

Physiological and quality changes of fresh-cut pineapple treated with antibrowning agents

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Abstract

The physiological responses of pineapple slices to antibrowning agents have been studied. Slices were immersed for 2 min in solutions of isoascorbic acid (IAA) 0.1 mol/l, ascorbic acid (AA) 0.05 mol/l or acetyl cysteine (AC) 0.05 mol/l, packaged in polystyrene trays, prior to storage for up to 14 days at 10°C. The use of these antibrowning agents reduced browning and decay of pineapple slices significantly. These treatments also reduced changes in L* and b* values as well as firmness loss. Changes of in-package atmosphere did not adversely affect quality of slices. Slices treated with 0.1 mol/l IAA had the best visual appearance and were more acceptable compared with the control slices. The best results were obtained using IAA, followed by AC and AA. Organoleptic attributes were not affected and no off-flavors were detected in the treated slices. We conclude that pineapple slices can be maintained in good condition for up to 14 days at 10°C following treatment with antibrowning agents.

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Keywords: Pineapple; Slices; Antibrowning; Decay; Ascorbic acid; Isoascorbic acid; Acetyl cysteine

1. Introduction

The convenience and quality of fresh-cut fruit are factors in their increasing popularity in the food supply. The practice of fresh-cut processing causes wounding, increases metabolic activities and decompartmentalizes enzymes and substrates. This may cause browning, softening, decay, and off-flavor development (Watada, Abe, & Yamauchi, 1990; Varoquax & Wiley, 1994). These manipulations result in increased rates of respiration and ethylene production within minutes (Abe & Watada, 1991) and may reduce the shelf-life from 1 to 2 weeks to only 1 to 3 days even at optimal temperatures (Ahvenainen, 1996).

The demand for various fresh-cut tropical and subtropical fruit is increasing; however, sensitivity of fruit to low temperature (<12°C) storage and inherent

perishability has been limiting in the ability to provide the fresh-cut items for markets. Fresh-cut processing may increase microbial spoilage of fruit through transfer of peel microflora to fruit flesh where microorganisms can grow rapidly upon exposure to nutrient rich juices. This has been a particular problem observed when pineapples were processed for fresh-cut purposes. The difficulty in maintaining quality of fresh-cut fruits such as honeydew, kiwifruit, papaya, pineapple and cantaloupe was studied (O'Connor-Shaw, Roberts, Ford, & Nottingham, 1994). These authors found that the main problem of fresh-cut pineapple was browning after 6 days of storage at 4°C, not microbial decay. However, this temperature is not normally used for marketing of fresh-cut produce, while 10°C is the most widely used temperature commercially. For most packaged salads and fresh-cut produce, modified atmosphere packaging (MAP) is a technology that is currently used with the 5–10°C storage. However, the benefits of MAP are used only to a lesser extent with fresh-cut fruit such as cantaloupe, pineapple and apple (O'Connor-Shaw et al.,

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1994). With some fruits such as apples, the problem of prevention of browning is not completely eliminated by the use of MAP.

Recently, the use of natural products and their derivatives have 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, *N*-acetylcysteine (AC), ascorbic acid (AA), isoascorbic acid (IAA), potassium sorbate, calcium chloride and propionate, alone or in combination at different concentrations, have been found to be effective in retarding browning and reducing decay of fresh-cut produce (Monsalve, Barbosa, McEvily, & Iyengar, 1995; Gunes & Lee, 1997; Kim & Klieber, 1997; Buta, Moline, Spaulding, & Wang, 1999; Buta & Abbott, 2000; González-Aguilar, Wang, & Buta, 2001). The effects of such treatments have not been reported in maintaining quality of fresh-cut pineapple.

In an attempt to preserve quality of fresh-cut pineapple by reducing browning and decay, treatments with antibrowning compounds in conjunction with the passive modification of atmosphere packaging will be evaluated. Their effects on reduction of browning, modification of texture and other quality attributes as well as microbial decay will be studied.

