RESPONSE OF 1-METHYLCYCLOPROPENE TREATED "GRANNY SMITH" APPLE FRUIT TO AIR AND CONTROLLED ATMOSPHERE STORAGE CONDITIONS

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ABSTRACT

In the study, the efficacy of 1-Methylcyclopropene (1-MCP) on the quality of apples cv. "Granny Smith" was examined. Fruits were stored for 120 and 180 days at 0 ± 0.5C and 90 ± 5% relative humidity (RH) under normal (NA) and controlled atmosphere (CA), and samples taken at 120 and 180 days of storage were kept at 20 ± 2C and 60 ± 5% RH for 7 days. Weight loss was higher in fruits stored under NA. The lowest respiration rates were in CA while the highest rates were found in NA-stored fruits without pretreated. 1-MCP + CA reduced the internal ethylene concentration from 10.63 μL/L to 0.60 μL. The incidence and severity of superficial scald was 68.10 and 77.00% in fruits stored in NA. 1-MCP consistently suppressed the expression of superficial scald. 1-MCP maintained the quality fruit kept in CA and NA environments to a higher degree than nontreated apples over a 180-day storage period. The results indicated that cv. "Granny Smith" could be stored successfully under 1-MCP + CA conditions and that 1-MCP + NA may be a viable alternative to CA for optimal eating quality.

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PRACTICAL APPLICATIONS

1-Methylcyclopropene (1-MCP) is an effective inhibitor of ethylene action and it binds irreversibly to ethylene receptors. 1-MCP delays the onset of the climacteric ripening of fruits. Recently research has been conducted on the effects of 1-MCP on postharvest behavior of fruits and vegetables with the objective of reducing physiological disorders and quality losses to prolong their commercial life. The use of 1-MCP is easy. It is important that the fruit treated with 1-MCP reach a good sensory quality at the commercial level. Superficial scald of apples is a physiological disorder, which following long-term storage has the potential to destroy the market value and utility of millions of tons of fresh apples annually. The present work evaluated a prestorage conditioning treatment to protect against this physiological disorder. Results will allow the long storage of apple cv. "Granny Smith," benefiting growers, exporters, shippers and distributors of this horticultural product.

INTRODUCTION

Superficial scald is a physiological disorder. Disorder has the potential to destroy the market value and utility of millions of tons of fresh apples annually (Wang and Dilley 1999). Scald can be induced by the conjugated triene product of α-farnesene oxidation (Whitaker *et al.* 1997). The concentration and time of appearance of these products is related to the severity of the disorder (Wang and Dilley 2000).

The postharvest gaseous application of 1-methylcyclopropene (1-MCP) has been shown to improve many physiological characteristics of different apple cultivars, such as reduced ethylene production and respiration (Weis and Bramlage 2002; Saftner *et al.* 2003), enhanced fruit firmness and acidity retention (Johnson 2003; Saftner *et al.* 2003; Zanella 2003), and reduced superficial scald development, peel greasiness, and various chilling-related disorders (Fan *et al.* 1999b; Deell *et al.* 2002; Bai *et al.* 2005). The efficacy of 1-MCP on apples is influenced by cultivar and storage conditions (Watkins *et al.* 2000), as well as treatment temperature and duration (Deell *et al.* 2002). Low temperature and low oxygen (0.5–3%) and/or high CO_2 (3%) can reduce ethylene production and loss of quality (Gorney and Kader 1996; Fan *et al.* 1999a). Effect of combining 1-MCP treatment and controlled atmosphere (CA) are greater than in air storage (Ghahramani and Scott 1998; Watkins *et al.* 2000; Weis and Bramlage 2002). For many cultivars, treatment with 1-MCP is most effective when fruit are harvested at CA maturity and 1-MCP is applied as soon as after harvest. On the other hand, in some cultivars there are reports of injury developing related to 1-MCP (Mattheis *et al.* 2001). Mattheis *et al.* (2001) reported that there appears to be CO_2 injury in 1-MCP-treated Braeburn and Golden Delicious apples after storage. Another way to reduce the risk of CO_2 injury is to maintain low CO_2 levels during the first 4 weeks in sensitive varieties (Watkins and Rosenberger 2002).

