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COMPARISON OF MAGNESS-TAYLOR'S PRESSURE TEST WITH MECHANICAL, NON-DESTRUCTIVE METHODS OF APPLE AND PEAR FIRMNESS MEASUREMENTS*

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A b s t r a c t. Comparison of Magness-Taylor's method (MT) with the quasi non-destructive, mechanical method of Fekete (F) and the measurement method for the modulus of elasticity using Instron texture press (EI) was carried out on the fruit of four apple and two pear cultivars. To get a broad range of firmness, fruit were stored under normal atmosphere, CA and ULO conditions for various periods of time and then, they were let to ripen for up to 14 days at 18 °C. Magness-Taylor's was used as the standard method. Based on the H_0 hypothesis, it was concluded that the methods do not have the same precision. However, a highly significant correlation coefficient r between the pairs of the individual methods allows to recalculate the results of one method by the results of the other method according to the linear y = a + bx formula. Correlation and regression coefficients varied in respect to the cultivar and growing season. The highest correlation coefficient ($r > 0.890$) between MT x F methods was observed for the pears with firmness below 20 N (measured by MT method). It may be concluded that the measurement method for the coefficient of elasticity using the Fekete instrument is particularly suitable for the firmness determination of elastic materials such as ripening pears, but it should not be recommended for the investigation of hard, freshly picked apples or pears.

K e y w o r d s: apples, pears, firmness measurement, non-destructive mechanical methods

INTRODUCTION

Firmness is one of the most important indices of fruit ripeness and quality, and is most widely used in the research work conducted all over the world. Investigating firmness of fresh apples group of EEC experts (called Apple Quality Group) recommended Magness-Taylor's (MT) pressure test as the only method [2]. The measurement is executed by using instruments such as Instron that allow linear, constant speed movement of the crosshead, and alternatively hand-held penetrometers, e.g., Effe-Gi. Bourne, who worked out theoretical basis of the punch tests [4,6] suggested, that measurements of apple deformation under low pressure (not causing permanent changes) might be used as an index of their firmness, too [5]. However, he did not find correlation between firmness measured by the non-destructive compression and firmness measured by the punch test (MT). He concluded that there may be two kinds of apple firmness, which are not correlated to each other and that each method may supply information on different aspects of fruit firmness.

Development and improvement of the non-destructive methods of texture measurements is the subject of intensive research work. Many techniques are investigated including acoustic and ultrasonic methods, magnetic resonance, dynamic deformation under pressure and other methods, whereas destructive methods are universally used as reference, verifying methods [1,3]. According to Watada [15], some developments are more promising for some fruit species and less suitable for others. In many countries active research is carried out to develop a

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sensing system that might be used on sorting lines [7]. Methods based on the measurement of the modulus of elasticity are of particular significance as they may be non-destructive [5,8]. The theory of elasticity states that the frequency of vibration of a spherical object depends on the elasticity modulus of the material, the object is composed of. A computerised technique, allows for these measurements to be taken within seconds both in the laboratory and field. By subjecting fruit to vibration at different wavelengths their modulus of elasticity may be measured. A simpler technique is hitting fruit with a light rod (seismic hammer) and the measurement of the vibration frequency distribution by using the fast Fourier's transformation (FFT), from which the Young's Modulus is calculated. This technique allows to determine changes in fruit ripeness before picking and during storage and allows predicting storage life for fruit [14]. New developments proposed by Shmulevich [13] rendered the use of the acoustic method on automatic sorting lines more feasible.

Taking into consideration that in the future non-destructive methods for the measurements of fruit firmness on sorting lines would become common technique, especially those based on the measurement of modulus of elasticity, it was justified to compare the Magness-Taylor pressure test with the mechanical non-destructive methods of firmness measurement for apples and pears also based on the modulus of elasticity. Feasibility of such a comparison is justified by the availability on the market of new kind of electronic instruments for the non-destructive, mechanical measurement of fruit firmness, outfitted with memory and a special programmes, easy to use, both in the laboratory and field [9,12].

