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Chilling Sensitivity of Avocado Fruit at Different Stages of the Respiratory Climacteric[1]

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ABSTRACT. Chilling sensitivity of 'Fuerte' and 'Hass' avocados *(Persea americana* Mill.) is a function of the stage of the climacteric. The least sensitive stage is postclimacteric where fruit can be kept at 2°C for 6 to 7 weeks. 'Hass' avocados on the climacteric rise and at the climacteric peak were most sensitive to chilling and showed injury after 19 days of treatment at 2°. Postclimacteric fruit could be transferred to 2° at 36 to 48 hours after the climacteric peak. The time preclimacteric fruit could be held at 2° varied during the picking season but could be as long as 30 days.

Two methods are used to increase storage life of fruit, conventional refrigerated storage and controlled atmosphere (CA) storage (16). Controlled atmosphere storage has proven successful for apple and pear but most other fruits are stored at low temperature to delay ripening.

The storage of avocado fruit in CA has been studied by Biale and Young (3, 20). They showed that an oxygen level lower than that of air reduced respiration rate, and delayed the climacteric peak (C-peak). Carbon dioxide at 5 or 10% concentration delayed the onset of respiratory rise, reduced respiration rate, and prolonged storage life. Manipulation of the ratio of both gases combined with low temp prolonged storage life of many cultivars of avocado, and yielded high quality fruit in the laboratory (2, 15, 18). In practice, CA storage of avocados has not proven economically feasible, and low temp is the only method commercially used to prolong storage life. Several studies of minimum storage temp for avocado indicated the optimum storage temp varies among cultivars. Some are cold-intolerant, requiring high storage temp up to 12.8°C; others are cold-tolerant, and can be stored as low as 4.5°. The 'Fuerte' cultivar is between the 2 groups, and is best stored at 7° (11). The optimum storage temp for 'Hass' is between 6 and 9°, and it ripens best at a humidity above 90% (5, 6). Overholser (13) reported that ‘Fuerte' fruits which were stored at 2.2° two days after picking had 25 days of optimum storage, while those stored at 4.4 or 2.2° for 3 days after picking exhibited surface scald and discolored flesh. At 7.2° both lots had about the same storage life. Biale (1) indicated that no climacteric rise was detectable in 'Fuerte' avocados exposed to 4-5° for 5 weeks. However, some physiological

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changes associated with the process occurred at 5°, between 6 and 8 weeks after harvest with a cycle of ethylene production as measured by the triple response of pea seedlings (13). When the fruits were transferred to an optimum ripening temp, they showed a respiration response typical of postclimacteric (post-C) fruit with symptoms of chilling injury (4). We report in this paper that avocado fruit are most sensitive to chilling during the C-peak phase and much less sensitive during the post-C phase. Optimum storage temp for post-C fruit is 2°. Off flavor developed in fruit held at 0-1°.

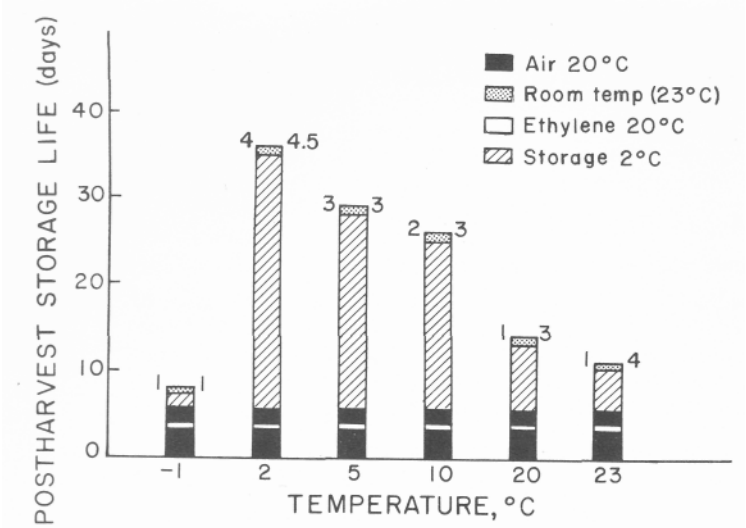

Fig. 1. Effect of temp on storage life of post-C 'Fuerte' avocado fruit picked March 4, 1974. Numbers on the left and right of each column are scores, quality increasing with the numbers of external appearance and internal quality, respectively.

