Available online at www.sciencedirect.com
SCIENCE DIRECT®
Postharvest Biology and Technology 39 (2006) 163–168
Postharvest Biology and Technology
www.elsevier.com/locate/postharvbio

Optimal temperature and modified atmosphere for keeping quality of fresh-cut pineapples

Antonio Marrero[a,*], Adel A. Kader[b]

[a] Instituto Canario de Investigaciones Agrarias, Apartado 60, La Laguna, Tenerife 38200, Spain
[b] Department of Pomology, University of California, Davis, Davis CA 95616, USA

Received 13 October 2005; accepted 18 October 2005

Abstract

The influences of storage temperature and modified O_2 and CO_2 concentrations in the atmosphere on the post-cutting life and quality of fresh-cut pineapple (*Ananas comosus*) were studied. Temperature was the main factor affecting post-cutting life, which ranged from 4 days at 10 °C to over 14 days at 2.2 and 0 °C. The end of post-cutting life was signaled by a sharp increase in CO_2 production followed by an increase in ethylene production. The main effect of reduced (8 kPa or lower) O_2 levels was better retention of the yellow color of the pulp pieces, as reflected in higher final chroma values, whereas elevated (10 kPa) CO_2 levels led to a reduction in browning (higher *L* values). Modified atmosphere packaging allowed conservation of pulp pieces for over 2 weeks at 5 °C or lower without undesirable changes in quality parameters.

Keywords: Color; Ethylene; Firmness; Respiration

1. Introduction

Pineapple (*Ananas comosus* L. Merrill) is a non-climacteric tropical fruit that shows moderate to low rates of respiration and ethylene production (Dull et al., 1967). Fresh-cut pineapple products are already found in supermarkets and food service distribution chains, but very few studies have been published regarding the optimal conditions for maintaining quality of these products. O'Connor-Shaw et al. (1994) reported that pineapple cubes stored in polypropylene containers at 4 °C kept their sensory attributes for 7 days, but after 11 days showed brown discoloration, and after 14 days off-odors and softening were apparent. Spoilage is associated with an increase in respiratory activity due to the growth of microbial flora (Iversen et al., 1989). The post-cutting life of pineapple has been reported to be very dependent on temperature, from a few hours at 20 °C to several weeks at 1 °C (O'Hare, 1994). In a preliminary study (Marrero and Kader, 2001), we found that post-cutting life of pineapple pieces ranged from 4 days at 10 °C to over 2 weeks at 0 °C.

The prolonged post-cutting life of fresh-cut pineapple products at such low temperatures is contrary to the susceptibility of whole fruits to chilling. Chilling injury develops when whole fruits are stored at temperatures below 10 °C for extended periods of time. The symptoms include dull shell color when ripe, wilting of crown, water-soaked appearance of pulp, increased susceptibility to decay and internal browning (Paull and Rohrbach, 1985; Paull, 1997). Some of these symptoms appear after the chilled fruits have been removed to non-chilling temperatures, and their incidence can be alleviated using controlled or modified atmospheres (Paull and Rohrbach, 1985; Chitarra and da Silva, 1999).

The objectives of this study were to determine the optimal temperature for conservation of fresh-cut pineapple pieces and to investigate the influence of atmosphere modification on quality maintenance of the product. The suitability of a new pineapple cultivar for minimal processing was also studied.

* Corresponding author. Present address: ETSIA, Carretera Geneto 1, Universidad de La Laguna, Tenerife 38200, Spain.
Tel.: +34 922318532; fax: +34 922318562.
E-mail address: anmarre@ull.es (A. Marrero).

0925-5214/$ – see front matter © 2005 Elsevier B.V. All rights reserved.
doi:10.1016/j.postharvbio.2005.10.017

2. Materials and methods

2.1. Plant material

Unless otherwise stated, experiments were performed using fruit of the Smooth Cayenne selection no. 3620 ('SC3620') cultivar. Fruit were received from Hawaii via air freight and stored at 10 °C until processed. For some experiments, fruit of 'Premium Select', a new commercial cultivar, were also obtained from Costa Rica and similarly handled.