MATERIAL AND METHODS

Three methods of firmness measurements were compared in the experiment: the Magness-Taylor punch test, measurements of the coefficient of elasticity (a quasi non-destructive method developed by Fekete) and the measurement of the apparent modulus of elasticity (a non-destructive method). The Magness-Taylor's as a standard method was used. The measuring instruments were: Instron Model 4303 texture press, which was used for Magness-Taylor test (MT) and for the apparent modulus of the elasticity measurement (EI) and a quasi non-destructive penetrometer Fekete (F).

The experiment was conducted on the fruit of four apple cultivars (Elstar, Jonagold, Gloster and Idared) and two pear cultivars (Alexander Lucas and Conference). To get rather a broad range of firmness, fruit was picked at least twice on different dates and stored under different conditions: normal atmosphere, CA and ULO conditions for various periods of time and then they left to ripen for up to 14 days at 18 °C.

The measurements were taken on the fruit with different degrees of hardness and ripeness: just after harvesting and during storage and ripening process. All the measurements were taken after the fruit reached 18 ^{o}C. For each test, a sample of at least 20 fruit was used. Fruit were numbered and the places for measurements were marked on two opposite sites at the largest circumference. Two measurements were taken on each fruit. The averages values from two results were taken for the calculations. The measurements were performed on the same fruit in the order of increasing destructivity: the apparent modulus of elasticity, coefficient of elasticity and firmness by MT. The first two methods were tested on the fruit with skin, whereas MT after skin removal. The measurements were taken on at least 750 fruit for each apple and pear cultivar in each of the seasons (Elstar and Jonagold were investigated for two seasons).

Measurements of the apparent modulus of elasticity (EI)

The measurement consisted in applying pressure to fruit with skin using a cylindrical probe with a flat end ∅ 6 mm (apples) or ∅ 4 mm (pears) until fruit's reactive force 4 N was achieved. The 10 N crosshead was used and the speed of 50mm/min. The fruit was supported by a standard Instron stainless steel support with a large concave surface (∅ 69 mm) and a hole in the middle (∅ 15.8 mm). During the measurements, fruit was held down by hand. Results were recorded in the force-deformation mode and the apparent modulus of elasticity was calculated as a tangent of the force toward deformation in the force range of 0.25-4 N. Results are expressed in megapascals.

Measurements of the coefficient of elasticity acc. to Fekete (F)

The measurements were taken using a hand held penetrometer. For the apples, a probe ∅ 6 mm was used, and for the pears ∅ 4 mm. During the experiment a force needed to press the probe into the fruit to a depth of 0.3 mm was recorded, and it was recalculated to the coefficient of elasticity according to the following formula given by Fekete and Felföldi [9]:

$$e_c = \sigma_z / z$$

where: σ_z - compressive stress that occurs at z deformation of the fruit, MPa; z - deformation of the fruit, mm.

Results are expressed in MPa mm^{-1}. All the measurements of the coefficient of elasticity were made by the same person to eliminate errors committed by the instrument operator.

The Magness-Taylor's destructive test (MT)

The investigation was carried out using a standard cylindrical probe with a convex tip ∅ 11 mm for the apples and ∅ 8 mm for the pears. The maximum force needed for pressing probes into the fruit flesh (after skin removal) to a depth of 8 mm was recorded as the MT value. The speed of the crosshead was 100 mm min^{-1}. The fruit was supported by a standard Instron stainless steel flat support and during the measurements fruit was held down by hand.

Statistical methods

Comparison of the tested methods for firmness measurement was made using the regression theory. The Magness-Taylor's method was used as a standard. Correlation coefficients (r) were calculated and regression parameters (a and b) for each cultivar and year of investigation were found assuming that between the methods investigated there is a linear relationship type $y = \alpha + \beta x$. To compare the methods, the hypothesis $H_0 : \beta = 1$, about the same precision and $H_0 ' : \alpha = 0$ about the same accuracy were tested. Regression coefficients (b) were compared together with constant values (a) for single cultivars and years. Significance of differences was estimated using the Student's "t" test at the level of 1%.

