Maintaining Quality of Fresh-Cut Mangoes Using Antibrowning Agents and Modified Atmosphere Packaging

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Treatments to inhibit browning and decay and prolong shelf life of fresh-cut mangoes were investigated. Combinations of antibrowning agents and modified atmosphere packaging (MAP) resulted in a reduction of browning and deterioration of fresh-cut mangoes stored at 10 °C. Combinations of several browning inhibitors were more effective than those applied individually. Among these treatments, solutions containing 4-hexylresorcinol (0.001 M) (HR) plus potassium sorbate (0.05 M) (KS) and HR plus KS plus D-isoascorbic acid (0.5 M) (ER) reduced changes in color (*L**, *a**, and *b**) and microbial growth and did not affect sensory characteristics of fresh-cut mangoes. In general, these treatments did not affect significantly the changes in organic acids and sugar content of slices during the 14 days of storage at 10 °C. High humidity created in the in-package atmosphere alleviated tissue dryness and was an important factor in the ability of the antibrowning solutions to prevent browning and decay. It appears that the maintenance of quality of fresh-cut mangoes is more related to particular combinations of the antibrowning agents used rather than the modified atmosphere created inside the package. HR + ER + KS treatment in combination with MAP could be used to inhibit browning, decay, and deterioration of fresh-cut mangoes.

Keywords: *d-Isoascorbic acid; 4-hexylresorcinol; potassium sorbate; modified atmosphere packaging; Mangifera indica; shelf life; antibrowning agents*

INTRODUCTION

Postharvest losses of tropical fruits are a serious problem due to rapid deterioration during handling, transport, and storage (Yahia, 1998). The practice of fresh-cut processing aggravates the problem because of wounding, increased metabolic activities, and decompartmentalization of enzymes and substrates. This may cause browning, softening, decay, and off-flavor development (Watada et al., 1990; Varoquax and Wiley, 1994). These manipulations of tropical fruit result in increased rates of respiration and ethylene production within minutes (Abe and Watada, 1991) and may reduce the shelf life from 1−2 weeks to only 1−3 days even at optimal temperatures (Ahvenainen, 1996).

Fresh-cut fruits and vegetables generally are packaged in film bags or containers overwrapped with film, which creates a modified atmosphere within the package (MAP). Low storage temperature and MAP are extensively used to extend the shelf life of many intact and fresh-cut fruit and vegetables products because they reduce rates of respiration and cut surface deterioration and browning (Gorny, 1997; Thompson, 1998). Passive modification of the atmosphere created naturally by the product may retard browning and spoilage and maintain fresh appearance; however, extremely low oxygen (<1%) levels produced by inappropriate film selection can intensify flavor loss and off-flavor (Kader et al., 1989; Yahia, 1998; Thompson, 1998). Browning of apple slices occurred even at extremely low oxygen levels (Gorny, 1997). The effect of low oxygen levels on delaying browning and decay of fresh-cut mango is not known. Different controlled atmosphere and films used in MAP have been reported to be effective in maintaining quality of intact mango (Thompson, 1998). No results have been published on how atmospheric modification may affect the shelf life of fresh-cut mango.

Recently, the use of natural products has been found to be effective in reducing browning and decay of many fresh-cut fruits and vegetables (Ahvenainen, 1996). These antibrowning agents and their derivatives such as 4-hexylresorcinol (HR), *N*-acetylcysteine, ascorbic acid, isoascorbic acid, potassium sorbate, calcium chloride, and propionate, alone or in combination at different concentrations, have been found to be effective in retarding browning and decay of processed fruits and vegetables (Monsalve-Gonzalez et al., 1995; Kim and Klieber, 1997; Gunes and Lee, 1997; Buta et al., 1999; Buta and Abbott, 2000). There are no published data on the efficacy of such treatments on fresh-cut mangoes.

The objectives of our work were to evaluate (1) the effect of antibrowning agents alone or in combination to reduce decay and browning of fresh-cut mango; (2) the effect of passive atmosphere on quality attributes, chemical changes, and shelf life of mango slices; and (3) the effectiveness of the combination of antibrowning agents and MAP treatments in maintaining the quality of fresh-cut mango slices.

