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Manipulation of tomato ripening using 1-methylcyclopropene

by

Abhijeet M. Patil

A thesis submitted to the graduate faculty
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Major: Horticulture

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Signatures have been redacted for privacy

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Abstract

1-Methylcyclopropene (1-MCP) strongly inhibits ethylene (C_2H_4) action in less mature tomato (*Lycopersicon esculentum* Mill.) fruits, and that control by 1-MCP over C_2H_4 action limits its commercial use. Our first objective was to determine whether ripening in less mature fruits could be reinitiated by exposure to C_2H_4 when tomatoes were treated previously with 1-MCP. A second objective was to determine the concentrations of 1-MCP that could be used commercially to retard ripening in tomatoes at less mature stages. For the reinitiation experiments, tomato fruits at the turning stage were treated with 0, 25, 50, 100, 150, or 200 $nL \cdot L^{-1}$ of 1-MCP. These fruits subsequently were exposed to 100 $\mu L \cdot L^{-1}$ of C_2H_4 on day 3 or day 4 after treatment with 1-MCP. To determine the appropriate low 1-MCP concentrations that may be used without subsequent C_2H_4 treatment, fruits in the turning stage were treated with 0, 25, 50, 75, 100, or 200 $nL \cdot L^{-1}$ of 1-MCP, and fruits in the pink stage were treated with 0, 50, 100, 200, 300, or 400 $nL \cdot L^{-1}$ of 1-MCP. Ethylene treatment on day 3 or day 4 could not reinitiate ripening in turning stage tomato fruits previously treated with any of the 1-MCP concentrations. In tomatoes treated only with lower 1-MCP concentrations, the rate at which ripening proceeded depended upon the 1-MCP concentration and the stage of ripeness at the time of treatment. Arrival at the full red stage of ripening in turning fruits was delayed by 48 h when fruits were treated with 25 $nL \cdot L^{-1}$ of 1-MCP, 72 h when treated with 50 $nL \cdot L^{-1}$, and 96 h when treated with 75 $nL \cdot L^{-1}$, when compared with the control. Ripening of pink fruits was delayed by 24, 48, and 96 h with 50, 100, and 200 $nL \cdot L^{-1}$ of 1-MCP, respectively, as compared with the control. Tomato ripening could not be reinitiated, but it could be delayed by using lower 1-MCP concentrations that depended upon the stage of ripeness at treatment. This research benefits

tomato wholesalers and retailers because they can use 1-MCP to adjust supply and demand cycles. Use of 1-MCP also will reduce losses caused by fluctuating market conditions and during transportation to distant markets.

Chapter 1. General introduction and literature review

Ethylene and postharvest physiology

The plant hormone C_2H_4 is involved in many physiological processes such as fruit ripening, abscission, senescence, leaf epinasty, and seed germination, and it is physiologically active at extremely small concentrations ($< 0.1 \mu L \cdot L^{-1}$) (Abeles et al., 1992). Horticultural commodities are classified as climacteric or nonclimacteric based on their capacity to produce C_2H_4 . Climacteric fruits undergo a large increase in carbon dioxide production from respiration, and changes in C_2H_4 production rates are accompanied by changes in color, composition, and texture of the commodity (Abeles et al., 1992). Ethylene biosynthesis occurs via the conversion of methionine to S-adenosyl methionine, then 1-aminocyclopropane-1-carboxylic acid and C_2H_4 in three reactions catalyzed by the enzymes S-adenosylmethionine synthetase, 1-aminocyclopropane-1-carboxylic acid synthase (ACS), and 1-aminocyclopropane-1-carboxylic acid oxidase (ACO), respectively (Saltveit, 1999).

The effects of C_2H_4 can be both desirable and undesirable. Loss of chlorophyll and development of carotenoids due to C_2H_4 in fruits such as tomatoes, apricots, peaches, and citrus are considered desirable changes. Other beneficial effects of C_2H_4 include promotion of thinning of apples and cherries, flower induction in pineapples, and degreening of nonclimacteric fruits such as citrus (Abeles et al., 1992). Undesirable effects of C_2H_4 include loss of chlorophyll and yellowing of broccoli (Ku and Wills, 1999), russet spotting on lettuce (Rood, 1956), sprouting of potatoes (Alam et al., 1994), toughening of asparagus (Saltveit, 1999), and loss of flowers and/or leaves from abscission-sensitive plants (Abeles et al., 1992). The most damaging effect of C_2H_4 is its effect on the postharvest shelf life of

horticultural commodities. Even trace amounts of C_2H_4 reduce the shelf life of horticultural commodities throughout the marketing chain (Wills et al., 2000).