The aim of the present study was to evaluate the combined effect of 1-MCP and atmosphere composition on the quality, superficial scald and internal ethylene concentration of apples cv. "Granny Smith." For this purpose, in the research was investigated the efficacy of 1-MCP in ultra low oxygen and low carbon dioxide conditions.

MATERIALS AND METHODS

Fruit Source

The fruits were harvested from 9-year-old trees grafted on MM106 rootstocks in the Research and Application Orchard of Department of Horticulture, Uludag University in 2003. Fruits of "Granny Smith" were harvested at optimum maturity for long-term CA storage on 4 Nov. The firmness (kg), total soluble solids (TSS) (%) and starch (on a 1–6 scale) means ± standard deviation ($n = 20$) at harvest were 9.60 ± 1.41, 15.73 ± 1.62 and 2.0 ± 0.1, respectively. After harvest, the fruits were immediately transported to the laboratory. Fruits were sorted for uniform size and maturity, without wounds or rots. Totally 720 fruits were used, being 60 fruits in each replicate.

1-MCP Treatments

1-MCP (AgroFresh Inc./Rohm and Haas Company, Philadelphia, PA) was applied within a few hours after harvest. 1-MCP (EthylBloc, Bio-Technologies for Horticulture, Walterboro, SC, 0.14% active ingredient) were weighed into test jar to obtain final gas concentrations of 625 ppb. 1-MCP was dissolved in 5 mL of warm pure water (40C) directly in the container. Test jars were shaken and placed in each container and an airtight lid closed immediately. After 24 h at 25C 1-MCP treatment, the plastic containers were vented. Control fruit were kept under the same conditions without 1-MCP treatment.

Fruit Storage and Sampling

The 1-MCP treated and untreated fruits cv. "Granny Smith" was stored in plastic containers (sealed for CA, unsealed for normal atmosphere [NA]) in NA (control) (0.03% CO_2 + 21% O_2) or CA (1% CO_2 + 1% O_2) at 0 ± 0.5C and 90 ± 5% RH for 120 and 180 days (scald appears following long-term storage). Following storage periods, fruits were kept at 20 ± 2C and 60 ± 5% RH for 7 days, to allow ripening and the development of physiological disorders during shelf life. Analyses were conducted with the samples (15 fruit per replicate were sampled) taken during storage and at the end of shelf-life periods.

Control of the Atmosphere Combination

The atmosphere composition in plastic containers was controlled by using "BBG Goerz Metrowatt" recorder, "Servomex 1420" O_2 analyzer and "Servomex 1410" CO_2 analyzer. In case of atmospheric changes, atmosphere combinations were maintained through full automatic gas addition and/or CO_2 scrubbers (activated charcoal). Changes in CO_2 and O_2 rates in each plastic container were controlled at the deviation level of not more than 0.1–0.2%.

Assessment of Fruit Quality

Weight loss during storage and shelf life was determined by weighing samples before storage and at different sampling times during storage and shelf life on a Sartorius precision balance (0.01 g precision) (Sartorius Co., Göttingen, Germany).

Changes in the respiration rate of the fruit were recorded from the day of harvest until the end of storage and shelf life. The rate was determined as $mgCO_2/kg/h$ using the Claypool and Keefer (1942) method based on CO_2 absorption.

TSS of fruits were determined using a NOW refractometer (0–32%) (Tech-Jam International Inc., Tokyo, Japan) at 20C.

Titratable acidity (TA) was titrated with 0.1 N NaOH to pH 8.1, and the results were expressed as percentage of malic acid (Cemeroglu 1992).

pH measurements of fruits were made by using NEL 890 brand (NEL Electronic, Istanbul, Turkey) pH meter.

Firmness of fruits was measured using 11-mm probe with an FT 327 penetrometer (Winopal Forschungsbedarf GmbH, Ahnsbeck, Germany) in each one of fruit.

