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Effects of Storage Conditions and 1-Methylcyclopropene on Some Qualitative Characteristics of Tomato Fruits

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ABSTRACT

A study was conducted on the effects of 1-Methylcyclopropene (1 - MCP) on Rapsodie tomato fruits. Four maturity stages (MS), 5 storage periods (SP) and 3 storage temperatures (ST) were investigated for some ripening related parameters including firmness, hue angle (Hº) and chroma. Analysis of variance revealed a significant difference between 15 nL L^{-1} 1 - MCP and control for Hº ($P < 0.01$). The storage temperatures had significant effects on firmness and Hº($P < 0.01$). The effect of maturity stages and storage periods were also significantly different for all traits. Interactions of MS × ST for Hº, MS × SP for all traits, 1 - MCP × SP for Hº and ST × SP for firmness were also significant ($P < 0.05$). The results showed that a single pretreatment with 1 - MCP slightly delayed tomato ripening according to Hº (control = 48.8 & 15 nL L^{-1} 1 - MCP = 49.9), firmness and chroma. At early breaker (EB) stage, the fruits were firmer and had higher Hº and chroma than other maturity stages. The fruits had also greater Hº at all three temperatures compared to other treatments. At all maturity stages the Hº and firmness decreased by increasing the SP. The tissue firmness decreased by increasing the ST, whereas Hº and chroma was not changed. However, firmness and Hº decreased by an increase in SP. The results showed that the effects of 1 - MCP on fruit ripening is related to storage temperature.

Key Words: *Lycopesicon esculentum;* 1 - Methylcyclopropene; Ripening; Storage temperature; Color; Firmness

INTRODUCTION

The ripening of tomato as a climacteric fruit is highly dependent on ethylene (Nagata *et al*., 1995 & de Wild *et al*., 2005). Postharvest application of volatile compound, 1 - methylcyclopropene (1 - MCP), irreversibly prevents ethylene binding to active sites thus controlling fruit ripening (Chahine *et al*., 1999). 1 - MCP as an ethylene receptor blocker has a good potential to be used commercially as opposed to three other well known ethylene binding inhibitors. It has been shown that 1 - MCP has substantially graeter improvising properties over DACP (Serek *et al*., 1995). 1 - MCP inhibits ethylene action in different fruits and vegetables (Wills & Ku, 2002; Trinchero *et al*., 2004) as well as many cut flowers and potted plants (Celikel *et al*., 2002). It has been shown that in 1 - MCP treated tomatoes the transcription of the genes for ACC synthase and ACC oxidase are suppressed, resulting in transient suppression of red color development (Nakatsuka *et al*., 1997).

Temperature is the most important environmental factor in the postharvest life of fresh vegetables because of its dramatic effect on the rates of biological processes, including respiration. Equations have been established to mathematically predict color development and softening in tomato fruit according to temperatures between 12 - 27ºC (Thorne & Alvarez, 1982). Shahidul Islam *et al*. (1996) found that tomatoes stored at 15ºC, show no defined respiratory climacteric and ripening proceeds at a slow rate. In contrast, at 25ºC they found a high climacteric respiration and ethylene production rates. Red color development of tomatoes optimally takes place between 16 - 26ºC (Türk *et al*., 1994). Based on all of these physiological changes considered together, the optimum temperature for ripening in tomatoes is between 20 - 25ºC (Grierson & Kader, 1986; Maul *et al*., 2000).

In this paper, the effect of 15 nl^{-1} 1 - MCP pretreatment on some ripening-related changes of whole tomato fruit at three different storage temperatures (15, 20 & 25ºC) is reported.

MATERIALS AND METHODS

Plant materials. Mature-green tomatoes (*Lycopersicon esculentum* Mill., cv. Rapsodie) were purchased from a local hot house in Vernon, BC. Fruit were picked from the plant just before being used for experiments and rapidly transferred by non-refrigerated truck to PARC. They were visually sorted according to color (using the BC hot house tomato color classification chart), uniformity, free of defects and blemishes. The fruit were then washed with tap water and treated for the prevention of development of postharvest decay by dipping for 2 min at 20ºC in 0.5 g L^{-1} aqueous solution of iprodione [3 - (3, 5 - dichlorophenyl) –N- (1 - methylethyl) –2 –4- dioxo – 1 - imidazolidinecarboxamide (Rovral), Rhône Poulenc, Canada Inc.Saskatoon, SASK] and then air dried for approximately 1 h.