2. Materials and methods

2.1. Plant material

Pineapple fruit (*Ananas comosus* L. Merr. Cv Cayena Lisa) obtained from a wholesale market in Hermosillo (Sonora, Mexico) were used for this study. Fruit were sorted to eliminate damaged or defective fruit, cleaned, crowns were removed, and washed in water containing 0.2 g/l active chlorine and dried. Fruit used for this experiment initially had a firmness of 54–58 N and soluble solids content of 12–13° Brix. Peels were manually removed with a sharp knife, the fruit halved and sliced transversely (8 mm thick). After slicing, mixtures of antibrowning agents previously selected were applied. Preliminary studies revealed that combinations of antibrowning agent were not as effective as when applied individually. The range of concentrations used was: IAA (0.05–0.1 mol/l), AC (0.025–0–0.1 mol/l) and AA (0.05–0.1 mol/l). From these concentrations the best results were obtained with IAA 0.1 mol/l, AC 0.05 mol/l and AA 0.05 mol/l, which were used for the experiment. Pineapple slices were dipped for 2 min in test solutions, drained and centrifuged for 30 s using a manually operated commercial salad spinner Essoreuse Model 1642. Two slices (average weight 85 ± 10 g) were placed in a 250 ml polystyrene plastic tray covered with lid and sealed with parafilm. Control samples were

dipped in distilled water. After sealing, 60 trays per treatment were stored at 10°C for up to 14 days.

In-package concentrations of O₂, CO₂ and C₂H₄ 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 (10 trays/treatment) were taken for evaluation of quality changes. Lids were removed, and each treatment was evaluated subjectively for the development of off-flavors. Slices were then evaluated for color (L* and b*), browning index, decay and acceptability. Two wedges were cut from each slice, and eight wedges from 16 slices from each treatment were juiced together for analysis of ethanol and acetaldehyde. Expressed juice, Ex=(liquid extracted/initial weight) × 100, was measured in six replicates from each treatment. Experiment was repeated seven times through January to November 2001. Results presented are the mean of at least three experiments.

2.2. Atmosphere composition

The changes in-package concentrations of O₂, CO₂ and C₂H₄ were measured at 3-day intervals by withdrawing air samples (1 ml) through a septum using a hypodermic syringe. The concentrations were analysed using a gas chromatograph (Varian star 3400 Cx with a flame ionization detector (FID) and a thermoconductivity detector (TCD). The gases were separated in a Haysep N column configuration consisting of a 2 m × 1/8 in stainless-steel column packed with 80/100 μm mesh Porapak.

2.3. Decay, browning index and acceptability

After color evaluation, slices from different treatments were evaluated subjectively based on scales previously applied (Cantwell, Orozco, Rubatzky, & Hernández, 1992; Mercado-Silva, Rubatzky, Heredia-Zepeda, & Cantwell, 1998). The symptoms of decay were evaluated on a 1–5 scale, where 1=none, 2=slight (up to 5% surface affected), 3=moderate (5–20% surface affected), 4=moderately severe (20–50% surface affected) and 5=extreme (> 50% surface affected). Browning was evaluated on a scale of 1–5, where 1=none, 2=slight, 3=moderate, 4=severe, and 5=extreme browning. The acceptability was evaluated on a 9 to 1 scale, where 9=excellent, no defects, 7=Very good, minor defects, 5=fair, moderate defects, 3=poor, major defects, 1=unusable. A score of 5 was considered the limit of marketability. Minor defects were usually attributed to color changes; major defects were usually due to decay.

2.4. Color

Tristimulus reflectance colorimetry was used to assess the extent of browning in pineapple slices (Sapers &

Douglas, 1987). The color of slices (L^* and b^*) was randomly obtained from two different areas of each slice using a Minolta CR-300 chroma meter. Ten replications (two slices per replicate) were evaluated from each treatment. A decrease of L^* values and lower b^* values indicated discoloration. The color of slices was measured initially and at 7-day intervals.

2.5. Expressed juice

The expressed juice was measured by the method used (Carlin, Nguyen-the, Hilbert, & Chambroy, 1990). Each slice was placed between two filter papers (Whatman No 1, 10 cm diameter), a force of 2 kg was applied for 10 s and the filter papers were weighed again. This measurement was done in six replications, values were expressed in g expressed liquid/100 g fw.

