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Effect of atmospheric modification, 1-MCP and chemicals on quality of fresh-cut banana

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Abstract

Fresh-cut banana slices have a short shelf-life due to fast browning and softening after processing. The effects of atmospheric modification, exposure to 1-MCP, and chemical dips on the quality of fresh-cut bananas were determined. Low levels of O_2 (2 and 4 kPa) and high levels of CO_2 (5 and 10 kPa), alone or in combination, did not prevent browning and softening of fresh-cut banana slices. Softening and respiration rates were decreased in response to 1-MCP treatment (1 μL L^{-1} for 6 h at 14 °C) of fresh-cut banana slices (after processing), but their ethylene production and browning rates were not influenced. A 2-min dip in a mixture of 1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + 0.5% (w/v) cysteine effectively prevented browning and softening of the slices for 6 days at 5 °C. Dips in less than 0.5% cysteine promoted pinking of fresh-cut banana slices, while concentrations between 0.5 and 1.0% cysteine delayed browning and softening and extended the post-cutting life to 7 days at 5 °C.

Keywords: Browning; Chemical dips; Controlled atmosphere; Ethylene; Firmness; 1-Methylcyclopropene; Respiration

1. Introduction

The greatest hurdle to marketing of fresh-cut fruits is the relatively short shelf-life of those products due to tissue softening and browning. These detrimental changes can be delayed by effective cooling and maintenance of the cold chain throughout the preparation and subsequent handling steps of fresh-cut fruit products. However, fruits that exhibit fast browning upon wounding during processing have a short post-cutting life. For such products, modified atmosphere packing, chemical dips, ethylene scrubbing, and/or other procedures may be effective in extending their shelf-life.

Brown discolorations in foods are more complex than is suggested by the simple classification of these reactions as enzymatic or non-enzymatic, because of the large number of secondary reactions that may occur (Sapers, 1993). The use of antioxidants and chelating agents is one way of preventing browning (Verlinden and Nicolaï, 2000). Cysteine, ascorbic acid, calcium chloride, calcium lactate and citric acid have been reported to prevent the browning and softening of fresh-cut fruits and vegetables (Agar et al., 1999; Dong et al., 2000; Gorny et al., 1998, 2002; Gunes and Lee, 1997; Moline et al., 1999; Rosen and Kader, 1989).

Shelf-life of fresh and fresh-cut fruits may be extended by atmospheres reduced in O_2 and elevated in CO_2, by means of modified atmosphere packaging (Agar et al., 1999; Gorny, 1997; Kader, 1986; Verlinden and Nicolaï, 2000; Watada and Qi, 1999), that slow deterioration and reduce ethylene production and respiration rates.

Ethylene production is stimulated by physical actions used in the processing of fresh-cut bananas and the accumulated concentration is sufficient to have an effect on product quality (Abe and Watada, 1991). A recently developed inhibitor of ethylene action, 1-methylcyclopropene (1-MCP) has been shown to be effective in delaying the ripening of several pre-climacteric fruits (Golding et al., 1998; Kim et al., 2001; Serek et al., 1995; Sisler and Serek, 1997). If 1-MCP is effective in delaying the ripening of partially ripe (climacteric or post-climacteric) fruits, it would be useful in extending the shelf-life of fresh-cut fruits.

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The objectives of this study were to extend the shelf-life and maintain fresh-like quality of fresh-cut banana by using atmospheric modification, 1-MCP, and chemical dips containing cysteine, ascorbic acid and calcium chloride.

2. Material and methods

2.1. Material, slice preparation and storage

'Grand Nain' bananas at ripeness stage or color 4 (peel more yellow than green — Dole, 1998) were purchased from a local supermarket in Davis, CA. The bananas were dipped in chlorinated water (1.3 mM NaOCl), peeled and sliced with a sharp knife. From each banana, six slices (15 mm thick) were obtained. Ten slices, from 10 different bananas, per replicate were placed in a plastic container and three plastic containers were placed in 10 L jars ventilated with a flow of humidified air or a specified gas mixture. The CO_2 concentration in the air control jars was maintained below 0.3 kPa at a flow rate of 15 mL s^{-1}. The fresh-cut banana slices were prepared at 10 °C, then stored at 5 or 10 °C.

