INFLUENCE OF RIPENING STAGE ON PHYSICAL AND CHEMICAL ATTRIBUTES OF 'GOLDEN' PAPAYA FRUIT TREATED WITH 1-METHYLCYCLOPROPENE (1)

ILANA URBANO BRON (2 *); ANGELO PEDRO JACOMINO (3); ANA LUIZA PINHEIRO (3)

ABSTRACT

The 1-methylcyclopropene (1-MCP) has been used to extent postharvest life of various species. Generally, 1-MCP effectiveness decreases when applied in fruits at advanced ripening stages. The aim of this work was to verify the influence of ripening stages on some physical and chemical attributes of 'Golden' papaya treated with 1-MCP. Papayas were harvested at five ripening stages and treated with 100 nL L^{-1} of 1-MCP during 12 hours at 23ºC. Fruit skin color and pulp firmness were daily analyzed while soluble solids, titratable acidity and ascorbic acid were evaluated when fruit reached the consumption firmness (20 N). 1-MCP delayed firmness loss during fruit ripening of all ripening stages. The use of 1-MCP prejudices the softening of fruit harvested at stage 0 (totally green), which did not reach the consumption firmness. Although 1-MCP application at early stages was responsible for a significant increment in commercialization period, treated fruit stayed in the consumption condition for few days. When applied to a more advanced stage, 1-MCP not only increased the commercialization period, but also prolonged the period in that fruit stayed in consumption condition. 1-MCP also delayed the color change, but with a lower effect when compared to firmness retention. Ascorbic acid, titratable acidity and soluble solids were not influenced by 1-MCP application. The application of 1-MCP in fruit harvested at more advanced ripening stages could be an interesting practice since it does not prevent the ripening and still could prolong the period in which fruit stay in consumption condition.

Key words: *Carica papaya*, postharvest, conservation.

RESUMO

INFLUÊNCIA DO ESTÁDIO DE AMADURECIMENTO EM ATRIBUTOS FÍSICOS E QUÍMICOS DO MAMÃO 'GOLDEN' TRATADO COM 1-METILCICLOPROPENO

O 1-metilciclopropeno (1-MCP) tem sido usado para estender a vida pós-colheita de várias espécies. Geralmente, a eficiência do 1-MCP diminui quando aplicado em frutos em estádio de maturação avançado. O objetivo deste trabalho foi verificar a influência do estádio de maturação em alguns atributos físicos e químicos do mamão 'Golden' tratado com 1-MCP. Os mamões foram colhidos em cinco estádios de amadurecimento e tratados com 100 nL L^{-1} de 1-MCP durante 12 horas a 23 ºC. Os frutos foram diariamente avaliados quanto à cor da casca e firmeza da polpa, enquanto os sólidos solúveis, a acidez titulável e ácido ascórbico analisados quando os frutos atingiram a firmeza de consumo (20 N). O 1-MCP retardou a perda de firmeza durante o amadurecimento dos frutos em todos os estádios de amadurecimento. O uso do 1-MCP prejudicou o amolecimento de frutos colhidos no estádio 0 (totalmente verde), os quais não atingiram a firmeza de consumo. Embora a aplicação do 1-MCP em estádios mais precoces tenha sido responsável por um incremento significativo no período de comercialização, os frutos tratados

---

(1) Received for publication in February 14, 2006 and approved in July 17, 2006.
(2) Instituto Agronômico, Centro Avançado de Pesquisa Tecnológica dos Agronegócios de Engenharia e Automação, Grupo de Pós-Colheita, Caixa Postal 26, 13201-970 Jundiaí (SP), Brasil. E-mail: ilana@iac.sp.gov.br * Corresponding author.
(3) Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz", Departamento de Produção Vegetal, Laboratório de Pós-Colheita de Produtos Hortícolas, Caixa Postal 09, 13418-900 Piracicaba (SP), Brasil. E-mail: jacomino@esalq.usp.br; alpinhei@esalq.usp.br

permaneceram na firmeza de consumo por poucos dias. Quando aplicado em estádio mais avançado, o 1-MCP não só aumentou o período de comercialização, como também prolongou o período em que os frutos permaneceram nas condições de consumo. A aplicação do 1-MCP retardou a mudança da coloração, mas com um efeito menor quando comparado à retenção da firmeza. O ácido ascórbico, acidez titulável e sólidos solúveis não foram influenciados pela aplicação do 1-MCP. A aplicação do 1-MCP em frutos colhidos em estádios mais avançados de maturação pode ser uma prática interessante uma vez que não impede o amadurecimento e ainda pode prolongar o tempo em que o fruto permanece na condição de consumo.

