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Postharvest Variation in Composition of Soursop (*Annona muricata* L.) Fruit in Relation to Respiration and Ethylene Production[1]

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Abstract. **Total soluble solids, ethanol insoluble fraction, pH, titratable acidity, total phenols, total ethanol-soluble sugars, ascorbic acid, respiration, and ethylene production were determined sequentially in individual soursop fruits from the day of harvest until the start of fruit breakdown. Total soluble solids increased from about 10° Brix to near 16° Brix during 3 days of ripening. Fruit pulp pH declined from 5.8 to 3.6 with a concomitant increase in titratable acidity over the same ripening period. Penetration force was high, generally greater than 7.5 kg, in the preclimacteric stage and then declined to less than 0.5 kg during ripening. Total phenols declined during ripening to one-third of the preclimacteric levels, while total ethanol-soluble sugars and ascorbic acid increased twofold and elevenfold, respectively. The maximum respiration rate was 108 ml/kg·hr. Ethylene production increased 24–48 hr after the fruit climacteric was initiated. The optimum eating stage occurred at day 5 to 6 from harvest at the peak of ethylene production. At a later stage, the fruit was more bland with a slight off-odor; this correlated with a decline in the titratable acidity and total phenols.**

Soursop, or guayabano, is indigenous to tropical America and is now spread throughout the lowland tropics. The fruit is prized for its very pleasant, distinctive, sub-acid, aromatic, juicy flesh. The fruit pulp is used for drinks and sherbets. These products have excellent marketing possibilities in the United States and Europe (13, 20).

There are few studies on the changes which take place during ripening of soursop fruit (8). Biale and Barcus (6) classified the fruit as climacteric with a multiphasic increase in respiration because of the aggregate fruit type. Akamine and Goo (2) did not find this multiphasic respiration when respiration rate was determined once daily. The mature fruit is characterized by a high starch content which is rapidly hydrolyzed to sucrose (16.5%), glucose (21.5%), and fructose (17.0%) (9), although Bernegau (5) had reported considerably less sucrose. The organic acids are reported as a mixture of malic and citric in the approximate proportion of 2:1 (14).

There is no precise information on the simultaneous compositional changes which occur in these fruit and their relation to respiration, ethylene production, and softening of the fruit. The difficulty of judging fruit maturity on the tree, the variation in the postharvest period before ripening commences, the rapidity of ripening, and the short period when the fruit is edible make knowledge of this relationship essential for processed pulp production and for storage and ripening studies. These changes are reported here in sequential measurements from individual fruits.

Materials and Methods

Measurements of respiration and ethylene production. Soursop fruits were received by air shipment in Honolulu on the afternoon of the day of harvest from the Waiakea Agricultural Experiment Station on the island of Hawaii. Fruits were mature green, weighing from 1.0 to 2.5 kg each with a penetrometer reading greater than 7.5 kg. Individual fruits were immediately placed in 2-liter glass jars at 22°C and flushed continuously with water-saturated ethylene-free air (380 ml/min). At hourly intervals, the outflow from each jar was passed through a Beckman 865 IRGA for the determination of CO_2 evolution. Each morning and afternoon the jars were disconnected from the airflow and sealed for 1 hr. A 1-ml sample was injected into a Varian Aerograph 1400 GC with alumina column and photoionization detector for determination of ethylene production.

Sample method. To avoid the variability existing between fruit in their rapid rate of ripening (2–3 days), samples for determination were taken randomly and aseptically from a single fruit each day. This method was modified from the procedure used by Awad and Young (3) for avocado. A 5-to-7-cm sample plug was removed with a sterile 13-mm stainless steel cork borer, annd the hole was immediately plugged with sterile cotton wool and covered with warm lanolin. The fruit was then returned immediately to the respiration jar. Respiration and ethylene production of control fruit were found not significantly different from those of the multiply sampled fruit.

The sequential results presented in Fig. 1 and 2 are from only 1 fruit. However, all determinations, except respiration, were carried out on many fruits. The start of the climacteric respiratory rise was used to align the changes in composition to allow comparison. Similar patterns were obtained for all other fruit samples; 43 fruit were used for respiration and ethylene production and at least 8 fruit were used for all other determinations.

