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Growth, maturation and ripening of soursop (*Annona muricata* L.) fruit

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Abstract

Flowers of soursop (*Annona muricata* L.) appeared to be protogynous and, following pollination, they entered a quiescent period of 6–15 weeks, during which time the stigmatic surface typically developed a sooty deposit. Further development was signalled by clumping of the carpels as the underlying tissue expanded. The time taken to reach fruit maturity from this 'take-off' point was found to be 15–21 weeks. Fruit growth was double sigmoidal. Maturity could be reliably detected when the density of the spurs on the fruit surface reached a minimum value (6 per 12 cm^2) and a slight paling of the initially dark-green skin occurred. This lightening of the skin probably reflected declining chlorophyll concentrations which fell to about 15% of their initial value. Mature fruit produced a biphasic respiratory climacteric, with CO_2 production reaching 100 ml kg^{-1} h^{-1} and then 350 ml kg^{-1} h^{-1} at 25–30°C. Peak ethylene production (250–350 ml kg^{-1} h^{-1}) occurred between the two respiratory maxima. The respiratory climacteric of harvested immature fruit tended to be higher and later than that of mature fruit.

Key words: Annona muricata; Fruit growth; Guanabana; Maturity; Ripening; Soursop

1. Introduction

The soursop, *Annona muricata* L., a native of Tropical America, is common throughout the islands of the Caribbean. There are over 100 species of *Annona* and several of these bear edible fruit (Mahdeem, 1990); however, only the cherimoya (*Annona cherimola*), custard apple (*Annona reticulata*), sugar apple (*Annona squamosa*) and soursop are of major commercial importance. Of these the soursop has the largest fruit and is the least cold-hardy (Morton, 1966). This

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fruit, like that of other *Annona* species is a syncarp, and the white, juicy pulp has a delightful aroma and a somewhat sour-sweet, yogurt-like taste. The fruit is potentially useful as a processed commodity (Anonymous, 1975) but also has value as an exotic fresh fruit in distant markets, despite its extreme perishability (Seaton, 1988).

Soursop has a high postharvest respiration rate (Biale and Barcus, 1970; Lakshminarayana et al., 1974; Paull et al., 1983; Bruinsma and Paull, 1984; Lam and Zaipun, 1986) but information about the development of this fruit is limited. Like other *Annona* species, soursop is dichogamous but both protogyny (Venkataratnam, 1959) and protandry (Juliano, 1935; Kennard and Winters, 1960; Coronel, 1990) have been reported. An understanding of the process of fruit development and the identification of suitable maturity indices are important prerequisites for rational development and exploitation of this fruit crop. This study was undertaken to (a) characterise fruit growth patterns and (b) investigate possible maturity indices.

2. Materials and methods

2.1. Plant material

Fruit development was studied in a backyard orchard at Sedgepond, St. Andrew, Barbados, from October 1989 to May 1990 on ten soursop (*Annona muricata* L.) trees of a common, but unnamed cultivar. The trees were of unknown age and raised from seed. Fruit for respiratory studies were harvested in triplicate from the same trees at an immature (dark green with spur density of 10 spurs per 12 cm^2) or mature (turning pale green with spur density of 6 spurs per 12 cm^2) stage, weighed, washed and allowed to air-dry before use.

2.2. Fruit growth and development

About 300 flowers, at a stage where the outer petals had just begun to gape, were tagged, labelled and monitored over a 3 month period. Weekly measurement of fruit length and maximum diameter, as well monitoring of the timing of sepal abscission, fruit curvature, shoulder initiation and spur development, were carried out on blossoms that were tagged at the 'take-off' point (the stage at which growth commenced). Dry and fresh weights were measured from fortnightly harvests of six fruit, the dry weight being determined on half fruit dried in an oven at 100–120°C for 3 days. For chlorophyll measurements, six replicate samples, each of ten skin discs, were prepared from frozen fruit of known age using a 7 mm diameter cork borer. Discs were ground in a mortar and pestle using 80% (v/v) aqueous acetone, centrifuged, and assayed for chlorophyll in the supernatant by absorbance at 647 and 664 nm (Porra et al., 1989).

