J. Amer. Soc. Hort. Sci. 103(1):70–73. 1978.

Evaluation of Two Objective Methods and a Subjective Rating Scale for Measuring Tomato Fruit Firmness[1]

A. A. Kader[2], L. L. Morris[2], and P. Chen[3]
University of California, Davis, CA 95616

Additional index words. Lycopersicon esculentum

Abstract. **Tomato fruit firmness is closely associated with its ripeness stage; as the fruit ripens it softens. Correct usage of the UC Fruit Firmness Tester requires that such variables as location of measurement on the fruit, removal of skin, and plunger (tip) diameter be specified. A negative and highly significant correlation (r = –0.75) exists between firmness measurements with the UC Firmness Tester (a destructive method) and the compression testing device (a nondestructive method). Values obtained by both methods were also highly correlated (r = 0.79, UC Firmness Tester; r = –0.81, compression testing device) with subjective evaluation scores based on finger feel. Two possible minimum firmness limits are suggested for tomato fruits at shipping point and at retail.**

The textural quality of tomatoes is influenced by flesh firmness, the ratio between pericarp and locular tissue, and skin toughness. Although, texture is perceived by both finger feel and mouthfeel, consumers use their fingers to test tomato firmness at the time of selection. Several laboratory instruments for measuring firmness have been used for tomatoes. While the relative values obtained in a given study are useful, it is difficult to compare data from one instrument to another, or to relate these data to sensory judgments.

Most of the objective methods of measuring fruit firmness are based on resistance to force of compression, shearing, cutting, or their combinations (14). Destructive methods which have been used for tomatoes include pressure testers, Instron Universal Testing Machine (11, 17), and Allo-Kramer Shear Press (1, 2, 14, 16). Instruments for nondestructive determination of tomato fruit firmness have been based on measuring resistance to compression force applied at a single or multipoints on the fruit. They include the Cornell Pressure Tester (10), Firm-o-meter (13), Asco Firmness Meter (8), Pressure-Load meter (5, 17), penetrometer (3, 4), and other deformation testers (15, 18). Gromley and Keppel (9) used a modified shear press to measure tomato firmness by compressing the fruit by 5 mm between two flat surfaces. Although nondestructive, this test caused some permanent change in fruit shape. They reported a good correlation between firmness determined by this method and that evaluated by a finger-feel panel. Voisey and Crête (20) found that the rate of force applied in sensory testing is greater than that customarily used in tests with instruments.

This study was conducted to: 1) evaluate 2 objective methods, i.e., the UC Fruit Firmness Tester (a destructive method) and a compression testing device (a nondestructive method) in measuring tomato fruit firmness; and 2) relate these objective measurements to a subjective rating scale based on finger feel.

Materials and Methods

UC Fruit Firmness Tester.[4] This instrument performs a test similar to that of the Magness-Taylor pressure tester, but is designed to foil attempts to punch the fruits. A Hunter force gauge is mounted on a stand for operation like a hand press. A plunger on the force gauge is pressed against the fruit, and force is increased until flesh failure is noted by a decrease or leveling-off of the force reading on the gauge. The design makes it very difficult for the oeprator to use excessive speeds.

Compression Testing Device. Fridley et al. (7) developed a nondestructive means of sensing maturity of pears based on their firmness. This method involves pressing two 1.3-cm steel balls against the opposite sides of the fruit using a 9.8-N compressive force and measuring its deformation at 1 sec. The fruits are supported as pendulums and the balls close against the fruit by moving the backstop or fixed ball. Then, the fixed ball is locked into position and the compressive force, produced by a dead weight, is exerted on the fruit. The deformation as a function of time is recorded on a strip-chart recorder. In this study, the same device (Fig. 1) was used for measuring tomato deformation but a smaller compressive force (2.2 N) was used. In a preliminary study, no effect of tomato fruit size (between 5.4 and 7.3 cm in diam) on the accuracy of this method was noted.

