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Intercultivar Variation in Composition of Locular and Pericarp Portions of Fresh Market Tomatoes[1]

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Abstract. **Locular content ranged between 14.4 and 35.0% among 7 cultivars of tomato (*Lycopersicon esculentum* Mill.): 'Calmart', 'Cal Ace', 'Ace 55', 'Early Pak 7', 'Earliana', 'Rick High Sugar', and 'Cherry'. There was a strong negative correlation between fruit weight and percent locular tissue. Based on means of all cultivars, the pericarp portion contained about 20% more reducing sugars and 36% more glucose than the locular portion. No significant differences in soluble solids content or fructose concentration were noted. The locular portion had 48 and 57% higher titratable acidity and citric acid, respectively, than the pericarp, but no differences in malic acid concentration or pH were observed. Cultivars with large locular portion and with high concentration of acids and sugars are those which have previously been found to be of good flavor quality.**

Several investigators (2, 3, 5, 6, 7, 9, 10, 11, 16, 17) have shown that the locular tissue of tomato fruit is more acid than the pericarp tissue. The relative distribution of soluble solids and/or reducing sugars is not as clear. While most previous studies (4, 5, 9, 16, 17) indicate that these components are higher in the pericarp than the locular tissue, some investigators (2, 10) found soluble solids content to be about equal between the locular and pericarp portions. In some cultivars, the locular tissue contained more soluble solids than the pericarp (2, 7). Although not completely accurate, in a botanical sense, pericarp is used here to include all the fruit regions other than the locular contents.

It is possible that the components in these heterogenous morphological regions differ in their importance to taste. For example, since the locular material is more fluid, its components are more readily accessible to the taste receptors and, therefore, may make a greater contribution to flavor. The purpose of this study was to determine differences in composition between the pericarp and locular tissue of the seven cultivars used for our studies of genotypic variation for flavor in fresh market tomatoes (15), as possible additional indexes for intercultivar flavor differences.

Materials and Methods

Fruits were harvested at the table-ripe stage from plants grown in the field at Davis, California. seven cultivars were sampled 3 times on separate days. All samples were harvested within a 12-day period to minimize possible seasonal effects on composition. Each sample contained 15 fruits of uniform size, color, and firmness. After washing and air drying, the intact fruits were weighed individually, then cut in transverse sections, and the locular material removed by suction. The remaining pericarp was weighed and locular content calculated by difference. The locular and pericarp portions for each 15-fruit sample were each blended, filtered, and the serum used for chemical analyses. Soluble solids content was determined as °Brix with a table-top model ABBE-3L Bausch & Lombe refractometer. Reducing sugars were determined using Hassid's method (8). Glucose was measured enzymatically (1) after precipitation of proteins and ascorbic acid with zinc sulfate. Titratable acidity was determined by titratating 10 ml of the serum to pH 8.1 with 0.1 N NaOH and pH was measured with a Corning digital 109 pH-meter. Citrate, malate, fructose, and glucose were separated by ion-exchange chromatography

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and their concn was determined by gas-liquid chromatography as previously described (14).

Results and Discussion

Fruit portions. The % locular tissue varied among the 7 cultivars included in this study (Table 1). 'Cherry' had the greatest % of locular tissue and 'Calmart' had the least. There was a strong negative correlation ($r = -0.85^{**}$) between fruit wt and % locular content (Table 1). This is in contrast to McCollum's (11) conclusion that large fruits have more locular tissue. We observed that those cultivars with a higher locular content in this study also had fewer locules than those with a lower locular content. This may be related to differences in fruit size since Paulson et al. (12) found a positive and significant correlation between number of locules and fruit size among 8 cultivars of fresh market tomatoes.