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Table 1. Solutions Used on Mango Slices, prior to Packaging and Storage at 10 °C[a]

treatment	concentration
1. control	water
2. HR	0.001 M
3. ER	0.5 M
4. KS	0.05 M
5. HR + KS	0.001 M + 0.05 M
6. HR + ER + KS	0.001 M + 0.5 M+ 0.05 M
7. ER + KS	0.5 M + 0.05 M
8. HR + KS	0.001 M + 0.05 M

[a] All solutions were adjusted to pH 5.6.

MATERIALS AND METHODS

Plant Material. Mangoes (*Mangifera indica* L.) cv. Kent obtained from a wholesale market near Jessup, MD, were used for this study. Fruit were sorted to eliminate damaged or defective fruit, cleaned, and washed in a 10% Clorox solution and dried. Fruit used for this experiment initially had a firmness of 35−40 N and soluble solids content of 11 °Brix. After disinfecting, fruit were manually sliced transversely (5 mm thick) with a commercial slicing machine model 827, Berkel Inc., and cut in rectangles (2 × 4 cm) with a sharp knife. After slicing, mixtures of antibrowning agents previously selected were applied.

Eight treatments were applied, which included D-isoascorbic acid (ER), a reducing agent; 4-hexylresorcinol (HR), a competitive inhibitor of polyphenol oxidase, and potassium sorbate (KS), an antimicrobial compound (Table 1).

Mango slices were dipped for 2 min in test solutions, drained, blotted dry with paper towels, and placed in a 1 L polystyrene plastic tray (eight slices/tray). Control samples were dipped in distilled water. Trays were thermoconglutinated with the Cryovac LDX-5406 film using a food pack machine (model FP Basic V/G, Ilpra, Italy). After sealing, 16 trays per treatment were stored at 10 °C for up to 14 days.

In-package concentrations of O_2, CO_2, and C_2H_4 were measured at 3-day intervals by withdrawing air samples (1 mL) through a septum using a hypodermic syringe. After 7 and 14 days of storage at 10 °C, samples (eight trays/treatment) were taken for evaluation of quality changes. Covering film was removed, and each treatment was evaluated subjectively for the development of off-flavor. Slices were then evaluated for color (L^*, a^*, and b^*), browning index, decay, area infected (percent), and number of colonies growing per slice. One wedge was cut from each slice, and all wedges from 30 slices from each treatment were juiced together for analysis of pH, soluble solids, and titratable acidity. After quality evaluation, four samples (2 g) were randomly taken from each treatment for analysis of organic acids and sugars. The experiment was repeated at least two times.

Atmosphere Composition. The changes of in-package O_2 and CO_2 concentrations were measured using an oxygen analyzer S-3A/I Ametek and a carbon dioxide analyzer CD-3A AEI-Technologies (Process and Analytical Instrument Division, Pittsburgh, PA), respectively. The accumulation of C_2H_4 in the package was analyzed using a Hatch Carle series 400 gas chromatograph with an FID detector.

Color. Tristimulus reflectance colorimetery was used to assess the extent of browning in mango slices (Saper and Douglas, 1987). The color of slices (L^*, a^*, and b^* values) was obtained from the center of each slice using a Minolta CR-300 chroma meter. Four replications (eight slices per replicate) were evaluated from each treatment. A decrease of L^* values indicated a loss of brightness, and a more positive a^* value indicated browning had occurred, whereas a more positive b^* indicated yellowing or discoloration. The color of slices was measured initially and after 14 days at 10 °C.

Decay and Browning Index. After color evaluation, slices from different treatments were evaluated subjectively for symptoms of decay and browning, using a hedonic scale where 0 = none, 1 = trace, 2 = slight, 3 = moderate, 4 = severe, and 5 = extemely severe. Numbers of colonies/slice/treatment were quantified and recorded. Percentage of area covered with fungal infections was evaluated subjectively on individual slices. Mean of total area infected/slice/treatment was calculated.