Respiration and ethylene production patterns between fruit with and without removal of plugs were very similar. The rapid rate of ripening (2–3 days) may mask the effect of tissue removal, but the compositional values obtained from fruit sampled only once at various stages of ripening were comparable to those in the multisampled fruit.

Dry matter and ethanol-insoluble material. A portion of the plug was placed in a tared vial and weighed. Following drying at 90°C overnight, the vial was weighed again and dry weight percentage of fresh weight was calculated. Another 1 g portion

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of the plug was homogenized with 5 ml of 80% (v/v) ethanol and centrifuged (× 5,000 *g*). The pellet was resuspended and recentrifuged twice with 5 ml of 80% (v/v) ethanol. The pellet was dried at 90° overnight and weighed. The ethanol-insoluble percentage of fresh weight was calculated.

Deformation force. A 1.5-cm disc was attached to a force gauge (Hunter Spring LKG-14) and brought into contact with the fruit. The force required to depress the disc 1 mm into the fruit was determined. The area of the fruit tested was removed aseptically for other measurements.

Total soluble solids, titratable acidity, and pH. Total soluble solids of 100 µl of expressed juice were determined with a Bausch and Lombe Abbe-3L refractometer at 22°C with water as the standard. After homogenizing 2 g of a plug with 10 ml of deionized water, pH was determined. The homogenate was titrated with 0.1 M sodium hydroxide to pH 7.8 and results were expressed as meq/100 g tissue.

Total phenols, total sugars, and ascorbic acid. We homogenized 2 g of tissue with 25 ml of 90% (v/v) ethanol, and an aliquot of the cleared supernatant was used for analysis. Total phenols were determined by the procedure of Singleton and Ross (18) with catechol as the standard. Total sugars were determined by the phenol-sulphuric acid procedure of Dubois et al. (10) with glucose as the standard. Ascorbic acid was determined on an aliquot from the supernatant fraction after homogenizing 1 g of tissue with 10 ml of 3% (w/v) oxalic acid using the dye reduction method (12).

Minerals. Pulp tissue was dried, dry-ashed at 500°C overnight, and cations were determined by atomic absorption spectroscopy.

Results and Discussion

Fruit weight varied from 1 to 2.5 kg. The mean fruit composition was 85.5% pulp, 3.3% seeds, 8.9% skin, and 2.3% fruit stem. This pulp percentage was higher than the 67.5% reported by Sanchez Nieva et al. (15) or the 61.6% reported by Benero and Rodriguez (4), possibly due to different cultivars, environmental factors, and degree of pollination. The coefficient of variation for seed weight was 62.3%; all others were about 30%. The correlation with seed weight explained 49% of the variation in fruit weight and 44% of the variation in pulp weight, indicating that pollination does play a significant role in fruit growth. Schroeder (17) found a good correlation between seed number and the fruit weight of the cherimoya, also.

The ripe fruit contained 189 mg N/100 g fresh weight of pulp. This value was 3 times the value reported (8), which could reflect different fertilizer practices and cultivars. Other values of 263 mg K, 21 mg Ca, 16 mg Mg, and 25 mg P per 100 g fresh weight of pulp agreed with the published values of Adams (1).

Trends in respiration and ethylene production (Figure 1) relate to changes in composition with ripening. A low level of ethylene production occurred during the preclimacteric postharvest stage. Ethylene production increased on the 4th day after harvest from 0.2 to 0.9 µl/kg·hr, 48 hr after the respiratory climacteric was initiated. Ethylene production peaked (290 µl/kg·hr) at about the same time as respiration rate reached a plateau of 108 ml/kg·hr at day 6. Ethylene peak production rates ranged from 80 to 720 µl/kg·hr. This variation in ethylene production rate was possibly due to the number of fruit segments ripening at any one time. All fruit showed a similar irregular increase in respiration, presumably due to the aggregate nature of the fruit, with different segments ripening at different times. The multiphasic respiration

