Doi: http://dx.doi.org/10.17584/rcch.2018v12i1.7209

Effects of 1-methylcyclopropene on postharvest quality of Roxo-de-Valinhos fresh ripe figs

Efecto del 1-metilciclopropeno en la calidad poscosecha de frutos de higos maduros de la var. Roxo-de-Valinhos

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Ripe fig of the Roxo-de-Valinhos variety.

Photo: M.B.D. Tofanelli

ABSTRACT

The fig is one of the most perishable fruits during the postharvest phase, which has prompted studies to evaluate the effects of substances applied on figs after harvest in order to extend their postharvest life. The aim of this work was to evaluate the effects of different concentrations of 1-methylcyclopropene (1-MCP) on the postharvest quality of Roxo de Valinhos figs. The research was conducted by applying 4 concentrations of 1-MCP (0 - control, 5, 10, and 20 μg L^{-1}) on figs, after which the fruits were evaluated at five different storage times (0, 4, 8, 12, and 16 days). The results showed that 20 μg L^{-1} of 1-MCP provided the best fruit firmness at day 12 after harvest. The 1-MCP treatments did not improve the total amount of total soluble solids (TSS), but we observed higher amount of total solids from 12 to 16 days of storage. Higher acidity was observed in the figs without a 1-MCP treatment at 8 days of storage and with 20 μg L^{-1} of 1-MCP after 12 days of storage. 1-MCP did not affect fruit weight loss. The figs treated with 1-MCP showed promising and rising values of firmness, acidity, and TSS at the highest dose. The TSS concentration tended to increase at the higher doses. As a result, it could be interesting to assay this substance with applications with higher concentrations than those used in the present study.

Additional key words: *Ficus carica*, 1-MCP, firmness, soluble solids, titratable acidity, weight loss.

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RESUMEN

El higo es una de las frutas más perecederas en la poscosecha, lo cual ha promovido estudios para evaluar el efecto a aplicación de sustancias en el fruto después de la cosecha con el fin de conservar su calidad. El objetivo de este trabajo fue evaluar el efecto de diferentes concentraciones 1-metilciclopropeno (1-MCP) en la calidad de poscosecha del higo variedad Roxo-de-Valinhos. El experimento fue realizado con aplicaciones de cuatro concentraciones de 1-MCP (0 - testigo, 5, 10 y 20 μg L^{-1}) en los frutos que fueran evaluados en cinco diferentes períodos de almacenamiento (0, 4, 8, 12 y 16 días). El tratamiento con 1-MCP no aumentó el contenido de sólidos solubles totales (SST), sin embargo se observó un considerable incremento en el período de 12 y 16 días de almacenamiento. La acidez elevada fue obtenida en los frutos no tratados con 1-MCP a los 8 días de almacenamiento y en los tratados con 20 μg L^{-1} de 1-MCP a los 12 días de almacenamiento. El 1-MCP no influenció en la pérdida de peso de los frutos. Los higos tratados con las dosis de 1-MCP mostraron valores prometedores y crecientes de firmeza, acidez y SST. Las concentraciones de SST tendieron a aumentar a una dosis más alta, por lo que puede ser interesante probar esta sustancia aplicada en las concentraciones más altas que las utilizadas en este trabajo.

Palabras clave adicionales: *Ficus carica*, 1-MCP, firmeza, sólidos solubles, acidez titulable y pérdida de peso.

Received for publication: 23-08-2017 Accepted for publication: 30-01-2018

INTRODUCTION

Figs are one of the most important commercial fruits around the world because of their nutritional compounds, taste, and traditional production. Figs are commercially grown in Brazil and 28,044 t of the fruit were produced in 2014, mainly in the southeastern and southern Brazilian regions (IBGE, 2016), for fresh fruit consumption or for industries. In Brazil, the fig for fresh consumption - called "mature fig" - is harvested at the maturation stage and the fig for processing - called "green fig" - is harvested before ripening.

However, certain concerns about fig tree (*Ficus carica* L.) plantations have prompted studies to find solutions, such as the need to address the perishable nature of the fresh fig, which rapidly decreases the quality of the fruit after harves, because it is subject to rapid physiological breakdown. This characteristic affects the efficiency of the commercialization and exportation of the fruit around the world (Gözlekçi *et al*., 2008; Paula *et al*., 2007; Sharma and Singh, 2013). The postharvest life of the fresh fig fruit is normally 7-10 d even when it is stored under low temperatures (Ozkaya *et al*., 2014).

