

Water-deficit Stress, Ethylene Production, and Ripening in Avocado Fruits¹

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ABSTRACT

Differential rates of water loss were achieved in picked avocado (*Persea americana* Mill.) fruits, either by controlling the evaporation rate or by supplying water through the fruit stalk. A negative linear correlation was found between the daily rate of water loss from fruits and their ripening, as determined by the time from harvest to peak of ethylene production. Ripening rate was hastened by 40% in fruits which had lost water at rate of 2.9% fresh weight per day, compared with those which lost only 0.5% per day.

The ripening of climacteric fruits is associated with an appreciable rise in endogenous levels of ethylene (2, 4, 6, 9). The rise in ethylene level begins before the onset of the respiratory climacteric (4, 9), and both processes are affected by temperature and by the concentration of CO₂ in the surrounding atmosphere (1, 11).

The ripening of climacteric fruits may be hastened by raising the endogenous levels of ethylene in the preclimacteric period. This can be achieved by application of exogenous ethylene (4, 5, 9) and by various types of wounding (3, 6). Irradiation of fruits also causes a stress and when it was given to "Fuerte" avocado fruits at their preclimacteric period, an immediate rise in ethylene production occurs (10). It has been reported recently that stress caused by water deficit increases the rate of ethylene production in petioles of cotton leaves (7). Since water deficit always occurs in picked fruit under conditions where loss of water is not prevented by special treatments, we tested the possibility that this deficit might enhance ethylene production and thus hasten the rate of ripening in picked avocado fruits. Water deficit in picked fruit can be regulated both by changing the rate of water loss and by addition of water through the fruit stalk to replenish that lost by evaporation.

Experiments were conducted with mature "Fuerte" and "Hass" avocado fruits which were picked from a commercial grove in November and March, respectively. Treatments and tests were conducted at 21 to 22 C.

Each day Fuerte and Hass fruits were hermetically sealed in 1250-ml and 750-ml jars, respectively; after 15 min, two

gas samples of 2 ml each were withdrawn from each jar and injected into a Packard gas chromatograph for determination of ethylene and CO₂ concentration.

Ethylene was determined using an alumina column and a flame ionization detector; CO₂ was determined using a Poropak type R column and a thermal conductivity detector.

We had previously found that the climacteric peaks in ethylene and CO₂ production in avocado fruits occur at about the same time (see Table II). All fruits were found to be soft and edible about 2 days after reaching the climacteric peaks. Thus, the rate of fruit ripening was determined by the lapse of time from picking to peak of ethylene and CO₂ production. The fruits were weighed every day, and the loss of fresh weight was used as a measure of the water stress.

Regulation of Water Deficit in Picked Fruit by Changes in Evaporation Rate. One hour after picking, 10 fruits were inserted into 15 × 100 cm polyethylene sleeves. A continuous flow of air at the rate of 5 or 10 l/min was used to regulate humidity and to ensure adequate ventilation in the sleeve. Air for the "wet" treatment was passed through water at room temperature, whereas air for the "dry" treatment was passed through a silica gel column. Relative humidity, measured in the air emerging from the sleeves, was 90 to 95% in the wet treatment and 10 to 20% in the dry treatment. Relative humidity in the wet treatment was no higher than 95% to prevent condensation on the fruit surface which might interfere with normal gas exchange. Ethylene and CO₂ concentrations in the atmosphere inside the sleeves were measured daily. CO₂ concentration was below 0.05% and ethylene concentration was below a 0.1 μl/l. Fruits were removed from the sleeves daily for weighing and the measurement of respiration and ethylene production. Figure 1 indicates that Fuerte fruits lost water in the dry treatment three times as fast as in the wet treatment and their ripening rate was hastened by an average of 3.3 days (32%). Ripe fruits in the dry treatment did not differ in appearance or taste from those in the wet treatment. Hass fruit responded similarly, and ripening was considerably hastened by water deficit stress (Table I). The rate of air flow had no specific effect, and the rate of ripening was influenced only by the rate of water loss. As may be seen from regression curves in Figure 2, the relationship between the rate of water loss from picked fruit and the rate of their ripening, is linear. If this linear relationship is also valid at lower rates of water loss than those examined in this study, the ripening rate of fruits not losing any water at all may be calculated. It seems obvious that the slope and intercept found in these experiments are applicable only to the ripening behavior of the fruit used under the specific experimental conditions, and that any changes in fruit characteristics (variety and maturity stage) or environ-

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mental conditions will influence the shape and the intercept of these curves.

Regulation of Water Deficit by Water Infusion. Since changes in the rate of evaporation from fruit might be accompanied by changes in additional unknown factors, we examined the effect of adding water through the fruit stalk upon the rate of ripening.

