40 replicates (each replicate corresponding to one fruit), except for SS, TA, ethylene and respiration analyses, in which four replicates (sub-samples obtained from 10 fruits) per treatment were used. Data were submitted to analysis of variance (ANOVA) using the SAS software (SAS Institute, Cary, NC, USA). The effect of treatments for each storage date was analyzed by the Tukey's test ($p < 0.05$). The effect of the storage time on flesh firmness in each treatment was adjusted through regression analysis to determine the monthly flesh firmness loss rate.

Results and Discussion

In the year 2013, at the harvest time, fruits had mean flesh firmness of 18.6 lbs, SS content of 14.6%, TA of 0.530% and starch index of 6.6. In 2014, fruits showed flesh firmness of 16.8 lb, SS content of 12.5%, TA of 0.359% and starch index of 5.7.

The ethylene production and respiration rates of 'SCS426 Venice' apples were reduced by storage under CA, without and with 1-MCP application, and under AA with 1-MCP application (Figure 1). The ethylene production rate was higher for fruits stored under AA without 1-MCP application, both after removal from the chamber and after seven days of shelf life at all storage times. After two months of storage, fruits treated with 1-MCP, regardless of storage condition, had lower ethylene production rate compared to fruits that did not receive treatment, for both storage conditions. However, from four months of storage, fruits stored under CA, regardless of 1-MCP application, and under AA with previous 1-MCP application presented lower ethylene production rate, without differing from each other (Figure 1).

The effects of storage of fruits under CA on the reduction of ethylene synthesis and action (BOTH et al., 2014) and respiration are well known (STEFFENS et al., 2007), as well as the effect of 1-MCP on ethylene inhibition (DE MARTINO et al., 2006). 1-MCP can also indirectly reduce the respiratory rate of fruits by inhibiting the autocatalytic ethylene production (WANG; SUGAR, 2013).

Storage under AA provided fruits a more yellow coloration compared to those stored under CA after two, eight and ten months of storage (Figure 1). 1-MCP application provided fruits stored under AA greener coloration both at two and ten months of storage. As for fruits stored under CA, 1-MCP application provided fruits greener coloration after two months of storage.

Flesh firmness was lower in fruits stored under AA and not submitted to 1-MCP application when compared to the other treatments, for both years evaluated, both after removal from the chamber and after seven days of shelf life. It was also observed that, in fruits not treated with 1-MCP, storage under CA reduced the loss of flesh firmness when compared to those stored under AA (Figure 2).

In fruits treated with 1-MCP in both years, no difference for flesh firmness between AA and CA storage was observed (Figure 2). However, comparing fruits treated and not treated with 1-MCP in each storage atmosphere, under CA, the application of the ethylene inhibitor resulted in fruits with greater flesh firmness only after the eighth month of storage, while under AA, flesh firmness was higher in fruits treated with 1-MCP for all storage periods (Figure 2).

The monthly flesh firmness loss rate (Table 1) was higher in fruits stored under AA without 1-MCP application (approximately 0.8 and 1.2 lbs / month after removal from the chamber and after seven days at room temperature, respectively, in the mean of the two years), followed by storage under CA without 1-MCP application (approximately 0.3 lbs / month after removal from the chamber and after seven days at room temperature, mean of the two years). In fruits treated with 1-MCP, the monthly flesh firmness loss rate was lower in fruits stored under both AA and CA (approximately 0.1 lb / month after removal from the chamber and after seven days at room temperature, mean of the two years).