2.6. Firmness

The maximum rupture force was determined transversally on slices using a Texture Analyzer TA-TX2 (Texture Technologies Corp., Scarsdale, NY, USA) with a light knife blade 5.4 cm probe at a penetration of 8 mm.

2.7. Ethanol and acetaldehyde analysis

The determinations were based on the method used (Davis & Chace, 1969). Tissue (5 g) was placed in amber-colored tubes with 20 ml capacity. Tubes were placed in a 65°C water-bath (Series 180 Precision Scientific; Chicago, IL, USA) for 15 min. Headspace samples of 1 ml were injected into a gas chromatograph (Varian star 3400 Cx.) equipped with a 2 m × 1/8 in Chromosorb stainless-steel column packed with 80/100 µm mesh Porapak 101. Retention times and standard curves of ethanol and acetaldehyde in water solutions were used for peak identification and quantification.

2.8. Statistical analysis

All data points represent the mean ± SE of all replicates. Analysis of variance (ANOVA), followed by Tukey's multiple range test for comparison of means and least significant differences (LSD) $P < 0.05$, were performed with the data using NCSS97 Statistical Software, ver. 6.0.

3. Results and discussion

Table 1 shows the subjective quality attributes of fresh-cut pineapples resulting from the different concentrations of antibrowning compounds used. According to these results, it appears that AA and its isomer

Table 1

Effect of different concentrations of antibrowning compounds on quality of fresh-cut pineapple

Treatment	Browning index		Decay index		Acceptability	
	Days at 10°C					
	7	14	7	14	7	14
Control	2.7	3.6	2.6	5	5	1
<i>IAA</i>						
0.1 (mol/l)	1	1.3	1.3	2.4	9	7
0.05 (mol/l)	1	1.5	1.33	2.9	9	6
0.025 (mol/l)	1.5	1.9	2.2	3	7	5
0.01 (mol/l)	1.8	2	2.6	3.2	7	4.5
<i>AA</i>						
0.1 (mol/l)	1.2	1.66	2.3	3.9	6.5	3.8
0.05 (mol/l)	1.3	1.5	2.2	3.2	6.8	4.8
0.025 (mol/l)	1.6	2.1	2	3.8	6.5	3
0.01 (mol/l)	1.9	2.2	2.3	4	6.5	2.5
<i>AC</i>						
0.1 (mol/l)	1.2	2.2	1.3	3.5	9	4
0.05 (mol/l)	1	2	1.2	3.1	9	6.6
0.025 (mol/l)	1.2	3.2	1.8	4.5	8	1.4
0.01 (mol/l)	1.4	3.6	2.4	4.7	7	1

Each value is the mean of 15 replications.

IAA, had different degrees of effectiveness in maintaining the quality of slices. IAA was more effective than AA in preventing browning, since application of the same concentrations of IAA resulted in less browning and more decay inhibition than the comparable AA application. The cysteine derivative, AC, at 0.05 mol/l was the most effective treatment in reducing the loss of quality of slices. AC is a more stable compound and could not be utilized as rapidly as AA and IAA. Apparently IAA and AA have modes of action different from AC and the efficacy of compounds can be altered by concentration used and characteristics of the produce. It appears that we have a combination of different reaction sites and stabilities and, therefore, we obtained differences in the capacity to reduce browning.

Fig. 1A shows the changes of O_2 and CO_2 in the in-package atmosphere of fresh-cut pineapple treated with the antibrowning agents. After 3 days of storage, the oxygen content was reduced in all treatments as well as controls. Afterwards, oxygen levels continued to decline in the packages of the control fresh-cut pineapples. However, the in-package O_2 content of pineapples treated with antibrowning agents remained stable at 14–15 ml/100 ml without significant differences among the treatments. After 9 days, a slight reduction in O_2 levels was observed in the fresh-cut pineapples treated with IAA and AA. CO_2 accumulation started after 3 days of storage, being more noticeable in the controls. A similar pattern was observed in fresh-cut pineapples treated with the antibrowning agents. However, a slight

