International Journal of Agriculture Innovations and Research
Volume 1, Issue 4, ISSN (Online) 2319-1473

Determination of Relaxation Model for Apple (cv. Shafiabadi&Golabkohanz)

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Abstract — **The relaxation phenomena are critical aspects of fruit rheological properties. In this research, effects of variety and sampling orientation on stress relaxation model parameters (equilibrium stress, decay stress and relaxation time) of two Iranian apple varieties (ShafiAbadi & GolabKohanz) were investigated. Sampling was performed in horizontal and vertical orientation and the stress relaxation tests were performed using Instron Universal testing machine. The results showed that interaction effects of variety and sampling orientation on all of parameters were significant except for relaxation time. At the end, four stress relaxation models were presented.**

Keywords — **Decay Modulus, Equilibrium Modulus, Relaxation Model.**

I. INTRODUCTION

The apple, with scientific name of *Malusdomestica*is a pomaceous fruit from *Rosaceae* family. There are more than 7500 known cultivars of apple in the world [1]. Iran, with 190000 ha of cultivation area (2.8% of the world production area) is third country of apple producer after China and USA countries in the world. In spite of 2.81 million tons of apple production in Iran, its export is very low [2]. One of the most important export problems is quality decrease of fruits in postharvest operations such as handling, processing, grading and packaging. Foods which exhibit characteristics of both liquid and solid are described as viscoelastic where stress relaxation and strength properties are time dependent. Knowledge of viscoelastic properties of foods and agricultural materials are important when considering harvesting, handling, transportation, processing, and storage. Also the data on viscoelastic properties are required as an input for mathematical models, which describe and predict internal stress and cracking during different handling and processing procedures [3]. The mechanical properties are considered one of the most important four parameters, which reflect the quality of food material [4]. Those parameters include texture, firmness and chewability. Viscoelastic material exhibit stress relaxation phenomena, which is of the most important factors in characterizing agricultural materials. The measured relaxation time show how fast the material dissipates stress after receiving a sudden deformation and as well to characterize the elastic and viscous parts in the behavior of a material. The constant of relaxation time for liquids is normally very small. For example, in the case of water it has the magnitude of 10^{-3} s. Solid elastic materials have very large relaxation time constants. Viscoelastic materials have time constants that fall in between, and can have values in the range of $T_{rel} = 10^{-1}. . . 10^{6}$ s [10]. Fully mature apples at all stages are subject to fracture mechanical damage through a series of static and dynamic loads. Such loads cause significant loss by decreasing the quality and increasing the susceptibility to deterioration during storage [5]. Many rheological and mechanical characteristics in addition to physical conditions affect the viscoelastic properties and should be investigated.

Several studies have been conducted on stress relaxation of vegetables and fruits. Lewicki and Wolf [6] studied the relationship between stress relaxations of raisins at different levels of moisture contents. They found that raisins could be classified as brittle body for moisture contents below 25% where the possibility of fracture during compression is high. The Universal Texture Machine was used to determine the viscoelastic properties of solar dried Sultana raisin cultivar [7]. They found that individual and bulk fruits follow a viscoelastic behavior where the internal portion of the fruit represents the viscous part while the outer skin represents the elastic part. Cenkowski*et al*[8] investigated the changes in the apparent modulus of elasticity of canola kernels from swathed and freshly harvested plants at different stages of maturity. The apparent modulus of elasticity increased 1.8 times after 17 days of maturation. Three stress relaxation properties for banana and plantain were determined [9]. They found that at constant speed and depth for the die movement, the relaxation properties for yellow banana were less than those for green ones. In another study they developed an empirical mathematical model, which related the elasticity of banana core and its components to the stress relaxation properties. Kojima *et al*[10] used a loading probe to measure the hardness of tomatoes where they monitored stress values as a function of time. They found that the maturity of tomatoes was related to a decreasing of the minimum stress relaxation time. Lima and Singh [11] determined the constants of relationship between the viscoelasticity of potato chips and its fracturability where the data showed that the average value of the modulus of elasticity was 8130 Pa and the time constant was 62 s.

A significant amount of information is available on the mechanical properties of fruits. Both elastic and viscoelastic properties of fruits have been the subject of intensive research in the past three decades by many researchers [12]-[13]-[14]-[15]. These studies generally focused on characterising some basic mechanical properties and rheological properties without considering the nonhomogeneous and anisotropic properties of fruits. Anisotropic mechanical properties were reported [16], but little detailed information is available on the non-homogeneous and anisotropic relaxation of fruits.