Materials and Methods

'Fuerte' and 'Hass' avocado fruit were harvested at the Univ. of California South Coast Field Station at Irvine. Only mature fruit having more than 8% fat were used. Twenty-four to 72 hr after picking (8), fruit were treated with 500 ppm C_2H_4 for 24 hr to induce uniform and rapid ripening. Respiration was monitored by a Beckman infrared analyzer Model 215A (9). Fruit at specific stages of the climacteric, preclimacteric (pre-C), climacteric rise (C-rise), C-peak and post-C were transferred to 1.5-mil polyethylene bags in which 16 holes, 6 mm in diameter were cut. The bags were then placed at 2° or at other temp shown in the results section.

Preclimacteric fruit not treated with C_2H_4 were held at 8° until slightly soft and then transferred to 2°, and other pre-C fruit were placed directly at 2°.

Observation of external appearance of fruit of each treatment was made every 3 to 7 days, and 2 to 5 fruits were left at room temp usually 1 to 5 days thereafter to allow firm fruit to become soft. The ripe fruit were cut open for evaluation of internal appearance and flavor. Scores were given as indices of quality: 5) normal appearance or eating quality, 3) about 25% brownish skin area, or eating quality having slightly off flavor or texture, and 1) 50% brownish skin area, eating quality not acceptable.

Results

The respiration rate of ethylene treated fruit was very uniform. The onset of C-rise was initiated within 4 hr of treatment. 'Fuerte' avocados which were 36 hr post-C were transferred to temperatures varying from -1 to +23°C, and their storage life and quality were rated on 5 fruit transferred to 23° at 4-day intervals. Fruit stored at 2° had the longest storage life (Fig. 1). They were in an acceptable condition when transferred to 23°, 35 days after picking. The storage life of fruit in other treatments was shorter than that of fruit held at 2°. At higher temp, over-ripeness and fruit decay were the major causes of deterioration. Black spots developed on fruit stored at 5 or 10°, 23 to 26 days after harvest. At -1° all fruits were frozen.

Fruit were usually treated with C_2H_4 to induce rapid and uniform ripening as we needed to make certain that no C-peak fruit were included in the 2°C treatments. It was of interest to determine whether fruit ripening without the aid of C_2H_4 could be stored at 2° as long as C_2H_4 treated fruit. One lot of 'Hass' fruit was treated with C_2H_4 for 40 hr and after softening were placed directly at 2°. Another lot was placed at 8° until a few fruit started to soften, when they were treated with C_2H_4 to cause all fruit to soften uniformly and then placed at 2° (Fig. 2). Fruit treated with C_2H_4 one day after picking were of acceptable quality after 46 days at 2° while those allowed to partially ripen at 8° were of equal quality after 40 days at 2° for a total storage period of 70 days.

We picked 192 mid-season 'Hass' fruit during July. Thirty-two were placed at 2°C one day after picking, the remainder were treated with 500 ppm C_2H_4 at 20° and their respiration monitored with the CO_2 analyzer. Eight groups of 4 fruit were transferred to 2° at the following stages of the climacteric: a) one-half to two thirds of the C-peak, b) C-peak, c) 36 hr post-C, d) 72 hr post-C, and e) 96 hr post-C. Two to 4 fruit from each of the 6 treatments were removed at intervals of 3 to 7 days, and transferred to 23° for evaluation of ripening appearance and taste tests.

After storage at 2°C for 19 days, C-peak fruit showed symptoms of chilling injury (Fig. 3). C-rise fruit showed chilling injury after 26 days, and pre-C fruit after 30 days. On the other hand, 36-hr post-C fruit showed no chilling injury at 2° for 40 days, and 72 or 96 hr post-C fruit for 32 or 29 days, respectively. The 72 or 96 hr post-C fruit stored at 2° developed off flavor if held at 23° for more than 6 hr. The peel of 'Hass' was not affected by black spots or other blemishes when stored at 2° except that these fruit had a dull appearance. Chilling injury was first manifest as grayish color in the mesocarp close to the seed coat, usually at the stylar end. When the damage was severe, the color became dark brown and the grayish color in the mesocarp surrounding the seed coat spread toward the stem end.