Palavras chave: *Carica papaya*, conservação, pós-colheita.

1. INTRODUCTION

Papaya is a very perishable fruit, showing high postharvest losses indexes among Brazilian fruits. 'Golden' papaya represents a great demand of the exported papaya, however, few studies have been conducted with this variety.

During ripening period, changes in skin color, firmness and flavor can be considered beneficial effects of ethylene when considering an ideal consumption quality. On the other hand, ethylene action can be harmful since it reduces fruit conservation period. Therefore, an efficient postharvest strategy should control the ethylene effects in fruit ripening to improve fruit quality and conservation.

Synthetic compounds that inhibit ethylene action are particularly interesting in postharvest practices since they inhibit the action of both endogenous and exogenous ethylene (FENG et al., 2000), besides providing a tool for study processes that are ethylene dependent. The 1-methylcyclopropene (1-MCP) occupies ethylene receptors such that ethylene cannot bind and elicit action (SISLER and SEREK, 1997). 1-MCP has been an effective antagonist of ethylene action in banana (GOLDING et al., 1998), apple (FAN et al., 1999), strawberry (TIAN et al., 2000), avocado (FENG et al., 2000), and papaya (JACOMINO et al., 2002).

The necessary 1-MCP amount to protect the tissue against ethylene varies with species and fruit ripening stage. Generally, 1-MCP effects decrease when applied in fruits at advanced ripening stages. HARRIS et al. (2000) have demonstrated that the time for ripening of treated bananas varied according to the ripening stages of the bunches, with greater ripening retention in those which received earlier application. WILLS and KU (2002), studying the use of 1-MCP in tomatoes, verified that to achieve an increase in postharvest life, a greater exposure to 1-MCP was required for ripe tomatoes when compared to green ones.

The objective of this work was to evaluate the influence of ripening stages on some physical and chemical attributes of 'Golden' papaya treated with 1-methylcyclopropene.

2. MATERIALS AND METHODS

'Golden' papaya (*Carica papaya* L.) fruit were harvested in March 2004, from a commercial orchard in Espírito Santo, Brazil, and transported in refrigerated truck at 10 ºC to São Paulo, Brazil. Papaya fruit were harvest at ripening stages 0, 1, 2, 3 and 4. The ripening stages were defined according to the skin color in: Stage 0= totally green; Stage 1= fruit with up to 15% of yellow skin; Stage 2= fruit with up to 25% of yellow skin; Stage 3= fruit with up to 50% of yellow skin; Stage 4= fruit with up to 75% of yellow skin.

Half of the fruit was placed into hermetic chambers (186 L) and exposed to 100 nL L^{-1} of 1-methylcyclopropene (1-MCP) during 12 hours at 23ºC. The other half was placed into the same kind of hermetic chambers, in the same temperature conditions, without 1-MCP treatment. After treatment, fruit were removed from the chambers and kept at 23±1.5°C and 80%-90% RH. During ripening, skin color and firmness were daily analyzed. When fruit were completely ripe (skin completely yellow and / or firmness ≤ 20N), soluble solids, titratable acidity and ascorbic acid were also determined to evaluate the final fruit quality. The time for complete ripening varied according to fruit ripening stage and 1-MCP treatment.

The edible firmness (20N) was determined with a sensorial evaluation (data not shown). For this evaluation, pieces of papaya removed from fruit with known firmness were placed into plastic recipient and offered to 40 non-training testers. Papayas with firmness between 5 and 80 N were evaluated with a three points scale (very hard, good, and very soft). Fruit with average firmness around 20 N was scored as good and considered appropriated for consumption.

The firmness of each fruit was measured using a digital penetrometer (53200-Samar, Tr Turoni, Forli, Italy) fitted with an 8 mm diameter probe tip. The skin was previously removed with a peeler and readings were taken in four opposite positions in the largest diameter area, averaged and recorded in Newton (N). Ten repetitions were used, being each one constituted of the average of a single fruit.