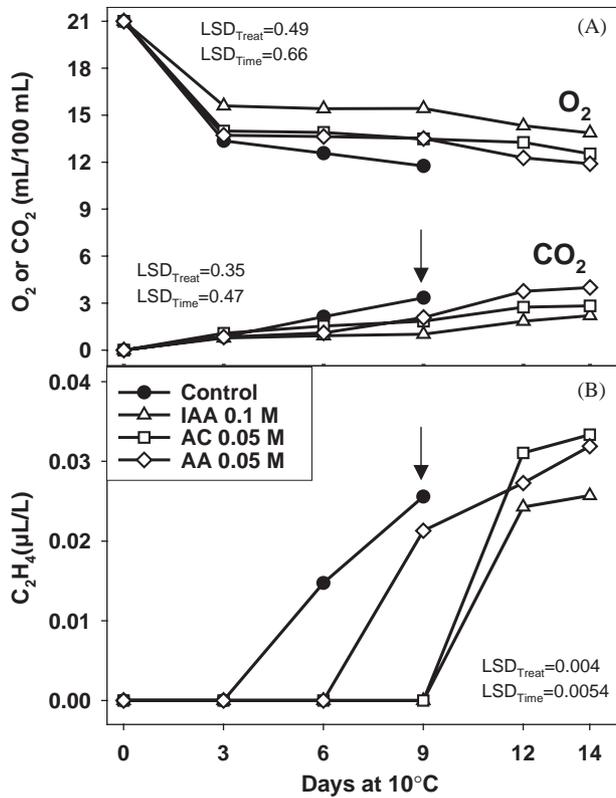


Fig. 1. In-package atmosphere changes of O₂, CO₂ (A) and C₂H₄ (B) of fresh-cut pineapples treated with different antibrowning agents during storage at 10°C. For all figures, data points are means of six replicates and LSD at 5% level for treatment and time are shown. Arrow indicates limit of shelf-life for controls.

increase in CO₂ content in the AA treatment was observed after 9 days of storage, reaching values close to 3–4.5 ml/100 ml. The highest reduction in O₂ and accumulation of CO₂ content observed in controls could be related to the deteriorative processes presented in these fruits. However, the changes in O₂ and CO₂ levels were not found to be significant among treatments applied.

Ethylene accumulation started after 3 days of storage in the packages containing the control fresh-cut pineapples (Fig. 1B). Afterwards, ethylene accumulated rapidly reaching the maximum at day 9 of storage. Antibrowning agents suppressed the ethylene accumulation, which started to accumulate after 6 days of storage, in the packages containing the fresh-cut pineapples treated with AA, while in those treated with IAA and AC started after 9 days of storage. No significant differences in the ethylene content were detected among the treatments used after 12–14 days. It appears that changes in the package atmospheres were influenced by the browning inhibitors and could play a role in reducing the deterioration processes of fresh-cut pineapples.

Deterioration was significantly reduced by the use of antibrowning agents (Fig. 2A). After 7 days of storage,

