THEORETICAL AND EXPERIMENTAL ASPECTS OF MODELING RESPONSE TO COMPRESSION STATIC LOADS OF APPLES

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This paper presents an experimental method to determine the apples relaxation time at static compression, maintaining their integrity. The theoretical bases of the method have been highlighted, using the yield test by considering the linear viscoelastic behavior of the descripted bodies as a rheological physical model described by the Burgers model. It has been found a mathematical model and the corresponding rheological equation which describes the behaviour of the apples at constant static loading. We present the experimental results for three local apple varieties: Idared, Jonathan, Golden Delicious and the testing of mathematical model of rheological behavior with experimental data. This information is useful in assessing the storage life of the known high packing imposing the distortion coefficient of geometric shape β or if required storage time, it may be determined the corresponding height of the boxes for storage.

Keyword: apples, relaxation period, creep, storaje time

1. Introduction

After harvest, by filling the various types of containers and packages with apples followed by short or long-term storage, the value and quality of apples are greatly reduced both by mechanical crushing injury (contusion) of flesh tissue, as well as by strains and errors from the geometric form feature.

Apples cellular tissue damage through contusion and the remanent visible strains with geometric shape modification, contribute to the loss of quality, and therefore is leading to the decrease of the commercial value of the fresh apples, [1,2,3].

The research previously performed shown that losses may exceed 10-12% of the quantity stored [1,4], if action is not taken in particular by appropriate choice of the packaging used to different varieties of apples, and in correlation with the duration of storage.

Thus the height of packaging used (particularly useful height) must not exceed certain limits which produce damages of fruits from the lower ranks, affecting thus the quality and the class of apples, [1,2,3]. These limits depend on

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the variety of apple and of ripening stage characterized by a mechanical property which may be a measure of the stiffness (firmness) characteristics of fruits pulp.

The limitation and even avoidance the defects of mechanical nature and/or geometric shape distortion can be made only by knowing the mechanical characteristics and the behaviour at various types of mechanical loading of apples. Based on these, one can make useful recommendations in designing and proper choice of the pack depending by: fruits category, ripeness level, the duration and storage conditions. Therefore, there is a preoccupation to carry out several theoretical and experimental research referring to these properties and at behaviour at different types of fruits mechanical loading, of the correlations of those with cellular tissue structure and the chemical composition, [1].

At the beginning, the studies were conducted considering the fruit as homogeneous and isotropic materials with linear elastic behaviour. Mathematical models have been developed referring to contact stress, strain and footprint size at the action of a compressive forces based on the theory of Hertz elastic contact in order to assess fruits mechanical injury through contusions cellular tissues, [1, 6, 7, 8].

These have allowed the development of adequate mathematical models concurring with reality and based on which to provide, in specific conditions, either the mechanical damage caused by storage in certain packages, or requiring the maximum level of injury or of defects related to the deviations from the geometric shape to design or to select the corresponding adequate packaging, [1, 2, 3, 6].

Research has been initiated in this sense in our country the results of these trials being contained in papers [6, 9].

Lately, research has been performed by considering the fruits as inhomogeneous and anisotropic materials with viscoelastic behavior - condition closer to the real behavior of fruits, [1, 5, 10,11].

On that basis, standard methodologies were developed for compression testing and for determining the mechanical characteristics (Young's modulus, strain modulus, force – deformation (strain) curve, point break, maximum stress), of apples, [8].

In this context, the objective of the paper is represented by development of a mathematical model for the description of static compression behavior of apples considered as linear viscoelastic material - Burgers model, and application of the results obtained to forecasting the packages height to ensure the avoidance of injury for some storage durations.

2. Theoretical aspects

Tests concerning the behavior at compressive stresses of apples have shown, through force-deformation curves the time effect of force and deformation velocity application, proving the effect of time it is a practical importance for the creep case of fruits under static load, [1,12].

Fruits are biological materials and they do not react to stress, in a pure elastic manner, their reaction combining an elastic and a viscous component.

In the experimental tests, the specimens were cylindrical, drawn from the pulp of the fruit, placed between two flat plates and loaded, usually, below the bioflow point.

