

Postharvest Quality of Grape Tomatoes Treated with 1-Methylcyclopropene at Advanced Ripeness Stages

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Abstract. Grape tomatoes (*Lycopersicon esculentum* Mill. ‘Santa’) harvested at light-red (>90% color) and full-red stages were treated with 1 $\mu\text{L}\cdot\text{L}^{-1}$ 1-methylcyclopropene (1-MCP) for 24 hours at 20 °C and stored at 20 °C. After 1 day of storage, fruit harvested at light-red stage treated with 1-MCP had a 56% lower respiration rate than untreated fruit. By day 7, respiration rates of the two treatments had converged at about 2 $\text{mL}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$. Ethylene production of light-red stage tomatoes treated with 1-MCP was 24% lower than untreated during storage, with rates converging by day 11. For fruit harvested full-red, 1-MCP had similar effects on respiration and ethylene production, although convergence occurred earlier, by day 5. Subsequent tests were conducted only with fruit harvested at full-red stage, since fruit harvested at the light-red stage had lower soluble solids content (4.3%) than fruit harvested at the full-red stage (5.5%). Several combinations of 1-MCP concentrations and exposure times were applied at 20 °C: 1 $\mu\text{L}\cdot\text{L}^{-1}$ for 24 h, 5 $\mu\text{L}\cdot\text{L}^{-1}$ for 6 or 12 h, 25 $\mu\text{L}\cdot\text{L}^{-1}$ for 6 or 12 h, and 50 $\mu\text{L}\cdot\text{L}^{-1}$ for 6 or 12 h; following the respective pretreatment fruits were stored at 20 °C. 1-MCP pretreatment extended marketable life by 1 d, irrespective of pretreatment regime, where untreated and pretreated fruit remained marketable (<15% of fruit soft, decayed and/or shriveled) for 6 and 7 d, respectively. However, 1-MCP did not affect whole fruit firmness, epidermal color, internal color, soluble solids content (6.5%), total titratable acidity (0.64%), or pH (4.3). In a third test simulating commercial handling procedures, full-red harvested tomatoes were treated with 1 $\mu\text{L}\cdot\text{L}^{-1}$ 1-MCP for 24 h at either 13 or 20 °C, stored for 4 d at 13 °C, and then transferred to 20 °C. Under these conditions, marketable life for untreated and 1-MCP-treated tomatoes was 7 and 8 d, respectively.

Fresh-market round-type tomatoes (*Lycopersicon esculentum*) are often harvested at the green stage to minimize handling injury and to maximize postharvest life. When harvested and handled properly, these tomatoes ripen with excellent flavor (Maul et al., 2000); however, poor handling can cause tomatoes to ripen with poor flavor due to lower concentrations of sugars and organic acids (Malundo et al., 1995). Bruised tomatoes were reported to have lower flavor acceptability, and lower carotenoids, vitamin C and total titratable acidity relative to unbruised fruit (Moretti et al., 1997, 1998). On the other hand, fruit harvested near full-ripe or at full-ripe stage possessed maximum flavor quality. The negative side of fruit harvested full ripe is limited storage life, since extended storage leads to a decrease in acidity, softening and development of moldy aroma or off-flavor (Janse, 1995; Kader et al., 1978).

Round-type tomatoes have long dominated fresh-market sales; however, since the mid-

1990s, the number of specialty tomato types has increased, notably roma, cluster, grape, and mini-pear types (Roberts et al., 2002). The increased demand for grape tomato is due to its smaller size, sweet flavor and firm texture, and has caused production of cherry tomato to significantly decrease. For example, sales of ‘Santa’ grape tomato were reported to have tripled during the first three months of 2003 (Ag-Mart Produce Inc., Plant City, Fla.).

Grape tomatoes are typically packed and shipped in hinged, clamshell containers. In contrast to round tomatoes which can be harvested mature green and ripened to high flavor (Maul et al., 2000), grape tomato flavor is best when the fruit is harvested at nearly full-red color (Roberts et al., 2002). Tomatoes often are shipped in mixed loads at temperatures lower than the recommended 12.5 °C (Geeson et al., 1985), which can induce chilling injury in tomatoes at any ripening stage (Hardenburg, 1986; Maul et al., 2000). To date, postharvest information specific to specialty tomato types is almost nonexistent for growers and retailers, therefore they are handled using recommendations that were developed for round (beefstake) tomato types.