Skin color was measured in hue angle (H°) with a colorimeter (Minolta Chromameter 300, Minolta Camera Co., Osaka, Japan). Readings were taken in four opposite positions in the largest diameter area and then averaged. Ten repetitions were used, being each one constituted of the average of a single fruit.

For soluble solids measurements, rectangular samples of fruit pulp, removed from two opposite sides in the largest diameter portion of fruit, were pressed, being the resulting juice evaluated in a digital refractometer (Atago PR-101, Atago Co Ltda., Tokyo, Japan). Results were expressed in °Brix. Ten repetitions were used, being each one constituted of the average of a single fruit.

The ascorbic acid and tritratable acidity were determined by titrimetry according to CARVALHO et al. (1990). The results were expressed in % citric acid and mg ascorbic acid per 100g of pulp, respectively. Four repetitions were used, being each one constituted of two fruits.

The experimental design was completely randomized and data were analyzed using the ANOVA procedure and the Tukey test ($p<0.05$) to compare means.

3. RESULTS AND DISCUSSION

Postharvest life was affected by both ripening stage and 1-MCP application. 1-MCP application delayed firmness loss during ripening of 'Golden' papaya fruit in all ripening stages ($p<0.05$) (Figure 1).

Firmness retention in fruits treated with 1-MCP has been verified in different species such as avocado (FENG et al., 2000), apricot (FAN et al., 2000), apples (FAN et al., 1999) and banana (GOLDING et al., 1998). 1-MCP competes for ethylene receptor molecules, blocking the ethylene binding and reducing or delaying its effects (SISLER and SEREK, 1997). According to OETIKER and YANG (1995), ethylene has a fundamental role in the processes that occur during ripening such as increase in respiratory activity, ethylene autocatalytic production and changes in fruit color and texture. In fact, LILIÈVRE et al. (1997) argued that firmness loss is one of the most ethylene sensitive processes during ripening. In addition, ethylene has a great influence on the activity of enzymes involved in cell wall degradation (BRUMMELL and HARPSTER, 2001). GUIS et al. (1997) reported that in melons that express the aminocyclopropane-1-carboxylic acid (ACC) antisense, the softening is completely blocked.

