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Responses of sapodilla fruit (*Manilkara zapota* [L.] P. Royen) to postharvest treatment with 1-methylcyclopropene

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The effect of 1-methylcyclopropene (1-MCP) on ripening and chilling injury in sapodilla fruits was investigated. Sapodilla fruits were treated with four different concentrations of 1-MCP (0.0, 0.2, 0.5 or 1.0 µL/L) and two exposure times (12 or 24 h) in sealed chambers under different temperatures (15 and 25°C). Following the previous treatment, fruits were stored at 25°C with 85 to 95% relative humidity (RH) for ripening assessment. Subsequently, we evaluated the effect of 1-MCP (1.0 µL/L for 24 h at 25°C) on chilling injury when fruits were stored at 6°C, and matured afterwards at 25°C. 1-MCP treatment delayed the ripening of sapodilla fruits (from 4 to 11 days). Ethylene and carbon dioxide production were reduced and delayed significantly ($P<0.05$) by 1-MCP treatment. In general, all quality characteristics of fruits were maintained. Sapodilla fruit stored at 6°C for 3, 10 and 14 days developed chilling injury. These chilling injury symptoms were reduced by 1-MCP treatment.

Key words: 1-methylcyclopropene (1-MCP), sapodilla, chilling injury, postharvest.

INTRODUCTION

Sapodilla tree (*Manilkara zapota* (L.) P. Royen) is native to tropical America and very widespread in southern Mexico. The fruit production is mainly consumed locally. However, this fruit could be exported either in fresh or processed form, due to its sweet taste and unique aroma, highly appreciated by consumers (Balerdi and Shaw, 1998; Ma et al., 2003; Sauri-Duch et al., 2010). Worldwide, one of the major producers of sapodilla fruit is India, with a production of 1,346,000 tons (Indian Horticulture Database, 2010). In Mexico, the production has been estimated at 20,000 tons produced principally in the States of Campeche, Yucatan and Veracruz (SAGARPA,

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2011). Sapodilla fruits are climacteric (Lakshminarayana, 1979); its ripening is rapid and is characterized by a significant increase in respiration and ethylene production, which makes this fruit highly perishable, and consequently very difficult to preserve and commercia-lize. The fruits ripen between 3 to 7 days after harvesting at 25°C and although it can be stored under refrigeration (15°C) (Broughton and Wong, 1979), the use of low temperatures is restricted as it can cause a physiological dysfunction referred to as “chilling injury” which leads to deterioration and loss of quality (Saltveit, 2002). Because sapodilla fruits are highly perishable, it became necessary to study its conservation, handling and postharvest methods, which may extend its shelf life in order to promote sales abroad (Ganjyal et al., 2003; Sauri-Duch et al., 2010).

To prolong the postharvest life of fruits, a promising solution is the use of chemical compounds in order to delay the ripening process and maintain quality. In this regard, 1-methylcyclopropene (1-MCP) is a compound that blocks the ethylene receptor sites, avoiding the physiological actions of this phytohormone by delaying ripening and senescence (Sisler and Serek, 1997). This chemical compound has been studied in various fruits and vegetables, finding a significant decrease in the production and action of ethylene. The effective concentrations used vary between 0.0025 and 1.0 µL/L at temperatures between 20 and 25°C for 12 or 24 h (Blankenship and Dole, 2003). The action of 1-MCP is affected by various factors, such as the species and treated variety, treatment conditions and the stage of fruit maturity or level of ethylene production at the moment of treatment (Blankenship and Dole, 2003).

The effect of 1-MCP has been evaluated in a broad variety of fruits in order to delay the ripening process, prolong shelf life and maintain quality, such as in papaya (Hofman et al., 2001; Manenoi et al., 2007), avocado (Adkins et al., 2005), pear (Liu et al., 2005; Calvo and Sozzi, 2009), plum (Manganaris et al., 2008; Luo et al., 2009), apple (Kashimura et al., 2010) and sapodilla (Qiuping et al., 2006; Kunyamee et al., 2008). It has also been reported that treatment with 1-MCP reduces symptoms of damage by chilling, such as internal browning, rot and superficial scald in pineapple, pear and apple (Selvarajah et al., 2001; Argenta et al., 2003; Sabban-Amin et al., 2011). The evidence supports that 1-MCP treatment could potentially represent a promising technology to extend the postharvest life of sapodilla fruits and to maintain quality for longer periods, however, the suitable conditions (doses, treatment duration and temperature) for commercial use of 1-MCP on sapodilla are far from being standardized, and there are several concerns regarding quality and appearance of the treated fruit. As far as we know, this is the first time 1-MCP is reported for reducing symptoms of damage by chilling on sapodilla fruits. Therefore, the objective of this work was to evaluate the influence of different treatments with 1-MCP on the ripening and chilling injury of sapodilla fruits, thereby increasing their commercial and economic viability.