2.3. Postharvest changes

Individual fruit were placed in 25 l plastic bell-jars at room temperature (25–30°C) and ventilated with humidified air (approximately 1.5 l min^{-1}), the exit flow entering a 225-MK3 infra-red gas analyser (ADC, Hoddesdon, UK) via a

WA-161 multi-channel switching unit (ADC). Linkage to a microcomputer allowed automatic half-hourly data logging. Ethylene production was monitored twice daily for the same fruit by temporarily reducing the flow rate to 0.18 l min^{-1} and injecting a 1 ml air sample from the exit air stream into a Photovac gas chromatograph (Photovac, Ont., Canada). Both instruments were calibrated with appropriate certified standards (Matheson Gas Products, NJ, USA). Fruit were assessed visually for skin blackening and fungal growth and by finger pressure for softening. The percentage of the surface area showing such features was estimated using a clear vinyl overlay sheet with a 1 cm × 1 cm dot grid and noting the percentage of dots overlying such affected areas.

3. Results

3.1. Initiation of fruit development

Several developmental stages were identified in the transition from receptive flower to young fruit (Fig. 1). At the time that flowers had petals just beginning to gape (Fig. 1(A)), their stigmatic surfaces were wet but anthers had not begun to dehisce. Two to three days later, when the petals were fully open, or in some cases had abscised, the stigmatic surfaces were dry and pollen had been shed. Following anther dehiscence, the stamens abscised (Fig. 1(B)) and the flowers appeared to enter a resting phase characterised by a darkening of the stigmatic dome of the carpels (Fig. 1(C)). This state persisted in the majority of flowers for 6–15 weeks (Fig. 2(A)) and it was at this stage that about 70% of the tagged flowers abscised. The first noticeable sign of further activity was a slight swelling at the base of the flower, often accompanied by partial to complete loss of the apical black coloration. This resumption of growth, which we designated 'take-off' (Fig. 1(D)), was characterised by a cracking at the distal end of the blossom

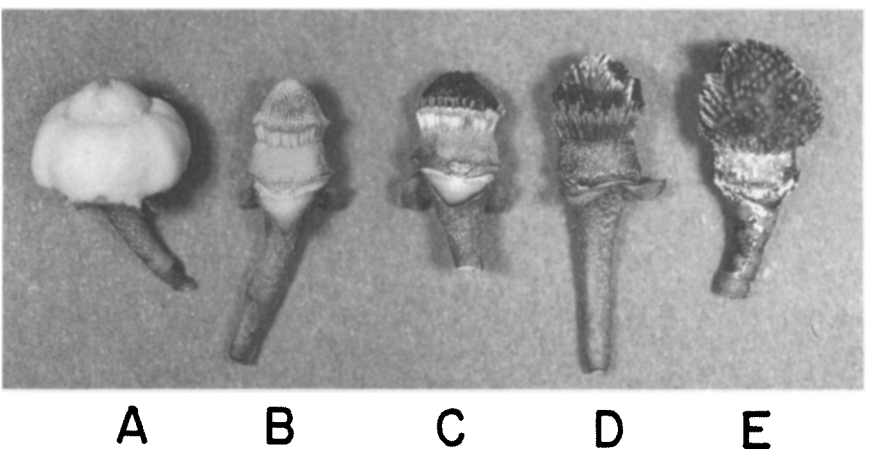

Fig. 1. Transition of a soursop flower to a young fruit (X1): (A) anthesis (petals have been removed); (B) anthers shed; (C) quiescent stage; (D) take-off point; (E) young fruit.

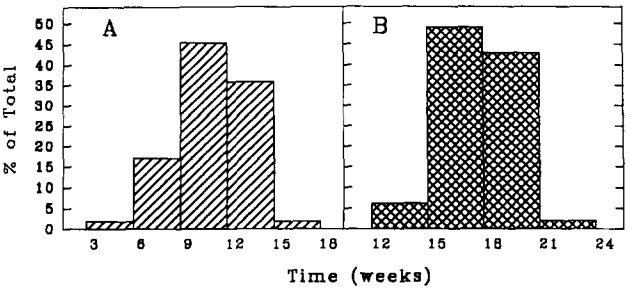

Fig. 2. (A) Time taken to reach take-off from anthesis in a sample of 53 soursop flowers. (B) Time taken to reach maturity from take-off in a sample of 49 soursop flowers.

with clumping of the carpels as the underlying tissues began to swell. Increases in length and diameter of the developing fruit then became evident (Fig. 1(E)).

