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Rheological Behavior of Tomato Fruits Affected By Various Loads Under Storage Conditions

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Abstract: Rheological properties of fruits and vegetables are of interest to plant physiologists, horticulturalists, agricultural engineers and food engineers, due to different causes. the rheological properties are relevant to several aspects of the study of these materials, including the causes and extent of damage during harvesting, transport and storage; the human perception of product quality. The rheological constants of the four element Burgers model when tomatoes were subjected to various fixed loads (stresses) on the main dimensions of the fruits were investigated .The rheological constants, K_1(instantaneous elasticity, N/mm), K_2 (retarded elasticity, N/mm), C_1 (free viscous element, N.min/mm and C_2 (retarded viscous element, N.min/mm) were decreased significantly with storage time.

Keywords: *rheological behavior, tomato, fixed load, burger model.*

I. INTRODUCTION

Texture is a quality attribute that is critical in determining the acceptability of fresh fruits. The handling and processing of fruits and vegetables involves special problems since the consumer has well-formed opinions and expectations regarding the proper texture of these products. Successful delivery of acceptable products requires care regarding texture changes, and this is most effectively applied when it is based on an understanding of the factors that influence texture. A better understanding of fruit texture and rheology and their relation to microscopic changes may lead to improvements in quality control and process design in the food industry and the marketplace. The rheological properties of foods are affected by their chemical composition which, in turn, affects the structural changes during handling and processing (Varela. P, et al., 2007).

Tomatoes are considering an agricultural biological material. Biological materials do not behave either as perfect elastic or perfect plastic materials. They exhibit both properties simultaneously. So, they are grouped under the definition of visco-elastic materials (Mohsenin, 1996, Faborode and Callaphan ,1989). In the same time, they show effects the dependent on time due to loading. The time dependent behavior of such viscoelastic materials may be described by constitutive equations whose variables are stress, deformation and time. These equations may be expressed by means of rheological models. Rheological models could describe and represent the behavior of biological materials. They help explain the stress, strain behavior of biological materials. The scope of the validity of such rheological models must be established by experiment. The most frequently applied quasistatic experimental methods, which can be utilized to determine viscoelastic properties of solid biological products like potatoes are creep and retardation and stress relaxation tests as well as increasing the stress or deformation under constant rate.

Storage of tomato in bulk is essential to ensure continuous supply of raw material for household consumption as well as for the tomato processing industry. However, tubers are living entities even after harvest and respire and transpire. These processes bring about physiological changes and water loss, which in turn affect the mechanical properties (Burton, 1989). Mechanical or rheological properties of potatoes have been frequently used as a measure of the textural characteristics (Laza, Scanlon, & Mazza, 2001; Scanlon, Day, & Povey, 1998; Thybo & Martens, 1999). Some rheological properties of tomatoes have been reported to be affected by storage time and temperature. However, information on the patterns of changes in the rheological properties during storage is lacking.

The increasing social and economic importance of food production, besides the technology complexity of producting, processing, handling and accepting these highly perishable and fragile food materials requires a more extensive knowledge of their physical properties; because of this, the rheological properties play an important role in the handling and quality attributes of both minimally processed foods, such as fruits and vegetables. One of the important characteristic of rheological behaviour is the material properties dependence on temperature (Rao and Steffe, 1992).

The rheological properties of fruits and vegetables are of interest to plant physiologists, horticulturalists, agricultural engineers and food engineers, due to different causes. First, fruits and vegetables are increasing in importance in the contemporary human diet. Secondly, the rheological properties are relevant to several aspects of the study of these materials, including the causes and extent of damage during harvesting, transport and storage; the human perception of product quality; and the physiological changes that take place in the product during growth, maturation, ripening and storage after harvest (Rao and Steffe, 1992).