The ripening of tomato, a climacteric fruit, is tightly regulated by ethylene (Hoeberrichts et al., 2002; Yang and Hoffman 1984). Ethylene synthesis and action in round-type tomatoes can be affected by application of

ethylene antagonists such as silver thiosulfate, 2,5-norbornadiene, diazocyclopentadiene or 1-methylcyclopropene (1-MCP), that inhibit various ripening-related biochemical changes such as polygalacturonase (EC 3.2.1.15) activity, lycopene accumulation and mRNA abundance of expansin 1 (Hoeberrichts et al., 2002; Liu et al., 1989; Mir et al., 2004; Mostofi et al., 2003; Sisler and Lallu, 1994; Tucker and Brady, 1987; Wills and Ku, 2002). 1-MCP is a very effective growth regulator limiting ethylene action in many fruits and vegetables (Blankenship and Dole, 2003). When applied to round-type tomatoes at advanced stages of ripening (light-red or full-red), 1-MCP temporarily interrupted the progression of ripening (Hoeberrichts et al., 2002; Hurr, et al., 2005; Mir et al., 2004).

The effects of harvest maturity and storage temperature on postharvest quality of grape tomato were studied by Roberts et al. (2002), who also modified grape tomato color classification from the United States grade standards for round tomatoes (U.S. Dept. of Agriculture, 1976). During grape tomato ripening the fruit passes from an orange stage (>90% red with translucent pericarp) to light-red stage (>90% red with opaque pericarp) to full-red stage (100% red) to over-ripe (deep red as water-soaked tissue becomes visible through the epidermis).

This report describes a series of experiments designed to determine the effects of harvest maturity, 1-MCP pretreatment regime (concentration, length of exposure, temperature) and subsequent storage conditions on postharvest quality and physiological responses of grape tomatoes.

Material and Methods

Plant material and pretreatment conditions. Grape tomatoes, commercially harvested and washed with water (150 to 200 $\mu\text{L}\cdot\text{L}^{-1}$ free-chlorine), were obtained from Ag-Mart Inc., Plant City, Fla., the day of harvest. The fruit were transferred to the Postharvest Horticulture Laboratory at the University of Florida, Gainesville, and either prepared immediately for experiments or stored overnight at 13 °C and prepared the following day. The fruit were sorted for defects and selected for color as either light-red (>90% red color) or full-red (100% red color) (Roberts et al., 2002) followed by treatment with 1-MCP.

1-MCP gas was prepared from SmartFresh (Agrofresh, Philadelphia, Pa.) commercial powder (active ingredient 0.14%) and quantified by the method described by Ergun and Huber (2004). Vial-headspace gas samples (based on the required 1-MCP concentrations for each experiment) were injected into sealed, glass jars (2-L void volume), containing the tomatoes. Following the 1-MCP pretreatment for the respective experiment, the fruit were then randomized into rigid, vented clamshells (473-mL volume; n = 20 fruit/container) and stored in air. Depending on the experiment 14 to 20 clamshells per treatment were used. Treatment conditions for each of the three experiments are summarized (Table 1).

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Table 1. Ripeness stage at harvest and pretreatment/storage regimes for Expts. 1, 2, and 3.

| Experiment | Pretreatment conditions | | | Storage temp (°C) |
|----------------|---|-----------------------|--------------------|-------------------------------------|
| | 1-MCP concn ($\mu\text{L}\cdot\text{L}^{-1}$) | Exposure duration (h) | Exposure temp (°C) | |
| 1 ^z | 0 (air control) | 24 | 20 | 20 |
| | 1 | 24 | 20 | 20 |
| 2 ^y | 0 (air control) | 24 | 20 | 20 |
| | 1 | 24 | 20 | 20 |
| | 5 | 6 | 20 | 20 |
| | 5 | 12 | 20 | 20 |
| | 25 | 6 | 20 | 20 |
| | 25 | 12 | 20 | 20 |
| | 5 | 12 | 20 | 20 |
| | 50 | 6 | 20 | 20 |
| 3 ^y | 0 (air control) | 24 | 13 | 13 (for 4 d) then transferred to 20 |
| | 0 (air control) | 24 | 20 | 13 (for 4 d) then transferred to 20 |
| | 1 | 24 | 13 | 13 (for 4 d) then transferred to 20 |
| | 1 | 24 | 20 | 13 (for 4 d) then transferred to 20 |
| | | | | |
| | | | | |

^zFruit were harvested at light-red or full-red ripeness stages.

^yFruit were harvested only at full-red stage.

Respiration rate and ethylene production. At 2-d intervals, respiration and ethylene production were measured by sealing individual fruit in 50 mL glass Wheaton vials (5 vials per treatment) at 20 °C. After 2 h, respiration and ethylene production was measured as described by Ergun et al. (2005).