The effect of atmospheric modification was evaluated in two experiments, at 10 °C, with the following concentrations of gases: air (control), 2 kPa O_2, 4 kPa O_2, air + 5 kPa CO_2, air + 10 kPa CO_2, 2 kPa O_2 + 5 kPa CO_2, 2 kPa O_2 + 10 kPa CO_2, 4 kPa O_2 + 5 kPa CO_2 and 4 kPa O_2 + 10 kPa CO_2 (balance N_2). Two more experiments were carried out at 10 °C to evaluate the effect of different concentrations of 1-MCP (0.1, 0.3, 0.65 and 1.0 μL L^{-1}) applied for 6 h at 14 °C before (on intact fruit) or after (on slices) processing. In a fifth experiment, 1-MCP (1 μL L^{-1} for 6 h at 10 °C) was applied to fresh-cut banana slices before storage at 10 °C under a flow of 0, 2, or 20 μL L^{-1} ethylene in air. 1-MCP was applied by injecting a measured volume of a stock dilution into 10 L sealed glass jars. Concentrations of 1-MCP were calculated based on the free space volume of every jar and verified by flame ionization gas chromatography (model 211 Carle gas chromatograph, Anaheim, CA) using an isothermal separation (80 °C) on a 610 × 3.2 mm stainless steel column packed with 60–80-mesh Porapak Q (Supelco, Bellefonte, PA). Injector and detector temperatures were set at 80 °C and nitrogen at a flow rate of 0.42 mL s^{-1} was used as a carrier gas. Isobutylene was used as the standard gas to prepare the calibration curve. The source of 1-MCP was Agrofresh Inc. Two more experiments were carried out to examine the effect of a chemical dip [0.09 M (1% w/v) $CaCl_2$ + 0.056 M (1% w/v) ascorbic acid + 0.041 M (0.5% w/v) cysteine] for 2 min followed by storage in 2 kPa O_2 + 10 kPa CO_2 (balance N_2) and/or treatment with 1-MCP (1 μL L^{-1} for 6 h at 10 °C). In one of the last two mentioned experiments, the pH of the chemical dip (naturally about 2.5) was adjusted to 7 with NaOH. Slices just dipped in distilled water were used as control. The effect of cysteine concentration was tested in two additional experiments using a mixture of 0.09 M (1% w/v) $CaCl_2$ + 0.056 M (1% w/v) ascorbic acid + 0.008 M (0.1% w/v), 0.025 M (0.3% w/v), or 0.041 M (0.5% w/v) cysteine or 0.09 M (1% w/v) $CaCl_2$ + 0.056 M (1% w/v) ascorbic acid + 0.041 M (0.5% w/v), 0.061 M (0.75% w/v), or 0.082 M (1.0% w/v) cysteine. The pH of the chemical dip was naturally about 2.5. All experiments with chemical dips were carried out at 5 °C. The source of cysteine HCl was Ajinomoto Co. Inc., Tokyo. Ascorbic acid and calcium chloride were purchased from Sigma Chemical Co., St Louis, MO.

2.2. Firmness

Firmness of each slice was determined with a University of California Firmness Tester (Western Industrial Supply Co., San Francisco, CA) by measuring force required for a 3 mm probe to penetrate the cut surface on both sides to a depth of 5 mm.

2.3. Color

Color on opposite sides of each slice was measured with a Minolta Chromameter (Model CR-300, Minolta, Ramsey, NJ) in the CIE L^*a^*b mode.

2.4. Visual quality

The visual quality of each fresh-cut banana slice was determined based on a hedonic scale of 1 = inedible; 2 = limit of usability; 3 = limit of marketability; 4 = very good; 5 = excellent. The scores of 10 slices per replicate were given by three non-trained judges based on color, visible structural integrity and general visual appeal.

2.5. Ethylene production and respiration rate

A gas chromatograph (model 211 Carle Instruments, Anaheim, CA) with FID detector and alumina column was used to determine ethylene concentration and an infrared CO_2 analyzer (model PIR-2000R, Horiba Instruments, Irvine, CA) for CO_2 measurements in samples taken from the exit flow from each jar. Injector, detector and oven temperature of gas chromatograph were set at 80 °C and the carrier gas was nitrogen at 0.42 mL s^{-1}.

2.6. Statistical analysis

Three replicates per treatment and 10 slices per replicate were used in all experiments. Data were treated for multiple comparisons by analysis of variance with least significant difference (LSD) between averages determined at 5% level.

