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The Tamarillo: Fruit Growth and Maturation, Ripening, Respiration, and the Role of Ethylene

Harlan K. Pratt[a] and Michael S. Reid

Plant Diseases Division, Department of Scientific and Industrial Research, Auckland, New Zealand

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The tamarillo (tree tomato, *Cyphomandra betacea* Sendt.) flowers and sets fruit over an extended period. Many blossoms and young fruits abscise; survival of tagged fruitlets ranged from 0 to 32%. Tagged fruits were harvested at known ages for measurement of size and shape, respiration rate, ethylene production, and response to ethylene treatment. Fruit growth followed a single sigmoid pattern, and fruits were commercially mature at 21–24 weeks after anthesis. The amount of red skin pigment increased with age from 15 weeks, but harvesting of immature fruits appeared to stop red pigment development. Fruits harvested at 12–19 weeks or younger shrivelled in storage. Respiration studies showed tamarillo fruits to be non-climacteric, and only traces of ethylene were produced until final senescence. Ethylene treatment increased the respiration rate and hastened senescence of harvested fruits of all ages. The yellow strain behaved similarly to the red and had a somewhat longer storage life.

1. Introduction

Commercial production of the tamarillo (tree tomato, *Cyphomandra betacea* Sendt.) in New Zealand has been described by Fletcher;[1] Strachan[2] summarised commercial storage and processing, the composition of the fruit was studied by Dawes and Callaghan,[3] and Wrolstad and Heatherbell[4] identified the principal pigments of the fruit, but there have been no studies on the general post-harvest physiology of this crop. In this paper we report on growth, respiration and the role of ethylene during maturation of tamarillo fruits.

It is common in studies of organ development to produce curves based on measurement of the same individuals at successive time intervals or to harvest groups of individuals from the developing population at appropriate times. Because any tamarillo plant may carry at one time fruits of a large age range, we took another approach. Flowers were tagged at anthesis, and fruits of a wide range of known ages were harvested at one time. Curves of growth and development were then deduced by plotting the data obtained from each specimen on a time axis representing its true age on the specified harvest date.

2. Experimental

2.1. Experimental material

Tamarillo fruits were obtained from a commercial orchard near Oratia (Auckland). In most experiments fruits of the red strain were used. They came from a block of trees of a line selected for fruits of a uniformly large size. The tamarillo flowers profusely and sets fruit over a long period; hence each tree carries fruits of many stages of growth and maturity at any one time. In order to have experimental fruits of known age, newly set fruits were tagged each week for 25 weeks (from 16 November through 12 April). Because so many tamarillo flowers abscise from each of the large

[a] On leave from the Department of Vegetable Crops, University of California, Davis, California 95616, USA.

inflorescences, young fruitlets which had apparently set were tagged instead of flowers. When the fruitlets were selected for tagging they were 1–1.5 cm long, the ovary was larger in diameter than the calyx, and the petals were withered and black. This stage of development was attained approximately 1 week after anthesis. About 100 fruitlets of each variety were tagged each week.

2.2. Sampling and fruit measurement

Fruits of known age were harvested as needed. The natural abscission layer leaves a long pedicel attached to the fruit; this was cut off at the base of the calyx. Fruit length was measured from the fruit apex to the base of the calyx, and diameters reported were the largest transverse measurement. Tamarillo fruits have a very regular shape, so volume was calculated from the length and diameter measurements on the assumption that the fruit approximates a prolate spheroid. Straight lines shown on growth graphs are calculated straight lines of best fit through the appropriate set of experimental data points. Growth data were obtained on four different occasions during 2 months of autumn.

2.3. Respiration and ethylene measurements

All gas exchange measurements and observations of postharvest changes in appearance were made on individual fruits held at 20°C in small glass jars through which a constant flow of humidified air was passed. Carbon dioxide production, as an estimate of respiration, was measured by the colorimetric method of Claypool and Keefer,[5] and ethylene production was measured by flame-ionisation gas chromatography; all rates were calculated on the basis of original fresh weight. Ethylene production less than 0.10 μl/kg.h was recorded as "trace" and all such individual determinations are not presented; this value was close to the limit of quantitative accuracy of our instrument. Ethylene treatments (at least 100 parts/10^6) were applied from pressure cylinders through flowmeter combinations and were continuous for several days after initial determinations of respiration. Respiration and ethylene production were measured daily at the start of each experiment but were later measured two or three times per week.