RESULTS AND DISCUSSION

Comparison of the Magness-Taylor with the coefficient of elasticity measurements acc. to Fekete and the apparent modulus of elasticity measurement

Statistical analysis of the results for whole apples population showed that the values of the elasticity coefficients were better correlated with the firmness measurements by the Magness-Taylor (MT) than the values of the apparent modulus of elasticity versus MT values. An exception was the Idared cultivar (Table 1). High correlation coefficient might be attributed to a broad range of firmness differentiated by using the material picked on different dates, stored under diversified storage conditions for variable periods of time. For the two apple cultivars investigated in two seasons (Elstar and Jonagold), the values of linear correlation coefficients were slightly higher in the second than in the first year. These two seasons differed in weather conditions which might have effected fruit texture parameters. There were large differences in the MT values, apparent modulus of elasticity and coefficient of elasticity of apples right after picking between the two years. Confirmation of this observation were statistically significant differences in the constant value (a) for both seasons. This means that even if the MT values were the same, the values

T a b l e 1. Correlation coefficient (r) and regression coefficient (b) for the comparison of the Magness-Taylor method versus the apparent modulus of elasticity (Instron) and the correlation of elasticity measurement acc. to Fekete for a new apple cultivars

Cultivar (source of variation)	Number of apples	MT x EI			MT x F		
		r	a	b	r	a	b
Elstar'95 (k_1)	804	0.543**	0.377	0.123	0.781**	1.270	0.206
Elstar'96 (k_2)	745	0.699**	0.634	0.102	0.855**	1.036	0.212
Jonagold'95 (k_3)	759	0.621**	0.310	0.176	0.688**	1.407	0.161
Jonagold'96 (k_4)	950	0.676**	0.707	0.103	0.835**	1.093	0.174
Gloster'96 (k_5)	948	0.709**	0.926	0.074	0.843**	0.906	0.139
Idared'95 (k_6)	761	0.751**	0.231	0.204	0.690**	1.497	0.101

** - significant at level 1%.

of the coefficient of elasticity (F) and the values of the apparent modulus of elasticity would be different. For example apples of Jonagold cv. in 1995 at 100 N firmness had the coefficient of the modulus of elasticity 3.08 MPa mm^{-1} and in 1996-2.89 MPa mm^{-1} based on the regression lines; for the firmness of 50 N, respectively, 2.26 MPa mm^{-1} and 2.00 MPa mm^{-1}. If the results obtained by one method of firmness measurement are recalculated into the results of the other, a few percentage errors are made.

Results of testing the hypothesis on the accuracy and precision of the methods investigated allow to conclude that the methods are neither equally accurate nor equally precise (Table 2). Therefore, in practice, one should accept that there is a correlation between the MT values and coefficient of elasticity (the Fekete's method) and express the results in units used in both methods.

Taking into account, the measurements of fruit firmness by the Fekete method are based on a different principle than the measurements of the MT values, it was interesting to investigate the relationship y = a + bx within different arbitrarily set classes of fruit firmness ac. to the MT values. The results for Elstar and Jonagold cvs were divided into classes in which values differed by 19.6 N (2 kG). In each class there were at least 100 results with an exception of a class 88.3 - 107.9 N (9 - 11 kG) that was less numerous. In the case of Elstar cv. this class was included into the lower class as there were only several results in it. The linear correlation coefficients between MT versus F were positive and significant in most cases at $\alpha = 0.01$. Only in the class 88.3 - 107.9 N, the correlation coefficient was not significant which might have resulted from a smaller number of results in this class. Taking into consideration that the values of correlation coefficients were rather small (in most cased did not exceed 0.500), we cannot say that there is a strict relation between both methods of firmness measurement at a

T a b l e 2. Testing hypothesis (MT x F and MT x EI)

Cultivar	t - Student values				df
	MT x F		MT x EI		
	$H_0: \beta = 1$	$H'_0: \alpha = 0$	$H_0: \beta = 1$	$H'_0: \alpha = 0$	
Elstar '95	136.3**	33.6**	131.0**	8.7**	802
Elstar '96	166.8**	38.5**	233.7**	28.9**	743
Jonagold '95	135.9**	35.7**	102.2**	6.0**	757
Jonagold '96	222.6**	46.9**	244.7**	30.7**	948
Gloster '96	299.1**	45.1**	389.5**	55.8**	946
Idared '95	236.4**	61.1**	122.5**	5.5**	777

