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Fruit ripening of Solo Sunrise, Tainung #2 and Red Lady papaya at two temperatures

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Abstract

The process of ripening was evaluated in three papaya cultivars, Solo Sunrise (SS), Tainung #2 (T2) and Red Lady (RL) with different mean fruit weights of 387, 1364 and 2266 g and fruit cavity void volumes of 56, 334 and 502 mL and fruit weight/cavity void volume ratios of 6.9, 3.8 and 4.3 g mL^{-1}, respectively. The evaluation was done by comparing physiological determinants of the ripening process; ethylene (C_2H_4) generation and respiratory CO_2 production, measured at two temperature ranges, 20-22°C and 28-30°C, by sampling cavity void volumes, with physico-chemical quality characteristics of ripening: skin colour, flesh firmness and pH. Fruit ripening of the three cultivars was delayed at the lower temperature range as measured both by physiological determinants including pre-and peak climacteric rates and physico-chemical quality characteristics. However, cv RL showed slower ripening than cvs SS and T2 at both temperature ranges, probably partly related to its low fruit weight/cavity void volume of 4.3 g mL^{-1}. Moreover, there were negative temporal displacements for skin degreening compared with those for flesh softening, respiration and ethylene generation in fruit of the three cultivars. Fruits of cvs SS and T2 were fully ripened in 8 days after harvest (DAH) and RL fruits in 10 DAH at the lower temperature range. Values for C_2H_4 generation and CO_2 production measured in the fruit cavity are judged to be sensitive indicators of the progress in the process of ripening.

Key words: Papaya, ripening, climacteric, ethylene, colour, firmness

Introduction

Papaya (*Carica papaya* L.; *Caricaceae*) is a native of Tropical America but is cultivated throughout the tropics, where there are several cultivars retained by inbreeding in their countries of selection. These include *Solo* in Hawaii, *Betty* in Florida, *Hortus Gold* in South Africa and *Improved Petersen* in Australia (Simpson, 1980). Moreover, although *Solo* originated in Barbados in the Caribbean, several improved lines were developed in Hawaii *e.g.* cvs Solo 5, Solo 8, Bush and Sunrise, where papaya is cultivated on a commercial scale for export to the United States and Canada.

The papaya fruit is a fleshy, hollow berry of 0.5 to 3.0 kg in weight. At the lower end of the weight range, the Solo cultivars are hermaphrodites with yellow flesh fruit except for the preferred cvs Bush and Sunrise, with red flesh fruits. Alternatively, cv *Hortus Gold* is dioecious with firm golden flesh fruits and weights of 1.5 -2.0 kg (Salunkhe and Desai, 1984). Most of the postharvest research on papaya including changes in physiology, composition and sensory characteristics with ripening has been done on fruits of cv Solo in Hawaii (Wills and Widjanarko, 1995). However, the wide range of respiratory rates in papaya fruit 3-32 mL CO_2 kg^{-1} hr^{-1} was noted by Biale and Barcus (1970) and recommended storage conditions of temperature and relative humidity reviewed by Thompson (1996).

Solo fruit are exported on a large scale from Hawaii, Malaysia and to a lesser extent from Jamaica in the Caribbean to the U.K., U.S. and Canada. Internationally, they are most popular because of their small size, red flesh colour and other quality attributes, suitable for use as a fresh fruit. However, because of their susceptibility to Bunchy Top, a microplasmic disease transmitted by a leaf hopper, several hybrids have been produced worldwide. Two of these hermaphroditic hybrids, cvs T2 and RL are cultivated in the Caribbean. They vary considerably in size and eating quality from cv SS but are sold locally and exported to regional and international markets (Zhang and Paull, 1990). Unfortunately, little work has been published on the ripening of cvs.T2 and RL. Accordingly, the objective of this study was to conduct a comparative evaluation of the effect of storage temperature on ripening as indicated by parameters of ethylene generation and carbon dioxide production as well as by quality changes of skin colour, flesh firmness and pH in order to detect characteristics of the process of ripening of fruits of the three cultivars, which may be useful in further studies. Gases were measured in the fruit cavity rather than in the void volume of containers in which the fruits were stored to ripen, because preliminary investigations revealed earlier detection of C_2H_4 and CO_2 in the former system by the gas chromatograph used in the investigations.

