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# Storage Life and Deterioration of Intact Cantaloupe (*Cucumis melo* L. var. *reticulatus*) Fruit Treated with 1-Methylcyclopropene and Fresh-cut Cantaloupe Prepared from Fruit Treated with 1-Methylcyclopropene Before Processing

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***Abstract.*** **A study was conducted to determine the influence of the ethylene action inhibitor, 1-methylcyclopropene (1-MCP), on the shelf life and deterioration during storage at 5 °C of intact netted muskmelon (*Cucumis melo* L. var. *reticulatus*) fruit and fresh-cut cubes prepared from those fruit. 'Durango', 'Magellan', and '7920' fruit (3/4 to full-slip stage) were treated with 1-MCP (1.0 μL·L$^{-1}$) for 24 h at 20 °C. Preliminary research with 'Athena' muskmelon had shown that the more physiologically advanced distal pericarp tissue developed significantly more watersoaking than the less advanced proximal and center portions during 5 °C storage; therefore, after treatment with 1-MCP and cooling to 5 °C, the center portions of the fruit were used to prepare the fresh-cut samples. Fresh-cut cubes and intact fruit were stored for 12 d at 5 °C. Intact fruit of all tested cultivars responded to 1-MCP application with improved firmness retention during storage, but no watersoaking was observed in intact fruit. The effect of 1-MCP treatment on the firmness retention and watersoaking of fresh-cut cubes from the different cultivars was inconsistent. Exposure of muskmelon fruit to 1-MCP did not significantly influence the flesh color or soluble solid contents of either intact fruit or fresh-cut cubes during storage at 5 °C.**

The increase in consumer demand for fresh-cut produce has prompted increased research interest in devising and implementing methods for improving and prolonging the quality of these highly perishable products. Fresh-cut fruit products have limited storage life because of excessive tissue softening, which is coordinated by ethylene and has been demonstrated to be a consequence of alteration in cell wall metabolism (Huber et al., 2001; Karakurt and Huber, 2003).

There are numerous chemical and physical preservation strategies that can be used to retard fruit tissue softening after cutting (Reyes, 1996). Low temperature has been used to preserve quality and extend storage life of fresh-cut produce. Although cold storage retards many biological processes in fresh-cut produce, tissue softening and deterioration continue at low temperature, especially for fresh-cut fruits, including fresh-cut muskmelon (Lamikanra et al., 2000). Postharvest treatments such as dipping with dilute hypochlorite solution (Ayhan et al., 1998) or calcium solutions (Luna-Guzman and Barrett, 2000; Saftner et al., 2003), controlled atmosphere (Qi et al., 1998), and modified atmosphere (MA) (Bai et al., 2003) have proven to be of limited benefit in extending the storage life of fresh-cut muskmelons.

Ethylene production is enhanced when plant tissues are injured by the physical action of fresh-cut processing, and ethylene can accumulate in packages of fresh-cut products (Watada and Qi, 1999), leading to undesirable effects on quality during subsequent handling. One of the ethylene action inhibitors available, 1-methylcyclopropene (1-MCP) (Sisler and Serek, 1997), has proven most effective at suppressing ripening and ethylene responses in a wide variety of fruits and vegetables (Blankenship and Dole, 2003). Of greater interest are studies demonstrating that 1-MCP can extend the period of optimum quality of tomato (*Lycopersicon esculentum* Mill.; Hoeberichts et al., 2002; Hurr et al. 2005; Wills and Ku, 2002), papaya (*Carica papaya* L.; Ergun and Huber, 2004), and 'Galia' and 'Athena' muskmelons (*Cucumis melo* L. var. *reticulatus*; Ergun et al., 2005; Jeong et al., 2007) fruit even when applied at advanced stages of ripening. Significant benefit from 1-MCP applied to nearly ripe or ripe fruit would seem to suggest that there could also be potential benefits from 1-MCP application for fresh-cut fruits. We have previously taken this approach in research with fresh-cut apple (*Malus* × *domestica* Borkh.; Bai et al., 2004), tomato (Jeong et al., 2004), and 'Galia' melon (Ergun et al., 2007).