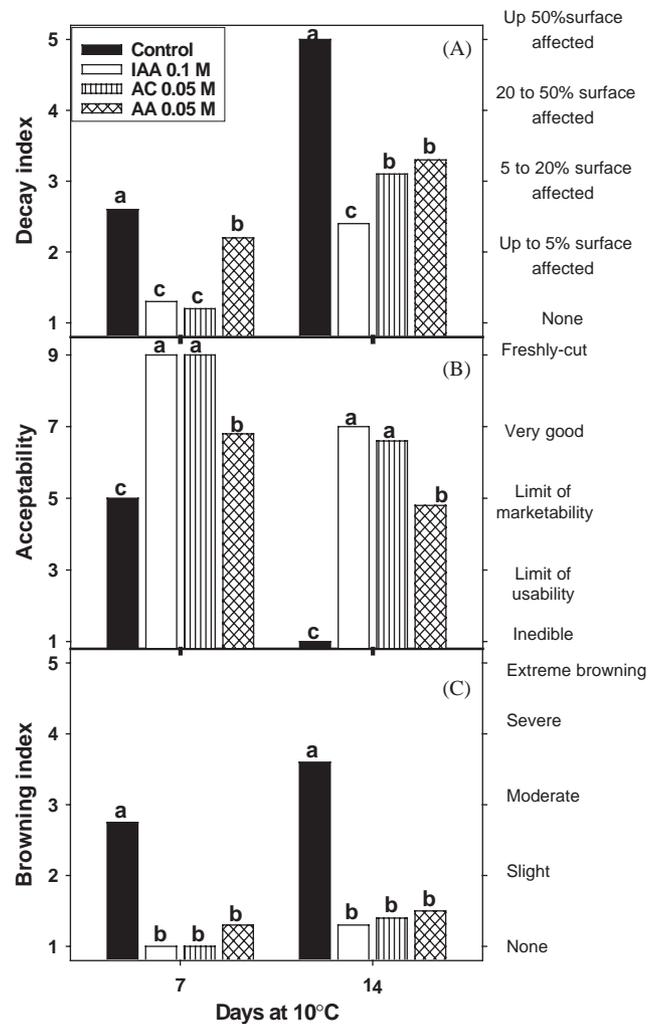


Fig. 2. Decay index (A), acceptability (B) and browning index (C) of fresh-cut pineapples treated with different antibrowning agents, after being stored for 7 and 14 days at 10°C. For all figures, data points are means of 10 replicates. Means with the same letters during the same period of storage are not significantly different according to the Tukey test ($P > 0.05$).

control fruits had up to 5% of the surface affected by fungal decay, with a lesser amount in the AA treatment. IAA and AC suppressed visual fungal growth on the fresh-cut pineapple surface. Fungal growth developed continuously and was more evident in control after 14 days. The effect of AA and AC in reducing decay symptoms was similar. However, only few slices treated with IAA showed slight symptoms of decay, but the rest maintained good appearance and freshness after 14 days at 10°C. It has been observed that the use of AA in air did not prevent cut surface deterioration of apples, possibly due to accelerated softening at the cut surface that allowed for microbial attack (Gil, Gorny, & Kader, 1998). For this reason, other studies employing the combinations of antibrowning agents were more effective in preventing deterioration and browning of apple slices (Buta et al., 1999).

It has been observed that AA treatment increased the concentration of phytoalexin terpenoids in fresh-cut cantaloupes (Lamikanra & Richard, 2002). The better retention of the phytoalexin compounds in AA-treated fresh-cut cantaloupe might be responsible in part for extending shelf-life of fruit. Kim and Klieber (1997) reported that citric acid dipping (10 g/l) reduced significantly black speck (goasho) and browning of minimally processed chinese cabbage.

Acceptability followed a similar trend. Slices treated with IAA and AC, received the highest values (9=freshly cut) followed by slices treated with AA (6.5) and controls (5=limit of marketability). Control slices did not withstand the storage period. Shelf-life of these slices was only 6–7 days at 10°C (Fig. 2B). However, slices treated with IAA and AC maintained good quality and visual appearance at the end of the storage.

At the same time, these two treatments were very effective in reducing browning of pineapple slices (Fig. 2C). Treatment with AA was less effective in maintaining the quality, but was very effective in reducing browning. After 7 days of storage, browning started to appear mainly in control slices and was more evident at the end of the storage period. Pineapple slices treated with IAA and AC maintained a fresh appearance, so at the end of the storage, these slices did not show any physiological deterioration, microbial spoilage or browning.

Fig. 3 shows changes in color (L^* and b^*) of pineapple slices treated with different antibrowning agents, after being stored for 7 and 14 days at 10°C. The effectiveness of antibrowning agents was evaluated by tristimulus colorimetry of cut surfaces and by visual observations of slices. Measurements of L^* (brightness) and b^* (browning or loss of yellow color) values clearly showed varying degrees of suppression of browning on cut surfaces that resulted from the antibrowning compounds used. L^* values of treated slices were reduced slightly, after 7 days of storage at 10°C and were significantly different from the untreated slices (Fig. 3A). After the same period of storage, there was a marked decrease in the lightness of control slices and differences increased after 14 days of storage.