Controlling the effects of ethylene

Over the years, several strategies to reduce the damaging effects of C_2H_4 have been studied. Maintaining lower concentrations of C_2H_4 and preventing its accumulation around commodities by controlling the surrounding atmosphere has successfully reduced C_2H_4 -related damage. Several compounds such as aminoethoxyvinyl glycine and (aminoxy)acetic acid, which inhibit C_2H_4 biosynthesis, have been identified (Amrhein and Wenker, 1979). However, these compounds do not offer protection against exogenous C_2H_4 . Another approach is the use of compounds that inhibit C_2H_4 action. These include compounds such as silver thiosulfate, 2,5-norbornadiene, and certain organic molecules such as diazocyclopentadiene and 1-methylcyclopropene (1-MCP) (Sisler and Serek, 1997).

1-Methylcyclopropene (1-MCP)

1-Methylcyclopropene is an inhibitor of C_2H_4 action. It acts by binding to C_2H_4 receptors, and it thus blocks subsequent C_2H_4 -regulated processes (Sisler and Serek, 1997). 1-MCP has proved to be more beneficial than other C_2H_4 action inhibitors in several ways. It is active at lower concentrations ($nL \cdot L^{-1}$), it is more stable than other organic molecules, and it is nontoxic (Sisler and Serek, 1997). Another advantage to both humans and plant materials is its efficacy on a wide range of horticultural commodities such as apple (Fan et al., 1999), banana (Jiang et al., 1999), broccoli (Ku and Wills, 1999), tomato (Mir et al., 2004) and ornamentals (Serek et al., 1994). 1-MCP also may decrease or delay C_2H_4 production depending upon the commodity. The Food and Drug Administration has approved the use of 1-MCP on ornamental plants, and more recently, apples.

Rationale

1-MCP effectively inhibits C_2H_4 action in several stages of tomato ripening. However, in tomatoes at less mature stages such as breaker and turning (USDA, 1975) the effect is too strong and the ripening is delayed to the point where 1-MCP cannot be used commercially (Rohwer and Gladon, 2001; Wills and Ku, 2002). In commercial wholesale operations, the emphasis is on handling the produce for a predictable, short period of time so that more produce is moved to market without incurring losses due to fluctuating market conditions. The first objective of this research was to determine whether ripening could be reinitiated by subsequent treatment with C_2H_4 in tomatoes treated previously with 1-MCP. The second objective was to determine the concentrations of 1-MCP that would be most appropriate for commercial use.

Thesis organization

This thesis has three chapters. The first chapter gives general information about C_2H_4 physiology and strategies to control the effects of C_2H_4 . Chapter one also deals specifically with 1-MCP and its role as an C_2H_4 action inhibitor. Chapter two is a manuscript to be submitted to *HortTechnology*, and it reports the results of my experiments. These experiments evaluated the effects of C_2H_4 on tomatoes treated previously with 1-MCP and the effects of six concentrations of 1-MCP on tomato ripening in the pink and turning stages. Finally, chapter three is a brief discussion that summarizes the results of these experiments.

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Chapter 2. Lower concentrations of 1-methylcyclopropene effectively delay ripening in turning and pink stage tomatoes

A paper to be submitted to *HortTechnology*

Abhijeet M. Patil¹ and Richard J. Gladon

ADDITIONAL INDEX WORDS. 1-MCP, lycopene, ethylene receptor, shelf life, color, ethylene

Abstract. 1-Methylcyclopropene (1-MCP) strongly inhibits ethylene (C₂H₄) action in less mature tomato (*Lycopersicon esculentum* Mill.) fruits, and that control by 1-MCP over C₂H₄ action limits its commercial use. Our first objective was to determine whether ripening in less mature fruits could be reinitiated by exposure to C₂H₄ when tomatoes were treated previously with 1-MCP. A second objective was to determine the concentrations of 1-MCP that could be used commercially to retard ripening in tomatoes at less mature stages of ripening. For the reinitiation experiments, tomato fruits at the turning stage were treated with 0, 25, 50, 100, 150, or 200 nL • L⁻¹ of 1-MCP. These fruits subsequently were exposed to 100 µL • L⁻¹ of C₂H₄ on day 3 or day 4 after treatment with 1-MCP. To determine the appropriate low 1-MCP concentrations that may be used without subsequent C₂H₄ treatment, fruits in the turning stage were treated with 0, 25, 50, 75, 100, or 200 nL • L⁻¹ of 1-MCP, and fruits in the pink stage were treated with 0, 50, 100, 200, 300, or 400 nL • L⁻¹ of 1-MCP. Ethylene treatment on day 3 or day 4 could not reinitiate ripening in turning stage tomato fruits previously treated with any of the 1-MCP concentrations. In tomatoes treated only with lower 1-MCP concentrations, the rate at which ripening proceeded depended upon the