Fruit with a shell color corresponding to stages 2 and 3 of the Dole pineapple color chart (between 25 and 50% shell color change) were peeled, cored and the pulp cut into 1-cm-thick wedges (about 8 g each), dipped in a 100 $\mu L\,L^{-1}$ sodium hypochlorite solution for 2 min, and blotted dry. For some experiments, peel and core tissues were similarly cut into pieces and treated with hypochlorite. In all experiments, three replicates of at least 10 pulp pieces each were used per treatment.

2.2. Storage conditions

For controlled atmosphere (CA) experiments, 1-L glass jars, each containing about 300 g of pulp wedges, were continuously flushed with a humidified flow of air or the desired gas mixture. Flow rates were adjusted so that CO_2 concentration did not exceed 0.2% in the humidified air controls. For modified atmosphere (MA) experiments, 500 mL oriented polystyrene (OPS) cups, containing 150 g of pulp wedges of the 'Premium Select' cultivar, were thermally sealed with Mylar® plastic film. In all cases, the containers (jars or cups) were placed in temperature controlled rooms for the duration of storage.

2.3. Gas analysis

Gas samples were taken from the outlet tubes of the jars or from the MA containers using disposable 1 mL syringes. O_2 and CO_2 concentrations were measured using an infrared gas analyzer (Horiba Instruments Co., Irvine, CA, USA). Ethylene concentrations were similarly determined using a Carle model 211 gas chromatograph (Carle Instruments Co., Anaheim, CA USA) equipped with an alumina column and a flame ionization detector. All gas production rates were calculated at 101 kPa and 20 °C.

2.4. Quality evaluation

Before assessment, pulp pieces were removed from their refrigerated storage and allowed to warm up at room temperature in air for 3–4 h. Annotation was made of any off-odors detected upon opening the jars or cups. At least 10 pulp pieces were used for each replicate.Quality evaluation of pulp pieces included determination of color parameters (*L*, hue angle and chroma) using a Minolta chromameter (Model CR-200, Minolta, Ramsey, NJ, USA), texture using a University of California fruit firmness tester with a 3 mm tip (Western Industrial Supply Co., San Francisco, CA, USA), total soluble solids with an Abbe refractometer (American Optical, Buffalo, NY), pH and titratable acidity with a pH-meter and automatic titrator (Radiometer, Copenhagen, Denmark), as well as a subjective visual quality scale (from 1 = completely unacceptable to 9 = excellent). Juice leakage from the pulp pieces was assessed by measuring the volume of juice at the bottom of the containers using a calibrated syringe. The detection of off-odors and off-flavors was also recorded.

Total ascorbic acid was determined according to the procedure described by Wright and Kader (1997), based on the method of Zapata and Dufour (1992). Extraction and analysis of α- and β-carotene were performed as described by Wright and Kader (1997), based on the method of Hart and Scott (1995) for determination of carotenoids by HPLC.

2.5. Statistical analysis

Results were analyzed using one-way or two-way analysis of variance. Significantly different means were separated using a Tukey's HSD (honest significant difference) test using Systat statistical software.

3. Results

3.1. Respiration and ethylene production rates of different fruit tissues

After an initial increase due to wounding, respiration rates 1 and 2 days after cutting at 10 °C were almost twice as high in peel pieces as in pulp and core pieces (Fig. 1). Whole fruit showed an intermediate respiration rate between those of peel and pulp pieces. Five days after cutting all pieces showed a much elevated CO_2 production rate and signs of microbial spoilage.

Ethylene production was always higher in tissue pieces than in whole fruits, especially on day 5 after cutting. A significant increase in ethylene production by pieces was apparent 2 days after cutting, when respiration rates were still at their basal levels (Fig. 1).

3.2. Effect of temperature on respiration, ethylene production and quality parameters of pulp pieces kept under humidified air

Temperature had a significant effect both on respiration rate and post-cutting life. The end of post-cutting life was indicated by a marked increase in respiration followed by visual signs of microbial spoilage. This stage was reached after 4 days at 10 °C, 8 days at 7.5 °C, 12 days at 5 °C and more than 15 days at 2.2 and 0 °C (Fig. 2).