Materials and methods

Mature papaya fruit of *cvs*. Solo Sunrise, Tainung #2 and Red Lady at the stage of colour break with yellow streaks comprising 6 - 8% of the fruit surface were harvested at the University Field Station and packed in cardboard boxes lined with shredded paper. Fruits were transported to the Food Biology Laboratory, Department of Food Production, at the University of the West Indies, St. Augustine within one hour of harvest. At the laboratory, the fruits were hand washed to remove surface debris. Forty fruits from each cultivar were treated for 20 minutes with hot water at 40°C in separate 150 L metal drums each equipped with

two VWT Scientific thermo-regulators (VWR Scientific, model #1222, Niles Illinois) on opposite ends. To keep fruit submerged, a padded stainless steel grill was placed at the surface level of the water. Fruits were cooled for 30 minutes in tap water, air-dried and allowed to ripen at 28-30°C, 85-90% RH (ambient room temperature) and 20-22°C, 50-60% RH on trolleys lined with foam of 2.22 cm thickness in an air conditioned room. The postharvest quality of the fruits was assessed over an eight day storage period. Carbon dioxide and ethylene evolution rates were measured at two-day intervals while physical and biochemical parameters were measured at 4-day intervals.

CO_2 production and C_2H_4 generation: External CO_2 and C_2H_4 concentrations from fruits were first attempted by enclosing fruit in sealed plastic buckets and extracting gas samples through a rubber septum for analysis. Since detection of C_2H_4 by this method was inconsistent, CO_2 production and C_2H_4 generation from the internal fruit cavity was adopted and production rates were determined by the use of a Finnegan gas chromatograph (Model #9001, Finnegan Corp. Austin, TX). Ethylene was measured using a Flame Ionization Detector (FID) set at 250°C, while carbon dioxide was measured using a Thermal Conductivity Detector (TCD) set at 200°C and analyzed simultaneously. A hollow 4-cm long hypodermic needle was inserted into the cavity and the area around the needle was sealed with petroleum jelly. Approximately 0.3 mL gas sample was withdrawn with a 1.0 mL syringe as described by Salveit (1982). Samples of gas were injected through a rubber septum in the gas chromatograph with oven temperature set at 28°C using helium as the carrier gas with a flow rate of 25 mL/min. The flow rates of hydrogen and air were 15 mL/min and 175 mL/min, respectively. Megabore columns of 0.53 mm diameter and 30 m in length were used. Quantification of carbon dioxide and ethylene production was done by calculation against instrument responses to standard gas mixtures.

Skin colour: Skin colour was measured with a portable tristimulus Minolta Chroma meter (Model CR-200, Minolta Corp., Ramsey, NJ), the meter was calibrated with "L" and "a" coordinates. The "L" values represented the lightness of colour and were greater for lighter colour whilst the "a" values were negative for green and positive for red. Colour was measured at four evenly spaced points along the equatorial region of each fruit.

Flesh firmness: Flesh firmness was determined using a Koehler digital penetrometer (Model #K 19550, Koehler Instrument Company, Bohemia, N.Y) using a K 20500 brass probe with a hardened stainless steel tip which was used to measure penetration depth. The probe had a mass of 2.5 g and the standard plunger used was 47.5 g in mass. A 2.2 cm slice was taken from the midpoint between the stem and the calyx end of the fruit and the plunger vertically pressed into the flesh at four equatorially spaced points along the surface; penetration was expressed in mm sec^{-1}. Increasing depths of penetration represented continuous loss of firmness in fruit.