MATERIALS AND METHODS

Harvested sapodilla fruits were collected in an orchard located in the rural community of “Cansahcab”, in the State of Yucatan, Mexico.

This study was conducted in two steps: The first experiment was carried out in order to evaluate the influence of various treatments with 1-MCP on the quality of sapodilla fruit during ripening; the second experiment was performed in order to evaluate the effect of treatment with 1-MCP on the onset of symptoms of chilling injury.

First experiment

640 sapodilla fruits were harvested in February of 2009. The fruits were identified according to quality based on the stage of physiological maturity and determined by the absence of latex (Sulladmath and Reddy, 1990). The fruits were weighed and measured, representing an average of 200 g, 10 cm of length, 176 N of firmness and 0.27 g of malic acid/100 g of fresh pulp at the time of harvest.

Treatment with 1-MCP

The fruits were divided into 32 lots of 40 fruits; each lot received a single treatment. The doses applied of 1-MCP in each treatment were as follows: 0 (control), 0.2, 0.5 or 1.0 µL/L of 1-MCP for 12 and 24 h. Treatments were applied in closed containers (0.07 m^3) at 15 and 25°C. Each treatment was performed twice. The commercial product SmartFresh® (Rohm and Haas, USA) in powder form (0.14% of the active ingredient), was the source of 1-MCP. The doses were calculated based on fruit weight and volume of the container, taking into account that 1.6 g of powder provides 1.0 µL/L of 1-MCP at 1.0 m^3. The chemical compound was dissolved in a pre-weighed flask with 25 mL of distilled water at 40°C (Akbudak et al., 2009). Subsequently, each flask was placed alongside the fruit, inside a sealed container. The period between harvest and the initiation of treatment was two days. During this period the fruits were stored at 25°C.

After treatments, the fruits of each lot were removed from the containers and maintained, until ripening, at 25°C and 85 to 95% RH. During the ripening process, certain parameters were measured as follows: Respiration rate, production of ethylene, percentage of mature fruits and percentage of weight loss. When the fruits reached ripeness-consumption stage (this being characterized by the time the fruits were soft to the touch), five fruits per treatment were removed from the containers in order to measure whole fruit firmness, titratable acidity, total soluble solids, reducing sugars and color of the pulp.

Respiration and ethylene production rates

Respiration and ethylene production were measured daily using the same fruits of each treatment. Three fruits from each replication were sealed for 2 h at 25°C in 2 L plastic containers prior to sampling. A 2 mL gas sample was withdrawn by a syringe through a rubber septum and analyzed by a gas chromatograph (Varian Star model 3400, Walnut Creek, CA, USA). Carbon dioxide and ethylene were determined using a thermal conductivity detector (TCD) and flame ionization detector (FID) respectively, with a Porapak Q column. Injector and detector temperatures were both set at 250°C, and an isothermal program was run at 30°C. Helium was used as the carrier gas at a flow rate of 1 ml/min. Based on