Forty Fuerte fruits were picked with a 25 to 50 cm piece of stalk plus branch attached. Glass tubes filled with 10 ml of distilled water were attached to the branches of 20 fruits with the aid of latex tubing. The volume in the tubes was made up every 12 hr. Water under pressure of 0.5 atm was applied through the peduncle to 10 fruits, while the remaining 10

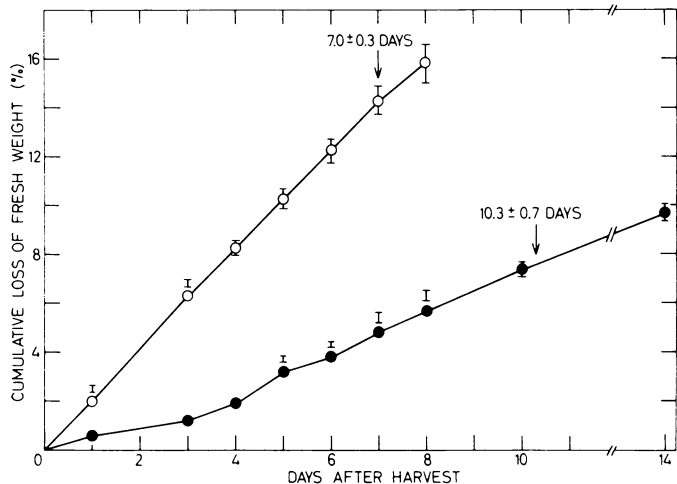


FIG. 1. Effect of relative humidity on the water loss and ripening rate of Fuerte avocado fruits. Relative humidity: 95% (●) and relative humidity: 10 to 20% (○).

Table I. Effect of Daily Loss of Water on the Rate of Ripening of Picked Avocado Fruits

Cultivar	Relative Humidity	Air Flow Rate	Daily Loss of Fresh Wt	Time to Peak of Ethylene Production
	%	l/min	%	days
Fuerte	90-95	5	0.5	7.3 ± 0.6
	90-95	10	0.6	7.3 ± 0.6
	10-20	5	1.5	5.5 ± 0.2
	10-20	10	1.9	5.3 ± 0.2
Hass	90-95	5	0.5	8.3 ± 0.2
	10-20	10	1.9	5.6 ± 0.2

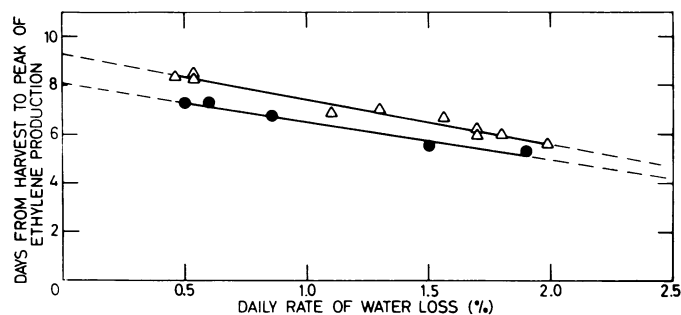


FIG. 2. Correlation between the rates of water loss and ripening in picked avocado fruits. Cv. Fuerte (●): $r^2 = 0.97$, $y = -1.6x + 8.1$ for $n = 5$; cv. Hass (△): $r^2 = 0.97$, $y = 1.8x + 9.3$ for $n = 10$.

Table II. Effect of Water Supply by Infusion to Picked Fuerte Avocado Fruits, on Fruit Abscission, and Ripening

Treatment	Daily Loss of Fresh Wt	Time to Fruit Abscission	Time to Peak of Ethylene Production	Time to Peak of CO ₂ Evolution
	%	days		
Water supplied to fruit	1.6	9.9	10.8	11.1
Control	2.7	7.4	8.0	8.0
Water supplied to fruit under pressure; fruit ventilated	0.5	9.6	11.6	11.5
Ventilated control	2.9	6.2	7.0	7.3
SE	0.2	0.4	0.5	0.5

fruits were supplied with water under atmospheric pressure. The 20 control fruits were hung from their stalks with no water supply, under the same temperature and humidity conditions as the water-infused fruits. The 10 fruits supplied with water under pressure and 10 of those with no water were ventilated by a fan.

The results given in Table II show that water-deficit stress first and foremost hastened fruit abscission. The average production of ethylene in abscised fruits was about $10 \mu\text{l}/\text{kg}\cdot\text{hr}^{-1}$. The rate of fruit ripening was also markedly affected. Water deficit brought the day of peak ethylene production and respiration forward by 40% or 25%, depending on the degree of stress. Under pressure, the fruits took up more water, and the water deficit could thus be reduced more effectively. A concomitant delay in the rate of fruit ripening was thus achieved.

Results of these experiments indicate that water deficit stress must be regarded as one of the factors determining the ripening rate of climacteric fruits, such as the composition of the atmosphere, the temperature (1, 11), and light (8). This fact is of importance in studies of ethylene production in fruits. These results are of some practical value, since they indicate the importance of the relative humidity during the storage period of avocado and possibly also of other climacteric fruits.

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