Fresh fruit weight and cavity volume: For measurement of C_2H_4 and CO_2, harvested fruits of each variety were weighed individually on a Mettler Toledo calibrated digital scale (Model #SB 8001 Toledo SD 8001, Schwerzenbach, Switzerland) to determine fresh weight. Each fruit was subsequently cut in half, seeds removed and weighed. Each half was then filled with distilled water which was poured into a graduated cylinder for cavity volume measurement. In a separate sample of papaya fruit of each cultivar, total fruit weight was measured and fruit void volumes determined as before. Seeds were then removed and weighed and fruit flesh weight calculated by subtracting seed weight from total fruit weight.

pH: The pulp pH was determined using an Orion Research digital pH meter (EA 920 Orion Research Inc. Boston, MA) standardized with two buffer solutions of pH 7.01 and 4.01. The extract was obtained by macerating 25 g of pulp with 100 mL demonized water (Products Corp. Hartford, CT).

Experimental design and statistical analysis: The experiment consisted of two replicates with each replicate containing four fruits. Data were analyzed as a completely randomized design with a factorial arrangement of variables and subjected to Analysis of Variance using Minitab. Comparisons of the means were done using the least significant difference (LSD) method at the 5% level.

Results

Fruit fresh weight and cavity volume: The fresh weights (fwt), cavity volume (cvo) and the fwt/cvo ratios of the fruit (Table 1) showed that there were considerable differences between values for fruit of the three cultivars. Thus, although mean fruit weights and cavity volumes of cv SS were considerably smaller than those of cvs T2 and RL, the fwt/cvo ratio of cv SS (6.9 g mL^{-1}) was 1.8 and 1.6 times those of cvs T2 and RL, respectively. The possible effect of these dimensional differences on C_2H_4 and CO_2 accumulation in the cavity and ripening will be described below. Since CO_2 production and C_2H_4 generation were measured in the fruit cavity, these differences could affect both the accumulation of gases and the interpretation of their effects on ripening.

Respiratory CO_2 and C_2H_4 generation changes with ripening: The time courses of the changes in climacteric patterns of (CO_2) respiration rate and ethylene (C_2H_4) generation varied with cultivars and storage temperatures (Fig. 1 and 2). Examination of initial rates over 0-2 DAH indicated that at both ambient temperature (28-30°C) (Fig. 1C) and at (20-22°C) (Fig. 2C) cv RL showed slower rates of CO_2 and C_2H_4 generation than cvs SS and T2 (Figs. 1A, 1B). Whereas rates of CO_2 and C_2H_4 generation in fruit of each cultivar were similar at ambient temperature (Figs. 1 A, B and C). C_2H_4 generation proceeded at a more rapid rate than CO_2 evolution at 20-22°C particularly in fruit of cvs SS and T2 (Figs. 2 A, B). Thus, the preclimacteric period of C_2H_4 generation occurred over 0-2 and 0-4 DAH at 28-30°C and 20-22°C, respectively in cv RL but was not recorded in cvs SS and

Table 1. Dimensional characteristics of fruit of three papaya cultivars

Cultivar	Fresh weight (g)			Fruit cavity void vol (mL)	Frut pulp weight/ cavity void volume (g mL^{-1})
	Whole fruit	Fruit seeds	Fruit pulp		
Solo Sunrise (SS)	387b	ND[Z]	387b	56a	6.9b
Training #2 (T2)	1364e	87a	1277d	334b	3.8a
Red Lady (RL)	2266g	124a	2142f	502c	4.3a
LSD (P=0.05)		109.3		81.5	1.3

[Z]ND: No data due to seedless nature of cultivar

Table 2. Effect of temperature, storage duration and cultivar upon colour development ("L" and "a" values) of papaya fruit

Colour/Day	28-30°C			20-22°C		
	Solo Sunrise	Tainung #2	Red Lady	Solo Sunrise	Tainung #2	Red Lady
"L" value						
0 DAH	33.65 cd	34.65 d	30.35 a	32.32 b	33.94 cd	31.23 ab
4 DAH	56.43 h	61.15 i	48.75 e	51.77 f	52.33 f	47.70 e
8 DAH	70.08 k	70.46 k	61.21 i	64.35 j	63.71 j	54.03 g
LSD (P=0.05)			1.13			
"a" values						
0 DAH	-11.67 a	-12.34 a	-1.59 d	-10.52 ab	-10.89 a	-12.93 a
4 DAH	-1.66 d	-0.72 d	-3.67 c	-5.19 c	-5.32 c	-8.21 b
8 DAH	5.25 e	7.85 f	0.64 d	4.02 e	4.66 e	-5.12 c
LSD (P=0.05)			2.54			

T2 at either temperatures (Figs. 1 and 2). Preclimacteric CO_2 evolution occurred over 0-2 DAH for cv RL at 28-30°C and over the same period for cvs SS and T2 at 20-22°C.

