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Accumulation and Loss of Sugars and Reduced Ascorbic Acid in Attached and Detached Tomato Fruits¹

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Abstract. Fruits of tomato (*Lycopersicon esculentum* Mill.) ripened on the plant had higher total solids, soluble solids, and reducing sugars than those which were analyzed at the "breaker" stage (incipient red color). Fruits detached as "breaker" and ripened off the plant lost solids and sugars during ripening. The total solids and reducing sugars concentration in fruits ripened on the plant were about 9% and 18% ('Ace 55') or 15% and 23% ('Rick High Sugar') higher, respectively, than in fruits ripened off the plant.

Fruits analyzed at the "breaker" stage contained only 69.2% ('Ace 55') or 43.6% ('Rick High Sugar') of their potential reduced ascorbic acid concentration if ripened on the vine to table-ripe. Fruits accumulated ascorbic acid during ripening on or off the plant, but the increase was 16% to 27% greater for those fruits left on the plant.

Most commercially-grown fresh market tomatoes are harvested at the mature-green or partially-ripe stages of ripeness and ripened off the plant. Field-ripened fruits have been shown to be of better flavor quality than those harvested as mature-green and ripened off the vine (1). On the other hand, it has been assumed that fruits harvested as partially-ripe and ripened directly at 20°C to table-ripe would be comparable in composition and therefore flavor quality to those ripened on the plant (11). In general, there is an increase in sugars and a decrease in starch content as the fruit ripens from the mature-green to the table-ripe stage (5, 12). Data for ascorbic acid changes are inconsistent. Several investigators (1, 2, 5, 10, 12) reported an increase in reduced ascorbic acid content with ripening, while others (5, 8) have indicated that reduced ascorbic acid content of fruits harvested at the mature-green stage and ripened off the plant was essentially the same as in those ripened on the plant. Malewski and Markakis (7) reported an increase in reduced ascorbic acid content from the green to the breaker stage with no differences beyond the latter stage. This report provides information on changes in total solids, soluble solids, reducing sugars, and reduced ascorbic acid content in tomato fruits of two cultivars, detached at the breaker stage and ripened off the plant and those kept attached to the plant until the table-ripe stage.

Materials and Methods

Fruits of 'Ace 55' and 'Rick High Sugar' (a high sugar breeding line 'R982' developed by C. M. Rick) were obtained from plants grown in the field at Davis, California, using standard cultural practices. At each sampling date, at least 80 fruits were selected at the breaker stage (incipient red color) and divided into four treatments of 15 to 20 fruits each as follows: A) Fruits harvested and immediately frozen in Scotch-pak bags. B) Fruits harvested and placed in open paper bags inside a ventilated box located in the shade of tomato vines. A Ryan recording thermometer was used in each box to monitor temp throughout the ripening period. These fruits were checked daily for visual color and when they attained table-ripeness, they were frozen. C) Fruits harvested and placed at 20°C in glass jars under a humidified air stream at a flow rate of 7-9 liter/hr for 'Rick High Sugar' or 15-17 liter/hr for 'Ace 55' until they reached the table-ripe stage, then were frozen.

Fruits in this treatment and treatment B were individually weighed at harvest and at the end of storage to determine their weight loss. D) Fruits tagged and left to ripen on the plant until the table-ripe stage, then harvested and frozen. This procedure was repeated 5 times for each cultivar during the period between August 16 and Sept. 29, 1975. All frozen samples were held at -40°C until analyzed. Daily, CO₂ production was determined colorimetrically (3) and C₂H₄ production was measured by flame-ionization gas chromatography during the ripening period at 20°C (treatment C).

All fruits in each sample were blended under nitrogen. A subsample was placed immediately in 1% oxalic acid for reduced ascorbic acid analysis according to the method of Loeffler and Ponting (6). This procedure compared favorably with direct maceration of tomato tissue in oxalic acid and it made possible using a more representative sample. Other subsamples were used for measuring soluble solids as °Brix with a Bausch and Lomb Abbe 3L desk refractometer, and reducing sugars by Hassid's method (4). For total solids determination, five 12-ml subsamples were weighed, dried in a water bath, then placed in a vacuum oven at 70°C for 2 hr, then reweighed. Corrections were made on all chemical analyses data for treatments B and C to account for wt loss during ripening as follows: reported value = measured value × (wt after ripening/wt at harvest).