Soluble solids and sugars. There were no significant differences in soluble solids content (SSC) between the locular and pericarp tissue of any of the 7 cultivars (Table 2). The relative distribution of reducing sugars was quite consistent among cultivars. The pericarp contained more reducing sugars than the locular tissue; this difference was statistically significant for 'Calmart' and 'Cal Ace'. In all cultivars, the pericarp tissue had a higher concn of glucose than the locular tissue and this difference was statistically significant for all cultivars except 'Early Pak 7' and 'Rick High Sugar' (Table 2). No differences in fructose concn were noted except for 'Earliana' where the pericarp tissue contained more fructose than the locular tissue.

When the means of all 7 cultivars were calculated, reducing sugars were about 20% and glucose concn about 36% higher in the pericarp than in the locular tissue (Fig. 1). Our data (Table 2) for the relative distribution of SSC vs. reducing sugars between locular and pericarp tissue help explain the apparent differences among previous reports. The conclusions of others (2, 7, 10) who reported the SSC of pericarp and locular tissue to be similar, or that it was higher in the locule in some cultivars do not necessarily represent the reducing sugars.

Glucose and fructose have been shown to be the major constituents of reducing sugars in tomato fruit (13). That the sum of glucose and fructose concn is slightly lower than reducing sugars concn (Table 2) is primarily due to the different methods of analyses used. Comparing the data for glucose concn obtained by the enzymatic method to the gas-liquid chromatographic method (Table 2), there are no differences in trends, but there are some quantitative differences. The enzymatic method is easier and makes it possible to handle a large number of samples which is advantageous in a breeding program.

Acids. No differences in pH values were found between locular and pericarp tissue of any cultivars except 'Cherry' and 'Rick High Sugar' where pH values were higher in the locule than in the pericarp (Table 2). In all cultivars, the locular portion contained significantly more titratable acidity than the pericarp portion. Citric acid concn followed the same trend. Distribution of malic acid was not consistent. It was higher in the locular than the pericarp portion of 'Ace 55', 'Cherry', and 'Earliana' while the opposite was true for 'Cal Ace', 'Early Pak 7', and 'Rick High Sugar'. In 'Calmart', malic acid concn was the same in both portions of the fruit.

Combining the data for all cultivars, the locular tissue contained about 48 and 57% more titratable acidity and citric acid, respectively, than the pericarp tissue (Fig. 1). Differences in malic acid concn were not significant. The sum of citric + malic acid concn is higher than titratable acidity (Fig. 1) because their concn represent total not just titratable acidity (14).

Previous reports (2, 3, 5, 6, 7, 9, 10, 11, 16, 17) indicated that the locular portion has a higher titratable acidity and lower pH than the pericarp portion of tomato fruits. While our data for titratable acidity is in agreement with these reports, no significant differences in pH values were observed across cultivars. This was not expected in view of the large differences in acids, and may indicate a higher buffering capacity in the locular than in the pericarp tissue. Stevens (13) found a wide range in the H+/titratable acidity ratio among 55 tomato lines and related this to differential buffering influenced by the phosphate content of the fruit.

Glucose and citric acid distribution. Glucose and citric acid concn showed the greatest variation between locular and pericarp portions. The relative distribution of glucose concn varied only slightly among the various cultivars. The locule/pericarp ratio for glucose concn was in the following ascending order: 'Cherry' (0.58), 'Calmart' (0.60), 'Early Pak 7' (0.60), 'Earliana' (0.62), 'Cal Ace' (0.66), 'Rick High Sugar' (0.71), and 'Ace 55' (0.71). There were larger variations among the cultivars for the relative distribution of citric acid. The locule/pericarp ratio for citric acid concn varied as follows: 'Ace 55' (1.34), 'Cal Ace' (1.89), 'Earliana' (2.27), 'Rick High Sugar' (2.27), 'Cherry' (2.58), 'Calmart' (2.88), and 'Early Pak 7' (3.32).