When handling of bulk and the high stack for storage, when fruits are subject to static load for a period of huge time, deformation and injury can appear at pressure, far below those required at normal compression test.

To get more details about creep (deformation) of fruits, a technique has been developed so that the continuous deformation under static load can be automatically recorded over time, [1,12].

One tried to find a mechanical model and the appropriate rheological equation which match with experimental creep curve, similar to that of fig. 1(b) by considering the Burgers model (fig. 1 (a)), where deformation - time curves obtained by this model are similar. Accordingly, one can appreciate that this curve simulates the behavior of apple fruit under static load.

In the scientific literature, it is known the stage differential equation in terms stress-strain relationship of this model, which requires performing the tests on samples taken from apple pulp a technique laborious and difficult to achieve. Since in the compressive test the entire apples were placed between two flat plates, deformation – time curves were developed with the same curve profile from fig. 1 (b); it can be concluded that this curve can be described by a Burgers model, fig. 2, [9,12]. This new type of model was obtained from the classical model by replacing: $\varepsilon \rightarrow \delta$, $\sigma \rightarrow F$, $E \rightarrow K$, $\eta \rightarrow \eta^*$, as one can pursue in fig. 2.

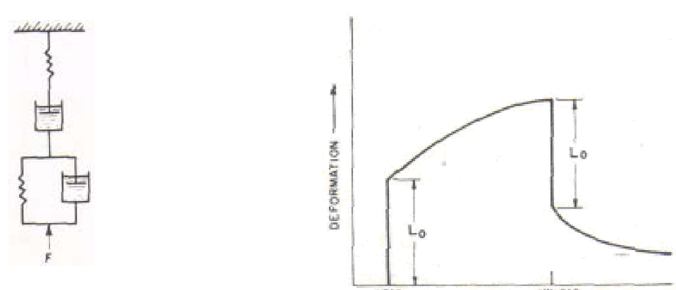


Fig. 1 The physical model Burgers (a) and deformation - time curve of this (b), [12]

Corresponding experimental tests have the advantage that they can perform more comfortably maintaining the integrity of the fruit.

In order to find the rheological equation corresponding to the behavior of apple at static compressive loads, according to the physical Burgers model, one can note that the status equations corresponding to ideal elements under the new conditions become:

- for the ideal elastic element, Hooke:

$$F = K\delta \quad (1)$$

- for the ideal viscous element, Newton

$$F = \eta^{*}\dot{\delta} \quad (2)$$

where δ is deformation; K- elastic component rigidity [N/m]; η^{*}- similar sized viscosity for ideal viscous element [Ns/m];

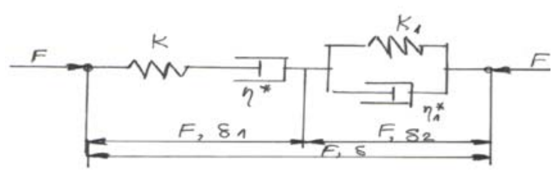


Fig. 2. Physical model type Burgers to describe behavior in compression of whole melon baller

With these notations, the relaxation time T_r and the elasticity time delayed T_i become:

$$T_r = \frac{\eta^{*}}{K} \quad (3)$$

$$T_i = \frac{\eta_1^{*}}{K_1} \quad (4)$$

As one knows, Burgers model is obtained from the Kelvin-Voigt, Maxwell model in series, fig.2. Admitting the Newtonian law of viscosity device damping and arch Hooke's law, the equations governing the behavior of the model are:

- for Maxwell model:

$$\dot{F} + \frac{F}{T_r} = K\dot{\delta} \quad (5)$$

where $T_r = \eta^{*}/K$

- for Kelvin-Voigt model:

$$\dot{\delta} + \frac{\delta}{T_i} = \frac{1}{\eta^{*}}F \quad (6)$$

where $T_i = \frac{\eta^{*}}{K}$

Body represented by the Burgers type model, subject to the action of a constant force compressive, $F = F_0$ = const., will likely result strain in time which will be produced, according to the principle of effects overlay, according to equation:

$$\delta = \frac{F_0}{K} + \frac{F_0}{\eta^*} t + \frac{F_0}{K_1}\left(1 - e^{-\frac{t}{T_i}}\right) \tag{7}$$