For ethylene determination, 1 mL of gas was drawn into a hypodermic needle inserted into the core activity of each fruit and analyzed for internal ethylene concentration (IEC) using a Agilent 6,890 N gas chromatography (Agilent 1100, G1311A, VWR International, PA, Santa Clara, CA) fitted with a 1.6-m activated alumina column and a flame ionization detector as described by Larrigaudiere *et al.* (1996).

Incidence of superficial scald (ISS) was presented as the percentage of fruit per treatment with scald (Wang and Dilley 2000; Zanella 2003).

Determination of scald was made by the five trained panelists. Severity of superficial scald (SSS) was evaluated according to Wang and Dilley (2000) based on the fruit surface area affected, where no scald = 0, <25% = 1, 25–50% = 2 and >50% = 3. The severity of scald was normalized to 100 by multiplying the values by 100/3.

Rotten fruit caused by physiological and fungal diseases was reported as the rotten fruit per treatment. Number of rotten fruit was determined in comparison to the total number of fruits as a result of the measurements made during storage and shelf life period and the degree of rotten fruits was calculated as percentage.

Evaluations of overall appearance and taste were made by five panelists with respect to overall external appearance and quality scorings were conducted as 10–9, perfect; 8–7, good; 6–5, medium; 4–3, bad and 2–1, very bad. Panelists who carried out the sensory analyses were academic personnel of faculty of agriculture and they were trained about the evaluation criteria of apples. The temperature and relative humidity (RH) values for the evaluation areas were 22C and 55% RH. Illumination in these areas was 700 lux at the table surface. Samples, consisting of 15 apples per replicate, were blind labeled with random three-digit codes to avoid bias, and sample order was randomized to avoid artifacts due to order of presentation. For overall appearance, the panelists made the evaluation by considering the color of pedicel, fruit skin color, water loss and its reflection as shriveling and the defects caused by various pests and diseases. For taste, the panelists also considered the existence of an off-flavor or taste, nearby the natural taste, during evaluation.

Skin color (*L, a, b*) of apples was measured by two readings on the two different symmetrical faces of the fruit in each replicate, using a Minolta Chromameter CR-300 (Konica-Minolta, Osaka, Japan; light source: pulsed xenon lamp, port size: 229 × 91 × 60 mm, standard observer: closely matches CIE 1931 standard observer curves, measuring area: 50 mm, receptors: six silicon photocells [three to measure source illumination, three to measure reflected light] filtered to detect primary stimulus values for red, green, and blue light) colorimeter calibrated with a white standard tile.

The analyses were carried out three parallels in each replicate.

Statistical Analyses

A Randomized Plot Factorial Experimental Design with three replicates, consisting of 15 kg of fruit per replicate was used. The results analyzed using analysis of variance and the means were compared using the least significant difference (LSD) test ($P < 0.05$).

RESULTS AND DISCUSSION

Weight Loss

Increases in weight loss took place during NA and CA storage (Table 1). Greater weight losses were recorded in the apples stored under NA conditions compared to those stored with CA. However, CA delayed maturation and reduced changes in mass compared to those stored without CA. Atmosphere surrounding the fruits were a good barrier to moisture transfer. In this study, the lowest changes in weight loss (0.43 and 1.02%) were observed in 1-MCP + CA treatment in which disorders were retarded or even suppressed. Thus, weight loss and fruit rot proceeded at a slow rate due to the reduced water loss in these treatments. Moreover, there were significant differences ($P < 0.05$) between NA and CA. The significant differences between weight losses of fruit sealed in 1-MCP + CA indicated that their weight losses were related to treatments. So the positive effects of storage of fruits in sealed plastic cold chambers may be, in certain cases, a combination of its effects on the CO_2 and O_2 content within the fruit and the maintenance of high moisture content. Weis and Bramlage (2002), determined that 1-MCP treatment was effective on reducing the weight loss along the storage period in "McIntosh" and "Red chief Delicious" apples and also at room temperature in addition to the storage in apples. Also in our study, such an effect was determined at the end of storage and shelf life period.