Sugars and Organic Acids. Two grams of tissue was homogenized with a Polytron homogenizer (Brinkmann Instruments, Westbury, NY) in imidazole buffer (20 mM, pH 7.0). The extracts were centrifuged, and the supernatants were dried in vacuo in derivatizing vials. Derivatization of sugars was carried out according to procedures described by Li and Schuhmann (1980). One microliter of the derivatized samples was injected for gas chromatographic separation and quantification. A Hewlett-Packard 5890 gas chromatograph equipped with a flame ionization detector was used. A known amount of β-phenyl-D-glucopyranoside was included in all samples as an internal standard. A 25 m cross-linked methyl silicon gum capillary column (0.2 mm i.d., 0.33 μm film thickness) was used. Chromatograph temperatures were as follows: injector, 250 °C; detector, 275 °C; and column, 100−250 °C programmed at 10 °C/min. Organic acids were analyzed after extraction with imidazole buffer and purification with a Baker-10 solid phase extraction system. Supernatants from the extracts were passed through quaternary amine columns that had been previously conditioned with hexane and methanol. The samples were then eluted from the columns with 0.1 N HCl. The eluates were concentrated to dryness in vacuo in derivatized vials. Procedures of derivatization and chromatography for organic acid were the same as those for sugars except that column temperatures were programmed from 180 to 250 °C at 10 °C/min. Separated sugars and organic acids were compared with the derivatized standards for qualitative and quantitative determinations. A Hewlett-Packard ChemStation was used to calibrate the peaks, record the data, and calculate the results.

RESULTS AND DISCUSSION

In-Package Atmosphere. Figure 1 showed the in-package (O_2 and CO_2) changes of fresh-cut mango under different treatments. Similar patterns in the reduction of oxygen and increase of carbon dioxide levels were observed in control, HR, HR + ER, and ER + KS treatments (Figure 1A,C,E,G). Oxygen levels decreased continuously in these treatments until concentrations of 4−5% O_2 were reached, whereas CO_2 levels increased more rapidly in control fruits and stabilized after 6 days of storage (Figure 1A). In ER, HR, HR + ER, and ER + KS treatments, CO_2 contents accumulated progressively, reaching slightly higher levels than those of the control at the end of the storage period. The behavior observed on HR, KS, HR + ER + KS, and HR + KS treatments was different (Figure 1B,D,F,H). In the HR and HR + ER + KS treatments the O_2 and CO_2 contents stabilized after 9 days of storage, reaching levels of 11−13 and 7−9%, respectively (Figure 1B,F). The changes in O_2 and CO_2 observed in the KS and HR + KS treatments are different from the others (Figure 1D,H). After 9 days at 10 °C, O_2 levels dropped and CO_2 levels increased in KS treatment, whereas no noticeable changes occurred in the HR + KS treatment. After 3 days of storage, ethylene accumulation (<1 ppm) was observed in packages of control, ER, and KS treatments (data not shown). There have been reports of low O_2 and elevated CO_2 acting synergistically to increase production of ethanol and acetaldehyde, which caused objectionable softening, browning, and development of off-flavor and off-odors in intact fruits and fresh-cut peaches and nectarines (Kader et al., 1989; Gorny et al., 1999). The modified atmospheres created in the packages of mango slices did not induce any noticeable increase of ethanol and acetaldehyde (data not shown). Previously, it had been observed that mango fruit was very tolerant