If after a period t_1, maintaining a constant force F_0, in which is produced a deformation $\delta(t_1)$ (this is obtained from eq. (7) replacing $t = t_1$), total unloading takes place by the removal of the force F_0, a delayed elastic recovery appears, according to the equation:

$$\delta = \frac{F_0}{K}\left(1 - e^{-\frac{t_1}{T_i}}\right) e^{-\frac{t}{T_i}} + \frac{F_0}{\eta^*} t_1 \tag{8}$$

where t is the time when the force F_0 is eliminated .

In this equation, by making $t \to \infty$ one obtains:

$$\delta = \delta_1 = \frac{F_0}{\eta^*} t_1 = \frac{F_0}{K T_r} t_1 \tag{9}$$

that represents the element deformation response which remains after removing the body of constant force F_0 during t_1.

Note that one can also solve this issue of the general differential equation for the Burgers body, by eliminating the partial deformations δ_1 and δ_2 from the eq. (5) and (6) for Maxwell and Kelvin bodies, of body composition of the Burgers, considering that $\delta_1 + \delta_2 = \delta$, obtaining:

$$T_i \ddot{\delta} + \delta = \frac{T_i}{K_1} \ddot{F} + \left(\frac{1}{K_1} + \frac{T_i}{T_r K_1} + \frac{1}{K_2}\right) \dot{F} + \frac{1}{K_1 T_r} F \tag{10}$$

For the creep tes, when $F = F_0$ =const., one replaces in eq. (10), obtaining:

$$T_i \ddot{\delta} + \delta = \frac{1}{K_1 T_r} F_0 \qquad t = 0, \quad \delta = \frac{F_0}{K} \tag{11}$$

The solution for eq. (11) after considering initial conditions is:

$$\delta = \frac{F_0}{K} + \frac{F_0}{\eta^*} t + \frac{F_0}{K_1}\left(1 - e^{-\frac{t}{T_i}}\right) \tag{12}$$

the same expression as eq. (7), used to represent the variation of the elastic deformation delayed produced by the constant force $F = F_0$ during $t = t_1$.

After experimental marking for deformation time curve for a known constant force $F=F_0$=const., one should test the agreement of equations (12) with experimental data, equation being arranged in the form:

$$\delta = Y = a - b e^{-ct} + dt \tag{13}$$

where: $a = \frac{F_0}{K} + \frac{F_0}{K_1}$; $b = \frac{F_0}{K_1}$; $c = \frac{1}{T_i}$; $d = \frac{F_0}{\eta^*}$

The coefficients a, b, c, d are obtained from the nonlinear regression equation type (13) with experimental data, using a special computer program for experimental data processing.

Having the coefficients a, b, c, d, using the notations (13), dimensions value K, K_1, η^*, η_1^*, T_i and T_r are determined. These values are useful in evaluation of residual strain

$$\delta_r = \frac{F_0}{\eta^*} t_1 = \frac{F_0}{KT_r} t_1$$

which enables, either storage period evaluation t_1, as not to exceed the dimensions imposed on δ_r, or evaluation of compression force F_0, for a time t_1 imposed and a allowed residual strain δ_r, needed to assess storage container height.

The significance of the K and η * in our consideration, is:

$$K = \frac{A}{l_0} E \quad and \quad \eta^* = \frac{A}{l_0} \eta \tag{14}$$

Thus, from consideration force-deformation Burgers model, one obtains that T_r and T_i have the same meaning from consideration stress-strain concerning Burgers model:

$$\frac{\eta^*}{K} = \frac{\eta}{E} = T_r \quad \text{and} \quad \frac{\eta^*}{K} = \frac{\eta}{E} = T_i \quad \text{meaning } T_r \text{ and } T_î \tag{15}$$

As shown in [6], the distortion coefficient of the geometric shape $\beta = \frac{\delta_r}{2R}$

has been defined, and then, using equation (9) one found:

$$\delta_r = \frac{F_0}{K\ T_r} t_1 = 2\beta R \qquad \text{from which } t_1 = \frac{2\beta RK\ T_r}{F_0}, \tag{16}$$

where R is equatorial radius of apple.