The objectives of this study were to characterize the physiological responses of fresh-cut netted muskmelon to 1-MCP applied to intact fruit before processing and to evaluate its usefulness as a postharvest tool for extending the storage life and maintaining the textural quality of fresh-cut netted muskmelon.

## Materials and Methods

*Plant material.* Muskmelon fruit of the Reticulatus Group, commonly known as muskmelons or netted muskmelons, cvs. Durango, Magellan, 7920, and Athena, were obtained from a local supermarket 1 d after delivery from the shipper to the distribution center and were transferred to the postharvest facilities at the University of Florida in Gainesville. Fruit were inspected carefully for bruises, compression damage, and the presence of fungus on the rind and culled if not in optimum condition. Fruit at the 3/4 to full-slip stage that were uniform in size were then selected for the experiments.

*Fresh-cut preparation and 1-methylcyclopropene treatment.* Before 1-MCP treatment, fruit were washed thoroughly in running tap water (24 °C), then submerged for at least 1 min in 1.34 mM sodium hypochlorite solution prepared by diluting a 5.25% commercial bleach solution with tap water (pH 8), rinsed in tap water, and air-dried. 1-MCP (1.0 μL·L$^{-1}$) was applied at 20 °C to half of the melons by releasing the gas from a commercial powder formulation (SmartFresh; AgroFresh Rohm & Haas, Philadelphia, PA) for 24 h (85% relative humidity) in a sealed, 174-L chamber. Two applications of 1-MCP were made at 12-h intervals to minimize possible interference with 1-MCP binding resulting from buildup of $CO_2$, a competitive inhibitor of ethylene binding; the rest of the fruit were held in air at 20 °C. Concentrations of $CO_2$ in the treatment chambers were monitored by gas chromatography and found to remain below 0.5% in all cases. All fruit were then transferred to air at 5 °C and maintained at that temperature for 24 h to allow temperature equilibration before cutting.

A preliminary experiment to evaluate the relationship between tissue physiological development and watersoaking of fresh-cut cubes showed that the more physiologically advanced (i.e., more ripe) distal tissue from

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'Athena' fruit developed significantly more watersoaking than the less advanced proximal and center portions during 13 d storage at 5 °C. Thus, in the 1-MCP experiments, the proximal and distal portions (2 to 3 cm) of the fruit were removed to reduce variability resulting from differences in tissue ripeness. The center portion of each fruit was sliced once longitudinally (from the blossom end to the stem end) and the seeds removed. The halves were cut into roughly 2.5-cm equatorial slices. Approximately 2 to 3 cm × 2.5-cm wedge-shaped pieces (21- to 23-g "cubes") were cut from the 2.5-cm wide slices. The cubes were submerged in 1.34 mM sodium hypochlorite solution for 10 s.

Twelve cubes each were placed in 1.7-L vented plastic containers with ridged bottoms (FridgeSmart; Tupperware, Orlando, FL). The containers were equipped with two toggle switches over 5-mm diameter holes and were vented during the experiments to avoid development of MAs inside the containers. A total of 50 containers (25 each for 1-MCP and control fresh-cut cubes) were stored at 5 °C, and 10 of these (five from each treatment) were removed at 2- or 3-d intervals for evaluation.

Additionally, 30 intact fruit (15 each of control and 1-MCP-treated fruit) were stored at 5 °C along with the fresh-cut cubes. Intact and fresh-cut controls were maintained continuously under identical storage conditions as the samples treated with 1-MCP. Quality evaluation was assessed on the basis of mesocarp firmness, watersoaking, soluble solids content, and mesocarp color at 2- or 3-d intervals during storage using fresh-cut muskmelon cubes not treated with 1-MCP, fresh-cut muskmelon cubes treated with 1-MCP, cubes from intact muskmelons not treated with 1-MCP, and cubes from intact muskmelons that had been treated with 1-MCP. Cubes were prepared from intact muskmelons immediately before each evaluation using the procedures described previously for fresh-cut processing.