1-MCP concentration and the stage of ripeness at the time of treatment. Arrival at the full red stage of ripening in turning tomato fruits was delayed by 48 h when fruits were treated with $25 \text{ nL} \cdot \text{L}^{-1}$ of 1-MCP, 72 h when treated with $50 \text{ nL} \cdot \text{L}^{-1}$, and 96 h when treated with $75 \text{ nL} \cdot \text{L}^{-1}$, when compared with the control. Ripening of pink fruits was delayed by 24, 48, and 96 h with 50, 100, and $200 \text{ nL} \cdot \text{L}^{-1}$ of 1-MCP, respectively, as compared with the control. Tomato ripening could not be reinitiated by treatment with C_2H_4 , but it could be delayed by using lower 1-MCP concentrations that depended upon the stage of ripeness at treatment. This research benefits tomato wholesalers and retailers because they can use 1-MCP to adjust supply and demand cycles, and it will reduce losses caused by fluctuating market conditions and transport to distant markets.

Introduction

Ethylene (C_2H_4) accelerates ripening and senescence in many fruits and vegetables. In tomatoes, the synthesis of lycopene and the eventual ripening of fruits is invariably associated with the rise in C_2H_4 production by the fruit tissue (Oetiker and Yang, 1995). However, C_2H_4 also plays an important role in reducing the postharvest life of tomatoes. 1-Methylcyclopropene (1-MCP), an C_2H_4 analog, inhibits C_2H_4 action in tomato (Mir et al., 2004; Wills and Ku, 2002). 1-MCP acts by binding to C_2H_4 receptor sites, and it blocks subsequent signal transduction and translation events that are associated with C_2H_4 action (Sisler and Serek, 1997). 1-MCP effectively inhibits C_2H_4 -induced responses in a wide range of commodities like flowers (Serek et al., 1994), apples (Fan et al., 1999), bananas (Jiang et al., 1999), and some vegetables (Ku and Wills, 1999). 1-MCP is effective at low ($\text{nL} \cdot \text{L}^{-1}$) concentrations (Sisler et al., 1996), and in some commodities, 1-MCP treatment has

improved postharvest quality and decreased decay (Sisler et al., 1996; Jiang et al., 2001).

The efficacy of 1-MCP in inhibiting C_2H_4 action also depends on factors such as temperature (Mostofi et al., 2003), duration of treatment (DeEll et al., 2002), and number of treatments (Mir et al., 2004).

In tomatoes at less mature stages, 1-MCP blocks C_2H_4 action almost irreversibly (Rohwer and Gladon, 2001) or for a considerably long period of time (Wills and Ku, 2002). Because commercial operations emphasize holding produce for a predictable, short time, sustained binding of 1-MCP may limit its commercial use when the commodity must continue ripening. Because the percentage of weight loss during the holding period is related directly to the quality of the tomato fruits (Kader, 2002), it also is important to understand how 1-MCP affects fresh weight retention in tomatoes. The objectives of this research were to determine whether ripening could be reinitiated by C_2H_4 treatment in less mature tomatoes treated previously with 1-MCP and to identify the concentrations of 1-MCP that can be used for commercial applications when delayed ripening of less mature tomatoes is desired.

Materials and Methods

1-Methylcyclopropene application. Tomato fruits at the visual ripeness stages of breaker (not more than 10% is yellow, pink, or red), turning (10 to 30% of the surface is yellow, pink, or red), pink (30 to 60% of the surface is light red or red), and light red (60 to 90% pinkish red or red) (USDA, 1975) were obtained from a tomato fruit wholesaler in Norwalk, IA. Tomatoes for each experiment were taken from one shipment from one producer, but we did not know the cultivar(s). Fruits were washed in detergent and surface-sterilized with 10% commercial bleach solution. Forty-eight fruits of each ripeness stage were selected for uniformity of visual color pattern and size and placed into 11L glass desiccators (4 fruits per

