ISSN 0100-2945 http://dx.doi.org/10.1590/0100-29452016791

INFLUENCE OF 1-METHYLCYCLOPROPENE ON THE BIOCHEMICAL RESPONSE AND RIPENING OF 'SOLO' PAPAYAS[1]

THAÍS LURI OHASHI[2], SOFIA FOUKARAKI[3], DANIEL SOUZA CORRÊA[4], MARCOS DAVID FERREIRA[5], LEON TERRY[6]

ABSTRACT-The market demand for tropical fruits has been growing steadily over the past two decades and global papaya production has grown significantly over the last few years. This sector, however, suffers greatly from postharvest losses due to reduced quantity and quality of fruits between harvest and consumption. The use of ethylene inhibitors after harvest could improve the final quality of the fruit to satisfy the consumer and also minimize waste. The physiological and biochemical responses of 'Solo' papayas treated with the ethylene inhibitor 1-methylcyclopropene (1-MCP) to extend storage shelf life and maintain quality during long-term storage are deeply discussed in this study. Papaya fruits arrived at Cranfield University (CU) and received a 24 h 1-MCP, being stored at 20 ºC for 10 days. The ethylene inhibitor 1-MCP application significantly delayed 'Solo' papaya ripeness on fruit storage by reducing respiration rate and ethylene production. There was a delay from 7 days in fruit firmness loss and the retention of green peel colour was increased. Inhibition of ethylene perception by 1-MCP did not prevent the accumulation of sugars and the mean values were similar and higher than those found for control fruits, which are possibly due to the lower reaction speed, leading to a higher accumulation.
Index terms:*Carica papaya* L., fruit quality, fruit waste, 1-MCP, tropical fruits.

INFLUÊNCIA DO 1-METILCICLOPROPENO SOBRE A RESPOSTA BIOQUÍMICA E AMADURECIMENTO DE MAMÕES 'SOLO'

RESUMO-O mercado de frutos tropicais cresceu constantemente ao longo das duas últimas décadas e a produção mundial de mamão tem crescido significativamente nos últimos anos. No entanto, esse setor sofre muito com as perdas pós-colheita devido à reduzida quantidade e qualidade dos frutos entre a colheita e o consumo. A utilização de inibidores de etileno após a colheita poderia melhorar a qualidade final do fruto para satisfazer o consumidor e também minimizar o desperdício. As respostas fisiológicas e bioquímicas de mamões 'Solo' tratados com o inibidor de etileno 1-metilciclopropeno (1-MCP) para prolongar a vida útil e manter a qualidade durante o armazenamento a longo prazo são detalhadamente discutidas neste estudo. Os frutos chegaram à Universidade de Cranfield (UC) e receberam tratamento com 1-MCP por 24 h, sendo armazenados a 20 ºC durante 10 dias. A aplicação do inibidor de etileno 1-MCP retardou significativamente o amadurecimento de mamões 'Solo' no armazenamento dos frutos, reduzindo a taxa de respiração e a produção de etileno. Houve um atraso de 7 dias na perda de firmeza e a retenção da cor verde da casca dos frutos foi aumentada. A inibição da percepção de etileno pelo 1-MCP não impediu o acúmulo de açúcares e os valores médios foram semelhantes e superiores aos encontrados para as frutas do tratamento controle, que são possivelmente devido à menor velocidade de reação, levando a um maior acúmulo.
Termos para indexação:*Carica papaya* L., qualidade, desperdício, 1-MCP, frutos tropicais.

[1](Trabalho 101-15). Recebido em: 16-04-2015. Aceito para publicação em: 08-09-2015.
[2]Biologist, Master. Center for Exact Sciences and Technology, Federal University of São Carlos, São Carlos-SP. E-mail: thais_ohashi@yahoo.com.br
[3]Plant / Food Analytical Scientist, PhD. Plant Science Laboratory, Cranfield University, College Road, MK43 0AL, Cranfield, Bedford, United Kingdom. E-mail: sofiafoukaraki@hotmail.com
[4]Materials Engineer, Research. Embrapa Instrumentation.São Carlos-SP. E-mail: daniel.correa@embrapa.br
[5]Agronomy Engineer, Research. Embrapa Instrumentation. São Carlos. SP. E-mail: marcos.david@embrapa.br
[6]Hons Applied Biology ARCS, Professor. Cranfield Soil and Agrifood Institute, Cranfield University, College Road, MK43 0AL, Cranfield, Bedford, United Kingdom. E-mail: l.a.terry@cranfield.ac.uk

INTRODUCTION

The quality of fruits and vegetables is closely associated with their physical features, such as surface colour, shape and firmness. These characteristics are associated with metabolism and respiration rate during ripening, in which living cells from harvested fruits use oxygen from its own reserves and from the environment, releasing ethylene and carbon dioxide (ROUPHAEL et al., 2010; NAYIK AND MUZAFFAR, 2014). Although the changes that take place during ripening are important, uncontrolled ripening process can lead to rapid degradation in quality, which that contributes to postharvest losses. Thus, it is important to control the ripening process during storage and distribution in order to maintain fruit quality at the best possible level until reaching the consumer (HAMZAH et al., 2013). In recent years, several techniques have been developed to regulate the effect of ethylene action (MEYER & TERRY, 2010; GARDIN et al., 2012; WATKINS & NOCK, 2012; ZHANG et al., 2013; CHIARA et al., 2014; RAZZAQ et al., 2014; CAO et al., 2015).

1-methylcyclopropene (1-MCP) is a compound employed as inhibitor of ethylene and plant growth regulator for many fruits, showing to be highly effective for fruit ripening and senescence control (CHIABRANDO & GIACALONE, 2011; ZHANG et al., 2012). 1-MCP is a gas that blocks the ethylene action by binding to its receptor on the cell membrane (IN et al., 2013), severely reducing the changes associated with ripening and extending the postharvest life of fruits and vegetables (PAUL et al., 2010; VIEIRA et al., 2012; WAGHMARE & ANNAPURE, 2013). This product is considered one of the most important tools in postharvest technology, both in storage and in the transportation of ethylene-sensitive fruits, maintaining quality as if they were freshly harvested (EGEA et al., 2010; TIWARI & PALIYATH, 2011; TREVISAN et al., 2013). The compound concentration required to promote inhibition of the ethylene action varies according to the species, cultivar, maturation stage, temperature and exposure time, and the production of new ethylene receptors on the cell membranes (WATKINS AND NOCK, 2012; PEREIRA et al., 2013).

Thus, this research aimed at studying the effects of 1-MCP as inhibitor in the ripening and postharvest quality of 'Solo' papayas. Comparisons of physiological (respiration rate, ethylene production, firmness, colour measurement) and biochemical responses (sugar analysis) of papaya edible (flesh) and non-edible parts (peel and seed separately) were carried out with 1-methylcyclopropene (1-MCP), aiming at extending storage shelf life and maintain fruit quality.

MATERIALS AND METHODS

Plant material

'Solo' papayas (*Carica papaya* L.) from South Africa were obtained from UNIVEG Katope Ltd. (UK) and transported properly packed in cardboard boxes to Cranfield University, UK within 1 h. Fruits were selected according to size, colour and external maturation stage 2 (corresponding to ¼ ripening fruit, with 15 to 25% of the yellow peel surface) discarding those with any physical and/or biological damage. The fruits were not pretreated with 1-MCP.

