DETERMINATION OF THE RELAXATION PERIOD AT STATIC COMPRESSION OF GOLDEN DELICIOS APPLES VARIETY
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DETERMINAREA PERIOADEI DE RELAXARE LA COMPRESIUNEA STATICĂ A MERELOR DIN SOIUL GOLDEN DELICIOS

Ph.D.Eng. Veringă D.[1)], Ph.D.Eng. Vintilă M.[1)], Ph.D.Eng. Popa L.[2)], Phd.Eng.Ştefan V.[2)], Phd.Eng.Petcu A.S.[2)]
[1)] I.C.D.I.M.P.H. – HORTING Bucharest / Romania; [2)] INMA Bucharest / Romania
Tel: 0745 148.071; E-mail: veringa.daniela@yahoo.com

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ABSTRACT
The paper presents the Golden Delicious apples experimental researches, that aimed to emphasize apples behaviour at mechanical static or quasi-static compression stress and mechanical and rheological characteristics of fruits correlated to deficiencies determined (contusions, form distorsion), in order to anticipate their conduct in different practical situations.

REZUMAT
Lucrarea prezintă cercetările experimentale efectuate pe soiul de mere Golden Delicious care au urmărit să pună în evidenţă comportarea lor la solicitările mecanice de compresiune statică sau cvasistatică şi caracteristicile mecanice şi reologice ale fructelor în corelaţie cu defectele cauzate (contuzii, distorsionări ale formei), pentru a le putea anticipa în diferite situații practice

INTRODUCTION
During the long term storage the compression stress of apples located in the package bottom rows in boxes or containers should not be neglected, especially when the packages are not appropriate, determining the fruits defects, especially geometrical shape modifications (visible changes), which make them non marketable, thus leading to losses *(Ghergi A., Iordăchescu C., Burzo I., 1979; Gherghi A., 1994)*.

Experimental researches performed aimed to emphasize the Golden Delicious apple behaviour at mechanical static or quasi-static compression stress and rheological characteristics of fruits correlated to deficiencies (contusions, form modifications) determined in order to anticipate their conduct in different practical situations *(Abbott J.A., Lu R.,1996; Amir H., et al, 2008; Roudot A.C, 1991)*.

The apple compression resistance has determined as bio-flowing compression force and appropriate deformation and, at the same time, the specific hysteresis energy per cycle when loading-unloading, elasticity level (respectively plasticity level) to compression, Mayer hardness test (a measure of structure and tissue hardness) completed by resistance to penetration of a cylindrical rod and a suitable cone of shearing strain limit of flow (τ_c) of epicarp-pulp of whole fruits *(Căsăndroiu T., Ivănescu D., Vintilă M., 2009; Căsăndroiu T., Ivănescu D., 2009)* have found out.

It has aimed to find the rheological behaviour at compression between plane parallel rigid surfaces and a cylindrical punch, at constant load, followed by total unloading of fresh Golden Delicious apples, after harvesting *(ASAE recommendation, 1979)*.

MATERIAL AND METHOD
In order to perform the compression tests, The Golden Delicious apples were used, the fruits being grouped by three in each ripening class and coded as: A_1, A_2, A_3 representing the green apples; A_4, A_5, A_6 represent average ripe level apples and A_7, A_8, A_9 represent mature apples.

It has aimed to choose geoid shape fruits to be as close as possible to the spherical shape. Before being subjected to compression, the fruits were weighed, and their geometrical dimensions and radius of spherical surfaces in contact points with stress surfaces (by means of spherical shape meter) were measured, being shown in tab.1.

Table 1

Physical characteristics of fruits studied

Code	Ripe level	Mass m [g]	Height H [mm]	Equatorial Diam. D_e [mm]		Point 1	Point 2
				$D_{e\ max}$	$D_{e\ min}$	R_1 [mm]	R_2 [mm]
A1	green	140.3	66.54	71.13	65.47	41.76	48.46
A2		154.3	72.8	71.24	65.5	38.20	35.85
A3		153.1	68.41	70.32	66.63	42.26	44.40
A4	average	146.8	68.79	70.45	66.28	30.60	39.72
A5		145.8	67.58	72.87	69.68	33.66	38.62
A6		149.1	66.70	71.79	68.60	39.79	32.87
A7	ripe	177.3	71.75	74.49	71.18	31.84	39.53
A8		142.9	64.62	69.69	68.34	28.25	28.05
A9		154.4	75.80	69.53	67.67	34.72	39.05

Fruits were subjected to compression at a load rating between plane parallel rigid plates, using the universal apparatus of mechanical tests Hounsfield H25 KT.