Fruits and firmness testing. 'Cal Ace' tomato fruits were obtained from fields at Davis, California for use in all experiments unless otherwise indicated. Fruits were picked at various stages of ripeness: 1-mature-green, 2-breaker, 3-turning, 4-pink, 5-light-red, 6-red (19). All firmness measurements were made along the fruit's equatorial diam, halfway between the stem

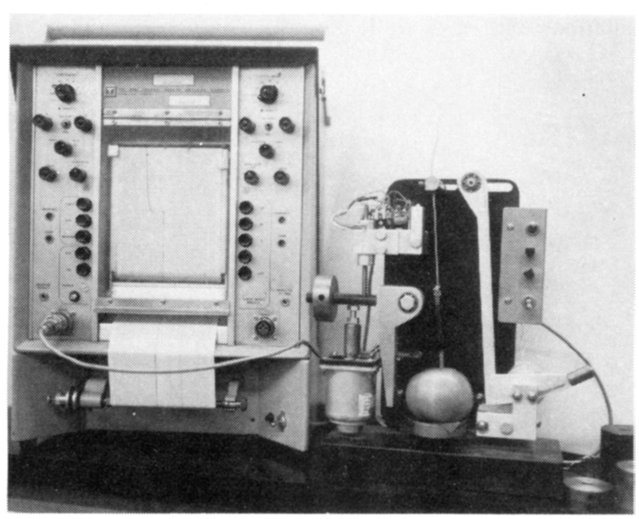

Fig. 1. The compression testing device used for measuring fruit deformation which was induced by compressing tomatoes between two 1.3-cm steel balls with a force of 2.2 N.

[1] Received for publication July 28, 1977. Research supported – in part – by the California Fresh Market Tomato Advisory Board.

[2] Department of Vegetable Crops.

[3] Department of Agricultural Engineering.

[4] Available from: Western Industrial Supply, Inc., 236 Clara Street, San Francisco, CA 94701.

Table 1. Tomato fruit firmness as determined by resistance to puncture using the UC Fruit Firmness Tester with various tip (plunger) sizes. Values shown are means of 20 measurements (without removing the skin) each and their standard deviations.

Tip diam (mm)	UC Fruit Firmness Tester reading (kg)	
	Mature-green	Light-red
1.6	0.68±0.09	0.50±0.14
3.2	1.50±0.23	1.04±0.23
4.8	2.50±0.36	1.72±0.45
6.4	3.86±0.50	2.27±0.45
7.9	5.22±0.45	3.04±0.45

scar and the blossom end, and efforts were made to position these measurements consistently over a locule rather than a radial wall. Using the compression testing device, deformation at 1 sec was determined for 360 'Cal Ace' tomato fruits picked at 6 ripeness stages. Firmness of the same 360 fruits was determined subjectively, then measured by the UC Fruit Firmness Tester without skin removal using a 7.9-mm plunger.

In another experiment, 200 large '6718 VF' tomato fruits were harvested at the pink stage (ripeness class 4) and held at 20°C for further ripening. Forty fruits in each firmness class were selected by finger feel. Lots for firmness classes 5 and 6 were selected on the day of harvest, while those for the other classes were sorted out after 2 to 4 days of holding at 20°. Deformation was measured by the compression testing device, then resistance to puncture was determined by the UC Fruit Firmness Tester.

Results and Discussion

UC Fruit Firmness Tester. Using comparable lots of mature-green and light-red tomatoes, 4 smaller plungers were compared with the 7.9-mm plunger, typically used in firmness determination. The pressure test values were proportional to plunger diam (Table 1) and the coefficient of variation in firmness values was higher for all 4 smaller plungers than for the 7.9-mm plunger. Also, the difference in mean values between mature-green and light-red fruits was greatest when the 7.9-mm plunger was used.