Wounding induced a permanent increase in ethylene production at 10 °C and a temporary one at 7.5 °C (Fig. 2). At this

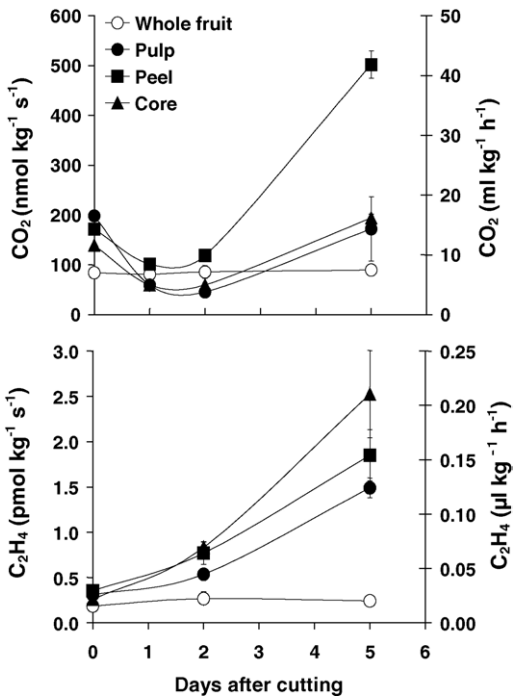

Fig. 1. Respiration and ethylene production rates of whole fruits and pieces of peel, pulp and core tissues of 'SC3620' pineapple kept under a continuous flow of humidified air at 10 °C. Data presented are the averages of six whole fruits or three jars of pieces. Vertical lines represent the S.D.

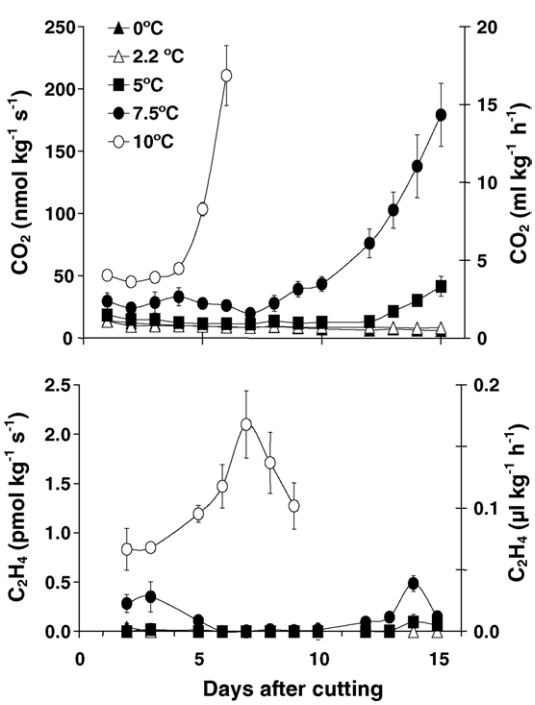

Fig. 2. Respiration and ethylene production rates of 'SC3620' pineapple pulp pieces kept under a continuous flow of humidified air at 0, 2.2, 5, 7.5 or 10 °C. Data presented are the averages of three replicates. Vertical lines represent the S.D.