desiccator). Each desiccator contained a 10-ml beaker that contained a magnetic stirring bar and either 0, 0.47, 0.95, 1.42, 1.89, 2.84, 3.79, 5.67, or 7.56 mg of Smartfresh Technology® (Rohm and Haas Company, Ambler, PA) to generate 0, 25, 50, 75, 100, 150, 200, 300, or 400 nL • L⁻¹ of 1-MCP, respectively, depending upon the experiment. The desiccators were sealed, and to release 1-MCP, 10 ml of warm water (60 °C) was injected into the beaker by using a syringe with a 30-cm needle that penetrated a septum in the desiccator lid. After 8 h of exposure to 1-MCP with stirring, fruits were removed from the desiccators and placed on polystyrene plates. Fruits were held at 21 ± 1 °C under continuous irradiance from fluorescent lamps at a flux density of 5 to 10 μmol • m⁻² • s⁻¹ throughout the experiment. Fruits were weighed and ripeness stage was assessed on each fruit daily. For the reinitiation studies, we used tomatoes in the turning stage and 1-MCP concentrations of 0, 25, 50, 100, 150, or 200 nL • L⁻¹. To determine the low concentrations of 1-MCP for possible commercial use, fruits in the turning and pink stages were selected. Fruits in the turning stage were treated with 0, 25, 50, 75, 100, or 200 nL • L⁻¹ of 1-MCP, and for fruits in the pink stage, the 1-MCP concentrations were 0, 50, 100, 200, 300, or 400 nL • L⁻¹.

Ethylene treatment for reinitiation. At 72 or 96 h after the beginning of 1-MCP treatment, fruits were placed in 3.78L jars and sealed. Fruits were treated with C₂H₄ gas at 100 μL • L⁻¹ for 24 h (Kays and Beaudry, 1987). To prevent carbon dioxide accumulation, the jars were flushed with fresh air every 8 h during the treatment period, and the C₂H₄ concentration was reestablished for the next 8-h period. After C₂H₄ treatment, fruits were removed from the jars and replaced on the polystyrene plates. Fruits were weighed and ripeness stage was assessed on each fruit daily for 10 days.

Color measurement. Fruit color was determined by using a Hunter Colorimeter (Hunter Lab, Reston, VA) standardized against a white tile. All color measurements were made at the end of the 10-day holding period. Three readings were taken on each of two fruits in a replicate along their equatorial axes. L, a, and b measurements were recorded, and the intensity of the color was reported as chroma $(a^2 + b^2)^{1/2}$, and hue $(\tan^{-1} b/a)$ values were calculated (Clydesdale, 1978).

Total soluble solids and pH measurements. On day 10, tomatoes were homogenized with a commercial blender at high speed for ≈ 2 minutes. Total soluble solids (TSS, °brix) was measured by using a table-top refractometer and the homogenate was used for measurement of pH.

Firmness measurements. Firmness was measured on day 10 of the holding period by using a penetrometer (Precision, Bellwood, IL). Two fruits in each replicate were penetrated at opposite sides of their equatorial axes, and the percent penetration was calculated.

Statistical analysis. Experiments were conducted as a completely randomized design that was replicated four times and each replicate consisted of four fruits. Each experiment was conducted twice, independently, and we tested for differences between the two times we conducted each experiment. To determine the effect of treatments on each of the ripeness stages, analysis of variance was performed by using the general linear model procedure (PROC GLM) (SAS Institute, 1988).

Results

Preliminary studies on reinitiation. Ripening of breaker tomatoes treated with $58 \text{ nL} \cdot \text{L}^{-1}$ of 1-MCP was inhibited almost completely. Fruits treated with 1-MCP at $58 \text{ nL} \cdot \text{L}^{-1}$ at the pink and light red stages ripened too quickly to assess the ability of C_2H_4 exposure to

reinitiate the ripening process. Therefore, tomatoes in the turning stage were used for the reinitiation studies. C_2H_4 treatments on day 3 or day 4 could not reinitiate ripening in turning stage tomatoes treated previously with various 1-MCP concentrations (data not presented). The C_2H_4 treatments also did not affect the retention of fresh weight in any of the concentrations of 1-MCP used (data not presented).

Statistical analysis. There were no differences between the two independent runs of each of the experiments. The results presented are based on the means of observations from the pooled data of the two independent runs.