Experimental design

The experiment was a completely randomized design and was carried out in a temperature controlled room at 20 ºC. Samples were collected on arrival (baseline sampling; n = 5) before the treatments. Papaya fruits were then treated with 1-MCP (1 μL L^{-1}) for 24 h. After the 24 h 1-MCP treatment, fruits were stored in 13 L boxes. Samples were taken at 3, 5, 7 and 10 days of storage for physiological assessments and biochemical analysis. The 24 h 1-MCP (1 μL L^{-1}) treatment was performed in 264 L water-sealed air tight polypropylene chambers. Electric fans (Nidec Beta SL, Nidec, Japan) were used to circulate the gas in the boxes. The 1-MCP was applied by adding 1.47 g SmartFresh (0.14%, Rohm and Haas, PA) to a 100 mL conical flask. To release 1 μL L^{-1} 1-MCP gas, 16.30 mL warm (50 ºC) water was injected into the conical flask (COOLS et al., 2011). Gas samples were taken periodically by using 60 mL plastic syringes, and were analyzed (TERRY et al., 2007) by extraction and injection into a GC 8340 gas chromatograph (Carlo Erba Instruments, Herts, UK). After 24 h of 1-MCP treatment, 5 fruits from each box were analyzed and the remaining fruits were distributed in 13 L sealed polypropylene boxes, being stored at 20 ºC for 10 days. The experiment was conducted using a randomized design with 2 factorial treatments, 6 sampling days, 5 fruits per experimental unit, 3 types of fruit tissue (flesh, peel and seed), 3 fruit sections (top, middle and bottom), and the duplicate samples storage at - 40 ºC and - 80 ºC.

Physiological parameters

Respiration rate. Respiration rate (mL kg^{-1} h^{-1}) of papaya fruits was measured using a Sable Respirometry System (model 1.3.8 Pro, Sable

Systems International, NV, USA). Five papayas were used per treatment and each fruit was placed in a 3 L air-tight glass jar. Three values were obtained per fruit and per treatment. Respiration rates were calculated using ExpeData (Release 1.3.8, Version: PRO).

Ethylene production. Papaya fruits were placed in 3 L glass jars containing air-tight lids and septum for 1 h at room temperature. Gas samples (n = 2 per jar) were taken with repeated withdrawal-injection displacements using 60 mL plastic syringes (COOLS et al., 2011) and were injected into a gas chromatography (GC Model 8340, Carlo Erba Instruments, Herts, UK).

Firmness. Firmness measurement was performed using an Instron Uniaxial Testing Machine (model 5542, Instron, Norwood, USA), equipped with a calibrated 500 N load cell and fitted with an 8 mm diameter cylindrical flat probe. The machine was programmed (Bluehill 2, version 2.11, Instron) with a crosshead speed set at 50 mm min^{-1} (ERGUN et al., 2006) and the force (N) at bioyield produced was recorded. Three penetrations were performed on each fruit (top, middle and bottom) after removing a small piece of skin carefully.

Colour measurement. Objective colour (lightness; L^*), chroma (colour saturation; C^*), and hue angle (Hº) of each fruit were determined as in Meyer and Terry (2010), using a Minolta CR-400 colorimeter and DP-400 data processor (Minolta Co. Ltd., Osaka, Japan). The colour measurement was spatially processed, at the top, middle and bottom of each fruit, resulting in an average of the colour parameters. The ΔE, C^* and h were calculated using the following equation (RUFIÁN-HENARES et al., 2006):

$$\Delta E^* = [(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

$$C = [(\Delta a^*)^2 + (\Delta b^*)^2]^{1/2}$$

$$h = \text{arctgb}^*/a^*$$

Biochemical parameters

Sample preparation, extraction and standard solutions preparation. Papayas were cut into 3 sectional slices divided as top, middle and bottom. The fruits were divided into 3 types of tissue: flesh, peel and seed, snap-frozen in liquid nitrogen and stored at two temperatures: - 40 ºC and - 80 ºC respectively. Frozen tissues (- 40 ºC) were freeze-dried (Scav Vac, Västerås, Sweden) in the dark at - 50 ºC for 10 days and they were used for the biochemical analysis. Fresh and dry weights were recorded before and after lyophilisation and were subsequently ground into fine powder. Sugars were extracted according to Downes et al. (2010). For each 150 mg of lyophilized sample, 3 mL of 62.5:37.5 methanol:water (v/v) solution (High-performance liquid chromatography, HPLC grade) were added and homogenized in plastic vials, which was then incubated in a low-speed shaking water bath at 55 ºC for 15 minutes, vortexing for 20 s at every 5 min. The samples were then allowed to cool at room temperature, filtered through 0.2 µm pore syringe filters, and stored at - 20 ºC. Samples were diluted 1:10 before injection into HPLC. The calibration standard solution with a concentration of 2.5 mg mL^{-1} was prepared by weighing 250 mg of each sugar: D-(+) sucrose, glucose and D-(-) fructose (Sigma) into a 100 mL volumetric flask and filled up with HPLC grade water. 1, 5, 10 and 25 mL of standard solution were pipetted into 50 mL volumetric flasks, which were filled up with HPLC grade water to give final standard concentrations of 0.05; 0.25; 0.50; 1.25 and 2.5 mg L^{-1} (sucrose, glucose and fructose, respectively). From each standard, 1.0 mL aliquots were dispensed into HPLC vials and stored at - 40 ºC until required (TERRY et al., 2007).

Identification and quantification of sugars. Sucrose, glucose and fructose levels in papaya extracts were determined by a HPLC equipment (Agilent) equipped with an Agilent Refractive Index Detector (RID, G1362A). The diluted extracts of papaya (1:10, v/v) were injected (20 µL) in a Ca^+ Rezex RCM monosaccharide column of 300 × 7.8 mm diameter, 8 µm particle size (Phenomenex, Torrance, CA; part no. 00H-0130-K0), fitted with a Carbo-Ca^{2+} guard column of 4 × 3 mm diameter (Phenomenex; part no. AJ0-4493). Thus, presence and abundance of the selected soluble sugars were calculated by sample peak area and standard comparison using Chromeleon (Dionex) software program, version 4.6. Assays were performed in triplicate (TERRY et al., 2007).

Statistical analysis

Statistical analysis was performed using Statistical Analysis System software (SAS INSTITUTE, 2010). Analysis of variance (ANOVA) was used to demonstrate the main effects to a probability of 5%.