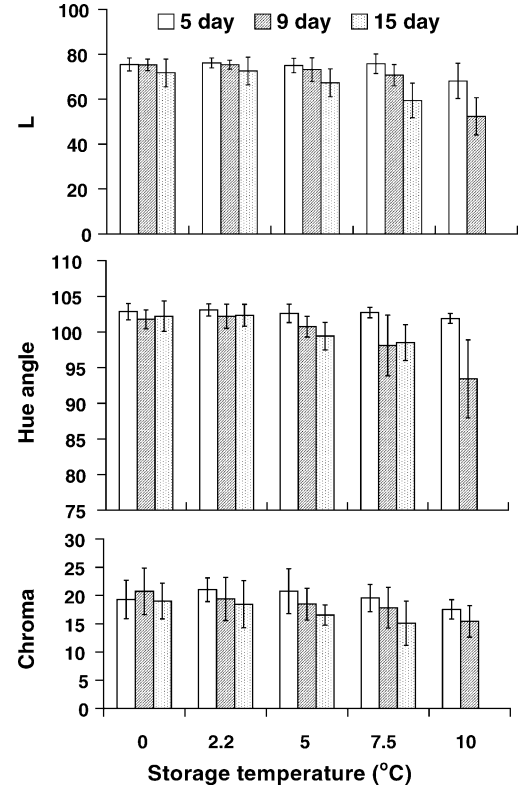

Fig. 3. Changes during storage in luminosity (*L*), hue angle and chroma of 'SC3620' pineapple pulp pieces kept under a continuous flow of humidified air at 0, 2.2, 5, 7.5 or 10 °C. Data presented are the averages of three replicates. Vertical lines represent the S.D.

temperature, as well as at 5 °C, a peak in ethylene production was apparent after increased respiration rates were detected. At 0 and 2.2 °C no ethylene production was detected with the experimental method used.

Over time there was a tendency toward diminishing values of luminosity (*L*), chroma and hue angle (Fig. 3), but at the lower temperatures (0 and 2.2 °C) these changes were not statistically significant ($P > 0.05$). No translucency (water-soaked areas) or browning symptoms that could be associated with chilling injury were detected at any temperature.

The volume of juice that leaked from the pieces increased linearly with time, but temperature had no detectable effect on it (Fig. 4). There were no differences in total soluble solids, acidity or texture of the pieces among the different temperatures (data not shown).

3.3. Effects of atmosphere modification

Reducing the oxygen concentration led to diminished respiration rates, but did not delay the onset of fermentation as revealed by a significant increase in CO_2 production (Fig. 5).

Increased (10%) CO_2 levels combined with low (8% or lower) O_2 concentrations led to higher final values of luminosity (*L*) and acidity of pulp wedges, whereas reduced O_2, with or without increased CO_2, improved the retention of

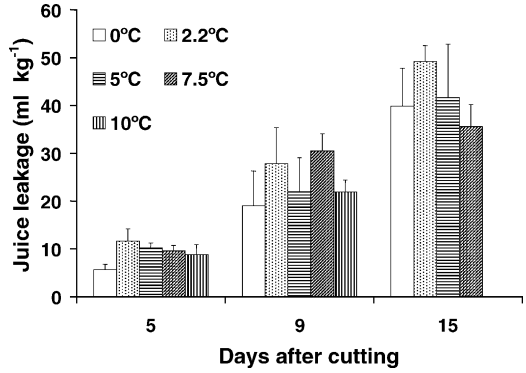

Fig. 4. Volume of juice leaked per kilogram of 'SC3620' pineapple pulp pieces kept under a continuous flow of humidified air at 0, 2.2, 5, 7.5 or 10 °C. Data presented are the averages of three replicates. Vertical lines represent the S.D.

color, as measured by the chroma values, compared to wedges kept under humidified air for 15 days at 5 °C (Fig. 6). There were no significant changes in soluble solids, pH or hue angle values, nor in the volume of juice leaked from the pieces (data not shown).

3.4. Comparison of the suitability of the 'SC3620' and 'Premium Select' cultivars for minimal processing

The cultivar 'Premium Select' had a significantly higher soluble solids content as well as higher acidity and pH than 'SC3620' (Table 1). The contents of β-carotene and total ascorbic acid of this cultivar were about two and three times higher, respectively, than those of 'SC3620'. Pulp color of 'Premium Select' is a more intense, brighter yellow than 'SC3620', as it is reflected in a significantly higher value of chroma and a lower hue angle. Respiration and ethylene production rates of pulp pieces at 10 °C under humidified air were significantly higher for 'Premium Select'.

When pulp pieces of the two cultivars were stored at 5 °C under humidified air for 2 weeks, those of the 'Premium

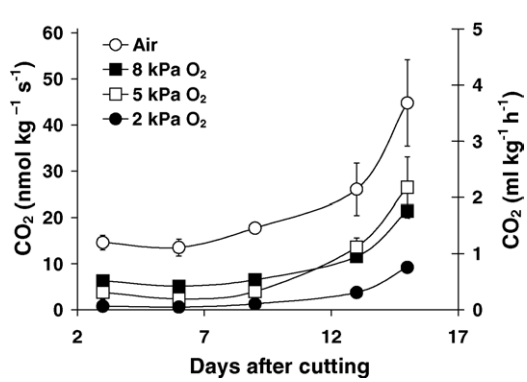

Fig. 5. Respiration rates of 'SC3620' pineapple pulp pieces kept under a continuous flow of humidified air or 2, 5 and 8 kPa O_2 (balance N_2) at 5 °C. Data presented are the averages of three replicates. Vertical lines represent the S.D.