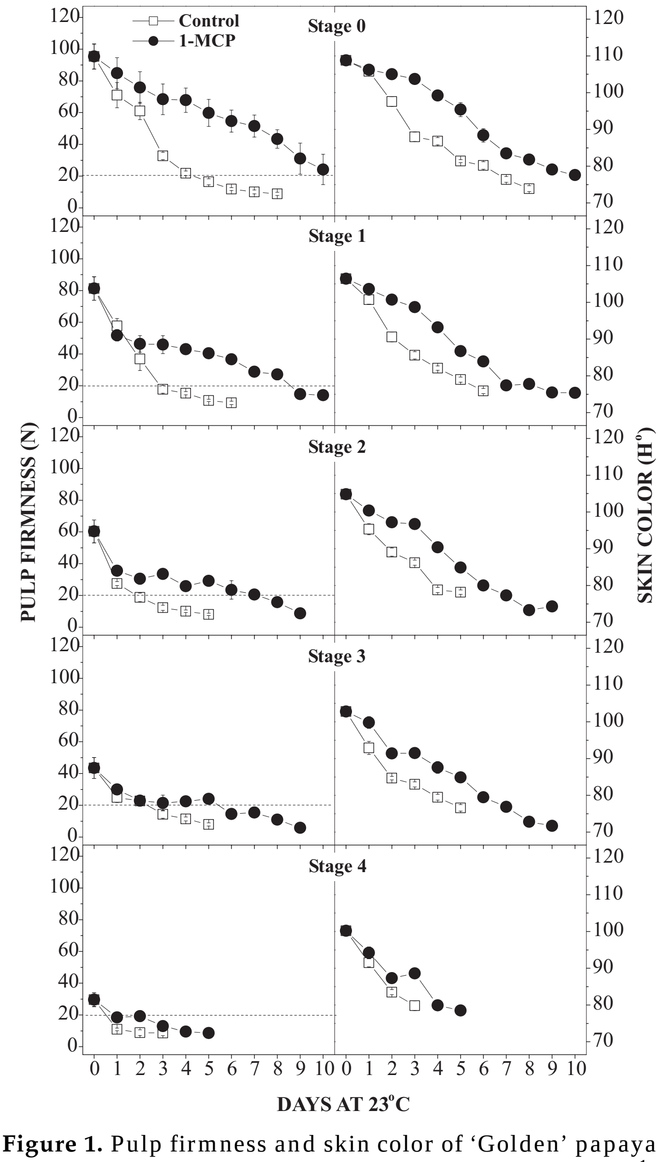

Figure 1. Pulp firmness and skin color of 'Golden' papaya fruit non-treated and treated with 1-MCP (100 $nL.L^{-1}$) at different ripening stages and stored at 23°C. Stage 0= totally green; Stage 1= fruit with up to 15% of yellow skin; Stage 2= fruit with up to 25% of yellow skin; Stage 3= fruit with up to 50% of yellow skin; Stage 4= fruit with up to 75% of yellow skin. Symbols represent the mean value of ten replications (±SE). Dotted lines indicate the edible firmness (≤ 20 N).

The use of 1-MCP prejudices the ripening of fruit harvested at stage 0. Even after ten days at 23ºC these fruit did not reach the ideal firmness for consumption (≤ 20N) (Figure 1). On the 11th day, fruit exhibited high disease incidence and had the appearance prejudiced. Fruit harvested at stage 0 that did not receive 1-MCP application presented ideal consumption conditions after five days of ripening (Figure 1). Even 1-MCP binding with the receptor in an irreversible way, fruit can reassume its ripening once new receptors are formed (SISLER et al., 1996). Probably, few molecules of receptor were formed or activated in fruit harvested at stage 0 at the application time, and, for that reason, 1-MCP could block a high percentage of receptor sites, prejudicing the receptor turnover and consecutively the ripening reassuming. TREWAVAS (1982) concluded that not only the hormonal concentration, but also tissue sensitivity were responsible for cell response, which is related to developmental stage.

For fruit harvested at stage 1, 1-MCP application prolonged the commercialization period in six days (Figure 1). Considering 20 N as the consumption firmness, consumption condition can be defined as the period in which fruit had a pulp firmness ≤ 20 N, and commercialization period as the time that fruit remain with firmness > 20 N. While non-treated fruit presented ideal consumption conditions after three days at 23 ºC, treated fruit only reached the ideal firmness on the 9th day of ripening (Figure 1). Although 1-MCP was responsible for a significant increment in commercialization period, treated fruit remained in the consumption condition for just one day (Figure 1). After ten days of ripening, the fresh appearance began to be harmed.

The ripening of fruit harvested at stage 2 and 1 was similar. Also, an increase in commercialization period of five days was possible when fruit were treated with 1-MCP at stage 2 (Figure 1). Treated fruit stayed in consumption conditions for a shorter period when compared to control fruit (Figure 1).

Fruit harvested at stage 3 and non-treated with 1-MCP, remained in the ideal consumption condition between the 3rd and the 5th day of ripening (Figure 1). Fruit in the same ripening stage, that received 1-MCP, reached ideal firmness on the 6th day and stayed in the consumption condition for four days (Figure 1). For fruit harvested at stage 3, 1-MCP application not only increased the commercialization period, but also prolonged period in that fruit stayed in the consumption condition.

1-MCP application was responsible for increasing in one day the commercialization period for fruit harvested at stage 4. Fruit that did not receive 1-MCP reached the consumption conditions on the 1st day of ripening, while those ones that received 1-MCP stayed for one more day at 23 ºC until reaching the consumption condition (Figure 1). Although 1-MCP has not caused expressive increase in commercialization period, treated fruit stayed in consumption condition for a longer period (Figure 1).

For the progress of biochemical events during ripening, it is necessary that the receptor sites remain exposed to ethylene for a determined period (GOLDING et al., 1998). Probably, fruit harvested at more advanced ripening stages have already had their receptor sites exposed to ethylene for a sufficient period to maintain the transcription of necessary ripening genes. This fact could explain the lower response when 1-MCP application was done in fruit at more advanced ripening stages. Accordingly, other studies show that harvest at early ripening stages enhances 1-MCP effectiveness (GOLDING et al., 1998; FAN et al., 2000; HARRIS et al., 2000; MIR et al., 2001).