Using relation (16) the apples storage time t_1 shall be assessed for known height packings (which allows the measurement of compressive force F_0 on the last row of fruit) imposing itself the distortion coefficient of the the geometric shape β. If one imposes the storage time t_1, height of storage crates can be determined.

3. Material, method and equipments

3.1Materials

To perform the experiments regarding the determining of relaxation duration at compressive static loading, three varieties were chosen: Jonathan (old and traditional variety), Golden Delicious and Idared, varieties provided for future development strategy of cultivating apples in our country

The samples of apples intended for experiments were harvested by hand in September 2011 in full ripeness phase of the Research-Development Institute for Zoology of Piteşti-Mărăcineni, Argeş. The samples contained fruits of different sizes, randomly selected from each variety, with a shape close to spherical. To perform experiments, apples were kept in the refrigerated cell at a temperature of 3-4° C and a relative humidity of 80-85%.

Before carrying out the experiments, the fruits have been removed from the cell and held in the laboratory at room temperature for at least 4-5 hours to take the environmental temperature.

3.2 Description of the equipment

In order to perform the apples yield tests at compressive static loading to test Eq. (7) put in the form of Eq. (13) with experimental data and the determination of the characteristics of the Burgers model fig. 2, (K1, K, Ti, η, Tr), the device whose layout is shown in fig. 3a was designed and manufactured. In fig 3 (b), (c) is presented the device ready for measurements. In accordance with the test procedure the apple is subjected to compressive static loading by pressing, with a constant load, either a flat rigid plate fig.3(b) or another half apple fig. 3(c) and the strain is measured using a dial indicator gauge, at different moments of time from the beginning of loading.

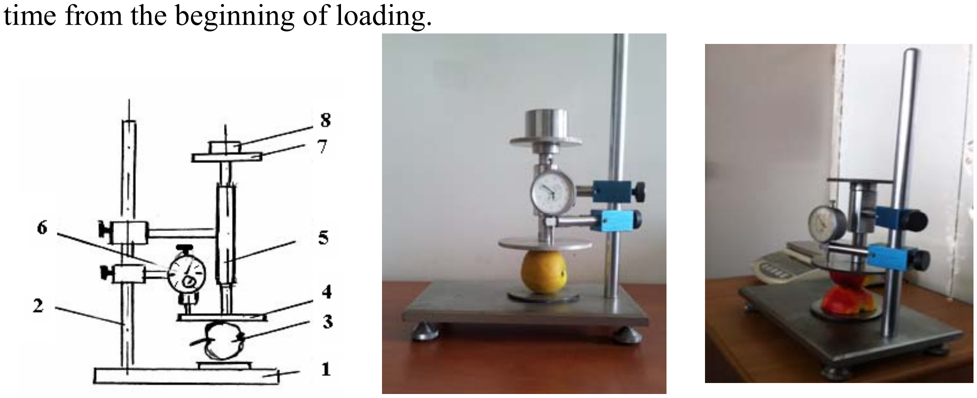


Fig. 3 Schematic device for testing the compression creep of apples 1-base plate; 2-stand; 3-apple 4- rigid plate of pressing; 5- guides; 6- comparator gauge; 7- pan; 8- task of loading

3.3 Experimental procedure

Before each test the apples were measured, in particular the equatorial diameters with a digital calliper with 0.02 mm accuracy.

Experiments have been carried out in two versions according to fig. 3 (b) and fig. 3 (c). For the version in figure 3 (b) the entire apples were used and for the version in fig. 3 (c) the apple has been sectioned by an axial plane (using a sharp knife with rigid blade) and one half was fixed on the surface of the device. The top pan was loaded with weights corresponding to three constant forces (F = 12,5 N; F = 15 N and F = 17,5 N). The rigid plate has been brought into contact with the apple surface and the rod pan has been freed to achieve compressive crushing stress.