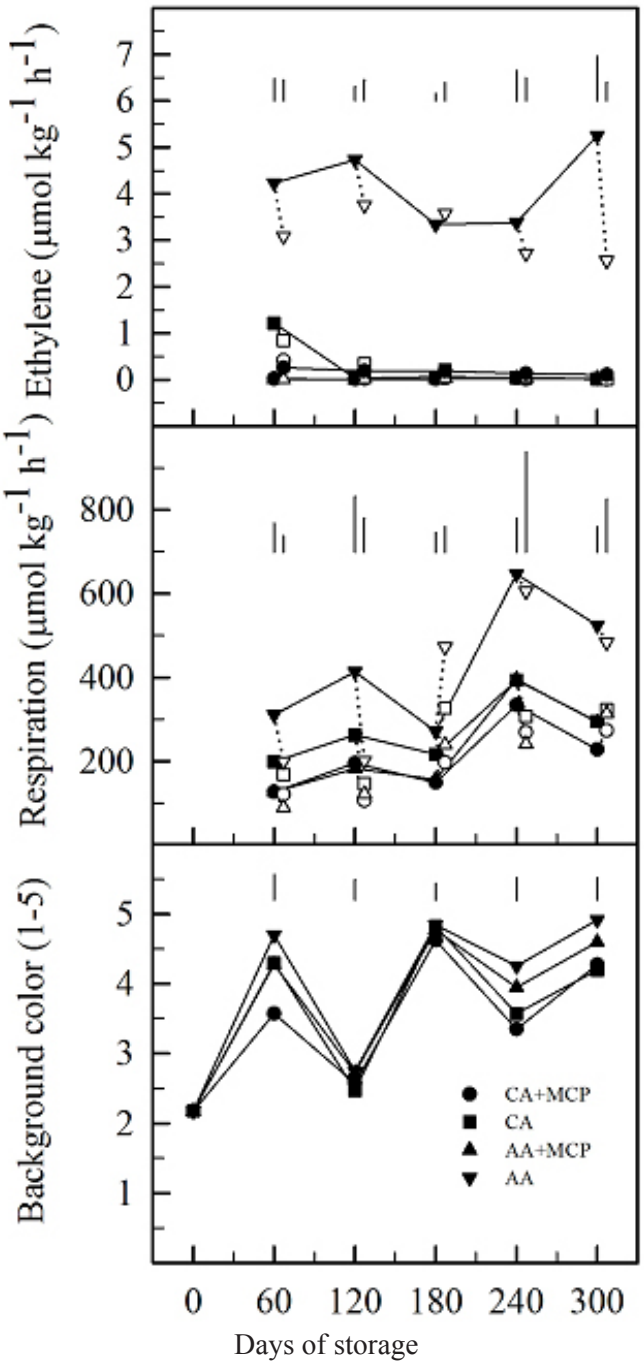

Figure 1 - Ethylene production rate, respiration rate and background color of 'SCS426 Venice' apples submitted or not to 1-MCP application and stored in air atmosphere (AA) or controlled atmosphere (CA) for different periods. Apples were kept at 23°C for 1 (filled symbols) or 7 (empty symbols) days before being analyzed. Fraiburgo, SC, 2014. Vertical bars in the graph represent the minimum significant differences for effects of treatments, for each storage period, determined by the Tukey's test ($p < 0.05$).

Fruits with lower flesh firmness, in general, present less succulence, since less firm fruits tend to have more farinaceous texture and with lower juice content, when compared to firmer fruits. According to Harker et al. (2002), fruits with flesh firmness below 12 lbs are not well accepted by the consumer market due to the increase in the incidence of farinaceous texture and significant reduction of juiciness and crispness of fruits. For the year 2013, only fruits stored for eight months under AA and not treated with 1-MCP showed, after seven days of shelf life, flesh firmness below 12 lb (11.8 lb). For year 2014, fruits not treated with 1-MCP and stored under AA had flesh firmness lower than 12 lb after six months of storage. Possibly, this result is associated to the harvest of fruits with lower flesh firmness in the year 2014 (16.8 lb) compared to those harvested in 2013 (18.6 lb), since the monthly flesh firmness loss rate was similar for both evaluated years (Table 1). AA storage with 1-MCP application and CA without and with 1-MCP application provided maintenance of flesh firmness above 14 lbs, both after removal from the chamber and after seven days under ambient condition, even at the end of the storage period (300 days). According to Harker et al. (2008), for maximum consumer acceptance, apples must have flesh firmness above 14 lb.

For both years evaluated, from four months of storage, AA without 1-MCP application provided lower TA in comparison to the other treatments (Figure 2). Fruits stored under AA with 1-MCP application and under CA without 1-MCP application provided similar TA values for both years.

Storage under AA without 1-MCP application provided fruits with lower SS levels after removal from the chamber when compared to the other treatments, after eight months of storage for the year 2013, and after two and four months of storage for the year 2014 (Figure 2). For evaluations carried out after seven days at 23 °C, in the year 2014, fruits stored under AA without 1-MCP application presented lower SS content in comparison to the other treatments from the six months of storage.