The objectives of the current study were: (1) measure the relaxation properties, i.e. the equilibrium stress, the decay stress, time of relaxation and the specific viscosity of two Iranian apple varieties, (2) determine the effects of variety and sampling orientation on these relaxation properties, and (3) to find the best model to describe the obtained stress relaxation data.

II. Materials and Methods

Two Iranian apple varieties (GolabKohanz & ShafiAbadi) were prepared in the summer of 2009 from an orchard located at the Horticultural Research Center, Agricultural Faculty, University of Tehran, Karaj, Iran. The fruits were cleaned to remove all foreign matters such as dust, dirt and chaff as well as immature and damaged fruits. After removing from the cool store and before testing, apples were kept during 24 h at 23 oC. The analysis was carried out at a room temperature of 23°C. The initial moisture content of fruit was determined using dry oven method at 77°C for 10 days [17].

Stress relaxation can be described as the ability of a material to alleviate an imposed stress under conditions of constant strain. In a stress relaxation test the sample is given an instantaneous strain and the stress required to maintain the deformation is observed as function of time. The stress relaxation test may be conducted in shear, uniaxial tension, or uniaxial compression. A generalized Maxwell model has frequently been used to interpret stress relaxation data of a linear viscoelastic material. The model contains n Maxwell elements and a spring in parallel; each element of Maxwell model consisting of a dashpot and a spring in series [18]. The generalized Maxwell model can be written as follows:

$$\sigma(t) = \sigma_e + \sum_{i=1}^{n} \sigma_{di} (e^{-t/T_i})$$

In this paper, the objective of our study was to determine the anisotropic relaxation properties of the apple, so the model was simplified and the three-element model was adopted to fit the curves (Fig. 1).

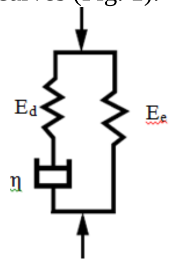

Fig.1. The three units model: E_e is the equilibrium odulus, E_d is the decay modulus and η is specific viscosity.

The model was expressed as

$$\sigma(t) = \sigma_e + \sigma_d (e^{-t/T_{rel}}) \quad (1)$$

Where: $\sigma_e = \epsilon_0 E_e$, $\sigma_d = \epsilon_0 E_d$ and $T_{rel} = \eta / E_d$

ϵ0 is initial strain and 3 mm was assumed. The experiment was performed in 5 minutes and stress in fifth minute was assumed as equilibrium stress. The obtained data from stress relaxation test in 5 minutes is shown in Table 1 which is the averages of 10 replicates for every test.

Table.1: Relaxation Data for *GolabKohanz&ShafiAbadi* in Orientations of horizontal and vertical.

Time (min)	Stress (KPa)			
	Golab Kohanz		ShafiAbadi	
	Horizontal	Vertical	Horizontal	Vertical
	Mean±SD	Mean±SD	Mean±SD	Mean±SD
0.00	121.52±28.19	136.05±25.12	203.32±45.72	222.27±2.50
0.01	119.66±29.49	134.32±26.80	203.10±47.59	222.08±53.34
0.02	110.25±30.41	125.35±24.75	192.75±47.50	212.38±51.24
0.03	106.25±29.69	119.94±24.72	187.62±47.34	207.42±49.11
0.04	102.48±30.08	117.12±23.86	183.65±46.51	202.88±49.30
0.06	98.40±29.63	112.78±23.32	178.23±45.65	196.55±47.54
0.08	95.88±29.22	110.05±22.97	174.44±44.91	192.54±46.62
0.10	93.68±28.9	107.57±22.62	170.96±44.27	188.91±45.74
0.15	89.82±28.24	103.29±22.06	164.99±43.13	182.58±44.20
0.20	87.09±27.73	100.25±21.64	160.75±42.33	178.09±43.02
0.25	84.86±27.31	97.79±21.28	157.38±41.69	174.48±42.11
0.30	83.13±26.99	95.91±21.03	154.77±41.23	171.77±41.40
0.40	80.46±26.40	92.87±20.57	150.78±40.47	167.52±40.38
0.50	78.39±25.95	90.54±20.27	147.75±39.90	164.27±39.62
0.60	76.64±25.60	88.59±20.02	145.22±39.42	161.60±39.01
0.70	75.21±25.27	86.99±19.77	143.16±39.02	159.42±38.46
0.80	73.92±24.99	85.53±19.55	141.37±38.69	157.51±38.06
0.90	72.79±24.81	84.31±19.38	139.85±38.39	155.86±37.68
1.00	71.74±24.56	83.19±19.19	138.49±38.16	154.34±37.35
1.50	67.78±23.71	79.08±18.57	132.89±37.06	148.51±36.00
2.00	64.74±22.83	76.03±17.77	128.75±36.37	144.38±35.03
3.00	60.36±21.52	71.54±16.41	122.99±35.70	137.88±34.02
4.00	57.20±20.51	67.52±15.64	118.58±35.04	132.64±33.02
5.00	54.47±19.75	64.85±14.90	114.70±34.64	128.13±32.24

