REGULATION OF FRUIT RIPENING IN BANANA USING 1-METHYLCYCLOPROPENE

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SUMMARY

Experiment was conducted to study the effect of different concentrations of 1-Methylcyclopropene (1-MCP) and durations on fruit ripening in two varieties of banana. Different concentrations and durations of 1-MCP treatment were 1µl/l 1-MCP for 6 hrs, 1µl/l 1-MCP for 12 hrs, 5µl/l 1-MCP for 6 hrs, 5µl/l 1-MCP for 12 hrs, 10µl/l 1-MCP for 6 hrs and 10µl/l 1-MCP for 12 hrs. Observations were recorded at four stages of ripening i.e. Stage 1: Full Green (FG), Stage 2: More Green than Yellow (MG), Stage 3: More Yellow than Green (MY) and Stage 4: Full Yellow (FY). 1-MCP treatment to banana caused a significant (68%) extension in shelf life in both the varieties studied. This delayed ripening due to 1-MCP treatment was associated with reduction in fresh weight, lower rate of respiration and ethylene evolution, a decreased pulp-peel ratio and TSS %. However, there was no significant difference among the different concentrations and durations of 1-MCP treatment. Thus, it was concluded that 1-MCP delays banana fruit ripening and 1 µl/l 1-MCP for 6 hrs is most effective among different combinations studied.

***Key words*: Ethylene, fruit ripening, 1-MCP, respiration**

INTRODUCTION

Banana is the fourth important food crop and contributes around 32% of the total fruit production in India. It is also a dessert fruit for millions, apart from a staple food owing to its rich and easily digestible carbohydrates. Delaying the ripening process in banana is of great interest because it increases the shelf-life of the fruit. The plant hormone ethylene has been shown to participate in almost all stages of plant growth and development including seed germination, fruit ripening, senescence and abscission, various stresses and pathogen attack (Abeles 1973). In climacteric fruits, ethylene not only induces ripening but also regulates and participates in its progression (Lelievre *et al.* 1997). Climacteric fruits, such as banana, are characterised by a surge in ethylene production at the onset of ripening (Marriott 1980). Their shelf life is, thereby, reduced by ethylene evolution. Shelf life extension has been achieved by using ethylene absorbents, such as potassium permanganate, in polyethylene bags (Scott and Soertini 1974). Such compounds maintain low ethylene levels. However, the general usefulness of sealed polyethylene bags with scrubbers is limited because prevailing environmental variables, such as temperature and relative humidity, and packaging constraints, such as restricted gas exchange, can interact to adversely influence fruit quality and shelf life (Blankenship and Sisler 1993). For example, package constraints can result in anaerobiosis, with attendant off-flavours and odours, and failure to ripen normally.

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1-Methylcyclopropene (1-MCP) is a highly promising compound among recently developed inhibitors of ethylene action (Blankenship and Dole 2003), having been shown to prevent ethylene-induced effects in tomato, banana (Sisler *et al.* 1995), plum (Abdi *et al.* 1998), and apple (Song *et al.* 1997) fruits, and in numerous ornamentals (Sisler *et al.* 1996). 1-MCP acts by binding irreversibly to ethylene-receptors so that ethylene cannot elicit subsequent signal transduction and translation (Sisler and Blankmenship 1996). Ornamentals treated even with low concentration of 1-MCP/l do not respond even to relatively very high concentrations of ethylene; e.g. 1000 nl/l (Sisler *et al.* 1995). Thus, 1-MCP has real potential for control of ripening and senescence of harvested fresh produce in commercial situations. The objective of this study was to standardize dose and duration on of 1-MCP to delay fruit ripening and other associated parameters in banana cultivars.