3.2. Fruit growth

Length and diameter of soursop fruit were measured until 19 weeks after take-off, by which time some fruit had started to soften on the tree. Most fruit required 15–21 weeks from take-off to reach maturity (Fig. 2(B)). Whether size or weight was monitored (Figs. 3(A) and 3(B)), soursop displayed double-sigmoidal growth kinetics. Fruit reached half their final size by the end of the initial rapid growth phase which was followed by an intermediate 'resting' phase of about 4 weeks. The final growth phase, leading to full size and maturity, then occurred (Fig. 3(A)). When dry and fresh weights were monitored, the transition period between the two phases of rapid growth appeared to be a phase of reduced growth rather than no growth (Fig. 3(B)).

Soursop is a compound fruit formed as an aggregate of berries, and the individual constituent carpels persist as spurs on the fruit surface throughout development. The density of these spurs decreased from an initial value of 23 per unit sampling area (12 cm^2) to a final value of 6 per unit area in fully grown fruit (Fig. 3(C)).

3.3. Colour changes

Chlorophyll *a* and *b* concentrations in the fruit skin declined during the last 7 weeks of development (Fig. 4). This confirmed our observations that skin colour lightened as fruit matured, which we quantified as an initial value of 3/6 on Munsell Color Chart 5GY and as 6/6 at maturity. This lightening of skin colour began as pale striations radiating around each spur, which later spread and coalesced in fully grown fruit.

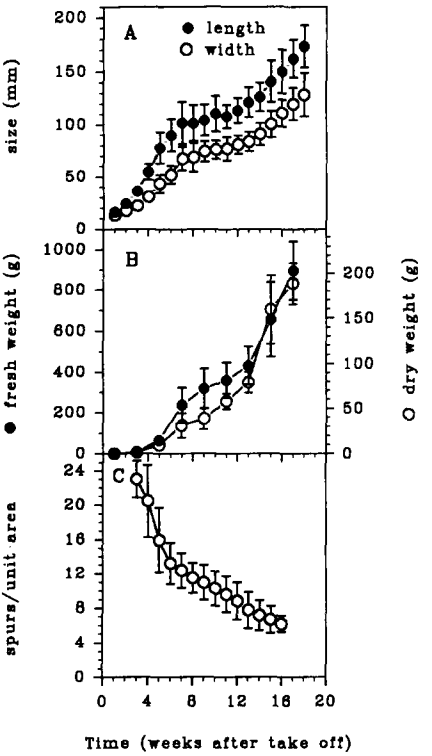

Fig. 3. (A) Growth of soursop fruit from take-off, as determined by length and width (mean ± SD of 15 fruit) (B) Growth of soursop fruit as determined by fresh and dry weight (mean ± SD of 15 fruit). (C) Growth of soursop fruit as determined by the number of fleshy spurs on the fruit surface per 12 cm^2 sampling area (mean ± SD of 15 fruit).

3.4. Morphological aspects of development

A number of qualitative aspects of fruit development were monitored. The three sepals of the soursop flower persisted to varying degrees during fruit development. While about 50% of the fruit monitored retained all sepals throughout growth, 7% had none at the start of growth and the remainder showed considerable variation in the timing and degree of sepal drop. Soursop fruit are characteristically curved, but the timing of the initiation of this curvature varied. Curvature tended to develop early, with about 33% of the fruit starting out curved and 44% developing curvature within the first 10 weeks after take-off. Soursop fruit also develop shoulders around the point of pedicel attachment. In most cases this began within the first half of growth. None of these parameters changed late enough or consistently enough in development to be of use as maturity indices.

