# Methyl Jasmonate Reduces Chilling Injury and Maintains Postharvest Quality of Mango Fruit

G. A. González-Aguilar,*,† J. Fortiz,† R. Cruz,† R. Baez,† and C. Y. Wang‡

Centro de Investigación en Alimentación y Desarrollo, AC, Dirección de Tecnología de Alimentos de Origen Vegetal, A.P. 1735, Hermosillo, Sonora (83000), Mexico, and Beltsville Agricultural Research Center, Agricultural Research Service, U.S. Department of Agriculture, Beltsville, Maryland 20705

Exposure of mango (*Mangifera indica* cv. Tommy Atkins) fruit to methyl jasmonate (MJ) vapors ($10^{-4}$ M) for 24 h at 25 °C reduced chilling injury during subsequent storage for 21 days at 7 °C and after 5 days of shelf life at 20 °C. The chilling tolerance induced by MJ was positively correlated with the reduction in the percent ion leakage of mango tissue. The overall quality of MJ-treated fruit was also better than that of control fruit. MJ treatment increased the total soluble solids but did not affect titratable acidity or pH. MJ also did not change the normal climacteric rise in respiration, water loss, and softening rates. The efficacy of MJ to reduce chilling injury and decay of mango could be related to the tolerance induced at low temperature. It was concluded that MJ treatment may prevent chilling injury symptoms of mango without altering the ripening process.

**Keywords:** *Mangifera indica; methyl jasmonate; chilling injury; ion leakage; overall quality*

## INTRODUCTION

Mangos, like many other tropical and subtropical fruits, are susceptible to chilling injury (CI) when held below some critical minimum temperature (Chaplin et al., 1991; Lizada, 1991). The most common visual symptoms of CI in mango fruit are dark, scald-like discoloration and pitting or sunken lesions on the peel (Chaplin et al., 1991). In addition, abnormal ripening and decay can be enhanced when mango fruit are exposed to temperatures below a threshold point. Chilling-injured fruits suffer from physical and physiological changes induced by reduced temperatures, and each commodity displays characteristic symptoms. The appearance of such symptoms is a function of plant species, degree of maturity, time and temperature of exposure, and environmental conditions during and after cold storage (Wang, 1990). It has been suggested that the temperature range of 10−13 °C is adequate to avoid the onset of CI in mangos (Hatton, 1990). Cv. Haden mangos can be maintained at 1.7 °C for 4 weeks without showing evidence of CI. Other papers indicate that temperatures below 13 °C for a period of 10 days produce CI in fully ripening cv. Kent mangos (Saucedo-Veloz et al., 1977). For these reasons, one of the main obstacles to postharvest handling of mango fruits is undoubtedly its susceptibility to CI and decay. Advances in the control of these disorders have been accomplished by using modified-atmosphere packaging, temperature management, and chemical treatments (Gonzalez et al., 1990; Yahia, 1993; Lonsdale, 1993).

It has been reported that applications of methyl jasmonate (MJ) as vapor or emulsion before exposure to low temperatures decreased the incidence of CI symptoms and decay of chilling-sensitive crops such as zucchini squash (Wang and Buta, 1994), bell peppers, and avocado (Meir et al., 1996) and that jasmonates play an integral role in the intracellular signal transduction cascade which acts in the inducible defense mechanisms that plants have developed against pathogens and other stresses. Because there was a lack of information on the influence of MJ on mango fruit quality during low-temperature storage, this study was undertaken to determine if MJ application was effective in reducing CI and decay and in maintaining quality of mango fruit.