**Explanation as in Table 1.

narrow range of firmness values. The difference between the middle values of the classes of 19.6 N corresponded to 0.33 MPa mm^{-1} and the repeatability of the measurement of the coefficient of elasticity was rather low. Maybe this was the reason why Fekete and Felföldi [9] were performing measurements on one fruit four to six times. It is then clear that the method of measurement of the coefficient of elasticity does not differentiate the investigated material to the same degree as the Magness-Taylor's pressure test. However, the method of Fekete may serve several purposes. Figure 1 shows a linear correlation between the MT values and the coefficient of elasticity values as average values for the investigated classes of fruit firmness. As shown the correlation calculated using the average values was very high (r = 0.958), which indicates that both methods may be used interchangeably, if the dynamics of changes in firmness during storage, i.e., the effect of storage atmosphere is a primary purpose of the experiment. The use of a non-destructive method allows the measurement to be made on the same material and to eliminate variability of the test material. Lower precision of the method is in this case compensated by elimination of errors due to sampling.

On the contrary, the results obtained by the MT and F method made on a single apple are not always correlated. The only exception was the Elstar cv. for which correlation coefficients in the sample of 25 apples were significant (above 0.600) in most treatments, if two measurements were made on a single apple. For Jonagold, Gloster and Idared cvs the correlation coefficients were in most cases insignificant, if a sample was 25 fruit. The results obtained confirm the information by Armstrong and Brown [3] and Galili and Baerdemaeker [11], that there is no correlation between the results obtained by a destructive method of firmness measurement and the method based on the measurement of the modulus of elasticity on a single fruit. Low values of the correlation coefficients might as well result from small differentiation of the test material within the investigated treatments (coefficients of variation V% in most cases did not exceed 10%). When a larger range of values is taken into consideration, i.e., by including the results for successive pickings, the correlation coefficients became significant, however dispersion of the results along the trend line was rather large.

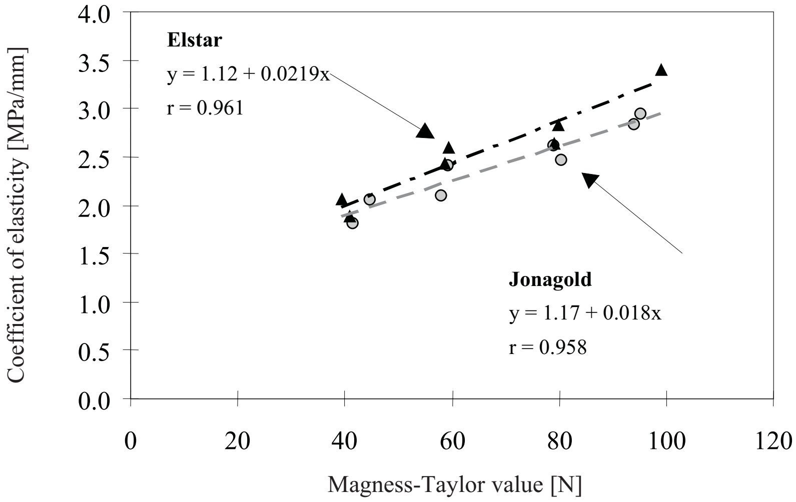

Fig. 1. Relation between the Magness-Taylor's values and the coefficients of elasticity (calculated on the average values for firmness classes).

Comparison of the Fekete's method based on coefficient of elasticity measurement with the method of the apparent modulus of elasticity measurement

Between the two methods there was a significant correlation. However, rather low correlation coefficients (r below 0.600) indicate that both of these methods cannot be used interchangeably. In principle, both methods are based on the measurement of elasticity of the material. The difference between the two is that in Fekete method the reaction of the material toward pressing into it a cylindrical probe to a predetermined depth is measured, whereas the force used depends on firmness of the material. The method of the apparent modulus of elasticity measurement is based on the measurement of a reaction of the material toward the specific force, whereas the deformation of the test sample under the force depends on the material elasticity. The method developed by Fekete is considered quasi non-destructive. During the measurement some cells may break down which is manifested by tissue browning [10]. Maybe this is the reason why the results obtained by the Fekete's method correlate with Magness-Taylor pressure test better than the method of the modulus of elasticity determination in which no destruction of tissue occurs (under specified conditions).

Summarising the above, it may be said, that the method of the coefficient of the elasticity determination is not suitable for the estimation of the degree of ripeness of a single apple, but may be used in the cases when the aim of the experiment is investigation of the effect of the specific treatment on the apple firmness.