The consumer preference for apples positively correlates with the SS content, with rejection of apples with SS content below 12 °Brix (HARKER et al., 2002). In this sense, 'SCS426 Venice' apples maintained SS content higher than 12 °Brix for all evaluations, except for fruits evaluated after seven days under ambient condition stored under AA for 10 months and not submitted to 1-MCP application (Figure 2).

Table 1 - Flesh firmness loss rate (lb / month) estimated by the linear regression models between storage period (x) and flesh firmness (y) in 'SCS426 Venice' apples from Fraiburgo, SC. Apples were submitted or not to 1-MCP application and stored under air atmosphere (AA) or controlled atmosphere (CA) for eight and ten months for years 2013 and 2014, respectively. Fruits were kept at 23 ° C for one to seven days before being analyzed.

Treatment	Coefficients of models		Probability	Flesh firmness loss rate (lb / month)
	a	b		
2013				
One day at 23 °C				
AA	18.46	-0.790	<0.0001	0.79
CA	18.84	-0.386	<0.0001	0.39
AA + 1-MCP	18.50	-0.104	0.0204	0.10
CA + 1-MCP	18.51	-0.095	0.0290	0.10
Seven days at 23 °C				
AA	18.32	-1.183	<0.0001	1.13
CA	18.59	-0.266	<0.0001	0.27
AA + 1-MCP	18.51	-0.104	0.0039	0.10
CA + 1-MCP	18.41	-0.113	0.0252	0.11
2014				
One day at 23 °C				
AA	16.44	-0.792	<0.0001	0.79
CA	16.77	-0.161	<0.0001	0.16
AA + 1-MCP	16.99	-0.104	<0.0001	0.10
CA + 1-MCP	16.78	-0.065	0.0078	0.06
Seven days at 23 °C				
AA	16.66	-1.125	<0.0001	1.10
CA	16.71	-0.255	<0.0001	0.25
AA + 1-MCP	16.74	-0.110	0.0003	0.11
CA + 1-MCP	16.78	-0.102	<0.0001	0.10

a, b: coefficients of the linear model (y = a + bx).

For both years, CA, as well as AA and CA with 1-MCP application, reduced the incidence of decay in relation to storage under AA without 1-MCP application for fruits submitted to prolonged storage (eight and ten months) (Figure 3). Most of the decay was identified as being caused by *Penicillium spp*. Regarding the incidence of moldy core, there was a low incidence (less than 0.5%) for both years, with no difference between treatments (data not shown).

In the year 2013, after fruit removal from the chamber, the flesh browning severity (light and diffuse browning) did not show differences between treatments, even in prolonged storage periods (up to eight months). However, after seven days at room temperature, there was greater severity of flesh browning in fruits stored under AA without 1-MCP application. In 2014, at eight months of storage, after fruit removal from the chamber, the flesh browning severity was higher in fruits not treated with 1-MCP and stored under AA, and absent in fruits treated with 1-MCP and stored under AA and CA. In evaluations carried out after seven days at room temperature and after six months of storage, fruits stored under CA and not treated with 1-MCP presented flesh browning. After eight months of storage, fruits stored under CA (with and without 1-MCP) had higher incidence of flesh browning when compared to those stored under AA and submitted to 1-MCP application.

The fact that flesh browning was reduced with 1-MCP application and under CA in 2013 indicates that this physiological disorder is possibly related to fruit senescence. However, the fact that the incidence and severity of this disorder was greater in fruits stored under CA in some of the storage periods in 2014 indicates that the damage could be an expression of low O_2 or high CO_2 damage. Further studies are needed to elucidate the causes of this disorder for 'SCS426 Venice' apples.