MATERIALS AND METHODS

Experimental material: The study was undertaken with two varieties of banana viz. Robusta and Dwarf Cavendish. Banana fingers from the same whorl of the hand representing a similar developmental stage were used for study. Mature green pre-climacteric banana fruits were kept for ripening at room temperature (28 ± 2^0C). Fruit ripening was classified into four stages i.e. Stage 1: Full Green (FG), Stage 2: More Green than Yellow (MG), Stage 3: More Yellow than Green (MY) and Stage 4: Full Yellow (FY) based on the peel appearance according to Stover and Simmonds (1987).

1-MCP treatment: Unripe fruits were kept in air tight plastic jar to expose them to the gas evolved from 1-MCP. The required quantity of 1-MCP in a small beaker was kept inside the jar with fruits. One ml distilled water was added to the beaker to evolve the gas. At the end of the treatment duration, the fruits were exposed to room temperature (28 ± 2 ^{0}C) until the fruits reached required ripening stage. The control set of fruits were kept in airtight containers with 1 ml distilled water without 1-MCP. The different treatments given were: 1 μl/l 1-MCP for 6 hrs, 1 μl/l 1-MCP for 12 hrs, 5 μl/l 1-MCP for 6 hrs, 5 μl/l 1-MCP for 12 hrs, 10μl/l 1-MCP for 6 hrs and 10μl/l 1-MCP for 12 hrs.

Shelf life: Fruits from both the varieties were observed daily. Number of days taken to reach the different stages was recorded.

Fresh weight: The fresh weight of banana fruits at different stages of ripening of both the varieties was recorded using a digital balance.

Pulp-peel ratio: Three banana fruits from each treatment were peeled off and the pulp and peel portions of each finger were weighed separately on a laboratory balance. The ratios of pulp to peel of each finger were calculated and mean value was recorded.

Respiration: Three fruits from each stage of maturity were weighed and their respiration rate was measured in a respirometer based on Infra Red Gas Analyzer (IRGA: Model; ADC, LCA2-6606). Respiration rate was expressed as μmol CO_2 g^{-1} FW min^{-1}.

Ethylene evolution: Ethylene production was measured by incubating a whole banana fruit in a 1 L air tight chamber for 3 h at room temperature. A 5 ml sample of the head space gas was withdrawn using a gastight Hamilton syringe and injected into a gas chromatograph (Perkin Elmer 8500) fitted with a Porapak N column maintained at 40 °C and a flame ionization detector to measure ethylene concentration. The rate of ethylene production was expressed as n mol $g^{-1}h^{-1}$.

Total soluble solids (TSS) %: Twenty-five g of banana fruit tissue was macerated in distilled water and volume was made up to 250 ml. The extract was filtered through glass wool. Fifty ml of filtrate was transferred to a beaker whose weight was known and evaporated over water bath to dryness and cooled in desiccator and weighed. The difference in the weight was calculated and expressed as total soluble solids in per cent.

RESULTS AND DISCUSSION

The objective of this study was to find out how 1-MCP treatment affects the physiological changes that occur during fruit ripening and to identify the best combination of concentration and duration of 1-MCP.

Shelf life: The effect of different concentrations and durations of 1-MCP treatment on ripening of banana fruit are presented in Table 1. In both Robusta and Dwarf Cavendish, the number of days taken to reach full ripe stage was higher under 1-MCP treatment compared to control. Robusta took 4.33 days, 7.33 days and 11.67 days under control to reach Stage 2, Stage 3 and Stage 4, respectively while it took 6.33 days, 13 days and 19.7 days, respectively under 1-MCP treatment. Similarly, Dwarf Cavendish took 4.33 days, 7.67 days and 12.33 days under control to reach Stage 2, Stage 3 and Stage 4, respectively while it was 7.22 days, 13.8 days and 20.8 days, respectively under 1-MCP treatment. Thus 1-MCP treatment has significantly delayed ripening of banana fruits in both the varieties under study. However, there was no significant difference between different concentrations and durations of 1-MCP treatment viz. 1 µl/l 1-MCP for 6 hrs, 1 µl/l 1-MCP for 12 hrs, 5 µl/l 1-MCP for 6 hrs, 5 µl/l 1-MCP for 12 hrs, 10 µl/l 1-MCP for 6 hrs and 10 µl/l 1-MCP for 12 hrs.

