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# INSTRUMENTAL METHOD OF FIRMNESS MEASUREMENTS IN TOMATOES TO BE HARVESTED MECHANICALLY

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A review of the existing methods of tomatoi firmness measurement provided a basis for evaluating the usefulness of three groups of methods: punch testing (different sizes and shapes), compression (compression force and deformation) and skin tension test (tension force and elongation). It was found that final compression force was the simplest and most useful index of tomato firmness, especially of tomatoes intended for mechanical harvesting.

The breeding of tomato varieties adapted to mechanical harvesting is aimed at producing plants with fruits having greater mechanical strength than traditional fruits. A maximally precise, suitably differentiating and at the same time simple method of measuring the mechanical strength of tomatoes is very helpful in assessing the effectiveness of the selection work.

Instrumental methods of tomato firmness measurement have a long history. Garret et al. [4] quote several methods used by various authors, such as the compression lever with a weight described by Fischer and Sengbusch in 1935, the Chatillion penetrometer of West and Syder (1938), and the pressure meter used by Paech (1938) and Lutz (1944). The work of Hamson (1952), Kattan (1957) and Mc Collum (1957) led to the construction of the Firm-o-meter and Asco Firmnes Meter measuring apparatus operating on the principle of fruit compression with a loop band [4].

Further methodological progress was due to Bourn who used the Instron universal rheological measurements apparatus [2] and the penetrometer [3]. The test used by this author consisted in compressing whole tomato fruits between two parallel plates with the force of one kilogram; the measured value was deformation in mm.

The Kramer press was also adapted to measuring tomato firmness [5] and it was assumed that a useful index of this quality was the force necessary to compress the fruit by 5 mm [6].

A detailed description of the applications of penetrometric methods in tomato firmness determinations is given by Holt [7].

The work of Dutch authors [11] led to the construction of a penetrometer measuring fruit deformation at pressure with a round-tipped mandrel weighing 300 g acting for 5 sec.

Recent years saw the proliferation of strength-measuring methods involving the compression of whole tomatoes between two plates [1, 10], tension tests of fruit skin [8] and skin strength tests (puncture) [9].

As we see from the above review, tomato firmness was determined with a variety of instruments, either universal or specially designed, subjecting the fruits to punching, compression or tension. However, there is no fixed methodology of measurements (conditions and working procedures of measurement( which makes comparisons difficult.

The objective of this research was the evaluation of methods of tomato fruit mechanical strength measurement and the selection of the best method of testing tomato material during breeding of varieties better adapted to mechanical harvesting.

The criteria used in assessing the usefulness of the various methods were as follows: ability to differentiate tomato varieties according to practical evaluation of firmness, repeatability of results, facility of measurement, and measurement time. Also considered were possibilities of employing the methods in portable devices enabling tomato firmness measurements in field conditions.

## EXPERIMENTAL

### MATERIAL

The material for study was obtained from the Garden Plant Breeding Stations in Pass and Ulrichów. The fruits were harvested in 1982 and 1983 in polyethylene-covered greenhouses. The varieties are listed and briefly characterized in Table 1.

The tomatoes for measurements were picked twice in the peak fructification period. Ripening fruits typical for the given variety were collected and divided into three ripeness groups: the green-yellow, the yellow-orange and the pink. To ensure that the investigations are performed with uniformly ripe fruits, the pink tomatoes were tested after five days, the yellow-orange after six days, and the green-yellow

Table 1. Characteristic of the investigated tomato varieties

| Variety | Characteristic | 1982 | 1983 |
|---|---|---|---|
| New Yorker | Commercial, consumption and industrial variety; fruit round or slightly flattened, soft | + | + |
| Chef | Variety adapted to mechanical harvesting; fruit round, fairly firm | – | + |
| Mechanical Harvester No. 6203 | As above; fruit elongated, firm | + | + |
| Cal-j | As above; fruit elongated, very firm | + | + |

after seven days of storage at room temperature. In 1982 the various measurements were performed with diffedent numbers of fruits harvested on several occassions, whereas in 1983 each measurement was performed in 120 fruits of each variety (two pickings x three determinations x 20 fruits).