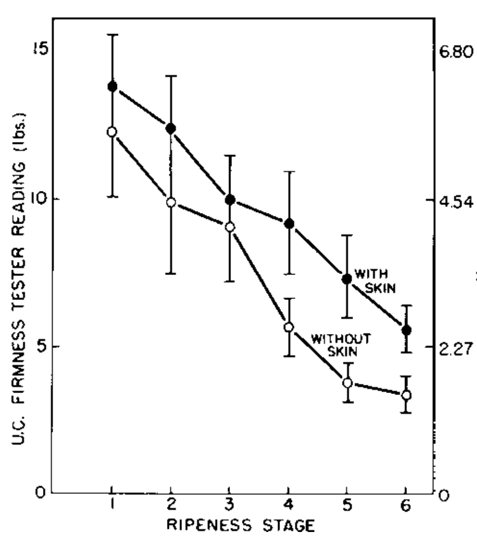

Fig. 2. Effect of skin removal on pressure test values obtained by the UC Fruit Firmness Tester with a 7.9-mm plunger. Each point is a mean of 20 measurements.

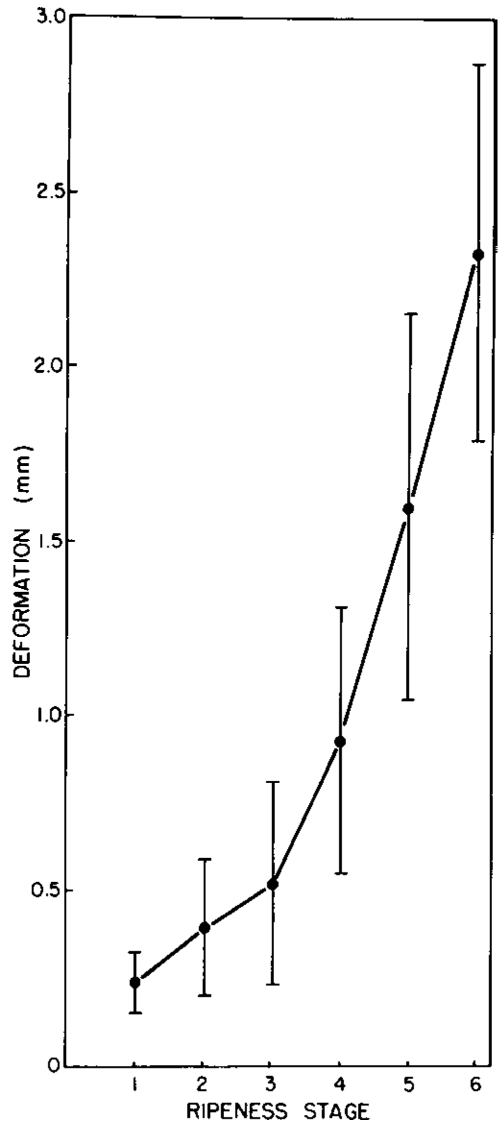

Fig. 3. Firmness of tomato fruits picked at various stages of ripeness as determined by deformation at 1 sec using the compression testing device (Fig. 2). Values shown are means of 60 fruits for each ripeness stage.

Table 2. Rating scale for tomato fruit firmness.

Score	Class	Description based on	
		Resistance to compression by fingers	Slicing characteristics
9	Extra-hard	Fruit does not yield to considerable pressure	No loss of juice or seeds when sliced
7	Hard	Fruit yields only slightly to considerable pressure	No loss of juice or seeds when sliced
5	Firm	Fruit yields slightly to moderate pressure	A few drops of juice, and/or seeds may be lost when sliced
3	Soft	Fruit yields readily to slight pressure	Some juice, and/or seeds are lost when sliced
1	Extra-soft	Fruit yields very readily to slight pressure	Most of the juice, and seeds are lost when sliced.

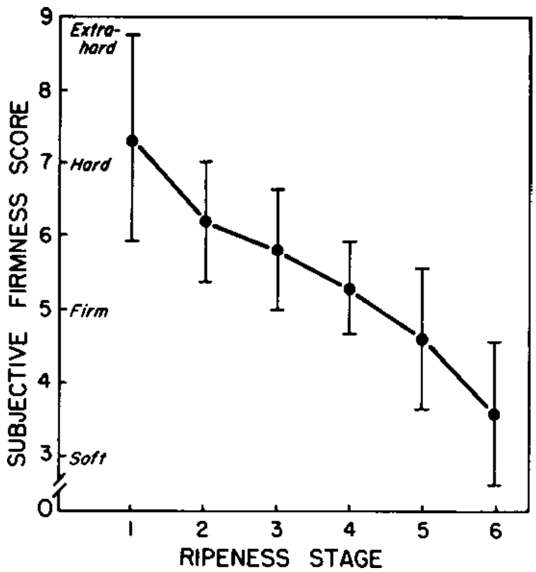

Fig. 4. Firmness of tomato fruits picked at various stages of ripeness as determined by finger feel using a subjective scoring system (Table 2). Values shown are means of 60 fruits for each ripeness stage.