Respiration Rate

The respiration rates of NA-stored (control) fruit were generally higher than those of the CA fruit. At the end of 120 days, there were no statistically significant differences in the respiration rates of the NA and CA treatments. However, there were significant differences between NA and CA at the end of shelf life. The lowest respiration rates at the end of storage (48.92 and 58.71 mgCO_2/kg/h) and shelf life period (38.64 and 46.27 mgCO_2/kg/h) were in CA and 1-MCP + CA while the highest rates were recorded in NA-stored fruit that was not pre-treated (Tables 1 and 2). In the storage period, there were no significant differences between CA and 1-MCP + CA. CA storage reduced the respiratory activity of the fruit. This reduction is attributed to high level of CO_2 concentration in the cabinets. Lower respiration rates are indicative of the retention of fruit quality and the prevention of detrimental internal changes in the fruit. Cool and CA storage of fruit retards respiration and ripening, changes in texture and moisture loss. Saftner *et al.* (2003) found that 1-MCP treatment and CA storage were effective on the reduction of respiration rate in "Golden Delicious" apples.

TABLE 1.
PHYSICAL AND CHEMICAL CHANGES DETERMINED DURING STORAGE OF APPLE CV. "GRANNY SMITH" TREATED WITH 1-MCP

Storage period (day)	Treatment 1	Treatment 2	Weight loss (%)	Respiration rate (mgCO_2/kg/h)	Total soluble solids (%)	Titratable acidity (%)	pH	Firmness (kg)	Overall appearance	Taste
0	NA	No 1-MCP	0.00e*	103.71a	15.73ab	0.83a	3.10b	9.60a	10.00a	10.00a
120	NA	1-MCP	1.63bc	99.44a	15.07ab	0.75ab	3.34a	7.20c	8.00d	7.30cd
		No 1-MCP	1.09cd	99.85a	15.33ab	0.65bc	3.30a	5.60d	8.00d	6.77de
	CA	1-MCP	0.28e	94.13a	15.73ab	0.72ab	3.32a	7.40c	9.00b	8.67b
		No 1-MCP	0.43e	108.94a	14.93ab	0.65bc	3.36a	7.50bc	9.00b	8.22b
180	NA	1-MCP	2.25a	78.58ab	14.67ab	0.82a	3.33a	7.70bc	7.67d	6.17ef
		No 1-MCP	2.17ab	78.97ab	15.83a	0.56c	3.33a	5.80d	7.00e	5.83f
	CA	1-MCP	0.43e	48.92c	15.60ab	0.81a	3.28a	8.20b	8.67cd	7.99bc
		No 1-MCP	0.53de	58.71bc	14.33b	0.74ab	3.36a	7.90bc	8.00d	6.83de
LSD			0.58	27.26	1.28	0.13	0.12	1.56	0.63	0.72

* Different letters in the same column indicate significant differences LSD ($P < 0.05$).
1-MCP, 1-methylcyclopropene; CA, controlled atmosphere; LSD, least significant difference; NA, normal atmosphere.

TABLE 2.
PHYSICAL AND CHEMICAL CHANGES DETERMINED DURING SHELF LIFE OF APPLE CV. "GRANNY SMITH" TREATED WITH 1-MCP

Storage period (day)	Treatment 1	Treatment 2	Weight loss (%)	Respiration rate ($mgCO_2$/kg/h)	Total soluble solids (%)	Titratable acidity (%)	pH	Firmness (kg)	Overall appearance	Taste
0	NA	No 1-MCP	0.00b*	103.71a	15.73a	0.83a	3.10b	9.60a	10.00a	10.00a
120 + 7	NA	1-MCP	2.47ab	79.43b	15.07ab	0.74ab	3.26a	7.00c	7.00cd	7.33cd
		No 1-MCP	2.02b	102.38a	14.93ab	0.62bc	3.30a	4.80d	6.33d	6.67d
	CA	1-MCP	0.99c	41.62f	15.07ab	0.70ab	3.29a	6.90c	8.67b	8.53b
		No 1-MCP	2.35ab	77.33b	14.33b	0.65bc	3.35a	6.80c	8.67b	7.67c
180 + 7	NA	1-MCP	2.84a	68.80c	14.47b	0.63bc	3.30a	8.20b	6.67d	6.67d
		No 1-MCP	2.97a	54.90d	14.53b	0.52c	3.36a	5.30d	4.33e	4.50e
	CA	1-MCP	1.02c	46.27e	14.93ab	0.66bc	3.27a	8.40b	8.50b	7.67c
		No 1-MCP	1.09c	38.64g	15.07ab	0.70ab	3.31a	7.90b	7.67c	7.17cd
LSD			0.15	25.56	1.31	0.18	0.11	1.54	0.84	0.81