3. Results

3.1. Fruit set

On 20 April, approximately 1 week after the last tagging, all tagged fruits surviving on the trees were counted. Of an original 100 fruitlets tagged each week, an average of 20 remained on the tree although survival ranged from 0 to 32; the variation in set and survival among tagging dates was probably caused by varying weather conditions, although toward the end of the tagging period fruit set may also have been influenced by the load of fruit already being carried by the plants.

3.2. Growth and maturation

On 17 May (approximately 4 weeks after the last tagging) a sample of five to seven fruits of each available age was taken; all these fruits were weighed and measured (Figure 1), and the state of colour development was noted. All parameters measured revealed the simple growth curve characteristic of most common fruits and other plant organs.[6] The calculated volume curve agrees closely with the curve of fruit weights and, like all growth curves obtained during the course of this study (see also Figure 3), shows a rapid and linear increase in size between the fifth and fifteenth weeks; growth then ceased. Maximum size was achieved later in later harvests, probably because of the cooler weather of later autumn.

Tamarillo fruits of the red strain remained entirely green until almost full size at about 15 weeks after anthesis (Figures 1 and 3). An apparently purple overlying pigment then appeared at the blossom end and subsequently spread over the entire fruit. At about 19 weeks the green ground colour began to fade to yellow, and the purple pigment was revealed as red.