The decrease in L^* values during storage, indicative of browning, was much greater for control slices than for those treated with the antibrowning agents (Fig. 3B). In general, AA, AC and IAA treatments, significantly suppress color changes (L^* and b^* values). These slices maintained surface brightness and good visual appearance. In general a significant difference in L^* and b^* values were found among the treatments used. The variability in the lightness could be explained by the physical condition of the cut surfaces that could have been altered by wetness of the slice surfaces. The effectiveness of the antibrowning agents was more

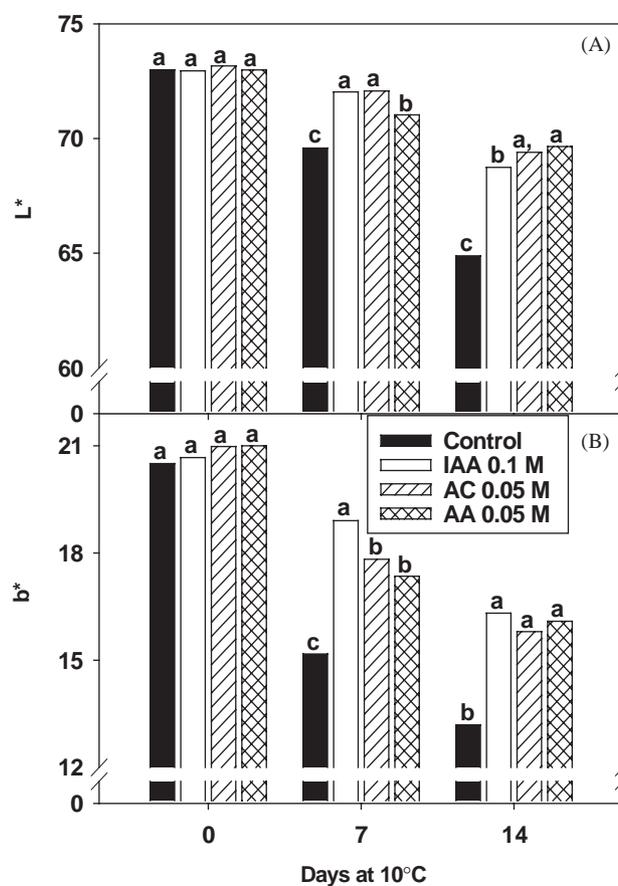


Fig. 3. Color parameters (L^* and b^*) of fresh-cut pineapples treated with different antibrowning agents, after being stored for 7 and 14 days at 10°C. For all figures, data points are means of 20 replicates. Means with the same letters during the same period of storage are not significantly different according to the Tukey test ($P > 0.05$).

noticeable after 14 days of storage. In some of the preliminary studies, we found that some slices treated with these compounds could withstand longer periods (20 days at 10°C). However, due to differences in maturity of pineapple slices at treatment deteriorated earlier. In all of the experiments, control pineapple slices only lasted 5–7 days at 10°C.

No additional benefits were obtained when AC, IAA and AA were combined. Individual applications of the antibrowning compounds reduced color changes and browning of pineapple slices during storage at 10°C. In contrast, better results were obtained in radish slices when hexyl resorcinol (HR) and IAA were combined (González-Aguilar et al., 2001). The use of AC combined with citric acid was found to be effective in reducing browning of banana slices stored at 5°C and 15°C (Moline, Buta, & Newman, 1999). It has been reported that an additive effect occurred when HR, AC and IAA were combined in apple, pear and mango slices, being more effective in reducing browning and decay than when applied individually (Monsalve et al., 1995; Sapers & Miller, 1998; Buta et al., 1999;

González-Aguilar, Wang, & Buta, 2000). Lambrecht (1995) reported that AA and erythorbic acid were effective in preventing browning of pineapple slices stored for up to 21 days at 0°C. However, this author did not report the effects of these treatments on other quality attributes. Also, the temperature used in this experiment was too low to be suitable for commercial purposes.

Expressed juice from tissue has been used as a measurement of freshness. Expressed juice increased continuously to different extents among treatments during storage at 10°C (Fig. 4A). We observed that control slices produced the lowest percentages of juice. However, slices treated with the antibrowning agents retained more liquid in the tissue, probably due to a lowered metabolism and to the reduction of the deteriorative processes induced by these treatments. The retention of liquid as indicated by the amount of juice expressed at time of measurement, is an indication of freshness of the tissue; the higher the amount of expressed juice the fresher the pineapple slices.

