

Postharvest Response of Avocado Fruits of Different Maturity to Delayed Ethylene Treatments¹

Received for publication April 9, 1974 and in revised form February 14, 1974

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ABSTRACT

The effect of 10, 100, 1000, 10,000 ppm of ethylene, applied for 3, 6, 12, and 24 hours, on the ripening rate of "Hass" avocado (*Persea americana* Mill.) fruits at three stages of maturity was investigated. Ethylene treatments were started either immediately after picking or 2 days later. A sharp peak of ethylene production was found to precede full softening by about 2 days and the occurrence of this peak was used to determine ripening rate. Hastening of fruit ripening was much more marked following ethylene treatment which began 2 days after harvesting than immediately after. The difference in response diminished gradually as the fruit became more mature.

These results can be explained by the assumption that the factors which prevent avocado ripening on the tree, continue to exert their influence for a limited period after harvest and inhibit the ripening response in the freshly picked fruit. This inhibition decreases with advancing fruit maturity.

The softening time of avocado (*Persea americana* Mill.) fruits after harvest depends on their maturity, less time being required as maturity increases (2, 8, 9, 12, 17, 19, 20). The softening process may be accelerated by applying ethylene to the picked fruits. The response of the fruit to ethylene applications also depends on its maturity: the more mature the fruit is at picking, the more prompt will be its response to ethylene treatment (2, 9, 10, 12).

The mature avocado does not undergo softening on the tree, but will soften after harvest. One of the possible explanations for this phenomenon is that as long as the fruit is still on the tree, it receives some factors from the tree which inhibit its ripening (8, 12). Gazit and Blumenfeld (11) found that avocado fruit did not respond at all to a 24-hr ethylene treatment started immediately after harvest, while a good response was attained when treatment was started 49 hr after picking.

In the present study, the response of avocado fruits to brief ethylene applications was investigated in order to follow the change in the activity of factors which inhibit fruit softening as a function of the time between picking and ethylene application, at successive stages of maturity.

MATERIALS AND METHODS

Ethylene Treatment. "Hass" avocado (*Persea americana* Mill.) fruits were picked in the morning from a commercial grove in the coastal plain. Data on picking dates and some fruit parameters are presented in Table I.

A total of 360 fruits were picked at each maturity stage: half of them (180) were picked 49 hr before the start of ethylene treatments, and left in the orchard until the second group of 180 fruits was picked 1 hr before the start of ethylene treatment. Each group was randomly divided into 16 treatment lots of 10 fruits each, and one control (untreated) lot of 20 fruits. The 16 ethylene treatments consisted of four ethylene concentrations (10, 100, 1,000, 10,000 ppm) \times four time durations (3, 6, 12, 24 hr). Eight lots (four picked 49 hr before and four picked 1 hr before the start of treatment) were enclosed in polyethylene bags and an ethylene-air mixture at the experimental concentration chosen was blown through the bag at a rate of 10 l/min. The CO₂ concentration in the bags did not rise above 0.05%. Ethylene concentrations were verified at the beginning and at the end of the treatments. After the fruits were removed from the bags, they were aired well for 2 hr and kept, separated, in a well ventilated room. Ethylene concentration in the storage room, which was checked regularly, was always below 20 ppb. The temperature during the treatments and storage period was kept at 21 C. Control fruits were kept near the treated fruits throughout the pretreatment, treatment, and storage periods.

Ethylene Production and Respiration Analysis. Each fruit was sealed every day in a 750-ml glass jar for 15 min at 21 C. Ethylene and CO₂ concentrations in the atmosphere of the jar were then determined. Under such conditions, CO₂ built up to approximately 1% at the end of the sealing period.

There seemed to be a possibility that this treatment, short as it was, might affect the fruit ripening rate. Hence, 15 fruits were sealed individually for 15 min either every day or every 3 days, but no significant effect on ripening rate or ethylene production was found.

Ethylene concentration was determined by means of a Packard gas chromatograph using an alumina column and a flame ionization detector. CO₂ was determined on a second sample using a Porapak type R column and a thermal conductivity detector.

Fruit Firmness Determination. The firmness of each fruit was tested just before determination of its CO₂ and ethylene production. Five arbitrary degrees of fruit firmness were used: hard, flexible, beginning of softening, soft (edible), and very soft.

Results of the experiments were analyzed statistically by means of a three-way analysis of variance, with Q test included.

¹ Contribution from The Volcani Center, Agricultural Research Organization, Bet Dagan, Israel. 1973 Series, No. 151-E.

