RESEARCH NOTE

AN ACCURATE, LOW COST FIRMNESS MEASURING INSTRUMENT*

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Abstract. A low-cost, automatic firmness measuring instrument was developed using commercially available components such as: dial gage, dashpot lowering mechanism, weight sets and probe tips. The details of the assembly and the names of parts manufacturers are given. The instrument is an automated modification of the original P-L Meter developed by Parker and Levin at Michigan State University. The application of the instrument to firmness measurements on cherries and tomatoes is summarized and illustrated with typical results. Tomato studies covered the relationship between firmness and variables such as: fruit size, cultivar type, changes in protopectin content, polygalacturonase and cellulase activity. The readings compared favorably with those obtained with the Instron Universal Testing machine.

1. Introduction

Firmness of fruits and vegetables is used as an indication of ripeness and maturity, as a measure of the effect of environment on plant growth, and as a means of determining the effect of various harvesting, handling, storage, and processing techniques.

Techniques for measuring stiffness of fruits and vegetables have been demonstrated by Mohsenin and Goehlich (1962), Bourne (1965), and Fridley *et al.* (1968). In 1969, Finney reported on a procedure for obtaining the slow loading rate or quasi-static stiffness, F/D. Techniques for obtaining the dynamic or fast loading rate stiffness, f^2M, have been successfully demonstrated by Finney (1968) and Abbott *et al.* (1968).

Equipment for these tests is expensive and not portable. In many cases data are taken in remote locations so that a portable firmness instrument is needed. In addition, the instrument must be of low cost and easy to operate.

The original version of the P-L Meter was described by Parker *et al.* (1966a). It was low in cost, portable, and very effective for measuring firmness of tart cherries. The instrument consisted of a commercial dial gage with a 0.20 radius probe tip. The probe was lowered onto the fruit and the amount of creep over a specified time was taken as an index of firmness: the smaller the amount of creep, the firmer the specimen. Use of the meter was somewhat inconvenient because of the comparatively long time

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required for each test. In addition, there was an inherent error due to the operator effect when lowering the probe. Deformation of the fruit at the support can also cause errors in this type of a test. Arnold and Mohsenin (1970) have suggested the use of a doughnut-shaped support under the fruit to reduce this error.

The objectives of the present study were:

(1) to develop a standardized version of the P-L Meter which eliminates the operator effect and minimizes the time for each test,

(2) to demonstrate the practical usefulness of the modified P-L Meter.

2. Design and Operation of the P-L Meter

A. DESIGN

A general view of the P-L Meter is depicted in Figures 1 and 2 showing the stand, dial gage, weight, probe tip and fruit seating support. The entire assembly, with the exception of the stand and the dashpot cover weight, was purchased commercially so as to make the construction of the P-L Meter as easy as possible for other investigators. The cost of the P-L Meter was about $200, complete.

1. *Dial Gage and Weight Set*

The dial gage assembly, tips and weights were purchased from the Federal Products Corporation, 1144 Eddy St., Providence, R. I. 02901. The model D81T dial gage which which has a 2 in. stroke was used and was ordered with the return spring removed, counterclockwise reading dial, cam-type lifting lever, and an adjustable back.

The dial gage itself weighs 20 g and can be used without added weights with small specimens such as tart cherries. A set of weights 50, 100, 200, 300, and 500 g suitable for placing over the gage were obtained from the Federal Products Corporation. The selection of the proper weight depends on the combination of the stiffness of the specimen and the size of the probe used which should be adjusted to give 0.020–0.100 in. deflection into the specimen.

2. *Probe Selection*

Round or 'button' probes were used since they are less prone to error due to change in radii in the specimen. They also subject the specimen to much smaller loads (Arnold and Mohsenin, 1970). A probe with a 0.18 in. radius came with the dial gage and a set of 0.25 in. and 0.375 in. radii were purchased separately.