Comparison of the investigated methods on pears

For pears similarly as for apples, correlation coefficients between the MT and Fekete's method were higher than between the MT method and the method of the apparent modulus of elasticity measurement (Table 3). Correlation coefficient for the MT versus F method calculated for the whole population of pears cv. Alexander Lucas was above 0.800 and for the Conference above 0.700. For the fruit of both cultivars just after picking it was shown that the correlation coefficients between the Magness-Taylor's pressure test and the quasi non-destructive method of Fekete's were very low (about 0.300). It may then be concluded that between both methods there is no strict relation. Distribution of data in Fig. 2 (the results as average values for the treatments) indicates that the fruit stored for three months at $0\,^{o}C$ behaved as if they were from other population. Their parameters were similar to freshly picked fruit. Interpreting this relation, one has to take into consideration that the method of Fekete relies on the measurement of elasticity of the material whereas pears investigated in December were still very hard and did not deform proportionally to the force used. This partly explains why, for freshly picked pears (very hard) and for pears stored for a few weeks, correlation coefficients were rather low. There was a linear correlation

T a b l e 3. Correlation coefficients (r) and regression coefficients (b) for pears resulting from the comparison of the Magness-Taylor's pressure values with the apparent modulus of elasticity (Instron) and the coefficient of elasticity values acc. to the Fekete's method

Cultivar (source of variation)	Number of pears	MT x EI			MT x F		
		r	a	b	r	a	b
Alexander Lucas	777	0.798**	0.619	0.206	0.866**	0.905	0.803
Conference	756	0.699**	0.612	0.129	0.713**	1.288	0.474

**Explanation as in Table 1.

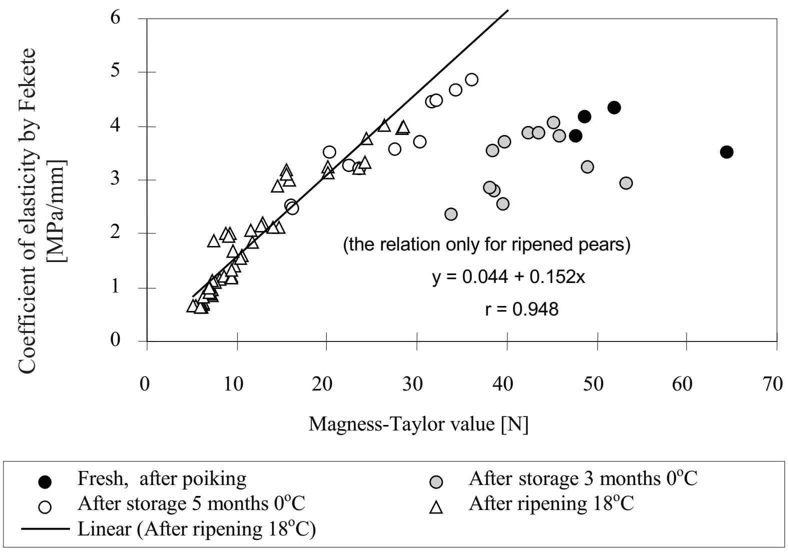

Fig. 2. Relation between the Magness-Taylor values and the coefficients of elasticity for pears (both cultivars).

between the two methods only in the range of the Magness-Taylor values between 5 and 20 N for the Conference cv. and between 5 and 30 N for the Alexander Lucas.

The data obtained allow to conclude that the Fekete's quasi non-destructive instrument may be used in the estimation of pears firmness during the softening stage of ripeness, but not wilted.

CONCLUSIONS

It was found out that the Magness-Taylor punch test and the method developed by Fekete (measurement of coefficient of elasticity) are neither equally accurate nor equally precise. The Fekete's method is characterised by the lower discrimination ability compared to the MT method. A highly significant correlation coefficient between the Magness-Taylor's method and the Fekete's method calculated for a large population of apples as well as the average values from the storage treatments indicate that there is a theoretical possibility of transposing results obtained by one method to the results obtained by the other method.

The method based on the determination of the coefficient of elasticity and the method of determination of the apparent modulus of elasticity as used in the experiments are not suitable for the estimation of the degree of ripeness of individual apples, but may be used in those cases when the aim of the experiment is estimation of the effect of storage treatment on fruit firmness.

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