*Firmness.* Mesocarp firmness of each fresh-cut cube was measured using an Instron Universal Testing Instrument (Model 4411; Canton, MA) fitted with a 7-mm convex probe and 5-kg load cell. After establishing zero force contact between the probe and the surface of the cube, the probe was driven to a depth of 3 mm at a crosshead speed of 30 mm·min$^{-1}$. Firmness data are reported as the maximum force (Newton) recorded during penetration.

*Flesh color and soluble solids content.* Flesh color of the centermost region of mesocarp cubes was measured using a Minolta Chroma Meter CR-200 (Minolta Camera Co. Ltd., Tokyo) and recorded as lightness, hue angle, and chroma. At selected intervals during storage, mesocarp tissue samples were placed in polyethylene freezer bags and stored at –20 °C until analyzed. Later, partially thawed mesocarp tissue (80 g) was macerated with a mortar and pestle and centrifuged at 10,000 × $g_n$ for 10 min at 20 °C. Soluble solids concentration (SSC) in the supernatant was determined using a digital Abbé refractometer (Mark-II; Cambridge Instruments, Buffalo, NY).

*Watersoaking.* The onset of watersoaking was subjectively rated based on the incidence of transparent regions in the fresh-cut cubes. A cube with the top face exhibiting at least 50% transparent area was considered as having watersoaking. The incidence of watersoaking was expressed as a percentage of cubes clearly showing symptoms.

*Statistical analysis.* The experiments were conducted using a completely randomized design with five replications per treatment. Statistical procedures were performed using the PC-SAS software package (SAS Institute, 1985). Data were subjected to analysis of variance using the General Linear Model (Minitab, State College, PA). Differences between treatments were determined by Duncan's multiple range test where appropriate.

## Results and Discussion

The relationship between development stage and watersoaking of fresh-cut cubes was examined by preparing cubes from three different regions (proximal, center, and distal part) of 'Athena' fruit. The percentage of watersoaked cubes from the distal region was significantly higher than that from proximal and center regions during 13 d storage at 5 °C (Fig. 1). These data indicate that watersoaking is increasingly prevalent as fruit tissue advances in ripeness. In tomato fruit, tissue from the distal portion is physiologically older than tissue from the proximal end (Brecht, 1987), and the development of watersoaking was consistently more rapid and severe in slices derived from tomato fruit of more advanced ripeness stage (Jeong et al., 2004). Therefore, in subsequent experiments involving 1-MCP treatment of the intact fruit before fresh-cut processing, we restricted the tissue samples to the center region of the fruit to reduce variability resulting from within-fruit tissue ripeness differences.

When 1.0 μL·L$^{-1}$ 1-MCP was applied to intact 'Durango' fruit for 24 h at 20 °C before slicing, mesocarp firmness remained significantly higher during storage at 5 °C for both fresh-cut cubes and intact fruit (Fig. 2A). At the time of cutting (i.e., fruit previously held for 24 h in air or 1-MCP at 20 °C plus 24 h in air at 5 °C), cubes from fruit treated with 1-MCP were 28.2% firmer (15.6 N) than control cubes (11.2 N). During the subsequent 12 d of storage at 5 °C, mesocarp firmness of 1-MCP-treated fresh-cut cubes and 1-MCP-treated intact fruit decreased by only ≈14% from the day 0 value compared with 40% loss of firmness in intact control fruit. No further softening occurred in 'Durango' fresh-cut control cubes during 12 d storage at 5 °C; however, the mesocarp firmness of 1-MCP-treated fresh-cut cubes and intact fruit remained significantly higher ($P < 0.05$) than the values noted for the fresh-cut control on day 12.