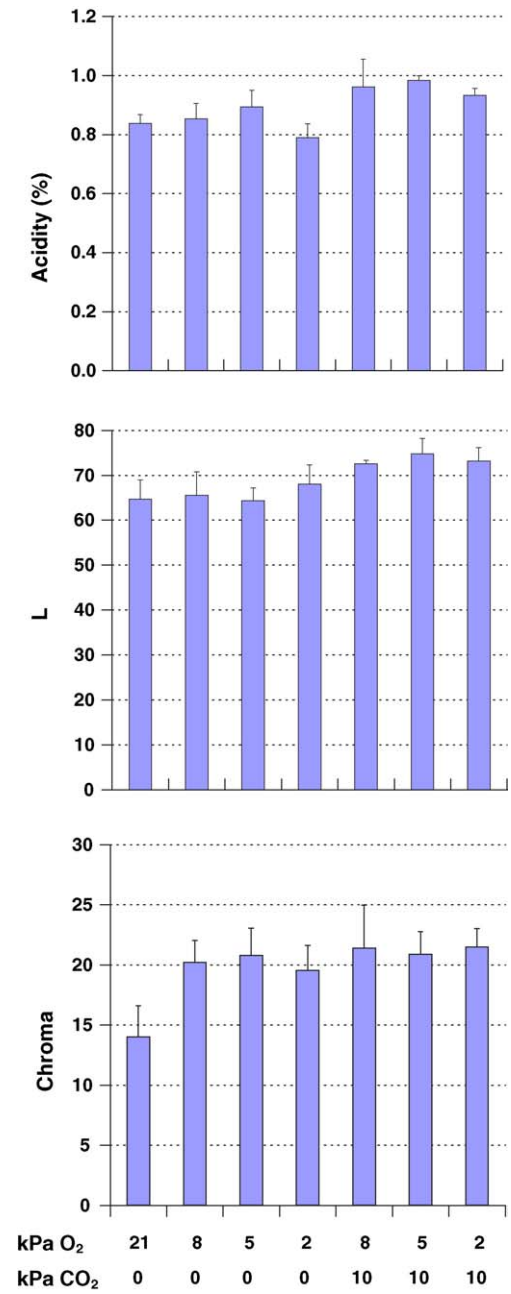

Fig. 6. Acidity (as percentage of citric acid), luminosity (*L*) and chroma of 'SC3620' pineapple pulp pieces that had been kept for 15 days under a continuous flow of humidified air or 2, 5 and 8 kPa O_2 (balance N_2) with or without 10 kPa CO_2. Data presented are the averages of three replicates. Vertical lines represent the S.D.

Select' retained their luminosity (*L*) better than 'SC3620', so the final difference in color among the two cultivars was even more prominent than at the beginning (Fig. 7). Neither cultivar showed a significant change in soluble solids, pH, acidity or firmness during storage. In terms of the volume of juice leaked, after 15 days of storage 'Premium Select' pieces leaked abut one third the volume of that from 'SC3620"s (Fig. 8).

Table 1
Initial quality and physiological parameters of pulp pieces of 'SC3620' and 'Premium Select' pineapple cultivars

	Cultivar		Statistical significance
	SC3620	Premium select	
TSS (%)	11.5	14.7	*
Acidity (mM H^+)	154	123	*
pH	3.35	3.41	*
Total ascorbic acid (mg kg^{-1})	260	789	***
β-carotene (μg kg^{-1})	350	670	***
Flesh color			
L value	75	74	NS
Hue angle	102	98	**
Chroma	24	40	***
Respiration rate[a] (nmol CO_2 kg^{-1} s^{-1})	63.2	88.0	NS
Ethylene production[a] (pmol kg^{-1} s^{-1})	1.69	3.63	**