With substituting (σ0- σe) instead σd in Eqn 1:

$$\sigma(t) = \sigma_e + (\sigma_0 - \sigma_e)(e^{-t/T_{rel}}) \quad (2)$$

With modifying the equation (2) and taking the natural logarithm of both sides:

$$Ln(\sigma(t) - \sigma_e) = Ln(\sigma_0 - \sigma_e) - \frac{t}{T_{rel}} \quad (3)$$

Ln (σ0- σe) versus time is plotted as shown in Fig. 2.

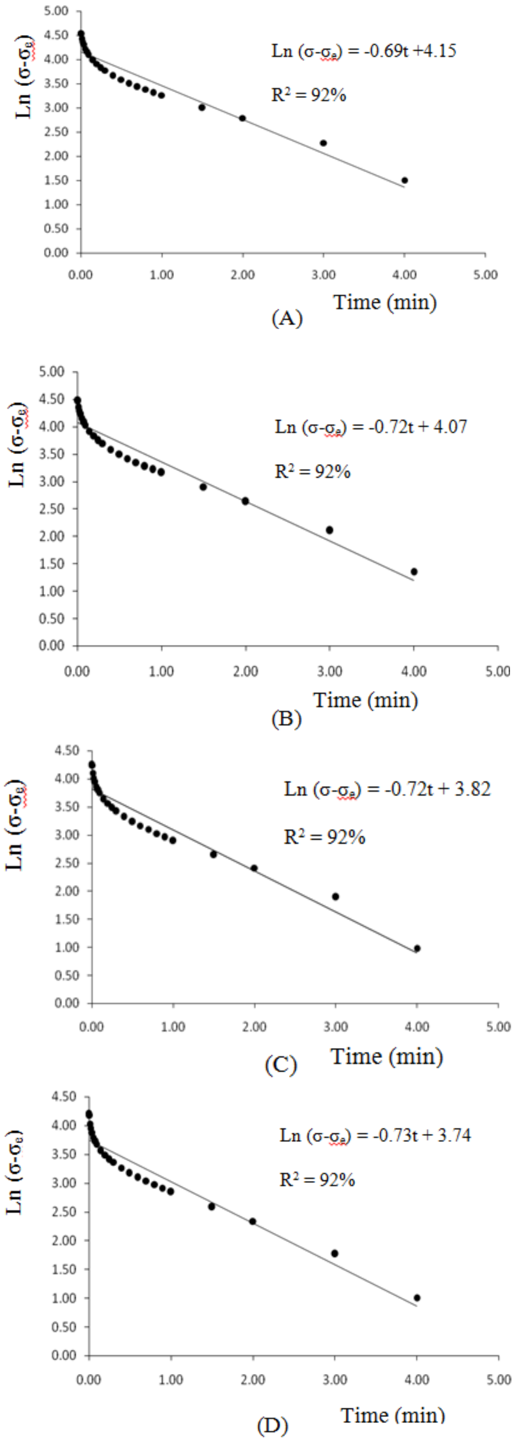

Fig.2. Stress relaxation curves for vertical (A) and horizontal (B) sampling form *ShafiAbadi* variety and vertical (C) and horizontal (D) sampling from *Golab Kohanz* variety.

From the linear regression, the slope, which is equal to (−1/Trel), relaxation time is determined and from the intercept, which is Ln (σ0- σe), (σ0- σe) is found. Then, other stress relaxation model parameters such as initial stress, decay stress, equilibrium modulus, decay modulus and initial modulus were determined.

The stress relaxation test was performed by Universal Testing Machine (Santam, MRT-5). This machine was equipped with a load cell of 20 N and two parallel plates that one is fixed and the other is versatile and moves at a compressive rate of 25.4 mm/min. Cylindrical specimens were cut in vertical and horizontal orientations with 10 mm in diameter and 24 mm in height (Fig. 3).