It is also recommended (Mohsenin, 1970) that the radius of the contacting bodies be at least 10 times the radius of the surface of contact to keep within the limits of the Hertz theory. This can be accomplished by a combination of large probes and small deformations.

3. *Lowering Mechanism*

The lowering mechanism, shown in Figures 1 and 2, uses an adjustable air dashpot purchased from the Airport Corporation, Norwalk, Connecticut 06852. For this

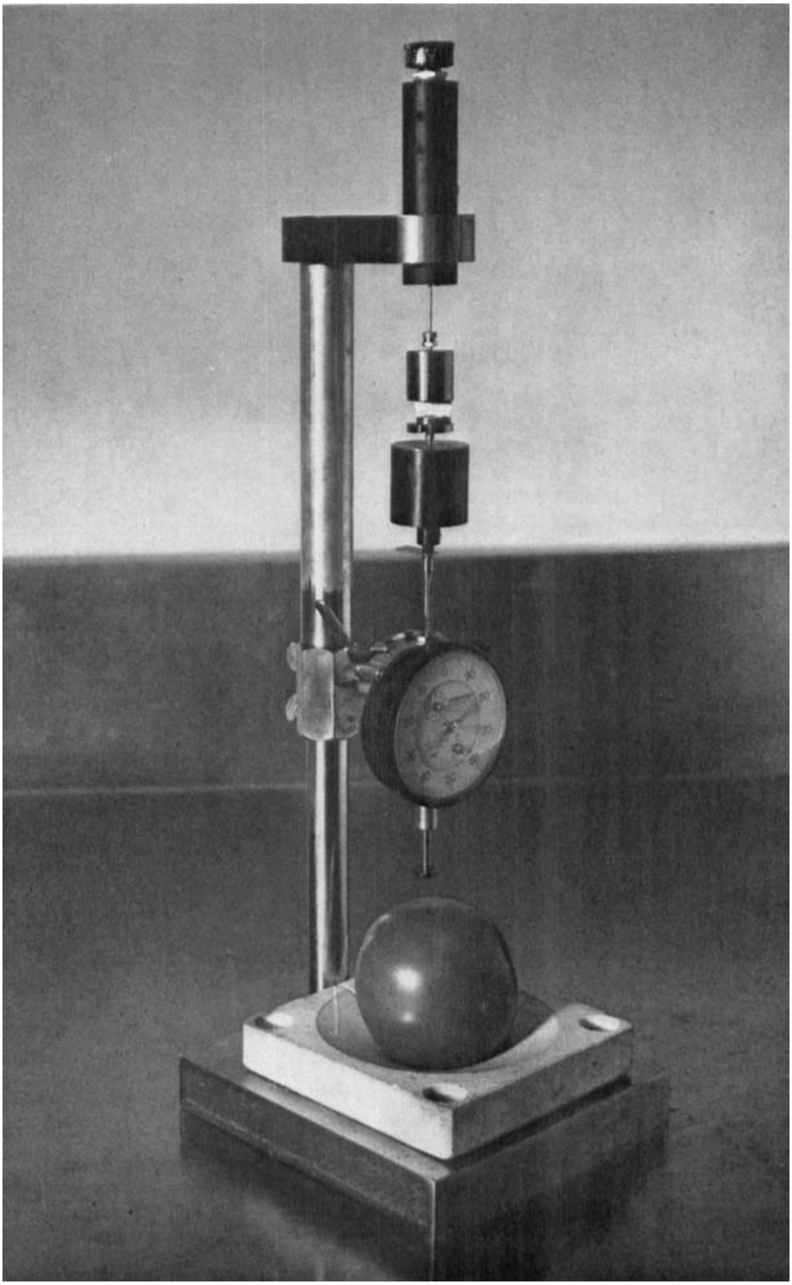

Fig. 1. Photograph of the standardized P-L Meter showing the stand, 2" dial gage, weight, probe tip, fruit seating support, and lowering mechanism.