Quality assessments. Fruit quality was assessed each 2 d during the first 4 d of storage, then daily until the end of marketable life. Individual fruits were subjectively rated for presence of absence of the primary defect (softening, shriveling or decay). Softening was determined by applying light pressure on each fruit with the thumb and forefinger, while shriveling or decay was noted upon appearance. No fruit were removed from any containers during storage. The end of marketable life for each container was defined as the point at which >15% of the fruit within an individual container exhibited softening, shriveling and/or decay (U.S. Dept. of Agriculture, 1976). Firmness was also determined nondestructively during storage using an Instron Universal Testing Instrument (model 4411; Canton, Mass.) equipped with a 5-kg load cell and an 8-mm-diameter convex probe according to Roberts et al. (2002). The probe was positioned at zero force in contact with the fruit surface (at the equatorial region, above the locule), and driven to a depth of 2 mm at a crosshead speed of 50 mm·min⁻¹. Firmness data were reported as the maximum force (Newton) recorded during deformation. Weight loss was determined during storage (fresh weight basis; n = 5 fruit/treatment).

Individual fruits were marked on the epidermis at the equatorial region for external color measurement (aperture = 11 mm; CR-2000; Minolta, Japan) at the same location over time (Hobson et al., 1983). For the internal color assessment, each fruit was sliced equatorially and the reading made on the cut surface of one fruit half. The color was reported as hue angle (the dimension of color that specifies a position on a color wheel of 360°, in which 0° = red and 90° = yellow (McGuire, 1992). At this point the fruit halves were stored at -20 °C for later compositional analyses.

Frozen fruit were thawed and homogenized at room temperature and centrifuged at 15,000 g for 20 min at 5 °C. The resulting supernatant was filtered through cheesecloth, and the filtrate was used to measure soluble solids content, pH, and total titratable acidity (TTA) as described

by Ergun et al. (2005). TTA was expressed as percent citric acid equivalents.

Statistical analysis. The experiments were conducted using a randomized complete block design. Statistical procedures were performed using PC-SAS software package. All data were subject to analysis of variance, and means were compared using Duncan's multiple range test.

Results

Experiment 1. Effect of harvest maturity and 1-MCP pretreatment on postharvest quality and physiological responses. The initial respiration rate of 1-MCP-treated fruit (1 $\mu\text{L}\cdot\text{L}^{-1}$ for 24 h at 20 °C) was 56% lower than that of control fruit (3.8 mL·kg⁻¹·h⁻¹ and 8.5 mL·kg⁻¹·h⁻¹, respectively) (Fig. 1A). The respiration rate of light-red harvested control fruit decreased throughout storage at 20 °C, whereas that for 1-MCP-treated fruit remained fairly constant after 3-d storage. Initial respiration rates of full-red harvested fruit were similar to the respective treatments of light-red harvested fruit; however, respiration rates of the both treatments were similar during storage (Fig. 1B). On day 7, respiration rates were