1-MCP application also delayed color change ($p<0.05$) (Figure 1), however its effect was less accentuate when compared to firmness retention. It is interesting to observe that even not reaching the ideal firmness, fruit harvested at stage 0 became yellow, reaching hue angle values similar to those ones of ripe fruit harvested at other ripening stages (Figure 1). Therefore, it is reasonable to assume that color development is less ethylene dependent when compared to softening process. According to FLORES et al. (2001), while loss of green color is ethylene dependent, synthesis of yellow pigments is not, occurring even without the hormone presence.

Soluble solids, titratable acidity and ascorbic acid amount were not influenced by 1-MCP application ($p>0.05$). The difference observed were exclusively due to ripening stage in which fruit were harvested (Figure 2).

The influence of 1-MCP on soluble solids, titratable acidity and ascorbic acid is much variable among species, being probably affected by experimental condition and different cultivars. GOLDING et al. (1998) reported that sugar composition in ripe bananas was unaffected by 1-MCP and JACOMINO et al. (2002) did not verified alteration in soluble solids in papayas treated with 1-MCP, neither. In contrast, soluble solids were higher in 1-MCP treated pineapple (SELVARAJAH et al., 2001) and apples (FAN et al., 1999). The lack of effect in papaya soluble solids is expected since this fruit does not present a significant quantity of starch to be hydrolyzed, which results in few variation in soluble solids content during ripening (SELVARAJ et al., 1982). According to SELVARAJ et al. (1982), sucrose content increase, when fruit begins to change its color, explains why fruit harvested at advance stages of ripening presented higher soluble solids (Figure 2).