* Different letters in the same column indicate significant differences LSD ($P < 0.05$).
1-MCP, 1-methylcyclopropene; CA, controlled atmosphere; LSD, least significant difference; NA, normal atmosphere.

TSS

When the TSS of fruits was examined at the level of treatments and storage period, the differences noted was determined to be insignificant statistically. 1-MCP treatments were found ineffective on the changes in TSS (Tables 1 and 2). These results are similar to those of a study conducted by Rupasinghe *et al.* (2000), Deell *et al.* (2002) and Zanella (2003) on 1-MCP.

TA and pH

In our study, reductions were observed in TA values during storage and shelf life (Tables 1 and 2). Acidity decrease was greater in the sweet cherries stored under NA conditions, than those stored under CA. The lowest TA values (0.56 and 0.52 %) in NA-stored apples were found in the fruits, which were put directly into NA without any pretreatment. The reduced TA was the result of the acids being involved in physiological processes such as respiration. This is another important factor with regard to the treatments, especially in terms of slowing the loss of fruit quality. With these methods, changes in fruit quality during storage could be kept within certain limits, since sugar accumulation was stable and loss of TA was retarded in the fruit stored under the CA. In previous studies, results were ambiguous as to the effects of 1-MCP on acid retention (Mattheis *et al.* 2001; Johnson 2003; Saftner *et al.* 2003; Zanella 2003). Similarly in the present study, the treatments with 1-MCP maintained the TA values of apples at higher levels under both ambient conditions (NA and CA), especially during storage. This situation persisted until 120 + 7, whereas such a marked effect could not be determined on 180 + 7 day in CA, as in the case of respiration rate. This is accordance with the recommendations of Mattheis *et al.* (2001) toward the repetition of 1-MCP treatments in long-term storage for the continuity of effectiveness. Nevertheless, TA values in CA were higher than those obtained in NA, even on 180 + 7 day.

The pH values of treatments increased during storage and shelf life. These time-dependent increases were found to be significant, whereas the differences between treatments were found insignificant. 1-MCP treatments were determined to be ineffective on the changes in pH. These results are similar to those of study conducted by Bai *et al.* (2005).

Firmness

1-MCP and/or CA storage retarded the loss of firmness, compared with the NA. Fruit treated with 1-MCP, regardless of storage atmosphere, remained firmer at the end of shelf life. The lowest and the highest firmness values at the end of the storage and shelf life were obtained from NA and 1-MCP + CA, respectively. The differences determined between these two treatments, and even between NA treatment and the other treatments were determined to be also statistically significant. 1-MCP were determined to have a positive effect toward the maintenance of firmness in the previous studies (Rupasinghe *et al.* 2000; Mattheis *et al.* 2001; Johnson 2003; Saftner *et al.* 2003; Zanella 2003). The results obtained from 1-MCP especially in NA during shelf life as well as during storage in our study are completely in accordance with the studies above.

Internal Ethylene Concentration

The efficacy of 1-MCP on IEC was especially notable under NA conditions (Fig. 1). The highest IEC values were determined in NA, whereas 1-MCP + NA maintained the IEC values at the initial levels. This efficacy of 1-MCP on IEC continued also during shelf life. The differences between NA in which the highest IEC was obtained at the end of the storage and the other three treatments were determined to be significant statistically. The positive effect of 1-MCP on the suppression of IEC is similar to the results of the studies made by Rupasinghe *et al.* (2000), Mattheis *et al.* (2001), Weis and Bramlage (2002) and Saftner *et al.* (2003). Furthermore, the most effective treatment on the suppression of IEC at the end of the shelf life (180 + 7 day) was determined as 1-MCP + CA combination, in our study. This result is in accordance with those determined by Watkins *et al.* (2000), Mattheis *et al.* (2001), Weis and Bramlage (2002).