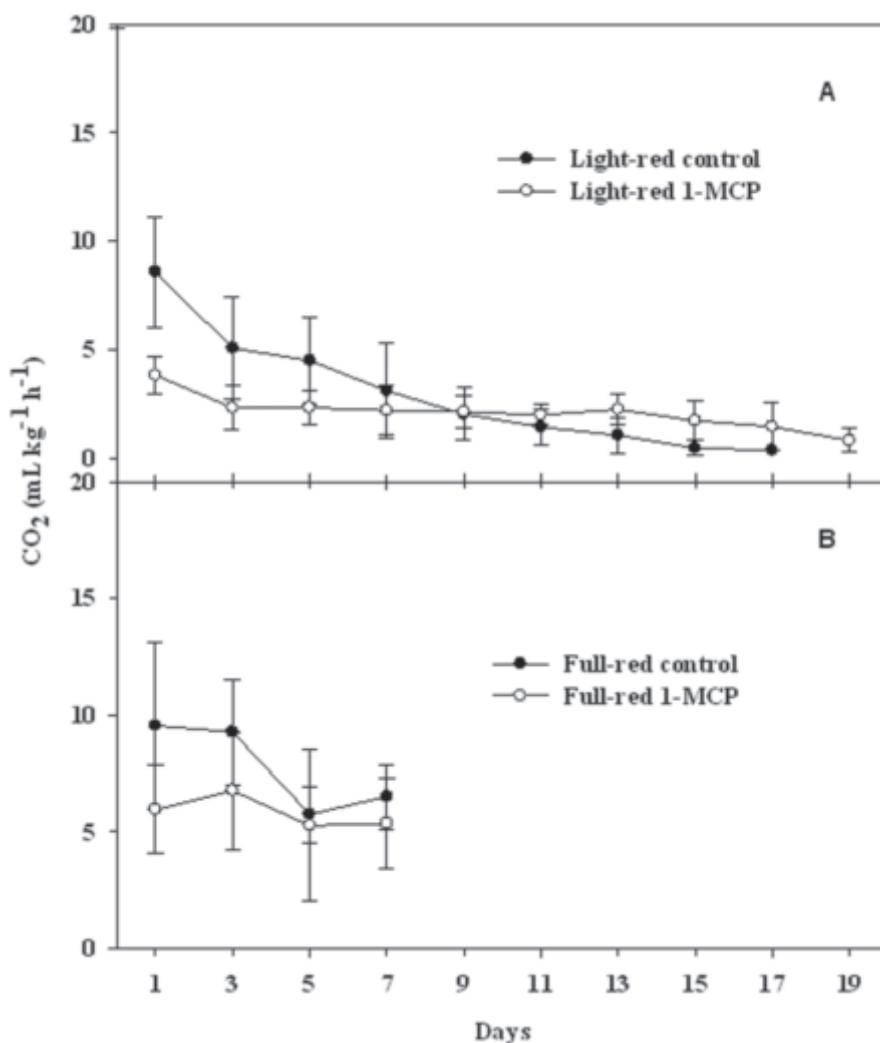


Fig. 1. Respiration rates of grape tomatoes harvested at light-red (A) and full-red (B) stages after ±1-MCP pretreatment (1 $\mu\text{L}\cdot\text{L}^{-1}$ for 24 h) during storage at 20 °C. Vertical bars represent standard deviation (n = 5) (Expt. 1).

Fig. 2. Ethylene production of fruit harvested at light-red (A) and full-red (B) stages after ± 1 -MCP pretreatment ($1 \mu\text{L}\cdot\text{L}^{-1}$ for 24 h) during storage at 20°C . Vertical bars represent standard deviation ($n = 5$) (Expt. 1).

$6.5 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ (control) and $5.4 \text{ mL}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ (1-MCP pretreated).

Ethylene production of light-red harvested tomatoes was similar for both treatments, declining only slightly by day 16 (Fig. 2A). Rates declined from 13.8 to $8.2 \mu\text{L}\cdot\text{g}^{-1}\cdot\text{h}^{-1}$ (control) and from 12.9 to $7.5 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$ (1-MCP). Initial ethylene production of full-red harvested control fruit was >2 -fold higher ($12.82 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) than that for 1-MCP fruit ($5.1 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$) (Fig. 2B). Ethylene production of control fruit declined to $5.1 \mu\text{L}\cdot\text{kg}^{-1}\cdot\text{L}^{-1}$ by day 7, while that for 1-MCP fruit remained fairly constant.

The initial firmness for light-red harvested fruit was 3.3 N ; after pretreatment (day 1) both treatments decreased to 2.9 N (data not shown). During the subsequent 18 d of storage, firmness of tomatoes from both treatments decreased by about 20%. Firmness of fruit harvested at full-red stage decreased from 3.0 to 2.7 N after 1-MCP treatment and remained constant during the following 6 d of storage (data not shown). Grape tomatoes harvested at either ripeness stage lost weight at similar rates during storage, irrespective of pretreatment. At the end of marketable life, light-red harvested fruit and full-red harvested fruit lost 11.5% and 6.5% mass (fresh weight basis), respectively (data not shown).

Pretreatment with 1-MCP did not affect fruit color at the end of marketable life. During storage the external color (hue angle) of light-red harvested fruit decreased from 45° to 39° and internal color decreased from 64° to 55° ; external color of full-red harvested fruit decreased from 37° to 36° and internal color decreased from 56° to 55° . Fruit harvested at full-red stage had initial soluble solids content of 5.5°Brix , 28% higher than that for fruit harvested at the light-red stage (4.3°Brix). TTA and pH were similar for fruit harvested at both ripeness stages (0.59% and 4.4, respectively) (data not shown). Since grape tomatoes harvested at the light-red stage had lower soluble solids content and consequently less flavor, subsequent experiments were confined to tomatoes harvested at full-red stage.