Among the cultivars studied there was no correlation ($r = 0.11$) between the acid content of the locule and that of the pericarp. The citric acid concn in the pericarp appeared more uniform among the cultivars than its concn in the locule (Table 2). Whether this relative distribution of citric acid between the locule and pericarp is under genetic control cannot be determined from these data, but since the distributions did appear to be cultivar-specific, it may indicate that there are genes which control the relative distribution of acids among fruit regions. In view of the great importance of citric acid to tomato flavor as

Table 1. Locular content and fruit wt of 7 tomato cultivars

Tomato cultivar	% locular tissue	Mean fruit wt (g)
Calmart	14.4a[z]	180.4e
Cal Ace	17.5b	171.2de
Ace 55	18.2c	171.2de
Early Pak 7	20.3d	158.0d
Earliana	21.6e	102.0c
Rick High Sugar	21.6e	80.0b
Cherry	35.0f	52.6a

[z]Mean separation in columns by LSD test at the 5% level.

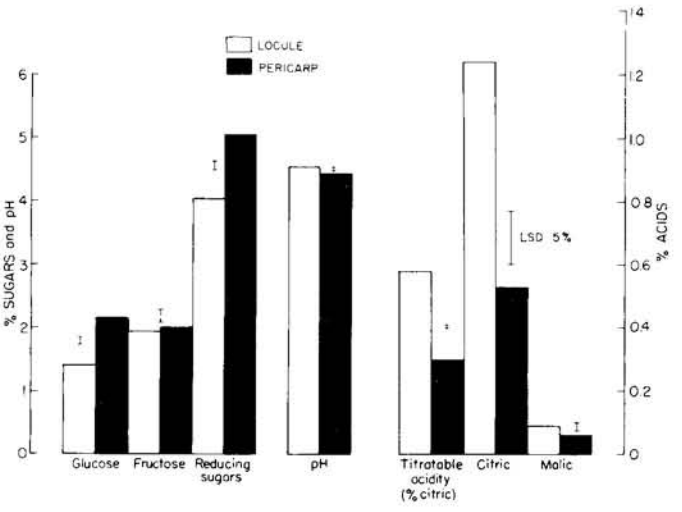

Fig. 1. Amounts of sugar and acid components and pH of locular and pericarp tissues of tomato fruits. Data are means of 7 cultivars.

Table 2. Mean composition of locular (L) and pericarp (P) tissue of 7 tomato cultivars.

Cultivar	Fruit portion	Total soluble solids (%)	Reducing sugars (%)	Glucose (%) (enzymatic method)	Glucose (%) (glc)	Fructose (%) (glc)	pH	Titratable acidity as % citric	Citric acid (%) (glc)	Malic acid (%) (glc)
Calmart	L	5.4	3.72 *	1.23 *	1.52 **	1.82	4.34	.67 **	1.21 **	.04
	P	5.8	4.55	2.05	2.08	1.99	4.55	.27	.42	.04
Ace 55	L	5.3	3.79	1.30 **	1.63	1.94	4.60	.47 **	1.03	.10
	P	5.1	4.57	1.82	1.90	1.71	4.52	.26	.77	.06
Cherry	L	7.0	4.65	1.57 **	1.97	2.26	4.51 **	.66 **	1.55 **	.17 *
	P	6.9	6.58	2.71	2.31	2.44	4.29	.34	.60	.06
Earliana	L	5.9	4.57	1.36 *	1.61 *	1.85 *	4.64	.51 *	1.00 *	.16 *
	P	5.9	5.33	2.19	2.17	2.17	4.35	.31	.44	.11
Early Pak 7	L	4.7	2.77	.98	1.11	1.76	4.29	.74 **	1.56 **	.04 *
	P	4.7	3.70	1.62	1.71	1.71	4.31	.33	.47	.06
Rick High Sugar	L	7.1	4.85	1.83	1.76	1.98	4.93 **	.41 *	1.09 **	.03
	P	6.7	5.46	2.57	1.96	2.03	4.65	.29	.48	.04
Cal Ace	L	5.9	3.50 **	1.23 **	1.32 **	1.87	4.60	.50 *	.72 **	.06
	P	5.9	4.14	1.87	1.91	1.91	4.58	.33	.38	.09

*, ** indicate significant difference at the 5% (*) and 1% (**) level.

discussed in a previous paper (15), and because it is likely that those acids in the locule are more readily perceived during consumption of tomatoes, these differences in distribution could have an impact on flavor differences among cultivars. It is possible that the flavor of a given cultivar is affected not only by the concn of citric acid in the whole fruit but also by its distribution among the various portions of the fruit.