Table I. Parameters Characterizing the Hass Avocado Fruits Used in the Ethylene Experiments

| Picking Date | Avg. Fruit Weight | Seed/Fruit | Oil Content of Fruit Mesocarp | Time from Harvest to Peak of Ethylene Production |
|--------------|-------------------|------------|-------------------------------|--|
| | g | % | % | days |
| Mid-Oct. | 193 ± 1.0 | 13.7 ± 0.8 | 7.6 ± 0.4 | 10.9 ± 0.3 |
| Mid-Dec | 192 ± 0.5 | 13.4 ± 0.5 | 8.7 ± 0.7 | 9.4 ± 0.3 |
| Mid-Feb. | 196 ± 0.8 | 13.4 ± 1.0 | 12.7 ± 0.6 | 7.4 ± 0.2 |

The standard error was calculated from the mean square of the error of the complete experiment.

RESULTS

Criteria for Ripening. The peaks of respiration and ethylene production coincided, and full softening of the fruit took place about 2 days later (Fig. 1). As the peak of ethylene production was much more clearly defined than the respiratory peak, ethylene production rate was used to determine the fruit ripening stage.

Fruit became soft and edible within 1 to 3 days after reaching the peak of ethylene production (about 88% within 1.5–2.5 days), regardless of prior short ethylene treatment (Table II).

Fruit Response to Ethylene Treatments. Fruits were sampled on three successive picking dates: in mid-October, December, and February. In October, the fruit was in the initial stages of maturation and seed coats were still fleshy, constituting about 8.5% of the whole seed. In December and February fruits were fully mature, with brown, dried seed coats. The percentage of oil, which can also serve as a parameter of fruit maturation, was continuously rising, while the number of days from harvest to peak of ethylene production was decreasing (Table I).

Results of fruit response to the various ethylene treatments are presented in Table III. Fruits responded to ethylene treatments by ripening earlier, the stronger effect being that of the duration of the treatment, while the concentrations of ethylene used had a lesser effect. The effect of the ethylene treatments on the individual fruit ripening was usually a "yes or no" type of response. Hence, partial response of a group occurred when some fruits had a full response while others did not respond at all.

Response to ethylene was clearly dependent both on the lapse of time from picking to start of treatment and on the stage of fruit maturity. Significant fruit ripening response to the brief ethylene treatments was markedly enhanced as the fruit became more mature (Table III). This tendency was quite obvious both when the ethylene treatment was begun immediately (1 hr) after picking, as well as when it was started 49 hr after harvest. However, at all the three maturity stages, fruit response to the later treatment was much greater than to the treatment started immediately after picking.

All fruits, even those treated with 10,000 ppm of ethylene for 24 hr, ripened in a normal manner and had the same pattern of ethylene production.

DISCUSSION

The relationship found between ethylene production, respiration, and fruit softening (Fig. 1) is in accordance with previous reports (1, 5, 6, 13). Softening occurred about 2 days after fruit had reached the respiratory and ethylene production peaks (Table II), which agrees with Biale's data (1) but differs from Eaks'

findings that softening coincides with the respiratory climacteric (10).

The respiratory climacteric has served for many years as an objective parameter for determining ripeness of climacteric fruits (3). The tremendous increase in ethylene production that occurs in most climacteric fruits during ripening (2, 4, 5, 15), and the important role of ethylene in this process (6, 17) justify the use of ethylene production as a better and more convenient parameter for determining the degree of fruit ripening.

Biale (2, 4) found that avocado fruits ripened at the same rate when put under continuous ethylene treatments at 10, 100, 1,000 and 10,000 ppm. Using brief treatments with the same concentrations, a gradual ripening response was achieved (Table III).

Gazit and Blumenfeld (11) found a lack of response to 24-hr ethylene treatments started immediately after harvest, a result which we also obtained in fruits harvested in December. On the other hand, we found that more mature fruit responded fully