Change in ripeness stage. Change in fruit ripeness stage was delayed and varied as a function of the 1-MCP concentration and initial stage of ripeness. Fruits treated in the turning stage with 25 and 50 $nL \cdot L^{-1}$ of 1-MCP were delayed in ripening by 48 h and 72 h, respectively, as compared with controls (Fig. 1). 1-MCP treatment at 75 $nL \cdot L^{-1}$ delayed ripening by 96 h. Fruits treated with 100 or 200 $nL \cdot L^{-1}$ of 1-MCP were delayed in ripening by one-half to one full stage of ripeness at end of the 10-day holding period (Fig. 1). Pink fruits treated with 50 or 100 $nL \cdot L^{-1}$ of 1-MCP delayed ripening by ≈ 24 and 48 h, respectively, as compared with controls (Fig. 1). When fruits in the pink stage were treated with 200 $nL \cdot L^{-1}$ of 1-MCP, ripening was delayed by ≈ 96 h as compared with controls (Fig. 1). Fruits treated with 1-MCP in the pink stage could not ripen to the final red stage during the 10 d holding period when treated with 300 or 400 $nL \cdot L^{-1}$ of 1-MCP, and ripening was delayed by about one-half of a ripening stage (Fig. 1).

Fresh weight loss. Fruits in the turning and pink stages treated with 1-MCP lost fresh weight at a slower rate than control fruits. Among the 1-MCP treatments in each stage, fresh weight retention occurred at a similar rate (Fig. 2).

Fruit color. Hunter L values indicate that the lightness of the tomatoes increased when treated with greater concentrations of 1-MCP in both the turning and pink stages (Table 1). Hue angle values indicate that the intensity of red color decreased with the increase in 1-MCP concentrations in both turning and pink stages of ripening. Similarly, when treated with 300 or 400 nL • L⁻¹ of 1-MCP, pink stage tomatoes also showed less color intensity as compared with the control fruits at the end of the 10-day holding period (Table 1) as indicated by hue values.

Total soluble solids, pH, and firmness. Control fruits in the turning stage had slightly greater total soluble solids content than fruits treated with 1-MCP (Table 1). For fruits in the turning stage, there were no differences in pH in any of the treatments. For fruits treated with 1-MCP in the pink stage, there were no differences in total soluble solids content or pH (Table 1). Fruits treated at the turning stage with 75, 100, or 200 nL • L⁻¹ of 1-MCP were firmer than those treated with 0, 25, or 50 nL • L⁻¹ (Table 1). Pink fruits treated with 300 or 400 nL • L⁻¹ of 1-MCP were firmer than fruits treated with 0, 50, 100, or 200 nL • L⁻¹ of 1-MCP (Table 1).

Discussion

Our objectives were to determine whether ripening in less mature tomatoes could be reinitiated by using C₂H₄ treatments on tomatoes treated previously with 1-MCP and to determine what appropriate low 1-MCP concentrations will delay ripening in less mature tomatoes. Our study showed that subsequent C₂H₄ treatment did not reinitiate ripening in tomatoes treated with 1-MCP at the turning stage. In bananas, however, subsequent C₂H₄ treatment of 1-MCP treated fruits enhanced fruit ripening (Jiang et al., 1999). Similarly, Cameron and Reid (2001) showed that subsequent C₂H₄ treatment of geranium (*Pelargonium*

peltatum L.), previously treated with 1-MCP, showed increased petal abscission. Our preliminary experiments showed that ripening of tomatoes in the breaker and turning stages could not be reinitiated by C_2H_4 even when applied 7 days after 1-MCP treatment. Our observation that tomato fruits treated with 1-MCP do not respond to C_2H_4 suggests the possibility of different physiological activities involved in different commodities. The differences in the responses also may be attributed to the ability of the fruits to hold 1-MCP at the binding sites (Dauny et al., 2003).

The rate at which ripening was delayed was a direct function of the initial 1-MCP concentration and the ripeness stage used. This is similar to what has been observed in bananas (Jiang et al., 1999), apples (Fan et al., 1999) and broccoli (Ku and Wills, 1999). Commodities treated with greater concentrations fail to ripen normally, and this could be a direct effect of the saturation of all C_2H_4 binding sites by 1-MCP at greater concentrations. Rohwer and Gladon (unpublished data) showed that C_2H_4 production resumes to normal levels a few days after 1-MCP treatment. Compounds that control C_2H_4 receptors lose their efficacy over time either by diffusion from receptor sites or due to synthesis of new receptor sites (Sisler and Serek, 1999). This suggests that at lower concentrations, 1-MCP could bind to the partially occupied C_2H_4 sites or the newly synthesized ones, which then could be responding to the endogenous C_2H_4 produced by the fruits.