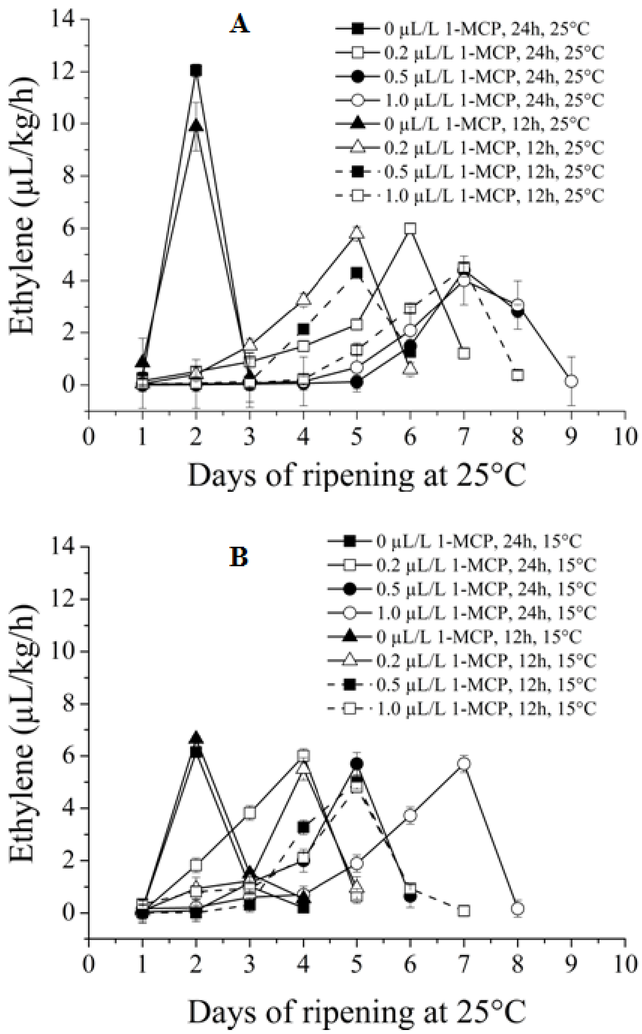

Figure 1. Ethylene production in sapodilla fruits treated with varying concentrations of 1-MCP with subsequent fruit ripening at 25°C. Average value of three determinations ± standard deviation. (A) Treated fruit at 25°C; (B) Treated fruit at 15°C.

areas of standard gases, concentrations of carbon dioxide and ethylene were calculated. Respiration rate was expressed as mL/kg/h while ethylene production rate was expressed as µL/kg/h.

Ripening and physicochemical characteristics

In order to determine the degree of ripeness in which the fruits reach the best edible quality, at each day of evaluation five fruits from each treatment were evaluated by a non-trained panel. Panelists were volunteers experienced in fruit tasting and selected from among the staff that work at the institute.

The accumulated weight losses were measured in percentage with respect to the initial weight of the fruits; ten individually weighed fruits were used each day after treatment. The measurement was made with a digital balance (OHAUS, Adventure Pro AV3102, USA) and results were expressed as percentage.

For determination of soluble solids content (SSC), titratable acidity (TA) and reducing sugar, five ripe fruits per replication were homogenized and the homogenates filtered through a cheese cloth to obtain clear juice. SSC was determined by a digital refractometer (Model PR-1, Atago, Tokyo, Japan) and expressed as °Brix. TA was determined by titrating 5 mL of juice with 0.1 N NaOH, to pH 8.1 and expressed as grams of malic acid per 100 g. Reducing sugars were determined following the colorimetric method described by Nelson (1944) and Somogyi (1952) and expressed as grams of glucose per 100 g of pulp.

Pulp color was measured with a Minolta portable colorimeter CR-200 (Minolta Co; Ltd., Osaka, Japan). Two measurements in the equatorial area of the pulp fruit were carried out, using ten fruits from each treatment. The parameters 'L*', 'a*' and 'b*' were measured and the final results were expressed as hue angle (h= arctan[b*/a*]) (McGuire, 1992).

The fruit firmness was determined on whole, unpeeled and full-ripe stage fruit using an Instron Universal Testing Instrument (Model 4422, Canton, MA, USA) fitted with a flat-plate probe (5 cm diameter) and 50 kg load cell. The force was recorded at 5 mm deformation and was determined at two equidistant points on the equatorial region of each fruit. Ten fruits per treatment were used. The mean values of the firmness were expressed as Newton (N).

This experiment demonstrated that 1.0 µL/L treatment of 1-MCP at 25°C for 12 or 24 h, significantly delays the fruit ripening (4 to 11 days); however, the lower production of ethylene and carbon dioxide in the fruit was achieved at 24 h (Figures 1 and 2). This criterion was taken into account for choosing 1.0 µL/L treatment of 1-MCP, 25°C and 24 h, for the second experiment.

Second experiment

Based on the results of the first experiment and in order to evaluate the effect of 1-MCP in the chilling injury during ripening under refrigeration conditions of sapodilla fruit, a second experiment was designed. Sapodilla fruits were randomly divided into 8 lots of 30 fruits each with two replications; four of these lots were randomly selected as control (0 µL/L of 1-MCP for 24 h at 25°C) and four treated with 1-MCP (1.0 µL/L for 24 h at 25°C). Following treatment, the fruits were stored at 6°C, 80-90% RH for 3, 10 and 14 days and subsequent to each period of cooling the fruits of each batch were matured at 25°C for 10 days and 50 to 60% RH. During ripening, the symptoms of chilling injury were visually evaluated in the pulp. The fruits were cut longitudinally in order to identify symptoms of tissue browning and watery areas in the pulp, lignification of vascular bundles and irregular softening of fruit (Téllez et al., 2009). Data were reported as percentage of fruits that had shown the indicated symptoms.