## METHODS

The aplied methods are described in Table 2. The results of determinations were plotted from force-deformation diagrams in absolute values (G) and in conversion to 1 g of fruit mass (G/g).

In 1983 we measured tomato firmness with the compression test, obtaining the following three indices from the measurement curve:

— initial compression force (at 5 mm fruit compression),

— compression force at bioyield point (BYP), i.e. at fruit break,

— limit compression force (at fruit compression of up to 12 mm).

The results were analysed statistically with three-factor variance analysis (factor A1 ÷ 2 — picking periods, B1 ÷ 4 — varieties, C1 ÷ 3 — determination periods). The significance of differences between mean values was determined with Student's t-test at two levels of significance: $\alpha_1 = 0.05$ and $\alpha_2 = 0.01$. The calculations were performed with an Odra 1305 computer.

## RESULTS AND DISCUSSION

The overall results (in conversion to values per tomato mass unit) of determinations performed in the 1982 season are given in Table 3, and those for the 1983 season are contained in Tables 4 and 5.

The methods of firmness measurement used in 1982 revealed significant differences between the three investigated varieties. The Mechanical Harvester and Cal-j tomato varieties adapted to mechanical harvesting

Table 2. Methods of tomato firmness measurement

| Measurement method | Working elements in apparatus | Velocity (cm · min$^{-1}$) | | Quantity | |
|---|---|---|---|---|---|
| | | deformation | recorder tape | recorded | calculated |
| Penetrometric (punch) test [7] | plunger (Ø 1 mm) with punch (Ø 2 mm) | 1 | 1 | skin strentgh | |
| | | 1 | 10 | | |
| | | 10 | | | |
| | spherically-ended plunger (Ø 4.7 mm) | 10 | 10 | G | G/g sample |
| | | | 20 | | |
| | | 5 | 20 | | |
| | spherically-ended plunger (Ø 12 mm) | 5 | 20 | | |
| Compression test [1.7] | flat compression plate and anvil | 2 | 10 | compression force to break fruit skin; bio-yield point (BYP) | |
| | flat compression plate and concave anvil | 2 | 10 | G | G/g sample |
| Compression to present deformation 12 mm | flat compression plate and anvil | 2 | 10 | compression force at BYP and final (limit) compression force<br>G | G/g sample |
| Compression to preset stress (0-2 kG and 0-10 kG) [4] | as above | 1<br>1 | 20<br>50 | compression force at BYP deformation at BYP final (limit) deformation | relative deformation (%) |
| Compression-extrusion [12, 13] | Ottawa Texture Measuring System chamber, compression up to 5 mm | 5 | 20 | compression-extrusion force<br>G | G/g sample |
| Tension test [8, 9] | rubber and crimped jaws, 15 mm apart, fruit skin section measuring 60 × 16 mm | 2 | 10 | tension force to break (G); elongation to break (mm) | relative elongation (%) |

were on the average twice as resistant to compression as the traditional New Yorker variety. Compression of fruits coupled with their extrussion through the grate bottom of the OTMS chamber required in the case of the former two varieties a compression -extrusion force three times greater than in the case of the last-mentioned variety.

The penetrometric (punch) tests with plungers of various diameter and shapes demonstrated that, similarly as in the compression tests, the New Yorker tomatoes are least resistant to breaking. The differences between varieties decreas considerably with the increase of punch velocity and plunger diameter.

This finding is at variance with Holt [7] who demonstrated that penetration force does not change with punch velocity.

The penetrometric tests appear to be of little use in the analysis of differences between varieties and breding matrial as regards mechanical strength because of the poor repeatability of measurements. The large differences in punch force necessary to break fruits of the same variety are due to the impossibility of standardizing the point of fruit penetration.