Discussion

Ordinarily, every effort is made to store and ship fruit in the pre-C stage and to allow ripening to occur at the retail outlet. The optimum storage temperature varies among species and cultivars, and is influenced by the geographical origin of the fruit (11, 19). Should temperature be too low, but above freezing, physiological dysfunction of the commodity will occur as a temp-time factor, and lead to chilling injury (12).

The minimum storage temperature recommended for 'Fuerte' avocados harvested at the mature pre-C stage is 7.2°C. It has been assumed that post-C fruit have the same requirement. We have shown that 36 to 48 hr post-C avocados can be stored at 2° for up to 6 to 7 weeks (Fig. 2 and 3), while the mature pre-C fruit can be stored at 8° for up to 3 to 4 weeks. It may be noted from the experiments reported that there is considerable variation in the time post-C fruit could be held at 2°. We believe this is partially due to the time during harvest season that fruit were picked with late season fruit being more susceptible to physiological disorders. Other environmental factors must also be involved, as in a few experiments even late season fruit were acceptable after 40 days at 2°. In our best experiments we have stored C_2H_4 treated fruit for 53 days after picking (47 days at 2°). Fruit held at 8° until ripening was initiated (30 days) followed by 3 days at 23° for ripening and then 40 days at 2° were acceptable 73 days after picking. Fruit allowed to undergo normal ripening had only a slightly shorter storage life at 2° (40 days) compared

to fruit treated with C_2H_4 one day after picking (46 days). Thus the post-C life of the fruit is nearly independent of the pre-C period and there is a clear advantage of holding the fruit at 7° to 8° until ripening is initiated in some fruit. It must be emphasized that it is important to use ethylene treatment to achieve uniform ripening of the entire lot of fruit before transfer to 2°. If pre-C fruit are put at 2°, chilling symptoms will result while if fruit more than 4 days post-C are used, off flavors develop soon after transfer to room temp. The post-C fruit must also be protected from desiccation or severe shriveling will occur.

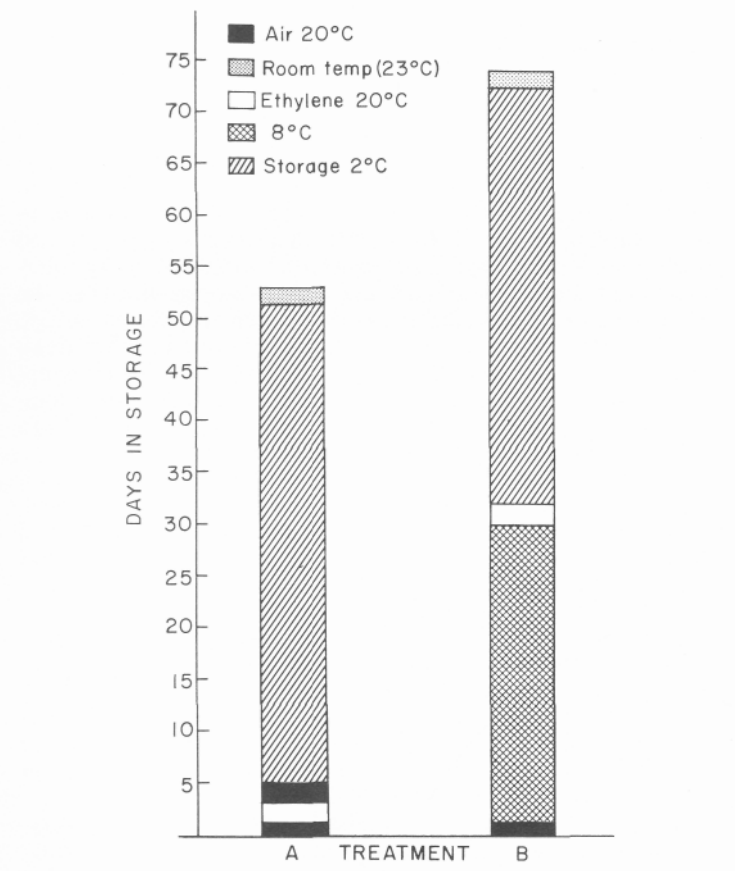

Fig. 2. The storage life of 'Hass' avocado fruit picked July 1, 1975. A, ethylene-treated fruit; B, fruit became post-C at 8°C after 30 days and were transferred to 2°.