3. Results and discussion

3.1. Firmness

Fresh-cut banana slices softened with time in storage. Atmospheres of 2 kPa O_2, 4 kPa O_2, 5 kPa CO_2 and 10 kPa

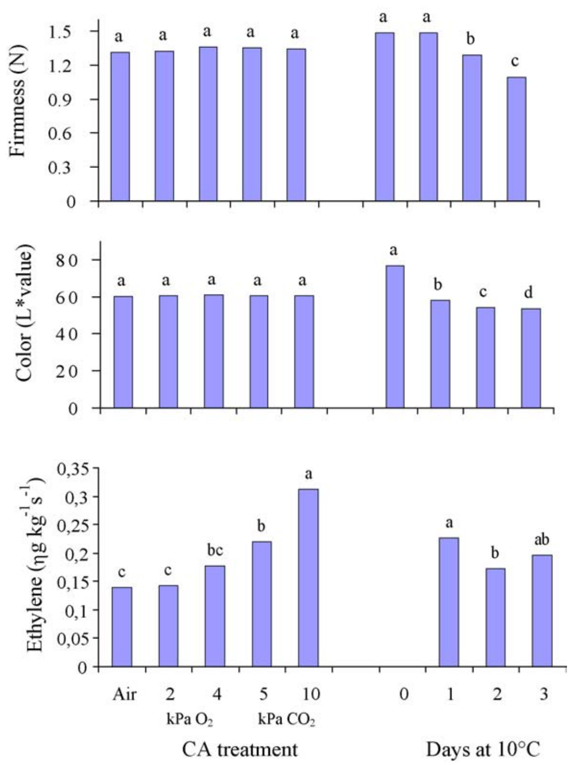

Fig. 1. Effect of controlled atmospheres (air, 2 and 4 kPa O_2 and 5 and 10 kPa CO_2) on firmness, color (L^* value) and ethylene production of fresh-cut bananas stored at 10 °C for 3 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

Table 1
Effect of controlled atmosphere and 1-MCP (applied at 14 °C for 6 h) on firmness and respiration rate (CO_2) of fresh-cut bananas stored at 10 °C

Treatment	Days at 10 °C			
	0	1	2	3
Firmness (N)				
Air control	1.49 a	1.52 a	1.40 a	1.12 b
2 kPa O_2 + 5 kPa CO_2	1.49 a	1.38 b	1.29 b	1.12 b
2 kPa O_2 + 10 kPa CO_2	1.49 a	1.34 b	1.26 b	1.14 ab
4 kPa O_2 + 5 kPa CO_2	1.49 a	1.31 b	1.34 ab	1.26 a
4 kPa O_2 + 10 kPa CO_2	1.49 a	1.45 a	1.28 b	1.11 b
Air control	1.51 a	1.40 a	1.10 a	1.01 a
2 $\mu L\,L^{-1}$ C_2H_4	1.51 a	0.87 c	0.91 c	0.87 b
20 $\mu L\,L^{-1}$ C_2H_4	1.51 a	0.92 c	0.81 d	0.87 b
2 $\mu L\,L^{-1}$ C_2H_4 + 1 $\mu L\,L^{-1}$ MCP	1.51 a	1.24 b	1.01 b	0.93 ab
20 $\mu L\,L^{-1}$ C_2H_4 + 1 $\mu L\,L^{-1}$ MCP	1.51 a	1.31 ab	0.96 bc	0.94 ab
CO_2 ($\mu g\,kg^{-1}\,s^{-1}$)				
Air control		16.88 b	6.59 a	
0.1 $\mu L\,L^{-1}$ MCP[a]		21.24 b	8.58 a	
0.3 $\mu L\,L^{-1}$ MCP[a]		18.74 b	7.38 a	
0.65 $\mu L\,L^{-1}$ MCP[a]		40.77 a	7.95 a	
1.0 $\mu L\,L^{-1}$ MCP[a]		43.10 a	7.33 a	

Values for each parameter followed by the same letter within columns (effect of treatment at each time) are not significantly different, $P < 0.05$.
[a] Applied on intact fruit.

CO_2 did not affect softening rate of fresh-cut banana slices stored for 3 days at 10 °C (Fig. 1). However, when low concentrations of O_2 (2 and 4 kPa) were combined with high concentrations of CO_2 (5 and 10 kPa) slice softening was slightly enhanced (Table 1). Similarly, Gorny et al. (2002) reported that low O_2 (0.25 or 0.5 kPa) and elevated CO_2 (5, 10 or 20 kPa) atmospheres alone did not effectively prevent softening of fresh-cut pear slices. On the other hand, Agar et al. (1999) found that kiwifruit slices exhibited delayed softening when stored in an ethylene-free atmosphere of 2–4 kPa O_2 and/or 5–10 kPa CO_2.