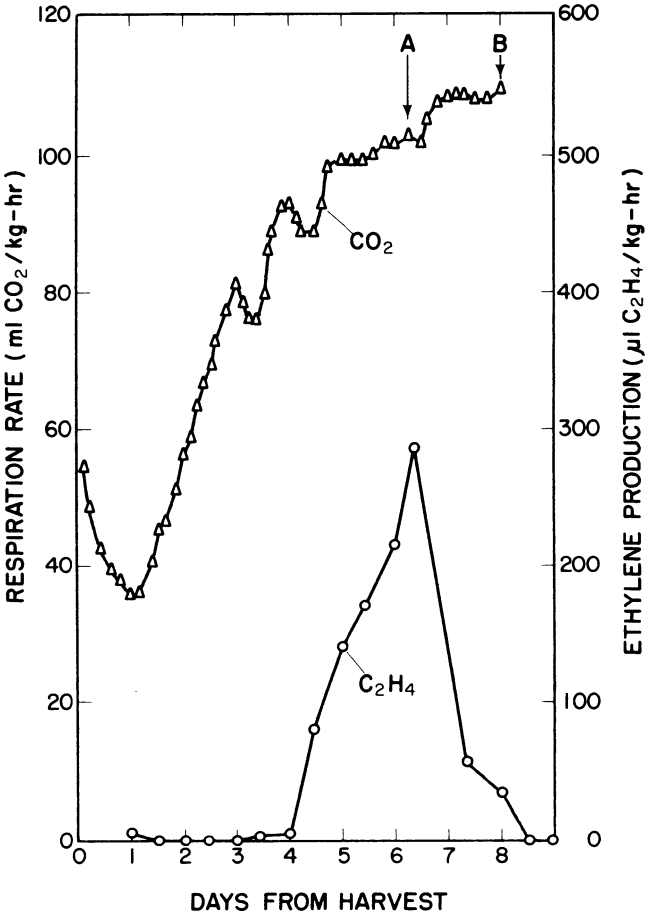

Fig. 1. Postharvest respiration rate (×) and ethylene production (○) trends of an individual soursop fruit. Fruit was soft and edible after 5 days. At points A and B the fruit skin was 20% and 80% black, respectively.

agrees with the finding of Biale and Barcus (6) for soursop fruits purchased in markets on the Amazon valley.

Soursop fruit respiration and ethylene production had similar patterns and production rates to those of cherimoya (*Annona cherimola* Mill. cv. Chaffeu) and sugar apple (*Annona squamosa* L.) fruits (7, 11). The delay in the ethylene production increase, after the initiation of the climacteric, suggests that ethylene is not directly involved in ripening. Low levels of internal fruit ethylene (50 ppb) were not found to initiate the climacteric rise and ripening in cherimoya (11). The method used in extracting cherimoya internal fruit ethylene gave an average ethylene content and did not allow for localized parts of the fruit having higher concentrations sufficient to initiate ripening in more responsive parts of the aggregate fruit. The alternate possibility is that ethylene peak serves only to accelerate and coordinate the ripening changes already initiated, as suggested by Trewavas (19). Endogenous ethylene response was dependent upon the sensitivity of the tissue to initiation of ripening, due to an increase in ethylene receptor sites and changes in the concentration of other plant growth substances with a decrease in inhibitors or an increase in activators.

The fruit was soft and edible in about 5 days. This varied; some fruit when received had already started their climacteric and were ready to eat in 2 to 3 days. Other fruit took up to 3 days before the start of the climacteric rise. In order to compare different fruit, the start of the climacteric rise was used to align