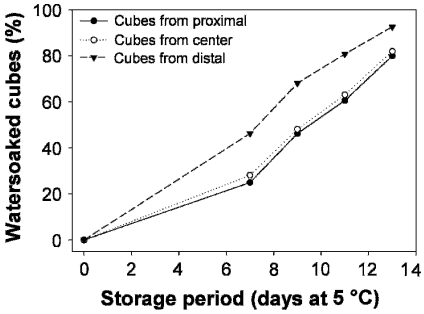


Fig. 1. Development of watersoaking incidence in fresh-cut cubes from three different regions (proximal, center, and distal) of 'Athena' muskmelon during 13 d storage at 5 °C. The incidence of watersoaking was expressed as a percentage of cubes clearly showing symptoms (n = 60 samples).

1-MCP treatment of intact 'Magellan' fruit before slicing maintained significantly higher mesocarp firmness of intact fruit during storage at 5 °C but did not significantly affect maintenance of mesocarp firmness during storage of fresh-cut cubes (Fig. 2B). Cubes from 1-MCP-treated fruit (17.5 N) were 14.9% firmer than control cubes (14.9 N) after the 1-MCP treatment. Mesocarp firmness of 1-MCP-treated intact fruit decreased by only ≈7.4% of the day 0 value during the subsequent 12 d at 5 °C compared with 14.1% loss of firmness in intact control fruit. The mesocarp firmness of 1-MCP-treated intact 'Magellan' fruit was significantly higher than the values noted for the 1-MCP-treated fresh-cut cubes, intact control fruit, or fresh-cut control cubes on day 12.

1-MCP treatment maintained significantly higher mesocarp firmness during storage at 5 °C for both intact and fresh-cut tissue of '7920' fruit (Fig. 2C). After 1-MCP treatment, cubes from 1-MCP-treated fruit were 19.3% firmer (23.3 N) than control cubes (18.8 N). Intact, 1-MCP-treated fruit softened only slightly (6.4%) during the subsequent 12 d at 5 °C compared with the day 0 value, whereas intact control fruit softened significantly (29.3%). Both fresh-cut control cubes and fresh-cut cubes from 1-MCP-treated '7920' fruit softened significantly (39.9% and 40.4%, respectively) during storage, but the mesocarp firmness of 1-MCP-treated fresh-cut cubes remained significantly higher than fresh-cut control cubes as a result of the initial firmness difference between the two treatments.

The results of these experiments with three different muskmelon cultivars imply that intact fruit respond more consistently than fresh-cut cubes to 1-MCP application in terms of improved firmness retention during storage at 5 °C. Initial mesocarp firmness of intact fruit used in our study varied even at similar ripeness stage (3/4 slip to full-slip stage), making it difficult to detect firmness differences for both intact and fresh-cut fruit during subsequent storage. 1-MCP treatment maintained significantly higher mesocarp firmness during storage of fresh-cut cubes