Several studies have indicated that the visco-elastic nature of agricultural and food materials can be analysed by rheological models (Bagley & Christianson, 1987; Bargale, Irudayaraj, & Marquis, 1994; Davis, McMahan, & Leung, 1983; Hamann, 1992; Pappas, Skinner, & Rao, 1988; Purkayastha, Peleg, Johnson, & Normand, 1985). Rheological characterization of fresh and cooked potatoes has been reported using creep tests (Alvarez & Canet, 1998; Alvarez, Canet, Cuesta, & Lamua, 1998; Purkayastha et al., 1985). However, the changes in the parameters of creep models with storage time and temperature were reported in these study.

The determined rheological parameters are a powerful tool in understanding changes in food structure during processing (Guerrero & Alzamora, 1998; Holdsworth, 1993). Considering the consumer demand for processed foods with high quality, there is a need to define changes in rheological properties of foods in processing operations that may affect their overall acceptability (Nindo. C. I, et al., 2007).

The knowledge of the rheological properties of fruit pulps is essential for processes and equipment development, quality evaluation, shelf-life control, and for understanding the structure and macromolecular conformation of pulp constituents (Barnes et al., 1989; Steffe, 1996). The rheological data are required for process engineering analyses (extrusion, pumping, mixing, agitation, heating, coating, process control), quality control and shelf-life estimation, texture evaluation, product development, and the development of constitutive equations for rheological characterization (Ofoli, 1990)

Models are mechanical analogues composed of element (springs and dashpots) where the ideal elastic behavior and the ideal viscous behavior are combined in different ways to model the actual behavior of the bio-materials. In stress relaxation test, the biological materials are deformed to a fixed strain and the strain is held constant. So the stress required to maintain this strain decreases with time. While in creep test, a constant load or stress is applied to the biological materials and the resulting (increasing) strain is measure with time. In fact this type of behavior is typical of fruits and vegetables. Besides it demonstrates the fact that the strain exhibited by the agricultural material under test is not independent of time (Mohsenin, 1996).

Pitt and Chen 1983 stated that this time dependent can have a significant effect on the accuracy of predicted damage levels in fruits and vegetables during harvesting, handling transportation and storage . Datta and Morrow. 1983, showed that the generalized kelven model (a series of kelven bodies) in series with Maxwell model must best represents the creep data obtained from apples, potatoes, and cheese. In this direction numerical attempts to fined a rheological model to represent the flesh of apples, potatoes, pear and other fruit as well as low, methoxyle pectingel preparations under condition of static creep have yielded the Burgers model (Mohsenin , 1996). It can be seen in figure (1). The creep curves of apples (Skinner 1983), tomatoes (Abdel Maksoud , 1992) and grain dust (Chang and Martin ,1983) showed behavior identical to that of the four element Burgers model. In addition , (Mohsenin, 1996) shows the behavior of the four elements Burger model as shown in figer (1) and added that the rheological equation biased on the model in creep and recovery test is given as follows:-

$$\varepsilon(t) = \sigma_0 \left[\frac{1}{E_0} + \frac{1}{E_r}(1 - e^{-t/T_{ret}}) + \frac{t}{\eta_v} \right]$$

Where:
ε = Strain;
t = time, min;
σ0 = stress, MPa;
E0 = instantaneous modulus or modulus at zero time;
η = viscosity coefficient of the liquid in the dashpot, Mpa.min;
ηv = Viscosity, Mpa.min; and Tret = η/ Er The time of relaxation.