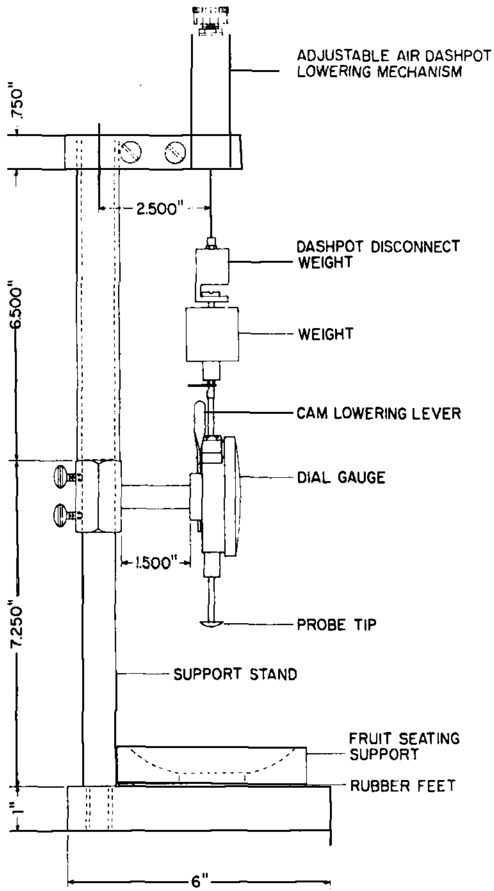

Fig. 2. Side view drawing of the P-L Meter.

application, the dashpot was ordered with pull damping, 3 in. body universal joint/nut, shock-proof case, 4 in. rod, super damping, and a knob. The dashpot assembly provides automatic lowering onto the specimen, thus eliminating the operator effect.

B. OPERATION

In actual use, the movable face on the dial gage is set to zero when the probe is lowered to just contact the specimen. The probe is then raised and released. The deformation (*D*), in thousandths of an inch, can be read directly from the dial gage.

The speed of the lowering mechanism is constant for any given setting of the plunger assembly clearance nut. When the probe contacts the specimen, it slows down while the plunger assembly continues to move at the initial rate and breaks contact with the probe. The probe is then free to settle into the fruit by itself. This removes the operator effect at the initial contact and allows the P-L Meter to compete on a favorable basis with the Instron machine (Figure 3).