3.5. Characterisation of the climacteric

Postharvest respiratory profiles were determined for triplicate fruit of two different stages of maturity (Fig. 5). The respiratory climacteric in the mature fruit

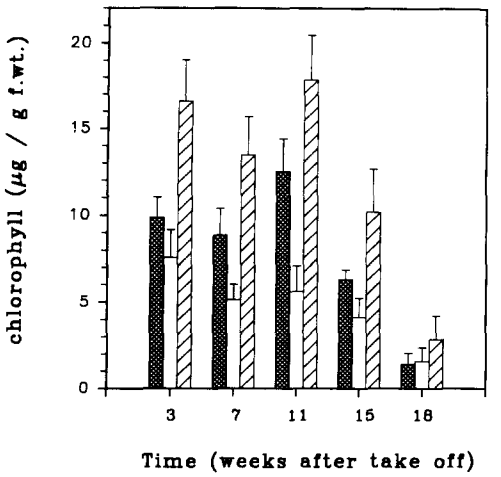

Fig. 4. Chlorophyll concentrations in the peel of soursop fruit during development (mean ± SD of six replicates): cross-hatching, Chl. *a*; blank, Chl. *b*; diagonal lines, Chl. *a*+*b*.

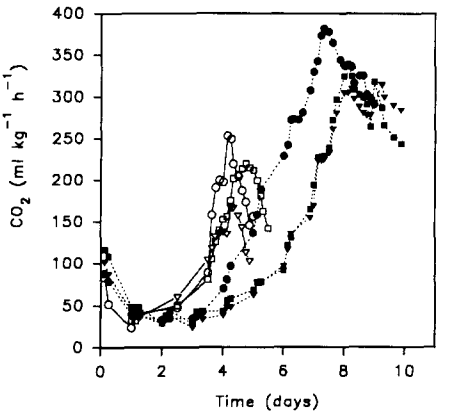

Fig. 5. Respiratory profiles of three mature (6 spurs per unit area) soursop fruit (open symbols) and three immature (10 spurs per unit area) soursop fruit (filled symbols).

reached a maximum of 150–250 ml CO_2 kg^{-1} h^{-1}, while the younger fruit gave respiratory peaks of 300–350 ml kg^{-1} h^{-1}. The climacteric occurred a few days later in the immature fruit than in the mature fruit.

Figure 6 shows the postharvest ripening behaviour of four mature soursop fruit. The respiratory drift of mature fruit exhibited a biphasic trend with the initial rise in CO_2 production reaching about 100 ml kg^{-1} h^{-1} followed by a brief lag

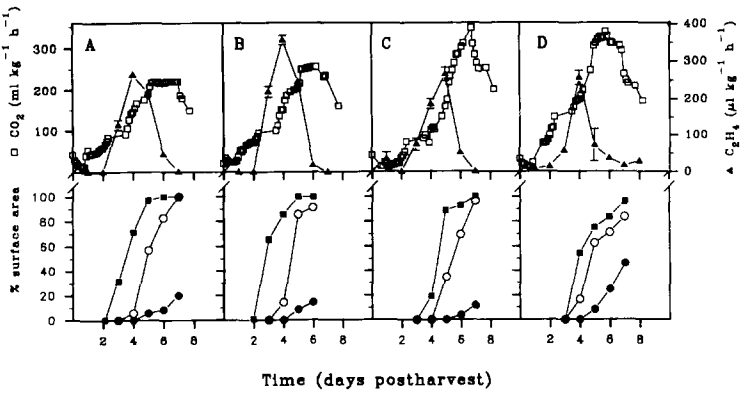

Fig. 6. Characterisation of postharvest ripening in four soursop fruit ((A)–(D)) as monitored by CO_2 and C_2H_4 production and by the percentage of the fruit surface showing softening, skin blackening and fungal growth: □, CO_2; ▲, C_2H_4; ■, softening; ○, skin blackening; ●, fungal growth.

before again increasing to a maximum of 250–350 ml kg^{-1} h^{-1} (Fig. 6). Ethylene production generally did not increase until after the first respiratory rise and reached a maximum of 250–350 ml kg^{-1} h^{-1}, between the two respiratory peaks. Softening seemed to begin with the C_2H_4 climacteric, all regions of the fruit fully soft by the time of peak C_2H_4 production. Skin blackening was coincident with the second phase of the respiratory climacteric. Toward the later stages of ripening, fungal growth became evident on the fruit surface.