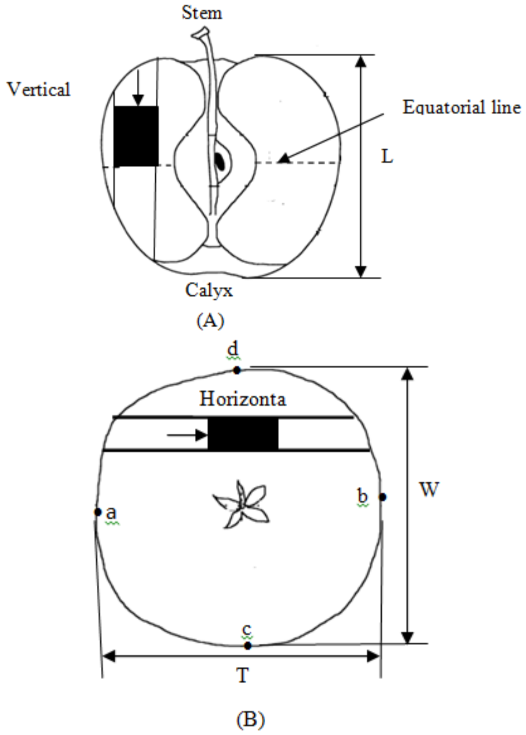

Fig.3. Sample orientations in two directions of vertical (A) and horizontal (B), L, W and T are length, width and thickness of apple, respectively.

Vertical orientation was along the length (equivalent distance of the stem to the calyx) and horizontal orientation was in radial direction, tangent to the stem-calyx axis. Lastly, data were subjected to statistical analysis using the analysis of variance (ANOVA) test, and means were compared using Duncan's multiple range tests at 5% level of significance.

III. Results and Discussion

The stress relaxation test was performed in 86% and 84% moisture contents for GolabKohanz and ShafiAbadi varieties, respectively. Results of variance analysis about effect of variety and sample orientation on the parameters of stress relaxation model were shown in Table 2.

International Journal of Agriculture Innovations and Research
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Table. 2: Analysis of the variance of stress relaxation model parameters under the effects of apple varieties and sampling orientation.

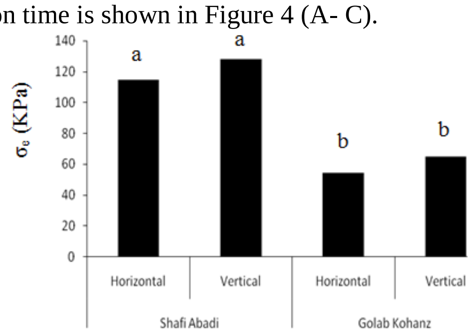
Variation source	DF	σ_0	σ_d	σ_e	E_e	E_d	E_0	T	η
		Mean Squares							
Treatment	3	21690.02*	1052.16*	13192.46*	1466.36*	117.1*	2410.31*	0.01^{ns}	8097269.5*
A	1	62483.49*	2989.78*	38137.41*	4239.06*	332.75*	6943.48*	0.01^{ns}	22596177.5*
B	1	2544.5^{ns}	163.94^{ns}	1416.69^{ns}	157.45^{ns}	18.23^{ns}	282.75^{ns}	0.003^{ns}	1335840.3^{ns}
A×B	1	42.08*	2.76*	23.27*	2.58*	0.31*	4.68*	0.01^{ns}	359790.7*
Error	36	1367.61	139.68	712.94	79.22	15.52	151.95	0.01	1226039.7

A: apple variety (Shafi Abadi and Golab Kohanz), B: sampling orientation (horizontal and vertical orientation) and A×B: interaction of variety and sampling orientation.

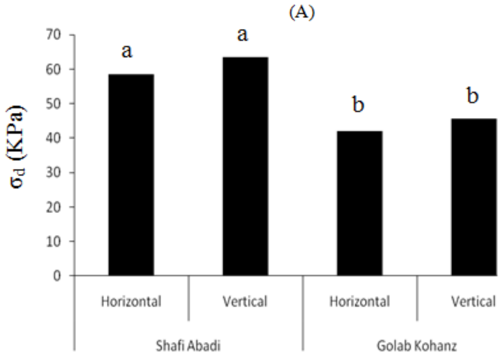
ns: Corresponding to no significant difference

* Corresponding to confidence of interval, 99%

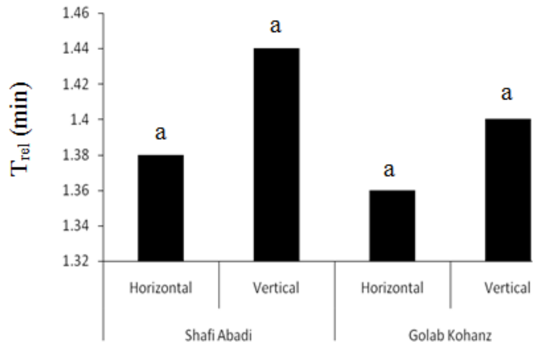
According to Table 2, effects of variety and interaction of variety and sampling orientation on the entire model parameters except for relaxation time were significant in 1% statistical level. The effects of variety and sampling orientation on equilibrium stress, decay stress and relaxation time is shown in Figure 4 (A- C).