Statistical analysis

Statgraphics® Plus, ver. 2.1 (Manugistic, Inc., Rockville, Md., USA) was utilized for the analysis of variance (ANOVA) between treatments. When the significant mean was obtained, comparison test was performed by using Tukey ($P<0.05$) (Montgomery, 2005). Analysis was carried out in triplicate.

RESULTS AND DISCUSSION

Effect of 1-MCP in ethylene production rates

Accordingly to the results obtained, the maximum ethylene production rates achieved by the fruits treated with 1-MCP (0.2, 0.5 and 1.0 µL/L), at 25°C and two exposure times evaluated, with a subsequent ripening 25°C), were significantly lower (4.0-6.0 µL/kg/h) (Figure 1A) when compared to the untreated fruits (0 µL/L of

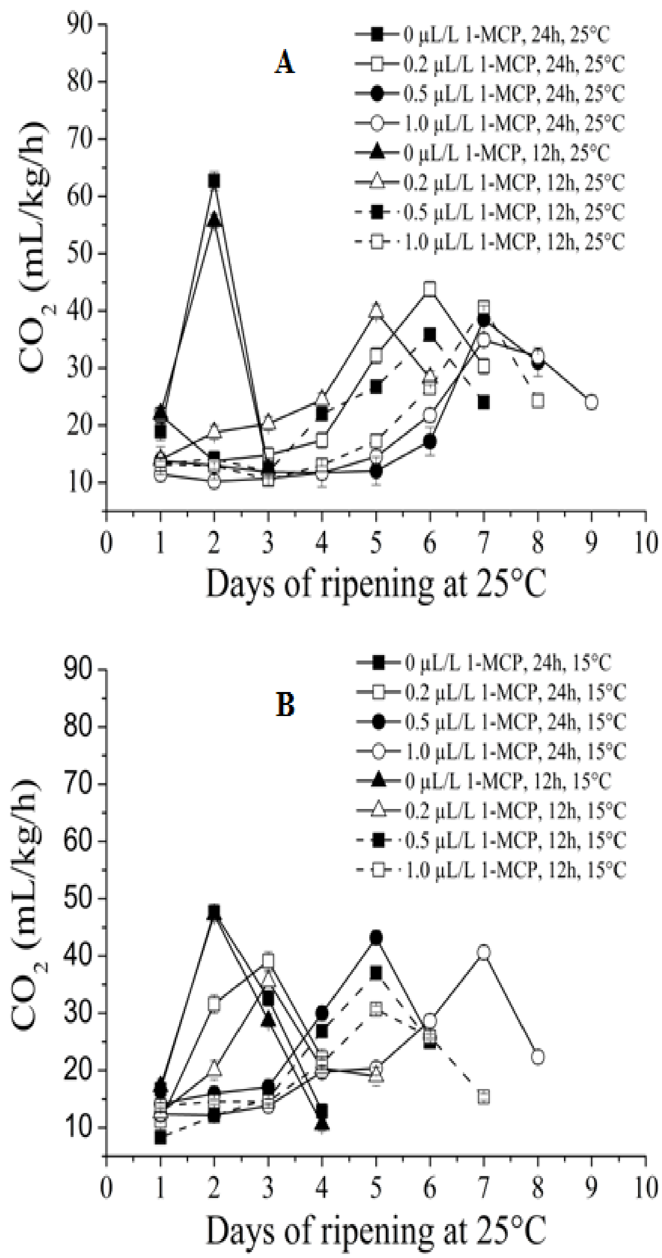

Figure 2. Carbon dioxide production in sapodilla fruits treated with varying concentrations of 1-MCP with subsequent fruit ripening at 25°C. Average value of three determinations ± standard deviation. (A) Treated fruit at 25°C; (B) Treated fruit at 15°C.