1-MCP blocks the ethylene receptors, and consequently prevents the effects of ethylene. Therefore, reduced ethylene synthesis and accumulation in fruit tissues would be an expected response to proper 1-MCP treatment and this has been confirmed for apple cultivars under various storage conditions (Fan *et al.* 1999a; Rupasinghe *et al.* 2000; Fan and Mattheis 2001; Deell *et al.* 2005a,b).

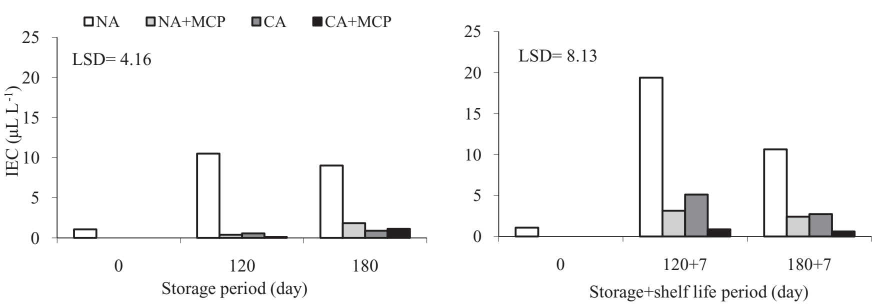

FIG. 1. CHANGES IN THE INTERNAL ETHYLENE CONCENTRATION (IEC) (µL L^{-1}) DURING STORAGE AND SHELF LIFE OF CV. "GRANNY SMITH" TREATED WITH 1-METHYLCYCLOPROPENE (1-MCP)

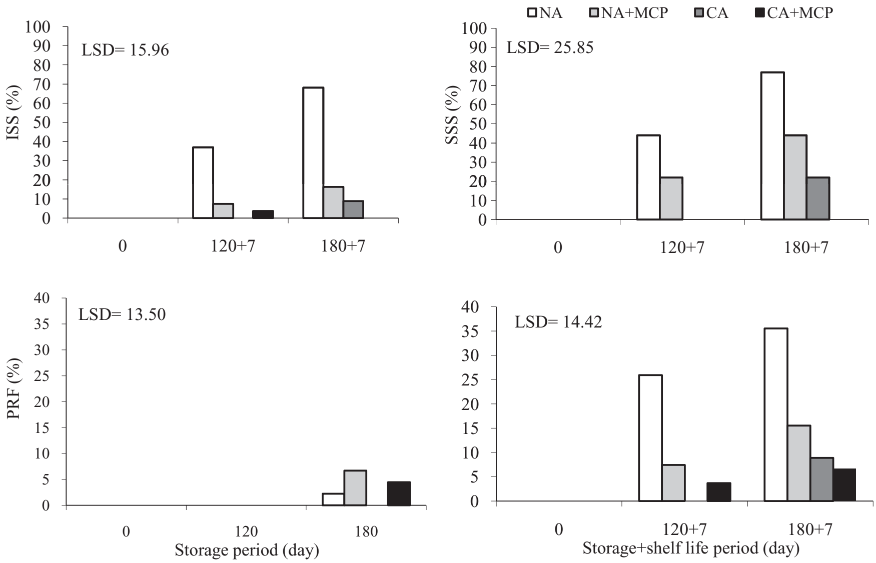

FIG. 2. CHANGES IN THE INCIDENCE OF SUPERFICIAL SCALD (ISS) (%), SEVERITY OF SUPERFICIAL SCALD (SSS) (%) AND PERCENTAGE OF ROTTEN FRUIT (PRF) DURING STORAGE AND SHELF LIFE OF CV. "GRANNY SMITH" TREATED WITH 1-METHYLCYCLOPROPENE (1-MCP)