Some studies have been conducted to investigate the effects of substances applied on figs to improve its postharvest conservation, such as calcium chloride, fungicides, sodium hypochlorite, and 1-methylcyclopropene (1-MCP) (Gözlekçi *et al*., 2008; Irfan, 2013; Paula *et al*., 2007; Watkins, 2008). 1-MCP is an unsaturated cyclic olefin that acts as a competitive ethylene antagonist, i.e. it blocks ethylene receptors and can be used to control ethylene production, respiration rate, and softening and extends the shelf-life of a wide range of fruits (Freiman *et al*., 2012; Sozzi *et al*., 2005; Terra *et al*., 2014; Watkins, 2008). However, 1-MCP applications on fruits may not always have similar results on the postharvest quality since its effect has been shown to vary according to the climacteric fruit species, cultivar, maturation and ripening stages of the fruit, and 1-MCP application forms (Freiman *et al*., 2012; Sozzi *et al*., 2005; Watkins, 2006; Zhang *et al*., 2017).

There are few reports on the postharvest behavior of figs treated with 1-MCP. Gözlekçi *et al*. (2008) showed that 10 μg L^{-1} of 1-MCP slowed the softening of Bardakci figs and retained fruit firmness during a 15-day storage period in styrofoam trays wrapped with commercial cling film at 0°C and 90-92% relative humidity (RH). D'Aquino *et al*. (2003) treated Bianca figs with 400 μg L^{-1} of 1-MCP at 20°C for 24 h and concluded that 1-MCP treatment of the figs and storage for 7 d at 15°C may improve their storability.

To the best of our knowledge, very few studies have reported on the postharvest management of fresh fig cultivars and even fewer have considered postharvest behavior after 1-MCP-treatment. The aim of this work was to evaluate the effects of 1-MCP applications on the postharvest quality of Roxo-de-Valinhos figs.

MATERIALS AND METHODS

Study area

Figs were harvested from plants grown in a orchard located in Pinhais County, Paraná State, Brazil (25°26' S and 49°16' W; 947 m a.s.l.), with a Cfb Koeppen climate, average temperature of 24°C maximum and 11°C minimum, and annual rainfall average of 1,500 mm. After harvest, the figs were immediately transported to the Postharvest Laboratory for the experiment procedures.

Plant material

The fig trees were 5-year-old Roxo-de-Valinhos cultivars. The plants were cultivated in an organic system, subjected to annual drastic pruning, and spaced at 1×3 m. Annual fertilization was done using cattle manure at 60 L per plant, three times every 60 d starting from August. Diseases were controlled by spraying with lime sulfur after pruning and a Bordeaux mixture during the vegetative and production stages of the fig trees. To control weeds, mechanical weeding in the crop rows and mowing were used, integrated with black oat (*Avena strigosa* L.), planted in July once a year. The figs were hand-harvested on 12 April, 2014, collecting fruits that showed changing skin color, green to reddish, at stage 5 (Freiman *et al*., 2012).

Experiment description

Harvested figs were separated into lots at the Postharvest Laboratory so that each lot had 10 figs, enabling storage for 0, 4, 8, 12, and 16 d, and they were placed in a paper box. Thereafter, the figs were ready to be treated with 1-MCP.

Postharvest 1-MCP treatments

1-MCP was used in the form of SmartFresh® powder (0.14% active ingredient). The figs were treated with the 1-MCP solution of the corresponding concentration. The 1-MCP doses were measured with a precision balance, and then they were dissolved in distillated water to obtain each deluded solution. The 1-MCP concentrations were 5, 10, and 20 μg L^{-1}. The untreated control (0 μg L^{-1}) only used distilled water.

The treatments were applied in plastic gallon containers (70 L), which already contained figs indoor. The 1-MCP solutions were injected into the containers using plastic syringes, which were immediately sealed in order to preserve the vapor of the solutions. Thus, the 1-MCP powder was introduced into a syringe, supplemented with water until a specific volume for the required concentration, and immediately applied to the containers. The duration of treatments was 24 hours.