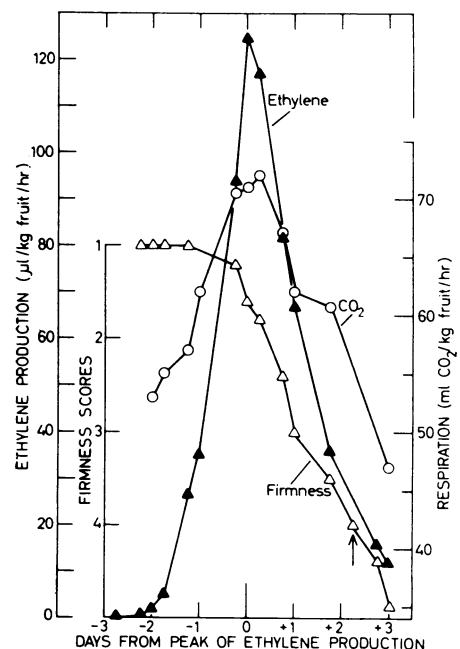


FIG. 1. Relationship between ethylene production, respiration, and fruit firmness (tested manually). Successive ethylene production, respiration, and manual firmness determinations were performed on the same fruits; each point represents an average of 20 fruits. Averages were calculated in accordance with the peak date of ethylene production and are not related to picking date. Arrow points to the day on which the fruits were judged edible.

Table II. Effect of Ethylene Treatment on the Relation between the Peak Date in Ethylene Production and the Softening of Hass Avocado Fruits

| Concn Ethylene Treatment for 3, 6, 12, or 24 hr | No. of Fruits per Treatment | Soft Fruits*1.5–2.5 Days After the Peak Date in Ethylene Production |
|---|-----------------------------|---|
| ppm | | % |
| 0 | 20 | 90 |
| 10 | 80 | 89 |
| 100 | 80 | 86 |
| 1,000 | 80 | 88 |
| 10,000 | 80 | 87 |

to the same treatment, and that a difference in response occurred only with ethylene treatments shorter than 24 hr (Table III).

The effect of ethylene on fruit ripening rate in relation to time of harvest is shown in Table III. Another legitimate way of presenting the same results is in relation to the start of ethylene treatment, and then differences between treatments started 1 hr and 49 hr after harvest would be extended by 2 more days. Figure 2 shows the change during the season in the response of the fruit to 24 hr of 10,000 ppm ethylene, in relation to the start of ethylene treatment. This pattern of change in response to ethylene during fruit maturation occurred in all the other effective ethylene treatments (Table III). This shows that the ability of ethylene to trigger the ripening process during the first day after harvest is related to avocado fruit maturity.

In most cases the importance of the time relationship between ethylene treatment and harvest time has not been taken into account (16). The effect of the time lapse between harvest and start of ethylene treatment should always be considered in experiments as well as in practice.

Inhibitory factors are assumed to prevent fruit ripening before harvest (8, 9, 15). It has been demonstrated that in avocado fruit these unidentified factors apparently continue to exert their inhibitory influence for a limited period after harvest, the inhibition gradually diminishing as substances are depleted, decomposed, or inactivated (11). The results reported herein (Table III) are in accord with this basic assumption.

As fruit becomes more mature, the activity of these inhibitory factors gradually decreases to a level at which most climacteric fruits will ripen on the mother plant (8, 19). Figure 2 demonstrates that the ripening response of the avocado fruit to ethylene is a function both of fruit maturity (aging) and of the time elapsed after harvest (senescence), and that aging may replace senescence and vice versa. It seems reasonable to explain this relationship by assuming that basically the same process operates in both cases, namely, a decrease in the activity of the ripening inhibitory factors.

Table III. Effect of Ethylene Treatments on Advancement (–days) or Retardation (+days) of Ripening of Hass Avocado Fruits as Compared with Untreated Controls

Results are presented as the difference in length of time elapsed from harvest to peak date of ethylene production. Treatments were given to fruits at three stages of maturity and were started 1 hr or 49 hr after picking. Results within the boxed areas are significantly different from the untreated controls ($P = 0.05$).

| | | ETHYLENE TREATMENT STARTED 1 hr AFTER HARVEST | | | | | | | | | | | |
|----------------|--------|---|------|------|------|------------|------|------|------|------------|------|------|------|
| | | OCTOBER | | | | DECEMBER | | | | FEBRUARY | | | |
| DURATION (hr) | | 3 | 6 | 12 | 24 | 3 | 6 | 12 | 24 | 3 | 6 | 12 | 24 |
| ETHYLENE (ppm) | 10 | +1.0 | +1.3 | +1.3 | +0.5 | -0.2 | -0.1 | +0.4 | -0.4 | 0 | -0.2 | -0.3 | -2.7 |
| | 100 | +0.7 | +1.0 | +1.7 | +0.1 | -0.1 | +0.8 | +0.4 | 0 | -0.1 | -0.7 | -1.5 | -3.3 |
| | 1000 | -0.1 | -0.8 | +0.7 | -0.4 | -0.1 | +0.1 | +0.2 | -0.8 | 0 | -1.0 | -1.6 | -2.8 |
| | 10,000 | -0.1 | 0 | +0.8 | -1.1 | 0 | 0 | -0.2 | -2.1 | -0.5 | -1.0 | -2.8 | -3.6 |
| | | S.E. = 0.6 | | | | S.E. = 0.5 | | | | S.E. = 0.4 | | | |