The climacteric peak of autocatalytic C_2H_4 generation occurred at 2 DAH in cvs SS and T2 at 28-30°C but at 4 DAH at 20-22°C. Alternatively, for cv RL fruits, this peak occurred on 4 and 6 DAH at 28-30°C and 20-22°C, respectively (Figs. 1 and 2). At 28-30°C, the respiration and ethylene peak heights were similar for cvs T2 and RL fruits but higher than those for cv SS fruits (Figs. 1B and C). At the lower storage temperature (20-22°C), the CO_2 and C_2H_4 peak heights were highest for cv T2 fruits despite their occurrence at the same time (4 DAH) as cv SS fruits and 2 days earlier than cv RL fruits (Figs. 2A and 2B). Temperature seemed to have greater inhibitory effect on initial respiration over 0-2 DAH than on C_2H_4 generation (Fig. 2) particularly in cvs SS and T2 fruits.

The lower peak heights for C_2H_4 and CO_2 accumulation in cv SS fruits at both temperatures were surprising in view of the lowest

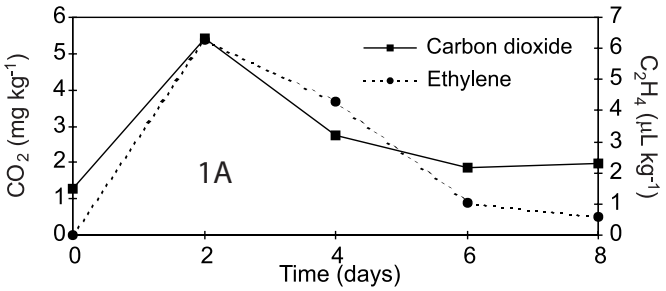

Fig.1A. Respiration and ethylene production rates of papaya cv. Solo Sunrise stored at 28-30°C. LSD (P=0.05) CO_2 = 1.11; C_2H_4 = 0.69.

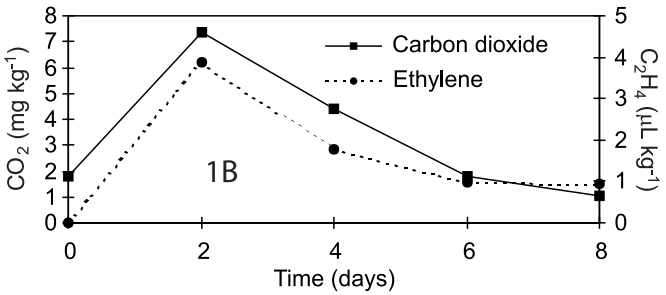

Fig.1B. Respiration and ethylene production rates of papaya cv. Tainung # 2 stored at 28-30°C. LSD (P=0.05) CO_2 = 1.11; C_2H_4 = 0.69.

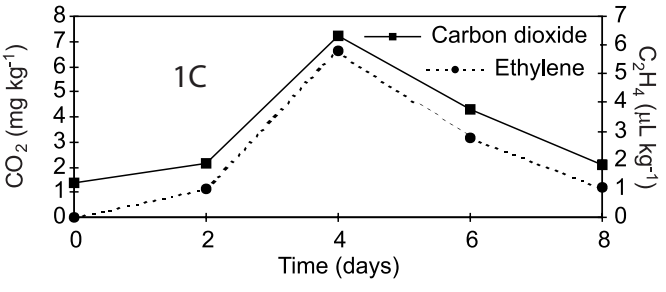

Fig.1C. Respiration and ethylene rates of papaya cv. Red Lady stored at 28-30°C. LSD (P=0.05) CO_2 = 1.11; C_2H_4 = 0.69.