RESULTS AND DISCUSSION

Physiological parameters

Respiration rate and ethylene production. According to Table 1, 1-MCP significantly reduced papayas respiratory rate ($p \leq 0.05$), immediately on the 1st day of analysis (corresponding to Day 0, after 24 h 1-MCP). Respiration can also be affected by cultivar, maturity, tissue, and storage temperature (TERRY et al., 2007). For ethylene production, 1-MCP inhibitor treatment presented lower average values compared to control treatment, even in non-significant levels. 1-MCP inhibited this hormone production, delaying production peak until the 5th storage day (Table 2). Ethylene rates in ripening papayas are 6 to 10 μL kg^{-1} h^{-1} (PAULL, 1993; TREVISAN et al., 2013), showing an effective production peak delay in all treated fruits. Comparing to other studies, the respiratory and ethylene climacterics were delayed in avocados treated with 1-MCP at 1 μL L^{-1} for 24 h at 20 ºC (PATHIRANA et al., 2011), and it was also reduced in mangosteens exposed to 1 μL L^{-1} for 6 h at 15 or 25 ºC (PIRIYAVINIT et al., 2011) and tomatoes treated with 1 μL L^{-1} for 24 h at 20 ºC (WANG et al., 2010). In addition, the maturation stage at which the fruits were treated influenced 1-MCP effective action. The maturation stage 2 set for papayas is early in the ripening, and presents higher chances of effective responses to the ethylene inhibitor 1-MCP. Studies have shown less effective responses of this inhibitor in fruits at advanced maturation stages (LU et al., 2013; JUNG AND WATKINS, 2014). This was observed for pears as more advanced stage of the fruit development provided shorter inhibition time of ethylene production (GAMRASNI et al., 2010; CHIRIBOGA et al., 2013), which indicates that fruit maturation stage interferes with 1-MCP effective response on ethylene production. 1-MCP is characterized as a competitor for the cell ethylene binding site. When applied at the correct time, 1-MCP occupies ethylene binding sites and prevents their effects, which include for example, synthesis of degradative enzymes, increase of respiratory rate and ethylene production (autocatalysis). Horticulture product conservation capability is inversely related to respiratory rate and, in many cases, with ethylene production rate (KELLER et al., 2013). Reductions of respiratory rate and ethylene production explain the higher preservation of fruits treated with 1-MCP (ZHANG et al., 2010; YAN et al., 2011; TREVISAN et al., 2013; SCOLARO et al., 2015).

Firmness. Fruits treated with 1-MCP tend to keep firmness for longer periods, significantly differing from control, as displayed in Table 3. Fruits do not ripen uniformly, starting from its internal tissue, and then proceeding toward external tissue, progressing from the bottom to the calyx (KLEE AND CLARK, 2010). Fruit flesh firmness is determined by the cohesion strength between pectins. Pectinolytic enzymes are released during the ripening evolution, which transform insoluble pectin into soluble and promote fruit softening (YOSHIOKA et al., 2011). Fruit softening is one of the ripening processes more sensitive to ethylene (PAYASI AND SANWAL, 2010). The greater firmness of fruits treated with 1-MCP is probably associated with a reduction of pectinolytic enzymes activity, caused by the lower ethylene action. Similar results were obtained with apples (HENDGES et al., 2011), bananas (YAN et al., 2011) and papayas (THUMDEE et al., 2010) treated with 1-MCP inhibitor. Firmness is an important quality attribute for papayas and direct influence fruit storage shelf life and consumer acceptance. Low firmness fruits present less resistance to transport, storage and manipulation, which makes it more vulnerable to mechanical injuries susceptible to diseases (AHMADI-AFZADI et al., 2013). The firmness average of treated papayas (18 N) was higher than in control fruits, with about 10 N (Table 3). In 1-MCP treatment, there was a reduction in the fruit firmness loss, especially until the 7th storage day, corresponding to the analysis 4. On the 7th storage day, 1-MCP treated fruits showed firmness values of about 20 N, compared to 7 N of control fruits (Table 3). In this treatment, the typical softening of papaya fruit during ripening was impaired by the presence of the ethylene competitor, giving papaya flesh fruit an undesirable hardness. Although there were changes in peel and flesh colour and fruits started to deteriorate, no additional softening was observed. Apparently, papaya fruit could not recover from 1-MCP treatment and became sensitive to ethylene. Similar results were observed by Fabi et al. (2007) and Chiriboga et al. (2013).

Colour measurement. 1-MCP treatment significantly reduced green colour of fruits ($p \leq 0.05$), affecting the measured colour parameters. The evaluation of 'Solo' papayas peel colour using *L* parameter, which indicates lightness, 1-MCP treatment yielded difference of control, and both control and treated fruits had *L* values higher than 50 (Table 4). As the scale ranges from 0 to 100, these treated fruits presented darker peel colour than control fruits, which had higher values, being

lighter. Chroma defines colour intensity, in which the positive values correspond to red, 0 (zero) to gray and negative values to green colour (IBRAHEEM et al., 2012). Chroma remained lower in all fruits treated with 1-MCP, while the hue angle remained higher, demonstrating that there was a higher retention of green colour in these fruits. It was observed a trend towards reduction in the green colour of 1-MCP treated fruits between the 3rd and 5th storage day. From then until the 10th day, chroma parameter presented values tending to reduce green colour, as well as hue angle values (Table 4), indicating intense process of peel yellowing. Degreening is due to chlorophyll degradation, mainly caused by chlorophyllase activity (WANG et al., 2015). The increase in this enzyme activity is generally associated with ethylene production during fruit ripening (CHAROENCHONGSUK et al., 2015). 1-MCP binds to the cell ethylene binding site, avoiding hormone action on the ripening physiological processes (SU; FINLAYSON, 2012). Green colour reduction, which results from the normal ripening process, was delayed by 1-MCP application. Peel colour is a factor that has an essential influence on papayas acceptance. The consumer has preference for fruits with smooth and yellow or orange bright colour peel in relation to light and green peel fruits. Consumers usually relate fruit colour with sweetness and other desirable attributes, which leads the purchase preference (PATHARE et al., 2013). Green colour retention in papaya fruits treated with 1-MCP was also verified by Krongyut et al. (2011) and Trevisan et al. (2013) as well as in other fruits, such as banana (YAN et al., 2011), avocado (MEYER; TERRY, 2010), plum (SINGH & SINGH, 2012), mango (SIVAKUMAR et al., 2012) and tomato (WANG et al., 2010). The reduction of ethylene production observed in papayas treated with 1-MCP (Table 2) may have a direct influence on reducing the fruit green colour.

Biochemical parameters

24 h control and 1-MCP treatments. The results for biochemical parameters, as sugar levels quantification (sucrose, glucose and fructose) of 'Solo' papayas treated with ethylene inhibitor 1-MCP for 24 hours are shown in Table 5 and Figs. 1 to 3. Besides flesh softening, sugar content is another important quality attribute of papaya fruit. In contrast to the effect on the firmness, inhibition of ethylene perception by 1-MCP did not preclude the accumulation of sugars. However, the differences observed can provide some clues regarding the metabolism of soluble sugars during ripening. Apparently, sucrose synthesis is operative during ripening, although rates of synthesis were lower than those described for fruit development (DE OLIVEIRA AND VITÓRIA, 2011). Moreover, when the results were compared to those of papaya fruit exposed to radiation (GOMEZ et al., 2002), the same conclusion of an operative sucrose synthesis during ripening can be achieved. Because the trace amounts of starch in the flesh of papayas could not account for the accumulation of soluble sugars, it is possible to speculate that some mechanisms of cell wall disassembly (NOGUEIRA et al., 2012; RAZALI et al., 2013) could provide a source of carbon for sugar synthesis during ripening, including sucrose. The similar profiles for glucose and fructose could be an indication that those sugars come from the accumulated sucrose, especially by the action of invertases in fully ripe fruits (PAULL et al., 2011). The intermittent sucrose level increase in 1-MCP treated fruit would also be in agreement with this idea. Additionally, the observed proportions between sucrose, glucose, and fructose content increase in 1-MCP treated fruit could be an indication of an additional source besides sucrose (FABI et al., 2007).