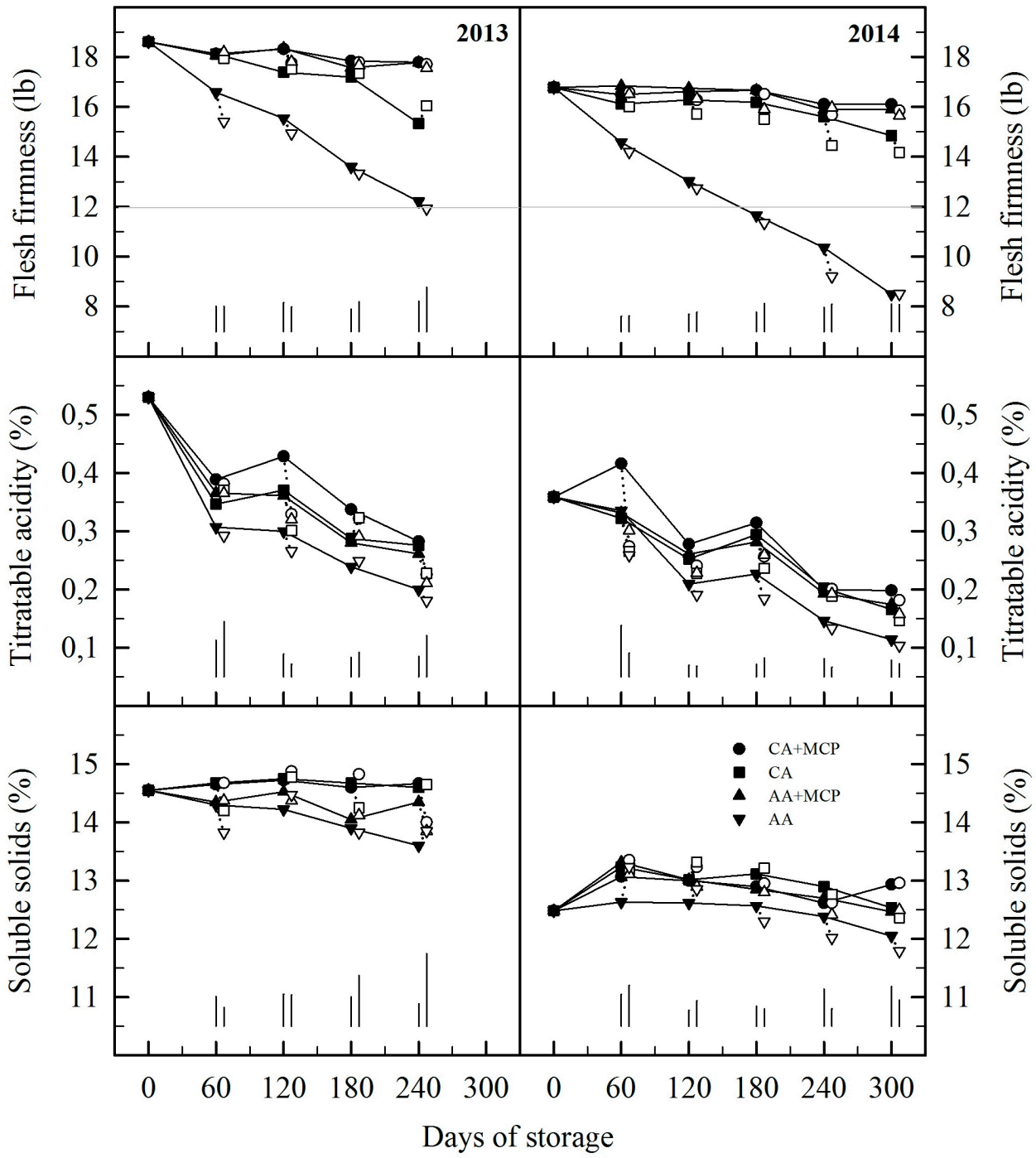

Figure 2 - Flesh Firmness, titratable acidity and soluble solids content of 'SCS426 Venice' apples submitted or not to 1-MCP application and stored in air atmosphere (AA) or controlled atmosphere (CA) for different periods. Apples were kept at 23°C for 1 (filled symbols) or 7 (empty symbols) days before being analyzed. Fraiburgo, SC, 2013 and 2014. Horizontal lines indicate lower flesh firmness limit, below which apples have lower value and commercial acceptance. Vertical bars in the graph represent the minimum significant differences for the effects of treatments, for each storage period, determined by the Tukey's test ($p < 0.05$).