Storage conditions

Following the 1-MCP treatment, the figs were placed in paper boxes capable of storing 8 fruits and stored at 4±1ºC and 90-95% RH for 16 d. For each treatment, three replicates of each sample with 10 figs per replicate were used for the physical and chemical quality analyses; two figs were analyzed immediately post 1-MCP-treatment and the other 8 figs were stored. There were five storage periods (0, 4, 8, 12, and 16 d) in order to evaluate the postharvest quality conservation.

Physical and chemical qualities

For measuring the firmness, total soluble solids (TSS) concentration, total titratable acidity (TTA), and weight loss (Instituto Adolfo Lutz, 2008; Leonel and Tecchio, 2008), samples were periodically withdrawn from the refrigerator and two figs per replicate were used for the analyses every 4 d. The peeled-fruit firmness was determined using a manual penetrometer (PTR-100) with a 7.9-mm-diameter tip and expressed in pounds (lb); the data were multiplied by 4.44 to be expressed in Newton (N). The stored figs were taken from the refrigerator to put them on the penetrometer so that they could be analyzed on the equatorial part of the fruit.

The fruit juice was extracted using a centrifuge to measure the TSS and TTA. The TSS content was measured with a handheld refractometer using a drop of juice and expressed as ºBrix. The TTA, expressed as % citric acid, was measured using 100 mL of the solution (10 mL of juice + 90 mL distilled water) that were immediately titrated with 0.1 N NaOH using three drops of phenolphthalein as an indicator.

The weight loss of the stored figs was analyzed using the relative weight variation (%) of two figs per replicate. These figs also represented a storage period of 16 d. The fruits were weighed at harvest and at every storage period, and the weight loss was also determined. The fruit weights were determined using an electronic balance.

Experiment design

The experiment was carried out as a completely randomized factorial design with three replicates and two figs per replicate. Thus, a 2^2 factorial arrangement was used: (1) 1-MCP concentration with four levels (0, 5, 10, and 20 μg L^{-1}) and (2) storage period at five levels (0, 4, 8, 12, and 16 d).

Statistical analysis

The data were submitted to analysis of variance (ANOVA) using the Sisvar Statistical Program, version 5.3 (Ferreira, 2010). When treatment effects were detected with ANOVA, multiple comparisons for the mean were done using the Tukey test at a 5% probability level. Regression analysis was used when a qualitative parameter expressed significant effect.

RESULTS AND DISCUSSION

Firmness

The 1-MCP treatments showed no influence on the firmness of the fig fruits. However, there were significant effects of the 1-MCP treatments on the fig firmness over the different storage periods (Tab. 1). The 20 μg L^{-1} 1-MCP treatment showed the best firmness result after 12 d in storage (26,8 N) although the 5 and 10 μg L^{-1} of 1-MCP showed similar results to 20 μg L^{-1} of 1-MCP after 8 and 16 storage days.

The apparent increase in fruit firmness observed during storage could be related to the fresh weight loss. Fruit shriveling may hamper penetration of a penetrometer tip into figs because weight loss causes laxity and elasticity. Pectins act as a cementing material and are found mainly in the cell wall, being responsible for fruit firmness (Álvarez-Herrera *et al*., 2016). Thus, the 1-MCP promoted less pectin solubilization in the treated figs, which probably caused delay of the ethylene effect on the pectinase enzymes present in the cell wall; consequently, fuit firmness was promoted (Blum and Ayub, 2009; Oliveira *et al*., 2005; Terra *et al*., 2014).

Ribeiro *et al*. (2012) observed that the resistance grape peels increased when they shriveled in their final ripening stage. Brunini *et al.* (2011) also reported that weight loss in pitaya fruit resulted in peel laxity, causing difficulty for penetrometer tip penetration. Brackmann and Saquet (1995) and Jeronimo *et al*. (2007) also studied the firmness of persimmons and mangos, respectively, and suggested that fruit firmness may increase because of fruit shriveling.

Total soluble solids

The results of the present study showed that the 1-MCP treatment influenced the TSS concentration. The °Brix degree reduced with increasing 1-MCP doses, until 12.2 μg L^{-1} (Fig. 1). According to Blum and Ayub (2009), 1-MCP exhibits ethylene biosynthesis and consequently affects the rate of starch

Table 1. Effects of the 1-MCP treatments and storage periods on the firmness of ripe figs.