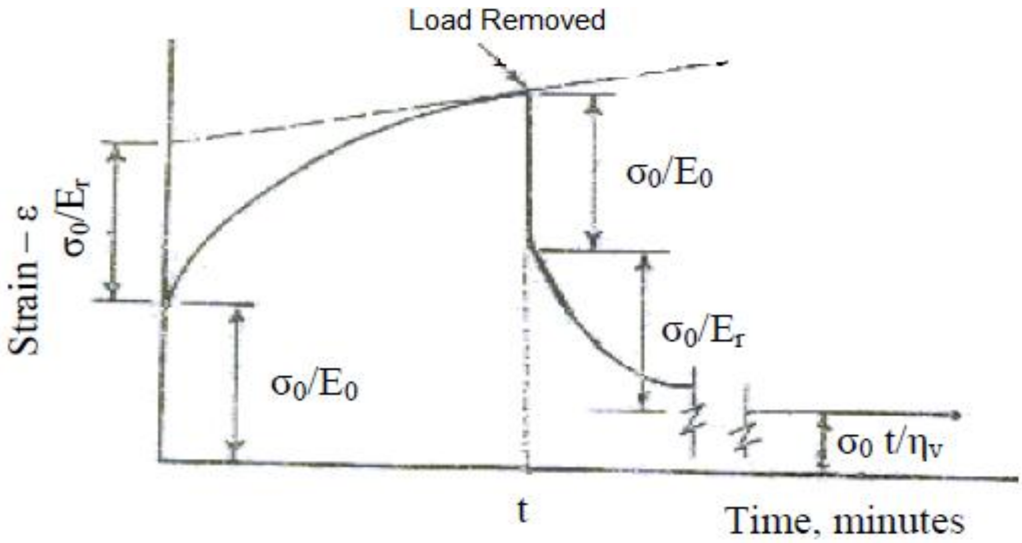


Figure. 1. Typical creep and recovery curve in a viscoelastic material exhibiting instantaneous elasticity, retarded elasticity and viscous flow.

This equation is based on the model consists of a Kelven model connected in series to a spring and a dashpot element. Mohsenin. 1996, illustrated a typical curve for creep and recovery test of Mackintosh apple as a relationship between deformation in inches and time in minuets as shown in figure (2).

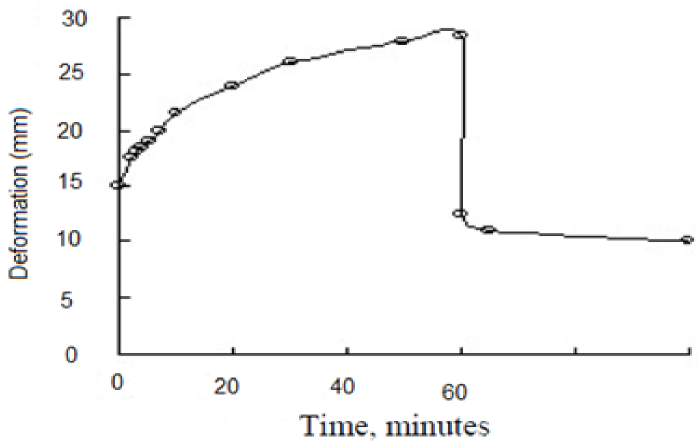


Figure. 2. Distortion of McIntosh apple under dead load of 210 N determined by axial creep and recovery test with 60 mm rigid plunger.

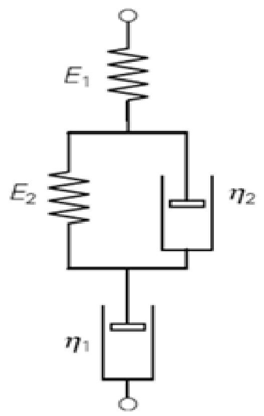


Fig. 3. Creep of the Four-element model (Burgers' model).

Similarly, Abd el Maksoud , 1992, Sabbah et al.1994 used the four element Burgers model and the following equation as illustrated in figure (3) to determine the rheological constants of the model (K_1, K_2, C_1, C_2) and their relations with fruit (tomatoes) parameters . Ayman Eissa et al., 2012, used the four element Burgers model and the following equation as illustrated in figure (3) to determine the rheological constants of the model (K_1, K_2, C_1, C_2) and their relations with fruit (pears) parameters.

$$\varepsilon = \sigma\left[\frac{1}{E_1} + \frac{1}{E_2}(1 - e^{-t/\tau}) + \frac{t}{\eta_1}\right]$$

Where:

ε=The total deformation at any time t; mm; σ = Constant load, N;
E_1 = Instantaneous elasticity, N/mm; E_2 = Retarded elasticity, N/mm;
η_1 = Free viscous element, N. min/mm; η_2 = Retarded viscous element, N. min/mm; and
$\tau = \eta_2/ E_2$ the time of retardation.