The amount of deformation resulting after the separation of the dash-pot and the

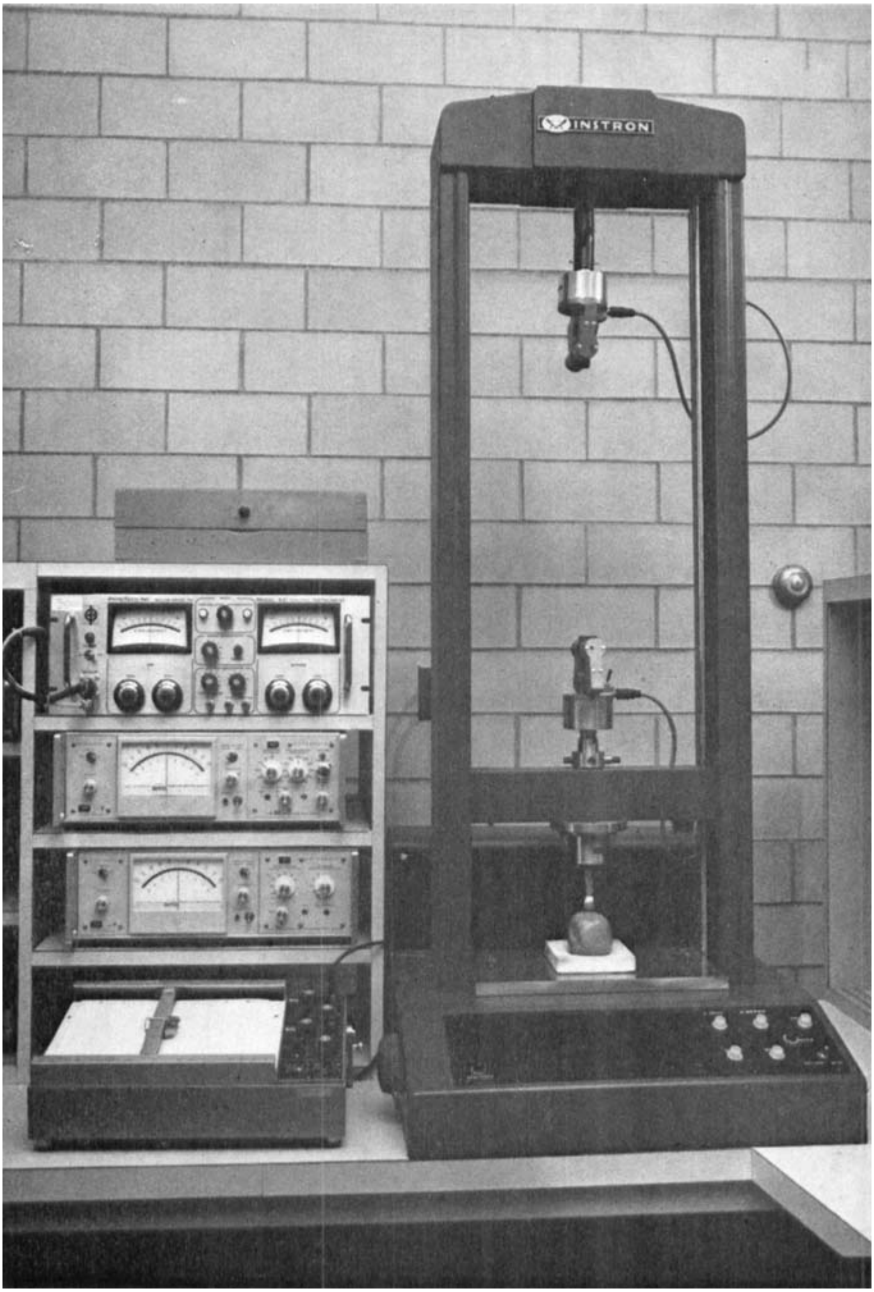

Fig. 3. Photograph of the Instron Universal Testing Machine showing load and displacement attachments used for measuring tomato firmness.

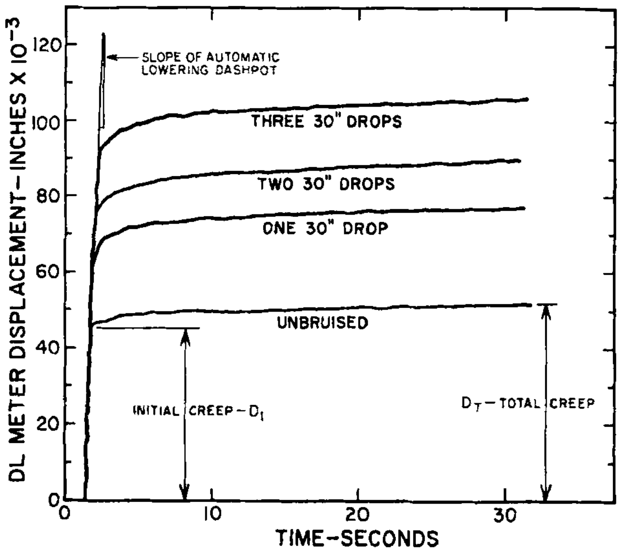

Fig. 4. P-L Meter deformation showing initial creep controlled by the dashpot lowering mechanism and total creep over a longer test period for bruised and unbruised Montmorency cherries. (Diener *et al.*, 1969).