MCP application. Fruit were placed in 24- liter-plastic boxes with an air-mixing fan and covered with a 5 - mil low density polyethylene bag. The 1 - MCP was generated from Ethylbloc® (obtained from Biotechnologies For Horticulture, Burr Ridge, Ill). Aliquots of 1 - MCP were calculated as described previously (Watkins *et al*., 2000) to provide a final concentration of 15 nL L^{-1}. Fruit were fumigated with this concentration of 1 - MCP for 24 h at 20ºC. Control fruit were sealed with ambient air in identical bags. Fruit were then removed from the control and fumigation bags and placed into 15, 20 and 25ºC rooms with 90 - 95% RH. For measuring the qualitative traits, fruit were sampled after removal from fumigation bags (Time 0), and samplings were then repeated every 6 days for the next 24 days after fumigation.

Firmness. Whole fruit tissue firmness was measured with an Instron Universal Testing Instrument (Model 4201, Burlington, Ontario, Canada). A 50 kg load cell was used in the compression mode and the recorder was calibrated to give a full-scale deflection at 10 kg. Crosshead speed was maintained at 100 mm min^{-1} and the probe was a Magness Taylor, 11 mm in diameter. Skin was removed at a point on the equatorial plane of the fruit and test was conducted. The fruit was then turned 180º and another skin section was removed and a second test performed. The two measurements were averaged for each fruit and expressed in newtons (N). In order to eliminate errors in force readings, the tomato fruit was supported in a sand filled cup when testing.

Color. CIE (Commission Internationale de l'Eclairage) a* and b* coordinates were determined with a Minolta chroma meter (Model CR - 200, Osaka, Japan), after calibration with a white tile. The hue was calculated from a* and b* values as follows: $H^o = [(\tan^{-1} b^*/ a^*) / 6.2832 + 180]$ representing the shade of color (McGuire, 1992). Chroma was calculated as follows: chroma = $(a^{*2} + b^{*2})^{1/2}$, representing the purity of color of specific hue. The surface color of the tomatoes was measured using the average of 12 measurements: 3 around the blossom pole, 3 around the calyx pole and 6 at equidistant points around the equatorial circumference of each tomato.

Statistical analysis. The experiment had factorial structure with 4 maturity stages, 2 treatments (fumigated, control), 3 temperatures (15, 20 & 25ºC) and 5 sampling times (0, 6, 12, 18, 24 days). The experiment had a complete random design for each factor combination with 3 replications. The effects of the factors on each variable were determined by analysis of variance using SAS PROC GLM (SAS, Cary, NC).

RESULTS

The summary of analysis of variance (ANOVA) revealed that maturity stages (MS) had significant effect on chroma, hueº and firmness ($P \leq 0.001$), whereas pretreatment with 1 - MCP showed significant effect only on hueº (Table I). The effects of different storage temperatures as well as sampling time (Time) were significant on firmness and hueº while on chroma significant effect was observed only through sampling time. Among different interactions, MSxTemp showed significant effect on hueº ($P \leq 0.05$). Significant interaction of MSxTime was observed for all studied traits. The interactions of time with 1 – MCP and time with temperature had significant effect on hueº and firmness ($P \leq 0.01$). The mean comparison for main effects and treatment combinations with significant effects on studied traits based on Duncan's Multiple Range Test. The maximum value for all studied traits were observed at EB maturity stage, which showed significant differences with other stages. The results indicated that the pretreatment with 1 - MCP had higher value for hueº, which significantly differ with that of control. The maximum firmness of fruits was observed at storage temperature of 15ºC, which had significant differences with 20 and 25ºC. Although the effect of storage temperature on hueº was statistically significant, biologically these differences were not important. The results revealed that with increased storage period, the firmness and hueº decreased and the higher value for the both traits were obtained at 0 – time, which significantly differed from others. Significant differences at different storage period for chroma were observed; however, there was no specific trend in increase or decrease of chroma value (Table II). The study of maturity stages and storage temperatures combinations on hueº showed that the hueº had maximum value at EB for all three storage temperatures. With the maturity of fruits and increased storage temperature, the hueº value was reduced (Table III). Mean comparison for MSxTime combinations revealed that the firmness and hueº reduced with maturity and increased sampling time. The maximum mean value for hueº and firmness were obtained at 0 - time and EB stage. However, with significant effect of this combination on chroma, chroma variation did not show any specific trend in changes. Chroma had the higher value at EB when samples were taken after 6, 12 and 18 days (Table IV)

DISCUSSION

Tissue firmness and chroma were similar for pre-treated fruit with 1 - MCP and controls and treatment combination of 1 - MCP with other factors. However, hue values in pre-treated fruit were higher than those of controls (2.35% increases). Moreover, as indicated in (Tables II & V), treatment combination of 1 - MCP × Storage periods showed that there were no significant differences between hueº value for control and 1 - MCP treated fruit in each sampling time intervals (at 0 - time: control = 63.74 vs. 1 - MCP = 67.71 and after 24 days: control = 44.8 vs. 1 - MCP = 44.3). It is apparent from these data that 1 - MCP interactions with MS and Temp were not significant for