Hoerberichts et al. (2002) showed that renewed exposure of tomatoes to 1-MCP after 5 to 7 days could further delay ripening. Inhibition of ripening by multiple or continuous applications of ripening inhibitors also has been reported (Mir et al., 2001). However, we do not recommend that greater concentrations or multiple treatments of 1-MCP be applied to turning or pink stage tomatoes to delay ripening because the delay may be unpredictable and

the eventual ripening could be unsynchronized. Also, the observation that tissue softening processes may still occur while color advancement is delayed, even with continuous application of 1-MCP (Mir et al., 2004), suggests that prolonged treatment would have no beneficial effects.

Red color development and firmness are among the major quality parameters that are considered by consumers. A concentration of 25, 50, 75, or 100 nL • L⁻¹ of 1-MCP applied to turning stage fruits or 50, 100, or 200 nL • L⁻¹ of 1-MCP applied to pink stage fruits slowed ripening to a rate we consider commercially desirable. Treatments with 1-MCP also showed retention of fresh weight even at concentrations as low as 25 nL • L⁻¹. In oranges, however, 1-MCP treatments do not show any effect on fresh weight loss (Porat et al., 1999). Because fruits are sold by fresh weight, retention of fresh weight can accumulate to significant amounts in commercial operations where large quantities of fruits are handled. Treatment with lower 1-MCP concentrations reduced fresh weight loss, allowed synchronized ripening of fruits, and at the same time, maintained tomato firmness. Our observation that 1-MCP treatments do not affect pH and total soluble solids content is consistent with a previous report (Mir et al., 2004).

Our study suggests that manipulation of 1-MCP concentrations can be used to obtain the desired extension of shelf life of turning and pink tomatoes. We conclude that delayed ripening in tomato fruits by using 1-MCP is most practical at concentrations < 100 nL • L⁻¹ in turning stage fruits and < 200 nL • L⁻¹ in pink stage tomatoes, depending upon the length of delay desired. These recommendations are based on the treatment and temperature regimes that we have followed. Different responses may be obtained with different treatment times (Wills and Ku, 2002), or especially, a different temperature (Mostofi et al., 2003). With use

of these 1-MCP concentrations, growers and wholesale tomato handlers can better schedule tomato fruit ripening according to market demands.

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Table 1. Quality attributes of tomatoes 10 days after treatment with 1-MCP for 8 h in the turning and pink stages and then held at 21 ± 1 °C. Values are the mean of readings of eight replicates with two fruits in each replicate.