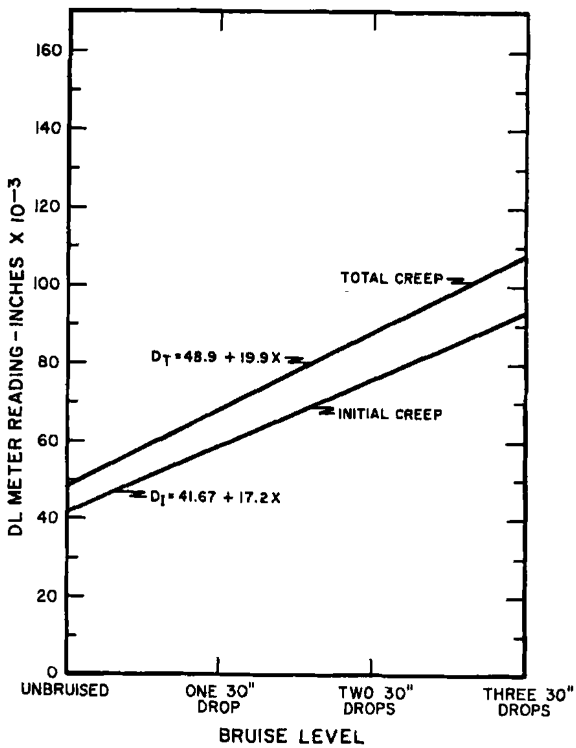

Fig. 5. Comparison of initial creep D_I and total creep D_T for Montmorency cherries of different bruise levels (Diener *et al.*, 1969).

probe was about 15% of the total deformation, D_T (Figures 4 and 5). Thus, at least for tart cherries, only the initial deformation D_I needs to be known since it was always 85% of the total deformation, D_T. By using only this initial part of the loading curve, the test time for each specimen can be reduced to 5 s or less depending on the speed of the dashpot.

The resulting F/D ratio from the P-L Meter using spherical probes and specimens may be arrived at by rearranging the Hertz equations presented by Mohsenin (1970):

$$F/D^{3/2} = \frac{1.33\,E_2}{(1 - \nu_2^2)}(R_1R_2/(R_1 + R_2))^{1/2},$$

where F is the load force, D is the deformation, E_2 is Young's modulus of elasticity, ν_2 is Poisson's ratio for the test specimen, R_1 and R_2 are the radii of the steel probe and the specimen, respectively. This arrangement of the equation assumes the ratio $(1-\nu_1^2)/E_1$ to be negligible. A further treatment of the nonlinear relation between F and D in the Hertz equation is presented by Arnold and Mohsenin (1970).

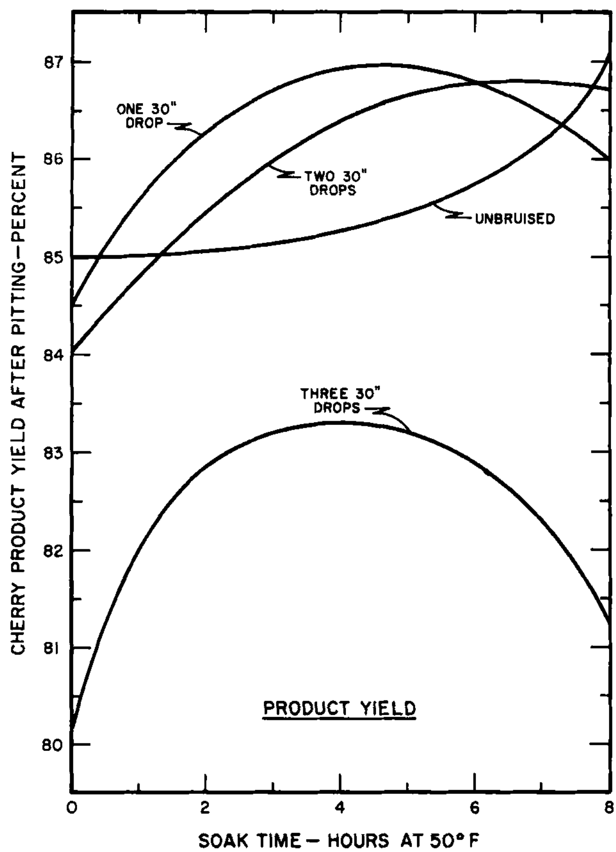

Fig. 6. Effectiveness of the P-L Meter in detecting bruise levels in cherries and the effect of soak time on firmness (Tennes *et al.*, 1969).