3 days control and 1-MCP treatments. Inhibition of ethylene perception by 1-MCP did not preclude the accumulation of sugars. Sugars analysis of 'Solo' papayas treated with 1-MCP after 3 storage days demonstrated that higher levels of sucrose, glucose and fructose were found in the flesh, followed by non-edible part, such as peel and seed, respectively. Even in non-significant levels, the mean values obtained for papayas treated with 1-MCP were similar and higher than those found for control fruits (Table 6). The lowest sugar values found in control treatment are possibly due to the faster reaction speed, leading to a lower accumulation. Soluble solid concentrations in treated products might be expected to be higher than in untreated products because of lower respiration rates, but they are also dependent on the product and the storage conditions (MAHAJAN et al., 2010; WANG et al., 2010; ZHANG et al., 2012). Although the storage conditions of papayas were equal, 1-MCP treatment reduced speed sugars consumption for metabolism maintenance (sucrose hydrolysis and monosaccharides consumption), making higher levels of sucrose, glucose and fructose in the most of tissues (Figs. 4 to 6). Thumdee et al. (2010) also observed higher concentrations of sugar in 1-MCP treated papayas. As discussed previously, an additional supply of carbon could come from the cell wall disassembly or even organic acids. From sugar results, problems associated with fruit ripening

interruption when using 1-MCP were not verified, contrarily to the negative and non-reversing effects on fruit softening. The pattern of sugar accumulation during 'Solo' papayas development (Table 6, Figs. 4 to 6) was similar to that observed by others (DE OLIVEIRA; VITÓRIA, 2011; NWOFIA et al., 2012; YAO et al., 2014).

TABLE 1 - Respiration rate in 'Solo' papayas treated with ethylene inhibitor 1-MCP, stored at 20 ºC for 10 days.

Treatments	Analysis (Storage days)					
	1st (Day 0)	2nd (3 days)	3rd (5 days)	4th (7 days)	5th (10 days)	Means
	Respiration Rate (mL kg^{-1} h^{-1})					
Control	71.66 aA	16.35 aC	16.67 aC	23.74 aB	25.44 aB	30.78 a
1-MCP	26.53 bA	13.87 aB	13.92 aB	16.41 bB	17.77 bAB	17.70 b
Means	49.10 A	15.11 C	15.29 C	20.08 B	21.61 B	

Means followed by horizontal and vertical different letters differ significantly by the LSD test ($p \leq 0.05$)

TABLE 2 - Ethylene production in 'Solo' papayas treated with ethylene inhibitor 1-MCP, stored at 20 ºC for 10 days.

Treatments	Analysis (Storage days)					
	1st (Day 0)	2nd (3 days)	3rd (5 days)	4th (7 days)	5th (10 days)	Means
	Ethylene Production (µL kg^{-1} h^{-1})					
Control	1.05	5.15	3.43	2.68	2.85	3.03 a
1-MCP	0.43	0.74	1.13	2.19	2.95	1.49 a
Means	0.74 A	2.94 A	2.28 A	2.44 A	2.90 A	

Means followed by the same letter do not differ significantly by the LSD test ($p \leq 0.05$)

TABLE 3- Firmness in 'Solo' papayas treated with ethylene inhibitor 1-MCP, stored at 20 ºC for 10 days.

Treatments	Analysis (Storage days)					
	1st (Day 0)	2nd (3 days)	3rd (5 days)	4th (7 days)	5th (10 days)	Means
	Firmness (N)					
Control	18.77	8.71	7.31	7.52	6.28	9.72 b
1-MCP	20.22	15.59	22.69	19.99	11.58	18.01 a
Means	19.49 A	12.15 B	15.00 AB	13.76 AB	8.93 B	

Means followed by horizontal and vertical different letters differ significantly by the LSD test ($p \leq 0.05$)

TABLE 4 - Colour measurement in 'Solo' papayas treated with ethylene inhibitor 1-MCP, stored at 20 ºC for 10 days.

Treatments	Analysis (Storage days)					
	1st (Day 0)	2nd (3 days)	3rd (5 days)	4th (7 days)	5th (10 days)	Means
	Lightness (*L**)					
Control	62.43	65.35	67.09	66.67	65.41	65.39 a
1-MCP	55.79	63.71	66.83	65.77	63.78	63.18 b
Means	59.11 C	64.53 B	66.96 A	66.22 AB	64.59 B	
	Chroma (*C**)					
Control	56.92	62.29	67.42	70.02	68.67	65.06 a
1-MCP	45.86	58.61	63.41	65.42	65.13	59.69 b
Means	51.39 C	60.45 B	65.42 A	67.72 A	66.90 A	
	Hue Angle (Hº)					
Control	91.79	84.76	80.47	74.52	72.49	80.81 b
1-MCP	100.07	88.97	85.89	81.04	75.64	86.32 a
Means	95.93 A	86.87 B	83.18 C	77.78 D	74.07 E	

Means followed by horizontal and vertical different letters differ significantly by the LSD test ($p \leq 0.05$)

TABLE 5 - Sucrose, glucose and fructose levels of flesh, peel and seed in 'Solo' papayas treated with ethylene inhibitor 1-MCP, stored at 20 ºC for 24 h.

Treatments	Sugars (mg g^{-1} DW)			
	Flesh	Peel	Seed	Means
		Sucrose		
Control	71.39	9.71	37.14	39.42 a
1-MCP	98.73	71.28	14.89	61.63 a
Means	85.06 A	40.50 A	26.02 A	
		Glucose		
Control	291.35	123.41	39.76	151.51 a
1-MCP	285.71	110.22	50.87	148.93 a
Means	288.53 A	116.82 B	45.32 C	
		Fructose		
Control	224.29	107.59	21.17	117.69 a
1-MCP	221.26	87.56	36.76	115.19 a
Means	222.77 A	97.58 B	28.97 C	

Means followed by horizontal different letters differ significantly by the LSD test ($p \leq 0.05$)

TABLE 6 - Sucrose, glucose and fructose levels of flesh, peel and seed in 'Solo' papayas treated with ethylene inhibitor 1-MCP, stored at 20 ºC for 3 days.