Exposure to 1 $\mu L\,L^{-1}$ 1-MCP for 6 h at 14 °C delayed the softening of fresh-cut banana slices stored for 3 days at 10 °C when applied after processing (Fig. 2). No effect of 1-MCP on the firmness of the slices stored for 2 days at 10 °C was noticed when it was applied on intact fruits, before peeling (Fig. 3), maybe because the time between the 1-MCP application and peeling was not enough to permit the permeation of the 1-MCP from peel to pulp. Therefore, if 1-MCP is used to slow down softening of fresh-cut banana slices, it should be applied at 1 $\mu L\,L^{-1}$, directly on the slices. Fresh-cut bananas tend to soften rapidly after cutting (Fig. 2). Mechanical wounding may promote an increase in ethylene production that can initiate physiological responses like softening related to cell wall degrading enzymes. Softening may be enhanced by the presence of ethylene at concentration as low as 0.1 $\mu L\,L^{-1}$

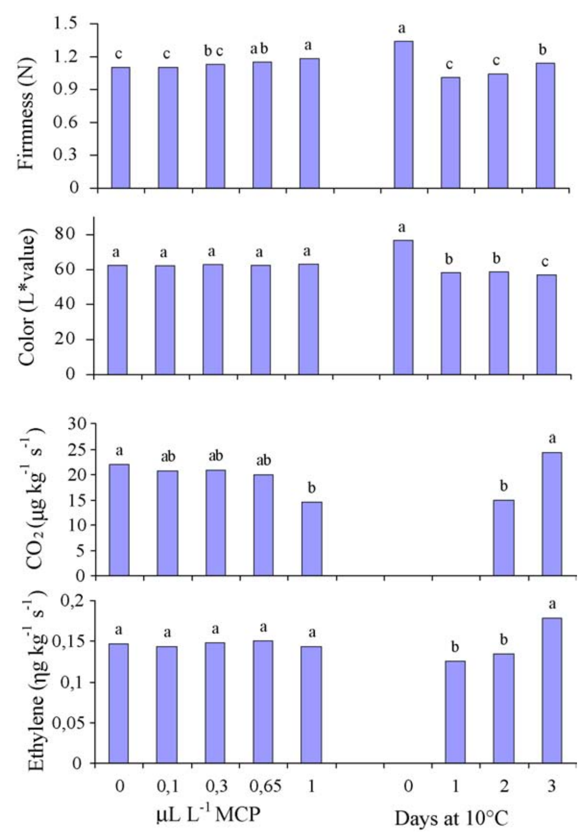

Fig. 2. Effect of 1-MCP concentration (applied on slices at 14 °C for 6 h) on firmness, color (L^* value), CO_2 and ethylene production of fresh-cut bananas stored at 10 °C for 3 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

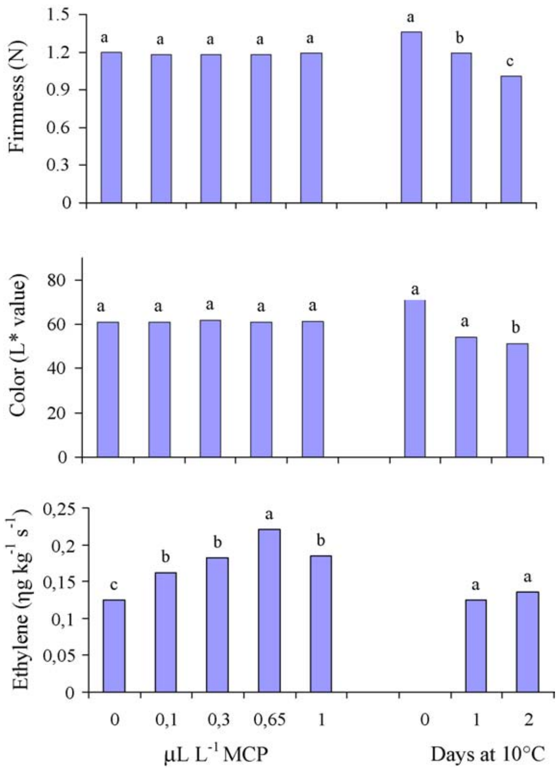

Fig. 3. Effect of 1-MCP concentration (applied on intact fruit at 14 °C for 6 h) on firmness, color (L^* value), and ethylene production of fresh-cut bananas stored at 10 °C for 2 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