## MATERIALS AND METHODS

**Materials and Experiments.** Mangos (*Mangifera indica* cv. Tommy Atkins) were harvested at Escuinapa, Sinaloa, Mexico, and transported to the laboratory the same day. Fruits were sorted, cleaned, and classified by size and color. Fruits of uniform size, shape, and maturity and those free from defects were used. A random sample of 20 fruits was used to measure respiration rate (mL of $CO_2$/kg·h), and 30 fruits were used to determine skin color, weight, firmness, percent ion leakage, total soluble solids (TSS), pH, and titratable acidity (TA). The remaining fruits were divided into two lots of 100 fruits for each treatment. Fruits from one lot were placed in 30-L jars, together with $10^{-4}$ M of MJ (100%) spotted onto filter paper, and incubated for 24 h at 25 °C. Afterward, jars were opened and ventilated, and the fruits were stored at 7 °C. Fruits from the other lot were handled the same way except without MJ treatment (control). The concentration of MJ was selected according to preliminary studies carried out in the laboratory and the higher reduction in physiological disorders. In addition, we observed that concentrations of MJ $>10^{-4}$ M significantly increased changes in color and abnormal ripening. At 7-day intervals, and after holding for 5 days at 20 °C, 25 fruits of each treatment were sampled. Fruits were evaluated for changes in respiration rate, weight loss, flesh firmness, color ($L'$, $a'$, $b'$, hue degree, and chroma), pH, TSS, TA, percent ion leakage, CI symptoms, and decay.

**Methods.** Respiration rate was evaluated immediately after MJ treatment and throughout the storage period. Individual fruits were placed in a plastic container (2.5 L) and connected

* Author to whom correspondence should be addressed [fax (301) 504-5107; e-mail mjxyz@hotmail.com or gustavo@cascabel.ciad.mx].

† Centro de Investigación en Alimentación y Desarrollo.

‡ U.S. Department of Agriculture.

10.1021/jf9902806 CCC: $19.00 
Published on Web 01/21/2000

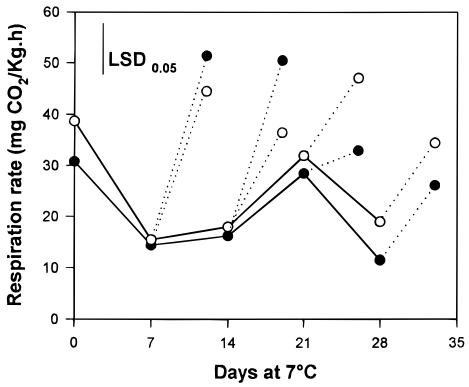


**Figure 1.** Respiration rate (mg of $CO_2$/kg·h) of MJ-treated Tommy Atkins mangos during storage at 7 °C. Open circles represent controls. Arrows and dotted lines indicate the shelf life period at 20 °C for 5 days, and the vertical bar represents the LSD ($p = 0.05$).

to a flow-board through which an 80−85% relative humidity air stream was passed. Carbon dioxide flow rates were maintained below 0.3% to prevent physiological disorders caused by accumulation of $CO_2$ inside the containers. Carbon dioxide concentrations were analyzed by collecting 1-mL gaseous samples from the headspace of each container and then injected into an infrared gas analyzer (model PIR-2000, Horiba Instruments, Inc., Irvine, CA).

Mangos were inspected for signs of decay every 3 days. Mangos that showed decay were recorded, removed from storage, and discarded when >40% total area presented symptoms of deterioration.

At each sampling, mangos were assessed for percentage of weight loss, color, firmness, quality, decay, percent ion leakage, and CI. Mangos were weighed before and after the storage intervals to calculate percentage of fresh weight loss. Skin color was assessed with a tristimulus color difference meter (Minolta CR 300) and expressed as $L'$, $a'$, and $b'$ values. These values were used to calculate hue degree and chroma values. Three locations around the circumference of each fruit were evaluated.

Flesh firmness was determined on four points of each fruit using a firmness tester (Chatillon DFG 50, John Chatillon & Sons, Inc., New York, NY) with an 8-mm tip and skin removed. TSS was determined using a temperature-adjusted refractometer, TA (as percent citric acid) using 0.1 M NaOH, and pH using a pH-meter according to AOAC (1990) procedures.

Electrolyte leakage was determined on eight disks (4 mm × 1 cm) taken with a cork borer from skin tissue from the surface. Disks were immersed in 20 mL of 0.3 M mannitol in glass vials, which were agitated at 20 °C for 120 min. Ion leakage was measured as the amount of increased conductivity ($\mu$S cm$^{-1}$) of the solution. After that, disks were boiled for 30 min and cooled to room temperature and the total conductivity was measured. Chilling-induced ion leakage was expressed as the percent of the total conductivity leaked per hour.