Treatments	Sugars (mg g^{-1} DW)			
	Flesh	Peel	Seed	Means
		Sucrose		
Control	165.25	29.86	17.56	70.89 a
1-MCP	200.07	62.87	37.65	100.20 a
Means	182.66 A	46.36 B	27.60 B	
		Glucose		
Control	276.97	87.41	51.16	138.51 a
1-MCP	252.63	106.23	53.97	137.61 a
Means	264.80 A	96.82 B	52.57 C	
		Fructose		
Control	204.04	75.63	32.09	103.92 a
1-MCP	179.99	88.66	31.86	100.17 a
Means	192.01 A	82.14 B	31.97 C	

Means followed by horizontal different letters differ significantly by the LSD test ($p \leq 0.05$)

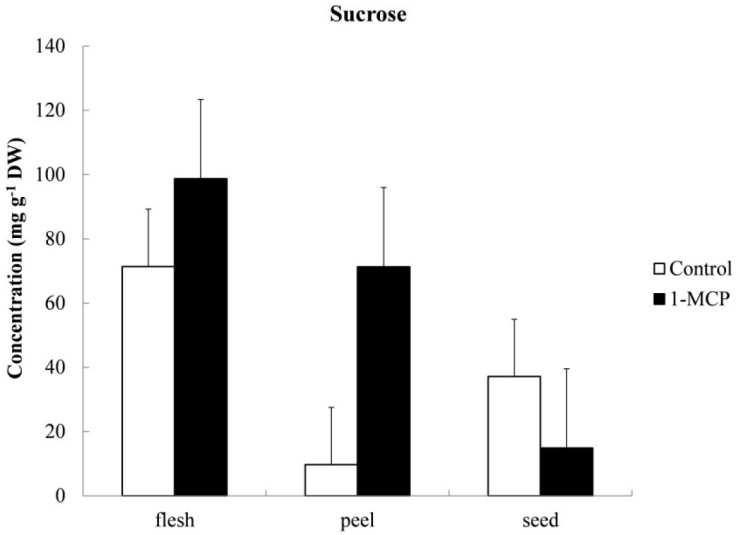

FIGURE 1 - Sucrose concentrations of flesh, peel and seed in 'Solo' papayas treated with 1-MCP for 24 h.

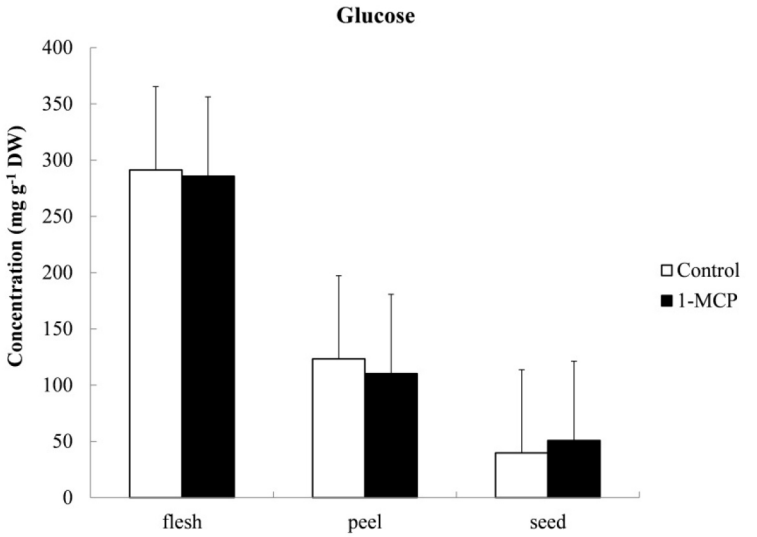

FIGURE 2 - Glucose concentrations of flesh, peel and seed in 'Solo' papayas treated with 1-MCP for 24 h.

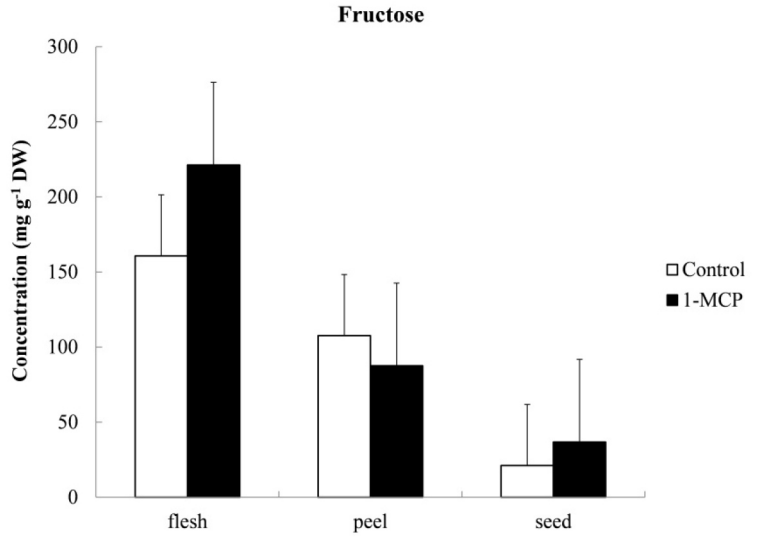

FIGURE 3 - Fructose concentrations of flesh, peel and seed in 'Solo' papayas treated with 1-MCP for 24 h.

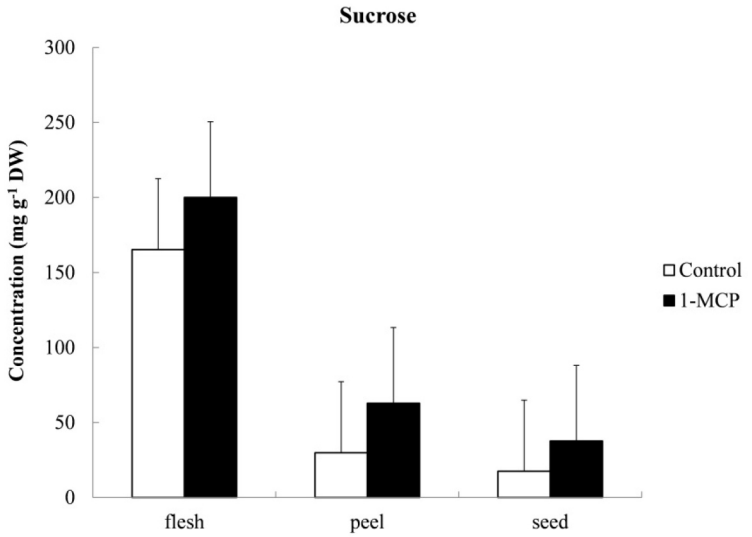

FIGURE 4 - Sucrose concentrations of flesh, peel and seed in 'Solo' papayas treated with 1-MCP for 3 days.

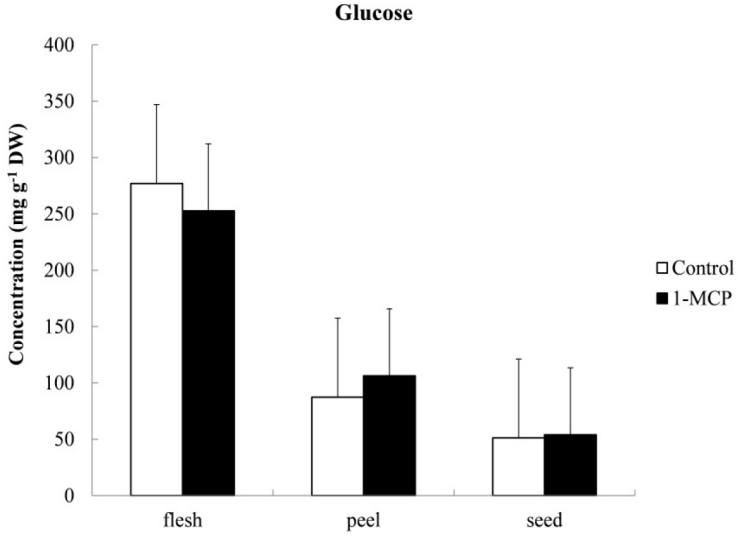

FIGURE 5 - Glucose concentrations of flesh, peel and seed in 'Solo' papayas treated with 1-MCP for 3 days .

