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Effect of prolonged solar exposure on the vitamin C contents of tropical fruits

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Five groups of fruits: mango, melon, orange, papaya, and pineapple were exposed to sun from 8 a.m. to 6 p.m. simulating open marketing practices in the tropics. Their internal temperatures were recorded every 30 min and samples were analyzed for vitamin C and total soluble solids every hour. Internal temperatures of the fruits were considerably higher than the ambient temperature and the differences ranged from 8·1 to 11·1°C. The level of vitamin C declined considerably (20–56%) until about 1 p.m. followed by an unexpected upsurge reaching close to the initial or even higher value by 6 p.m. On average the total soluble solids, during solar exposure, gradually increased by about 14% of their initial values.

INTRODUCTION

Fruits and vegetables are important sources of dietary nutrients in many developing countries. Tropical fruits are particularly important because of their high vitamin C contents. For example, a 100 g portion of papaya provides 84 mg which represents 140% of the US Recommended Daily Allowance for vitamin C. A large proportion of the tropical fruit production is consumed locally and hence they make a substantial contribution toward the total ascorbic acid intake of local population. Vitamin C, however, is known to be rather unstable (Kennedy *et al.*, 1989, 1992) and hence appropriate postharvest measures should be taken to optimize the availability of this natural and abundant source of vitamin.

There have been several studies on the effects of postharvest handling and storage practices on vitamin C levels in fruits and vegetables. Stafford (1983) cited a few studies on mango indicating decreases in the level of ascorbic acid at room temperature storage and increases under refrigerated storage. Vasques-Salinas & Lakshminarayana (1985) observed the effect of ripening temperature ranging from 16 to 28°C on the ascorbic acid contents in four mango varieties. The tendency, they observed, was a gradual decline in ascorbic acid level as the temperature increased. Dudek *et al.* (1980) reported that the rate of postharvest degradation of ascorbic acid in fresh produce is very high during marketing and storage at ambient temperature. They attributed this to the high postharvest activity of ascorbic acid oxidase.

In the tropics the fruits and vegetables are often sold in the open market or on the roadside with very little shading. Occasionally, the seller would have an umbrella for protection from the sun, but the produce would remain exposed to the sun and other elements of nature throughout the entire merchandizing period. Rickard & Coursey (1979) reported that because of the continuous exposure to sunlight the internal temperature of the produce can increase as much as 12·4°C above the ambient temperature. In their observation darker colored produce such as aubergine and potato tended to absorb more solar heat than the lighter colored produce such as cabbage and turnip. They expressed serious concern about the possible detrimental effect of such temperature differential on the nutritional quality of fruits and vegetables. However, no data were reported on any specific nutrient.

The purpose of this study was to determine the effect of prolonged sunlight exposure on the ascorbic acid contents of various tropical fruits. Total soluble solids, which are primarily glucose, were also measured because of their relevance to fruit quality (Vasquez-Salinas & Lakshminarayana, 1985, Medlicott *et al.*, 1987) and particularly because glucose serves as the precursor of vitamin C in plants (Loewus & Loewus, 1987).

MATERIALS AND METHODS

Samples

The study was conducted in the Caribbean island of Dominican Republic. Five sets of experiments were carried out involving mango (var. keit), melon (cantaloupe), orange, papaya (var, solo), and pineapple on five different days over a two-week period. The fruits were purchased from wholesalers at the public market of Santo Domingo. Based on prior arrangements with the wholesalers eighty fruits of each specific variety with uniform size and maturity were obtained for each set of experiments. The fruits were harvested in nearby plantations and transported to Santo Domingo at ambient temperature in pick-up trucks. They were received within 48 h of harvest. The fruits were brought to the laboratory the day before the experiment and kept overnight in the nonairconditioned Chemistry Laboratory of the Autonomous University of Santo Domingo.

Temperature measurement

In the morning a few minutes before 8 a.m. half of the fruits (40) were taken out of the laboratory and spread on a concrete pad away from the building and trees to avoid any shade. The fruits were exposed to the sunlight until 6 p.m. The other forty fruits were kept in the shade (inside the laboratory with open windows) as the control. Starting at 8 a.m. and every 30 min thereafter the air temperature outside the building, and the temperature inside the fruits were measured by an Extec digital thermometer model 420 (Extec Instruments, Boston, Mass.). For recording the internal temperature the metallic probe was inserted approximately halfway between the surface and the perceived center of the fruit. Each temperature measurement was made on two fruits and the average recorded for plotting.

Ascorbic acid and total soluble solids determination

Starting at 8 a.m. and every hour thereafter three fruits from those exposed to the sun and three from those in the shade were randomly selected for analysis of ascorbic acid and total soluble solids. The fruits were peeled, finely sliced and blended for 1 min. A 25 g sample from each fruit was weighed into a beaker containing 2 g of oxalic acid and 150 ml distilled water. The mix was homogenized for a minute and the volume adjusted to 250 ml followed by filtration through filter paper. Twenty-five ml of the filtrate were taken into an Erlenmeyer flask to which were added 5 ml of 4% KI, 2 ml of 10% acetic acid, and three drops of starch indicator. The ascorbic acid was titrated with standard *N*-bromosuccinimide solution until a faint blue end point. Duplicate samples were analyzed for each fruit and the average vitamin C content of three fruits per observation were recorded for plotting. This method of determining ascorbic acid is similar to that described by Haddad (1977). It may be mentioned that this method was reported to be more accurate than the more common method of titration with 2,6-dichlorophenol indophenol.