Since 1-MCP is thought to inhibit ripening by irreversibly occupying ethylene binding sites, so that ethylene is unable to bind and, thereby, elicit a response (Sisler and Blankenship 1996), in all experiments reported herein, 1-MCP treated banana fruit had extended shelf life compared to untreated fruits as judged by the number of days taken to achieve complete ripening. Similar results were observed in the previous reports also. Jiang *et al.* (1999) reported that banana ripening was inhibited effectively by the addition of 1-MCP into sealed polyethylene bags. Arias *et al.* (2009) studied the extension of fresh-cut pear shelf-life by 1-MCP treatment after harvest, where they observed that treatment with 1-MCP could be a viable alternative to common technologies for extending the shelf life of pears.

Fresh weight, respiration and ethylene evolution: Robusta recorded a fresh weight of 121.67 g, 119 g and 115.67 g under control at Stage 2, Stage 3 and Stage 4, respectively while it was 118.5 g, 114.9 g and 111.4 g, respectively under 1-MCP treatment. The corresponding values for Dwarf Cavendish were 77.14 g, 73.67 g and 67.67 g under control and 71 g, 63.8 g and 57 g under 1-MCP treatment at Stage 2, Stage 3 and Stage 4, respectively (Table 2). It was clearly evident that 1-MCP treatment has significantly decreased fresh weight during ripening of banana fruits in both the varieties under study.

In the control untreated fruits of both the varieties, the respiration rate increased to a maximum at Stage 3 (122.56 µmol CO_2 g^{-1} FW min^{-1} after 7.33 days in Robusta and 121.01 µmol CO_2 g^{-1} FW min^{-1} after 7.67 days in Dwarf Cavendish), and further declined in Stage 4 (54.43 µmol CO_2 g^{-1} FW min^{-1} after 11.67 days in Robusta and 52.04 µmol CO_2 g^{-1} FW min^{-1} after 12.33 days in Dwarf Cavendish). This peak marks the climacteric stage of ripening (Table 3). 1-MCP treatment

Table 1. Effect of 1-MCP treatment on shelf life (days) of banana fruit.

		Robusta				Dwarf Cavendish			
		Stages				Stages			
Treatments	**Duration**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Control		-	4.33	7.33	11.67	-	4.33	7.67	12.33
1µl/l MCP	6h	-	7.33	13.33	19.67	-	7.33	14.33	20.67
	12h	-	6.33	13.67	19.67	-	7.67	14.67	21.0
5µl/l MCP	6h	-	6.67	13.33	20.67	-	7.67	13.67	21.67
	12h	-	6.67	12.67	20.33	-	8.0	14.33	21.67
10µl/l MCP	6h	-	5.67	12.67	18.67	-	6.33	12.67	19.33
	12h	-	6.0	12.33	19.33	-	6.33	13.33	20.67
Mean		-	6.33	13	19.7		7.22	13.8	20.8
CD at 5%			1.29	2.04	3.43		1.49	2.04	2.91

Table 2. Effect of 1-MCP treatment on fresh weight (g) during banana fruit ripening.

		Robusta				Dwarf Cavendish			
		Stages				Stages			
Treatments	**Duration**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Control		125.33	121.67	119.00	115.67	78.67	77.14	73.67	67.67
1µl/l MCP	6h	125.33	118.41	114.58	108.92	78.67	75.84	69.44	63.99
	12h	125.33	117.94	115.84	106.67	78.67	76.67	67.84	64.07
5µl/l MCP	6h	125.33	119.33	115.61	108.67	78.67	76.14	67.99	63.84
	12h	125.33	119.08	114.91	107.98	78.67	75.83	68.07	63.28
10µl/l MCP	6h	125.33	117.89	113.99	107.29	78.67	76.08	69.11	63.01
	12h	125.33	118.57	114.57	106.96	78.67	75.18	67.08	64.19
Mean		125.33	118.5	114.9	111.4	78.7	71	63.8	57
CD at 5%		NS	1.78	5.48	6.0	NS	4.10	4.66	6.34