Displacement δ (t) was measured using a dial indicator gauge with 0.01 mm accuracy, at different moments of time measured in seconds from the beginning of the load, thus, the first 10 readouts at 15 seconds, the following 5 readouts at 30 seconds, then, 5 readouts at 1 minute, followed by other 5 readouts at 5 minutes, then five readouts at 10 minutes, and finally 5 readouts at 15 minutes, that required a period of 2.5 hours for each experiment. 35 readouts have been performed, i.e. 35 values were obtained.

4. Results and discussion

Compressive creep experiments have been carried out with three varieties of apples: Idared, Golden Delicious and Jonathan at pressure loads of 12.5 N, 15N, 17.5N for those two diagrams, apple between flat surfaces(fig. 3b) and apple on apple (fig.3c). The displacements δ have been measured for various times, as mentioned above. The data obtained are presented selectively for 18 readings of the 35 of the experiments and for each variety of apples in Tab.1, Tab.2 and Tab.3.

Using the program Microcal Origin data obtained from experimentations were processed and presented in three tables, by testing eq. (13) for creep phase of non-linear regression with experimental data. Then, the values of characteristics elements of the Burgers model which appear in eq. (7), which describes the rheological behavior of the compressive apples were determined.

The values of the coefficients a, b, c, d from eq. (13) together with the correlation coefficient R^2 appropriate for all situations contained in these three tables are shown in table 4, and the values of characteristics elements from Burgers model representing the rheological behavior of apples, are shown in table 5. Noting the values of correlation coefficients R^2, from tab.4, for all experimental situations (the 3 values of the compressive forces, the 3 varieties of apples and the loading between the compressive rigid plates and the loading between fruits) one can note that, testing eq. (13) with experimental data, the correlation coefficients R^2 are higher than 0.989, which proves a good description of the rheological behavior at compressive, by a model similar to the model Burgers (fig.2), whose status equation (10), with the solution given by eq. (7) and represented by the general model expressed in eq. (13).

The values of the coefficients a, b, c, d from table 4, based on eq. (13), allow to calculate the values of the characteristics model, where K, T_r, are useful in evaluating the duration of apples storage (eq. (16)) for the type of packaging used and a allowable value for residual deformation of the fruits - coefficient β of geometric shape distortion.

The very good level of agreement given by eq. (13) with experimental data, can be noted in fig. 4(a, b), fig. 5 (a, b) and fig. 6 (a, b) where the corresponding curves from eq. (13) have been represented and compared with experimental data for 6 situations selected of the 18 ones referred in data from Table 1, Table 2 and Table 3.

Table 1

Experimental data for the creep test at compression loading at force F = 12,5 N, for 3 apples varieties, (deformation δ (t) at different intervals of time t - selective data)

Time[s]	Idared		Jonathan		Golden Delicious	
	δ [mm] apple between plates	δ [mm] apple/apple	δ [mm] apple between plates	δ [mm] apple/apple	δ [mm] apple between plates	δ [mm] apple/apple
15	0,507	0,525	0,528	0,579	0,562	0,656
45	0,564	0,585	0,560	0,635	0,687	0,779
75	0,586	0,618	0,578	0,67	0,741	0,85
105	0,605	0,653	0,590	0,69	0,784	0,897
135	0,616	0,673	0,599	0,701	0,826	0,933
180	0,629	0,696	0,608	0,724	0,863	0,975
240	0,644	0,718	0,620	0,741	0,907	1,02
300	0,652	0,733	0,629	0,759	0,935	1,056
420	0,666	0,76	0,641	0,78	0,974	1,107
540	0,673	0,779	0,657	0,795	1,024	1,148
900	0,678	0,809	0,687	0,821	1,146	1,236
1500	0,685	0,837	0,729	0,8405	1,285	1,319
2100	0,689	0,853	0,758	0,852	1,372	1,37
3300	0,693	0,885	0,806	0,881	1,502	1,438
4500	0,696	0,9125	0,850	0,899	1,562	1,47
6000	0,714	0,95	0,891	0,928	1,604	1,537
7800	0,730	0,993	0,933	0,959	1,655	1,568
9600	0,754	1,031	0,972	0,999	1,706	1,602