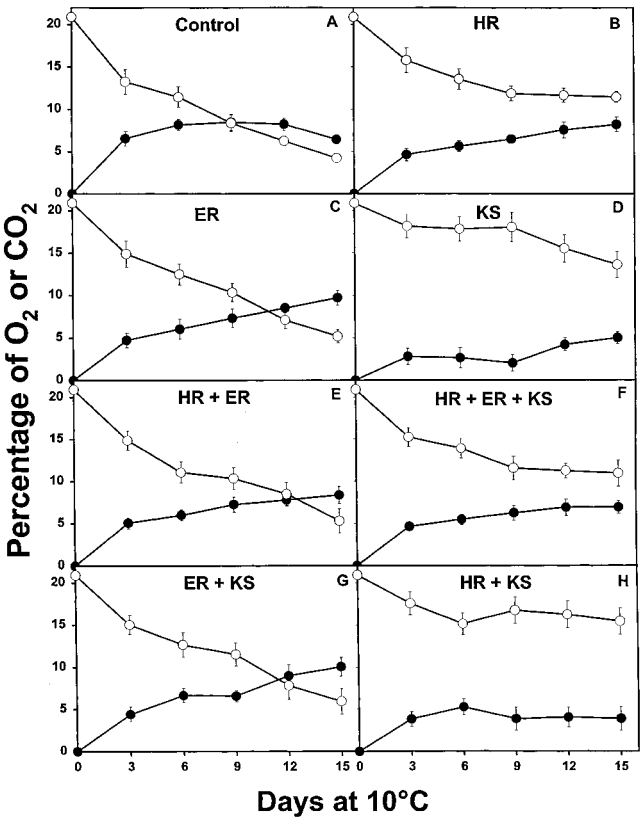

Figure 1. In-package atmosphere changes of O_2 (○) and CO_2 (●) of fresh-cut mangoes treated with different antibrowning agents during storage at 10 °C. Vertical bars represents standard error of the mean ($n = 8$).

to very low O_2 (<0.5%) (Yahia and Vasquez, 1993). Generally, the tolerance of fresh-cut slices is higher than that of intact fruit (Wiley, 1994).

The different pattern in the atmospheric changes was associated with the variation in tissue deterioration. However, because the ripening process had already been induced before slicing, the in-package modified atmosphere created in most of the combinations used did not affect senescence and deterioration of tissue to any meaningful extent.

Color Changes. Fruit color is crucial in purchase decisions, especially if the product is packaged and cannot be touched or smelled. In most fresh-cut fruit and vegetables, packages are needed to contain the processed product, and modified atmospheres (low O_2 and high CO_2) could be used to retard ripening and delay senescence (Garret, 1994; Wiley, 1994). After 14 days of storage at 10 °C, fresh-cut mango treated with HR + ER + KS resulted in the best maintenance of *L** and *b** values followed by the HR + KS treatment (Figure 2A,C). Fresh-cut slices under these treatments presented the best visual appearance and fewer symptoms of browning and decay (Figure 3). Control fruit showed the lowest *L** and the highest *a** values (Figure 2A,B). The lower *L** level could be correlated with the rapid reduction of O_2 and increase of CO_2 inside the control packages (Figure 1A). A rapid deterioration of the fruit involved an increase in respiration rate and enzymatic metabolic processes that led to a loss of quality of fresh-cut produce. These values corresponded to samples with the major deterioration and browning symptoms of the other treatments when compared to slices treated with HR + KS and HR + ER + KS (Figure 3A,B). The application of individual antibrowning agents

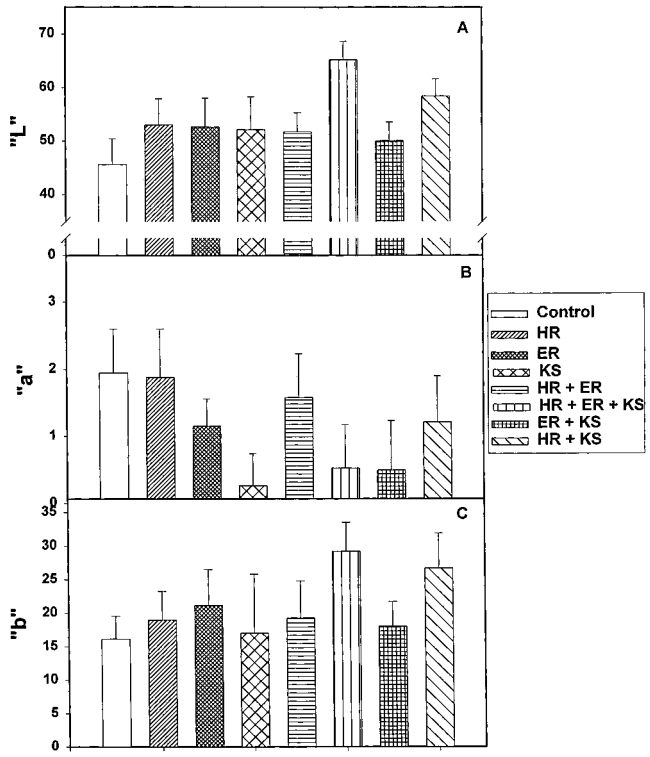

Figure 2. Color parameters (*L**, *a**, and *b**) of fresh-cut mangoes treated with different antibrowning agents, after being stored for 14 days at 10 °C. Vertical bars represents standard error of the mean ($n = 64$).