4. Discussion

Our observations of an initially wet stigmatic surface prior to anther dehiscence, followed by a dry stigmatic surface at the time of pollen release 2 days later, suggest that soursop is protogynous, as reported by Venkataratnam (1959), and not protandrous as suggested by other workers (Juliano, 1935; Kennard and Winters, 1960; Coronel, 1990). The prolonged quiescent state of the pollinated flowers has not been reported previously, and does not occur in cherimoyas (M.L. Arpaia, personal communication, 1992). This resting period does not seem to be a result of correlative inhibition, where the development of newly pollinated flowers is suppressed by pre-existing developing fruit, since this quiescent phase occurs on trees without flowers or developing fruit. Furthermore, this lag occurs in flowers borne in both the wet and dry seasons, suggesting it may not be environmentally imposed. This phenomenon requires further study as it has important implications from a horticultural standpoint.

Double sigmoidal, triphasic growth such as that seen in soursop (Figs. 3(A) and 3(B)), comprising initial and final phases of rapid growth interspersed by a period of reduced growth, is relatively common in fruits and has been reported for blueberry, fig, grape, kiwifruit, persimmon, pineapple and all stone fruit

(Coombe, 1976; Monselise, 1986). Since pineapple and fig, like soursop, are compound fruits, but others in this list are not, double sigmoidal growth is not dependent on fruit type. In blueberry, the intervening lag phase is associated with embryo and endosperm growth, while in peach it is dominated by endocarp lignification (Monselise, 1986). It would be interesting to learn what internal changes characterise this phase in soursop.

Variation in final fruit size from 0.2 to 1.5 kg, probably related to the proportion of carpels fertilised, renders size unreliable for estimating maturity. Days from anthesis are also meaningless owing to the extended and variable post-anthesis quiescent period we have described. Our recognition of a take-off point from which fruit development should be monitored partly clarifies this variation; however, the time from take-off to full size and maturity varied by as much as 6 weeks (Fig. 2(B)). Neither sepal drop, fruit curvature nor shoulder development were useful indicators of maturity. In contrast, spur density was a reliable, size-independent measure of maturity, with 6 spurs per 12 cm^2, indicating full size attainment. We have successfully used this in conjunction with a slight paling of skin colour as maturity indices for this fruit.

Our finding of higher and delayed peaks of C_2H_4 and CO_2 production in immature fruit compared with mature fruit (Fig. 5) differs from that of Lam and Zaipun (1986), who found no consistent differences in the postharvest C_2H_4 and CO_2 production in the two maturation stages. This discrepancy may reflect a greater difference in maturity (10 vs. 16 weeks after take-off) in our fruit relative to those used in the other study (10 vs. 12 weeks). The biphasic respiratory climacteric reported for soursop by earlier workers is confirmed although our CO_2 values were invariably twice those previously reported (Biale and Barcus, 1970; Lakshminarayana et al., 1974; Paull et al., 1983; Bruinsma and Paull, 1984). Similarly, our values for C_2H_4 production were higher than those of previous reports (Paull et al., 1983; Bruinsma and Paull, 1984; Lam and Zaipun, 1986). In both instances, our higher measuring temperatures might account for these differences, or even our use of a flow-through rather than a static system for gas analysis. A further difference relates to the kinetics of C_2H_4 evolution. Paull et al. (1983) and Bruinsma and Paull (1984) showed the C_2H_4 peak coincident with the final, major respiratory peak while our fruit showed peak C_2H_4 production between the two respiratory peaks (Fig. 6), as shown for cherimoya (Kosiyachinda and Young, 1975; Brown et al., 1988). The surface microbial growth reported (Fig. 6) is problematic and was no doubt facilitated by the high humidity within the flow-through system. We believe, however, that this was limited and occurred too late to compromise the C_2H_4 or CO_2 data. The eventual decrease in CO_2 production and the postclimacteric return of C_2H_4 production to preclimacteric values support this interpretation.

Soursop is eaten soft but at a stage where there is no skin blackening or, at most, when this is only beginning. Since this period of prime consumption quality coincides with the end of the first respiratory climacteric, respiration monitoring may be of some value in predicting the timing of optimum eating quality. Future

efforts must address extending the preclimacteric postharvest life of this highly perishable fruit.

Acknowledgement

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