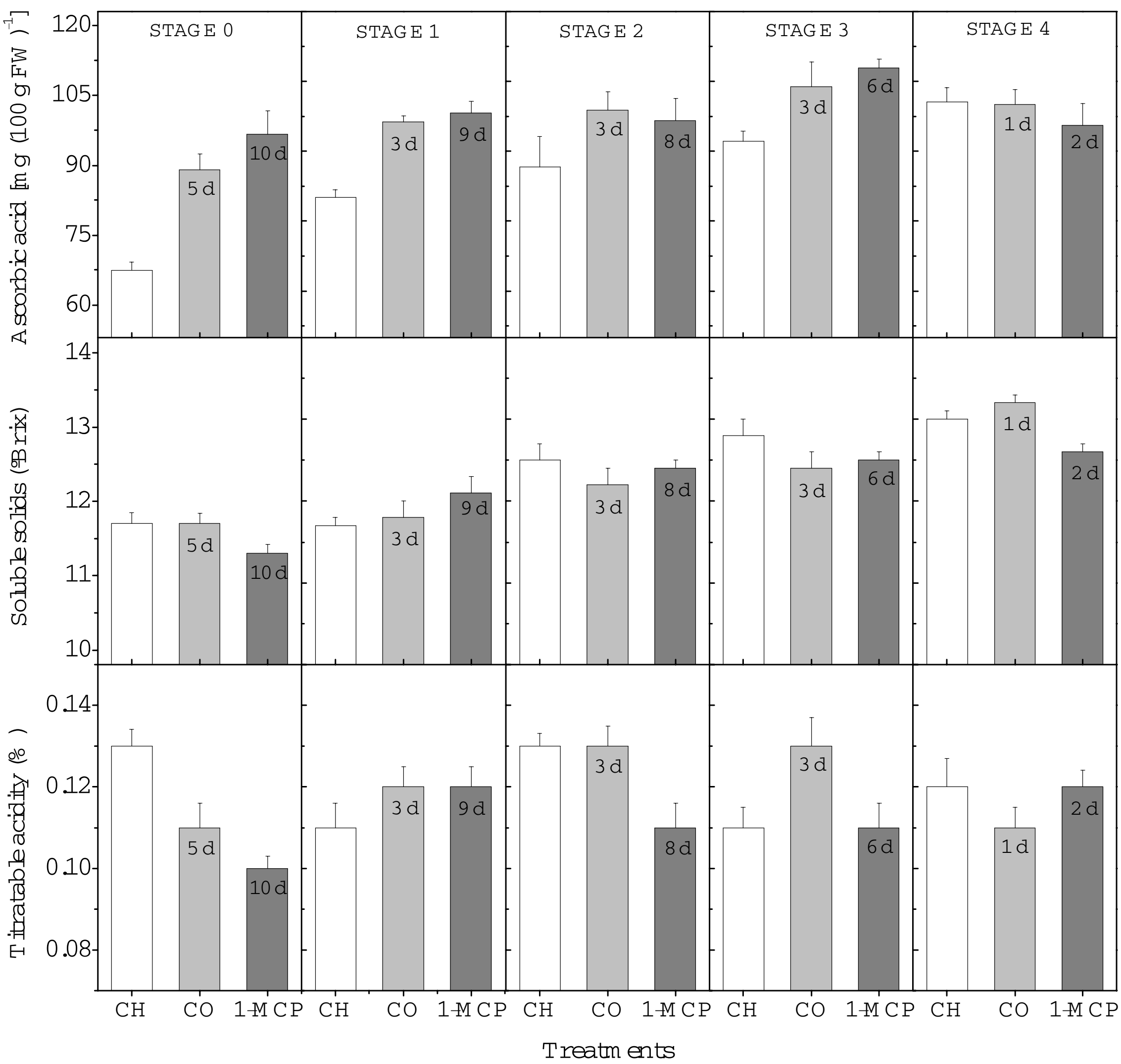

Figure 2. Physical and chemical attributes of ‘Golden’ papaya fruit non-treated and treated with 1-MCP (100 nL L^{-1}) at different ripening stages and stored at 23ºC until full ripe (firmness ≤ 20 N). Stage 0= totally green; Stage 1= fruit with up to 15% of yellow skin; Stage 2= fruit with up to 25% of yellow skin; Stage 3= fruit with up to 50% of yellow skin; Stage 4= fruit with up to 75% of yellow skin. Treatments: CH=characterization (day 0); CO=control (non treated fruit); 1-MCP=treated fruit. Numbers inside the bars indicate the days in which fruit remained at 23ºC until they were analyzed. Bars represent the mean value of four replications (+SE).

As happens with soluble solids, the effect of 1-MCP on titratable acidity is variable, with some species being affected and others not. 1-MCP application inhibited acidity loss in plums, but did not affect the acidity in apricots (Dong et al., 2002). In this experiment, 1-MCP had no effect in papaya titratable acidity ($p>0.05$) (Figure 2). Compared to other fruits, papaya has a very low acidity content, and therefore non-significant for fruit flavor.

Ascorbic acid content increased with the ripening stage in which fruit were harvested. Although ascorbic acid amount had increased with ripening process, 1-MCP treatment did not influence this quality attribute when fruit were ripe (Figure 2).

Summarizing, there is an interaction between fruit ripening and 1-MCP treatment, since sensitivity to ethylene increases with increasing physiological fruit age. Special attention should be given to 1-MCP application in fruit harvested at stage 0, since inhibition of receptor sites in fruit harvested at early ripening stages could reflect in slow recovery capacity of ethylene action and production, impairing the normal ripening.

The application of 1-MCP in fruit harvested at more advanced ripening stages could be an interesting practice since it does not prevent the ripening and still could prolong the time in which fruit remain in consumption condition.

REFERENCES

BRUMMELL, D.A.; HARPSTER, M.H. Cell wall metabolism in fruit softening and quality and its manipulation in transgenic plants. **Plant Molecular Biology**, Dordrecht, v.77, p.311-340, 2001.

CARVALHO, C.R.L.; MANTOVANI, D.M.B.; CARVALHO, P.R.N.; MORAES, R.M.M. **Análises químicas de alimentos**. Campinas: ITAL, 1990. 121p.

DONG, L.; LURIE, S.; ZHOU, H. Effect of 1-methylcyclopropene on ripening of 'Canino' apricot and 'Royal Zee' plums. **Postharvest Biology and Technology**, Amsterdam, v.24, p.135-145, 2002.

FAN, X.; ARGENTA, L.C; MATTHEIS, J.P. Inhibition of ethylene action by 1-methylcyclopropene prolongs storage life of apricots. **Postharvest Biology and Technology**, Amsterdam, v.20, p.135-142, 2000.

FAN, X.; BLANKENSHIP, S.M.; MATTHEIS, J.P. 1-Methylcyclopropene inhibits apple ripening. **Journal of the American Society for Horticultural Science**, Alexandria, v.124, p.690-695, 1999.

FENG, X.; APELBAUM, A.; SISLER, E.C.; GOREN, R. Control of ethylene responses in avocado fruit with 1-methylcyclopropene. **Postharvest Biology and Technology**, Amsterdam, v.20, p.143-150, 2000.