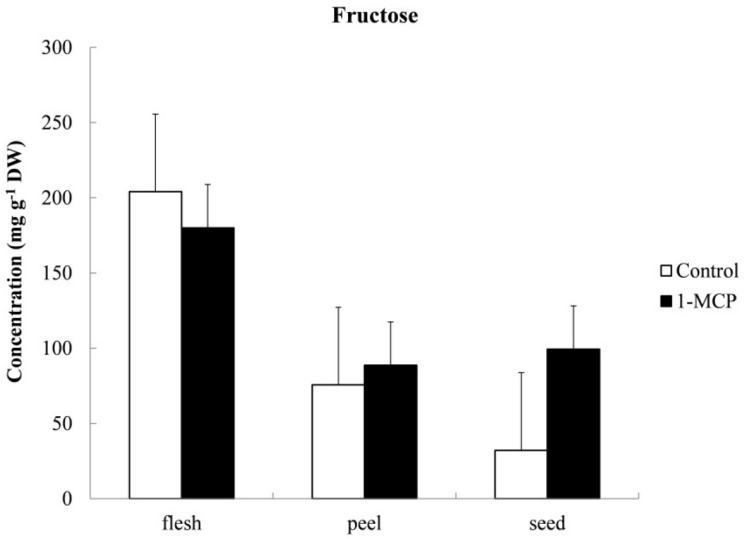

FIGURE 6 - Fructose concentrations of flesh, peel and seed in 'Solo' papayas treated with 1-MCP for 3 days.

CONCLUSION

The use of 1-MCP for fruits significantly increased 'Solo' papayas shelf life, as a consequence of the ability to inhibit ethylene action in tissues, delaying fruit ripening. Storage shelf life increase under environmental conditions is important, considering the high perishability of papaya after postharvest. The gain of seven days of shelf life allows fruit transportation over long distances and an extension of the marketing period. The use of 1-MCP provides strategies to increase fruit shelf life and improve efficiency/cost relation for fruits in general. Despite the positive results obtained for 1-MCP treated fruits, common ripening problems were still observed, leading for instance, to immature fruits even with the peel completely yellow, and fruits presenting green spots, even after 10 days of storage, demonstrating an irregular ripening. In contrast to the effect on the firmness, inhibition of ethylene perception by 1-MCP did not preclude the accumulation of sugars and the mean values obtained for papayas treated with 1-MCP were similar and higher than those found for control fruits, which are possibly due to the ripening delay. Higher levels of sucrose, glucose and fructose were found in the flesh, followed by non-edible part, such as peel and seed, respectively.

ACKNOWLEDGMENTS

The authors are grateful to CNPq, FAPESP, CAPES and Embrapa from Brazil for all support.

REFERENCES

AHMADI-AFZADI, M.; TAHIR, I.; NYBOM, H. Impact of harvesting time and fruit firmness on the tolerance to fungal storage diseases in an apple germplasm collection. **Postharvest Biology and Technology**, Amsterdam, v.82, p.51-58, 2013.

CAO, J.; LI, X.; WU, K.; JIANG, W.; QU, G. Preparation of a novel $PdCl_2$–$CuSO_4$–based ethylene scavenger supported by acidified activated carbon powder and its effects on quality and ethylene metabolism of broccoli during shelf-life. **Postharvest Biology and Technology**, Amsterdam, v.99, p.50-57, 2015.

CHAROENCHONGSUK, N.; IKEDA, K.; ITAI, A.; OIKAWA, A.; MURAYAMA, H. Comparison of the expression of chlorophyll-degradation-related genes during ripening between stay-green and yellow-pear cultivars. **Scientia Horticulturae**, New York, v.181, p.89-94, 2015.

CHIABRANDO, V.; GIACALONE, G. Shelf-life extension of highbush blueberry using 1-methylcyclopropene stored under air and controlled atmosphere. **Food Chemistry**, Berlin, v.126, n.4, p.1812-1816, 2011.

CHIARA, M.L.V.; AMODIO, M.L.; SCURA, F.; SPREMULLI, L.; COLELLI, G. Design and preliminary test of a fluidised bed photoreactor for ethylene oxidation on mesoporous mixed SiO_2/TiO_2 nanocomposites under UV-A illumination. **Journal of Agricultural Engineering**, Pantnagar, v.45, n.4, p.146-152, 2014.

CHIRIBOGA, M.A.; SALADIÉ, M.; GINÉ BORDONABA, J.; RECASENS, I.; GARCIA-MAS, J.; LARRIGAUDIÈRE, C. Effect of cold storage and 1-MCP treatment on ethylene perception, signalling and synthesis: Influence on the development of the evergreen behaviour in 'Conference' pears. **Postharvest Biology and Technology**, Amsterdam, v.86, 212-220, 2013.

COOLS, K.; CHOPE, G.A.; HAMMOND, J.P.; THOMPSON, A.J.; TERRY, L.A. Onion gene expression in response to ethylene and 1-MCP. **Plant Physiology**, Chicago, v.156, n.3, p.1639-1652, 2011.

OLIVEIRA, J.G.; VITÓRIA, A.P. Papaya: Nutritional and pharmacological characterization, and quality loss due to physiological disorders. An overview. **Food Research International**, New York, v.44, n.5, p.1306-1313, 2011.

DOWNES, K.; CHOPE, G.A.; TERRY, L.A. Postharvest application of ethylene and 1-methylcyclopropene either before or after curing affects onion (*Allium cepa* L.) bulb quality during long term cold storage. **Postharvest Biology and Technology**, Amsterdam, v.55, n.1, p.36-44, 2010.

EGEA, I.; FLORES, F.B.; MARTINEZ-MADRID, M.C.; ROMOJARO, F.; SÁNCHEZ-BEL, P. 1-methylcyclopropene affects the antioxidant system of apricots (*Prunus armeniaca* L. cv. Búlida) during storage at low temperature. **Journal of the Science of Food and Agriculture**, Chichester, v.90, n.4, p.549-555, 2010.

ERGUN, M.; HUBER, D.J.; JEONG, J.; BARTZ, J.A. Extended shelf life and quality of fresh-cut papaya derived from ripe fruit treated with the ethylene antagonist 1-methylcyclopropene. **Journal of the American Society for Horticultural Science**, Alexandria, v.131, n.1, p.97-103, 2006.

FABI, J.P.; CORDENUNSI, B.R.; BARRETO, G.P.M.; MERCADANTE, A.Z.; LAJOLO, F.M.; NASCIMENTO, J.R.O. Papaya fruit ripening: Response to ethylene and 1-methylcyclopropene (1-MCP). **Journal of Agricultural and Food Chemistry**, Washington, v.55, n.15, p.6118-6123, 2007.

GAMRASNI, D.; BEN-ARIE, R.; GOLDWAY, M. 1-methylcyclopropene (1-MCP) application to Spadona pears at different stages of ripening to maximize fruit quality after storage. **Postharvest Biology and Technology**, Amsterdam, v.58, n.2, p.104-112, 2010.