Firmness decreased continuously during storage to different extents among treatments. The firmness of control slices was reduced rapidly from 55 to 37 N after

9 days of storage at 10°C (Fig. 4A). The rapid loss of firmness was related to losses in visual appearance, deterioration and browning of slices. In the same manner, treating slices with antibrowning agents significantly reduced firmness loss and maintained the quality of pineapple slices to a higher extent. IAA treatment was significantly the most effective treatment in maintaining the quantity of expressed juice (freshness) and reducing loss of firmness, followed by AC and AA treatments (Fig. 4A and B). No significant differences were found between AC and AA treatments at the end of storage period. The reduction in firmness loss by antibrowning agents could be related to the suppression of deteriorative processes and lowering of the metabolism of slices, which in turn prevents breakdown of tissue. We hypothesize that texture loss during storage was due to enzymatic hydrolysis of cell wall components.

IAA-treated slices did not show any symptoms of dehydration. However, control slices that lost firmness more rapidly, exhibited the major symptoms of surface dehydration that could be related to the higher accumulation of ethylene in the packages. Watada et al. (1990), found that the softening rate of kiwifruit slices was reduced by C₂H₄ scrubbing (charcoal with palladium chloride). It has been observed that firmness loss of fresh cut tomato slices was probably linked to the ripening stage of the whole fruit (Gil, Hernández, Conesa, & Artés, 1999). When a combination of IAA and HR were applied, browning and firmness loss of pear slices was prevented (Buta & Abbott, 2000). It has been reported by several authors that calcium salts can be used to prevent firmness losses of different fresh-cut products (Agar, Massantini, Hess-Pierce, & Kader, 1999; Luna-Guzmán, Cantwell, & Barrett, 1999; Gorny, Hess-Pierce, Cifuentes, & Kader, 2002). When calcium chloride and potassium sorbate were tested in pineapple slices, no beneficial effects were obtained (data not shown).

Acetaldehyde and ethanol content in pineapple slices increased during 14 days storage at 10°C (Fig. 5A and B). No significant increases in ethanol and acetaldehyde content were observed during the first 6 days of storage. Only the slices treated with AC showed a constant increase during the storage period. On the other hand, a sharp increase in ethanol and acetaldehyde content was observed in pineapple slices treated with IAA after 6 days of storage, reaching the highest values at the end of the storage.

No significant change in ethanol and acetaldehyde was observed in control and slices treated with AA, during 9 days storage at 10°C. A slight increase in acetaldehyde was observed in these treatments, after 9 days at 10°C. Afterward, no significant changes on ethanol content was observed in slices tissue treated with AC. This increase was more evident in the content of