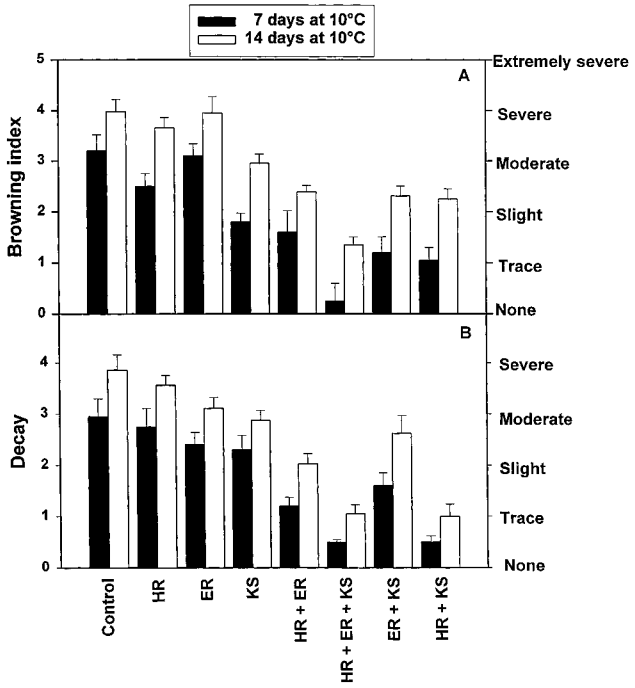

Figure 3. Browning index (A) and decay (B) of fresh-cut mangoes treated with different antibrowning agents, after being stored for 7 and 14 days at 10 °C. Vertical bars represents standard error of the mean ($n = 64$).

did not reduce the increases in browning index and decay of fresh-cut mango. The combination of HR + ER + KS proved to be the treatment that was the most effective in reducing browning and decay of mango slices (Figure 3). Other combinations were moderately effective in reducing browning and decay symptoms, but only in shortened periods of storage. Only the combination

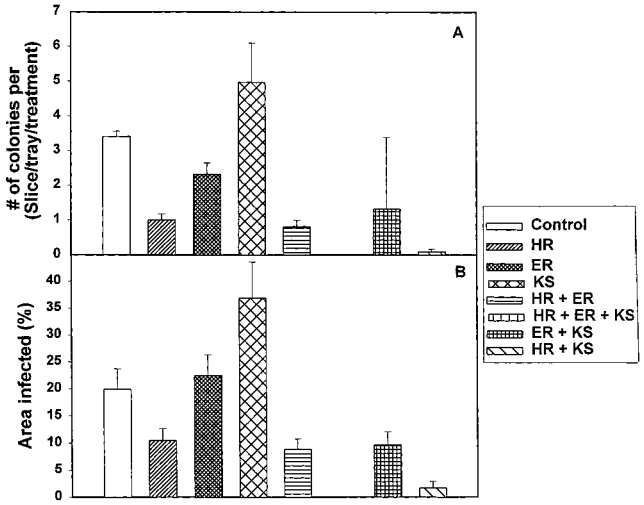

Figure 4. Number of colonies (A) and percentage of area infected (B) of fresh-cut mangoes treated with different antibrowning agents, after being stored for 14 days at 10 °C. Vertical bars represents standard error of the mean ($n = 64$).

of HR + KS reduced decay in a manner similar to the HR + ER + KS treatment (Figure 3B). After 14 days at 10 °C, slices treated with both treatments showed only trace symptoms of decay, whereas moderate to severe decay symptoms were observed in control and other treatments.