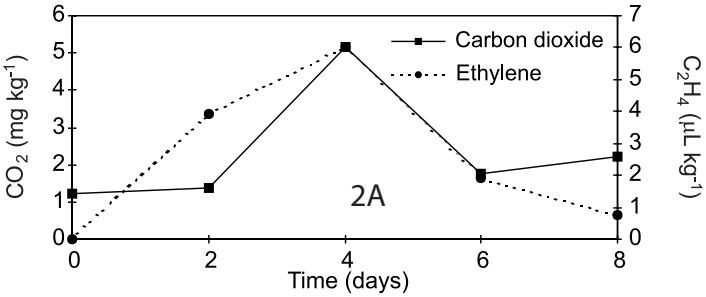

Fig. 2A. Respiration and ethylene rates of papaya cv. Solo Sunrise stored at 20-22°C. LSD (P=0.05) CO_2 = 1.11; LSD (P=0.05) C_2H_4 = 0.69.

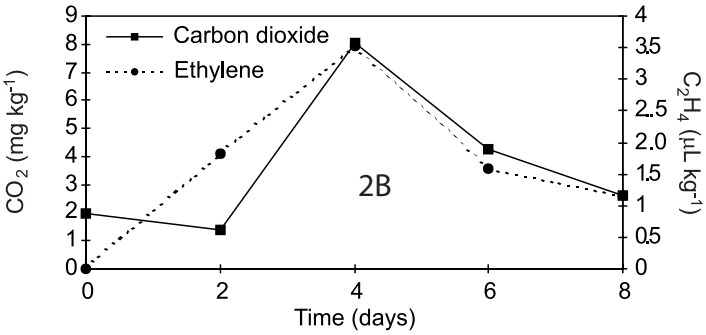

Fig. 2B. Respiration and ethylene production rates of cv. Tainung #2 stored at 20-22°C. LSD (P=0.05) CO_2 = 1.11; LSD (P=0.05) C_2H_4 =

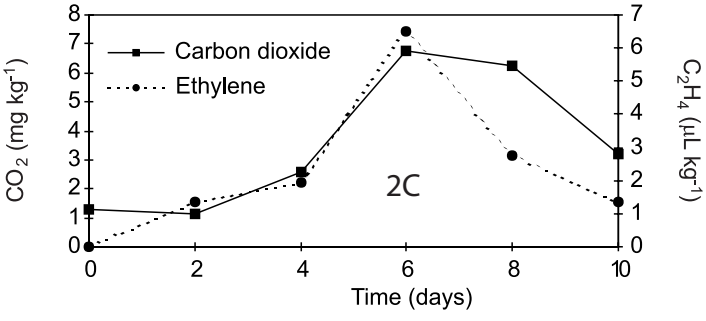

Fig. 2C. Respiration and ethylene production rates of cv. Red Lady stored at 20-22°C. LSD (P=0.05) CO_2 = 1.11; LSD (P=0.05) C_2H_4 = 0.69.

Table 3. Effect of storage duration and cultivar on pH of papaya

Cultivar	pH		
	0 DAH	4 DAH	8 DAH
Solo Sunrise (SS)	5.14bc	4.64a	4.49a
Training #2	5.60cd	4.86ab	4.53a
Red Lady (RL)	5.63e	4.92ab	4.52a
LSD (P=0.05)		0.47	

Table 4. Interaction effects of cultivar x storage duration upon firmness of papaya

Cultivar	Firmness		
	0 DAH	4 DAH	8 DAH
Solo Sunrise (SS)	16.19b	87.76d	99.91e
Training #2	13.89ab	86.46d	104.37f
Red Lady (RL)	10.19a	66.47c	88.05d
LSD (P=0.05)		3.92	

Table 5. Interaction effects of temperature x storage duration upon firmness of papaya

Temperature (^{0}C)	Firmness		
	0 DAH	4 DAH	8 DAH
28-30^{o}C	13.38a	84.89c	101.19e
20-22^{o}C	13.48a	75.68b	93.70d
LSD (P=0.05)		3.20	

void cavity volume (56 mL) and highest flesh fwt/cvo ratio (6.9 g mL^{-1}) recorded in fruit of this cultivar. Alternatively, the extension of the preclimacteric phase in cv RL to 4 DAH at 20-22^{0}C could possibly be related to the low flesh fwt/cvo ratio (4.3 g mL^{-1}) of this cultivar. In cvs SS and T2, there were preclimacteric phases of respiratory CO_2 production over 0-2 DAH at 20-22 ^{0}C but autocatalytic C_2H_4 generation had apparently already began at 2 DAH. This early separation of CO_2 and C_2H_4 production rates did not occur in cv RL.