significantly delayed the climacteric peak of respiration in both the varieties (109.96 µmol CO_2 g^{-1} FW min^{-1} on 13 days after treatment in Robusta and 110.17 µmol CO_2 g^{-1} FW min^{-1} on 13.8 days after treatment in Dwarf Cavendish).

Ethylene evolution followed the pattern of respiration during the course of fruit ripening in banana. In the control untreated fruits of both the varieties, ethylene evolution increased to a maximum at Stage 3 (0.6 n mol $g^{-1}h^{-1}$ after 7.33 days in Robusta and 0.54 n mol $g^{-1}h^{-1}$ after 7.67 days in Dwarf Cavendish), and further declined in Stage 4 (0.087 n mol $g^{-1}h^{-1}$ after 11.67 days in Robusta and 0.083 n mol $g^{-1}h^{-1}$ after 12.33 days in Dwarf Cavendish) (Table 4). This peak coincides with the climacteric peak of respiration observed previously. 1-MCP treatment significantly delayed the climacteric peak of ethylene evolution, similar to its effect on respiration, in both the varieties (13 days after treatment in Robusta and 13.8 days after treatment in Dwarf Cavendish).

Table 3. Effect of 1-MCP treatment on respiration rate (µmol CO_2 g^{-1} FW min^{-1}) during banana fruit ripening.

		Robusta				Dwarf Cavendish			
		Stages				Stages			
Treatments	**Duration**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Control		23.45	81.50	122.56	54.43	24.51	80.80	121.01	52.04
1µl/l MCP	6h	23.45	25.65	109.66	45.72	24.51	24.20	108.97	45.64
	12h	23.45	22.79	108.66	48.41	24.51	22.54	110.31	46.79
5µl/l MCP	6h	23.45	23.06	113.27	49.23	24.51	22.04	111.89	48.07
	12h	23.45	23.19	112.69	47.91	24.51	22.43	110.19	46.39
10µl/l MCP	6h	23.45	23.01	109.38	52.59	24.51	22.04	110.98	50.50
	12h	23.45	22.86	109.96	47.73	24.51	23.04	110.17	47.51
Mean		23.45	23.43	110.6	48.6	24.51	31	111.9	48.1
CD at 5%		NS	4.49	5.1	NS	NS	3.441	6.72	NS

Table 4. Effect of 1-MCP treatment on ethylene evolution (nmol g^{-1} h^{-1}) during banana fruit ripening.

		Robusta				Dwarf Cavendish			
		Stages				Stages			
Treatments	**Duration**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Control		0.007	0.433	0.600	0.087	0.008	0.393	0.540	0.083
1µl/l MCP	6h	0.007	0.260	0.460	0.117	0.008	0.247	0.423	0.110
	12h	0.007	0.257	0.430	0.120	0.008	0.277	0.483	0.093
5µl/l MCP	6h	0.007	0.240	0.373	0.120	0.008	0.203	0.440	0.137
	12h	0.007	0.220	0.507	0.103	0.008	0.247	0.443	0.097
10µl/l MCP	6h	0.007	0.233	0.477	0.130	0.008	0.257	0.447	0.120
	12h	0.007	0.227	0.447	0.117	0.008	0.213	0.500	0.143
Mean		0.007	0.239	0.449	0.118	0.008	0.26	0.47	0.112
CD at 5%		NS	0.079	0.125	NS	NS	0.092	NS	NS

Thus, the results in the present investigation indicate that 1-MCP treatment cause a significant decrease in fresh weight and delay in appearance of climacteric peak of respiration and ethylene evolution. 1-MCP treated banana fruits had significantly less fresh weight compared to untreated fruits at all stages of ripening. The extended shelf life resulted in greater total respiration of the tissue due to longer time which resulted in less fresh weight under 1-MCP treatment compared to control.