Experiment 2. Effect of several 1-MCP pretreatment regimes on postharvest quality and physiological responses. Tomatoes from all treatments were marketable after 5 d storage at 20°C (Table 2). After 6 d of storage control fruit had 23.2% defects and were out of grade, and after 7 d all 1-MCP treated tomatoes were out of grade, with total defects ranging from 27.9% ($5 \mu\text{L}\cdot\text{L}^{-1}$ for 12 h) to 44.9% ($25 \mu\text{L}\cdot\text{L}^{-1}$ for 12 h). In all treatments softening was the primary cause for defects, followed by decay then shriveling. Fungal decay (pathogen not identified) usually started at the stem end and spread over fruit during storage at 20°C . At the end of marketable life (5 d for control, 6 d for 1-MCP treated) there were no significant differences with respect to firmness (2.2 N), weight

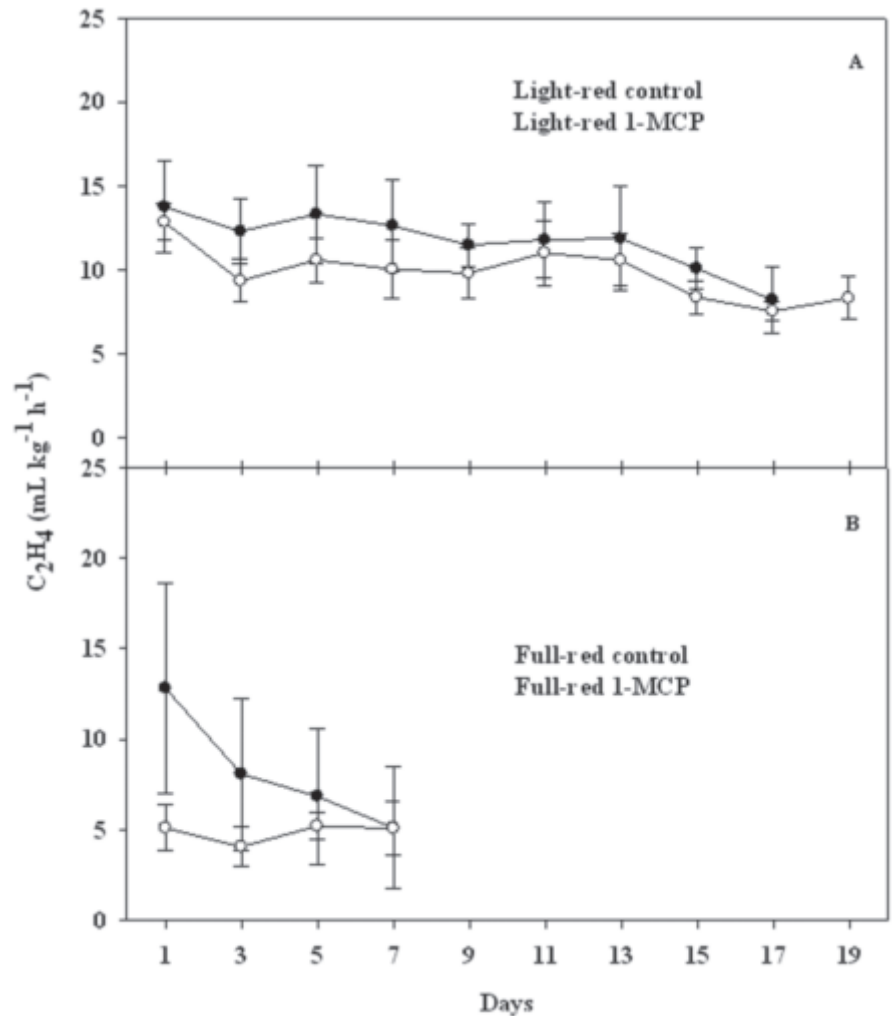


Table 2. Appearance of grape tomato defects during storage in air for several pretreatment regimes of 1-MCP concentrations ($\mu\text{L}\cdot\text{L}^{-1}$) and exposure durations (h) at 20°C (Expt. 2).