After the compression, it aimed to test the firmness of fruit texture, sometimes called texture ‚rigidity" by using the method named « method of Magnes –Taylor pressing test", measuring the pressing force of a cylindrical rod calibrated of Φ 11.1 mm that penetrates into the fruit pulp to a certain depth, named ,,penetration resistance". Measurements were made with the Penetrometer FT 327 with a precision of 0.01 mm *(Manual of penetrometer presentation)*.

The fruit pulp texture resistance was determined in 12 points of each fruit, 4 points on every diameter (equatorial, apical and peduncle), according to fig. 1, in tab.2 being shown the data for the average penetration resistance between the 4 points on equatorial diameter.

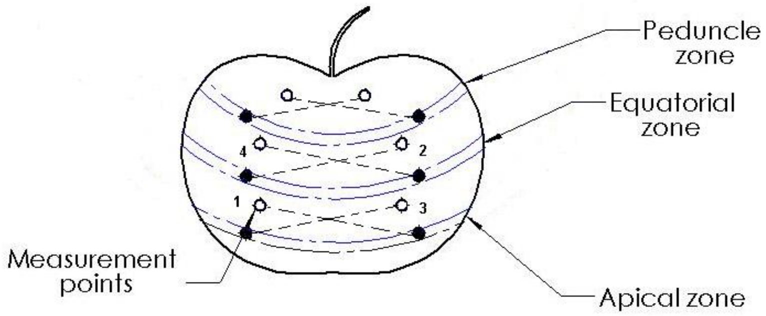
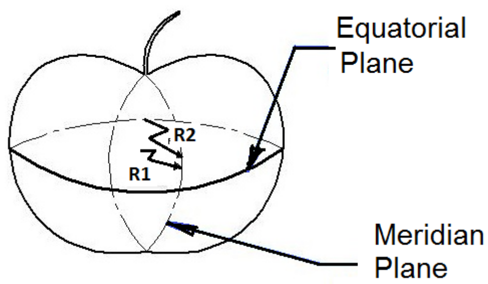


Fig.1 - Areas on fruit surface and points of measuring the penetration resistance



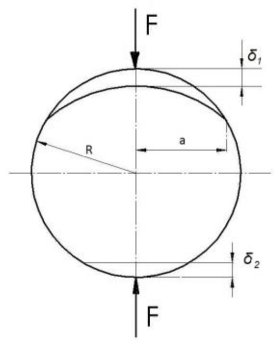


Fig.2 - Representation of radius measured in two plans **Fig.3 - Scheme for calculating the radius mark**

There were calculated the elasticity module Young, E corresponding to bio-flow point and maximum normal tension $\sigma_{c\ max}$ of bio-flow, using the relations from the theory of elastic contact Hertz *(Mohsenin M. N., 1986)*, ec. (1):

$$E = 0{,}749\frac{F\left(1-\upsilon^2\right)}{\delta^{3/2}}\left(\frac{1}{R_1^{1/3}}+\frac{1}{R_2^{1/3}}\right)^{3/2} \tag{1}$$

For the apples, it was considered υ=0,35; R_1 and R_2 representing the radius of curvature between the two contact points (fig.2), *δ* represents the total deformation (according to table 2), and *F* representing the force corresponding to bio-flow point (F_1 according to table 1).

After performing the calculations, the values from table 2 resulted.

Bio-flow tension was calculated by relation (2), where it represents the radius of track, in compliance with fig.3 *(Mohsenin M. N., 1986)*:

$$\sigma_c = \frac{3}{2}\frac{F}{\pi a^2} \tag{2}$$

RESULTS

Based on data obtained in tests one has aimed to research the possibility of establishing the correlations between the mechanical values measured and their compliance with the theoretical relations proposed for achieving the calculations.