Firmness (N)					
1-MCP	Storage period (d)				
(μg L^{-1})	0	4	8	12	16
0	16.7 aAB	18.6 abAB	21.0 aA	6.8 bB	7.4 aB
5	13.0 aAB	22.4 aA	19.9 aAB	21.2 aAB	9.1 aB
10	16.0 aA	21.9 aA	22.5 aA	15.9 abA	12.3 aA
20	12.0 aB	9.7 bB	21.1 aAB	26.8 aA	15.5 aAB

Values followed by the same uppercase letter in a row and lowercase letter in a column are not significantly different from each other according to the Tukey test ($P \leq 0.05$).

degradation, which is responsible for increasing the concentration of TSS. In the present study, 1-MCP likely exhibited ethylene production mainly from the dose of 12.2 μg L^{-1}. Sisler *et al*. (1996) showed that exposure to 1-MCP for 6 h at 500 mL L^{-1} made bananas insensitive to ethylene for 12 days and carnations for 24 h, but mature-green tomatoes became insensitive to ethylene for 8 days at 5000 mL L^{-1} of 1-MCP. Freiman *et al*. (2012) showed that preharvest untreated and 1-MCP-treated figs showed different concentrations of SS, implying that the level of SS in untreated figs increased significantly (about 22%), but not in treated figs.

The storage periods also demonstrated a significant effect on the SS concentration. The SS levels increased as the 1-MCP doses increased (Fig. 2). Blum and Ayub (2009) also studied the effect of 1-MCP applied on persimmon and observed that SS levels increased for 20 d. The increase of TSS in fruits can be explained by the hydrolysis of various polysaccharides, such as starch, pectins, and other oligosaccharides in the cell wall, which, when solubilized in the aqueous phase, become part of the cellular juice, as well as by starch accumulation during fruit maturation, which degrades into sugars through the enzymatic action of α-amylase, β-amylase, and starch phosphorylase, increasing TSS concentration (Deaquiz *et al*., 2014). There was no interaction effect of the levels of 1-MCP treatment and storage time.

Total titratable acidity

The acidity of the figs was affected by the interaction between the 1-MCP treatment and storage time (Tab. 2). Higher acidity was observed in the 1-MCP-untreated figs stored for 8 d and in the figs treated with 20 μg L^{-1} of 1-MCP stored for 12 d. In general, little

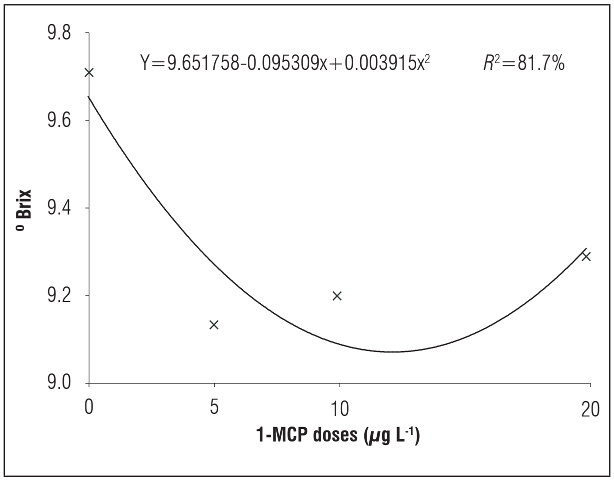

Figure 1. Effects of the 1-MCP treatments on the total soluble solids (°Brix) in the ripe figs.

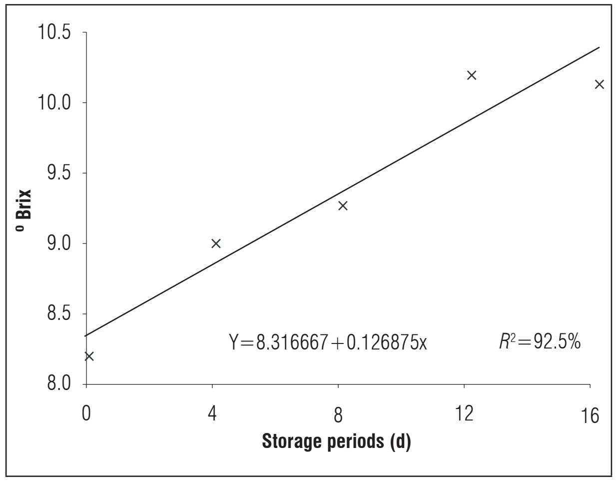

Figure 2. Concentration of total soluble solids (°Brix) in the ripe figs after different storage periods after harvest.