| Storage time (d) | Pretreatment conditions (1-MCP/h) | Defect ^z | | | Total defects ^y (%) |
|------------------|-----------------------------------|---------------------|-------------|-----------|--------------------------------|
| | | Soft (%) | Shrivel (%) | Decay (%) | |
| 5 | Air control | 10.0 | 0 | 0 | 10 a ^x |
| | 1/24 | 5.0 | 0 | 0 | 5.0 c |
| | 5/6 | 6.6 | 0 | 0 | 6.6 bc |
| | 5/12 | 1.6 | 1.6 | 5.0 | 8.2 ab |
| | 25/6 | 3.0 | 1.6 | 1.6 | 6.2 bc |
| | 25/12 | 0 | 0 | 5.0 | 5.0 c |
| | 50/6 | 0 | 0 | 5.0 | 5.0 c |
| | 50/12 | 1.6 | 0 | 6.6 | 8.2 ab |
| 6 | Air control | 15.0 | 1.6 | 6.6 | 23.2 a |
| | 1/24 | 10.0 | 0 | 5.0 | 15.0 b |
| | 5/6 | 8.3 | 1.6 | 3.3 | 13.2 b |
| | 5/12 | 8.3 | 1.6 | 5.0 | 14.9 b |
| | 25/6 | 8.3 | 1.6 | 5.0 | 14.9 b |
| | 25/12 | 8.3 | 0 | 5.0 | 13.3 b |
| | 50/6 | 10.0 | 0 | 5.0 | 15.0 b |
| | 50/12 | 8.3 | 0 | 6.6 | 14.9 b |
| 7 | Air control | --- | --- | --- | --- |
| | 1/24 | 21.0 | 0 | 10.0 | 31.0 cd |
| | 5/6 | 25.0 | 3.3 | 8.3 | 36.6 bc |
| | 5/12 | 18.0 | 1.6 | 8.3 | 27.9 d |
| | 25/6 | 23.0 | 5.0 | 8.3 | 36.3 bc |
| | 25/12 | 30.0 | 6.6 | 8.3 | 44.9 a |
| | 50/6 | 25.0 | 3.3 | 13.3 | 41.6 ab |
| | 50/12 | 21.0 | 3.3 | 8.3 | 32.6 cd |

^zEach fruit was classified by the primary defect (soft, shrivel, or decay).

^yEnd of marketable life: total defects $>15\%$.

^xMeans with different letters within the column and for the same storage time are significantly different according to Duncan's multiple range test ($P < 0.05$).

Table 3. Appearance of grape tomato defects under simulated commercial handling conditions. Fruit pretreated in air (control) or 1-MCP ($1 \mu\text{L}\cdot\text{L}^{-1}$) for 24 h at 13 or 20 °C, followed by storage at 13 °C for 4 d and transfer to 20 °C until end of marketable life (Expt. 3).

| Storage time (d) | Pretreatment conditions | Defect ^z | | | Total defects ^y (%) |
|------------------|-------------------------|---------------------|-------------|-----------|--------------------------------|
| | | Soft (%) | Shrivel (%) | Decay (%) | |
| 6 | Control, 13 °C | 0 | 1.6 | 0 | 1.6 a ^x |
| | 1-MCP, 13 °C | 1.6 | 0 | 0 | 1.6 a |
| | Control, 20 °C | 0 | 5.0 | 1.6 | 5.6 ab |
| | 1-MCP, 20 °C | 1.6 | 0 | 0 | 1.6 a |
| 7 | Control, 13 °C | 16.0 | 1.6 | 1.6 | 19.2 a |
| | 1-MCP, 13 °C | 8.3 | 0 | 1.6 | 9.9 b |
| | Control, 20 °C | 10.0 | 5.0 | 3.3 | 18.3 a |
| | 1-MCP, 20 °C | 10.0 | 3.3 | 0 | 13.3 b |
| 8 | 1-MCP, 13 °C | 15.0 | 1.6 | 1.6 | 18.2 b |
| | 1-MCP, 20 °C | 25.0 | 3.3 | 0 | 28.3 a |

^zEach fruit was classified by the primary defect (soft, shrivel, or decay).

^yEnd of marketable life: total defects >15%.

^xMeans with different letters within the column and for the same storage time are significantly different according to Duncan's multiple range test ($P < 0.05$).