Fridley (6) suggested using a small plunger to concentrate the stresses near the surface, causing a puncture type of failure. He stated that since a large-diameter plunger presses against a large section of the pericarp, resistance to failure is affected greatly by the position of the locule relative to the plunger's position. Also, the internal stresses induced by a large plunger tend to penetrate deeply within the fruit. Our results do not substantiate Fridley's observations for tomatoes, but his recommendation of using plungers smaller than 7.9 mm may be useful for other fruits, especially when more than one determination per fruit is desirable. It is obvious that pressure test values are meaningless without specifying the plunger size used.

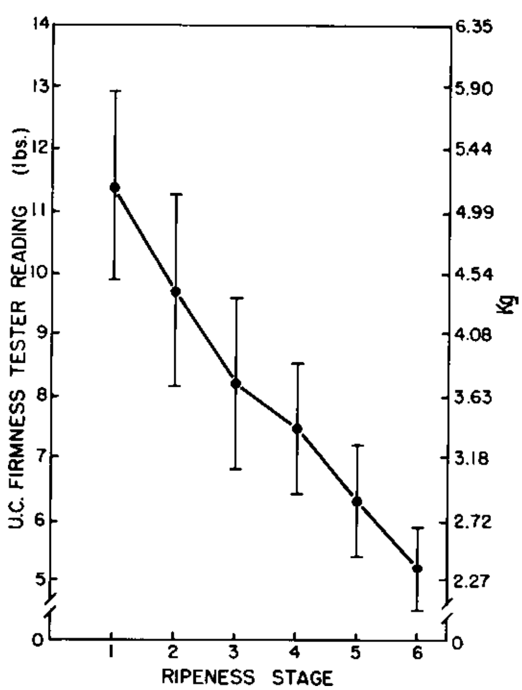

Fig. 5. Firmness of tomato fruits picked at various stages of ripeness as determined by the UC Fruit Firmness Tester with a 7.9-mm plunger. Values shown are means of 60 fruits (skin not removed) for each ripeness stage.

Table 3. Relationship between subjective and objective firmness measurements of large, '6718VF' tomato fruits (ripeness classes 4, 5 and 6). Data shown are means and standard deviations for 40 fruits in each category which were selected on the basis of finger feel, then used for the deformation test followed by the pressure test with skin removed.

Subjective firmness score and class	Deformation (mm) at 1 sec using a 2.2 N compressive force	UC Fruit Firmness Tester reading (kg) with a 7.9-mm plunger
6 = Very firm	0.8±0.4	2.18±0.48
5 = Firm	1.3±0.5	1.81±0.39
4 = Fairly firm	1.6±0.6	1.27±0.27
3 = Soft	2.3±0.6	1.00±0.20
2 = Very soft	2.7±0.3	0.73±0.25

In another experiment using the UC Fruit Firmness Tester with a 7.9-mm plunger, the impact of removing the skin on pressure test values was investigated. Skin removal resulted in lower force values for fruits picked at various ripeness stages, but the trend of firmness changes with ripeness and the extent of variability were similar in both cases (Fig. 2). While the pressure test values on fruits without skin reflects primarily outer wall (flesh) firmness, the values for fruits with the skin reflects skin toughness in addition to flesh firmness. Although removing the skin is recommended for other fruits (apples, pears, etc.), it does not seem to be essential for tomatoes. However, it is important to specify whether the skin was removed or not in reporting pressure test data.