After performing the compression tests with the apparatus Hounsfield H25 KT at 5 mm/min speed, using the cell of 1000 N, by processing the data gathered with Hounsfield Microsoft Windows Based program, graphics with force-deformation curves were obtained, from which were extracted the force and deformation values corresponding to the bio-flow point. These bio-flow point values are presented in table1.

From graphics and tables was extracted the value of force (F_1) corresponding to point C of bio-flow, displacement (total deformation up to bio-flow point) and slope corresponding to bio-flow point (table 2) and Figures 5-13 representing the force-deformation curve for each apple.

Data obtained from tests designed to determining fruit pulp texture resistance with Penetrometer FT 327 are given in table 3.

Table 2

Characteristics corresponding to bio-flow point (Hounsfield apparatus)

Code	Force F_1 [N]	Displacement (deformation) δ [mm]	Slope [N/mm]
A1	119.3	4.176	28.48
A2	64.0	2.616	24.43
A3	78.0	2.632	29.51
A4	42.0	2.120	19.69
A5	63.6	4.128	16.85
A6	120.4	5.300	22.72
A7	75.5	3.224	23.37
A8	35.0	2.392	14.60
A9	77.3	3.192	24.22

Noticing from graphics made by Hounsfield apparatus that deformation is delayed by certain quota, the correction of deformation δ, given in table 2 was made, using it in calculations

Table 3

Data of equatorial area referring to la R_{pmed}, E, E_{med}, σ_c, σ_{cmed}

Fruit	Force F [N]	Deformation δ corrected [mm]	$R_{p\,med}$ [N]	R_{pmed} [N]	E [Pa]	E_{med} [Pa]	σ_c [Pa]	σ_{cmed} [Pa]
A1	119.3	3.976	44.145	44.73	$4.19 \cdot 10^6$	$5.426 \cdot 10^6$	$0.352 \cdot 10^6$	$0{,}374 \cdot 10^6$
A2	64.0	2.276	44.120		$5.72 \cdot 10^6$		$0.381 \cdot 10^6$	
A3	78.0	2.292	45.910		$6.37 \cdot 10^6$		$0.390 \cdot 10^6$	
A4	42.0	1.720	47.995	42.66	$5.89 \cdot 10^6$	$4.56 \cdot 10^6$	$0.387 \cdot 10^6$	$0.34 \cdot 10^6$
A5	69.6	3.858	37.817		$2.85 \cdot 10^6$		$0.264 \cdot 10^6$	
A6	120.4	4.900	42.158		$3.44 \cdot 10^6$		$0.371 \cdot 10^6$	
A7	75.5	2.954	45.224	42.31	$4.66 \cdot 10^6$	$4.15 \cdot 10^6$	$0.393 \cdot 10^6$	$0.31 \cdot 10^6$
A8	35.0	2.052	39.534		$4.19 \cdot 10^6$		$0.296 \cdot 10^6$	
A9	77.3	2.792	42.183		$5.1 \cdot 10^6$		$0.389 \cdot 10^6$	

Graphically representing penetration resistance depending on the elasticity module in bio-flow point and penetration resistance depending on bio-flow resistance, the following graphics were obtained, fig. 4