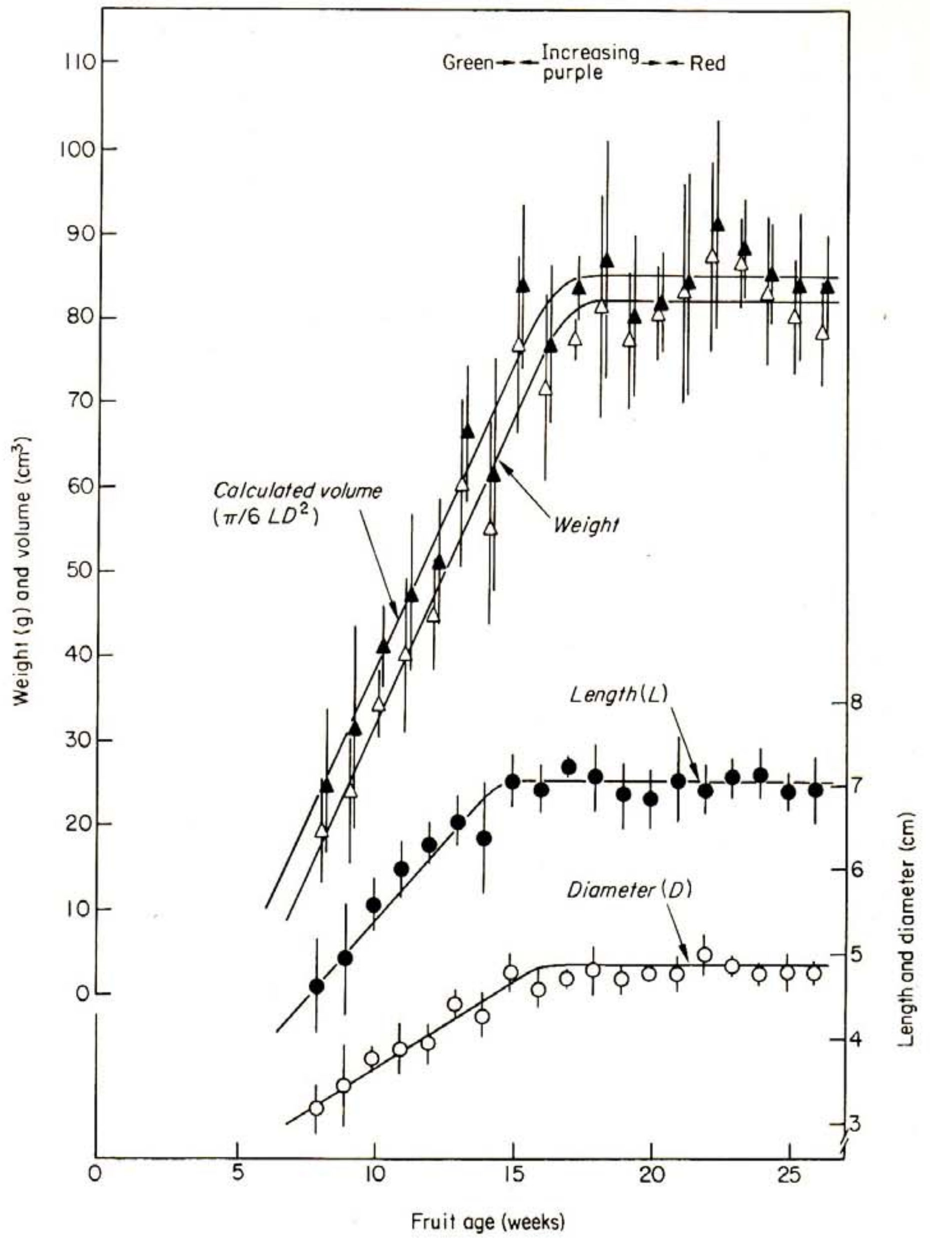

Figure 1. Parameters of growth measured on fruits of different known ages harvested on 17 May. Vertical lines are standard deviations ($n = 5$–7).

3.3. Respiration, ethylene production, and response to ethylene treatment

Figure 2 presents typical examples of respiration, ethylene production, and colour change in individual tamarillo fruits after harvest at two different ages. The respiration rates were always relatively high immediately after harvest but soon dropped to a pattern of slow decline; this trend was maintained until the onset of senescence. A trace of ethylene was produced by these fruits throughout their life. At the onset of senescence, the rates of ethylene production and respiration rose abruptly. These phenomena invariably coincided with the appearance of small decay spots and occasionally with fruit cracking.

On 26 April, two fruits of each available age were harvested and weighed, their colour was noted, and they were placed in containers for measurement of respiration and ethylene production. After 3 days, one fruit of each pair was treated with ethylene for 1 week. The results in Figure 3 show the trends with fruit age in respiration rate and response to ethylene. The plotting of the ethylene-