Objective vs. subjective measurements. Deformation increased with ripeness (Fig. 3), and the increase was much greater for fruits picked at stage 4 or riper than for those picked at earlier stages. These fruits were then rated individually by finger feel using a rating scale (Table 2) proposed by Kader and Morris (12). On this scale, a score of 5 (firm) is considered as the lower limit for tomatoes at the shipping point to insure their subsequent handling with minimum physical damage. A score of 3 (soft) is considered as the lower limit of acceptability at the retail level. Subjective scores decreased with fruit ripeness (Fig. 4). No fruits were rated 9 (extra hard), 2 (very soft), or 1 (extra soft), and very few fruits were scored 8 (very hard) or 3 (soft). The subjectives scores (Fig. 4) were highly correlated with the deformation measurements (Fig. 3); $r = -0.81$. The pressure test values were inversely proportional to ripeness stages (Fig. 5). These measurements were also highly correlated with the subjective firmness scores ($r = 0.79$) and with the deformation values obtained by the compression testing device ($r = -0.75$).

For '6718 VF' fruits harvested at the pink stage, higher deformation values and lower pressure test values were closely related to lower subjective firmness scores (Table 3). The relatively large standard deviations reflect variation in the subjective selection of fruits.

Well correlated with sensory evaluation, the compression testing device used in this study is a relatively simple nondestructive method for evaluating tomato firmness. The potential of developing this device for an on-line firmness testing system for use at the packinghouse to eliminate soft fruits merits further investigation. A mean deformation value of 1.3 mm, corresponding to subjective score 5 (firm), might be used as an upper limit for sorting out fruits which most likely will not withstand shipping to distant markets. A mean deformation value of 2.3 mm, corresponding to subjective score 3 (soft), is assumed to be the limit of acceptability for fresh tomatoes at the retail level. This, however, needs further evaluation for other cultivars and using a large scale consumer acceptance study before establishing minimum firmness requirements for marketing tomatoes.

Literature Cited

1. Abdel-Kader, A. S., L. L. Morris, and E. C. Maxie. 1968. Physiological studies of gamma-irradiated tomato fruits. III. Effects on ascorbic acid content, acidity and texture. *Proc. Amer. Soc. Hort. Sci.* 93:843-853.
2. Berkholst, C.E.M. 1972. Cutting-firmness of tomato fruits. *Gartenbauwissenschaft* 37:191-200.
3. Bourne, M. C. 1973. Use of the penetrometer for deformation testing of foods. *J. Food. Sci.* 38:720-721.
4. Brinton, R. H. and M. C. Bourne. 1972. Deformation testing of foods. III. Effect of size and shape on the magnitude of deformation. *J. Text. Stud.* 3:284-297.
5. Diener, R. G., F. E. Sobotka, and A. E. Watada. 1971. An accurate, low cost firmness measuring instrument. *J. Text. Stud.* 2:373-384.
6. Fridley, R. B. 1976. Texture, firmness, and strength. p. 35-40. *In* Proc. 2nd Tomato Quality Workshop, July 12-14, 1976, Vegetable Crops Series 178, Univ. of Calif., Davis.
7. Fridley, R. B., P. Chen, J. J. Mehlschau, and L. L. Claypool. 1974. Mechanical sensing of pear maturity for improved cold storage. Amer. Soc. Agr. Eng. Paper 74-3041, ASAE, St. Joseph, Mich.
8. Garrett, A. W., N. W. Desrosier, G. D. Kuhn, and M. L. Fields. 1960. Evaluation of instruments to measure firmness of tomatoes. *Food. Technol.* 14:562-564.
9. Gormley, T. R. and D. Keppel. 1976. A method for measuring tomato fruit firmness using a modified shear press. *J. Food Technol.* 11:607-617.
10. Hamson, A. R. 1952. Measuring firmness of tomatoes in a breeding program. *Proc. Amer. Soc. Hort. Sci.* 60:425-433.
11. Holt, C. B. 1970. Measurement of tomato firmness with a Universal testing machine. *J. Text. Stud.* 1:491-501.
12. Kader, A. A. and L. L. Morris. 1976. Tomato firmness as a quality attribute. P. 30-34. *In* Proc. 2nd Tomato Quality Workshop, July 12-14, 1976, Vegetable Crops Series 178, Univ. of Calif., Davis.
13. Kattan, A. A. 1957. Changes in color and firmness during ripening of detached tomatoes, and the use of a new instrument for measuring firmness. *Proc. Amer. Soc. Hort. Sci.* 70:379-384.
14. Kramer, A. and B. A. Twigg. 1970. Quality control for the food industry, Vol. 1 – fundamentals, 3rd ed., Chapt. 7 (p. 83-105). The AVI Publ. Co., Inc., Westport, CT.
15. Shafshak, S. A. and G. W. Winsor. 1964. A new instrument for measuring the compressibility of tomatoes and its application to the study of factors affecting fruit firmness. *J. Hort. Sci.* 39:284-297.
16. Simandle, P. A., J. L. Brogdon, J. P. Sweeney, E. O. Mobley, and D. W. Davis. 1966. Quality of six tomato varieties as affected by some compositional factors. *Proc. Amer. Soc. Hort. Sci.* 89:532-538.
17. Sobotka, F. E., A. E. Watada, and R. G. Diener. 1972. Effectiveness of the pressure-load meter in measuring firmness of tomato fruit. *HortScience* 7:34-36.
18. Stenvers, N., J. W. Rudolphij and J. Bruinsma. 1973. Growth, ripening and storage of tomato fruits. I. The measurement of softening during the ripening of tomato fruits. *Gartenbauwissenschaft* 38:517-531.
19. U.S.D.A. 1976. United States standards for grades of fresh tomatoes. Agr. Mktg. Serv., USDA, Washington, D.C., 10 p.
20. Voisey, P. W. and R. Crête. 1973. A technique for establishing instrumental conditions for measuring food firmness to simulate consumer evaluations. *J. Text. Stud.* 4:371-377.