Respiration rate of banana fruit recorded an increasing trend, reached a peak and finally decreased rapidly (Table 4). 1-MCP treatment resulted in a decrease in the rate of respiration as well as a delay in appearance of climacteric peak compared to that of control fruit in both the varieties (13 days after treatment in Robusta and 13.8 days after treatment in Dwarf Cavendish compared to 7.33 days and 7.67 days, respectively under control). Similar results were reported by Zhang *et al.* (2006). In climacteric fruits like banana, increase in ethylene evolution is accompanied by an increase in respiration during ripening (Biale and Young 1981). Thus, the data presented here confirm that 1-MCP can effectively prevent ethylene action in banana fruit.

The effect of 1-MCP treatment on ethylene evolution was similar to its effect on respiration rate and respiratory climacteric peak. The normal pattern of ethylene production was observed in untreated ripening banana fruit. Ethylene production was almost undetected during the pre-climacteric phase. A sharp increase in ethylene evolution was observed at Stage 3 and then decreased rapidly. The sharp increase in ethylene evolution early in the climacteric phase was in agreement with a previous study by Liu *et al.* (1999). Once the onset of ethylene production commenced, an autocatalytic effect was observed, whereby the ethylene production is markedly increased. 1-MCP treatment significantly reduced the ethylene evolution compared to control fruits and delayed the climacteric peak (13 days after treatment in Robusta and 13.8 days after treatment in Dwarf Cavendish compared to 7.33 days and 7.67 days, respectively under control). This delayed climacteric peak of ethylene evolution is believed to be responsible for extended shelf life of ripening banana fruits. Thus, present results confirm that 1-MCP can effectively prevent ethylene action in banana fruit.

The above results also suggest that there was no significant difference among different concentrations and durations of 1-MCP treatment on fresh weight, respiration and ethylene evolution during ripening of banana fruit.

Pulp-peel ratio: Pulp-peel ratio increased with advancement in fruit ripening in both the varieties under study (Table 5). In control, it was 1.467, 1.637, 1.87 and 2.057 in Robusta and 1.43, 1.633, 1.853 and 2.017 in Dwarf Cavendish at Stage 1, Stage 2, Stage 3 and Stage 4, respectively. 1-MCP treatment caused a decrease in pulp-peel ratio compared to control (1.47, 1.58, 1.77 and 1.98 in Robusta and 1.43, 1.56, 1.79 and 1.98 in Dwarf Cavendish at Stage 1, Stage 2, Stage 3 and Stage 4, respectively). However, this decrease was significant only at Stage 2 and Stage 3 and not at Stage 4. There was no significant difference between different concentrations and durations of 1-MCP treatment on pulp-peel ratio.

The ripening of banana fruit was accompanied by increase in pulp-peel ratio. Similar observations have been reported by Pathak (2003). Rise in pulp-peel ratio during fruit ripening was suggested to be due to change in sugar concentrations in the two tissues. A rapid increase in sugar concentration in pulp compared to peel leads to a change in osmotic pressure, as a result of which water is withdrawn from the peel and hence pulp-peel ratio increases accordingly. 1-MCP treatment reduced this increase in pulp-peel ratio leading to a delay in banana fruit ripening. Similar results were reported by Srivastava and Dwivedi (2000), who observed that pulp-peel ratio increased with the progress of ripening in banana.