During the first 7 days of storage, decay symptoms were observed only in untreated slices (control) and in slices treated with HR + ER + KS (data not shown). After this period, deterioration became more noticeable. Slices treated with KS contained the highest number of colonies and area infected followed by control slices and those treated with ER (Figure 4). The combination of HR + KS was effective in reducing decay symptoms. However, small areas of some slices showed some decay and slight microbial growth. Slices treated with HR, ER + KS, or HR + ER showed similar symptoms of deterioration but greater than those treated with HR + ER +KS and HR + KS (Figure 4).

Fresh-cut mangoes treated with the combination of HR + ER + KS showed the lowest changes in L^* and b^* values, as well as the lowest browning and symptoms of decay. Previously, we found that the addition of *N*-acetylcysteine to HR and KS was necessary to reduce browning and decay of radish slices (unpublished data). However, it appears that the response of tissue to antibrowning agents differs considerably with different fruits and vegetables. Different combinations of these antibrowning agents were found to be effective in reducing browning and decay of apple and pear slices (Monsalve-Gonzalez, 1995; Saper and Miller, 1998; Buta et al., 1999; Buta and Abbott, 2000). With some of the less effective combinations of antibrowning agents, vaccum packaging along with these compounds was required to inhibit browning of apple slices stored at 0.5 °C (Luo and Barbosa-Canovas, 1996).

Browning was observed to be attributed to degradation of the tissue induced by dryness of the surface. Therefore, the use of MAP to maintain high humidity was helpful in reducing browning. However, MAP by itself was not effective in preventing browning and reducing deterioration of fresh-cut mangoes. An additive effect could be attributed to treatment witn antibrowning agents. Nevertheless, control slices as well as those treated with HR+ ER + KS developed severe symptoms

Table 2. Effect of Antibrowning Agents on Organic Acid Content of Mango Cv. Kent Slices Stored for 7 and 14 Days at 10 °C[a]

	organic acid content (mg/g of FW)				
treatment	malic	shikimic	citric	quinic	total
Storage for 7 Days at 10 °C					
control	0.232^{ab}	0.428^{ab}	3.660^{b}	0.093^{ab}	4.412
HR	0.179^{b}	0.465^{a}	5.806^{ab}	0.176^{a}	6.625
ER	0.308^{a}	0.417^{ab}	2.175^{b}	0.129^{ab}	3.029
KS	0.263^{ab}	0.499^{a}	6.476^{a}	0.068^{b}	10.335
HR + ER	0.278^{ab}	0.360^{ab}	2.377^{ab}	0.099^{ab}	3.115
HR + ER + KS	0.277^{ab}	0.378^{ab}	6.242^{a}	0.151^{a}	7.048
ER + KS	0.186^{b}	0.363^{ab}	5.917^{ab}	0.117^{ab}	6.582
HR + KS	0.186^{b}	0.334^{b}	2.406^{b}	0.092^{ab}	3.019
Storage for 14 Days at 10 °C					
control	0.185^{ab}	0.332^{b}	1.046^{b}	0.182^{ab}	1.745
HR	0.085^{bc}	0.460^{a}	0.702^{b}	0.288^{a}	1.537
ER	0.109^{bc}	0.362^{ab}	0.979^{b}	0.181^{ab}	1.631
KS	0.187^{b}	0.532^{a}	2.591^{a}	0.141^{b}	3.451
HR + ER	0.055^{c}	0.281^{b}	0.834^{b}	0.069^{b}	1.239
HR + ER + KS	0.224^{ab}	0.332^{b}	1.894^{ab}	0.175^{ab}	2.625
ER + KS	0.128^{bc}	0.461^{a}	1.160^{b}	0.189^{ab}	1.938
HR + KS	0.285^{a}	0.376^{ab}	1.849^{ab}	0.241^{a}	2.751

[a] Initial contents of organic acids were 0.277, 0.499, 3.518, and 0.064 mg/g of FW of malic, shikimic, citric, and quinic acid, respectively. Each value is the mean of three replications. Means with same letter within columns and during the same period of storage are not significantly different according to the Tukey test ($p = 0.05$).

of decay and growth of microbial infections. It appears that the extent of the beneficial effect is dependent on the particular combinations of the antibrowning agents used rather than the modified atmosphere created.