1-MCP) (9.9-12.0 µL/kg/h). There is evidence indicating that this effect may be due the 1-MCP is an inhibitor of ethylene perception in plant tissues; it is thought that it binds irreversibly to ethylene receptors (Sisler et al., 1996), reducing the production of ethylene in treated fruits (Moya-León et al., 2004). According to figure 1B, the maximum ethylene production was similar in control and 1-MCP treated fruits at 15°C. This behavior may be because the lower temperatures might decrease the affinity of the binding site for 1-MCP (Blankenship and Dole, 2003). Also, fruits treated with 1-MCP at 25 and 15°C achieved climacteric peak between 4 and 7 days, whereas normally untreated fruits reach this peak at 2 days. This result indicates that 1-MCP treatment at two temperatures delayed the ethylene peak in sapodilla fruit.

Several studies also have shown that 1-MCP delays the onset of ethylene peak such as in banana (Zhang et al., 2006), persimmon (Luo, 2007) and Hami melon (Li et al., 2011). It has also been shown that 1-MCP not only delayed the ethylene peak but also caused a decrease in ethylene production; this behavior has been observed in other fruits such as in pineapples (Selvarajah et al., 2001), kiwi (Boquete et al., 2004) and fresh-cut melon (Guo et al., 2011). There were no significant statistical differences due to the dose, exposure time and temperature in the treated fruits. Furthermore untreated fruits, stored in closed containers at 25°C and transferred for ripening at the same condition (25°C), showed an increase in the production of ethylene (9.9 µL/kg/h for 12 h and 12.0 µL/kg/h for 24 h), unlike the untreated fruits, stored and matured at 15°C (6.6 µL/kg/h for 12 h and 6.1 µL/kg/h for 24 h). This indicates that storing fruits in closed containers at temperatures lower than room temperature, leads to a decrease in production of ethylene. In relation to this fact, Bron et al. (2005) observed that guava fruit stored at a relatively low temperature (11°C) produced significantly less ethylene than guava fruit stored at a temperature above 21°C, approximating room temperature.

Based on these results, post-harvest application of 1-MCP on sapodilla fruit significantly decreased and delayed the climacteric peak, retarding ripening when compared to untreated fruits.

Effect of 1-MCP on respiration rates

1-MCP treatment (Figure 2A) (0.2, 0.5 and 1.0 µL/L) at 25°C and two exposure times with the subsequent ripening of sapodilla fruits (25°C) showed a significant reduction in the maximum respiratory rate (30.7 - 43.8 mL/kg/h carbon dioxide) when compared to the untreated fruits (0 µL/L of 1-MCP) (47.3 - 62.7 mL/kg/h carbon dioxide). No statistically significant differences were found due to doses of 1-MCP, temperature and exposure time between treated sapodilla.A reduction of maximum respiratory rate (30.7-37.0 mL/kg/h carbon dioxide) was observed in treated fruits exposed to 15°C for 12 h (Figure 2B) and matured afterwards (25°C), when compared to untreated fruits (47.3 mL/kg/h carbon dioxide). However, this effect was not observed in fruits treated for 24 h, which suggests that treatment time influences respiration rate. The action of 1-MCP delayed in all treatments the increase of the respiratory peak (3-7 days) when compared to untreated fruits (two days).

The reduction in respiration rate in fruits and vegetables due to the action of 1-MCP has also been

Table 1. Ripening percentage, time to ripen and firmness when sapodilla fruits reached their ripening at 25°C after treatment with 1-MCP.

Doses of 1-MCP (µL/L)	Treatment temperature (°C)	Treatment time (h)	Ripening percentage* (%)	Time to ripen (days)	Firmness* (N)
0	15	12	91.6	7	11.85
0	25	24	91.6	4	11.85
0	25	12	91.6	4	11.85
0	15	24	91.6	7	11.95
0.2	15	12	91.6	8	11.85
0.2	25	24	91.6	10	11.95
0.2	25	12	91.6	7	11.85
0.2	15	24	91.6	8	11.85
0.5	15	12	91.6	8	11.85
0.5	25	24	91.6	10	11.85
0.5	25	12	95.8	7	11.85
0.5	15	24	91.6	9	11.85
1.0	15	12	95.8	9	11.95
1.0	25	24	91.6	11	11.85
1.0	25	12	91.6	11	11.85
1.0	15	24	95.8	9	11.85

*There was no significant difference at P<0.05 (Tukey test). The values are averages of three determinations.

observed in several other studies, such as in tomato (Choi and Huber, 2008), banana (Zhang et al., 2006) and persimmon (Luo, 2007). It has been suggested that changes in the respiratory rate in fruits is due to the action of ethylene (Golding et al., 1998), which causes the deterioration of horticultural products; consequently the delay in respiration rate could increase or decrease the shelf life of fruits (Perera et al., 2003).