3. Applications of the Instrument

A. TART CHERRIES

Parker *et al.* (1966) first used the P-L Meter for measuring the bruise level of Montmorency tart cherries and found it effective in preliminary tests.

Figures 6 and 7 show later work on red tart cherries relating firmness to soak time and to product yield from the pitter (Tennes *et al.*, 1967). Originally, it was thought that bruised cherries became firmer when soaked in water. This was proven not to be generally true as shown by the data in Figure 6. Cherries at all bruise levels decreased in firmness during the first few hours except the 3-X (three drops) group which in-increased in firmness. In the last few hours, firmness increased except for the 3-X cherries which showed a decrease in firmness. The 3-X sample remained least firm at all bruise levels during the entire soaking period.

Firmness differences from bruise treatment in Figure 7 were shown to relate highly to the product yield from the pitter. Soak time was another important contributing

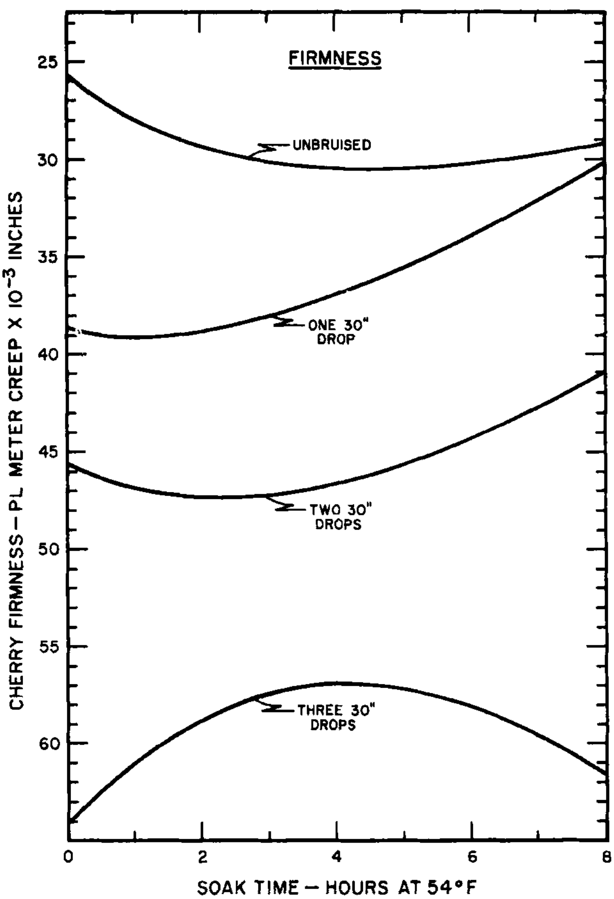

Fig. 7. Effect of firmness and bruise level on product yield from the cherry pitter (Tennes *et al.*, 1969).

factor. For each bruise level, a somewhat different soak time was required for optimum product yield.

B. TOMATOES

During the summer and fall of 1969, Sobotka (1970) made firmness measurements on five cultivars of tomato: Manhattan, West Virginia '63, T-3640, T-3624, and T-3585. These cultivars were grown on the Horticulture Farm, West Virginia University Experiment Station, Morgantown. In this study, the modified P-L Meter readings were correlated with changes in pectin content and polygalacturonase and cellulase activity of the various cultivars at different stages of ripening.

1. *Firmness vs Maturity and Fruit Size*

Figure 8 shows the effectiveness of the P-L Meter in detecting firmness of tomatoes during ripening using the Manhattan cultivar as a typical example. Data obtained with the Instron Universal Testing Machine are included for comparison.