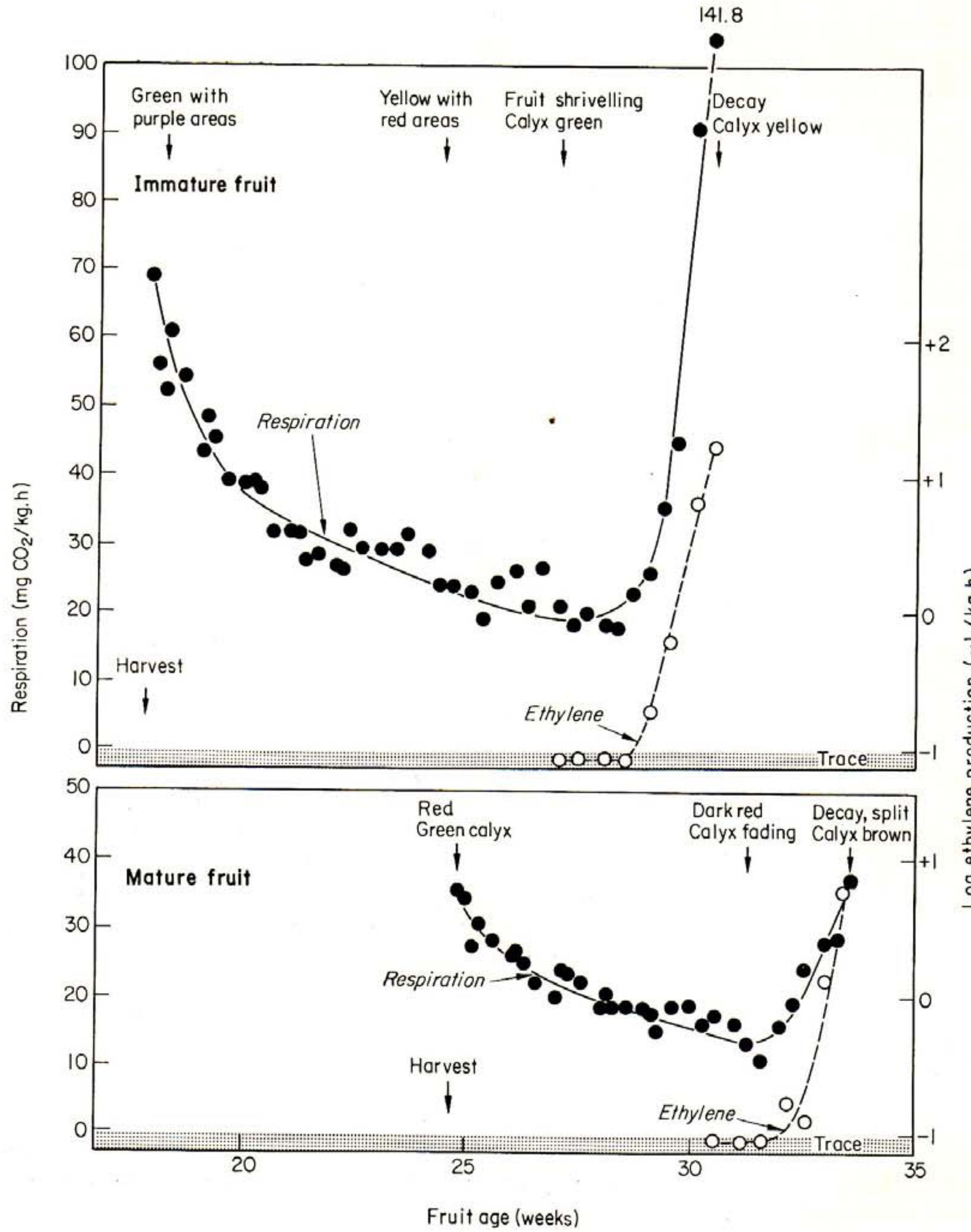

Figure 2. Respiration and ethylene production of single fruits harvested on 25 June. Above: young fruit, about 2/3 grown at time of harvest. Below: mature fruit.

treated specimens was terminated when the fruits started to spoil, and that of the control specimens was terminated when the data would overlap the plot of the next age pair. Not only was the initial postharvest respiration rate shown by each individual, relatively high (as in Figure 2), but it was a function of fruit age at harvest. The initial rate shown by the youngest fruits was exceedingly high (too high to plot in Figure 3), but the rate dropped rapidly during storage. Each older fruit age pair showed a successively lower initial rate at time of harvest, and the postharvest fall in rate was less pronounced. From the time the fruits were about half-grown, the rate shown by each successively older fruit tended, after its initial rapid drop, to fall on approximately the same curve of slowly descending respiration rate which was maintained until the fruit senesced.

Treatment of harvested fruits with ethylene increased the respiration rate of fruits of all ages