These results indicates that application of 1-MCP on sapodilla fruit after harvest decreased and delayed maximum respiratory rate when compared to untreated fruit, which represent a noteworthy effect in delaying fruit ripening.

Effect of 1-MCP on ripening of sapodilla fruit

Fruits treated with 1-MCP took longer to reach an edible maturity (7-11 days), providing an increase in sapodilla fruit shelf life at 25°C. No significant changes were found in the percentage of maturation in treated fruits (91.6-95.8%) and non-treated fruits (91.6%) (Table 1). In this sense, it is known that 1-MCP blocks ethylene action and delays fruit ripening (Blankenship and Dole, 2003). Posteriorly following the inhibitory action of ethylene the fruits ripen. This effect could be explained on the basis that new ethylene receptors are constantly formed in the fruit during storage (Liu et al., 2005). The effectiveness of 1-MCP in delaying fruit ripening has also been observed in several studies, such as in banana (Pelayo et al., 2003), plums (Salvador et al., 2003), papaya (Moya-León et al., 2004), pears (Liu et al., 2005) and sapodilla fruit (Morais et al., 2006).

It should be noted that treated and untreated fruits demonstrated similar firmness when mature for consumption (11.85-11.95 N) with no significant difference between them. This data corresponds to the firmness when sapodilla fruit normally matures (data not shown). In this regard, Morais et al. (2006) found that when sapodilla fruits treated with 1-MCP reach ripeness, firmness values are similar to control fruits without significant differences between them. With respect to this matter, evidence suggests that the characteristic firmness value of a mature fruit is achieved because the ethylene stimulates the activity of enzymes that degrade the cell wall (Abeles et al., 1992), which explains why the treated sapodilla fruit had a normal maturation.

It is worth mentioning that when treated and untreated fruits reached their maturity, the fruits showed a normal pulp with the characteristics appreciated by consumers, such as color brownish-orange, soft and smooth texture, juicy and sweet taste.

On the other hand, fruits exposed to 1-MCP at the evaluated temperatures (25 and 15°C) (Figure 3A and 3B) showed an increase in weight loss when exposed to ripen at 25°C. Furthermore, fruits treated at 25°C, showed more weight loss than those treated at 15°C.

In relation to time of treatment, fruits at 25°C, exposed to 0.2 and 0.5 µL/L of 1-MCP for 24 h, showed a loss of weight (15.7-17.0%) at maturity, significantly greater than those treated for 12 h (10.2-12.0%), indicating that longer treatment times causes greater weight loss. In this sense, Calvo (2004) suggested that the effect of 1-MCP in weight loss has not been entirely elucidated and Porat et