Table I. Analysis of variance for several tomato fruit quality characteristics

		MS		
Source of variation	**Df**	**Firmness**	**Hue°**	**Chroma**
Maturity Stages (MS)	3	1.624***	1148.080***	68.612***
1-MCP	1	0.307^{ns}	123.632**	3.533^{ns}
Temperature (Temp)	2	1.212***	81.744**	4.381^{ns}
Time	4	16.962***	6178.126***	35.708***
MS ×1-MCP	3	0.176^{ns}	27.106^{ns}	3.972^{ns}
MS × Temp	6	0.159^{ns}	38.050*	7.087^{ns}
MS × Time	12	1.522***	1039.708***	8.074*
1-MCP × Temp	2	0.005^{ns}	8.584^{ns}	1.160^{ns}
1-MCP × Time	4	0.062^{ns}	69.335**	1.759^{ns}
Temp × Time	8	0.289**	7.898^{ns}	6.389^{ns}
MS × 1-MCP × Temp	6	0.033^{ns}	2.251^{ns}	1.858^{ns}
Error	238	0.0976	15.524	4.120

ns,*,**,*** Nonsignificant or significant at P = 0.05,0.01,or 0.001, respectively.

Table II. Means comparison for different tomato fruit quality characteristics for different studied treatments using DMRT

	MS		
	Firmness	**Hue°**	**Chroma**
Treatment			
1-MCP	0.84 ± 0.023^{a}	49.928 ± 0.294^{a}	24.93 ± 0.151^{a}
Control	0.78 ± 0.023^{a}	48.751 ± 0.294^{b}	25.13 ± 0.151^{a}
	Storage Temperatures		
15ºC	0.93 ± 0.028^{a}	49.71 ± 0.364^{a}	25.11 ± 0.187^{a}
20ºC	0.77 ± 0.028^{b}	48.39 ± 0.359^{b}	25.17 ± 0.185^{a}
25ºC	0.74 ± 0.028^{b}	49.040 ± 0.359^{a}	24.81 ± 0.185^{a}
	Storage periods		
0	1.64 ± 0.036^{a}	66.73 ± 0.464^{a}	24.36 ± 0.239^{b}
6	0.82 ± 0.037^{b}	47.60 ± 0.473^{b}	25.62 ± 0.244^{b}
12	0.61± 0.036^{c}	44.43 ± 0.464^{c}	25.94 ± 0.239^{a}
18	0.53 ± 0.036^{cd}	44.37 ± 0.464^{c}	24.69 ± 0.239^{b}
24	0.45 ± 0.036^{d}	44.55 ± 0.464^{c}	24.54 ± 0.239^{b}
	Maturity Stages		
EB	0.99 ± 0.032^{a}	54.12 ± 0.415^{a}	26.33 ± 0.213^{a}
LB	0.82 ± 0.033^{b}	49.90 ± 0.422^{b}	24.73 ± 0.217^{b}
PR	0.76 ± 0.032^{bc}	47.30 ± 0.415^{c}	24.41 ± 0.213^{b}
TR	0.68 ± 0.032^{c}	46.03 ± 0.415^{c}	24.67 ± 0.213^{b}

studied traits, thus it can be concluded that a single application of 15 nL L^{-1} 1 - MCP separately and combined with other factors was not very effective in delaying tomato fruit ripening.

In other studies it has been shown that 1 - MCP as a new anti-ethylene compound can inhibit or delay ripening of different fruits and vegetables thus extending shelf life of fruits and vegetables (Trinchero *et al*., 2004). It has been shown that in tomatoes 1 - MCP prevents the accumulation of a number of mRNAs responsible for the expression of ACC synthase, ACC oxidase and ethylene receptor involved in positive feedback regulation of autocatalytic (System 2) ethylene production (Nakatsuka *et al*., 1997). According to findings maturity stage of EB was better than the others (Table II): the fruit at EB had higher hue° compared to other maturity stages at all three temperatures (Table III); mean comparison of treatment combination of MS × Time provided only a transient effect on fruit firmness and Hue° at all maturity stages and first sampling time, followed by a quick reduction afterward. Furthermore, it can be concluded that using fruits at EB stage separately or combined with other factors is more effective to control the fruit ripening. This is in agreement with Harris *et al.* (2000) who showed that the effectiveness of 1 - MCP varied in respect with fruit maturity. According to Grierson and Kader (1986), ethylene production triggers a cascade of various biochemical processes leading to physico-chemical changes during ripening processes, and the fruit at EB stage is one in which ethylene biosynthesis and fruit ripening has not been initiated yet.