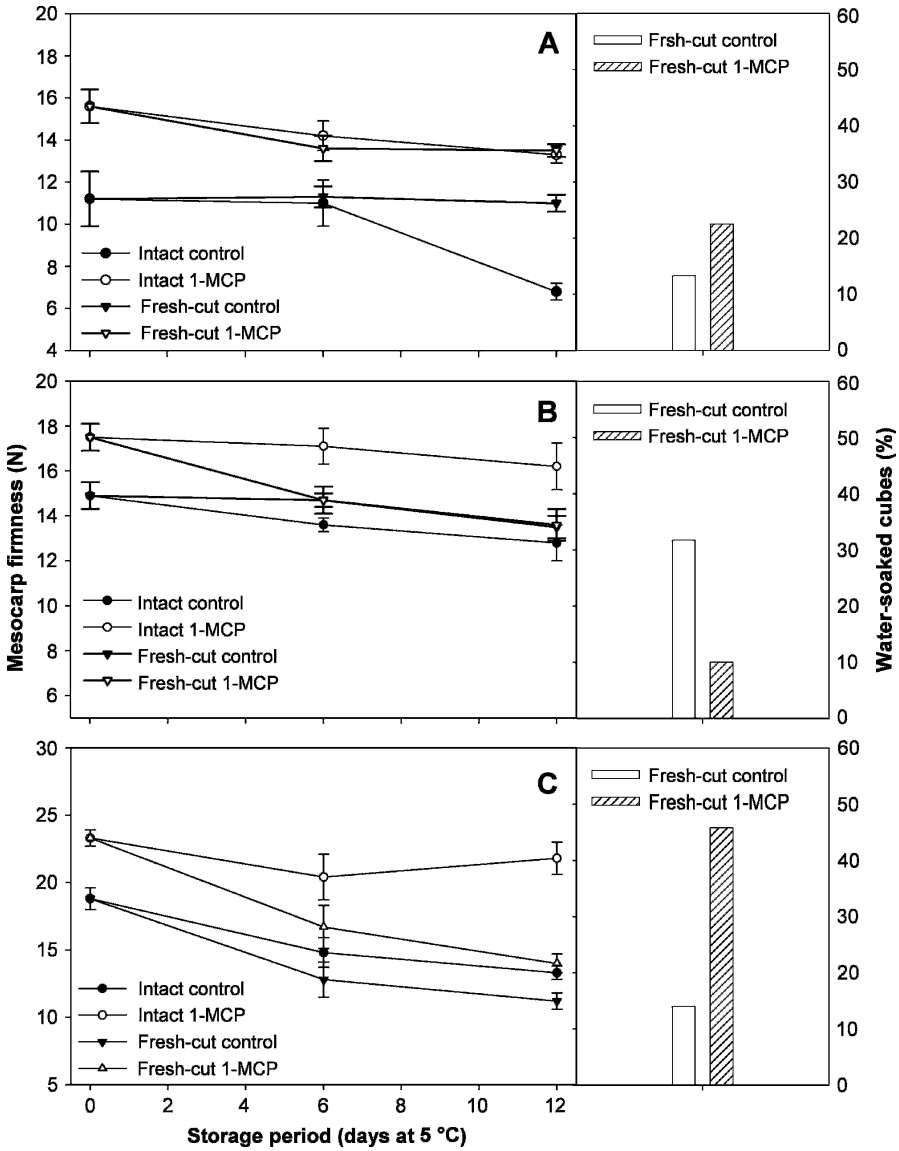


Fig. 2. Changes in mesocarp firmness (N) during storage for intact and fresh-cut muskmelon derived from intact fruit treated with air or 1-methylcyclopropene (1 μL·L$^{-1}$ at 20 °C for 24 h) and then stored at 5 °C for 12 d, and incidence of watersoaking in fresh-cut muskmelon cubes at the end of storage. There was no watersoaking in intact fruit during storage. (**A**) 'Durango', (**B**) 'Magellan', and (**C**) '7920'. Vertical bars for mesocarp firmness represent SD of 30 independent samples. Each value of watersoaking incidence was based on 60 independent samples.

for 'Durango' and '7920' but had no effect on firmness of 'Magellan' fresh-cut cubes. We had previously found that 1-MCP treatment of 3/4 slip 'Galia' melons results in better firmness retention of fresh-cut cubes during storage (Ergun et al., 2007). Other intact fruits that have shown better firmness retention than the corresponding fresh-cut products in response to 1-MCP applied at advanced stages of ripening include tomato (Jeong et al., 2004), papaya (Ergun et al., 2006), and 'Galia' melon (Ergun et al., 2005).

Fresh-cut cubes from 'Durango' and '7920' fruit treated with 1-MCP before processing developed 1.7- and 3.3-fold greater incidence of watersoaking, respectively, after 12 d at 5 °C than fresh-cut control cubes (Figs. 2A, C). In contrast, the incidence of watersoaking in cubes from 'Magellan' fruit was 3.2-fold less after 12 d storage at 5 °C when the intact fruit were treated with 1-MCP before processing (Fig. 2B). There was no development of watersoaking in intact fruit during 12 d storage at 5 °C whether treated with 1-MCP or not (data not shown). These results show that wounding (i.e., cutting) promotes the development of watersoaking in muskmelon pericarp tissue and that watersoaking is likely not a response to low temperature. 1-MCP pretreatment of intact fruit did not consistently reduce watersoaking development in fresh-cut cubes during storage and, in fact, may have increased this disorder. In contrast, watersoaking of fresh-cut 'Galia' melon was consistently reduced in several experiments by pretreatment of the intact fruit with 1-MCP (Ergun et al., 2007).