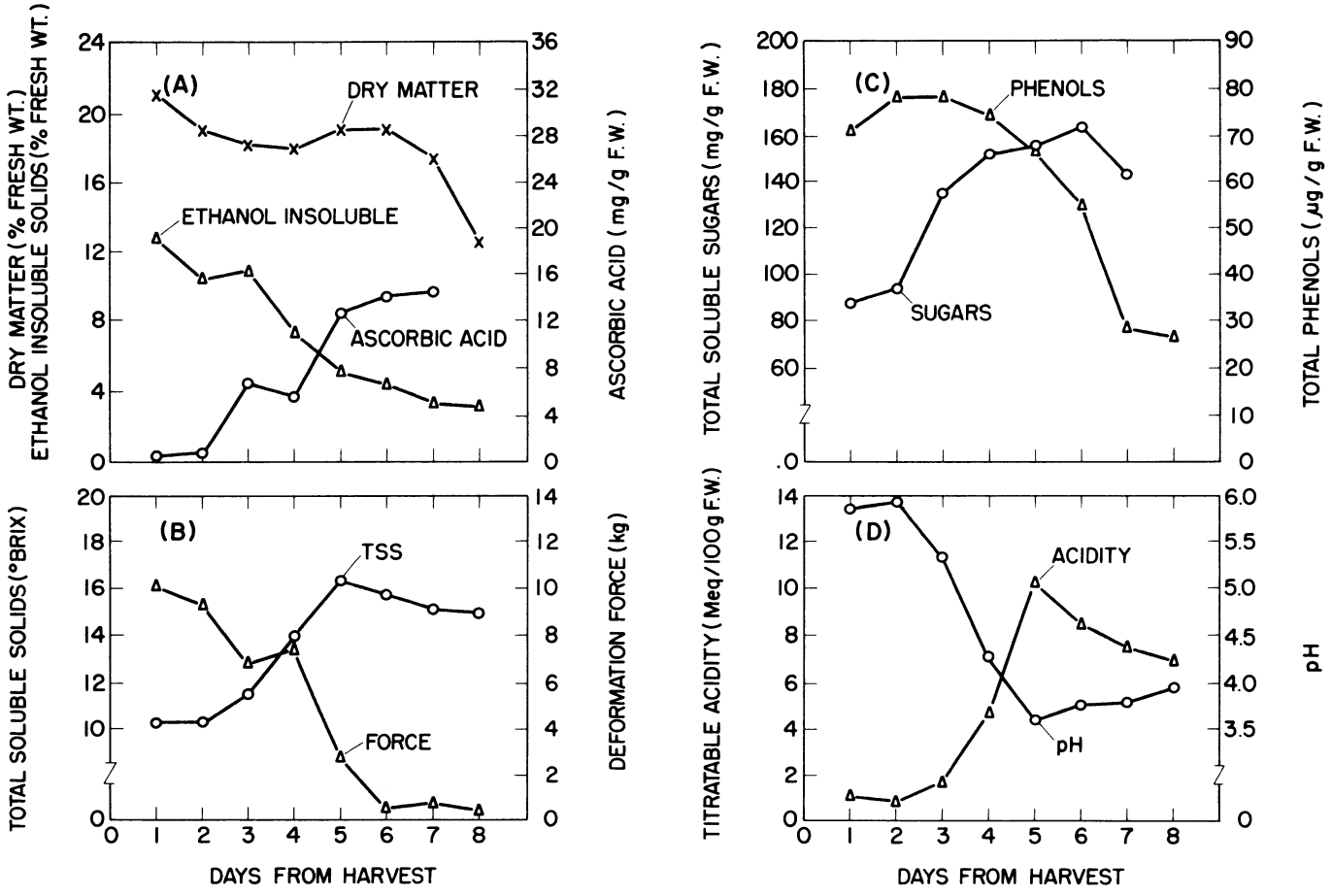

Fig. 2. Postharvest trends in composition during the ripening of individual soursop fruit: A) percentage dry matter, ethanol insoluble material, and ascorbic acid, B) deformation force and total soluble solids, C) total soluble sugars and total soluble phenols, and D) titratable acidity and pH. Fruit was soft and edible after 5 days.

the different fruit results. The variation (Table 1) indicated that aligning results from different fruits in this way gave meaningful and useful data. Higher variation was found during sampling for total soluble sugars and total soluble phenols (Table 1), possibly due to internal variation in fruit composition.