Table 2
Effect of chemical dip [1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + 0.5% (w/v) cysteine], alone or combined with CA (2 kPa O_2 + 10 kPa CO_2) and 1-MCP (1 μL L^{-1} applied at 10 °C for 6 h) on firmness and color (L^* value) of fresh-cut bananas stored at 5 °C

Treatment	Days at 5 °C				
	0	2	4	5	7
Firmness (N)					
Control	1.45 a	0.69 b			
Dip (pH 2.5)	1.45 a	1.15 a	1.11 a		0.72 a
Dip + MCP	1.45 a	1.19 a	1.04 a		0.72 a
Dip + CA	1.45 a	1.17 a	1.08 a		0.67 a
Dip + MCP + CA	1.45 a	1.23 a	1.03 a		0.63 a
Control	1.31 a	0.65 b			
Dip (pH 7.0)	1.31 a	0.96 a		0.63 a	
Dip + MCP	1.31 a	0.94 a		0.62 a	
Dip + CA	1.31 a	0.94 a		0.64 a	
Dip + MCP + CA	1.31 a	0.97 a		0.63 a	
Color (L^* value)					
Control	80.94 a	61.34 b			
Dip (pH 2.5)	80.94 a	75.35 a	65.96 b		63.17 b
Dip + MCP	80.94 a	74.99 a	66.38 b		62.07 b
Dip + CA	80.94 a	75.89 a	71.41 a		66.36 a
Dip + MCP + CA	80.94 a	75.60 a	70.24 a		65.82 a
Control	75.62 a	48.07 b			
Dip (pH 7.0)	75.62 a	59.34 a		51.11 ab	
Dip + MCP	75.62 a	57.65 a		49.43 b	
Dip + CA	75.62 a	59.68 a		52.78 a	
Dip + MCP + CA	75.62 a	58.56 a		51.78 ab	

Values for each parameter followed by the same letter within columns (effect of treatment at each time) are not significantly different, $P < 0.05$.

that can occur within packages of fresh-cut fruit products and in the ambient atmosphere at distribution centers and retail stores. When 1-MCP (1 μL L^{-1}) was applied at 10 °C for 6 h on fresh-cut bananas before storage at 10 °C in air + 2 μL L^{-1} or 20 μL L^{-1} ethylene, it was effective in preventing the softening enhanced by ethylene (Table 1). Similarly, Abe and Watada (1991) observed that 2 or 20 μL L^{-1} ethylene hastened the softening of fresh-cut kiwifruits and bananas held at 20 °C. Use of ethylene absorbents prevented the accumulation of the ethylene and was effective in reducing the rate of softening in those fresh-cut fruits (Abe and Watada, 1991; Agar et al., 1999). Therefore, 1-MCP can be useful to prevent the softening and extend the shelf-life of fresh-cut bananas, considering the normal accumulation of ethylene into packages containing those products.

After 7 days of storage at 5 °C the firmness of banana slices treated with the chemical dip [1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + 0.5% (w/v) cysteine] was higher than that of control slices (dipped in distilled water) that lasted for less than 2 days (Table 2). Dips in $CaCl_2$ have been reported to retard softening of sliced fruits (Rosen and Kader, 1989; Agar et al., 1999). Combination of 1-MCP (1 μL L^{-1} for 6 h) treatment, CA (2 kPa O_2 + 10 kPa CO_2) or 1-MCP + CA with the chemical dip did not promote changes in the firmness of fresh-cut bananas beyond the chemical dip alone (Table 2). This may be due to the fact that we kept the slices under a dynamic system that prevented ethylene accumulation. In a static or closed system, as in a package, where ethylene is likely to accumulate, the efficacy of CA and 1-MCP in minimizing ethylene-induced softening could be demonstrated. Fresh-cut bananas treated with chemical dip pH 7 showed a shorter shelf-life in terms of firmness (Table 2). The 0.75% (w/v) and 1% (w/v) cysteine levels retained firmness better than the 0.5% level (Fig. 4). The lower levels of cysteine in mixtures with pH 7 were not effective in maintaining slice firmness (Table 3). Most enzymes, including cell wall associated enzymes during fruit softening, show maximum activities in the pH range 4.5–8.0. The chemical dip at pH 2.5