1-MCP did not significantly influence flesh color or SSC of either intact melons or fresh-cut cubes during storage at 5 °C (data not shown). There was no visible microbial development at any time during storage, probably as a result of initial selection of healthy specimens, surface sanitation, short storage time, and low processing and storage temperature.

Many factors may affect the storage life of fresh-cut muskmelon, including initial tissue firmness and stage of ripeness as well as the storage regime before processing. 1-MCP did not consistently reduce the negative textural consequences of slicing (accelerated softening and watersoaking development) in the three cultivars we tested. Considerable variability has also been reported in the response to 1-MCP among different cultivars of other fruit species. For example, Jiang and Joyce (2002) and Perera et al. (2003) reported that 1-MCP maintained more acceptable quality in fresh-cut 'Golden Delicious' apples and Bai et al. (2004) reported the same for 'Gala', whereas Calderon-Lopez et al. (2005) noted that the effects of 1-MCP treatment in extending the storage life of 'Delicious', 'Empire', 'Idared', 'Law Rome', and 'Mutsu' fresh-cut apple slices were generally insignificant.

The variable response to 1-MCP treatment that we observed in our experiments suggests that ethylene may not be involved in watersoaking development in fresh-cut muskmelon. The greater propensity for watersoaking in fresh-cut muskmelon derived from the more physiologically advanced distal tissue of the fruit implies that watersoaking may be an aspect of fruit senescence that is unrelated to ethylene. It was suggested by du Chatenet et al. (2000) that watersoaking in intact 'Charentais' muskmelon melon is related to calcium deficiency in the affected tissue and does not involve ethylene. They found that a particular calmodulin-binding protein was absent in watersoaked but not in sound mesocarp tissue and that fruit in which ethylene action had been blocked by 1-MCP still developed watersoaking. Madrid et al. (2004) also observed that calcium deficiency was associated with watersoaking in intact muskmelons as well as demonstrating that ethylene production was reduced in calcium-deficient fruit that were prone to watersoaking. Symptoms of the calcium deficiency disorder, blossom-end rot, appear at the distal end of melons, and Bernadac et al. (1996) have shown that there is less total calcium in the distal part of melon fruit. Our results demonstrate that cutting accelerates the development of watersoaking in muskmelon melon fruit whether ethylene action has been blocked by 1-MCP treatment or not. It is not clear whether 1-MCP treatment might actually have been responsible for the higher incidence of watersoaking observed in fresh-cut 'Durango' and '7920' fruit nor for the lower incidence observed in fresh-cut 'Magellan' fruit.

High water mobility as measured by nuclear magnetic resonance imaging was also reported by du Chatenet et al. (2000) in melon tissue exhibiting watersoaking. This suggests that increased membrane permeability might be affecting osmotic concentration

and water movement into the apoplast and intercellular spaces during development of the disorder. Calcium is involved in maintaining the integrity of plant cellular membranes (Poovaiah, 1988) and in stabilizing cell walls by establishing bridges between pectin polymers (Carpita and Gibeaut, 1993). Calcium also regulates the activity of many enzymes through the formation of functional complexes with calcium-activated calmodulin (Zielinsky, 1998). Thus, lack of calcium or calcium binding might lead to changes in cellular organization resulting in development of watersoaking symptoms.

Although intact fruit of all tested cultivars responded to 1-MCP application with improved firmness retention during storage, watersoaking of fresh-cut cubes was not reduced by pretreatment of intact fruit with 1-MCP before processing. Based on the results of our study, application of 1-MCP to muskmelons before fresh-cut processing cannot be recommended.

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