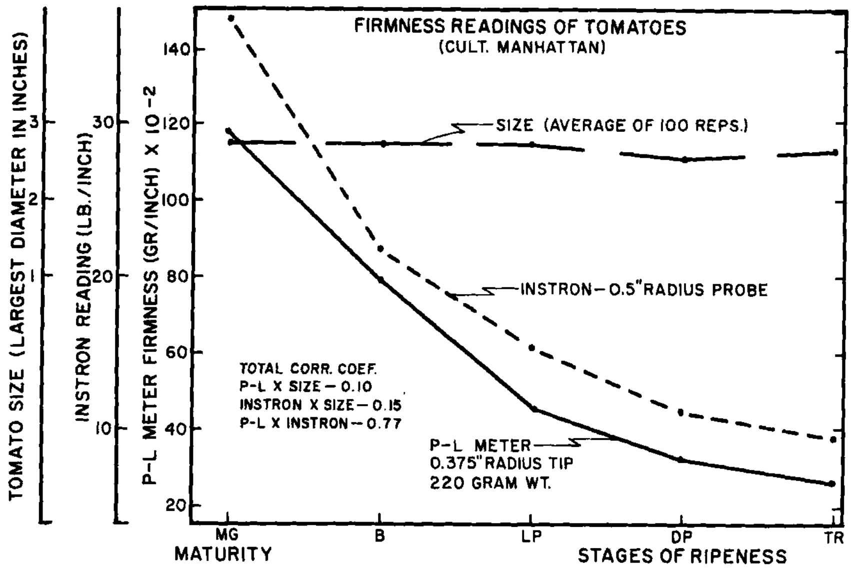

Fig. 8. Effectiveness of the P-L Meter and the Instron in detecting changes in tomato firmness related to maturity.

Correlations between fruit size (1.5–3.5 in. diam.) and firmness readings were 0.10 and 0.15 for the P-L Meter and the Instron, respectively, indicating that neither instrument was affected by fruit size. This was because (1) spherical probe tips were employed so that small load forces could be used and compression of the entire fruit was avoided, and (2) a seating mechanism was used which reduced the amount of deformation of the fruit at its support.

2. *Firmness vs Cultivar*

Figure 9 shows the ample sensitivity of the P-L Meter in differentiating between firmer and softer cultivars. In this case, a well-defined difference is shown between T-3640, a firm cultivar and Manhattan, a soft cultivar. Firmness readings for other cultivars fell within these extremes. The most rapid softening period appeared between the mature green stage and 4 days after the inception of fruit color.

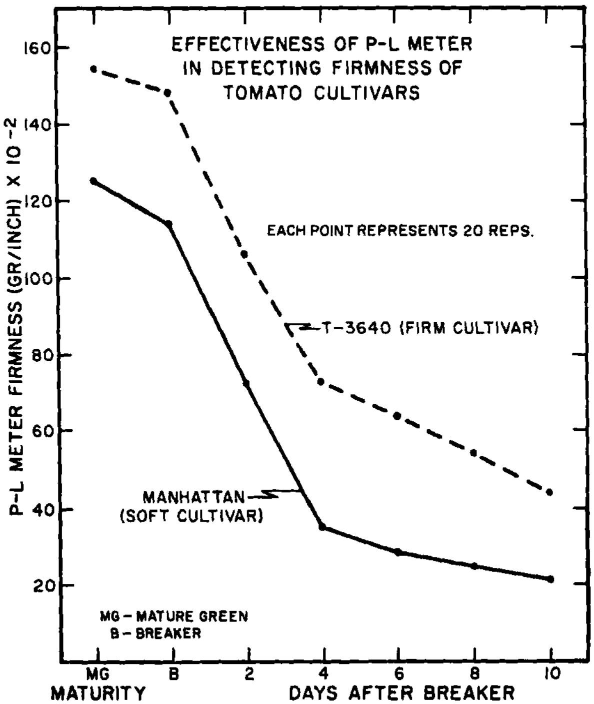

Fig. 9. Effectiveness of the P-L Meter in detecting firmness differences in tomatoes due to maturity and type of cultivar.