Results and Discussion

Ripening. Fruits ripened on the plant took slightly longer to attain table-ripeness than those ripened off the plant under similar temp conditions (in the field) or at 20°C (Table 1). Detached fruits ripened in the field lost 3 to 5 times more weight than fruits ripened in the storage room at 20°C. This was primarily due to lower relative humidity under field conditions relative to storage room conditions where it was kept near 100%. Although there were differences in mean temp between field and storage room (Table 1), the weighted mean temp (accounting for time and temp) for field conditions was very close to 20°C. 'Rick High Sugar' fruits had a higher weight loss than 'Ace 55' fruits (Table 1), which may be related to differences in fruit size; 'Rick High Sugar' has smaller fruits with larger surface to volume ratio. The mean fruit wt has 80 and 170 g for 'Rick High Sugar' and 'Ace 55', respectively. 'Rick High Sugar' fruits also had higher CO₂ and C₂H₄ production rates than 'Ace 55' during ripening at 20°C (Fig. 1). Based on CO₂ production data, weight loss due to respiration was calculated to be about 0.5 and 0.7% for 'Ace 55' and 'Rick High Sugar', respectively. Comparing these values with the measured weight loss data (Table 1) for fruits ripened at 20°C, weight loss due to respiration accounted for all the mea-

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Table 1. Temp conditions, mean percent weight loss, and mean ripening period for tomatoes ripened on and off the plant.

Cultivar	Treatment ^z	Temp (°C)			Mean % wt loss	Mean no. of days to table-ripe
		Min	Max	Mean		
Ace 55	B	14.4	33.4	23.9	2.9b ^y	9.8a
	C	19.5	20.5	20.0	0.5a	9.8a
	D	14.7	33.3	24.0	—	11.8b
Rick High Sugar	B	15.4	32.7	24.1	4.2b	10.0a
	C	19.5	20.5	20.0	1.4a	10.6a
	D	15.1	32.8	24.0	—	11.8b

^z“B” fruits harvested breaker and ripened under field conditions; “C” fruits harvested breaker and ripened at 20°; “D” fruits ripened on the plant.

^yMean separation within columns for each cultivar by LSD test, 5% level.

sured weight loss by ‘Ace 55’ fruits, but only for half the total weight loss by ‘Rick High Sugar’ fruits. The differences in the latter case is attributable to water transpirational loss.

Solids and sugars. In both cultivars, fruits ripened on the plant had a higher total solids, soluble solids, and reducing sugars than fruits analyzed at the breaker stage or those ripened off the plant, whether under field conditions or in the storage room at 20°C (Fig. 2). Fruits analyzed at the breaker stage had 97.5% (‘Ace 55’) or 94.6% (‘Rick High Sugar’) of their potential total solids if ripened on the plant. This was also reflected in soluble solids and reducing sugar content, but the magnitude of the difference between the 2 cultivars was greater. Breaker fruits had 92.8% (‘Ace 55’) or 79.6% (‘Rick High Sugar’) of the reducing sugar content of fruits ripened on the plant. This points out the possible intercultivar differences in sugar accumulation rate during maturation and ripening which may be related, in part, to the plant growth habit, i.e., fruit/leaf ratio.

Detached fruits contained more total solids, soluble solids, and reducing sugars at the breaker stage (treatment A) than when fully-ripe (treatments B and C). Fruits ripened off the plant lost about 6.7% and 12.9% (‘Ace 55’) or 10.7% and 6.4% (‘Rick High Sugar’) of their total solids and reducing sugars content, respectively, relative to the breaker stage. At the same time, fruits ripened on the plant gained about 2.8% and 7.7% (‘Ace 55’) or 5.7% and 25.7% (‘Rick High Sugar’) in total solids and reducing sugars, respectively.