NS: not significant.
[a] Respiration and ethylene production rates were determined, 24 h after cutting, in pieces kept at 10 °C under a continuous flow of humidified air.
* $P < 0.05$.
** $P < 0.01$.
*** $P < 0.001$

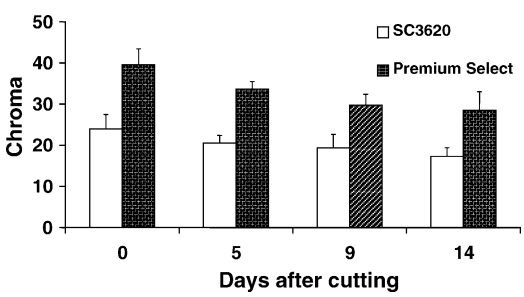

Fig. 7. Change in chroma of 'SC3620' and 'Premium Select' pineapple pulp pieces kept for 14 days under a continuous flow of humidified air at 5 °C. Data presented are the averages of three replicates. Vertical lines represent the S.D.

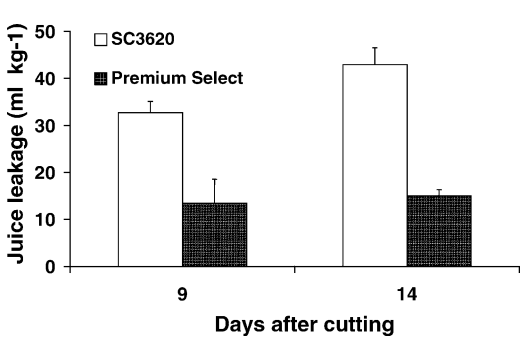

Fig. 8. Volume of juice leaked from 'SC3620' and 'Premium Select' pineapple pulp pieces kept under a continuous flow of humidified air at 5 °C for 14 days. Data presented are the averages of three replicates. Vertical lines represent the S.D.

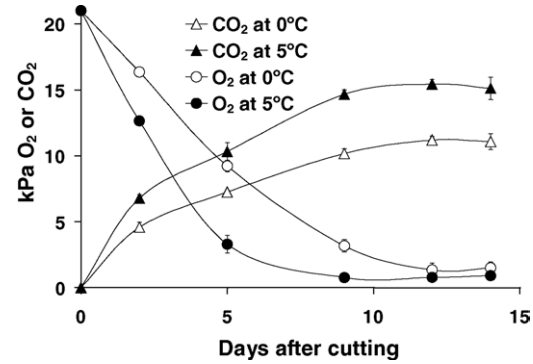

Fig. 9. Changes in O_2 and CO_2 concentrations inside MA containers of 'Premium Select' pineapple pulp pieces stored for 14 days at 0 or 5 °C. Data presented are the averages of three replicates. Vertical lines represent the S.D.

3.5. Modified atmosphere packaging of 'Premium Select' cultivar

The use of modified atmosphere packaging for pulp pieces of 'Premium Select' allowed 14 days storage at 0 or 5 °C without undesirable changes. At 5 °C O_2 levels dropped below 1% and CO_2 levels reached 15% after 9 days in storage (Fig. 9). At 0 °C, it took 12 days to reach the equilibrium levels of 1.5% O_2 and 11% CO_2. In spite of these very low levels of O_2, when the cups kept at 5 °C were opened after a 14-day storage period, only a slight off-odor was detected but it quickly dissipated and no off-flavors were apparent when the pieces were consumed. Packages kept at 0 °C showed no undesirable aroma. Otherwise, the pieces stored at both temperatures for 14 days showed no signs of deterioration while maintaining acceptable levels of soluble solids, acidity, pH and firmness (data not shown).

4. Discussion and conclusions

The main factor studied affecting the quality of fresh-cut pineapple was temperature. The post-cutting life of pulp pieces varied from 4 days at 10 °C to over 2 weeks at 0 °C. This extended life at temperatures well below the chilling injury limit for whole fruits had been previously reported (O'Connor-Shaw et al., 1994; O'Hare, 1994). At all temperatures, the end of commercial life was characterized by a sharp rise in respiration preceding an increase in ethylene production (Fig. 1). Continuation of storage beyond this point led to the appearance of off-flavors and odors and microbial spoilage.