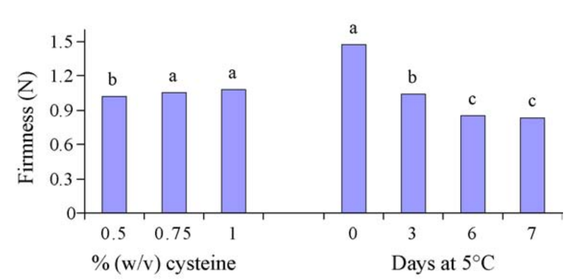

Fig. 4. Effect of cysteine concentration in a chemical dip of 1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid on firmness of fresh-cut bananas stored at 5 °C for 7 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

Table 3
Effect of chemical dip [1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + cysteine] at pH 2.5 or 7.0 on firmness and color (*L** value) of fresh-cut bananas stored at 5 °C

Treatment		Days at 5 °C					
Cys	pH	0	2	3	4	6	7
Firmness (N)							
0.1% 2.5	1.56 a	1.23 b	0.87 b				
0.3% 2.5	1.56 a	1.31 b	1.11 a	0.94 a	0.76 b		
0.5% 2.5	1.56 a	1.47 a	1.16 a	1.01 a	0.97 a		
0.1% 7.0	1.56 a	1.31 b	0.95 b				
0.3% 7.0	1.56 a	1.18 b	0.97 b	0.74 b	0.70 b		
0.5% 7.0	1.56 a	1.27 b	0.91 b	0.77 b	0.77 b		
Color (*L** value)							
0.1% 2.5	80.15 a	60.76 c	56.88 c				
0.3% 2.5	80.15 a	70.12 a	67.64 a	63.61 b	60.79 b		
0.5% 2.5	80.15 a	72.84 a	70.99 a	70.01 a	65.01 a		
0.1% 7.0	80.15 a	56.57 d	51.70 d				
0.3% 7.0	80.15 a	61.62 c	57.14 c	52.91 d	49.98 d		
0.5% 7.0	80.15 a	65.32 b	61.67 b	59.02 c	56.07 c		
Color (*L** value)							
0.5% 2.5	78.06 a		68.84 b		61.82 c	60.15 b	
0.75% 2.5	78.06 a		69.20 b		65.75 b	62.34 b	
1.0% 2.5	78.06 a		73.15 a		68.92 a	66.13 a	

Values for each parameter followed by the same letter within columns (effect of treatment in each time) are not significantly different, $P < 0.05$.

may have prevented or inhibited enzymic reactions associated to the softening of fresh-cut bananas. In contrast, Gorny et al. (2002) found that a mixture of 2% (w/v) ascorbic acid + 1% (w/v) calcium lactate + 0.5% (w/v) cysteine at pH 7 was more effective in preventing softening of fresh-cut pears than the same mixture at pH 3.7.

3.2. Visual quality

Color *L** value tends to decrease rapidly in association with browning of fresh-cut bananas during storage. CA, as well as 1-MCP, applied before or after processing, did not affect the *L** value of fresh-cut bananas stored at 10 °C for 3 days (Figs. 1, 2, 3, 5 and 6).

A 2-min chemical dip [1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + 0.5% (w/v) cysteine, pH 2.5 or 7.0] was extremely effective in delaying the browning and maintaining the visual quality of fresh-cut bananas stored at 5 °C; the best results were seen with the mixture at pH 2.5 (Tables 2–4). Combination of 1-MCP treatment, CA or 1-MCP + CA with the

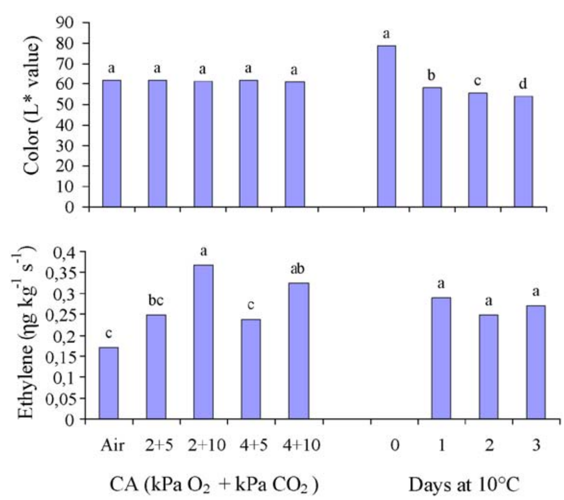

Fig. 5. Effect of controlled atmospheres on color (*L** value) and ethylene production of fresh-cut bananas stored at 10 °C for 3 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