GARDIN, J.P.P.; ARGENTA, L.C.; SOUZA, E.L.D.; ROMBALDI, C.V.; SOUZA, A.L.K. D. Quality of 'Rama Forte' perssimon following cold storage influenced by 1-MCP and/or CO_2 treatments. **Revista Brasileira de Fruticultura**, Jaboticabal, v.34, n.4, p.1043-1050, 2012.

GOMEZ, M.; LAJOLO, F.M.; CORDENUNSI, R.B. Evolution of soluble sugars during ripening of papaya fruit and its relation to sweet taste. **Journal of Food Science**, Chicago, v.67, n.1, p.442-447, 2002.

HAMZAH, H.M.; OSMAN, A.; TAN, C.P.; GHAZALI, F.M. Carrageenan as an alternative coating for papaya (*Carica papaya* L. cv. Eksotika). **Postharvest Biology and Technology**, Amsterdam, v.75, p.142-146, 2013.

HENDGES, M.V.; STEFFENS, C.A.; ANTONIOLLI, L.R.; DO AMARANTE, C.V.T.; BRACKMANN, A. Qualidade de maçãs 'Royal Gala' submetidas ao dano mecânico por impacto e aplicação de 1-metilciclopropeno em dois sistemas comerciais de armazenamento. **Revista Brasileira de Fruticultura**, Jaboticabal, v.33, n.1, p.32-39, 2011.

IBRAHEEM, N.A.; HASAN, M.M.; KHAN, R.Z.; MISHRA, P.K. Understanding color models: A review. **ARPN Journal of Science and Technology**, London, v.2, n.3, p.265-275, 2012.

IN, B.C.; STRABLE, J.; BINDER, B.M.; FALBEL, T.G.; PATTERSON, S.E. Morphological and molecular characterization of ethylene binding inhibition in carnations. **Postharvest Biology and Technology**, Amsterdam, v.86, p.272-279, 2013.

JUNG, S.K.; WATKINS, C.B. Internal ethylene concentrations in apple fruit at harvest affect sensitivity of fruit to 1-methylcyclopropene. **Postharvest Biology and Technology**, Amsterdam, v.96, p.1-6, 2014.

KELLER, N.; DUCAMP, M.; ROBERT, D.; KELLER, V. Ethylene removal and fresh product storage: A challenge at the frontiers of chemistry. Toward an approach by photocatalytic oxidation. **Chemical Reviews**, Easton, v.113, n.7, p.5029-5070, 2013.

KLEE, H.J; CLARK, D.J. Ethylene signal transduction in fruits and flowers. **Plant Hormones**, Palo Alto, p.377-398, 2010.

KRONGYUT, W.; SRILAONG, V.; UTHAIRATANAKIJ, A.; WONGS-AREE, C.; ESGUERRA, E.B.; KANLAYANARAT, S. Physiological changes and cell wall degradation in papaya fruits cv. 'Kaek Dum' and 'Red Maradol' treated with 1-methylcyclopropene. **International Food Research Journal**, Serdang, v.18, n.4, p.1251-1259, 2011.

LU, X.; NOCK, J.F.; MA, Y.; LIU, X.; WATKINS, C.B. Effects of repeated 1-methylcyclopropene (1-MCP) treatments on ripening and superficial scald of 'Cortland' and 'Delicious' apples. **Postharvest Biology and Technology**, Amsterdam, v.78, p.48-54, 2013.

MAHAJAN, B.V.C.; SINGH, K.; DHILLON, W.S. Effect of 1-methylcyclopropene (1-MCP) on storage life and quality of pear fruits. **Journal of Food Science and Technology**, Mysore, v.47, n.3, p.351-354, 2010.

MEYER, M.D.; TERRY, L.A. Fatty acid and sugar composition of avocado, cv. Hass, in response to treatment with an ethylene scavenger or 1-methylcyclopropene to extend storage life. **Food Chemistry**, London, v.121, n.4, p.1203-1210, 2010.

NAYIK, G.A.; MUZAFFAR, K. Developments in packaging of fresh fruits-shelf life perspective: A review. **American Journal of Food Science and Nutrition Research**, New York, v.1, n.5, p.34-39, 2014.

NOGUEIRA, S.B.; LABATE, C.A.; GOZZO, F.C.; PILAU, E.J.; LAJOLO, F. M.; DO NASCIMENTO, J. R. O. Proteomic analysis of papaya fruit ripening using 2DE-DIGE. **Journal of Proteomics**, New York, v.75, n.4, p.1428-1439, 2012.

NWOFIA, G.E.; OJIMELUKWE, P.; EJI, C. Chemical composition of leaves, fruit pulp and seeds in some *Carica papaya* (L) morphotypes. **International Journal of Medicinal and Aromatic Plants**, v.2, n.1, p.200-206, 2012.

PATHARE, P.B.; OPARA, U.L.; AL-SAID, F.A. Colour measurement and analysis in fresh and processed foods: A review. **Food Bioprocess Technology**, New York, v.6, n.1, p.36-60, 2013.

PATHIRANA, U.A.P.; SEKOZAWA, Y.; SUGAYA, S.; GEMMA, H. Effect of combined application of 1-MCP and low oxygen treatments on alleviation of chilling injury and lipid oxidation stability of avocado (*Persea americana* Mill.) under low temperature storage. **Fruits**, Paris, v.66, n.3, p.161-170, 2011.

PAULL, R.E.; CHEN, N.J.; TURANO, H.; IRIKURA, B.; WU, P. Tropical fruit genomes and postharvest technology. **Acta Horticulturae**, The Hague, p.237-244, 2011.

PAULL, R.E. Pineapple and Papaya. In: SEYMOUR, G.; TAYLOR, J.; TUCKER. G. **Biochemistry of fruit ripening**. London: Chapman and Hall, 1993. p.291-323.

PAUL, V.; PANDEY, R.; SRIVASTAVA, G.C. Ripening of tomato (*Solanum lycopersicum* L.). Part I: 1-methylcyclopropene mediated delay at higher storage temperature. **Journal of Food Science and Technology**, Oxford, v.47, n.5, p.519-526, 2010.

PAYASI, A.; SANWAL, G.G. Ripening of climacteric fruits and their control. **Journal of Food Biochemistry**, Oxford, v.34, n.4, p.679-710, 2010.

PEREIRA, M.E.C.; SARGENT, S.A.; SIMS, C.A.; HUBER, D.J.; MORETTI, C.L.; CRANE, J.H. Aqueous 1-methylcyclopropene extends longevity and does not affect sensory acceptability of Guatemalan-West Indian hybrid avocado. **HortTechnology**, Alexandria, v.23, n.4, p.468-473, 2013.

PIRIYAVINIT, P.; KETSA, S.; VAN DOORN, W.G. 1-MCP extends the storage and shelf life of mangosteen (*Garcinia mangostana* L.) fruit. **Postharvest Biology and Technology**, Amsterdam, v.61, n.1, p.15-20, 2011.