ISS and SSS

ISS was not encountered in anyone of the treatments during storage (Fig. 2). However, high ratios of superficial scald were determined especially in the fruits stored in NA during shelf life. 1-MCP + CA treatment controlled the incidence of superficial scald very effectively. Similar situation was also encountered during the control of SSS. Significant increases were found in the SSS especially under NA conditions with or without 1-MCP during shelf life, with the prolonging storage. The SSS was effectively controlled in 1-MCP + CA, as well as its incidence. The positive effect of 1-MCP on the ISS and SSS was more pronounced under NA. The same positive effect was also noted under CA, though at lower levels. One of the positive results obtained in the studies carried out with different apple cultivars on the efficacy of 1-MCP is the reduction in the ISS and SSS (Watkins *et al.* 2000; Deell *et al.* 2002; Johnson 2003; Shaham *et al.* 2003; Zanella 2003).

Percentage of Rotten Fruit

1-MCP treatments led to increase in percentage of rotten fruit (PRF) under both ambient conditions during storage. 1-MCP treatments maintained the PRF in 1-MCP + NA at quite lower levels compared with NA alone at the end of shelf life. Nevertheless, PRF determined in 1-MCP + NA was observed to be higher compared with CA (Fig. 2). This situation is similar to the results of Mattheis *et al.* (2001). Researchers determined deteriorations in "Golden Delicious" apples depending on the CO_2 injury in 1-MCP + CA (2% CO_2 + 1% O_2). In this connection, storage under 1% CO_2 + 1% O_2 following the 1-MCP treatment was realized in our study, considering the recommendation toward determining lower application rates of 1-MCP and/or lower CO_2 concentration for storage. In addition, lower PRF was determined in 1-MCP treatments (1-MCP + NA and 1-MCP + CA) at 180 + 7 days while no brown heart injury caused by CO_2 damage was encountered under these conditions. Nevertheless, further studies are needed in which the combinations of CA conditions with different 1-MCP ratios are investigated, in order to clarify the relatively high PRF determined in 1-MCP treatments at the end of the storage, though not at significant levels.

Overall Appearance and Taste

Declines were observed in the overall appearance values with the prolonging storage period (Table 1). Declines became more pronounced especially in NA (NA; 1-MCP + NA) during shelf life. Treatments with 1-MCP were determined to keep the overall appearance values at higher levels under both environment conditions (1-MCP + NA and 1-MCP + CA) at the end of storage and shelf life. CA treatments (CA and 1-MCP + CA) were noted to give better results compared with NA treatments (NA and 1-MCP + NA). The best appearance was obtained from 1-MCP + CA. These differences between CA and NA observed at the end of the storage and shelf life were significant statistically. This situation may be explained as a natural consequence of the positive effects of 1-MCP, such as the retardation of ripening due to the reduction in ethylene production and respiration rate, as well as the retention of TA, firmness and green color, and also the inhibition of superficial scald. Mattheis *et al.* (2001) determined that 1-MCP had a positive effect on the external appearance of apples by retarding the loss of chlorophyll and green color from the skin.

It was determined that the taste scores were maintained at higher levels in CA compared with NA (Table 2). Differences between treatments gained significance during shelf life, and taste scores were determined to exhibit a change parallel to the change in overall appearance. 1-MCP allowed obtaining higher taste scores during storage and shelf life of the apples. This situation can be considered as a consequence formed in relation to the retention of TA, nearby the inhibition of the reduction of sugars, which constitute the major part of TSS consumed, due to the decline in respiration rate caused by 1-MCP.

Fruit Skin Color

In the study, statistically insignificant reductions and increases were determined in the color contents (*L, a, b*) of apples. Reductions occurred in the brightness (*L*) values of skin color toward the end of storage and shelf life. The decline observed in NA was greater compared with the other treatments. Therefore, color change proceeded (became dark, low *L* value) more rapidly in apples subjected to NA, due to high O_2 and low CO_2 concentration especially at the end of storage. Similarly, declines and increases were also recorded in the green (*a*); and yellow (*b*) color, respectively. The treatment in which the loss of green color was highest was again determined in NA. 1-MCP + CA gave the best result with respect to color change (Fig. 3). Therefore, at the end of storage period, the fruit color of this treatment was very similar to the initial