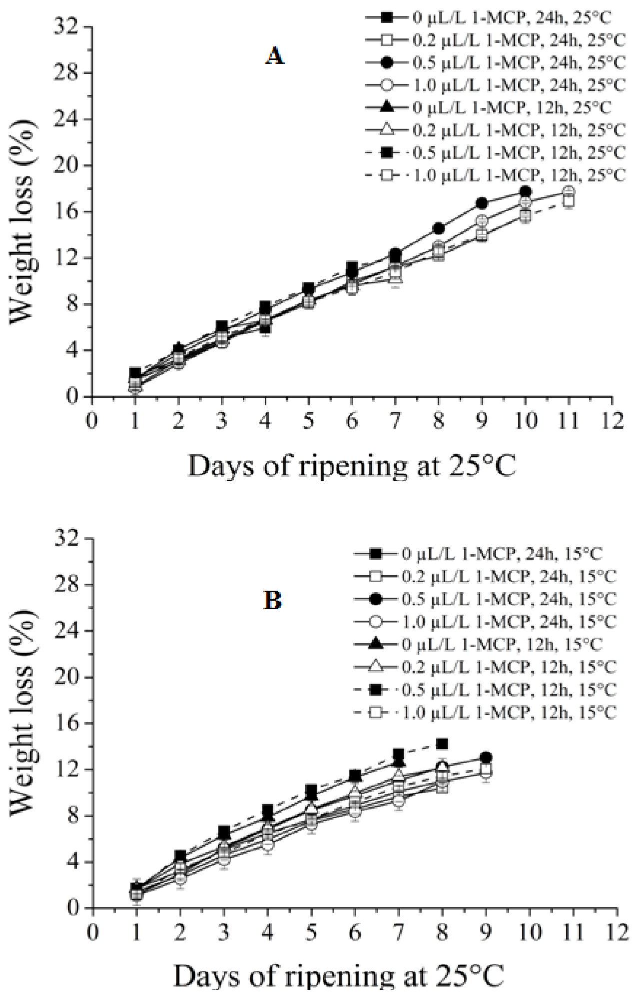

Figure 3. Weight loss (%) in sapodilla fruits treated with varying concentrations of 1-MCP with subsequent fruit ripening at 25°C. Average value of three determinations ± standard deviation. (A) Treated fruit at 25°C; (B) Treated fruit at 15°C.

al. (1999) found that 1-MCP had no effect on weight loss in fruits such as orange, whereas Cao et al. (2012) found that 1-MCP reduced weight loss in green bell peppers.

One of the most important findings, after analyzing the results, is that treatments with 1.0 µL/L of 1-MCP at 25°C for 12 or 24 h significantly increased the time to ripen of sapodilla fruit up to 11 days, while fruits not treated under the same conditions had a time to ripen of 4 days only.

Effect of 1-MCP on the physicochemical properties of mature sapodilla fruit

The physicochemical characteristics of fruits at maturity at 25°C following treatment did not demonstrate significant differences in titratable acidity (0.12-0.13 g of malic acid/100 g), reducing sugars (9.9-10.0 g/100 g), pulp color measured as hue angle (79.5-80.3 °hue) and lightness (50.0-50.8 L*) (Table 2).

The total soluble solids content of treated fruit with 0.5 and 1.0 µL/L of 1-MCP, at the times and temperatures evaluated, was significantly higher (16.6-17.1 °Brix) when compared to untreated fruit (15.8 °Brix), except the dose of 0.5 µL/L at 15°C for 12 h (16.3 °Brix). This increase in the content of soluble solids due to the effect of 1-MCP has been also observed in apples (Fan et al., 1999) and papaya (Hofman et al., 2001). However, Watkins et al. (2000) observed that 1-MCP treatment did not influence the sugar content in apples, which indicates that exposing fruits to 1-MCP does not affect the metabolism of sugars (Salvador et al., 2003). These results indicate that the effect of 1-MCP on the total soluble solids content is variable. Consequently, it has been suggested that this effect in treated fruits could be attributed to low respiration rates; however, it may also depend on the type of crop and storage conditions (Watkins et al., 2000).

Other studies have demonstrated that 1-MCP does not affect the development of acidity in fruits such as plums (Menniti et al., 2004), peach and apple (Mir et al., 2001; Salvador et al., 2003). In addition, significant differences in color of treated apricots were not detected (Fan et al., 2000; Botondi et al., 2003).

The results obtained in this study indicate that postharvest application of 1-MCP on sapodilla fruit only produced a significant effect when high doses were used, which increased total soluble solids (°Brix), without modifying the other physicochemical characteristics of the pulp. The similarity in the results between mature fruits treated and untreated indicates that although 1-MCP delays the physiological ripening of sapodilla fruit, the characteristics of a mature fruit are practically unmodified, producing fruits with highly valued characteristics of quality.

Effect of 1-MCP on the development of chilling injury symptoms

Fruits treated and untreated with 1-MCP stored at 6°C for short periods of time (3 days) showed chilling injury (6.67% of fruits) (Figure 4). The damages found were as follows: Irregular pulp softening, hardening and browning of vascular tissue in various areas of the pulp. The fruits treated with 1-MCP (6.67 and 20% for 10 and 14 days, respectively) and refrigerated for a longer period of time thereafter (10 and 14 days) at 6°C showed a significant reduction of chilling injury symptoms when reached maturity, compared to refrigerated (6°C) and untreated fruits (20 and 30% for 10 and 14 days), which demonstrates the effectiveness of 1-MCP in reducing chilling injury in sapodilla fruit. It has also been suggested that chilling injury symptoms are less, as 1-MCP causes a lower production of ethylene in treated fruits, such as found in apple, avocado and pineapple (Watkins, 2006).

Table 2. Effect of 1-MCP in the physicochemical characteristics of ripe sapodilla fruits.