Mean comparison of Time × Temp combination revealed that the amounts of hue° and chroma were not affected by these factors (Table VI). However, ascending storage temperatures and lengthy periods of storage

Table III. Means comparison for tomato fruit quality characteristics of fruit maturity stages and temperature combinations using DMRT

		MS		
MS	**× Temp**	**Firmness**	**Hue°**	**Chroma**
	15ºC	1.066 ± 0.0570^{a}	54.573 ± 0.7193^{a}	26.117 ± 03706^{a}
EB	20ºC	0.913 ± 0.0570^{a}	51.655 ± 0.7193^{bc}	26.315 ± 0.3706^{a}
	25ºC	1.017 ± 0.0570^{a}	56.136 ± 0.7193^{a}	26.559 ± 0.3706^{a}
	15ºC	1.026 ± 0.0598^{a}	50.474 ± 0.7545^{b}	24.629 ± 0.3887^{a}
LB	20ºC	0.753 ± 0.0570^{a}	48.905 ± 0.7193^{bcd}	25.359 ± 0.3706^{a}
	25ºC	0.6837 ± 0.0570^{a}	50.328 ± 0.7193^{b}	24.210 ± 0.3706^{a}
	15ºC	0.879 ± 0.0570^{a}	48.109 ± 0.7193^{cde}	24.351 ± 0.3706^{a}
PR	20ºC	0.732 ± 0.0570^{a}	46.981± 0.7193^{def}	24.751 ± 0.3706^{a}
	25ºC	0.677 ± 0.0570^{a}	46.811 ± 0.7193^{def}	24.135 ± 0.3706^{a}
	15ºC	0.754 ± 0.0570^{a}	45.703 ± 0.7193^{f}	25.372 ± 0.3706^{a}
TR	20ºC	0.706 ± 0.570^{a}	46.025 ± 0.7193^{ef}	24.270 ± 03706^{a}
	25ºC	0.586 ± 0.570^{a}	46.362± 0.7193^{ef}	24.368 ± 0.3706^{a}

Table IV. Means comparison for tomato fruit quality characteristics of fruit maturity stages and storage periods combinations using DMRT

		MS		
MS	**× Temp**	**Firmness**	**Hue°**	**Chroma**
	0	2.558 ± 0.0736^{a}	89.633 ± 0.9287^{a}	24.931 ± 0.4784^{fg}
	6	0.890 ± 0.0736^{de}	49.320 ± 0.9287^{e}	27.658 ± 0.4784^{ab}
EB	12	0.629 ± 0.0736^{efgh}	43.704 ± 0.9287^{e}	27.574 ± 0.4784^{a}
	18	0.509 ± 0.0736^{fgh}	43.760 ± 0.9287^{e}	26.010 ± 0.4784^{ab}
	24	0.406 ± 0.0736^{h}	44.189 ± 0.9287^{e}	25.477 ± 0.4784^{cdef}
	0	1.628 ± 0.0736^{b}	66.017 ± 0.9287^{b}	23.563 ± 0.4784^{defg}
	6	0.829 ± 0.0795^{defg}	47.629 ± 1.0031^{de}	25.108 ± 0.517^{abcde}
LB	12	0.622 ± 0.0736^{efgh}	45.243 ± 0.9287^{e}	25.69 ± 0.4784^{bcdef}
	18	0.551 ± 0.0736^{efgh}	45.030 ± 0.9287^{e}	25.020 ± 0.4784^{efg}
	24	0.474 ± 0.0736^{gh}	45.592 ± 0.9287^{e}	24.280 ± 0.4784^{g}
	0	1.354 ± 0.0736^{bc}	55.958 ± 0.9287^{c}	1.534 ± 0.0736^{bc}
	6	0.850 ± 0.0736^{def}	47.682 ± 0.9287^{de}	24.655 ± 0.4784^{cdef}
PR	12	0.607 ± 0.0736^{efgh}	44.438 ± 0.9287^{e}	25.45 ± 0.4784^{abcde}
	18	0.542 ± 0.0736^{efgh}	44.503 ± 0.9287^{e}	23.893 ± 0.4784^{abcd}
	24	0.459 ± 0.0736^{gh}	43.937 ± 0.9287^{e}	24.569 ± 0.4784^{abcde}
	0	1.055 ± 0.0736cd	51.318 ± 0.9287^{d}	25.093 ± 0.4784^{abcd}
	6	0.730 ± 0.0736^{defgh}	45.785 ± 0.9287^{e}	25.093 ± 0.4784^{abcde}
TR	12	0.590 ± 0.0736^{efgh}	44.357 ± 0.9287^{e}	25.084 ± 0.4784^{abcde}
	18	0.552 ± 0.0736^{efgh}	44.188 ± 0.9287^{e}	23.861 ± 0.4784^{cdef}
	24	0.482 ± 0.0736^{fgh}	44.507 ± 0.9287^{e}	23.853 ± 0.4784^{cdef}