For determining the total soluble solids about 25 g blended sample from each fruit was filtered through a double layered cheese cloth. The percent soluble solids was read by a hand refractometer model 10431 (Reichert Scientific Instruments, Buffalo, NY). Similar to vitamin C, the average total soluble solids of three fruits per observation was recorded for plotting.

RESULTS AND DISCUSSION

Temperature difference

All the fruits exhibited very similar patterns in the absorption of solar heat, fluctuation of vitamin C content, and the accumulation of total soluble solids. Hence, for the sake of brevity, representative graphs (Figs 1 and 2) are being presented only for one fruit, mango. Maxima/minima data for all the fruits have been summarized in Table 1. It can be seen in Fig. 1 that the temperatures inside the fruits were at their minima at the beginning of the day and for those exposed to the sunlight (unshaded) gradually increased reaching their maxima at 2 p.m. Subsequently, a downward trend continued as the ambient temperature declined throughout the late afternoon. It can be seen that the highest temperatures in the shaded fruits were somewhat lower than the ambient temperature for most of the day and during the late afternoon they overlapped. In regard to those exposed to the sun (unshaded), the highest temperatures within were much higher than the ambient temperatures, similar to the observations made by Rickard & Coursey (1979). The temperature maxima difference between the ambient air and the unshaded fruits ranged from 8·1 to 11·1°C. Papaya with its dark green color absorbed the highest amount of solar heat and melon, being light brown, the lowest. This is similar to the observation made by Richard & Coursey (1979). The temperature maxima difference between the shaded and unshaded fruits were even greater than the corresponding values between the shaded fruits and the ambient air. This clearly indicates that shading not only provides protection from direct solar heat but also from the heat of the ambient air to some extent.

Vitamin C

The vitamin C contents of mango at various stages of exposure to sunlight are presented in Fig. 1. For unshaded mango, the vitamin C content gradually declined from 8 a.m. (33·2 mg/100 g) to 10 a.m. (32·4 mg/100 g) followed by a rapid decline until 1 p.m. (15·4 mg/100 g). Then quite unexpectedly, the vitamin C level

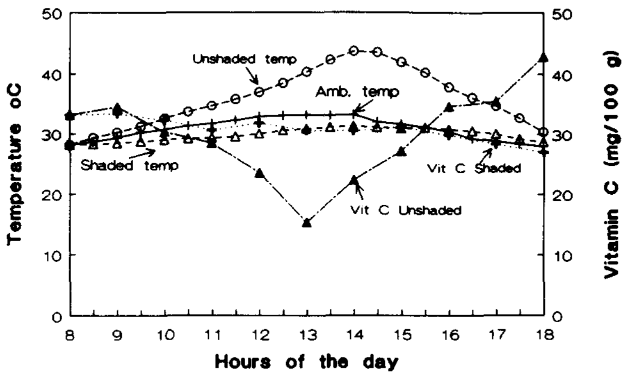

Fig. 1. Internal temperature and vitamin C content of mango during prolonged sunlight exposure.

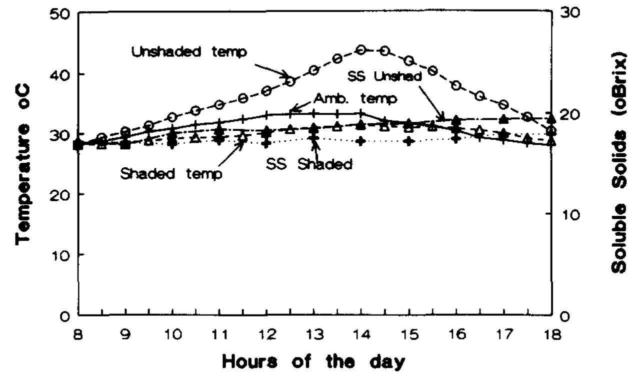

Fig. 2. Internal temperature and soluble solids content of mango during prolonged sunlight exposure.

began to increase rather rapidly, and by 6 p.m. the concentration (42·9 mg/100 g) exceeded even the initial value. For the mangoes in the shade, the vitamin C levels showed a slow but consistent decline throughout the day. From an initial concentration of 33·2 mg/100 g at 8 a.m. the vitamin C level declined to 27 mg/100 g. Equally surprising, similar trends in vitamin C level were observed in unshaded melon, orange, papaya, and pineapple. The maxima/minima data on vitamin C for all these fruits are summarized in Table 1. This observation of resynthesis of vitamin C in unshaded fruits is quite contrary to what has been suggested by Rickard & Coursey (1979). It should be mentioned that because of this highly unexpected observation in regard to vitamin C, this study was repeated. The data presented here are those obtained during the second replicated study which confirm the phenomenon of vitamin C resynthesis observed in all the fruits the first time.