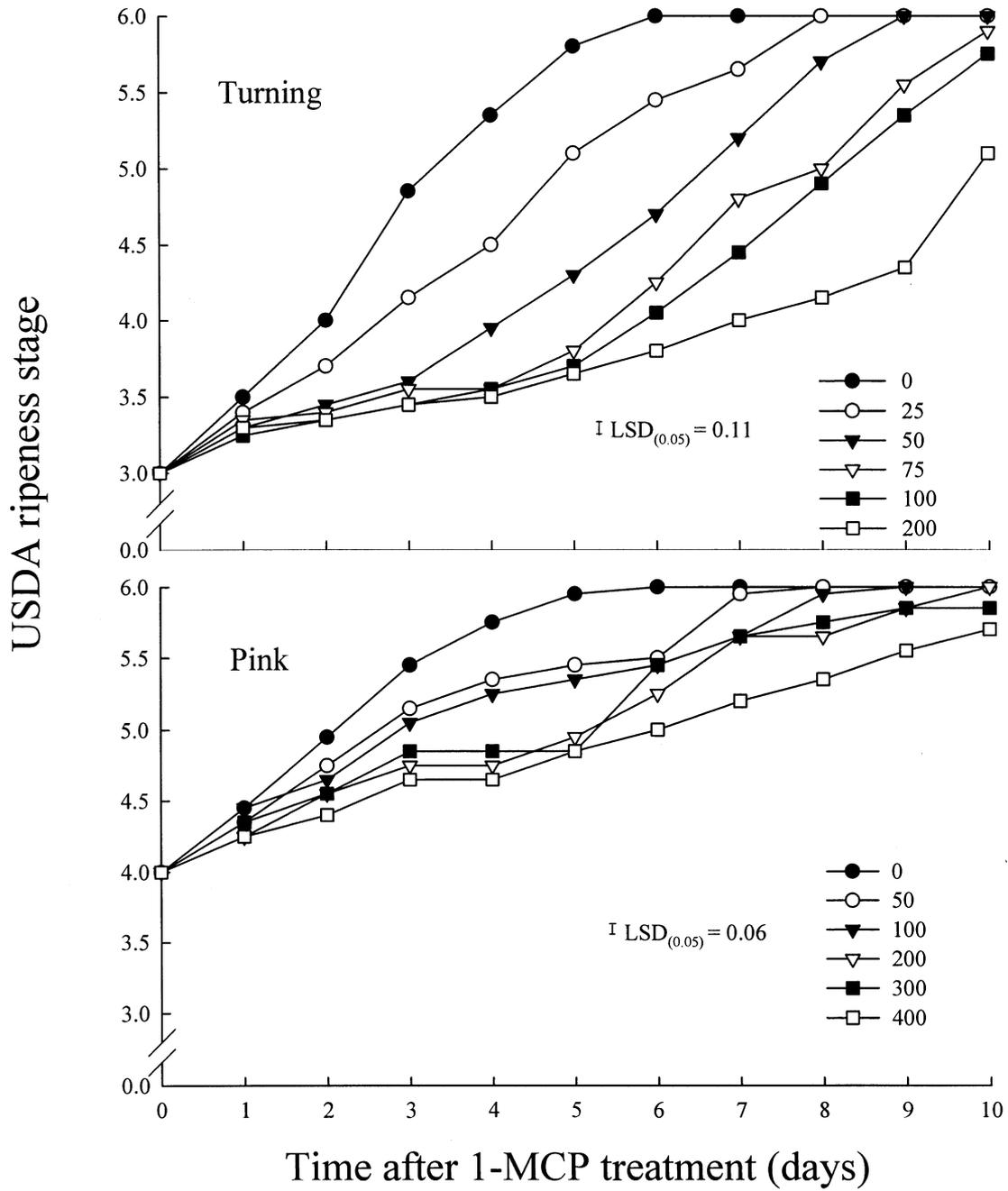
1-MCP (nL • L ⁻¹)	Color					TSS ^z	pH	Firmness
	Turning							
	L	a	b	Chroma	Hue			
0	30.2	19.2	16.3	25.2	40.3	4.7	4.5	1.3
25	33	19	18.7	26.7	44.5	4.5	4.4	1.3
50	36.1	17.8	20.7	27.3	49.3	4.4	4.5	1.2
75	36.3	18.3	20.9	27.3	47.9	4.3	4.3	1.0
100	41.6	12.9	23.8	27.1	61.5	4.4	4.4	1.0
200	41.8	11.7	22.6	24.9	62.6	4.5	4.4	0.9
LSD	2.17	2.75	2.14	2.39	5.05	0.23	0.21	0.19
	Pink							
0	31.9	22.6	16.7	28.1	36.4	4.6	4.4	1.4
50	32.3	23.3	15.9	28.2	38.6	4.4	4.5	1.3
100	32.8	20.1	17.5	26.6	41.1	4.3	4.4	1.3
200	37.2	17.9	19.4	26.4	47.2	4.4	4.3	1.2
300	39	13.1	20	23.9	56.9	4.5	4.4	1.1
400	38.9	12	19.8	23.9	59.8	4.5	4.3	1.0
LSD	2.33	3.11	1.58	3.0	3.96	0.27	0.22	0.17

