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Respiration and Ethylene Production During Ontogeny of Fruit[1]

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ABSTRACT. Respiration (ml CO_2/kg/hour) decreased as fruits matured in mango *(Mangifera indica* L. cv. Haden), avocado *(Persea americana* Mill. cv. unknown), and lychee *(Litchi chinensis* Sonn. cv. Kwai Mi). With ripening, a respiratory rise commenced in the climacteric mango and avocado, but not in the nonclimacteric lychee. Ethylene (µl/mg/hour) production in all species also decreased as the fruit matured, became undetectable, then reappeared upon fruit ripening (mango and avocado) or senescence (lychee). The possible relationship between respiration and ethylene production in the ontogeny of fruit is discussed.

Respiration and ethylene production in intact fruit of citrus (1, 4, 11), apricot (9), pineapple (10, 13), olive (19), apple (15, 16, 21), and avocado (23) during ontogeny, has been studied using fruits harvested at increasing time intervals from anthesis. The present paper reports similar studies on the relationship between CO_2 (index of respiration) and C_2H_4 production in developing fruits of mango *(Mangifera indica* L. cv. Haden), avocado *(Persea americana* Mill. cv. unknown), and lychee *(Litchi chinensis* Sonn. cv. Kwai Mi).

Materials and Methods

The inflorescences of mango, avocado, and lychee are panicles composed of racemes. Racemes with about 75% of the flowers opened (anthesis) were tagged on a single tree of each species growing side by side on the grounds of a private domicile in Honolulu. The period between early and late anthesis in a raceme was about 4 days. The day of tagging, however, was taken to be the date of anthesis for each raceme. Sample fruits for CO_2 and C_2H_4 analyses were obtained from tagged racemes. The first samples from each species were taken when there was visible evidence of ovary growth after anthesis. Thus the first samples of mango, avocado, and lychee were collected 4, 4, and 12 days after anthesis, respectively. Subsequent samples were collected at various intervals. Mangoes were collected until the fruit dropped, which corresponded with the full-ripe stage or shortly thereafter; lychees, until the fruit deteriorated on the tree; and avocados, until they dropped during the initial stages of ripening. Depending on the size of the individual fruits and the volume of the fruit containers used for respiration and C_2H_4 sampling, the number of fruits per sample was 2 to 85, 1 to 100, and 1 to 50, respectively, for lychee, mango, and avocado. Duplicate samples constituted a collection.

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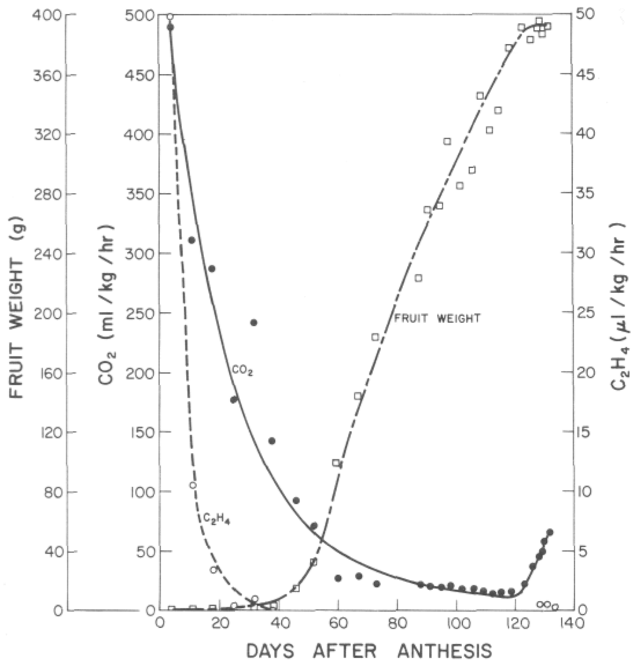

Fig. 1. Respiration, C_2H_4 production, and growth (wt) in mango fruit.