The initial decline in the vitamin C contents of the fruits can be explained in light of the accelerated activity of ascorbic acid oxidase as observed by Dudek *et al.* (1980). However, the sudden but consistent increase in the vitamin C level of unshaded fruits during the afternoon is rather difficult to explain. This could not have been due to any shrinkage in the volume since the fruits with their thick peels did not appear to have suffered any appreciable dehydration under the hot and humid weather of Santo Domingo. The elevated temperature within the fruits may have inactivated the ascorbic acid oxidase with a simultaneous accumulation of ascorbic acid precursors. Most probably, a biosynthetic mechanism is triggered in the unshaded fruits because of the absorption of solar heat.

There is a dearth of literature on the effect of postharvest solar exposure of produce in regard to ascorbic acid content. However, Hamner *et al.* (1945) studies the effect of sunlight on the ascorbic acid content of tomato fruit prior to harvest. They observed 39% increase in the ascorbic acid content of tomato fruits transferred from shade to sunlight at mature green stage. In a study involving mechanical injury of potato, Asselbergs & Francis (1952) found a 300% increase in ascorbic acid of potato slices when kept for 2 days at 23°C in a humid chamber or in aerated distilled water.

Total soluble solids

Figure 2 presents the changes in the total soluble solids of shaded and unshaded mango from 8 a.m. to 6 p.m.

Table 1. Fluctuations of temperature, vitamin C and soluble solids (SS) in shaded and unshaded tropical fruits

Fruits		Ambient	Shaded			Unshaded[a]		
		Temp. (°C)	Temp. (°C)	Vit. C (mg/100 g)	SS (%)	Temp. (°C)	Vit. C (mg/100 g)	SS (%)
Mango:	Minima	28·0	28·2	27·0	17·1	28·2	15·4	17·2
	Maxima	33·3	31·4	33·5	17·9	43·7	42·9	19·5
Melon:	Minima	27·4	27·3	4·0	9·5	27·3	4·1	9·5
	Maxima	31·6	29·9	5·2	10·1	39·7	5·3	10·9
Orange:	Minima	28·1	28·4	40·4	10·8	28·4	37·7	10·8
	Maxima	32·7	30·2	50·6	11·0	43·6	66·7	11·4
Papaya:	Minima	26·9	26·4	88·1	11·6	26·9	72·4	11·6
	Maxima	32·6	31·6	117·8	11·9	43·7	117·9	12·5
Pineapple:	Minima	27·4	27·2	23·2	10·9	27·2	11·7	11·1
	Maxima	32·9	29·4	26·4	11·6	40·6	26·4	14·0

[a] Temperature maxima in all fruits were usually observed at 2 p.m. while the Vitamin C minima is unshaded fruits were observed at 1–2 p.m. Soluble solids maxima were observed at the end of the day.

In general, for all the five fruits there was a very slow increase in the total soluble solids during the observation period. However, those exposed to sunlight had accumulated considerably more total soluble solids than those in the shade. This change in the total soluble solids is analogous to the changes observed during the ripening of fruits (Vasques-Salinas & Lakshminarayana, 1985; Sharaf *et al.*, 1989). Among all the fruits, pineapple (Table 1) had the highest increase in total soluble solids due to exposure to sunlight. From an initial value of 11·1 °Brix at 8 a.m., it reached 14 °Brix at 6 p.m. Mangoes however, had the highest values both at the beginning and at the end of the observation. For mango the total soluble solids increased from 17·2 °Brix at 8 a.m. to 19·5 °Brix at 6 p.m.

Loewus & Loewus (1987) reviewed the biosynthesis and metabolism of ascorbic acid in plants. Glucose and L-galactone-1,4-lactone are the main precursors for the synthesis of ascorbic acid. It is quite conceivable that the formation of higher levels of these precursors, indicated by higher total soluble solids, may trigger an accumulation of ascorbic acid in the fruits. A similar explanation has been suggested for the simultaneous increase of soluble carbohydrates and vitamin C in wounded potato tubers (Trautner & Somogyi, 1965). Furthermore, the enzymes responsible for vitamin C biosynthesis, may have temperature optima similar to those achieved within the fruits due to prolonged solar exposure. Obviously, additional studies involving the metabolic enzymes of the fruits are necessary. Until then, the observation of vitamin C resynthesis in the unshaded fruits will remain an enigma.

CONCLUSION

This study demonstrated that the overall vitamin C levels do not necessarily decrease in fruits because of prolonged exposure to sunlight, as often perceived, under the tropical marketing conditions. Internal temperatures of the sun-exposed fruits do elevate along with a rapid decline in vitamin C only until the early afternoon. This trend is then reversed by resynthesis of vitamin C at least until the end of day-light hours.

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