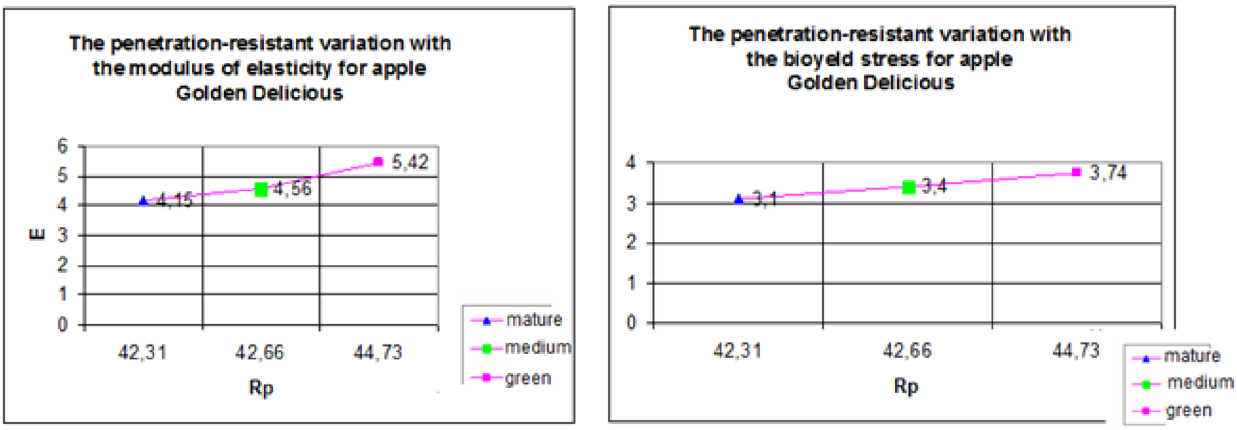


Fig.4 - Correlations (E, Rp) and (σc, Rp) for 3 degrees of ripening of Golden Delicious apple variety

From fig.4 it can observe that the correlations (E, R_p) and (σ_c, R_p), for Golden Delicious apple variety can be put in correlation with the apples ripeness.