The score of CI was based on the percentage of total surface areas affected by sheet pitting; 0 = no injury, 1 = slight, 2 = moderate, 3 = severe. The analysis of variance (ANOVA) and Tukey multiple-range test for comparison of means and least significant differences (LSD) ($p < 0.05$) were performed with the data using the SAS system (1990).

## RESULTS AND DISCUSSION

Rate of respiratory activity is associated with rate of ripening process. The respiration rate measured as $CO_2$ production is shown in Figure 1. The respiration rate of control and MJ-treated fruits decreased after 7 days at 7 °C. However, the respiration rate increased and reached a peak after 21 days in control and MJ-treated fruits. After 28 days, $CO_2$ production decreased in fruits from both treatments. No significant differences were

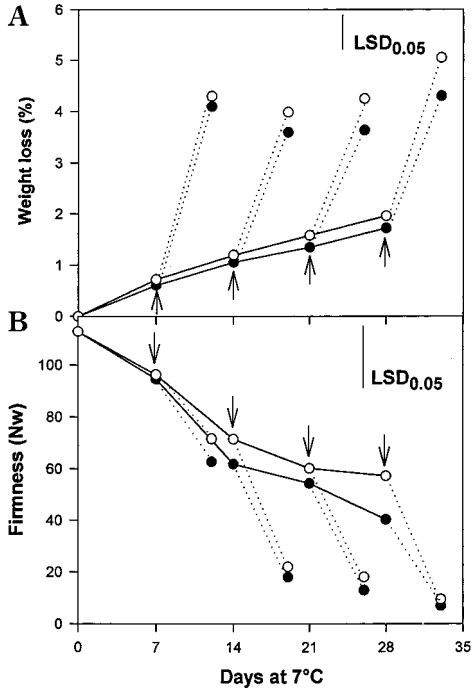


**Figure 2.** Changes in weight loss (%) and firmness (N) of MJ-treated Tommy Atkins mangos during storage at 7 °C. Open circles represent controls. Arrows and dotted lines indicate the shelf life period at 20 °C for 5 days, and the vertical bar the LSD ($p = 0.05$).

detected in $CO_2$ production between treatments during storage at 7 °C. $CO_2$ production also did not show any consistent difference after the fruit were transferred for 5 days to 20 °C. Perez et al. (1997) found that MJ treatment increased the respiration rate and ethylene production of strawberries. Saniewsky et al. (1997) reported that MJ treatment promotes the ethylene production in preclimacteric apples but inhibited it in postclimacteric fruits. It has been shown previously that MJ treatment increased $CO_2$ production, independent of the stimulation or inhibition of ethylene biosynthesis in Jonagold apples (Miszczak et al., 1995). Application of MJ vapors to Golden Delicious apples has been shown to slightly increase the ACC content and the ACC oxidase activity and to significantly stimulate ethylene formation in the cortical and peel tissue (Olias et al., 1991). In the present study, ethylene production (<0.2 ppm) was observed in only a few fruits treated with MJ after being transferred 5 days at 20 °C (data not shown).

As the fruits were held longer at 7 °C, weight loss increased, but the rates of weight loss at 20 °C were similar in control and MJ-treated fruits (Figure 2A). In general, comparable weight losses were detected in control and MJ-treated mangos. MJ treatment barely affected weight loss and firmness of mangos during cold storage (Figure 2). However, these values were slightly lower in fruits treated with MJ. A similar decline in firmness (or a similar trend of softening) was found in fruits treated and untreated with MJ during storage at 7 °C and after a shelf life period. The most noticeable differences among treatments in firmness were observed after 28 days at 7 °C; however, no statistical differences were found (Figure 2B). In a previous study, it was observed that MJ treatment slightly decreased the firmness of strawberries (Perez et al., 1997). In the present study mangos were tasted immediately after removal from cold storage and shelf life period, and no off-flavors were detected in control and treated fruits.