Table 4
Visual quality scores of fresh-cut banana slices stored at 5 °C for 5 d

Days at 5 °C	Control		Chemical dip		Dip + MCP		Dip + CA		Dip + MCP + CA	
	pH 2.5	pH 7	pH 2.5	pH 7	pH 2.5	pH 7	pH 2.5	pH 7	pH 2.5	pH 7
0	5	5	5	5	5	5	5	5	5	5
1	1	1	4.5	4	4.5	4	4.5	4	4.5	4
2	–	–	4	3	4	3	4	3	4	3
3	–	–	4	2.5	4	2.5	4	2.5	4	2.5
4	–	–	3.5	2	3.5	2	3.5	2	3.5	2
5	–	–	2	1	2	1	2	1	2	1

1 = Inedible; 2 = limit of usability; 3 = limit of marketability; 4 = very good; 5 = excellent.

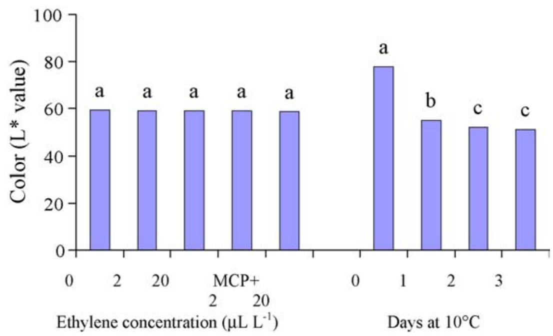

Fig. 6. Effect of 1-MCP (1 µL L^{-1} at 10 °C for 6 h) on color (*L** value) of fresh-cut bananas kept in air + 0, 2, or 20 µL L^{-1} ethylene at 10 °C for 3 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

chemical dip did not affect the visual quality of fresh-cut bananas in comparison with the chemical dip alone (Table 4), although CA combined with the chemical dip at pH 2.5 has determined higher *L** value from the fourth day (Table 2). In some cases, the chemical dip at pH 7 promoted a pink color in the fresh-cut surface, especially in the areas of the vascular system. Levels of cysteine below 0.5% and pH 7 were related with a higher incidence of pinking (Table 5). In contrast, 1% (w/v) cysteine was effective in inhibiting the pinking for 7 day at 5 °C (Table 5). The higher levels of cysteine and lower pH resulted in less browning (higher *L** value) and better visual quality (Tables 3–5). Richard-Forget et al. (1992) reported that when cysteine is used as an inhibitor of enzymatic browning, pinkish-red colored compounds are formed due to phenol regeneration with deep color formation. Gorny et al. (2002) found that a mixture of 2% (w/v) ascorbic acid + 1% (w/v) calcium lactate + 0.5% (w/v) cysteine at pH 3.7 significantly reduced darkening of pear slices for up to 4 days at 0 °C. However, after 4 days the mixture or 0.5% cysteine alone resulted in the formation of undesirable pinkish-red pigments. Contrary to our results they observed that the pinking was inhibited by increasing the pH of the solutions to 7. Moline et al. (1999) found that a mixture of 0.5 M citric acid and 0.05 M N-acetylcysteine provided the best protection against browning (smallest change in *L** value) of fresh-cut banana slices kept at 5 and 15 °C for 1 week.

3.3. Ethylene production

Ethylene production rates were not affected by low O_2 (2 and 4 kPa), but were stimulated by 5 and 10 kPa CO_2 enriched air or 10 kPa CO_2 with 2 or 4 kPa O_2 in fresh-cut banana slices stored for 3 days at 10 °C (Figs. 1 and 5). Similarly, Liu et al. (2004) observed that the magnitude of ethylene climacteric peak in bananas stored under 60% CO_2 + air was 2–3 times higher than that of the fruit stored under regular atmosphere. Conversely, Agar et al. (1999) observed that low levels of O_2 (2 and 4 kPa) and high levels of CO_2 (5 and 10 kPa) decreased ethylene production by fresh-cut kiwifruits.