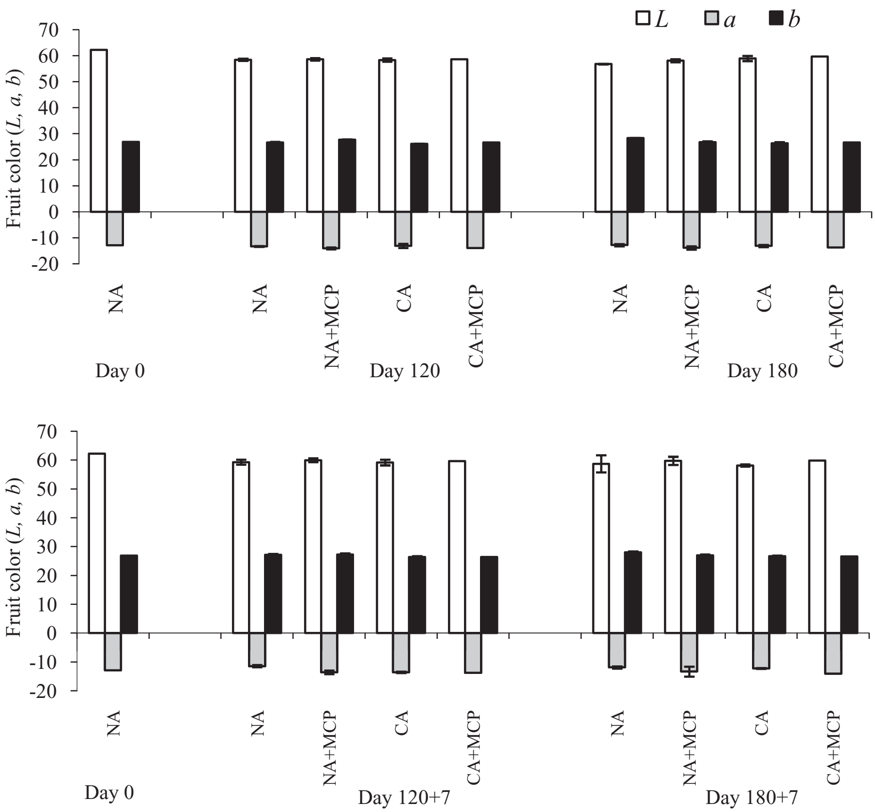

FIG. 3. CHANGES IN THE FRUIT SKIN COLOR (*L*, *a*, *b*) DURING STORAGE AND SHELF LIFE OF CV. "GRANNY SMITH" TREATED WITH 1-METHYLCYCLOPROPENE (1-MCP)

values. This situation that occurred due to the inhibition of chlorophyll loss in fruit skin is known to maintain the green color of the apples subjected to 1-MCP. This result that is desirable in "Granny Smith" apples and undesirable in "Golden Delicious" apples shows similarity to the reports of Mattheis *et al.* (2001), Johnson (2003) and Saftner *et al.* (2003).

CONCLUSION

This work demonstrates that 1-MCP treatment of "Granny Smith" apples effectively delay fruit ripening responses during storage, plus during a ripening period of 7 days at 20C. 1-MCP was determined to be effective on the minimization of weight loss and losses in TA and firmness, suppression of respiration rate and IEC. It was also determined that this treatment had quite positive effect on ISS and SSS in cv. "Granny Smith," a cultivar susceptible to superficial scald, and this effect increased with CA combination. 1-MCP maintained the quality on the fruits kept in CA and NA environments to a higher degree than nontreated apples over 180 days storage period. These results presented suggest that the storage under CA at low oxygen and carbon dioxide levels could be a valid alternative to chemical treatments against superficial scald development for the apples cv. "Granny Smith." Moreover, 1-MCP can have differential effects on apple quality and disorders, depending on storage conditions and storage period. Insignificant changes were determined in TSS, pH, PRF and fruit color rates of the apples. Therefore, detailed studies to be made in these parameters may be beneficial.

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