More attention was devoted to fruit compression between two flat or one flat and one concave plates up to a predetermined deformation (12 mm) or stress (2 or 10 kG). The force at BYP, i.e. the stress (force) causing skin (fruit) rupture, and limit stress (or deformation) were recorded. The obtained results (Table 3) show that compression to predetermined deformation may be used in the breeding and selection of tomatoes, being a simple and rapid test differentiating the firmness of the studied material with sufficient precision.

The compression of fruits to a preset stress value (O-2 kG and 0-10 kG) makes it possible to record the force at BYP as well as fruit deformation by compression force (in mm and per cent). At compression force in BYP comparable to that in the previous determinations, the absolute deformation at this point was lower in the New Yorker variety (11.4 mm) than in the other two varieties (13.3 and 13.5 mm); this again shows that the New Yorker variety is the one most susceptible to crushing. The higher final deformation (34.3 mm) in this variety (the other varieties: 28.3 and 26.5 mm) also indicates a softer internal structure of these tomatoes. The measurement of final deformation enables the evaluation of breeding material of various firmness, but is a laborious method requiring additional measurement equipment.

The results of studies of tensile strength of tomato skin performed in abstraction from differences due to the anatomic structure of whole fruits demonstrated the relative independence of this strength from the variety: the tension force to break differed from one variety to another by 18-25%. Thus, the 2-3-fold differences in firmness (resistivity to compression) obtained in previous determinations are due to the cha-

Table 3. Tomato firmness measured by various methods in 1982

| Measurement method | Working elements in apparatus | Speed of travel of working element ($cm \cdot min^{-1}$) | Index |
|---|---|---|---|
| Penetrometric (punch) test | plunger (Ø 1 mm) with punch (Ø 2 mm) | 1<br>10 | force to break skin (G/g sample) |
| | spherically-ended plunger (Ø 4.7 mm) | 5 | as above |
| | spherically-ended plunger (Ø 12 mm) | 5 | as above |
| Compression to fruit break | flat compression plate and anvil*) | 2 | compression force at BYP (G/g sample) |
| Compression to preset limit deformation (12 mm) | flat compression plate and anvil | | compression force at BYP (peeled fruit) (G/g) |
| | | 2 | compression force at BYP (G/g)<br>limit final compression force (G/g) |
| Compression to preset stress (0-10 kG) | as above | 1 | compression force at BYP (G/g)<br>compression-extrusion force (G/g) |
| Compression-extrusion | OTMS chamber | 5 | compression-extrusion force (G/g) |
| Tension test | rubber crimped jaws, fruit skin section measuring 60 × × 16 mm | 2 | tension force to break (G)<br>relative elongation (%) |

*) concave anvil was used for the varieties Mechanical Harvester and Cal-j

racteristic anatomic structure of every variety, particularly to the number of internal cells and to their volume in relation to the total volume of fruit flesh.

The tomato fruit firmness measurements performed in 1983 (Table 4) demonstrated that the index of initial compression force (at 5 mm

