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J. AMER. SOC. HORT. SCI. 112(4):663–665. 1987.

Firmness of Tomato Fruit Tissues According to Cultivar and Ripeness

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Additional index words. *Lycopersicon esculentum*, pericarp, placenta, maturity

Abstract. **The firmness of tissues of a transverse equatorial slice of fruits of 'Flora-Dade', 'Walter', 'MH-1', and 'Homestead 24' tomatoes (*Lycopersicon esculentum* Mill.) was determined at different stages of ripeness by use of an Instron Food Testing System. The outer, radial, and inner pericarp tissues of 'Flora-Dade' and 'MH-1' were firmer than those of 'Walter' when ripened 6, 8, or 10 days at 20°C after incipient color formation. 'Walter' tissues were intermediate in firmness between 'MH-1' and 'Flora-Dade' at the mature green stage, but had softened much more than either at the incipient color stage. Most of the softening of the tissues of the three cultivars had occurred by 4 days after incipient color. The placental tissue of 'Homestead 24' fruit was much firmer than that of 'Walter' and 'Flora-Dade' over a period of 7 to 19 days after incipient color stage, although the outer pericarp tissue was much softer than that of the latter two.**

Firmness is an important attribute of tomato quality. A number of instruments have been used to measure firmness of tomatoes (1, 2, 11, 14, 16) based on the compression of whole fruits, either at a single point or surface (11) or by compression of the total equatorial circumference (14). These types of instruments measure the overall firmness but do not determine the firmness of individual fruit tissues. In studies on the relationship of cell wall constituents to firmness, tissue firmness should be determined rather than overall fruit firmness. Foda (4) used this approach with the Illinois Pressure Tester devised by McCollum (15). The large plunger diameter (1.25 cm) restricted its use to inner pericarp tissue of a median slice. Holt (12) measured firmness of different tissues by driving a 1.02-mm-diameter plunger tip into fruit through the skin using an Instron Universal Tester. The penetrated tissues were determined by dissecting the fruit.

In this study, firmness of the pericarp wall tissues of a transverse slice was determined for several cultivars at various stages of ripeness.

Materials and Methods

Plants were grown in 22.5-cm black plastic pots filled with a commercial Vermiculite–peat mix in a greenhouse equipped with cooling pads and fans. The plants were fertilized with a 12N–10P–20K soluble mixture containing Ca, Mn, and minor elements. Plants for the first three tests were grown in the spring with harvests in May and early June when the temperature ranged from 20° to 35°C. Plants for the last two tests were grown in the fall with harvests in December and January when temperatures ranged from 15° to 27°.

Fruit were picked at the mature-green stage and placed at 20°C and 85% RH. Fruit showing incipient color on the stylar end (15) were assigned at random to the treatments and held under the same conditions.

Fruit tissue firmness was measured with an Instron Food Testing System (Model 1132) machine fitted with a 2-kg compression load cell. The machine was calibrated to give full deflection for a 1-kg weight. Crosshead and chart speeds were 5 $cm \cdot min^{-1}$. A 1.25-cm-thick transverse slice, taken by use of two attached blades, midway between the stylar and stem ends was placed on a stainless steel plate with proximal side up. A cylindrical probe, 4.9 mm in diameter, with a flat surface was made to penetrate 5 mm into the tissue. Three readings were taken for each tissue on each slice. The peak heights of each three readings were averaged and converted to newtons (13). The designations of the fruit tissues are as given by Davies and Hobson (3).

In the first test, the firmness of the outer pericarp (opposite the locules), the radial pericarp, and the inner pericarp (columella) was determined with fruit ripened 6 days using 'MH-1', 'Flora-Dade', and 'Walter'.

Received for publication 1 Aug. 1986. Florida Agricultural Experiment Stations Journal Series no. 7430. The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

The firmness of the outer and inner walls of 'Flora-Dade' and 'Walter' were compared at 6, 8, and 10 days after incipient color in the second test.

The third test compared the firmness of the same portions and cultivars as in the first test at five stages of ripeness: mature green, incipient color, and 2, 4, and 6 days after incipient color. At the incipient color stage, only a tinge of color was apparent around the stylar scar. The 6-day fruit were fully red.

The fourth and fifth tests were made comparing the firmness of the outer wall and the placental tissues of 'Flora-Dade', 'Walter', and 'Homestead 24' fruit. One was after 7, 9, and 11 days and the second after 13 and 17 days from incipient color.

Results

In the first test, the outer tissue was firmer than the inner (columella) tissue but did not differ from the radial tissue when ripened 6 days (Table 1). The radial and inner tissues were of similar firmness. 'Flora-Dade' and 'MH-1' did not differ in firmness but were firmer than 'Walter'. There was no cultivar-tissue interaction.

In the second test, both pericarp tissues of 'Walter' decreased in firmness with increased ripeness (Table 2). Only the radial tissue of 'Flora-Dade' decreased in firmness and only between 8 and 10 days. The analysis of variance (ANOVA) showed 'Flora-Dade' to be firmer than 'Walter' and the outer pericarp firmer than the radial. There was no interaction between any of the main effects. The magnitude of the differences at 10 days is small. An ANOVA of the 10-day data showed that the 0.7 N difference between cultivars and the 0.24 N difference between tissues were significant at the 1% and 5% levels, respectively.