Quality changes in colour, texture and pH with ripening: Degreening measured by "L" and "a" values progressed significantly (P<0.05) as storage time increased for each cultivar, more so at 28-30^{o}C than at 20-22^{o}C, as expected (Table 2). Changes in flesh colour, although not measured paralleled skin degreening. Colour development in both skin and flesh was also cultivar specific. Thus at 28-30^{o}C cvs SS and T2 changed from colour-break to a bright uniform yellow colour (skin and flesh) at 8 DAH but cv RL developed a bright orange colour 2 days later. At 20-22^{o}C, these changes were realized at 10 DAH. There was also evidence of decay in some fruit particularly at the 28-30^{o}C temperature range at 10 DAH.

At the climacteric phase over 0-2 DAH at 28-30^{o}C cvs SS and T2 showed an estimated 30% (approx.) yellow skin colour, which increased to 60% at the post climacteric stage over 4-6 DAH. These colour changes accounted for almost a doubling of "L" values and much greater increases for "a" values (Table 2). The orange colour changes in cv RL proceeded similarly but at a slower rate as indicated by the lower "L" and "a" values at both temperatures compared to cvs SS and T2. The rate of fruit softening as measured by penetration depths (Tables 4 and 5) increased with increasing storage durations and was affected by cultivar and temperature and indicated by significant interactions (Tables 4 and 5). As observed previously in the development of skin colour and rise in CO_2 and C_2H_4 evolution, cvs SS and T2 showed similar rates of softening while in cv RL softening was significantly less pronounced. The pH values decreased in fruit of all three cultivars during ripening (Table 3).

Discussion

Ripening in climacteric fruit is the collective process in which many physiological and physico-chemical changes occur, more or less in parallel to each other and in a time relation to the climacteric. However these changes are themselves not necessarily causally related (Pratt and Goeschl, 1969). The physico-chemical changes *e.g.* skin degreening and flesh softening are those by which fresh fruit quality is judged and the physiological changes (*e.g.* respiratory CO_2 production and C_2H_4 generation) are those which determine the time relation of the physico-chemical changes to the completion of the ripening process and hence to the storage life of the fruit.

In this study, ripening of fruit of the commercial cv SS was compared with that in two disease resistant hybrids of greater size, cvs T2 and RL recently introduced to the Caribbean from Taiwan. This was done by measuring C_2H_4 generation and CO_2 in the fruit cavity of the hollow berry as well as skin colour and flesh texture of the ripening fruit. It had previously been demonstrated that C_2H_4 generation in papaya occurred in the pericarp tissue of the fruit (Allong *et al.,* 2001). It is generally agreed that C_2H_4 plays a stimulatory role, albeit imprecisely defined, in fruit ripening, either by its increasing concentration or by increased sensitivity of mature-green fruit tissues to a threshold level of C_2H_4. In either case, the low fresh fruit weight/cavity volume ratio in cv RL (4.3 g mL^{-1}) could have delayed realization of the threshold level of C_2H_4 needed to stimulate ripening. However, whilst the high value of this ratio in cv SS (6.9 g mL^{-1}) could explain its more rapid ripening than cv RL, the lowest ratio (3.8 g mL^{-1}) and rapid ripening in cv T2 did not support the explanation of the influence of cavity dimensions on the ripening process. Moreover, autocatalytic production of C_2H_4 has also been considered to be a product of the ripening process. Notwithstanding the possible role of cavity volume in realized CO_2 and C_2H_4 accumulation and concentration, the effect of temperature on such accumulation differed for the two gases. Thus, at 28-30^{o}C no preclimacteric period was recorded for either gas in cvs SS and T2 but such periods were recorded for both gases in cv RL. Alternatively, at 20-22^{o}C (Fig. 2) preclimacteric periods occurred for CO_2 production in all three cultivars but only for C_2H_4 generation in cv RL. This could mean either that respiratory inhibition was affected to a greater extent by lowered temperature than C_2H_4 generation, leading to 2.33 to 2.66 times greater levels of C_2H_4 in cavities of cvs SS and T2 respectively than that in cv RL by 2 DAH at 20-22^{o}C (Fig. 2). Thus at this temperature, increase in C_2H_4 generation preceded that in respiration in cvs SS and T2 and hence could have stimulated the climacteric respiratory response in fruit of these cultivars.