RAZALI, M.; ALI, Z.M.; OTHMAN, R. Effects of 1-methylcyclopropene on activities of ethylene biosynthesis and cell wall degrading enzyme during ripening of papaya "Sekaki". **Journal of Tropical Agriculture and Food Science**, Kuala, v.41, n.1, p.1-13, 2013.

RAZZAQ, K.; KHAN, A.S.; MALIK, A.U.; SHAHID, M.; ULLAH, S. Role of putrescine in regulating fruit softening and antioxidative enzyme systems in 'Samar Bahisht Chaunsa' mango. **Postharvest Biology and Technology**, Amsterdam, v.96, p.23-32, 2014.

ROUPHAEL, Y.; SCHWARZ, D.; KRUMBEIN, A.; COLLA, G. Impact of grafting on product quality of fruit vegetables. **Scientia Horticulturae**, New York, v.127, n.2, p.172-179, 2010.

RUFIÁN-HENARES, J.Á.; GUERRA-HERNANDEZ, E.; GARCÍA-VILLANOVA, B. Colour measurement as indicator for controlling the manufacture and storage of enteral formulas. **Food Control**, Oxford, v.17, n.6, p.489-493, 2006.

SAS INSTITUTE. **SAS/IML® 9.22 user's guide**. Cary, 2010.

SCOLARO, A.; TOMAZINI, M.; ARGENTA, L.C.; AMARANTE, C.V.T.; PETRI, J.L.; HAWERROTH, F.J. Preharvest control of 'Royal Gala' apple fruit maturation by the inhibition of ethylene action or synthesis. **Revista Brasileira de Fruticultura**, Jaboticabal, v.37, n.1, p.38-47, 2015.

SINGH, S.P.; SINGH, Z. Postharvest oxidative behaviour of 1-methylcyclopropene treated Japanese plums (*Prunus salicina* Lindell) during storage under controlled and modified atmospheres. **Postharvest Biology and Technology**, Amsterdam, v.74, p.26-35, 2012.

SIVAKUMAR, D.; VAN DEVENTER, F.; TERRY, L.A.; POLENTA, G.A.; KORSTEN, L. Combination of 1-methylcyclopropene treatment and controlled atmosphere storage retains overall fruit quality and bioactive compounds in mango. **Journal of the Science of Food and Agriculture**, Chichester, v.92, n.4, p.821-830, 2012.

SU, H.; FINLAYSON, S. 1-methylcyclopropene prevents cotton physiological and molecular responses to ethylene. **Plant Growth Regulation**, Netherlands, v.68, n.1, p.57-66, 2012.

TERRY, L.A.; ILKENHANS, T.; POULSTON, S.; ROWSELL, L.; SMITH, A.W.J. Development of new palladium-promoted ethylene scavenger. **Postharvest Biology and Technology**, Amsterdam, v.45, n.2, p.214-220, 2007.

THUMDEE, S.; MANENOI, A.; CHEN, N.J.; PAULL, R.E. Papaya fruit softening: Role of hydrolases. **Tropical Plant Biology**, New York, v.3, n.2, p.98-109, 2010.

TIWARI, K.; PALIYATH, G. Microarray analysis of ripening-regulated gene expression and its modulation by 1-MCP and hexanal. **Plant Physiology and Biochemistry**, Kalyani, v.49, n.3, p.329-340, 2011.

TREVISAN, M.J.; JACOMINO, A.P.; CUNHA JUNIOR, L.C.; ALVES, R.F. Aplicação de 1-metilciclopropeno associado ao etileno para minimizar seus efeitos na inibição do amadurecimento do mamão 'golden'. **Revista Brasileira de Fruticultura**, Jaboticabal, v.35, n.2, p.384-390, 2013.

VIEIRA, M.J.; ARGENTA, L.C.; AMARANTE, C.V.T. do; VIEIRA, A.M.F.D.; STEFFENS, C.A. Qualidade pós-colheita de quivi 'Hayward' tratado com 1-MCP e armazenado sob diferentes atmosferas. **Revista Brasileira de Fruticultura**, Jaboticabal, v.34, n.2, p.400-408, 2012.

WAGHMARE, R.B.; ANNAPURE, U.S. Combined effect of chemical treatment and/or modified atmosphere packaging (MAP) on quality of fresh-cut papaya. **Postharvest Biology and Technology**, Amsterdam, v.85, p.147-153, 2013.

WANG, M.; CAO, J.; LIN, L.; SUN, J.; JIANG, W. Effect of 1-methylcyclopropene on nutritional quality and antioxidant activity of tomato fruit (*Solanum lycopersicon* L.) during storage. **Journal of Food Quality**, Trumbull, v.33, n.2, p.150-164, 2010.

WANG, Y.; LUO, Z.; DU, R. Nitric oxide delays chlorophyll degradation and enhances antioxidant activity in banana fruits after cold storage. **Acta Physiologiae Plantarum**, Berlin, v.37, n.4, p.1-10, 2015.

WATKINS, C.B.; NOCK, J.F. Rapid 1-methylcyclopropene (1-MCP) treatment and delayed controlled atmosphere storage of apples. **Postharvest Biology and Technology**, Amsterdam, v.69, p.24-31, 2012.

YAN, S.C.; CHEN, J.Y.; YU, W.M.; KUANG, J.F.; CHEN, W.X.; LI, X.P.; LU, W.J. Expression of genes associated with ethylene-signalling pathway in harvested banana fruit in response to temperature and 1-MCP treatment. **Journal of the Science of Food and Agriculture**, New York, v.91, n.4, p.650-657, 2011.

YAO, B.N.; TANO, K.; KONAN, H.K.; BÉDIÉ, G.K.; OULÉ, M.K.; KOFFI-NEVRY, R.; ARUL, J. The role of hydrolases in the loss of firmness and of the changes in sugar content during the post-harvest maturation of *Carica papaya* L. var solo 8. **Journal of Food Science and Technology,** Mysore, v.51, n.11, p.3309-3316, 2014.

YOSHIOKA, H.; HAYAMA, H.; TATSUKI, M.; NAKAMURA, Y. Cell wall modifications during softening in melting type peach "Akatsuki" and non-melting type peach "Mochizuki". **Postharvest Biology and Technology**, Amsterdam, v.60, n.2, p.100-110, 2011.

ZHANG, Z.; HUBER, D.J.; RAO, J. Antioxidant systems of ripening avocado (*Persea americana* Mill.) fruit following treatment at the preclimacteric stage with aqueous 1-methylcyclopropene. **Postharvest Biology and Technology**, Amsterdam, v.76, p.58-64, 2013.

ZHANG, Z.; TIAN, S.; ZHU, Z.; XU, Y.; QIN, G. Effects of 1-methylcyclopropene (1-MCP) on ripening and resistance of jujube (*Zizyphus jujuba* cv. Huping) fruit against postharvest disease. **LWT-Food Science and Technology**, Amsterdam, v.45, n.1, p.13-19, 2012.

ZHANG, Z.; ZHANG, Y.; HUBER, D.J.; RAO, J.; SUN, Y.; LI, S. Changes in prooxidant and antioxidant enzymes and reduction of chilling injury symptoms during low-temperature storage of 'Fuyu' persimmon treated with 1-methylcyclopropene. **HortScience**, St Joseph, v.45, n.11, p.1713-1718, 2010.