(A)



(B)



(C)

Fig. 4. Effects of Variety and sampling orientation on equilibrium stress (A), decay stress (B) and relaxation time (C), (bars with different letters are significantly different at P<0.01 and with equal letters are no significant difference).

These results showed for ShafiAbadi variety, the entire parameters were bigger than Golab Kohanz variety and the values in vertical orientation were bigger than horizontal orientation in both of the varieties. The mean and standard deviation values of model parameters in stress relaxation test were shown in Table 3.

Table. 3: The mean and standard deviation values of stress relaxation model parameters.

Relaxation parameter	Variety: ShafiAbadi, Horizontal (Mean ± SD)	ShafiAbadi, Vertical (Mean ± SD)	Golab Kohanz, Horizontal (Mean ± SD)	Golab Kohanz, Vertical (Mean ± SD)	Significant level
σ_0(Kpa)	173.25^{a}±44.39	191.56^{a}±46.01	96.56^{b}±23.24	110.45^{b}±29.02	*
σ_d(Kpa)	58.55^{a}±12.49	63.43^{a}±15.28	42.09^{b}±8.75	45.6^{b}±9.62	*
σ_e(KPa)	114.7^{a}±34.64	128.13^{a}±32.24	54.47^{b}±14.9	64.85^{b}±19.75	*
E_e(MPa)	38.23^{a}±11.55	42.71^{a}±10.75	18.15^{b}±4.97	21.61^{b}±6.58	*
E_d(MPa)	19.51^{a}±4.16	21.14^{a}±5.09	14.03^{b}±2.92	15.2^{b}±3.21	*
E_0(MPa)	57.75^{a}±14.8	63.85^{a}±15.34	32.18^{b}±7.75	36.81^{b}±9.67	*
Time(min)	1.38^{a}±0.1	1.44^{a}±0.13	1.36^{a}±0.09	1.38^{a}±0.09	ns
η(MPas)	4893.9^{a}±1174.77	5449.1^{a}±1315.21	3580.4^{b}±889.63	3756.2^{b}±1001.43	*

As seen in Table 3, the average values of equilibrium stress, decay modulus and relaxation time were obtained 121.41 KPa, 61 KPa and 1.41 min for ShafiAbadi variety and corresponding values for GolabKohanz variety were 59.66 KPa, 43.84 KPa and 1.37 min, respectively. According to the results, ShafiAbadi variety had more rigid tissue than GolabKohanz variety and firmness was more in vertical direction than horizontal direction (Fig. 3). Among the factors can affect firmness, weather and genetic factors (variety, maturity at harvest, Calcium rate and etc) are more important [19]. In research of Wang, [20], effects of specimen orientation and location with the pear on the equilibrium modulus, the decay modulus, time of relaxation, and specific viscosity in the relaxation model were determined based on this research values of equilibrium modulus, decay modulus and specific viscosity had maximum values in vertical status of sampling but relaxation time had maximum values in tangential orientation. According to obtained original parameters (Table 3) and considering Eq. (1), four models were fitted and results were presented in Table 4.

Table. 4: The stress relaxation models for SHafiAbadi & GolabKohanz in horizontal and vertical orientations

Variety	Sampling orientation	Stress relaxation model	R^2 (%)
ShafiAbadi	Horizontal	$\sigma(t)=114.7+58.55(e^{-t/1.38})$	0.92
	Vertical	$\sigma(t)=128.13+63.43(e^{-t/1.44})$	0.92
GolabKohanz	Horizontal	$\sigma(t)=54.47+42.09(e^{-t/1.36})$	0.92
	Vertical	$\sigma(t)=64.85+54.6(e^{-t/1.38})$	0.92

IV. Conclusions

The stress relaxation work was carried out using various sampling orientations with two Iranian apple varieties. The equilibrium stress and modulus, decay stress and modulus, initial stress and modulus, and specific viscosity in the relaxation model are significantly influenced by variety and interaction variety with sampling orientation. The effects of variation sources on relaxation time are not significant. This study has provided data on the fundamental relaxation properties of apple and the relationship with sampling orientation. The results may have some important implications in developing computer simulation model to study rheological behavior of fruit, to sort intact fruit, and store and transport fruit with better positions.

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