In the third test, the ripeness–cultivar and ripeness–tissue interactions were significant (Table 3). 'Walter' was intermediate in firmness between 'MH-1' and 'Flora-Dade' at the mature-green stage of ripeness but was much softer than the latter two at the incipient color stage. The relative decrease in firmness was 50% for 'Walter', 30% for 'Flora-Dade', and 20% for 'MH-1' from the mature green values. These changes were not associated with carotenoid pigment development because no red color was detected in the tissues tested (equatorial). All the cultivars softened noticeably 2 days after incipient color, with smaller changes at 4 and 6 days. In each instance, 'Walter' fruits were softer than 'MH-1' and 'Flora-Dade'.

The radial and inner tissues were firmer than the outer tissue at the mature-green stage but softer at the incipient color and 2-day stages. There was little difference at 6 days. The radial tissue was softer at the incipient, 2-day, and 4-day stages than either of the other tissues.

In the fourth and fifth tests, the placental tissue of 'Homestead 24' fruit was much firmer than that of 'Walter' and 'Flora-Dade', although the outer tissue of 'Homestead 24' was softer than that of the other cultivars in both tests (Table 4). The placental and outer tissues of 'Flora-Dade' were firmer than those of 'Walter'. The cultivar–tissue interaction was significant for each test, but the cultivar–ripening period (days) interaction was not. Although both tissues softened from 7 to 9 to 11 days and from 13 to 17 days after incipient color stage, the placental tissue of 'Homestead 24' remained much firmer than that of 'Walter' and 'Flora-Dade' (data not shown).

Table 1. Firmness of three fruit tissues of three tomato cultivars ripened at 20°C for 6 days.

	Newtons			
	Tissue			Cultivar
Cultivar	Outer	Radial	Inner	means[z]
Walter	2.0	1.2	1.5	1.63 A
Flora-Dade	2.6	2.4	2.3	2.46 B
MH-1	3.2	2.9	2.4	2.81 B
Tissue means[y]	2.60A	2.25AB	2.06B	

[z,y]Mean separation by Duncan's multiple range test, 1% level.

Table 2. Firmness of two fruit tissues of two tomato cultivars ripened at 20°C for 6, 8, and 10 days.

	Newtons			
	Walter		Flora-Dade	
Days	Outer	Radial	Outer	Radial
6	1.8	1.5	2.1	2.0
8	1.6	1.2	2.1	2.1
10	1.2	1.1	2.0	1.7
Significance				
F value[z]	L*	L*	L^{NS}	L*
b	−0.14	−0.08	−0.01	−0.09
r^2	0.98	0.96	0.36	0.57

[z]The effects were linear (L) at the 5% (*) level of significance or not significant (NS). The quadratic components were not significant.

Discussion

Either of the pericarp tissues could be used for determining fruit firmness, because there was no interaction of tissue type and cultivar. The use of the Instron machine as described is not as fast a method for measuring firmness as the use of the Cornell Firmness Tester (11). The same relative results were obtained with the latter machine with 'Walter', 'MH-1', and 'Flora-Dade' (9) as with the Instron in these tests. The advantage of the Instron is that firmness of specific tissue can be determined in a study of factors affecting firmness.

One advantage of the Instron machine is that measurements can be made at the incipient color stage and detect cultivar differences. Selection of uniformly mature fruit can be done more easily at that stage. Selection of fruit of different cultivars at the red-ripe stage without knowing the degree of ripeness (time from incipient color) can confound the results, since fruit continue to soften with time (6, 7) and cultivars may differ in color at the same stage of ripeness.

The greater softening of the radial wall tissue than the outer and inner tissues from incipient color to 4 days after (Table 3) may be related to the commonly observed ripening characteristic of color development in the outer tissue opposite the radial walls much before it develops in outer tissue opposite the locules. These streaks of color from the stylar end to the stem end are evident in many cultivars, but are very characteristic of 'MH-1' fruit (personal observation).

The differences between cultivars in placental firmness of ripe and overripe fruit indicate a genetic difference that could be exploited to advantage. Previous work (6, 8, 10) showed that 'Homestead 24' fruits were highly resistant to placental breakdown when subjected to pressure. Slices in which the placental tissue has broken down or disintegrated have a poor appearance and in some cases the locular contents drop out.

Rapid changes in firmness found in the early stages of ripening were similar to those found by Holt (12) using 'Craigella'. These results indicate that studies on the mechanism of the ini-

Table 3. Interactions of fruit tissues and cultivars with stages of ripeness on tomato firmness.

	Newtons					
	Ripeness–tissue[z]			Ripeness–cultivar[z]		
	Tissue			Cultivar		
Ripeness	Outer	Radial	Inner	MH-1	Walter	Flora-Dade
Mature green	15.9	17.8	18.3	15.8	16.5	19.7
Incipient color	13.8	9.6	11.2	12.6	8.5	13.6
Ripened 2 days	4.7	2.8	3.2	4.0	2.6	4.0
Ripened 4 days	2.6	2.1	2.6	2.6	1.9	2.8
Ripened 6 days	2.2	2.0	2.0	2.4	1.6	2.4

[z]The interaction is significant at the 1.0% level.

Table 4. Tissue–cultivar interaction[z] for placental and outer wall tissue firmness with three cultivars ripened for various periods.

	Newtons		
	Cultivar		
Tissue	Homestead 24	Walter	Flora-Dade
	7, 9, and 11 days test		
Outer	1.76	2.28	2.87
Placenta	2.44	1.26	1.56
	13 and 17 days test		
Outer	1.11	1.34	1.94
Placenta	2.07	0.88	1.79

[z]The tissue–cultivar interaction is significant at the 1.0% level for each test.

tiation of softening should be made on green tissues of fruit showing the earliest indication of ripening. A comparison of outer and radial tissues of the same fruit would be of value because of the difference in softening.

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