Symptoms of superficial scald from six months of storage were only observed for year 2013 (Figure 3). After eight months of storage, CA (with and without 1-MCP) caused lower superficial scald severity when compared to AA with 1-MCP application.

There was no incidence of superficial scald in 2014, when apples were harvested in more advanced maturity level, and the incidence was low (less than 5%) for most evaluations in the year 2013, when greener fruits were harvested. These results demonstrate that although the cultivar presents susceptibility to superficial scald, late harvesting and / or storage under CA may be sufficient to control this physiological disorder. For both harvests evaluated, there was no incidence of bitter pit and symptoms of CO_2 damage (characterized by well-defined dark brown spot and / or fruit cavities) (data not shown). These results demonstrate that the SCS426 Venice cultivar presents low susceptibility to the manifestation of the main physiological disorders when compared to other apple cultivars.

Considering flesh firmness data, it could be concluded that 'SCS426 Venice' apples under AA and treated with 1-MCP, and under CA (regardless of 1-MCP application), can be stored with quality for up to ten months. However, fruits under AA not submitted to 1-MCP application should be kept in cold chamber for maximum of six months due to the risk of fruits presenting low flesh firmness and high incidence of decay after this period (Figures 2 and 3).

The effects of CA and 1-MCP on the maintenance of fruit quality have already been studied for other apple cultivars (BRACKMANN et al., 2008; STEFFENS et al., 2008; AKBUDAK et al., 2009). Since both CA and 1-MCP reduce the ethylene production rate (WATKINS et al., 2006; BRACKMANN et al., 2008), both technologies decrease the activation of enzymes that degrade the cell wall and are induced by this hormone (WETI et al., 2010; ORTIZ et al., 2011), reducing the flesh firmness loss rate and extending the storage period of fruits. This delay in flesh firmness loss may have provided fruit tissues less susceptibility to pathogen infection, thus reducing the incidence of decay. The lower yellowing of the skin may also be associated with the reduction of ethylene production in fruits stored under CA or treated with 1-MCP, reducing the activity of chlorophyllases and peroxidases enzymes, which act in the degradation of chlorophylls (WHALE; SINGH, 2007). The higher TA and SS values in these fruits are possibly related to the lower consumption of soluble acids and soluble sugars in the respiratory process, since both technologies reduce the respiratory activity of fruits (STEFFENS et al., 2007).

Regarding superficial scald, although 'SCS426 Venice' has presented low susceptibility, storage under CA may have prevented the development of the disorder due to the lower ethylene production and low O_2, necessary for the oxidation of α-farnesene (WEBER et al. al., 2013). According to Amarante et al. (2010), the presence of ethylene in the storage environment stimulates α-farnesene formation, and O_2 favors its oxidation to trienes conjugates and 6-methyl-5-hepten-2-one (MHO-ona), responsible for the appearance of superficial scald on the fruit epidermis.
Figure 1 - Ethylene production rate, respiration rate and background color of 'SCS426 Venice' apples submitted or not to 1-MCP application and stored in air atmosphere (AA) or controlled atmosphere (CA) for different periods. Apples were kept at 23°C for 1 (filled symbols) or 7 (empty symbols) days before being analyzed. Fraiburgo, SC, 2014. Vertical bars in the graph represent the minimum significant differences for effects of treatments, for each storage period, determined by the Tukey's test ($p < 0.05$).