Table 2

Idem tab.1 for compressive loading for the constant force F=15N

Time [s]	Idared		Jonathan		Golden Delicious	
	δ [mm] apple between plates	δ [mm] apple/apple	δ [mm] apple between plates	δ [mm] apple/ apple	δ [mm] apple between plates	δ [mm] apple/ apple
15	0,599	0,766	0,580	0,615	0,681	0,87
45	0,659	0,829	0,630	0,691	0,763	0,971
75	0,679	0,861	0,658	0,73	0,811	1,022
105	0,697	0,881	0,674	0,754	0,841	1,061
135	0,710	0,899	0,682	0,774	0,863	1,091
180	0,736	0,921	0,700	0,796	0,898	1,123
240	0,762	0,941	0,717	0,819	0,931	1,158
300	0,783	0,959	0,729	0,834	0,955	1,182
420	0,813	0,98	0,743	0,861	1,000	1,212
540	0,839	0,998	0,760	0,876	1,029	1,232
900	0,876	1,011	0,790	0,912	1,101	1,268
1500	0,917	1,019	0,829	0,946	1,173	1,282
2100	0,936	1,026	0,857	0,974	1,230	1,299
3300	0,962	1,039	0,891	1,019	1,303	1,321
4500	0,985	1,06	0,926	1,054	1,359	1,352
6000	1,010	1,089	0,955	1,083	1,405	1,389
7800	1,029	1,102	0,993	1,136	1,462	1,422
9600	1,058	1,112	1,020	1,161	1,523	1,46

Table 3

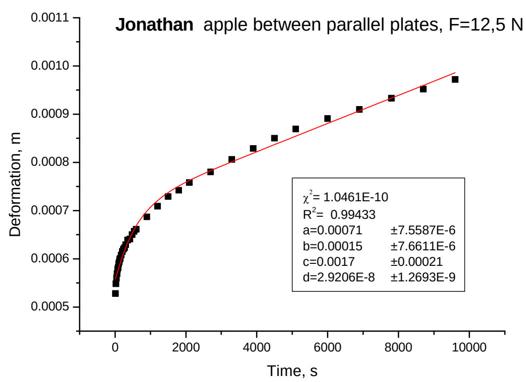
Idem tab.1 for compressive loading for the constant force F=17,5N

Time [s]	Idared		Jonathan		Golden Delicious	
	δ [mm]] apple between plates	δ [mm] apple/apple	δ [mm] apple between plates	δ [mm] apple/app le	δ [mm]] apple between plates	δ [mm] apple/ apple
15	0,578	0,757	0,605	0,98	0,679	0,814
45	0,602	0,822	0,643	1,064	0,760	0,894
75	0,624	0,855	0,708	1,098	0,793	0,933
105	0,643	0,876	0,735	1,123	0,823	0,954
135	0,659	0,893	0,754	1,144	0,842	0,972
180	0,682	0,915	0,771	1,165	0,869	0,992
240	0,708	0,94	0,794	1,195	0,891	1,009
300	0,729	0,956	0,814	1,218	0,913	1,021
420	0,758	0,977	0,829	1,245	0,943	1,033
540	0,781	0,996	0,848	1,264	0,969	1,043
900	0,806	1,028	0,871	1,295	1,020	1,044
1500	0,831	1,058	0,894	1,315	1,072	1,051
2100	0,855	1,077	0,926	1,32	1,110	1,052
3300	0,876	1,114	0,956	1,327	1,158	1,072
4500	0,891	1,134	0,983	1,346	1,206	1,083
6000	0,916	1,156	1,030	1,386	1,253	1,114
7800	0,941	1,169	1,068	1,436	1,302	1,147
9600	0,981	1,19	1,102	1,486	1,344	1,176