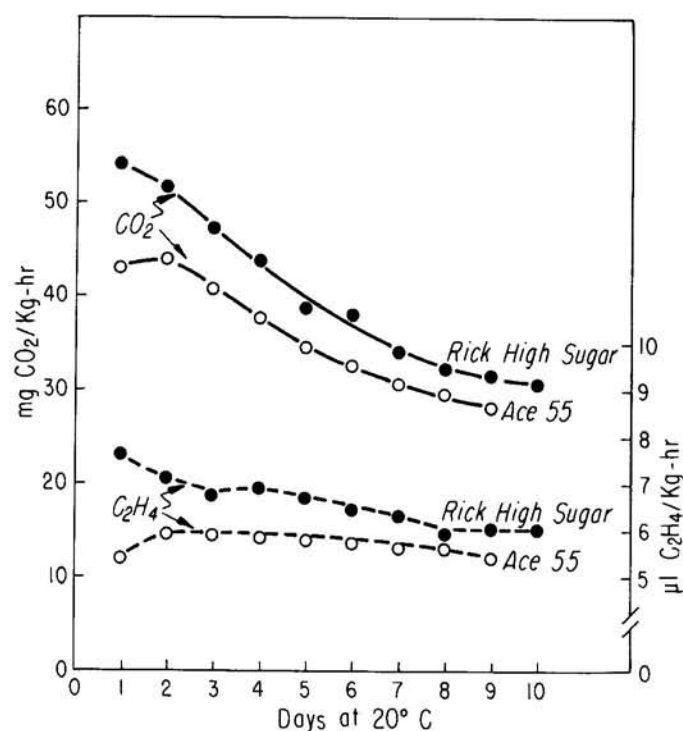


Fig. 1. Respiration and ethylene production rate of ‘Ace 55’ and ‘Rick High Sugar’ tomato fruits harvested at the breaker stage and ripened at 20°C.

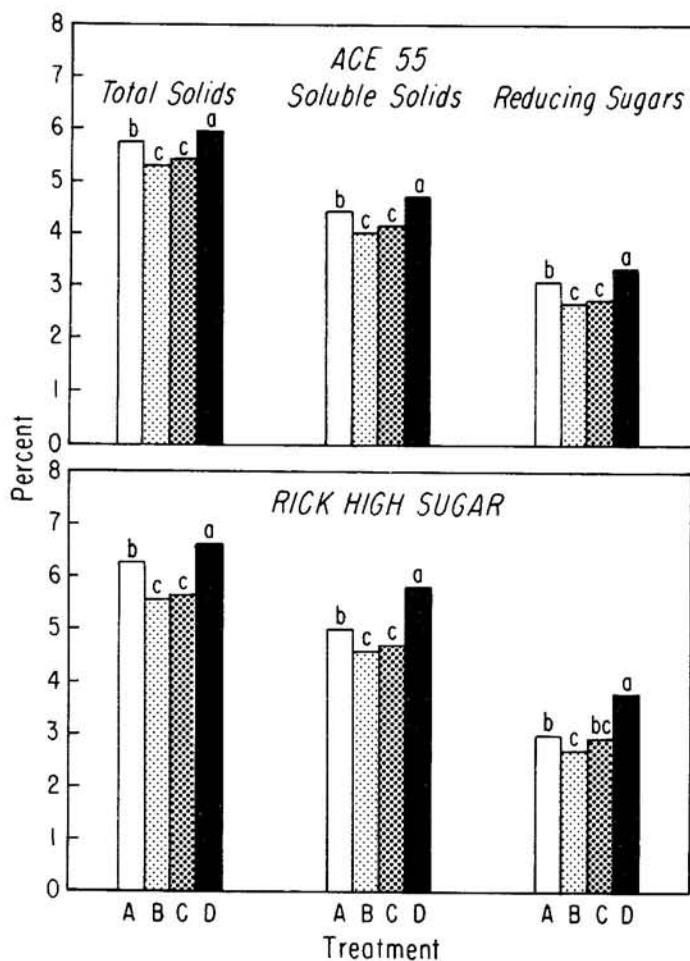


Fig. 2. Mean % total solids, soluble solids, and reducing sugars in tomato fruits: (A) analyzed at the breaker stage, (B) harvested breaker and ripened under field conditions, (C) harvested breaker and ripened at 20°C, (D) ripened on the plant. Means not labeled by the same letter differ significantly at the 5% level.