^zTSS = Total soluble solids

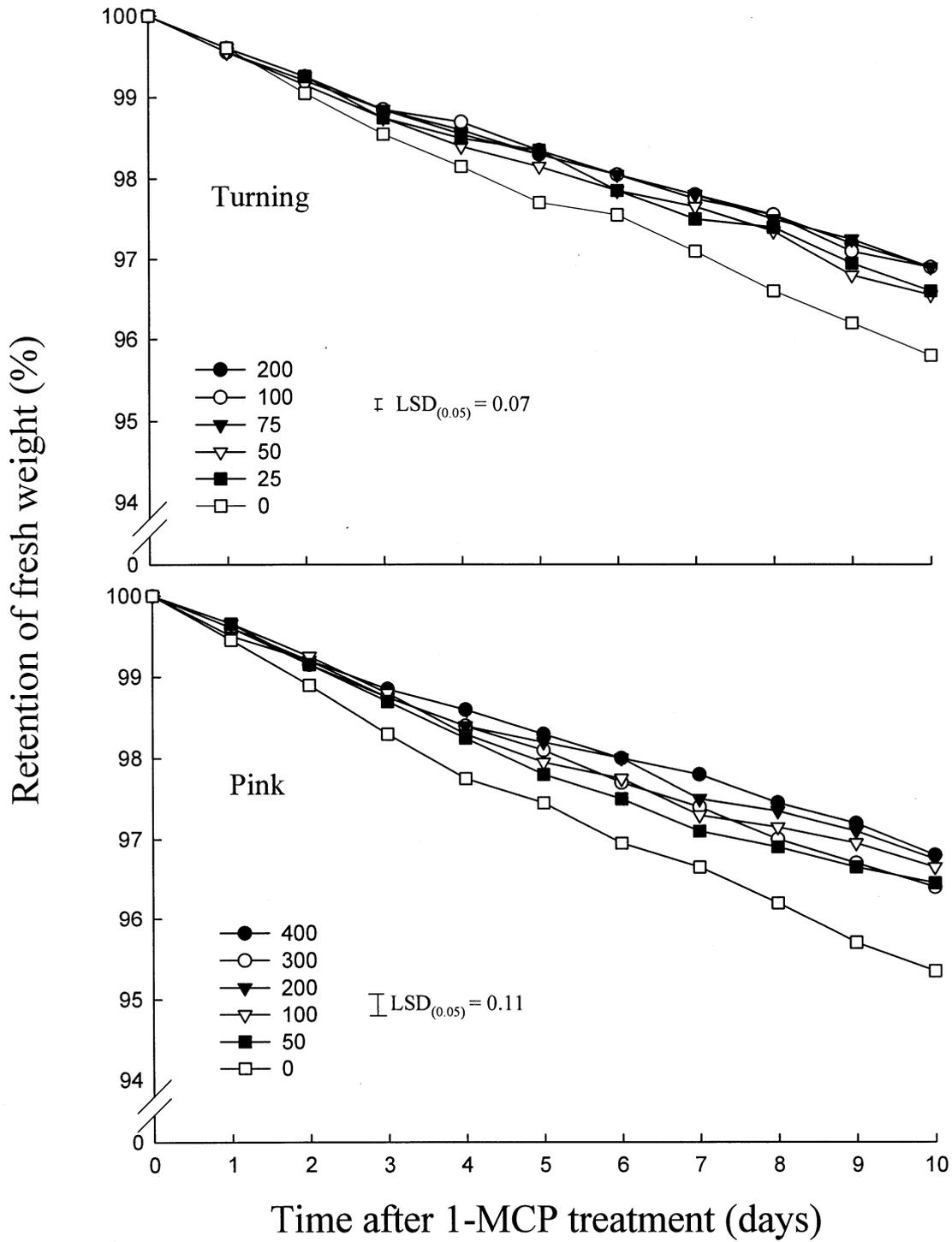
Figure Captions

Fig. 1. USDA ripeness stage advancement of turning and pink stage tomatoes treated with 0, 25, 50, 75, 100, or 200 nL·L⁻¹ of 1-MCP and 0, 50, 100, 200, 300, or 400 nL·L⁻¹ of 1-MCP, respectively, for 8 h at 21 ± 1 °C. Each point is the mean of eight replicates each containing four fruits as observations.

Fig. 2. Fresh weight loss from turning and pink stage tomatoes treated with 0, 25, 50, 75, 100, or 200 nL·L⁻¹ and 0, 50, 100, 200, 300, or 400 nL·L⁻¹ of 1-MCP, respectively, for 8 h at 21 ± 1 °C. Each point is the mean of eight replicates each containing eight fruits as observations.



(Fig. 1)



(Fig. 2)

Chapter 3. General conclusions

General discussion

Manipulation of tomato ripening is possible by using appropriate 1-MCP concentrations, treatment times, and temperature regimes. These are critical factors that must be considered if the desired extension of shelf life of tomato fruits is to be achieved (Mostofi et al., 2003; DeEll et al., 2002). 1-MCP concentrations greater than 100 and 300 nL•L⁻¹ would not be desirable for use on tomatoes treated with 1-MCP at the turning and pink stages, respectively. Eventually, ripening can be achieved when these greater concentrations are used, but the treatments have undesirable effects on the rate of ripening and the appearance of the fruit due to water loss.

The ability of 1-MCP to delay ripening without decreasing the quality of the fruits provides several commercial advantages. These advantages include cost savings on repacking and refrigeration of fruits. The fact that delays in ripening of less mature tomatoes can be achieved without using greater concentrations of 1-MCP is an advantage as it reduces use of chemicals during marketing.

Recommendations for future research

I propose continuing evaluation of the quality attributes of 1-MCP treatments on tomato fruits. I also suggest evaluating whether or not 1-MCP has any residual effect on the tomatoes and whether or not it has any effect on the taste attributes of the fruit. I also suggest these experiments be conducted in large-scale operations where different factors may be involved. Finally, I recommend extending this study to specific cultivars of tomato and other crops and the identification appropriate concentrations of 1-MCP that could be used.

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