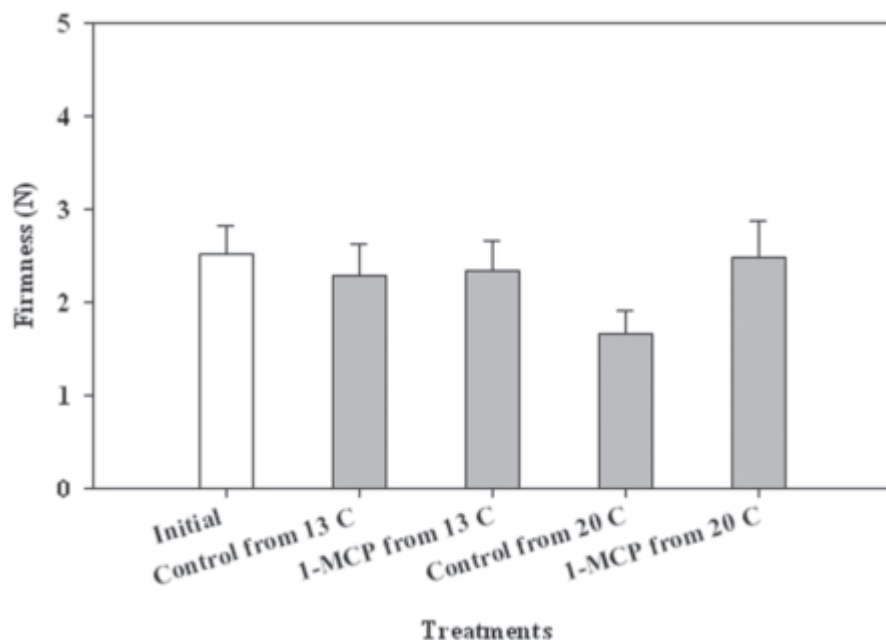


Fig. 3. Firmness (N) of full-red harvested fruit at the end of marketable life (± 1 -MCP pretreatment: $1 \mu\text{L}\cdot\text{L}^{-1}$ at 13 or 20 °C for 24 h, storage at 13 °C for 4 d, then transfer to 20 °C) (Expt. 3).

loss (8%), external/internal color ($38^\circ/60^\circ$ hue angle), SSC (6.3 °Brix), TTA (0.65%), or pH (4.3) (data not shown).

Experiment 3. Simulated commercial handling of full-red harvested grape tomatoes pretreated with $1 \mu\text{L}\cdot\text{L}^{-1}$ 1-MCP. Since there were few differences in quality parameters due to the 1-MCP concentration/exposure time regimes in Expt. 2, the final study used one 1-MCP concentration ($1 \mu\text{L}\cdot\text{L}^{-1}$ for 24 h) and two pretreatment-storage temperature regimes (13, 20 °C).

As in previous tests, control tomatoes became unmarketable 1 d before the 1-MCP treated tomatoes; however in this test both treatments lasted 1 d longer than in the previous tests (Table 3) Softening was again the main limiting factor, increasing dramatically from day 6 to day 7. Shriveling symptoms due to water loss were observed on control fruit on day 6, whereas fruit pretreated 1-MCP at 13 °C exhibited these symptoms on day 7 and fruit pretreated 1-MCP at 20 °C on day 8. 1-MCP neither promoted nor

retarded decay development in grape tomatoes harvested at either ripeness stage. Fruit pretreated with air at 20 °C as a control softened significantly during storage (from 2.5 to 1.6 N), whereas the other treatments remained firm (Fig. 3). Weight loss ranged from 5% to 6% and was not affected by 1-MCP treatment or by pretreatment temperature (13 or 20 °C) (data not shown). External and internal hue angles were similar to respective values in Expts. 1 and 2 (data not shown). There were no significant differences due to pretreatment for soluble solids content (6.7%), TTA (0.76) or pH (4.4) after storage (data not shown).

Discussion

Grape tomatoes harvested at light-red and full-red stages and treated with 1-MCP ($1 \mu\text{L}\cdot\text{L}^{-1}$ for 24 h) had suppressed decline in the respiration rate during subsequent storage at 20 °C, whereas the rate in untreated fruit gradually decreased during this time (Fig. 1). 'Clarion'

tomatoes (round type) treated at full-ripe stage (stage not defined by authors) with 10, 20 or $100 \mu\text{L}\cdot\text{L}^{-1}$ 1-MCP at 20 °C for 2 h had lower respiration rates after 5 or 8 d at 20 °C than untreated fruit (Wills and Ku, 2002). The postclimacteric suppression in the respiration decline and/or suppression of respiration reveal that ethylene regulates respiration in tomatoes even at advanced stages of maturation.

In the first experiment ethylene production of untreated light-red and full-red harvested fruit declined approximately 50% during storage at 20 °C. 1-MCP pretreatment significantly suppressed the decline in ethylene production in full-red harvested fruit (Fig. 2B); however in light-red harvested fruit, ethylene production rate and pattern were similar, irrespective of the treatments (Fig. 2A). This is similar to results reported in fully ripe 'Clarion' tomatoes after 5 d at 20 °C (Wills and Ku, 2002). However, Hoerberichts et al. (2002) found no effect of 1-MCP treatment (50 to $150 \text{nL}\cdot\text{L}^{-1}$ for 20 h at 20 °C) on ethylene production of full-red tomato ('Prisca') during storage at 20 °C.