Ethylene production of fresh-cut banana slices exposed to different doses of 1-MCP increased at third day. However, exposure of fresh-cut banana slices to 1-MCP did not affect their ethylene production during storage at 10 °C; some effect was observed when 1-MCP was applied on intact fruits, before processing (Figs. 2 and 3). Even as low as 0.1 µL L^{-1} 1-MCP (applied on intact fruits) increased the ethylene production of the slices. Similarly, 1-MCP has been observed

Table 5
Visual quality and pinking scores of fresh-cut banana slices stored at 5 °C for 7 days

Days at 5 °C	Cysteine concentration							
	0.1%		0.3%		0.5%		0.75%	1%
	pH 2.5	pH 7	pH 2.5	pH 7	pH 2.5	pH 7	pH 2.5	pH 2.5
Visual quality score								
0	5	5	5	5	5	5	5	5
1	3	1	4.5	3.5	5	4	5	5
2	2.3	–	4.2	2.3	5	3.7	5	5
3	1.2	–	3.2	1.5	4.3	3	4	4.5
4	–	–	2	1	3.5	1.3	3.5	4
5	–	–	1	–	3	–	3	3.5
6	–	–	–	–	2	–	2.5	3
7	–	–	–	–	1.3	–	2	2.5
Pinking score								
0	1	1	1	1	1	1	1	1
1	1	2	1	1	1	1	1	1
2	2	3	1	2	1	1	1	1
3	3	–	2	3	1	2	1	1
4	–	–	2	–	1	3	1	1
5	–	–	3	–	2	–	2	1
6	–	–	–	–	2	–	2	1
7	–	–	–	–	3	–	2	2

1 = Inedible; 2 = limit of usability; 3 = limit of marketability; 4 = very good; 5 = excellent.1 = no pinking; 2 = slight pinking; 3 = severe pinking.

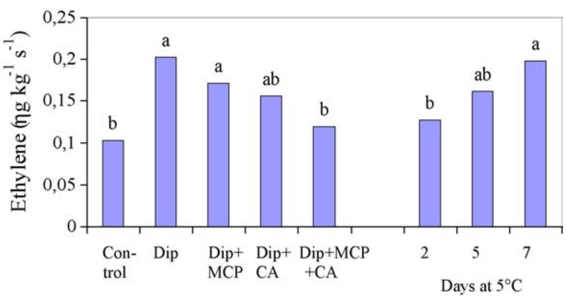

Fig. 7. Effect of chemical dip [1% (w/v) $CaCl_2$ + 1% (w/v) ascorbic acid + 0.5% (w/v) cysteine, pH 2.5] combined with 1-MCP (1 $\mu L\,L^{-1}$ at 10 °C for 6 h) and/or CA (2 kPa O_2 + 10 kPa CO_2) on ethylene production of fresh-cut bananas stored at 5 °C for 7 days. Data shown in the left set of histograms are the means of all times and in the right set, means of all treatments.

stimulating ethylene production in intact bananas (Golding et al., 1999; Pelayo et al., 2003). Golding et al. (1999) speculated that 1-MCP may block the normal feedback regulation of ethylene production and presumably the translation of ACC synthase may be enhanced or the malonylation of its substrate ACC may be prevented. That speculation can be used to explain the effect of high CO_2 magnifying the ethylene production, since CO_2, as 1-MCP, may prevent the effect of ethylene.

Fresh-cut banana slices treated with the chemical dip showed a higher ethylene production rate than control and MCP + CA were effective in inhibiting that increase during storage at 5 °C (Fig. 7). Ethylene production is stimulated when plant tissues are injured and it can accumulate in packages of fresh-cut product, which can lead to undesirable effects (Watada and Qi, 1999).

3.4. Respiration rate

Exposure to 1-MCP at 1 $\mu L\,L^{-1}$ decreased the respiration rate of fresh-cut bananas when applied to the slices (Fig. 2) while 0.65 and 1 $\mu L\,L^{-1}$ applied to intact fruits increased the respiration rate, although just during the first day of storage (Table 1). Decreased respiration rate has been observed in sliced bananas treated with ethylene absorbent (Abe and Watada, 1991).

4. Conclusions

Low O_2 (2 and 4 kPa) and elevated CO_2 (5 and 10 kPa), alone or in combination did not prevent browning and softening of fresh-cut banana slices. Treatment with 1-MCP (1 $\mu L\,L^{-1}$ for 6 h at 14 °C) after processing, slowed softening and decreased the respiration rate, but did not affect ethylene production and browning of fresh-cut bananas. A 2-min dip in a mixture of 1% (w/v) $CaCl_2$, 1% (w/v) ascorbic acid and 0.5% (w/v) cysteine effectively retarded browning and softening of the slices for 6 days at 5 °C. Dips including less than 0.5% (w/v) cysteine promoted pinking in the banana slices. Higher cysteine concentrations delayed browning and softening and maintained higher visual quality for 7 days at 5 °C.

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