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ELASTICITY CHARACTERISTICS OF FRUITS

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A b s t r a c t. The objective of the paper reported herein is to determine elasticity characteristics of fruits for the evaluation of fruit firmness. The coefficient of elasticity - the ratio of the compressive stress to the deformation - was introduced to characterize the firmness of the fruit. Since the deformation is limited to a value that is below the inflection point of the stress-strain curve, this coefficient can be measured by a non-destructive method. Tests were performed with different penetrometers and good correlation was found between the coefficient of elasticity and other properties - bioyield and rupture stresses and the Young's modulus of elasticity and the coefficient of elasticity - with apple and tomato. The coefficient can be used as a good characteristic of the fruit firmness for either scientific or practical evaluation.

K e y w o r d s: apple, tomato, elasticity, deformation, compressive stress

INTRODUCTION

There are several fields of quality evaluation of fruits. The firmness is a principal characteristic of the bioproduct and it can be evaluated:
- by subjective characteristics and
- by objective characteristics.

In the case of subjective evaluation panel sensory tests are performed where different sensory terms - such as crispy, crunchy, chewy, creamy, juicy, etc. - are used.

With the objective evaluation the mechanical properties are determined by different tests and by the means of different instruments [1-7].

The firmness is an engineering term when the evaluation is performed by mechanical tests. Generally speaking the firmness is the resistance of the material when a probe penetrates into the specimen.

Therefore the firmness is characterized by force-deformation (or stress-strain) curve. Usually such a curve is deformined by an INSTRON-type testing machine that is fitted with a circular probe. From the test results calculated characteristics are as follows:
- rupture stress (and strain),
- yield stress (and strain),
- modulus of elasticity (Young's modulus),
- and others.

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ELASTICITY CHARACTERISTICS

The fruit tested by an INSTRON-type testing machine gets damaged when measuring the force-deformation curve. However, with the pressure tests there is a range of elasticity in which the fruit is not damaged. Therefore it is reasonable to find elasticity properties to characterize the firmness.

The elasticity properties can be measured by non-destructive methods that is of significant importance.

The Young's modulus of elasticity is a good measure of the elasticity of ideal materials (e.g., steel). The behaviour of ideal materials are described by the Hooke's law and the model of which is a spring without damper.

The Young's modulus of elasticity for compressive and tensile stresses is expressed as follows:

$$E = \frac{\sigma}{\varepsilon} \quad (1)$$

where σ - stress, MPa, ε - specific strain

$$\varepsilon = \frac{\Delta l}{l} \quad (2)$$

where Δl - variation in the length (deformation), mm, l - length, mm.

As it is shown the modulus of elasticity is a function of the orginal length, or size of the specimen tested.

However, the agricultural materials are of viscoelastic character, therefore rheological models are used to describe such materials. The principal rheological models are as follows:

- the Kelvin model where a spring and a damper are in parallel connection,
- the Maxwell model where a spring and a damper are in serial connection.

The mentioned models are used to describe the deviation of the stress-strain curve of viscoelastic materials from that of the ideal material.

Since the Young's modulus of elasticity is influenced by the length of the specimen, or the size (e.g. diameter) of the fruit, another elastic characteristic should be introduced that is dependent on the deformation and independent on the length or size.

The coefficient of elasticity is the ratio of compressive stress to the deformation where the stress is not higher than that at the inflection point of the stress/strain curve.

The coefficient of elasticity is expressed as follows:

$$e_c = \frac{\sigma_z}{z} \quad (3)$$

where σ_z - compressive stress that occurs at 'z' deformation of the fruit, kPa, z - deformation of the fruit, mm.

Since the deformation in the above equation is below the permanent deformation of the fruit the compressive stress will not damage the fruit tested.