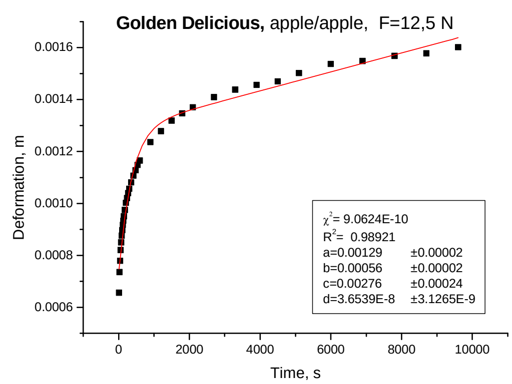
Table 4

The values of the coefficients a, b, c, d and of the correlation coefficient R^2 from testing the eq.(13)

Variety	The load Chart	Force applied [N]	a [m]	b [m]	c [s^{-1}]	d [m/s]	R^2
Idared	apple between parallel plates	12,5	0,00067	0,00017	0,00869	$0,82698 \cdot 10^{-8}$	0,992
		15	0,0009	0,00028	0,00273	$1,7484 \cdot 10^{-8}$	0,9962
		17,5	0,00081	0,00024	0,00329	$1,7244 \cdot 10^{-8}$	0,999
Jonathan		12,5	0,00071	0,00015	0,0017	$2,9206 \cdot 10^{-8}$	0,9943
		15	0,00091	0,00024	0,00182	$3,6308 \cdot 10^{-8}$	0,9931
		17,5	0,00085	0,00027	0,00646	$2,7962 \cdot 10^{-8}$	0,9932
Golden Delicious		12,5	0,00136	0,00068	0,0013	$3,909 \cdot 10^{-8}$	0,99
		15	0,00115	0,00042	0,00229	$4,1561 \cdot 10^{-8}$	0,99319
		17,5	0,00103	0,00031	0,00027	$3,5268 \cdot 10^{-8}$	0,99252
Idared	apple/apple	12,5	0,00079	0,00026	0,0051	$2,6013 \cdot 10^{-8}$	0,9957
		15	0,001	0,00023	0,00617	$1,3326 \cdot 10^{-8}$	0,99514
		17,5	0,00104	0,00026	0,00363	$1,7791 \cdot 10^{-8}$	0,9894
Jonathan		12,5	0,00081	0,00022	0,00505	$2,01551 \cdot 10^{-8}$	0,9955
		15	0,0009	0,00026	0,00432	$2,9516 \cdot 10^{-8}$	0,99
		17,5	0,00127	0,00028	0,0057	$2,1276 \cdot 10^{-8}$	0,993
Golden Delicious		12,5	0,00129	0,00056	0,00276	$3,654 \cdot 10^{-8}$	0,989
		15	0,00124	0,00037	0,00626	$2,3676 \cdot 10^{-8}$	0,9959
		17,5	0,00129	0,0004	0,0061	$3,316 \cdot 10^{-8}$	0,9958

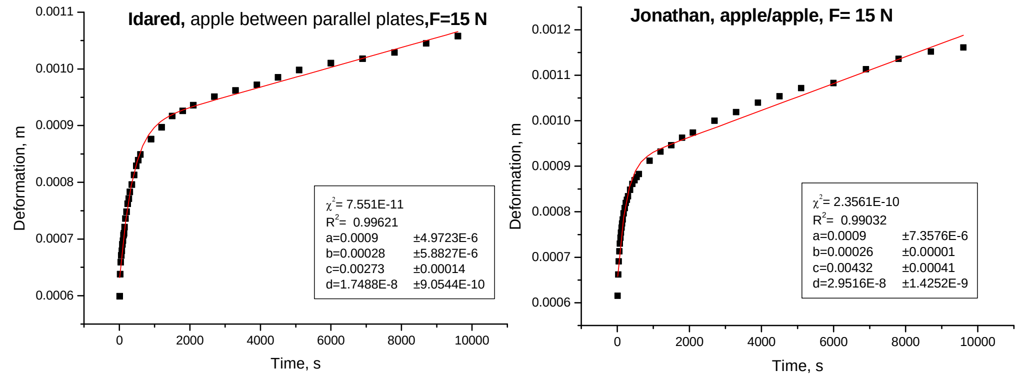


a)