No signs of chilling injury were detected at any point in the pulp pieces, even for those kept at 0 °C for 2 weeks. This could be due to the short duration between removal from refrigerated storage and quality evaluation (about 3 h), since some of the symptoms do not develop until several days after transfer to non-chilling temperatures (Paull and Rohrbach, 1985). This is not likely to be a commercial problem since, due to

the nature of fresh-cut products, they should be consumed shortly after removal from refrigeration. In addition, the elevated CO_2 and reduced O_2 levels associated to the CA and MA might also have reduced the incidence of internal browning (Rohrbach and Paull, 1982; Chitarra and da Silva, 1999).

With temperature being the main factor in fresh-cut pineapple conservation, the main advantage of atmosphere modification was a better retention of color. Reduction of O_2 concentration to 8% or lower improved the final appearance as reflected by higher final chroma values. Increasing CO_2 concentration to 10% had the added advantage of retained luminosity (L) of the pulp pieces. This could be due to a lower activity of browning enzymes such as polyphenol oxidase. Also, elevated CO_2 atmospheres may have delayed microbial growth.

Juice leakage from pulp pieces could be an important factor of deterioration of fresh-cut pineapple. Neither refrigeration nor atmosphere modification reduced the incidence of this problem. However, the 'Premium Select' cultivar was less prone to leakage than 'SC3620'.

The very low respiration rates (CO_2 production of about 0.3 $\mu L\ kg^{-1}\ s^{-1}$) of pulp pieces at 0, 2.2 and 5 °C allowed the use of a MA film such as Mylar®, with a low O_2 transmission rate, without development of permanent off-odors or flavors due to anaerobiosis.

Acknowledgements

Antonio Marrero was the recipient of a Ministerio de Educación y Ciencia scholarship. We thank Dole Fruit International for partial funding of this research.

References

Chitarra, A.B., da Silva, J.M., 1999. Effect of modified atmosphere on internal browning of 'Smooth Cayenne' pineapples. Acta Hort. 485, 85–90.

Dull, G.G., Young, R.E., Biale, J.B., 1967. Respiratory patterns in fruit of pineapple, *Ananas comosus*, detached at different stages of development. Physiol. Plant. 20, 1059–1065.

Hart, D.J., Scott, K.J., 1995. Development and evaluation of an HPLC method for the analysis of carotenoids in foods, and the measurement of the carotenoid content of vegetables and fruits commonly consumed in the UK. Food Chem. 54, 101–111.

Iversen, E., Wilhelmsen, E., Criddle, R.S., 1989. Calorimetric examination of cut fresh pineapple metabolism. J. Food Sci. 54, 1246–1249.

Marrero, A., Kader, A.A., 2001. Factors affecting the post-cutting life and quality of minimally processed pineapple. Acta Hort. 553, 705–706.

O'Connor-Shaw, R.E., Roberts, R., Ford, A.L., Nottingham, S.M., 1994. Shelf life of minimally processed honeydew, kiwifruit, papaya, pineapple cantaloupe. J. Food Sci. 59, 1202–1206.

O'Hare, T.J., 1994. Respiratory characteristics of cut pineapple tissue. Postharvest Group, DPI, Queensland, Australia, 1994 Report.

Paull, R.E., Rohrbach, K.G., 1985. Symptom development of chilling injury in pineapple fruit. J. Am. Soc. Hort. Sci. 110, 100–105.

Paull, R.E., 1997. Pineapple. In: Mitra, S. (Ed.), Postharvest physiology and storage of tropical and subtropical fruits. CAB International, Wallingford, UK, pp. 123–143.

Wright, K.P., Kader, A.A., 1997. Effect of slicing and controlled-atmosphere storage on the ascorbate content and quality of strawberries and persimmons. Postharvest. Biol. Technol. 10, 39–48.

Zapata, S., Dufour, J.P., 1992. Ascorbic, dehydroascorbic and isoascorbic acid simultaneous determinations by reverse phase ion interaction HPLC. J. Food Sci. 57, 506–511.