During ripening, the fruit skin changed color from dark green to a light matte-green-yellow and finally to black after the respiration rate had reached a plateau. There was a rapid decrease in the force required to depress the skin, (Fig. 2B), with the decline occurring as the respiration rate increased. The edible stage occurred when the deformative force was less than 2 kg and the skin was light matte-green to 10% brown. The decline in deformation force paralleled the decrease in ethanol-insoluble fraction (Fig. 2A). The decline in force and ethanol insoluble fraction was probably due to starch hydrolysis and some wall breakdown similar to that found for custard apple (7). Dry matter percentage was constant until the fruit skin was greater than 50% brown to black, and then it began to decrease (Fig. 2A). The final value agreed with the findings of Sanchez Nieva et al. (16).

Concomitant with the decrease in the ethanol insoluble fraction was an increase in ascorbic acid (Fig. 2A), total soluble solids (Fig. 2B), total soluble sugars (Fig. 2C), and total titratable acidity (Fig. 2D). Total soluble solid and total titratable acidity increases began between 2 to 3 days from harvest. Total soluble sugars began increasing 1 to 2 days (Fig. 2C) from harvest at the same time as the increase in respiration. Though there was a variation in the total soluble sugar results (Table 1), this pattern of an earlier increase was consistent in the other fruit tested. Total soluble solids increased from ca. 10° to ca. 16° Brix between days 2 and 5, while the total soluble sugars indicated a change of ca. 8% over the period of 1 to 5 days. The difference was probably due to the total soluble solids being performed on expressed juice, while the total soluble sugars was performed on a total extract. Also, the total soluble sugar assay (10) gives different responses to different sugars.

There was marked decrease in pH from 5.5 to 3.7 over the 3 days of ripening (Fig. 2D). This decrease was matched by an increase in titratable acidity from ca. 1 meq/100 g to 10 meq/100 g fresh weight. The major titratable acids are malic and citric (14). Ascorbic acid increased over the same period (Fig. 2A), although this probably did not contribute to titratable acidity, as it was most likely present as a salt. Similar ripening pattern and concentration changes have been reported for custard apple (7). The decline in titratable acidity (Fig. 2D) after 5 days and the major decrease in the amount of extractable phenols (Fig. 2C) of the same stage correlated with the change in flavor of the fruit. Fruit after day 6 developed a more bland flavor and a slight objectionable off-odor. Work is underway to characterize the change in flavor and odor during fruit ripening.

The ripening of the climacteric soursop fruit involves a conversion of starch to soluble sugars and organic acids. Soluble sugars increased at the same time as the climacteric rise in respiration, before the increase in titratable acids. The peak of ethylene production agreed with the edible stage of the fruit and

Table 1. Trends in composition of 4 soursop fruit at 3 stages of ripening. The start of the respiratory climacteric rise was used to align the data from the different fruit.

	Preclimacteric		Climacteric rise		Climacteric peak	
Variable	Mean	SD	Mean	SD	Mean	SD
Dry matter (%)	22.0	1.67	1.97	2.14	15.3	3.27
Ethanol insoluble dry matter (%)	11.8	1.56	5.9	0.82	4.0	0.56
Total soluble solids (° Brix)	10.6	0.69	15.3	1.04	16.3	1.01
Penetrometer force (kg)	15.5	1.29	2.6	0.95	0.5	0.07
pH	5.9	0.12	4.6	0.32	3.7	0.08
Titratable acidity (meq/100 g fresh wt)	1.2	0.66	3.2	1.6	9.8	1.57
Total soluble sugars (mg/g fresh wt)	91.8	9.83	127.5	64.34	164.1	14.94
Total phenols (μg/g fresh wt)	70.3	6.38	54.8	7.61	27.8	4.55
Ascorbic acid (mg/g fresh wt)	0.1	0/08	7.6	3.11	13.8	3.68

peak of aroma production at day 5 to 6. After day 5 to 6, the titratable acidity and ethylene production declined along with the total phenols, and the fruit developed a more bland flavor and a slightly objectionable odor.

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