Table V. Means comparison for tomato fruit quality characteristics of 1-MCP and storage periods combinations using DMRT

		MS		
**1-MCP × **	**ST**	**Firmness**	**Hue°**	**Chroma**
	0	1.57 ± 0.052[a]	63.74 ± 0.656[b]	24.37 ± 0.338[a]
	6	0.82 ± 0.053[a]	46.34 ± 0.670[cd]	25.77 ± 0.345[a]
Control	12	0.61 ± 0.052[a]	44.37 ± 0.656[d]	26.17 ± 0.338[a]
	18	0.49 ± 0.052[a]	44.47 ± 0.656[d]	24.56 ± 0.338[a]
	24	0.42 ± 0.052[a]	44.80 ± 0.656[d]	24.78 ± 0.338[a]
	0	1.71 ± 0.052[a]	67.71 ± 0.656[a]	24.34 ± 0.338[a]
	6	0.82 ± 0.053[a]	48.86 ± 0.670[c]	25.48 ± 0.3452[a]
1-MCP	12	0.61 ± 0.052[a]	44.48 ± 0.656[d]	25.72 ± 0.338[a]
	18	0.58 ± 0.052[a]	44.26 ± 0.656[d]	24.82 ± 0.338[a]
	24	0.48 ± 0.052[a]	44.30 ± 0.656[d]	24.30 ± 0.338[a]

Table VI. Means comparison for tomato fruit quality characteristics of storage temperatures and storage periods combination using DMRT

		MS		
Temp ×	**Time**	**Firmness**	**Hue°**	**Chroma**
	0	1.58 ± 0.063[a]	67.12 ± 0.804[a]	23.88 ± 0.414[a]
	6	1.069 ± 0.067[b]	48.23 ± 0.85[a]	26.25 ± 0.439[a]
15ºC	12	0.80 ± 0.063[c]	44.51 ± 0.804[a]	25.95 ± 0414[a]
	18	0.65 ± 0.063[cd]	44.36 ± 0.804[a]	24.61 ± 0.414[a]
	24	0.54 ± 0.063[cd]	44.35 ± 0.804[a]	24.87 ± 0.414[a]
	0	1.63 ± 0.063[a]	64.30 ± 0.804[a]	24.48 ± 0.414[a]
	6	0.78 ± 0.063[c]	46.39 ± 0.804[a]	25.88 ± 0.414[a]
20ºC	12	0.57 ± 0.063[cd]	43.74 ± 0.804[a]	26.42 ± 0.414[a]
	18	0.47 ± 0.063[d]	43.50 ± 0.804[a]	24.98 ± 0.414[a]
	24	0.42 ± 0.063[d]	44.01 ± 0.804a	24.09 ± 0.414[a]
	0	1.72 ± 0.063[a]	65.76 ± 0.804[a]	24.71 ± 0.414[a]
	6	0.62 ± 0.063[cd]	48.18 ± 0.804[a]	24.74 ± 0.414[a]
25ºC	12	0.46 ± 0.063[d]	45.04 ± 0.804[a]	25.46 ± 0.414[a]
	18	0.48 ± 0.063[d]	45.24 ± 0.804[a]	24.48 ± 0.414[a]
	24	0.40 ± 0.063[d]	45.30 ± 0.804[a]	24.66 ± 0.414[a]

decreased tissue firmness. This trend was slower at 15º than at 20 and 25ºC and fruits were firmer until 18 days. One final point, in this work, 15 nL L^{-1} of 1 - MCP has not been demonstrated to be effective in controlling fruit ripening. Previous reports have recommended concentrations of 5 - 7 nL L^{-1} (Sisler & Serek, 1997) 1 - MCP to prevent or delay ethylene-induced ripening in tomatoes.

CONCLUSION

Different cultivars of tomato could express different levels of sensitivity to 1 - MCP. This work demonstrated that Cv. Rapsodie has indeterminate growth habit with large beef steak-type fruit and specifically bred for greenhouse production. Therefore this particular cultivar required much higher levels of 1 - MCP to significantly inhibit its fruit ripening.

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