FLORES, F.; BEN AMOR, M.; JONES, B.; PECH, J.C.; BOUZAYEN, M.; LATCHÉ, A.; ROMOJARO, F. The use of ethylene-suppressed lines to asses differential sensitivity to ethylene of the various ripening pathways in Cantaloupe melons. **Physiologia Plantarum**, Copenhagen, v.113, p.128-133, 2001.

GOLDING J.B.; SHEARER, D.; WYLLIE, S.G.; MCGLASSON, W.B. Application of 1-MCP and propylene to identify ethylene-dependent ripening processes in mature banana fruit. **Postharvest Biology and Technology**, Amsterdam, v.14, p.87-98, 1998.

GUIS, M.; BOTONDI, R.; BEN AMOR, M.; AYUB, R.; BOUZAYEN, L.M.; PECH, J.C.; LATCHE, A. Ripening-associated biochemical traits of cantaloupe Charentais melon expressing an ACC oxidase transgene. **Journal of the American Society for Horticultural Science**, Alexandria, v.122, p.748-751, 1997.

HARRIS, D.R.; SEBERRY, J.A.; WILLS, R.B.H.; SPOHR, L.J. Effect of fruit maturity on efficiency of 1-methylcyclopropene to delay the ripening of banana. **Postharvest Biology and Technology**, Amsterdam, v.20, p.303-308, 2000.

JACOMINO, A.P; KLUGE, R.A.; BRACKMANN, A.; CASTRO, P.R.C. Amadurecimento e senescência de mamão com 1-metilciclopropeno. **Scientia Agricola**, Piracicaba, v.59, p.303-308, 2002.

LELIÈVRE, J.M.; LATCHÉ, A.; JONES, B.; BOUZAYEN, M.; PECH, J.C. Ethylene and fruit ripening. **Physiologia Plantarum**, Copenhagen, v.101, p.727-739, 1997.

MIR, N.A.; CURELL, E.; KHAN, N.; WHITAKER, M.; BEAUDRY, R.M. Harvest maturity, storage temperature, and 1-MCP application frequency alter firmness retention and chlorophyll fluorescence of 'Redchief Delicious' apples. **Journal of the American Society for Horticultural Science**, Alexandria, v.126, p.618-624, 2001.

OETIKER, J.H.; YANG, S.F. The role of ethylene in fruit ripening. **Acta Horticulturae**, Leuven, v.398, p.167-178, 1995.

SELVARAJ, Y.; SUBRAMANYAN, M.D.; IYER, C.P.A. Changes in the chemical composition of four cultivars of papaya (*Carica papaya* L.) during growth and development. **Journal of Horticultural Science**, Kent, v.57, p.135-143, 1982.

SELVARAJAH, S.; BAUCHOT, A.D.; JOHN, P. Internal browning in cold-stored pineapples suppressed by a postharvest application of 1-methylcyclopropene. **Postharvest Biology and Technology**, Amsterdam, v.23, p.167-170, 2001

SISLER, E.C.; DUPILLE, E.; SEREK, M. Effect of 1-methylcyclopropene and methylenecyclopropane on ethylene binding and ethylene action on cut carnations. **Plant Growth Regulation**, Dordrecht, v.18, p.79-86, 1996.

SISLER, E.C.; SEREK, M. Inhibitors of ethylene responses in plants at the receptor level: recent developments. **Physiologia Plantarum**, Copenhagen, v.100, p.577-582, 1997.

TIAN, M.S.; PRAKASH, S.; ELGAR, H.J.; YOUNG, H.; BURMEISTER, D.M.; ROSS, G.S. Responses of strawberry fruit to 1-methylcyclopropene (1-MCP) and ethylene. **Plant Growth Regulation**, Dordrecht, v.32, p.83-90, 2000.

TREWAVAS, A.J. Growth substance sensitivity: the limiting factor in plant development. **Physiologia Plantarum**, Copenhagen, v.55, p.60-72, 1982.

WILLS, R.B.H.; KU, V.V.V. The use of 1-MCP to extend the time to ripen of green tomatoes and postharvest life of ripe tomatoes. **Postharvest Biology and Technology**, Amsterdam, v.26, p.85-90, 2002.