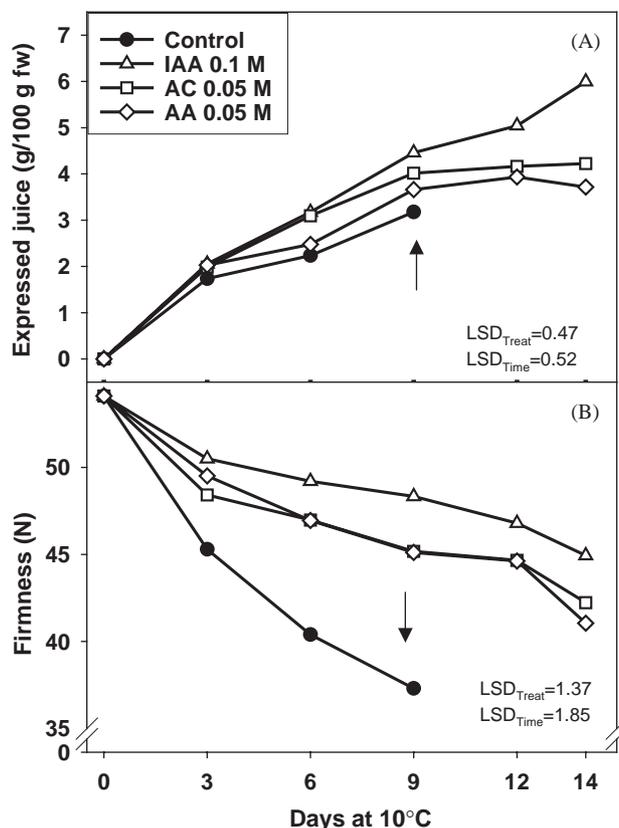


Fig. 4. Expressed juice (A) and firmness (B) of fresh-cut pineapples treated with different antibrowning agents during storage at 10°C. For all figures, data points are means of 10 replicates and LSD at 5% level for treatment and time are shown. Arrow indicates limit of shelf-life for controls.

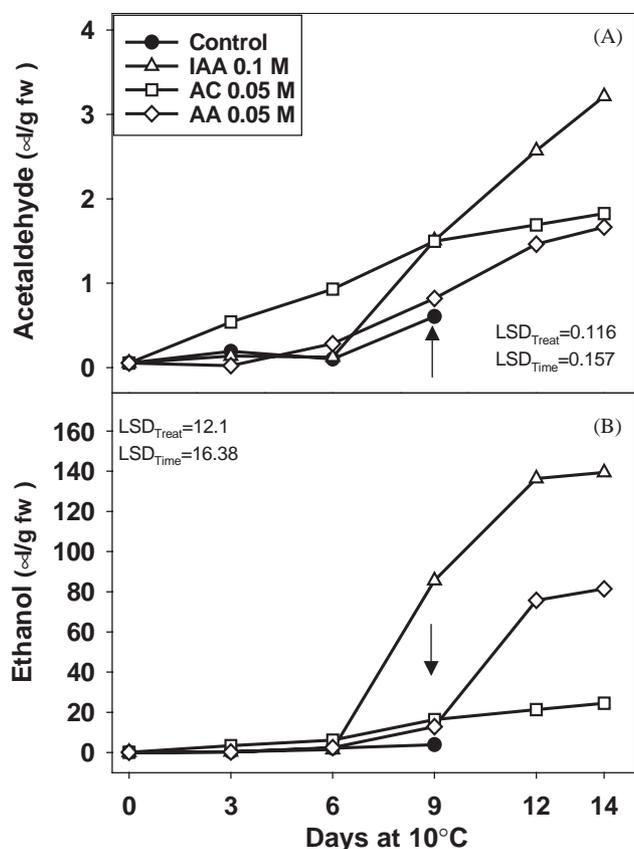


Fig. 5. Concentration of acetaldehyde (A) and ethanol (B) of fresh-cut pineapples treated with different antibrowning agents during storage at 10°C. For all figures, data points are means of five replicates and LSD at 5% level for treatment and time are shown. Arrow indicates limit of shelf-life for controls.

acetaldehyde, reaching similar levels than slices treated with AA.

Generally, the lower the O₂ in-package, the higher the acetaldehyde and ethanol concentration. However, in this study it appears that volatile accumulation could be more related to the treatment applied than to changes in the control in-package atmosphere. The O₂ and CO₂ content observed in the packages containing the pineapple slices, was not sufficient to cause an anaerobic respiration (Fig. 1). It is well known that ethanol and acetaldehyde normally accumulates during maturation of pineapple (Paull, 1997). Therefore, the accumulation observed in the tissue of fresh-cut slices, could be more related to the treatment applied and ripening processes rather than to changes in the atmosphere during storage.

Antibrowning agents apparently have a more complex mode of action than just simple antibrowning activity, since overall quality was maintained as expressed by firmness and freshness retention and inhibition of ethylene accumulation and microbial growth. These compounds having different structure–activity relationships result in extended shelf-life of pineapple slices.

4. Conclusions

According to the results obtained in this study the application of different antibrowning agents could be used to prolong the shelf-life of fresh-cut pineapples. The IAA was the most effective treatment after 14 days of storage at 10°C, followed by AC and AA treatments. The IAA treatment prevented in higher extent firmness loss, decay and cut surface browning and prolonged the shelf-life for 7 days compared with control slices.

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