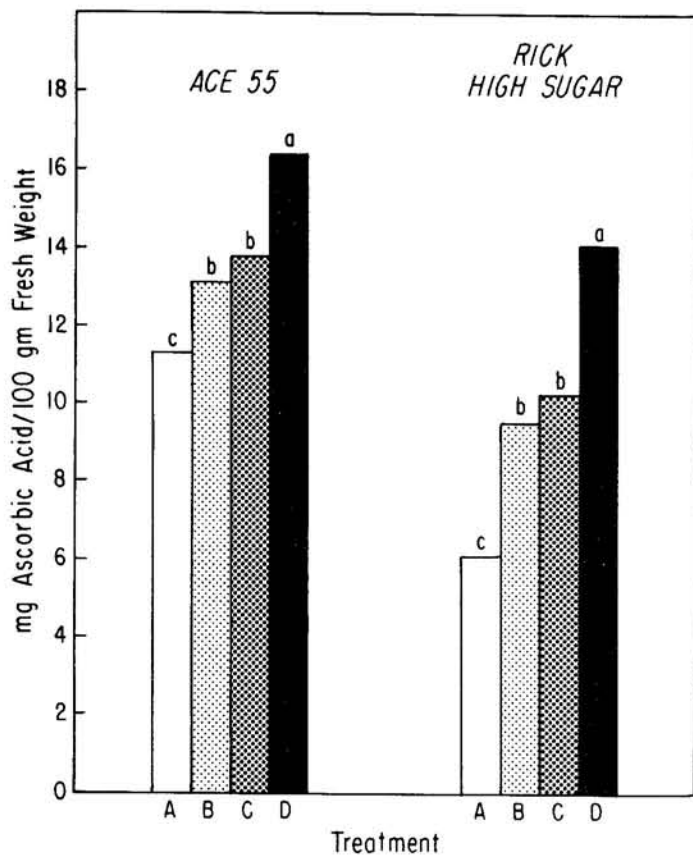


Fig. 3. Mean reduced ascorbic acid concn in tomato fruits: (A) analyzed at the breaker stage, (B) harvested breaker and ripened under field conditions, (C) harvested breaker and ripened at 20°C, (D) ripened on the plant. Means not labeled by the same letter differ significantly at the 5% level.

The accumulation of solids and sugars in attached fruits between the breaker and the table-ripe stage indicates that their translocation into the fruit continues after the breaker stage. This is supported by the findings of McCollum and Skok (9). Using ^{14}C -glucose applied to leaves, they found that it moved most rapidly into developing green tomato fruits, that the movement decreased to a low point at the mature-green stage, increased again at the turning stage, and became negligible when the fruit had attained table-ripeness. They estimated that most of the organic constituents entered the fruit about 5 days past the turning stage. Removal of fruits from the plant cuts off their supply of photosynthates. In addition, some loss of solids occurs due to respiratory activity.

The measured loss in total solids was 0.3% ('Ace 55') and 0.6% ('Rick High Sugar').

Ascorbic acid. Fruits picked and analyzed at the breaker stage contained only 69.2% ('Ace 55') or 43.6% ('Rick High Sugar') of their potential reduced ascorbic acid concn if ripened on the plant to table-ripe (Fig. 3). Fruits ripened on the plant accumulated more ascorbic acid than those ripened off the plant. This accumulation indicates that reduced ascorbic acid synthesis continues beyond the breaker stage in both attached and detached fruits. Fruits ripened off the plant had 80-84% ('Ace 55') or 68-73% ('Rick High Sugar') of the reduced ascorbic acid content in fruits ripened on the plant. Exposure of the fruits to light may have been a factor since light plays an important role in ascorbic acid accumulation in tomato fruits (5). Brecht et. al. (2) reported no difference in total ascorbic acid content between mature-green and table-ripe fruits of several tomato cultivars, although the reduced ascorbic acid was higher in the table-ripe fruits. We did not measure changes in total ascorbic acid content. However, the accumulation of reduced ascorbic acid in detached fruits may have been due in part to conversion of dehydroascorbic acid into the reduced form.

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