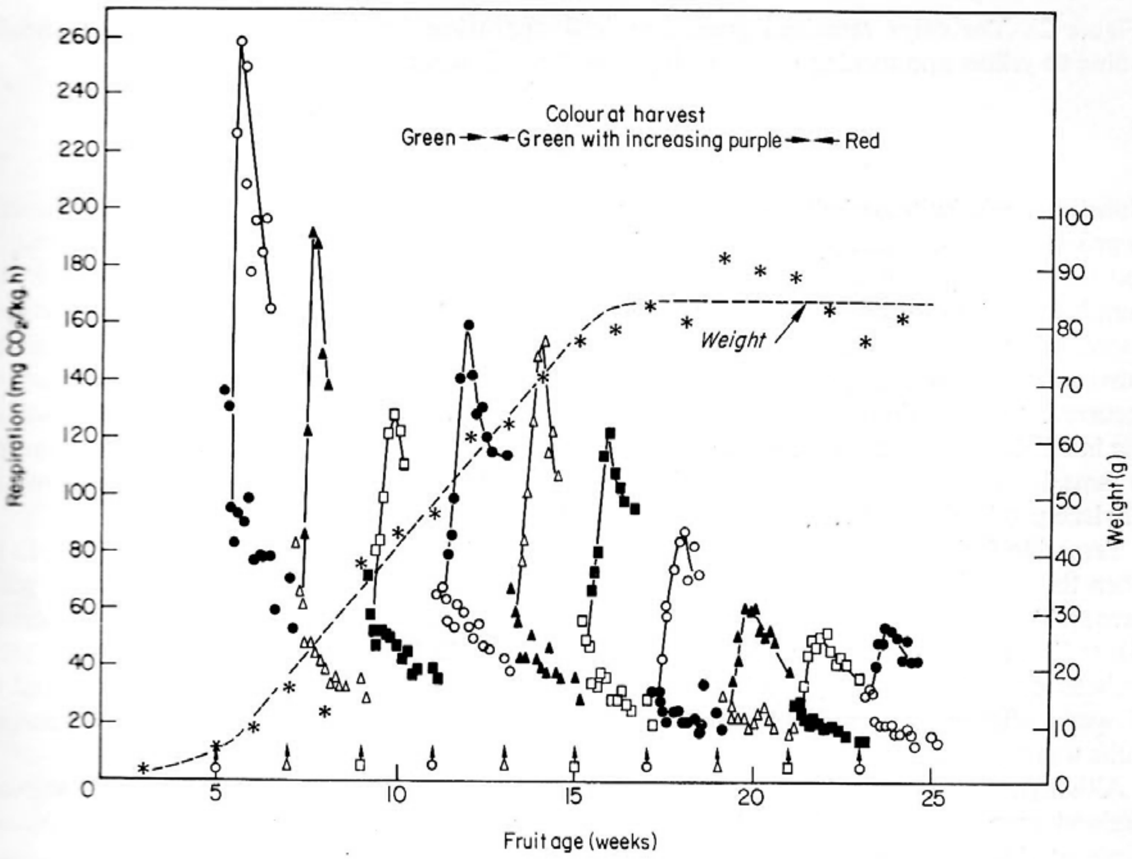

Figure 3. Weights and respiration rates of control and ethylene-treated fruits of different known ages, all harvested on the same date. Vertical arrows, with corresponding symbols attached, show the age at the time of harvest for each plotted pair of fruits. (Whether the symbols are open or solid is without significance; this was alternated to separate more distinctly the data sets for successive fruit ages.) Fruit weights and the first three respiration readings are averages of the two fruits harvested at each age. After ethylene treatment commenced, each point is a single reading on a single fruit, readings for the treated fruits being connected by solid lines.

(Figure 3). The age of the fruit at harvest influenced the pattern of the respiratory response to ethylene just as it did the observed endogenous respiration rate. Treatment of younger fruits, which have a very high endogenous rate, caused a dramatic respiratory increase, whilst fruits that were half-grown or more showed a medium level of response to ethylene. After full size was attained, the older the fruit the less was the response to treatment. All fruits treated with ethylene were softened, and all developed yellow flesh colour; no new anthocyanin pigment appeared to be formed in response to the treatment.