Doses of 1-MCP (μL/L)	Treatment temperature (°C)	Treatment time (h)	Titratable acidity (g malic acid/100 g)	Reducing sugars (g/100 g)	Soluble solids content (°Brix)	Color (°hue)	Lightness (L*)
0	15	12	0.13[a]	10.0[a]	15.8[ab]	79.9[a]	50.0[a]
0	25	24	0.13[a]	9.9[a]	15.8[ab]	80.0[a]	50.8[a]
0	25	12	0.12[a]	9.9[a]	15.8[ab]	80.0[a]	50.1[a]
0	15	24	0.12[a]	9.9[a]	15.8[ab]	79.9[a]	50.0[a]
0.2	15	12	0.12[a]	10.0[a]	15.5[a]	79.6[a]	50.2[a]
0.2	25	24	0.12[a]	9.9[a]	15.7[ab]	80.0[a]	50.3[a]
0.2	25	12	0.13[a]	9.9[a]	15.5[a]	80.3[a]	50.5[a]
0.2	15	24	0.12[a]	9.9[a]	15.7[ab]	79.7[a]	50.2[a]
0.5	15	12	0.12[a]	9.9[a]	16.3[bc]	79.6[a]	50.7[a]
0.5	25	24	0.13[a]	10.0[a]	16.7[cd]	80.0[a]	50.7[a]
0.5	25	12	0.13[a]	9.9[a]	16.6[cd]	80.1[a]	50.2[a]
0.5	15	24	0.13[a]	10.0[a]	16.6[cd]	79.7[a]	50.6[a]
1.0	15	12	0.13[a]	10.0[a]	16.9[cd]	79.5[a]	50.8[a]
1.0	25	24	0.13[a]	10.0[a]	17.0[d]	79.7[a]	50.5[a]
1.0	25	12	0.13[a]	10.0[a]	17.1[d]	79.9[a]	50.2[a]
1.0	15	24	0.13[a]	10.0[a]	16.8[cd]	79.7[a]	50.8[a]

[a, b, c, d]Different letters in column show significant difference at P<0.05 (Tukey test). The values are averages of three determinations.

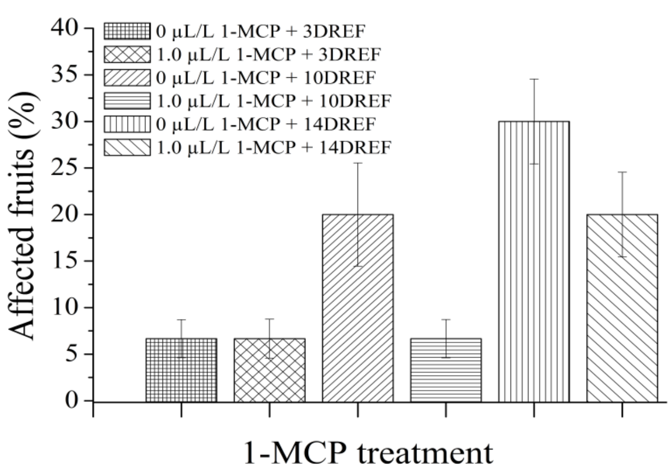

Figure 4. Chilling injury severity in fruits of sapodilla treated with 1-MCP, stored at 6°C for 3, 10 and 14 days and ripens at 25°C. Average value of three determinations ± standard deviation. DREF: Days of refrigeration.

Conclusions

This study demonstrates that using 1-MCP significantly reduces and delays maximum production of ethylene and carbon dioxide in sapodilla fruits. As a result of the effect of 1-MCP, fruit ripening was delayed by an average of 4 to 11 days, which represents a significant 7 day increase in shelf life at room temperature (25°C). Also, fruits treated with 1-MCP showed a normal ripeness, with no significant differences in quality parameters between treated and untreated fruits; excepting for some treatments where a slight increase of total soluble solids content and weight loss were found. According to the results, it is possible to infer that the use of 1-MCP is a suitable alternative to extend the shelf life of sapodilla fruits, which in turn, could greatly facilitate its commercialization. In this regard, the recommended doses of 1-MCP in sapodilla fruits are as follows: 1.0 μL/L of 1-MCP at 25°C for 12 or 24 h of treatment. In addition, treatment with 1-MCP could reduce the symptoms of chilling injury when sapodilla fruits are going to be stored at 6°C for 10 and 14 days, which represents a beneficial effect of 1-MCP in sapodilla fruit conservation and ensuing positive economic implications.

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