We have shown that avocado fruit become increasingly sensitive to chilling temp as the climacteric progresses to the peak and then become less sensitive in the post-C stage. Kidd and West [quoted by Fidler (7)] reported in 1933 that apples were also more sensitive to chilling at the C-peak. Overholser (13) carried out cold storage experiments on avocados furnished by fruit companies. The fruit were shipped by express, and arrived in a hard, unripe condition, presumably 2 or 3 days postharvest. He reported that 'Fuerte' fruit stored 3 days postharvest exhibited discolored flesh and surface scald at 4.4° or 2.2°C, while those stored 2 days postharvest at the same temp had 25 days of optimum storage. In the first case the fruit were probably close to C-peak stage due to shipment condition, and the latter case in C-rise stage where we have shown them to be less sensitive. Pratt and Biale (14) showed that 'Fuerte' avocados stored at 5° produced ethylene for a short period and may have had a C-peak of very small magnitude. It appears that fruit at any climacteric stage are damaged by sufficient low temp. The periods of highest sensitivity are correlated with high metabolic activity, the C-peak stage. The post-C fruit are least sensitive and while the rate of respiration is higher than the pre-C or some C-rise fruit, the rates of respiration in the post-C is decreasing. As respiration rises on the climacteric, we may expect increasing levels of intermediates to accumulate while in the post-C phase with declining respiration, the pools of intermediates are likely to decrease. Evidence now points to chilling injury being caused by a change in the activity of regulatory enzymes such that intermediates accumulate to levels which are associated toxic to the cells. Salminen and Young (17) have shown, for example, a large increase in the activity of phosphofructokinase associated with the C-rise in banana fruit with the expected increase in the levels of intermediates of glycolysis up to

the C-peak followed by a decrease in intermediates in the post-C phase. We have also found (10) that the activation energy of avocado fruit mitochondrial succinoxidase increases at temperatures where chilling occurs in the intact pre-C and C-peak fruit, but increases at a lower temperatures in post-C fruit. This suggests that enzymes which regulate rates of turnover and pool size of intermediates before and at the C-peak, cease to be regulatory in the post-C phase. As a consequence, pools of intermediates do not build up to toxic levels.

The storage life of avocados can be extended by transferring the fruit to 2°C after the C-peak of respiration. There is considerable variation in the time that fruit harvested at the same time reach the C-peak. As fruit at the C-peak are most sensitive to chilling injury, it is necessary to make certain that all fruit are post-C at the time of transfer to 2° by treating with ethylene for at least 24 hr. The 2° treatment extends storage life both by delaying the final processes of senescence and suppressing the growth of organisms. While we report the storage of ripe avocado fruit for as long as 46 days, we certainly do not recommend this as a practical storage period. We use these experiments to emphasize that the marketing period can be extended by several days and the high quality of fruit maintained for a much longer period by storage of ripe fruit at 2-5°C.

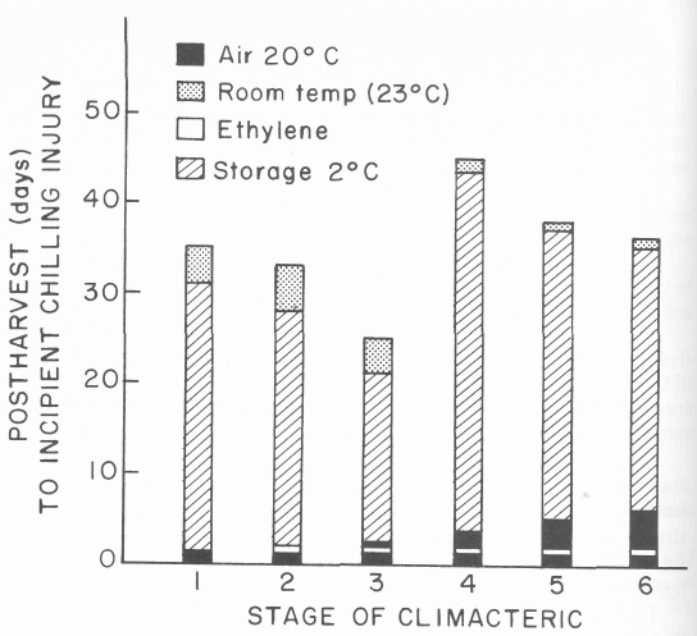

Fig. 3. Effects of climacteric stage on storage life of 'Hass' avocado fruit picked July 29, 1974. 1) pre-C, 2) 1/2 to 2/3 of the C-rise, 3) C-peak, 4) 1 1/2-day post-C, 5) 3-day post-C, and 6) 4-day post-C.