**Table 1. Changes in pH, Total Soluble Solids (TSS), Titratable Acidity (TA; Expressed as Percent Citric Acid), and Color (Hue Degree and Chroma) of Cv. Tommy Atkins Mango, Pretreated with MJ Vapors for 24 h before Storage at 7 °C**

| treatment | days of storage 7 °C | | 20 °C | pH | TSS | TA (%) | hue degree | chroma |
|---|---|---|---|---|---|---|---|---|
| | initial | | | 3.32[b] | 5.2[c] | 1.040[a] | 95.27[a] | 240.99[e] |
| control | 7 | + | 5 | 3.33[b] | 6.8[c] | 0.914[ab] | 60.54[bc] | 577.51[b] |
| | 14 | + | 5 | 3.35[b] | 7.2[cb] | 0.907[b] | 52.16[c] | 653.32[a] |
| | 21 | + | 5 | 3.22[c] | 8.6[b] | 0.548[c] | 58.54[bc] | 439.03[c] |
| MJ | 7 | + | 5 | 3.33[b] | 9.0[b] | 0.935[ab] | 66.20[b] | 505.55[b] |
| | 14 | + | 5 | 3.35[b] | 12.0[a] | 0.608[c] | 62.90[bc] | 380.01[d] |
| | 21 | + | 5 | 3.61[a] | 13.6[a] | 0.516[c] | 55.55[c] | 227.60[e] |
| significance | | | | | | | | |
| treatment (T) | | | | ns | * | ns | ns | * |
| time (t) | | | | * | * | * | * | * |
| T × t | | | | * | * | ns | * | * |

[a] Mean separation in columns by Tukey's multiple-range test ($p = 0.05$).

Table 1 shows quality changes of fruits during storage. MJ treatment increased soluble solids and decreased acidity of mangos. The storage time significantly affected TSS but not acidity or pH values. MJ treatment barely affected the values of pH; only treated fruits showed higher values after 21 days at 7 °C plus 5 days at 20 °C.

Color of mangos expressed as hue degree and chroma values changed during cold storage and shelf life period (Table 1). Storage time and treatment significantly affected the changes in color (hue degree and chroma values). MJ treatment enhances uniformly the fruit color compared to control. Lesser changes in color were observed in MJ-treated fruits, during the whole storage period. MJ-treated mangos maintained lower $a'$ values than the control fruits, which indicates that the treated fruit retained more green color during storage (data not shown). On the other hand, higher $L'$ and $b'$ values were detected in the control than in the treated fruit, indicating that control fruits had more yellow color and were brighter than treated fruits (data not shown). The most noticeable changes in color were observed after 14 days at 7 °C in control and MJ-treated fruits. Control fruits showed higher chroma values than MJ-treated ones. We found that hue degree values were significantly affected by shelf life period (Table 1). According to these results MJ treatment apparently delayed color changes of mango fruit. However, in previous work it has been observed that exposure to MJ vapors (8 ppm) for 4 h at 25 °C greatly promoted $\beta$-carotene accumulation and chlorophyll degradation in Golden Delicious apple peel (Perez et al., 1993). Fan et al. (1997) found that in whole apples, MJ promoted fruit ripening as indicated by increased ethylene synthesis, accelerating the yellowing of surface color, and increased loss of flesh firmness. It appears that response of mango fruit to MJ depends on maturity stage and subsequent storage temperature.

Figure 3 shows the CI index and percent of ion leakage of mango fruits treated with MJ during exposure to 7 °C and after transferring the fruit to 5 days of storage at 20 °C. MJ treatment could protect against CI, during both cold storage and subsequent shelf life period. CI, manifested as surface pitting, started to appear on the skin surface of control fruits after 7 days of exposure to 7 °C and progressed rapidly after 14 days, being more apparent in control fruits. Most significantly, MJ suppressed ion leakage and reduced CI of mangos