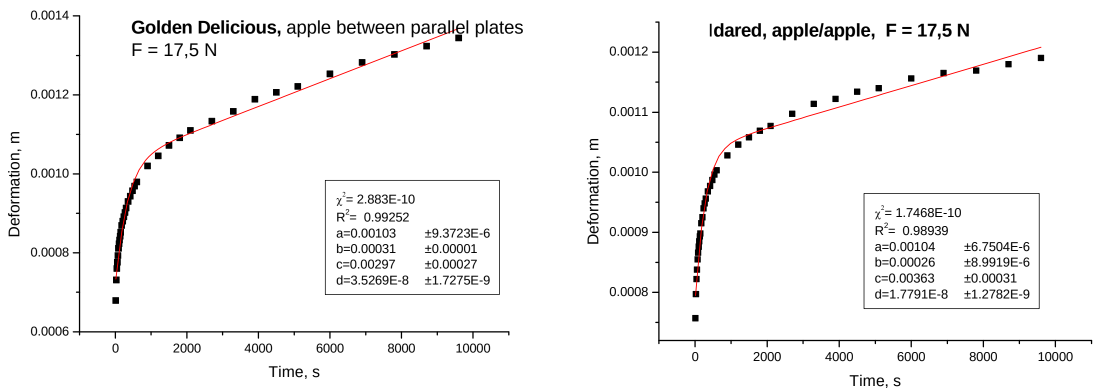
b)

Fig.4 The curve for delayed elastic deformation δ (t) at creep test in function of time for Jonathan (a) and Golden Delicious (b) to F_0 = 12,5 N



a) b)

Fig.5 The curve for delayed elastic deformation δ (t) at creep test in function of time for Idared (a) and Jonathan (b) to $F_0 = 15$ N



a) b)

Fig.6 The curve for delayed elastic deformation δ (t) at creep test in function of time for Golden Delicious (a) and Idared (b) to $F_0 = 12{,}5$ N

Table 5

Characteristic values for Burgers model K, K_1, η^* from eq.(7)

Variety	Chart	K_1 [N/m]	K [N/m]	$\eta^*\ 10^7$ [N/s^{-1}]	T_i [s]
Idared	apple between parallel plates	73529,4	25000	15	115,07
		53571,4	24193,5	88	366,3
		72916,6	30701,7	10,1	303,95
Jonathan		83333,3	22321,4	43,1	588,23
		62500	22388,1	41,3	549,45
		64814,8	25862,06	62,7	154,79
Golden Delicious		18382,3	18382,3	32,05	769,23
		35714,2	20547,9	36,1	436,68
		56451,6	24305,5	49,7	344,82

Idared	apple/apple	48076,9	23584,9	48,07	196,07
		65217,3	19480,5	112,7	162,07
		67307,6	22435,8	98,3	275,48
Jonathan		56818,18	21186,4	62,18	198,01
		57692,3	23437,5	50,84	231,48
		62500	15151,51	82,27	175,43
Golden Delicious		22321,4	17123,28	34,21	362,3
		40540,5	17241,3	63,37	159,74
		43750	19662,92	52,87	163,93

5. Conclusions

In chain of operations from harvest to commercialization (including keeping for long time) at each stage of operations, in fruits, defects that affect quality may appear in addition to mechanical injury which are produced when stresses exceeding the ultimate strength of fruit flesh, manifesting by crushing the tissue.

In this paper, it was described an experimental method to determine the duration of relaxation at loading static compressive, with maintenance of the integrity of the fruit considered with a linear viscoelastic behavior, described by a model physical rheologic, similar to Burgers model (fig.2), using creep test. A mathematical model - eq. (7) is presented for a description of behavior at static compression for apples considering viscoelastic linear materials. The model was tested with experimental data, showing a good agreement. This data is necessary to predict packaging height to ensure the avoidance of defects deviations form for storage time and for evaluation (prediction) of the duration of storage in certain packages, (eq. (16)). It should be underlined also that the model expressed by eq. (7) describes very well the experimental data, at loading static compression of the fruits on rigid surfaces and between fruits themselves.

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