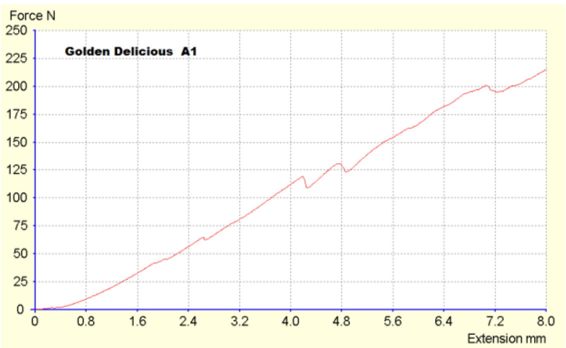


Fig.5 - Variation force - deformation for Delicious A1

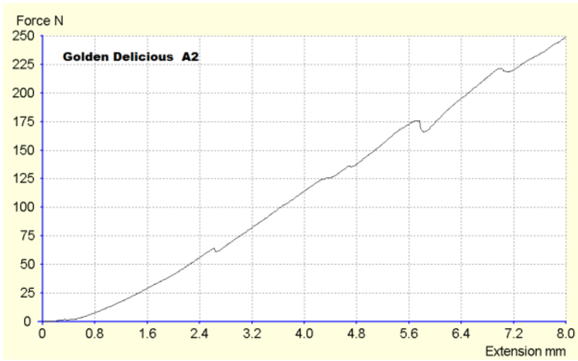


Fig.6 - Variation force - deformation for Delicious A2

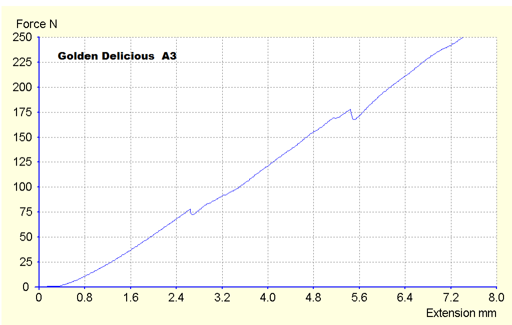


Fig.7 - Variation force – deformation for Delicious A3

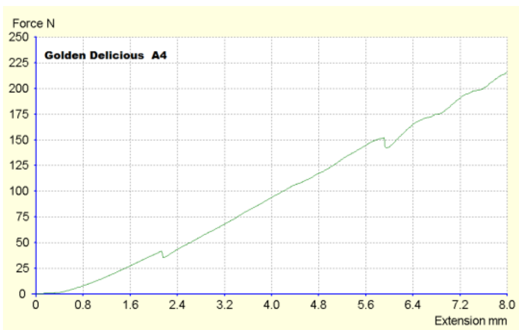


Fig.8 - Variation force – deformation for Delicious A4

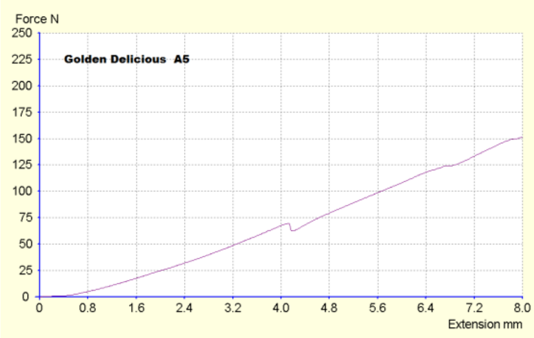


Fig.9 - Variation force – deformation for Delicious A5

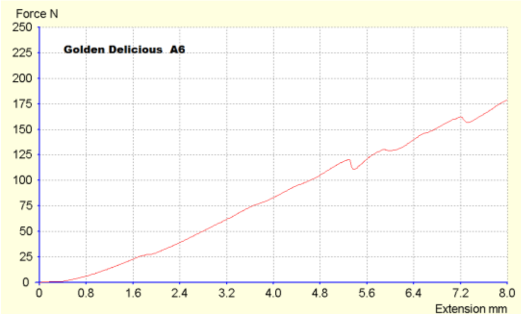


Fig.10 - Variation force – deformation for Delicious A6

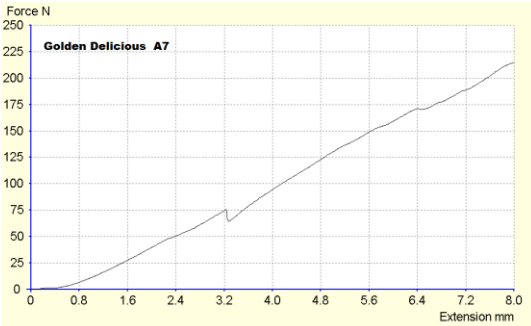


Fig.11 - Variation force–deformation for Delicious A7

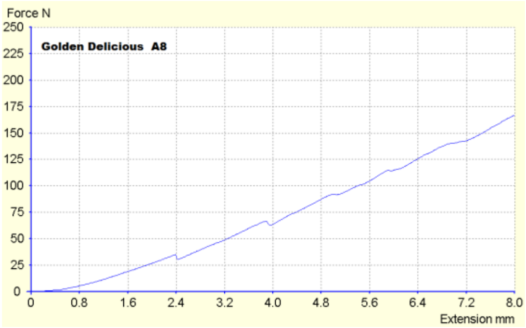


Fig.12 - Variation force–deformation for Delicious A8

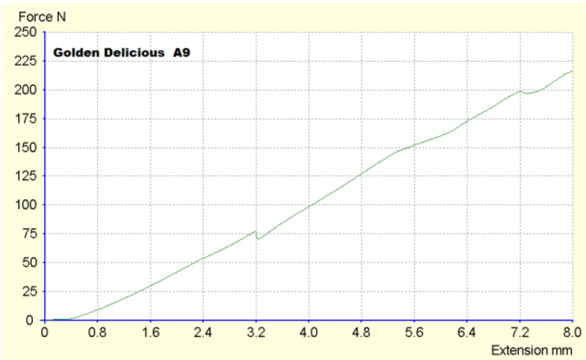


Fig.13-Variation force-deformation for Delicious A9

CONCLUSIONS

Following the analysis of apple varieties existing in Romania, we have oriented towards the Golden Delicious study, because this variety is most demanded by market and presents technological features for a long storage period.

Losses and damages appearing during apples conservation are caused by static and quasi-static stress as well as, metabolic processes and diseases.

Considering the fruit as a viscous-elastic body, knowing the rheological parameters such as elasticity modules, viscosity parameters, relaxing time etc. allows to anticipate the fruit behaviour when is subjected to mechanical strain.

Experimental researches performed aimed to emphasize the apples behaviour at static and quasi-static compression and their mechanical characteristics related to their faults (contusions, modifications of shape) in order to anticipate their conduct in different practical situations.

The compression resistance was determined as bio-flow force and related deformation, between two plane parallel plates, the elasticity module Young and penetration resistance, a measure of firmness.

Elasticity module and penetration resistance, as well as bio-flow tension may be put into correlation with ripening level of Golden Delicious apples (these values increasing along with apple ripening degree).

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