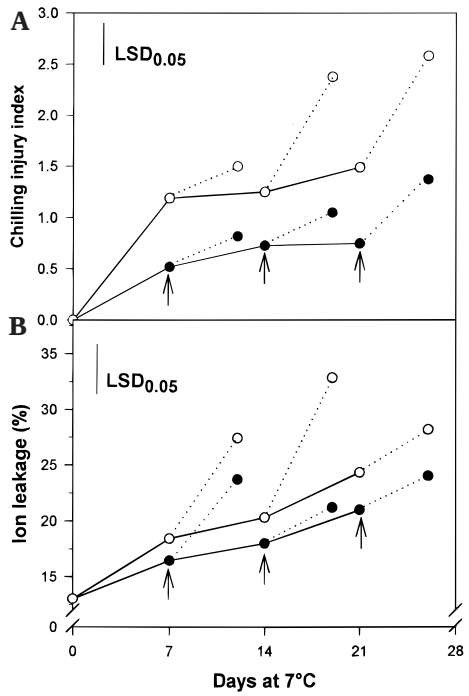


**Figure 3.** CI index and ion linkage (%) of MJ-treated Tommy Atkins mangos during storage at 7 °C. Open circles represent controls. Arrows and dotted lines indicate the shelf life period at 20 °C for 5 days, and the vertical bar the LSD ($p = 0.05$).

during cold storage (Figure 3). Control and MJ-treated fruits stored at 7 °C showed an increase in respiration rates upon transfer to a ripening temperature of 20 °C (Figure 1). These elevated values were greater in control fruits than those treated with MJ and correlated with the appearance of chilling injury in the fruits. The effect of temperature on metabolic respiration has been considered as a secondary response to CI, and a respiratory burst is a common response of chilling-sensitive tissues transferred from refrigerated to higher temperatures (Jackman et al., 1988).

The susceptibility to low temperatures of mango fruit varies among species. Thomas and Joshi (1988) observed CI symptoms in fully ripened Alphonso mangos exposed to 5, 10, or 15 °C for 2 or 4 days. Medicott et al. (1990) observed the disorder in Amelie, Tommy Atkins, and Keitt mangos after 21 days at 8 and 10 °C. Kengston mangos displayed external CI symptoms after being refrigerated for 1 week at 1 and 5 °C (Chaplin et al., 1991). Cv. Manila mangos stored at 12 °C displayed the first symptoms of CI after 20 days plus 5 days of ripening (Gutierrez et al., 1996). In our study, control fruits began to show CI symptoms after 7 days at 7 °C, which became more apparent after the fruits were transferred to 20 °C for 5 days. Heat treatment can also reduce the incidence of CI symptoms in Keitt mangos stored at 5 °C. No internal breakdown was reported in the late study, although fruit ripening was accelerated as indicated by firmness, sugar content, and pulp color (McCollum et al., 1993). It has been reported that an increase in the activities of the enzyme peroxidase and cellulase is part of the chilling syndrome which developed during storage of mango fruit at low temperatures (Zauberman et al., 1988). Lederman et al. (1997) found that apparently there is no direct connection between CI development and changes in the activity of ACC oxidase in Keitt mango stored at 0, 2, 5, and 14 °C for 4 weeks. Our study is in agreement with previous work

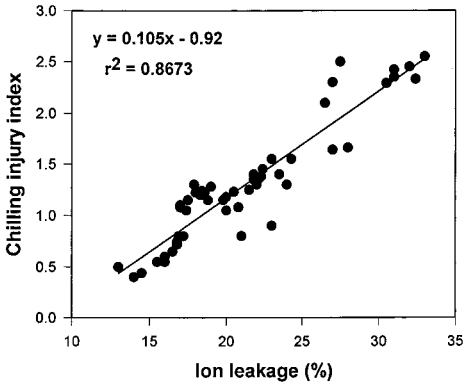


**Figure 4.** Correlation between CI index and ion linkage (%) in mango fruit during storage.

during which MJ treatment was effective in alleviating CI of cv. Hass avocado, grapefruit, zucchini squash, and peppers when it was applied as either a dip or a gas (Meir et al., 1996: Wang and Buta, 1994). Further studies are necessary to elucidate the mechanisms by which MJ reduces CI in mango fruit. In preliminary studies we observed an increase in polyamine content in MJ-treated fruits (data not shown). This increase could be related to the tolerance induced by MJ treatment against CI.