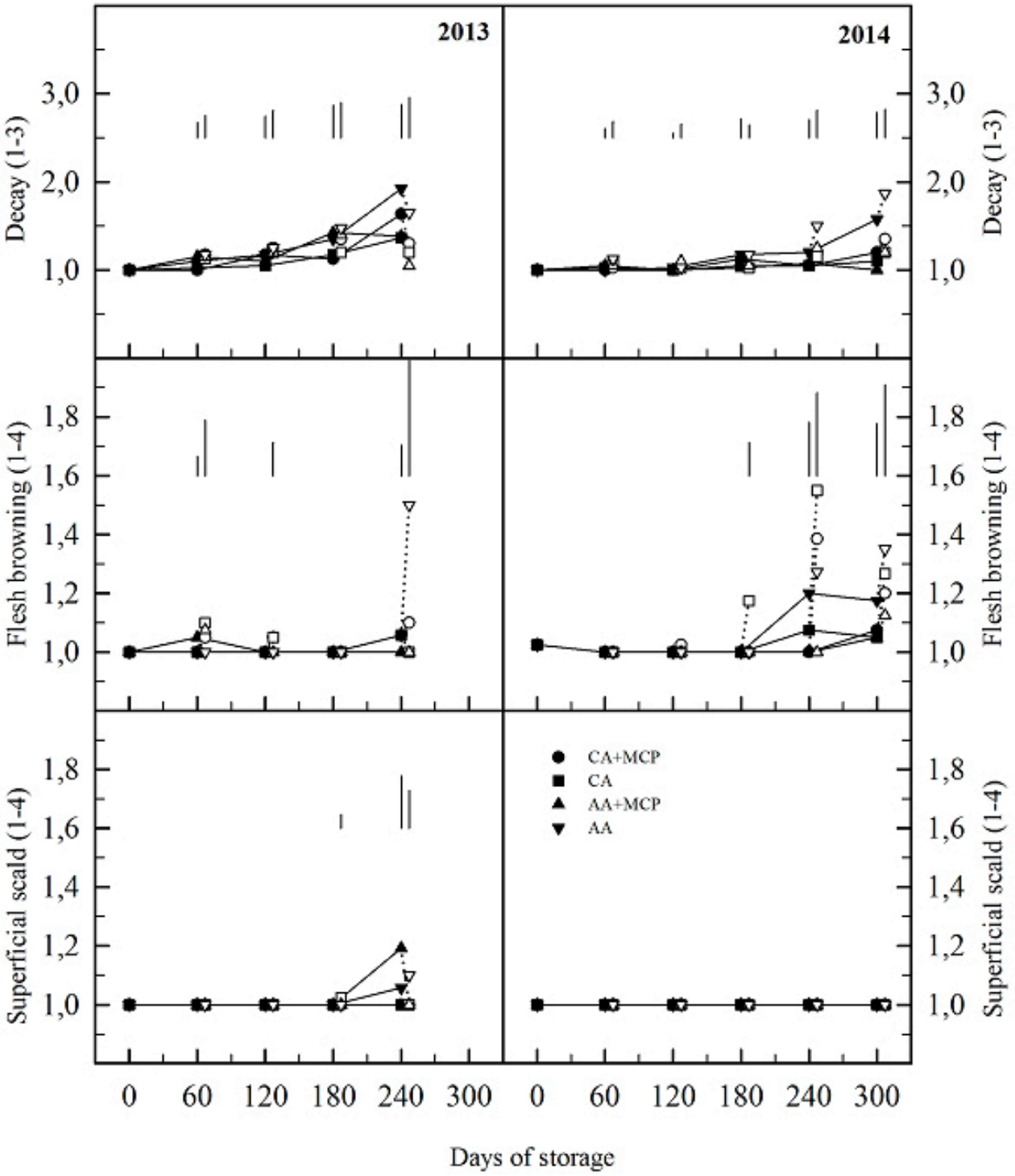

Figure 3 - Severity of decay, flesh browning and superficial scald of 'SCS426 Venice' apples submitted or not to 1-MCP application and stored under air atmosphere (AA) or controlled atmosphere (CA) for different periods. Apples were kept at 23°C for 1 (filled symbols) or 7 (empty symbols) days before being analyzed. Fraiburgo, SC, 2013 and 2014. Vertical bars in the graph represent the minimum differences significant for treatment purposes, for each storage period, determined by the Tukey's test ($p < 0.05$).

Conclusions

'SCS426 Venice' apples under AA and treated with 1-MCP, or maintained under CA (1.5 kPa O_2 and 1.5 kPa CO_2), regardless of 1-MCP treatment, can be stored for up to 10 months with quality.

When submitted to AA storage without 1-MCP application, the storage of 'SCS426 Venice' apples should not extend over six months.

The use of 1-MCP does not provide advantages for 'SCS426 Venice' apples stored under CA (1.5 kPa O_2 and 1.5 kPa CO_2).

'SCS426 Venice' apples may develop diffuse flesh browning and superficial scald after long storage periods depending on the atmosphere and treatment with 1-MCP.

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