| Variety | | | | | |
|---|---|---|---|---|---|
| New Yorker | | Mechanical Harvester | | Cal-j | |
| no. of fruits in sample (n) | mean index value (range) | no. of fruits in sample (n) | mean index value (range) | no. of fruits in sample (n) | mean index value (range) |
| 12 | 4.1(2.1-6.9) | 18 | 8.8(6.4-10.9) | — | — |
| 24 | 7.3(3.8-15.1) | 24 | 9.3(6.5-15.4) | 9 | 10.0(7.5-12.9) |
| 24 | 21.0(17.3-24.9) | 24 | 23.9(20.1-28.5) | 24 | 21.9(16.2-26.1) |
| 10 | 35.9(20.3-50.5) | 6 | 53.5(49.2-57.8) | — | — |
| 81 | 67.1(53.6-81.0) | 110 | 123.5(14.5-131.6) | 60 | 122.8(97.4-131.6) |
| 5 | 61.7(54.6-68.4) | 3 | 127.0(80.0-145.0) | 3 | 177.3(161.6-190.7) |
| 6 | 65.5(54.6-75.3) | 12 | 102.8(63.5-141.7) | 12 | 118.5(84.4-161.9) |
| 6 | 197.0(145.0-287.3) | 12 | 291.3(175.3-375.0) | 12 | 361.2(265.4-513.4) |
| 7 | 74.4(44.9-111.4) | 7 | 88.1(57.3-123.0) | 7 | 105.5(68.8-142.2) |
| 3 | 75.4(68.3-79.3) | 3 | 64.9(59.5-68.2) | 3 | 63.0(59.2-65.2) |
| 4 | 148.7(136.2-168.1) | 4 | 442.4(298.7-641.0) | 4 | 449.5(290.0-707.7) |
| 5 | 564(450-985) | 6 | 696(485-870) | 7 | 659(485-800) |
| 5 | 22.6 | 6 | 28.6 | 7 | 32.6 |

compression) cannot serve as an indicator of fruit firmness since the obtained results do not reflect the real value of the fruits known from practice and measured with other methods. For example, the results failed to reveal differences between the New Yorker tomatoes and the firm-fruit varieties adapted to mechanical harvesting (Mechanical Harvester and Cal-j).

Table 4. Mean values (n = 120) of compression force applied to tomato fruits (1983)

| Variety | Fruit mass | Compression force | | | | | |
|---|---|---|---|---|---|---|---|
| | | initial | | at BYP | | limit (final) | |
| | g | G | G/g | G | G/g | G | G/g |
| New Yorker | 105.4 | 1764.2 | 17.26 | 6148.7 | 59.82 | 14187.5 | 135.56 |
| Chef | 108.6 | 2282.9 | 21.12 | 8133.3 | 75.71 | 19593.3 | 181.75 |
| Mechanical Harvester na 6203 | 91.7 | 1555.8 | 17.17 | 7973.3 | 87.88 | 21834.6 | 240.10 |
| Cal-j | 105.4 | 1730.4 | 16.63 | 8395.4 | 81.00 | 26938.7 | 257.14 |
| NIR $\alpha = 0.05$ | 8.36 | 169.4 | 1.22 | 705.5 | 5.79 | 1313.5 | 25.15 |
| NIR $\alpha = 0.01$ | 11.79 | 239.0 | 1.72 | 995.4 | 8.17 | 1853.6 | 35.50 |

Table 5. Variance analysis ($F_{calc.}$) of instrumental indices of tomato firmness (1983)

| Source of variation | Degress of freedom | Fruit mass | Compression force | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | initial | | at BYP | | limit (final) | |
| | | g | G | G/g | G | G/g | G | G/g |
| A (repetitions) | 1 | 0.69 | 0.61 | 4.66 | 0.01 | 0.13 | 4.28 | 0.79 |
| B (varieties) | 3 | 7.85**) | 35.15**) | 27.77**) | 20.42**) | 41.25**) | 156.10**) | 47.50**) |
| C (determination times) | 2 | 5.63*) | 0.12 | 7.55**) | 0.81 | 11.83**) | 0.10 | 1.82 |
| B×C | 6 | 0.95 | 0.62 | 2.02 | 1.46 | 2.01 | 3.08 | 0.61 |