| | | ETHYLENE TREATMENT STARTED 49 hr AFTER HARVEST | | | | | | | | | | | |
|----------------|--------|--|------|------|------|------------|------|------|------|------------|------|------|------|
| | | OCTOBER | | | | DECEMBER | | | | FEBRUARY | | | |
| DURATION (hr) | | 3 | 6 | 12 | 24 | 3 | 6 | 12 | 24 | 3 | 6 | 12 | 24 |
| ETHYLENE (ppm) | 10 | 0 | +0.3 | 0 | -1.2 | -0.4 | -0.6 | -1.6 | -2.3 | 0 | +0.2 | -1.7 | -3.6 |
| | 100 | -0.1 | +0.6 | -1.4 | -2.8 | -1.1 | -1.8 | -2.1 | -3.7 | 0 | -0.4 | -2.2 | -3.4 |
| | 1000 | -0.7 | -0.6 | -1.4 | -3.9 | -0.6 | -2.2 | -2.9 | -4.0 | -0.3 | -1.0 | -3.0 | -3.4 |
| | 10,000 | -0.1 | +0.4 | -0.5 | -3.4 | -0.8 | -2.5 | -2.1 | -3.8 | -1.6 | -2.8 | -2.3 | -3.5 |
| | | S.E. = 0.6 | | | | S.E. = 0.5 | | | | S.E. = 0.4 | | | |

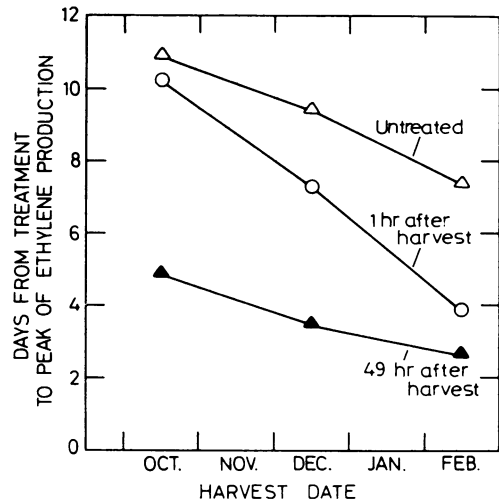


FIG. 2. Effect of 10,000 ppm ethylene for 24 hr, on the number of days elapsing from the beginning of treatment until the peak of ethylene production in Hass avocado fruits. Treatment started 1 hr after harvest (○); Treatment started 49 hr after harvest (▲); Control—untreated fruits (△).

We believe that the same situation exists in other kinds of climacteric fruits because during quite a long period of their development, they will ripen only after detachment from the mother plant (7, 14). It would seem that climacteric fruits may be divided into three groups in accordance with the supply of factors which inhibit ripening from the mother plant to the fruit. The difference between the groups depends on the stage at which such supply ceases.

1. The first group includes fruits in which no inhibitory factors are translocated from other parts of the plant long before the fruits become mature. This is apparently the case with the honeydew melon where 28- to 35-day-old fruits will ripen at the same time whether picked or left connected to the mother plant (17).

2. The second group includes most of the climacteric fruits, which eventually ripen while still connected to the plant. The supply of inhibitory factors to these fruits decreases with their advancing maturity in similarity to the supply of all other substances translocated from the mother plant to the fruit (8), until the fruit reaches the climacteric phase and ripens while still on the plant.

3. In fruits of the third group, the supply of inhibitory factors from the plant to the fruit continues as long as the fruit is connected to the tree, so that the fruit is capable of ripening only after harvest. The avocado belongs to this group. It is possible that the continuation of meristematic activity during avocado maturation (18) ensures the continuous supply of these inhibitory substances.

It is suggested that the increasing sensitivity of climacteric fruits to ethylene during maturation is due mainly to a decrease (which occurs also in avocado) in the amount of the ripening-inhibiting factors which are supplied by the plant.

Acknowledgments—We wish to thank Mrs. M. Elimeleh and Mr. Z. Ben Chetz for their valuable technical assistance.

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