Within 2 hr after collecting, the samples were placed in gaslight glass containers varying in volume from 15 to 6,300 ml, at 25°C. The holding period in the container for CO_2 and C_2H_4 determinations was 1 hr, except for the mango which was held for 4 hr for C_2H_4 analysis. At the end of the holding period, 1 ml gas samples, each, for CO_2 and C_2H_4 were withdrawn with a gaslight syringe from the atmospheres surrounding the fruits and analyzed with gas chromatography. A thermal conductivity detector unit (Varian Aerograph 90-P) with a silica gel column was used for CO_2 analyses, and hydrogen flame ionization unit (Aerograph Hy-Fi 600-D) with an alumina column for C_2H_4 analyses.

Results

In the 3 species studied, respiration decreased as the fruit matured (Fig. 1, 2, and 3). Similar results were obtained with other fruit species (1, 4, 7, 9, 10, 11, 13, 19, 23). Mangoes normally attain full ripe stage on the tree and drop. As they are climacteric fruit (6), the ripening process is accompanied by increased respiration (Fig. 1) and yellow surface coloration. Avocados do not usually ripen until detached from the tree (5), but the unknown cultivar employed in this investigation, when fully matured, began to ripen on the tree. The ripening of the cultivar we used was accompanied by surface purple coloration and increased respiration (Fig. 2). Approximately 1 week after ripening commenced, though not yet fully ripe, it detached from the tree due to the softening of the tissues surrounding the receptacle. Lychees normally ripen on the tree and, unless harvested, remain attached even in the deteriorated condition. The ripening process in this nonclimacteric fruit (3) is not accompanied by an

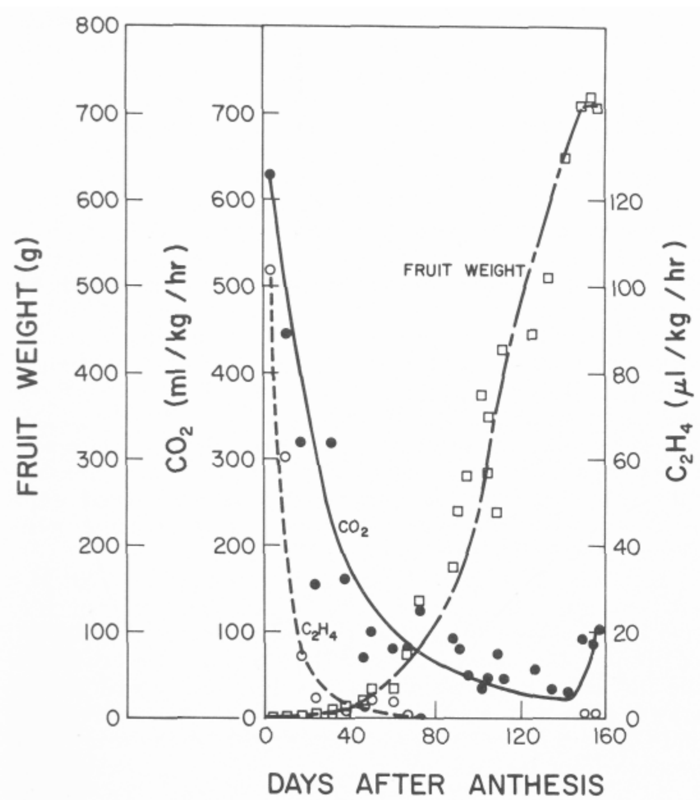

Fig. 2. Respiration, C_2H_4 production, and growth (wt) in avocado fruit.

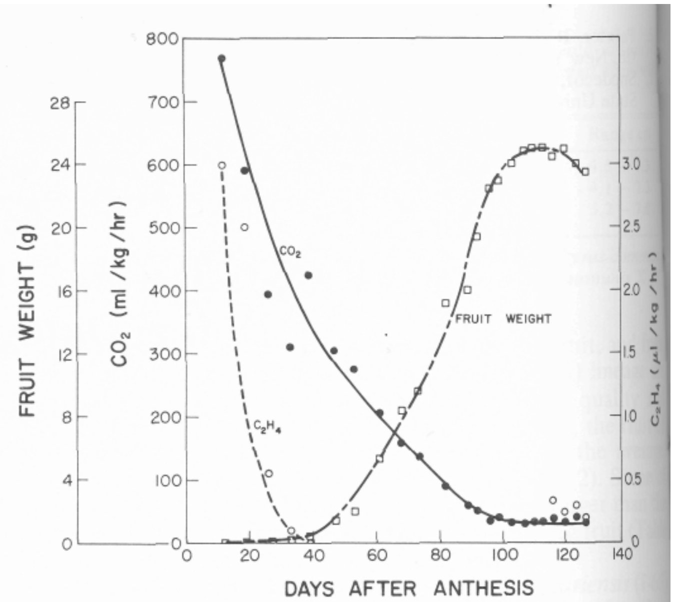

Fig. 3. Respiration, C_2H_4 production, and growth (wt) in lychee fruit.

upsurge of respiratory activity (Fig. 3).