*) significance level $\alpha_1 = 0.05$

**) significance level $\alpha_2 = 0.01$

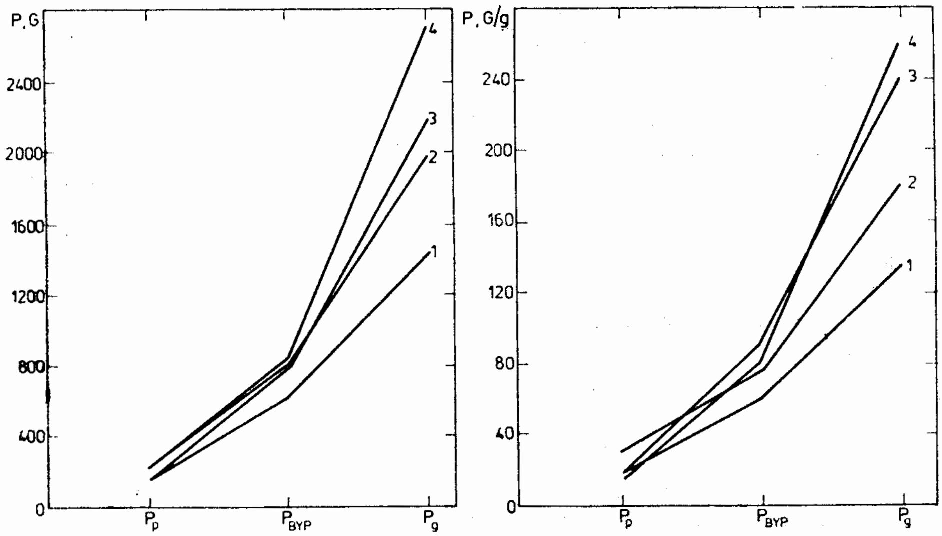


Fig. Compression force P(A — in G, B — in G/g mass) in tomato fruits of various varieties: 1 — New Yorker, 2 — Chef, 3 — Mechanical Harvester, 4 — Cal-j $P_p$ — initial compression force, $P_{BYP}$ — force at BYP, $P_g$ — limit (final) compression force

Our studies did reveal significant inter-species differentiation as regards the bioyield point BYP and the final deformation force. The differentiation was also confirmed by statistical analysis (Table 5).

It emerged that the best test of firmnesss of the studied tomato varielies is the measurement of limit compression force. This measurement arranged the varieties in agreement with their practically observed firmness and made possible a more precise differentiation of varieties.

## CONCLUSIONS

1. Methods of determining tomato fruit firmness differ as to the amount of supplied information, accuracy, precision and simplicity.
2. The test of compression to preset deformation provides six firmness indices: in tial force, force at bioyield-fruit break point, and limit force, in absolute values and per fruit mass unit.
3. The value of final (limit ) compression force is a simple index of tomato firmness, most useful in breeding and selection work.

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## INSTRUMENTALNA METODA OCENY TWARDOŚCI POMIDORÓW PRZEZNACZONYCH DO MECHANICZNEGO ZBIORU

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Streszczenie

Przeprowadzono badania mające na celu opracowanie instrumentalnej metody oceny twardości pomidorów przeznaczonych do zbioru mechanicznego. Zastosowano metodę penetrometryczną (przebijanie owocu trzpieniem o różnej średnicy i kształcie, pomiar siły przebicia), metodę ściskania (pomiar siły ściskającej i odkształcenia) oraz oznaczanie wytrzymałości mechanicznej skórki na rozciąganie (pomiar siły zrywającej i wydłużenia).

Jako kryterium przydatności metod przyjęto zróżnicowanie odmian pomidorów zgodnie z praktyczną oceną ich twardości, powtarzalność wyników, łatwość wykonania pomiarów i czas trwania oznaczeń. Za pomocą testu ściskania do ustalonego odkształcenia uzyskać można sześć wskaźników twardości siłę początkową, siłę w punkcie przegięcia (pęknięcia owocu) oraz siłę graniczną w wartościach bezwzględnych i w przeliczeniu na jednostkę masy owocu.

Stwierdzono, że wartość siły ściskającej granicznej jest prostym i najbardziej przydatnym miernikiem oceny twardości pomidorów w pracach hodowlano-selekcyjnych.