Table 2. Effects of the 1-MCP treatments and storage periods on the total titratable acidity (TTA) of ripe figs.

Total titratable acidity (%)					
1-MCP	Storage period (d)				
(μg L^{-1})	0	4	8	12	16
0	0.17 aC	0.21 abB	0.28 aA	0.17 bC	0.20 aB
5	0.16 aB	0.21 aA	0.21 bA	0.20 aA	0.19 abAB
10	0.16 aB	0.22 aA	0.21 bA	0.18 abB	0.17 bB
20	0.16 aC	0.19 bB	0.22 bA	0.24 aA	0.19 abAB

Values followed by the same uppercase letter in a row and lowercase letter in a column are not significantly different from each other according to the Tukey test ($P \leq 0.05$).

increase in acidity was observed during the initial of storage period and, thereafter, it decreased during the final of storage period for all treatments, indicating an apparent acidity establishment. Candan *et al*. (2011) treated plums with 1-MCP and observed that Royal Zee cultivar fruits showed similar values of TTA in both control and in treated fruits. According to the authors, maintained TTA levels might affect a fruit's final sensory quality. Paula *et al*. (2007) also observed increased acidity initially, and, later, decreasing acidity in figs treated with fungicide and calcium chloride, which they attributed to fruit quality improvement through mainly lower weight loss and higher firmness.

Weight loss

As expected, the fruit weight loss was very prominent as the storage period was prolonged (Fig. 3). Paula *et al*. (2007) also showed similar results. The 1-MCP did not significantly influence the fruit weight loss; neither did the interaction between storage time and 1-MCP. However, Ozkaya *et al*. (2014) showed that a 1-MCP treatment inhibited ethylene evolution and decreased fruit respiration in 'Bursa Siyahi' figs, which likely resulted in less weight loss in the 1-MCP treated fruit. They highlighted the fact that weight loss is one of the most important causes of fruit quality deterioration.

Figs are highly perishable fruits, in which events such as respiration, dehydration, and degradation happen very fast (Gözlekçi *et al*., 2008; Ozkaya *et al*., 2014). In addition to this, figs are morphologically interesting fruits that have a particular structure called ostiole that increases water loss through evaporation by exudation of a syrupy liquid through this orifice (Campos, 1994; D'Aquino *et al*., 2003; Freiman *et al*., 2012). It is possible that the ostiole is one factor masking 1-MCP treatments of fig. For this reason, it may be interesting to investigate the effects of higher 1-MCP-doses and longer treatment periods combined with other techniques, such as bagging or wrapping, on the conservation and quality of Roxo-de-Valinhos figs.

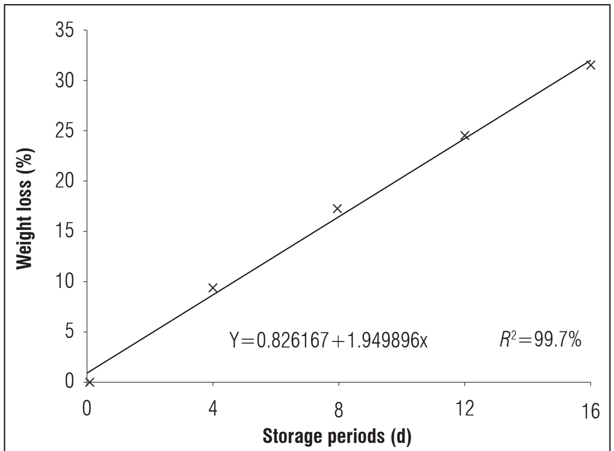

Figure 3. Weight loss in the ripe figs after different storage periods after harvest.

CONCLUSION

The 1-MCP treatment improved the quality (firmness and acidity) of ripe Roxo-de-Valinhos figs during storage. Testing doses higher than 20 μg L^{-1} of 1-MCP would be interesting because it was observed that the soluble solids tended to increase from 10 to 20 μg L^{-1}. On the order hand, the 1-MCP treatment was not able to reduce the high weight loss in the Roxo-de-Valinhos fresh ripe figs.

Conflict of interests: the manuscript was prepared and reviewed with the participation of the authors, who declare that there exists no conflict of interest that puts in risk the validity of the presented results.

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