As the fruit of each species grows, C_2H_4 production rapidly decreases from initial high levels and becomes undetectable during the early stages of development (Fig. 1, 2, and 3). Mango and lychee are about 4% and avocado is about 10% of their final wt when C_2H_4 can no longer be detected. Similar decreases in C_2H_4 production were observed for citrus (1, 11), pineapple (10), and other fruits (7). In mango and avocado, some C_2H_4 is produced when ripening begins and in the lychee when deterioration sets in (Fig. 1, 2, and 3).

Maximum fruit wt of mango and avocado (Fig. 1 and 2) is attained when the surface color breaks, and the fruit is in transition between the mature green stage and commencement of ripening. Maximum fruit wt of lychee (Fig. 3) is attained at the full color stage when it is also ripe. The typical sigmoid growth pattern is evident in fruit wt of the 3 species (Fig. 1, 2, and 3). Because of the early detachment of the mango and avocado from the tree, wt data after ripening are unavailable. Lychee wt decreases after ripening, mostly due to the desiccation of the deteriorating fruit (Fig. 3).

Discussion

Diffusible auxin is present in pollen grains of different plant species (20) including orchids (Akamine, E. K., unpublished data), and pollination and IAA application to the stigma stimulate C_2H_4 production in the orchid flower (8). Pollination increases C_2H_4 production by blueberry and strawberry flowers (14). In our investigation, it appears that immediately upon pollination, there is a stimulation of C_2H_4 production which in turn stimulates respiration, concomitant with initiation of cell division of the developing embryo.

During the initial stages of embryogenesis in cotton, respiration rate increases with the growth of the embryo, increase in respiration rate is attributed to an increase in cell number due to cell division (12). Respiration also increases in the orange during the cell division stage (4). Perhaps a similar increase in respiration occurs during the early cell division phase in mango, avocado, and lychee. At the time the initial samples were collected for each species, the ovary was visibly growing, and this was apparently the stage when cell division decreased and cell enlargement commenced. This transitional period was characterized by the highest production of CO_2 and C_2H_4 followed by a rapid decrease (Fig. 1, 2, and 3). With the apparent cessation or near cessation of cell division, C_2H_4 production became undetectable, but CO_2 liberation continued to decrease until cell enlargement ceased, and the fruit was fully developed. In apple, a similar rapid decline in respiration occurs during the late period of cell division, and a less marked decrease occurs during the cell enlargement phase (15).

A hypothetical scheme (17) of hormonal changes in developing fruit suggests that during cell division and early cell) enlargement stages, C_2H_4 levels are low and that towards the end of the cell enlargement stage, these levels begin to rise and continue to rise rapidly to a peak during the ripening stage. Our data, however, indicate very high levels of C_2H_4 during the initial stages of development, followed by a rapid decrease (Fig. 1, 2, and 3). The hypothetical scheme was apparently based, at least, in part, on the investigations of cantaloupe fruit (18) in which reliable data for the youngest fruit were obtained from samples collected when the fruit was about 38% developed (14 days after anthesis; fruit matures 37 days after anthesis). Samples collected earlier during the ontogeny of the fruit would probably yield high levels of C_2H_4, similar to those obtained from mango, avocado, and lychee fruits.

In a mature fruit, it is generally conceded that endogenous C_2H_4 triggers the respiratory rise of only the climacteric class of fruits in the ripening process (22). In the growing fruit of species in our investigation, however, this gas apparently functioned similarly in both climacteric and non-climacteric classes of fruits soon after pollination. In the relationship between C_2H_4 production and respiration, it seems that in the life of a fruit, C_2H_4 is involved only in the cell division and early cell enlargement stages and in ripening and senescence. It is not actively involved during the later stage of cell enlargement when the fruit rapidly increases in size and matures.

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