3.4. Postharvest colour change

Although no analyses were done, little or no additional pigment appeared to develop in the skin after harvest. If an immature fruit was blotched with purple at harvest, it was blotched with red over yellow at senescence (Figure 2), and fruits which had a uniform but not fully developed purple pigment at harvest were orange at the end of the experiment because of the thin red pigment over the yellow ground colour. Fruits of the red strain were full red, and mature enough for commercial harvest at 21–24 weeks after anthesis. Those harvested at 12 weeks or younger shrivelled in storage, and the skin retained a greenish aspect over a pale yellow ground colour; no red pigment developed in the skin. Fruits harvested at 13 weeks and older retained no green colour in the skin, the ground colour turned dark yellow, and the amount of red pigment present increased with age at harvest. In a later experiment (25 June) fruits harvested at 19 weeks and younger shrivelled in storage

(Figure 2). The calyx remained green and fresh-appearing for some time after harvest, finally fading to yellow and turning brown or black as the fruit senesced.

4. Discussion

Nonclimacteric fruits are believed to be those that do not show an adequate self-stimulated increase in production of ethylene with a consequent respiratory rise as part of their ripening behaviour,[7,8] and this is the pattern of respiration shown by tamarillo fruits not treated with ethylene. In no sample was a typical climacteric observed, nor was a climacteric pattern detected by plotting initial, respiration rates of the various fruit ages which might have suggested a climacteric on the plant. Furthermore, all tested ages of fruits responded to ethylene, suggesting that no climacteric had yet occurred. Our data do not allow us to say whether the rise in respiration preceded or followed the rise in ethylene production coinciding with the appearance of decay. The latent infections common in tamarillo fruits can become active when the fruit enters senescence,[9] and we think the increased ethylene production and respiration are in response to the then-active infection.

Tamarillo fruits have a reasonably long storage life, even at 20°C, if decay can be avoided. Even when the storage period was terminated by decay, the sound flesh of mature fruits retained good flavour. Tamarillos show a phenomenon which has been observed in various fruits from herbaceous plants (including the tomato); when held at 20°C, the fruits tend to senesce at the same age after anthesis even though they have been harvested at different ages.[10] Red tamarillos harvested at 21 weeks after anthesis and older started into senescence at 32.4 ± 1.4 weeks; the life of younger fruits was more variable and generally shorter.

Although the red strain of tamarillo is commercially more important, about 10% of the New Zealand crop is yellow-fruited. Experiments similar to those described above (except ethylene treatments) were carried out with fruits from seedling trees of a true yellow strain (not a reverted red); the seed had been obtained directly from Popaian, Colombia. No important differences were observed, although the yellow fruits tended to be longer lived and a little more variable in time to final senescence (38.2 ± 5.3 weeks after anthesis). Fruits of the yellow strain showed the same pattern of skin pigment changes as did the red strain, except that relatively little red pigment ever developed. The final skin colour was pale orange (thin red over yellow ground colour); no red pigment developed in the arils.

Acknowledgement

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References

1. Fletcher, W. A. *Growing Tamarillos* 1975, New Zealand Dept. Agr. Bul. 307.
2. Strachan, G. *Fd Tech. New Zealand* 1970, **5**, 304.
3. Dawes, S. N.; Callaghan, M. E. *New Zealand J. Sci.* 1970, **13**, 447.
4. Wrolstad, R. E.; Heatherbell, D. A. *J. Sci. Fd Agric.* 1974, **25**, 1221.
5. Claypool, L. L.; Keefer, R. M. *Proc. Amer. Soc. Hort. Sci.* 1942, **40**, 177.
6. Bollard, E. G. In *The Biochemistry of Fruits and Their Products* 1970, Vol. 1, pp. 387–425 (Hulme, A. C., Ed.) London, Academic Press.
7. Rhodes, M. J. C. In *The Biochemistry of Fruits and Their Products* 1970, Vol. 1, pp. 521–533 (Hulme, A. C. Ed.), London, Academic Press.
8. Reid, M. S.; Pratt, H. K. *Plant Physiol.* 1972, **49**, 252.
9. Davison, S.; Shackleton, D. A. *Orchardist of N.Z.* 1966, **39**, 53, 55.
10. Pratt, H. K. In *The Biochemistry of Fruits and Their Products* 1971, Vol. 2, pp. 207–232 (Hulme, A. C., Ed.), London, Academic Press.