Composition related to fruit structure. Since the discussion of intercultivar differences in composition of fruit regions may be misleading without taking the relative distribution of these regions into account, a ratio of the concn of several components was related to the locular/pericarp ratio for each cultivar (Table 3). 'Cherry' had the highest ratios for reducing sugars, glucose, and fructose. No statistical differences were observed among the other cultivars, except 'Calmart' which had the lowest ratios. 'Cherry' also had a significantly higher ratio for titratable acidity, citric, and malic than the other cultivars. No significant differences in malic ratio were found among the other 6 cultivars. For the citric ratio, these cultivars can be divided into 2 groups: ('Earliana', 'Early Pak 7', and 'Rick High Sugar') with a higher ratio than ('Calmart', 'Ace 55', and 'Cal Ace'). It may be expected that the higher the ratio the greater the impact of the locular portion.

In general, the relative order of these 7 cultivars based on their acid or sugar ratios is comparable to that previously reported on the basis of analyzing whole fruits (15). This also indicates that blending a composite sample of entire fruits or wedges taken from whole fruits without loss of locular contents can be an

Table 3. Ratio of sugars and acids concn in locular and pericarp tissue when related to the relative distribution of fruit portions in 7 tomato cultivars.

	Ratio (Concn in locule × % locular tissue/Concn in pericarp × % pericarp tissue)					
Cultivar	Reducing sugars	Fructose	Glucose	Titratable acidity	Citric	Malic
Calmart	0.14a[z]	0.17a	0.10a	0.42ab	0.49abc	0.17a
Ace 55	0.19ab	0.21ab	0.16ab	0.41ab	0.36a	0.43a
Cherry	0.36c	0.40c	0.29c	0.98c	1.29e	1.40b
Earliana	0.25b	0.30b	0.19b	0.49b	0.71cd	0.43a
Early Pak 7	0.19ab	0.22ab	0.15ab	0.56b	0.84d	0.19a
Rick High Sugar	0.25b	0.29b	0.20b	0.39ab	0.68bcd	0.25a
Cal Ace	0.18ab	0.21ab	0.14ab	0.31a	0.40ab	0.15a

[z]Mean separation in columns by LSD test at the 5% level.

adequate substitute for analysis of specific regions. Squeezing juice out of the fruit would not be an accurate representation of the whole fruit. Analyses of specific fruit portions would not be necessary for evaluation of compositional differences among cultivars and breeding lines in a breeding program unless the percent locular tissue varies significantly.

Conclusions

Cultivars that have higher percent locular content will most probably have higher acids and not necessarily lower sugars than those with low locular portion, as indicated by some of the cultivars used in this study, i.e., 'Cherry' and 'Earliana'. However, 'Rick High Sugar' and 'Early Pak 7' which also have a relatively high locular portion do not fit this generalization. While these two cultivars had a similar reducing sugars ratio, 'Rick High Sugar' had a lower titratable acidity ratio (Table 3). These observations indicate that increasing the locular portion in fruits of new cultivars must be accompanied by increasing the acid and/or sugar content of both the locular and pericarp portions to ensure good flavor quality. In a breeding program for improving flavor quality of fresh market tomatoes, compromises may be necessary between larger locular portion and other fruit characteristics such as fruit size and firmness. When this is added to the complexities of increasing sugars and acids concn, it is not an easy task but it is feasible.

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