According to Fuchs et al. (1989), electrolyte leakage cannot serve as an indication of development of CI symptoms in mango fruit. However, in our study the ion leakage (percent) was positively correlated ($r^2$ = 0.86) with the severity of CI (Figure 4). Ion leakage was consistently lower in MJ-treated tissue than in control, during storage at 7 °C, and after transfer to 20 °C. Likewise, CI of mango fruits was also less severe in MJ-treated fruits than in control fruits. After 3 weeks at 7 °C, the damage was more apparent in control fruits (1.7) as indicated by chilling index than in MJ-treated ones (0.8). CI symptoms increased in both treatments with time of storage and after a shelf life period and reached values of 2.5 and 1.4 in control and MJ-treated fruits, respectively. Previous papers have shown that pretreatment of plant material with MJ prior to exposure to cold temperature stress resulted in decreased chilling injury, indicating that biochemical defense mechanisms against environmental stress were activated (Wang and Buta, 1994). These authors found that MJ delays the onset of chilling symptoms by mechanisms that involve the increase in abscisic acid and polyamine levels.

Minimal symptoms of decay were observed during the cold storage and shelf life period of control and MJ-treated fruits (data not shown). Buta and Moline (1998) found that MJ treatment increased shelf life and reduced microbial development in cut celery and peppers. Apparently, MJ treatment could activate the plant defense mechanisms effective against pathogens such as bacteria and fungus.

According to the results, we found that MJ when applied exogenously to mango fruit can induce resistance to CI. We concluded that MJ treatment reduced ion leakage and CI but did not affect ripening process of mangos as indicated by a normal climacteric rise in respiration and softening.

## LITERATURE CITED

AOAC (Association of Official Agricultural Chemists). *Official Methods of Analysis of the AOAC*, 12th ed.; AOAC: Washington, DC, 1990.

Buta, J. G.; Moline, H. E. Methyl jasmonate shelf life and reduces microbial contamination of fresh-cut celery and peppers. *J. Agric. Food Chem*. **1998**, *46*, 1253−1256.

Chaplin, G. R.; Cole, S. P.; Landrin, M.; Nuevo, P. A.; Lam, P. F.; Graham, D. Chilling injury and storage of mango (*Mangifera indica* L.) held under low temperatures. *Acta Hortic.* **1991**, *291*, 461−471.

Fan, X.; Mattheis, J. P.; Fellman, J. K.; Patterson, M. E. Effect of methyl jasmonate on ethylene and volatile production by Summer apples depends on fruit development stage. *J. Agric. Food Chem*. **1997**, *45*, 208−211.

Fuchs, Y.; Zauberman, G.; Rot, I.; Wexsler, A. Chilling injury and electrolyte leakage in cold stored mango and avocado fruits. *Acta Hortic.* **1989**, *258*, 303−308.

Gonzalez, G.; Yahia, E.; Higuera, I. Modified atmosphere packaging (MAP) of mango and avocado fruit. *Acta Hortic.* **1990**, *269*, 335−344.

Gutierrez, B.; Cruz, J.; Parkin, K. L.; Garcia, H. S. Effect of refrigerated storage on manila mangoes (*Mangifera indica* L.) after hydrothermal treatment; Proceedings of the 5th International Mango Symposium; Lavi, Degani, Gazit, Lahav, Pesis, Prusky, Tomer, Wysoki, Eds. *Acta Hortic.* **1996**, *455*, 679−686.

Hatton, T. T. Reduction of chilling injury with temperature manipulation. In *Chilling Injury of Horticultural Crops*; Wang, C. Y., Ed.; CRC Press: Boca Raton, FL, 1990; Chapter 17, pp 269−280.

Jackman, R. L.; Yada, R. Y.; Marangoni, A.; Parkin, K. L.; Stanley, D. W. Chilling injury. A review of quality aspects. *J. Food Qual*. **1988**, *11*, 253−278.

Lederman, I. E.; Zauberman, G.; Weksler, A.; Rot, I.; Fuchs, Y. Ethylene-forming capacity during cold storage and chilling injury development in 'Keitt' mango fruit. *Postharvest Biol. Technol*. **1997**, *10*, 107−112.