Literature Cited

1. Biale, J. B. 1941. The climacteric rise in respiration rate of the 'Fuerte' avocado fruit. *Proc. Amer. Soc. Hort. Sci.* 39:137-142.
2. _____. 1942. Preliminary studies on modified air storage of the 'Fuerte' avocado fruit. *Proc. Amer. Soc. Hort. Sci.* 41:113-118.

3. _____. 1946. Effect of oxygen concentration on respiration of the 'Fuerte' avocado fruit. *Amer. J. Bot.* 33:363-373.

4. _____ and R. E. Young. 1970. The avocado pear. p. 1-63. *In* A. C. Hulme. (ed.) The biochemistry of fruits and their products. Vol. 2. Acad. Press, London and N.Y.

5. Erickson, L. C. and Y. Kikuta. 1964. Ripening 'Hass' avocados in high and low humidities. *Calif. Avocado Soc. Yrbk.* 48:90-91.

6. _____ and T. Yamashita. 1964. Effect of temperature on the ripening of 'Hass' avocados. *Calif. Avocado Soc. Yrbk.* 48:92-94.

7. Fidler, J. C. 1968. Low temperature injury to fruits and vegetables, p. 271-283. *In* J. Hawthorn and E. J. Rolfe (eds.) Low temperature biology of foodstuffs. Recent Advances in Food Science. Vol. 4. Pergamon Press.

8. Gazit, S. and A. Blumenfeld. 1970. Response of mature avocado fruits to ethylene treatments before and after harvest. *J. Amer. Soc. Hort. Sci.* 95:229-231.

9. Kosiyachinda, S. and R. E. Young. 1975. Ethylene production in relation to the initiation of respiratory climacteric in fruit. *Plant Cell Physiol.* 16:595-602.

10. _____ and _____. 1976. Succinoxidase activity of avocado fruit mitochondria in relation to temperature and chilling injury throughout the climacteric cycle. *Plant Physiol.* (in press).

11. Lutz, J. M. and R. E. Hardenberg. 1968. The commercial storage of fruits, vegetables, and florist and nursery stocks. *U. S. Dept. Agr. Handb.* 66.

12. Lyons, J. M. 1973. Chilling injury in plants. *Annu. Rev. Plant Physiol.* 24:445466.

13. Overholser, E. L. 1925. Cold storage behavior of avocados. *Calif. Avocado Assoc. Annu. Rpt.* 1924-25:3240.

14. Pratt, H. K. and J. B. Biale. 1944. Relation of the production of an active emanation to respiration in the avocado fruit. *Plant Physiol.* 19:519-528.

15. Reeder, W. F. and T. T. Hatton. 1970. Storage of 'Lula' avocados in controlled atmosphere 1970 test. *Fla. State Hort. Soc.* 83:403-405.

16. Ryall, A. L. and W. T. Pentzer. 1974. Handling, transportation, and storage of fruits and vegetables. AVI, Conn.

17. Salminen, S. O. and R. E. Young. 1975. The control properties of phosphofructokinase in relation to the respiratory climacteric in banana fruit. *Plant Physiol.* 55:45-50.

18. Spalding, D. H. and W. F. Reeder. 1972. Quality of 'Booth 8' and 'Lula' avocados stored in a controlled atmosphere. *Fla. State Hort. Soc.* 85:337-341.

19. Wilkinson, B. G. 1970. Physiological disorder of fruits, p. 537-554. *In* A. C. Hulme (ed.) The biochemistry of fruits and their products. Acad. Press, London and N.Y.

20. Young, R. E., R. J. Romani, and J. B, Biale. 1962. Carbon dioxide effects on fruit respiration. II. Response of avocados, banana, and lemons. *Plant Physiol.* 37:416422.