In the present study grape tomato quality was minimally affected by treatment with 1-MCP (Tables 2 and 3). The 1-MCP treatment regimes used in these experiments were relatively equivalent in extending marketable life. Increased 1-MCP concentration (from $1 \mu\text{L}\cdot\text{L}^{-1}$ to 5, 25 or $50 \mu\text{L}\cdot\text{L}^{-1}$) and the concomitant decrease in exposure time (from 24 h to 12 or 6 h) did not increase marketable life, did not affect the incidence of defects and did not significantly affect quality parameters. However, fully ripe 'Clarion' tomatoes responded to higher 1-MCP concentrations (20 or $100 \mu\text{L}\cdot\text{L}^{-1}$ for 2 h at 20 °C) compared to $1 \mu\text{L}\cdot\text{L}^{-1}$ by extending storage life from 16 to 21 d (Wills and Ku, 2002). In the present study, 1-MCP extended the storage life of full-red grape tomatoes by only 1 d (from 6 to 7 d or from 7 to 8 d), indicating that 1-MCP efficacy on tomatoes is strongly cultivar dependent.

Full-red harvested grape tomatoes treated with several 1-MCP concentrations for 6 or 12 h had similar marketable life, firmness, color, soluble solids content, pH and TTA, suggesting that 1-MCP concentrations greater than $1 \mu\text{L}\cdot\text{L}^{-1}$ may be applied to grape tomatoes for shorter durations if necessary. Wills and Ku (2002) noted that 1-MCP treatment at $5 \mu\text{L}\cdot\text{L}^{-1}$ for 2 h at 20 °C was sufficient to slow ripening in fully ripe tomato. In our tests, the effects of 1-MCP treatments to full-red harvested grape tomatoes at 13 °C were similar to fruit treated at 20 °C; thus tomatoes could be treated with 1-MCP at 13 °C with the additional benefit of delayed ripening due to the cooler storage temperature.

Grape tomatoes pretreated with 1-MCP ($1 \mu\text{L}\cdot\text{L}^{-1}$ at 20 °C for 24 h) (Expt. 3) were firmer at the end of marketable life compared with untreated fruit held at 20 °C (Fig. 3). Hoerberichts et al. (2002) noted insignificant effects of 1-MCP on firmness in light-red and full-red tomatoes. However, Mir et al. (2004) reported that 1-MCP ($250 \text{nL}\cdot\text{L}^{-1}$ at room temperature for 16 h) applied to light-red and full-red roma-type tomato ('Plum Dandy') delayed softening during 11 d of storage at 22 °C.

Delays in ripening due to 1-MCP treatment did not significantly affect the color (hue angle) of either the surface or internal tissues of light-red or full-red harvested grape tomato. Lycopene accumulation has been reported to decrease as ripening progresses (Mostofi et al., 2003). Hoberichts et al. (2002) and Mir et al. (2004) showed that 1-MCP suppressed red color development (hue angle) when applied to light-red tomatoes but not when applied to full-red fruit.

In these tests no changes in soluble solids content or pH were observed for 1-MCP-treated fruit from either harvest maturity during storage at 20 °C. Wills and Ku (2002) reported, however, that the decrease in TTA was suppressed in fully ripe tomatoes treated with 1-MCP compared to untreated fruit. The present study also confirmed that soluble solids content and TTA were higher for fruit harvested at the full-red stage compared to fruit harvested at the light-red stage. Roberts et al. (2002) reported that soluble solids content was significantly higher for grape tomatoes harvested at full-red stage compared to those harvested breaker/turning (10% to 30% red) and ripened at either 13 or 20 °C. Therefore, for best flavor grape tomato should be harvested at or close to full-red stage.

1-MCP concentrations greater than 1 $\mu\text{L}\cdot\text{L}^{-1}$ (5, 25, or 50 $\mu\text{L}\cdot\text{L}^{-1}$) did not have a significant effect on the parameters measured in the present study, suggesting that the saturation response to 1-MCP in ripe grape tomato is $\leq 1 \mu\text{L}\cdot\text{L}^{-1}$. Mir et al. (2004) concluded that 1-MCP saturation in roma-type tomatoes ranged from 0.25 to 1 $\mu\text{L}\cdot\text{L}^{-1}$ for 16 h at 22 °C.

For best quality under commercial handling conditions, grape tomatoes should be harvested at or near the full-red stage. The 1-d extension of postharvest life by 1-MCP treatment at 13 or 20 °C may be commercially viable. Postharvest life may be further extended by employment of rapid cooling techniques and precise temperature management to make treatment with 1-MCP more effective.

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