Lizada, M. C. Postharvest physiology of the mango—A review. *Acta Hortic.* **1991**, *291*, 437−453.

Londsdale, J. H. Strategies for the control of postharvest diseases of mango. *S. Afr. Mango Growers Assoc. Yearb*. **1993**, *13*, 109−116.

McCollum, T. G.; D'Aquino, S.; McDonald, R. E. Heat treatment inhibits mango chilling injury. *HortScience* **1993**, *28*, 197−198.

Medicott, A. P.; Sigrist, J. M. M.; Sy, O. Ripening of mangos following low-temperature storage. *J. Am. Soc. Hortic. Sci*. **1990**, *115*, 430−434.

Meir, S.; Philosoph-Hadas S.; Lurie, S.; Droby, S.; Akerman, M.; Zauberman, G.; Shapiro, B.; Cohen, E.; Fuchs, Y. Reduction of chilling injury in stored avocado, grapefruit, and bell pepper by methyl jasmonate. *Can. J. Bot*. **1996**, *74*, 870−874.

Miszczak, A.; Lange, E.; Saniewski, M.; Czapski, J. The effect of methyl jasmonate on ethylene production and $CO_2$ evolution in Jonagold apples. *Acta Agrobot*. **1995**, *48*, 121−128.

Olias, J. M.; Sanz, L. C.; Perez, A. G. Influencia del jasmonato de metilo en la maduración postcosecha de manzana. In *El etileno en la maduración y postcosecha de frutos y hortalizas*; Recasens, J., Graell, M., Vendrell, M., Eds.; Paper Kite: Lerida, Spain, 1991; pp 60−67.

Perez, A.; Sanz, C.; Richardson, D. G.; Olias, J. M. Methyl jasmonate promotes $\beta$-carotene synthesis and chlorophyll degradation in Golden Delicious apple peel. *J. Plant Growth Regul*. **1993**, *12*, 163−167.

Pérez, A. G.; Sanz, C.; Olias, R.; Olias, J. M. Effect of methyl jasmonate on *in vitro* strawberries ripening. *J. Agric. Food Chem*. **1997**, *24*, 3733−3737.

Saniewsky, M. The role of jasmonates in ethylene biosynthesis. In *Biology and Biotechnolgy of the Plant Hormone Ethylene*; Kanellis, A. K., Ed.; Kluwer Academic Publishers: Dordrecht, The Netherlands, 1997; pp 39−45.

SAS Institute. *SAS User's Guide: Statistics*, version 6.03; SAS Institute, Inc.: Carey, NC, 1990.

Saucedo-Veloz, C.; Esparza, T. F.; Laksminarayana, S. Effect of refrigerated temperatures onn the incidence of chilling

injury and ripening quality of mango fruit. *Proc. Fla. State Hortic. Soc.* **1977**, *90*, 205−210.

Thomas, P.; Joshi, J. Reduction of chilling injury in ripe Alphonso mango fruit in cold storage by temperature conditioning. *Int. J. Food Sci. Technol.* **1988**, *23*, 447−455.

Wang, C. Y. Alleviation of chilling injury of horticultural crops. In *Chilling Injury of Horticultural Crops*; Wang, C. Y., Ed.; CRC Press: Boca Raton, FL, 1990; pp 281−302.

Wang, C. Y.; Buta, J. G. Methyl jasmonate reduces chilling injury in Cucurbita pepo through its regulation of abscisic acid and polyamine levels. *Environ. Exp. Bot.* **1994**, *34*, 427−432.

Yahia, E. Responses of some tropical fruits to insecticidal atmospheres. *Acta Hortic.* **1993**, *343*, 371−376.

Zauberman, G.; Fuchs, Y.; Rot, I.; Wexsler, A. Chilling injury, peroxidase and cellulase activities in peel of mango fruit at low temperature. *HortScience* **1988**, *23*, 732−733.

Received for review March 12, 1999. Revised manuscript received November 20, 1999. Accepted December 1, 1999. This research was funded by the Centro de Investigación en Alimentación y Desarrollo, AC (CIAD, AC) and Consejo Nacional de Ciencia y Tecnologia (CONACYT) from Mexico.

JF9902806