Organic Acids and Sugars. The changes in organic acids content of fresh-cut mango during storage at 10 °C are shown in Table 2. Citric acid was the major organic acid detected followed by shikimic, malic, and quinic acid. After 7 days at 10 °C, in general, levels of malic and shikimic acid decreased. However, a significant increase (1.5−2-fold) in citric acid was observed in slices treated with HR, KS, HR + ER + KS, and ER + KS, and decreases from 3.5 mg/g of FW to 2.17, 2.37, and 2.4 mg/g of FW in ER, HR + KS, and HR + KS treatments were found. Levels of quinic acid increased in all treatments with significant ($p < 0.05$) values in HR and HR +ER + KS treatments (Table 2). After 14 days of storage, a significant reduction in citric acid was observed. Malic acid decreased but to a lesser extent than citric acid. However, quinic and shikimic acids increased, in most of the treatments, during the same period. In general, higher levels of organic acids were observed in fresh-cut slices treated with antibrowning agents. The best antibrowning treatments (HR + ER + KS and HR + KS) maintained relatively higher levels of citric acid, a major organic acid present in mango fruit. The levels of total organic acid were not correlated with the antibrowning efficacy of the treatments. The least effective treatment (KS) contained higher levels of citric acid and total organic acids than the more effective ones (HR + KS and HR + ER + KS).

The sugar content varied considerably among treatments during the storage period (Table 3). Sucrose was the major sugar present in mango fruit followed by fructose and glucose. After 14 days of storage at 10 °C, an appreciable increase in fructose and glucose was observed in the best antibrowning treatments. Some of the treatments used modified the changes in sugar contents. During ripening, sugars increase significantly. The fact that the best treatment (HR + ER + KS)

Table 3. Effect of Antibrowing Agents on Sugar Content of Cv. Kent Mango Slices Stored for 7 and 14 Days at 10 °C[a]

	sugar content (mg/g of FW)			
treatment	glucose	fructose	sucrose	total
Storage 7 Days at 10 °C				
control	6.13[b]	22.79[ab]	56.15[b]	85.07
HR	8.67[b]	18.38[ab]	25.79[de]	52.84
ER	6.57[b]	28.23[a]	72.21[a]	107.01
KS	8.39[b]	20.54[ab]	47.89[bc]	76.82
HR + ER	7.66[b]	13.92[b]	41.44[c]	63.02
HR + ER + KS	6.91[b]	16.20[ab]	21.19[e]	44.30
ER + KS	13.69[a]	28.66[a]	37.30[cd]	79.65
HR + KS	7.43[b]	20.18[ab]	39.33[cd]	66.94
Storage for 14 Days at 10 °C				
control	5.69[b]	17.57[b]	60.77[a]	84.03
HR	6.20[b]	14.94[b]	47.01[ab]	68.15
ER	5.34[b]	17.75[b]	56.89[a]	79.98
KS	10.63[ab]	23.44[b]	40.48[bc]	74.55
HR + ER	11.18[a]	36.95[a]	26.07[cd]	74.20
HR + ER + KS	10.47[ab]	36.38[a]	24.95[d]	71.80
ER + KS	12.38[a]	27.17[ab]	37.45[bcd]	77.00
HR + KS	9.48[ab]	42.95[a]	34.50[bcd]	86.93

[a] Initial contents of glucose, fructose, and sucrose were 5.10, 18.36, and 47.79 mg/g of FW, respectively. Each value is the mean of three replications. Means with the same letter within columns and during the same period of storage are not significantly different according to the Tukey test ($p = 0.05$).

maintained the lowest sucrose levels could be related to the suppression of the ripening process during the storage period as well as to a decrease in senescence symptoms. The changes in sugars were not sufficient to cause a change in taste when an informal taste panel sampled the variously treated fruit after being stored for 7 and 14 days at 10 °C.

According to the results obtained in this study the combination of HR + KS could be used to prolong storage of fresh-cut mangoes for a shorter period of time (3 days). The HR + ER + KS treatment gave the best results after 14 days of storage at 10 °C. This treatment prolonged storage life for 7 days compared with control slices, without detrimentally affecting the sensory characteristics. We conclude that HR + ER + KS treatment in combination with MAP could be used to inhibit browning, decay, and deterioration of fresh-cut mangoes.

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