Total soluble solids (TSS) %: TSS % increased with advancement in fruit ripening in both the varieties under study (Table 6). In control, it was 16.26, 23.34, 31.76 and 34.8 % in Robusta and 16.09, 23.16, 31.7 and 34.75 % in Dwarf Cavendish at Stage 1, Stage 2, Stage 3 and Stage 4, respectively. 1-MCP treatment caused a decrease in TSS % compared to control (16.26, 18.54, 28.4 and 34.9 in Robusta and 16.09, 18.73, 27.3 and 35.19 in Dwarf Cavendish at Stage 1, Stage 2, Stage 3 and Stage 4, respectively). However, this decrease was significant only at Stage 2 and Stage 3 and remained unchanged at Stage 4. There was no significant difference in TSS % among different concentrations and durations of 1-MCP treatment. As ripening progresses, TSS % of the ripening banana fruits recorded an increasing trend (Figure 6). This result supports the earlier findings (Grierson and Kadar, 1986). Increase in TSS % might be due to formation of soluble carbohydrates, organic acids and other substances.

CONCLUSION

Present investigation unequivocally suggests that 1-MCP treatment delays banana fruit ripening by approximately 68% in both the varieties under study. This delayed ripening was associated with reduction in

Table 5. Effect of 1-MCP treatment on pulp-peel ratio during banana fruit ripening.

		Robusta				Dwarf Cavendish			
		Stages				Stages			
Treatments	**Duration**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Control		1.467	1.637	1.870	2.057	1.430	1.633	1.853	2.017
1µl/l MCP	6h	1.467	1.570	1.737	2.007	1.430	1.533	1.767	1.973
	12h	1.467	1.560	1.780	1.993	1.430	1.547	1.757	1.980
5µl/l MCP	6h	1.467	1.593	1.800	1.973	1.430	1.587	1.770	2.003
	12h	1.467	1.567	1.763	1.977	1.430	1.530	1.763	1.963
10µl/l MCP	6h	1.467	1.603	1.777	1.967	1.430	1.557	1.763	1.980
	12h	1.467	1.600	1.757	1.970	1.430	1.553	1.747	1.987
Mean		1.47	1.58	1.77	1.98	1.43	1.56	1.79	1.98
CD at 5%		NS	0.04	0.56	NS	NS	0.053	0.036	NS

Table 6. Effect of 1-MCP treatment on Total Soluble Solids (TSS) (%) during banana fruit ripening.

		Robusta				Dwarf Cavendish			
		Stages				Stages			
Treatments	**Duration**	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
Control		16.26	23.34	31.76	34.80	16.09	23.16	31.7	34.75
1µl/l MCP	6h	16.26	18.31	27.9	35.01	16.09	17.45	27.49	34.4
	12h	16.26	17.53	26.5	34.77	16.09	18.32	27.59	34.42
5µl/l MCP	6h	16.26	18.71	27.7	35.42	16.09	19.84	27.54	34.14
	12h	16.26	19.15	29.31	34.81	16.09	18.75	25.59	34.69
10µl/l MCP	6h	16.26	19.02	28.79	34.43	16.09	18.69	28.06	34.73
	12h	16.26	18.55	30.12	35.02	16.09	19.35	27.72	35.15
Mean		16.26	18.54	28.4	34.9	16.09	18.73	27.3	35.19
CD at 5%		NS	1.81	1.87	NS	NS	1.91	1.41	NS

fresh weight, respiration rate, ethylene evolution, pulp-peel ratio and TSS%. 1-MCP treatment did not affect the climacteric peak of respiration and ethylene evolution. However, there was substantial reduction in rate of respiration and ethylene evolution in treated fruits as ripening stages were substantially delayed. There was no significant difference among different concentrations and durations of 1-MCP treatment viz. 1 µl/l 1-MCP for 6 hrs, 1 µl/l 1-MCP for 12 hrs, 5 µl/l 1-MCP for 6 hrs, 5 µl/l 1-MCP for 12 hrs, 10 µl/l 1-MCP for 6 hrs and 10 µl/l 1-MCP for 12 hrs. Hence, 1 µl/l 1-MCP for 6 hrs appears to be the best combination for delaying banana fruit ripening.

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