METHODS AND MATERIALS

Comparative tests were performed with different penetrometers:

- with a hand-held penetrometer (signed by '*p*' in the following) where the penetration depth of the probe is limited to the wanted/allowed deformation to determine the coefficient of elasticity (probe diameter: 6 mm),
- with a simple hand-held penetrometer (signed by '*MT*' in the following) to determine the Magness-Taylor rupture stress (probe diameter: 8 mm),
- with an INSTRON-type testing machine (signed by '*f*' in the following) to determine the stress-strain curves (probe diameter: 8 mm).

Apple and tomato were tested by the penetrometers. The measured and calculated characteristics are as follows:

- the coefficient of elasticity was determined from the results measured by the '*p*' penetrometer, where the force was measured at a definite - 0.6 mm - deformation and by the '*f*' penetrometer;
- the Magness-Taylor rupture stress measured by the '*MT*' penetrometer;
- the stress-deformation behaviour, including stress and deformation at the inflection, bioyield and rupture points and the coefficient of elasticity.

RESULTS

In general the coefficient of elasticity was calculated from the data measured by the '*p*' penetrometer. However, this coefficient was calculated from the range of the stress-deformation curve being below the inflection point (measured by '*f*' penetrometer). The relationship between the two coefficients was determined for apple and tomato (Fig. 1).

The coefficient of elasticity (measured by '*p*' penetrometer) was shown as the function of the bioyield and rupture stresses (measured by 'f' penetrometer) for apple (Fig. 2). The probability level is 5.0 % for both cases.

The coefficient of elasticity (by 'p' penetrometer) was analysed as the function of the bioyield and rupture stresses (by 'f' penetrometer) for tomato (Fig. 3). The probability level was found to be 1.0 % for the bioyield and 5.0 % for the rupture stress.

The coefficient of elasticity (measured by 'f' penetrometer) was shown as the function of the Young's modulus of elasticity and as the function of the rupture stress (both measured by penetrometer) for apple (Figs 4 and 5, respectively). The figures show three points that means three groups

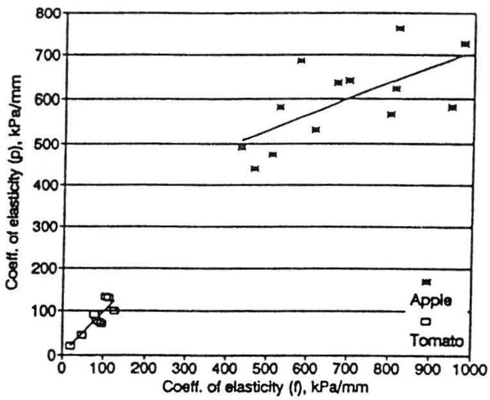

Fig. 1. Coefficient of elasticity (measured by 'p' penetrometer) versus the coefficient of elasticity calculated from the stress-deformation curve (measured by 'f' penetrometer) for tomato and apple. For tomato: y=0.963 x + 1.377, r=0.864; for apple: y=0.353 x + 354.3, r=0.650.

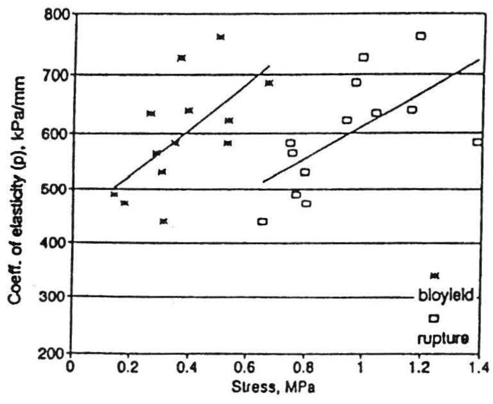

Fig. 2. Coefficient of elasticity (measured by 'p' penetrometer) versus the stress (measured by 'f' penetrometer) for apple. For bioyield stress: y=406.3 x + 444.5, r=0.626; for rupture stress: y=285.6 x + 327.8, r=0.627.