Differences in CO_2 and C_2H_4 production rates among commercial lines of papaya were also reported in previous studies on "Kapoho" (Akamine and Goo, 1976, 1979), "Solo Sunrise"(Paull and Chen, 1983) and in "Taiping" and "Bentong" (Nazeeb and Broughton, 1978).

Even after optimal ripeness, cv RL had firm flesh which was judged to be ideal for fresh-cut purposes (Allong *et al.,* 2001).The

slower softening rate of cv RL fruit would also allow for greater flexibility in harvesting and handling of the fruit throughout the marketing chain. The intensity of the orange skin colour and corresponding firmer flesh have the added advantage of allowing harvesters to pick fruits at a later stage when more sugar has accumulated. According to Chan *et al*. (1979) papaya fruits on the whole have no starch reserves for production of soluble sugars after harvest. Thus, a fruit that remains on the tree accumulates more sugars and develop a higher quality (Zhang and Paull, 1990). Although the mode of action of slower ripening in cv RL fruits is unknown it could provide material for generating commercial lines with longer shelf life as well as to conduct research on the genetic regulation of flesh softening in papaya ripening either through changes in pectin or pectolytic enzyme activity.

The negative temporal displacement of skin degreening, compared to softening, respiration and ethylene production rates in this study is in agreement with Zhang and Paull (1990) and appears to be unique when compared both with results of Grumet *et al.* (1981) and Tigchelaar *et al.* (1978) in tomatoes as well as those with Brecht *et al.* (1984) with nectarines. However, in view of the rapid degreening response of most fruits to low C_2H_4 concentrations, the apparent inhibition of degreening in our investigation could be due to the lower C_2H_4 concentration in the laboratory atmosphere compared with that in the fruit cavity.

The pH values decreased in all three cultivars during storage. This may be explained by the observation that papayas are one of the few fruits in which ascorbic acid content increased with ripening (Selvaraj *et al.*, 1982). However, storage temperature had no significant effect on these changes.

Fruit of three papaya cultivars, *cvs* SS, T2 and RL stored at the 20-22°C temperature range showed distinct pre-climacteric phases, delayed climacteric peaks (2 days later) and ripened more slowly, than fruit stored at 28-30°C as assessed by C_2H_4 generation and CO_2 production as indicated by the physico-chemical quality characteristics measured. Such fruit were also more attractive as judged by even colour, ripened firmness and reduced incidence of disease lesions. They were more likely to be acceptable to consumers. As a result, the 20-22°C temperature range was used in the following experiments on the inhibition of ripening by 1-MCP. However, fruit of cv RL ripened more slowly than those of cvs SS and T2. This could have been induced by higher concentrations of C_2H_4 in the fruit cavity of cv RL than in that of cv SS; associated with a lower fresh fruit/cavity volume ratio in cv RL. However, the rapid ripening/low ratio characteristics of fruit of cv T2 did not support this interpretation.

The negative temporal displacement of skin degreening compared with C_2H_4 generation and CO_2 production and flesh softening was explained by the difference in C_2H_4 concentration between the fruit cavity and the laboratory environment. It was concluded that occurrence of preclimacteric C_2H_4 and CO_2 concentrations and climacteric peak levels of the fruit cavity were sensitive indicators of the progress of ripening in papaya fruit and may be used in studies of the effect of 1-MCP on ripening.

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