J. Amer. Soc. Hort. Sci. 103(1):73–76. 1978.

Influence of Irrigation and Environmental Factors on Grapefruit Acidity[1]

Y. Levy[2], A. Bar-Akiva[3], and Y. Vaadia[3,4]

Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel

Additional index words. Citrus paradisi, water stress, fruit quality, acclimatization

Abstract. **Summer water stress in grapefruit (*Citrus paradisi* Macf.) trees caused high titratable acidity levels during the winter. The after effect of water stress lasted up to 6 months. Brief sudden rises in acidity during the winter were correlated with short durations of relatively high day temperatures. Such episodes did not affect the percentage total soluble solids.**

The concn of juice acidity declines during fruit development and maturation in most citrus fruits, with the possible exception of lemons and limes. This is true for many non-citrus, acid containing fruits. Grapefruit are picked in the Negev Desert (Southern Israel) during the winter, between Nov. and April. The fruit continues to grow and its weight may double during this time. The acid concn delcines until Nov. and remains more or less constant thereafter (2, 3). A similar pattern was described for grapefruit in California (19), Texas (5), and in certain years in Florida (7). Concn of titratable acidity in juice may be stable, but the absolute amount of acid calculated on a per fruit basis actually increases due to fruit growth and accumulation of acid during this time. Sinclair (20) showed the absolute amount of acid per fruit increased under Florida's climatic conditions, even when acid concn in juice decreased during the winter. Grapefruit is very different from the orange in this respect (13, 15).

Acidity levels in desert-grown grapefruit increase in certain years during the winter months, particularly in Jan. (9). The fruit is less palatable when this happens than it was in Nov. There are reports which indicate that acid levels in citrus fruit is related to environmental conditions (4, 5, 13, 15, 16, 19, 20). Rasmussen et al. (15), for example, reported a correlation between high temp and acid content of young orange fruit, and an inverse relationship between mean acid content of 'Ruby Red' grapefruit and rainfall.

This paper is concerned with the relationship between certain environmental factors before and during harvest and acid levels

[1]Received for publication March 14, 1977. Contribution from the Agricultural Research Organization, The Volcani Center, Bet Dagan, Israel, 1976 Series, No. 272-E.

[2]Gilat Regional Experiment Station, Mobile Post Negev, Israel.

[3]Division of Citriculture, P. O. Box 6, Bet Dagan, Israel.

[4]The authors are indebted to Dr. H. Bielorai of the Institute of Soil and Water for supervision of the irrigation experiment.