3. *Firmness vs Protopectin*

Figure 10 shows the relationship between changes in protopectin during the various stages of tomato fruit ripening and changes in fruit firmness as detected by both the P-L Meter and the Instron Machine.

Protopectin is the parent pectin compound found most abundantly in the primary cell wall and in the intercellular interstices of mature fruit tissues. It serves mainly as a cementing substance between primary plant cell walls and as such functions in conjunction with cellulose and hemicellulose to add rigidity to fruit tissues. Mature tomato fruit tissue contains an abundance of protopectin which is broken down and thought to be metabolized during fruit ripening. This results in extensive softening of the fruit.

With both the P-L Meter and the Instron machine, the loss in firmness of the tomato

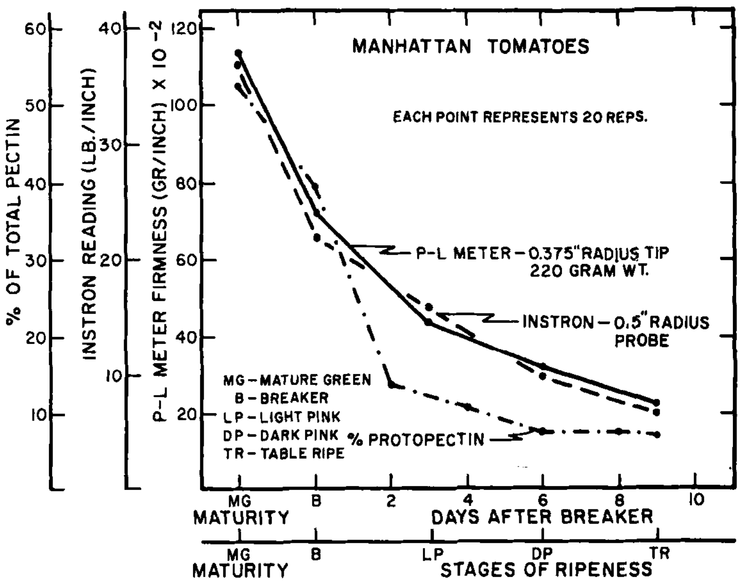

Fig. 10. Relationship between protopectin content of Manhattan tomatoes and firmness readings obtained with the P-L Meter and the Instron.

fruit of the Manhattan cultivar (Figure 10) closely followed changes in protopectin during different stages of ripeness.

4. *Firmness as Related to Polygalacturonase and Cellulase Activity*

Poly-a-1,4-galacturonide glycanohydrolase, PGU, (EC 3.2.1.15), and cellulase (C_x) β-1,4-glucan 4-glucanohydrolase, (EC 3.2.1.4), are enzymes that degrade pectin and cellulose and have been indicated in the softening process of tomato fruit tissue.

It was observed that, during ripening, both PGU and C_x increase in a number of tomato fruit cultivars. In addition, it was found that increases in these enzymes are significantly related to fruit softening as measured with the P-L Meter and the Instron machine. This indicates that the P-L Meter is sufficiently accurate and sensitive to be used in establishing bioassays for softening enzyme studies.

C. COMPARISON WITH THE UNIVERSAL TESTING MACHINE

A highly significant correlation coefficient of 0.77 was obtained between the modified P-L Meter and the Instron. This shows the effectiveness of the P-L Meter in direct comparison to a highly sophisticated instrument.

4. Conclusion

(1) A dial gage firmness meter was constructed which is portable, low in cost, and has an automatic lowering mechanism to eliminate the operator effect.

(2) The instrument is able to detect bruise damage and pitter loss in tart cherries,

and to measure firmness as related to maturity and the protopectin content in tomatoes. Readings are not affected by the size of the tomato fruit.

(3) Values obtained with the instrument show a statistically significant correlation with the Instron Universal Testing Machine readings.

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