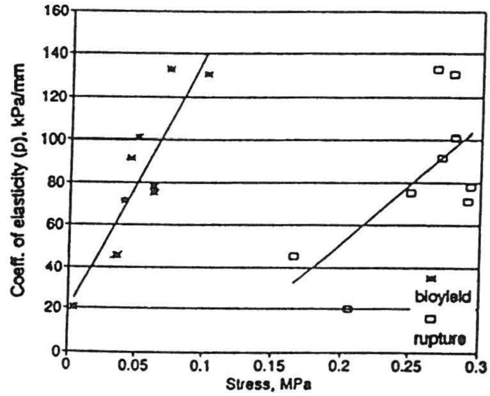

Fig. 3. Coefficient of elasticity (measured by 'p' penetrometer) versus the stress (measured by 'f' penetrometer) for tomato. For bioyield stress: y=1216 x + 18.94, r = 0.876; for rupture stress: y=552.5 x - 58.55, r=0.654.

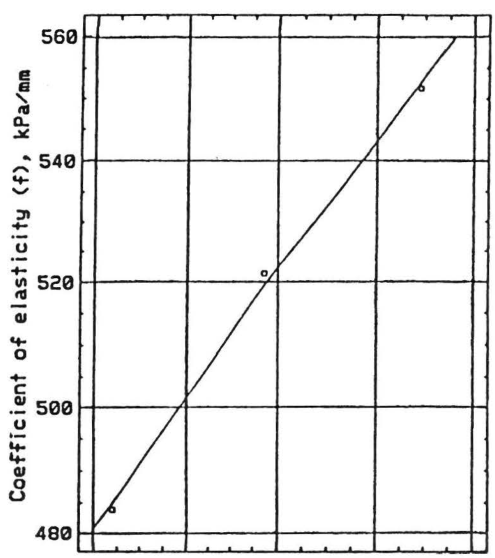

Fig. 4. Coefficient of elasticity (measured by 'f' penetrometer) versus the Young's modulus of elasticity (measured by 'f' penetrometer) for apple: y=10.38 x + 148.64, r = 0.9988.

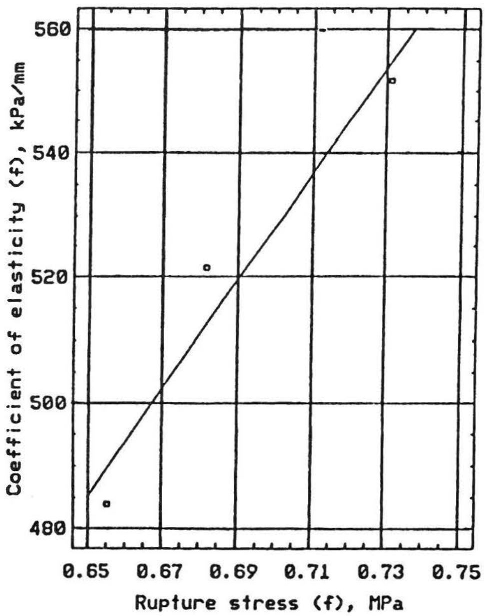

Fig. 5. Coefficient of elasticity (measured by 'f' penetrometer) versus the rupture stress (measured by 'f' penetrometer) for apple: y=858.77 x - 73.07, r=0.9737.

of measured points. A very close correlation was found between the coefficient and the modulus and a good one between the coefficient and the rupture stress.

CONCLUSIONS

The coefficient of elasticity - the ratio of the compressive stress to the deformation - was introduced to characterize the firmness of the fruit. This coefficient is to be measured by non-destructive method, because the deformation is limited to a value that is below the inflection point of the stress-strain curve.

The coefficient of elasticity shows a close correlation with the bioyield stress and an acceptable correlation with the rupture stress for apple and tomato. However, a very close correlation was found between the coefficient and the modulus of elasticity.

Consequently the coefficient of elasticity can be used to characterize the firmness of fruits for both scientific and practical evaluation.

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