Sabbah et al., 1994 reported that the deformation increases with increasing of loading level and stage of maturity Generally, it was inversely proportional with fruit size under the same loading .Meanwhile, they observed considerable variations throughout creep tests on individual fruits due to the non homogenous nature of tomatoes and the stress concentration set up by its irregular shape surface.

Knowledge of the rheological model constants by creep test experiments helps in describing the behavior of the biological material under the static load applied. These are essential for the designer of harvesting and handling equipment to estimate and even predict the amount of material damaged an applied load or deformation. The specific objectives addressed by this investigation are:

1- Using the creep and recovery test to determine the viscoelastic properties of tomatoes through the constants of the rheological Burgers model.

2- Studying the effect of the storage time under different temperatures on the rheological constants of the model.

II. MATERIAL AND METHODS

100 for creep and recovery test experiments including, three load levels (10, 14 and 18N) and two loading positions (L – longitudinal , D – diameter axis). The procedure to conduct the creep test was run by using the creep test device. It was constructed specifically according to the creep test device used by (Ayman Eissa et al., 2012) as shown in figure (4). Experiments were run by placing the tomato between two parallel plates. The tomato was placed on the base of the apparatus in the considered position while, the crosshead was just touching its surface at zero loading condition. The tomato was then loaded by the concerned fixed load. The instantaneous deformation with time was indicated by the dial micrometer and then recorded. The total time of every test was one hour. It divided into 30 minutes loading period and 30 minutes unloading period (retardation). The obtained data from tests of this investigation were used for plotting creep curves for calculating the constants of the rheological Burgers model (E_1, E_2, η_1, η_2) for tomatoes.

Then tomato was loaded by a specific load, and the experiments were conducts at three levels of temperature (5, 15, 25 ^{0}C) the instantaneously deformation was indicated by dial micrometer, and the reading of micrometer was continuously read as samples was deformed. The total test time was one-hour and distributed to two parts during the first half hour the fruit loaded and reading of micrometer was continuously read (creep period), while during the second half hour period the load lifted for fruit (retardation period), and then the test was finished.

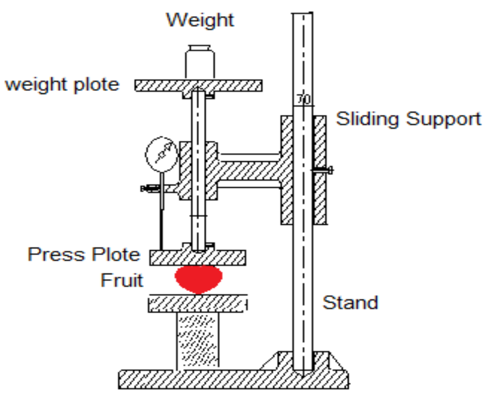


Fig. 4. Creep test apparatus.

III. RHEOLOGICAL PROPERTIES EXPERIMENTS:

Fig.(5), show typical creep test curves and the rheological constants of Burgers model for tomato using 10 N static load at the tomato harvesting day. Considerable variations were obtained throughout the results of the creep tests on individual tomato. Two reasons for this are the nonhomogenous nature of the tomato sample and the stress concentration set up by its irregular shape or surface. The latter is considered to be an important factor is apparent through comparing the results of tomatoes tested at longitudinal and diameter axis position. The mean creep data which obtained from testes were analyzed by Four-elements model (Burgers model) to determine the model constants (k_1 = Instantaneous elasticity, N/mm; K_2 = Retarded elasticity, N/mm; C_1 = Free viscous element, N.min/mm; and C_2 = Retarded viscous element, N.min/mm) as the following:

3.1. Instantaneous elasticity (k_1), N/mm:

Figures. (6); and (7), show the instantaneous elasticity (k_1) decreased during storage time for tomato at three levels of temperture. The instantaneous elasticity (k_1) values increased as the temperture increased, its values increased as the static load increased from 10 N to 18 N.

Significant differences between the instantaneous elasticity (k_1) values for the three levels temperture were observed for all sampels. The instantaneous deformation of tested samples specimens when subjected to the constant step load increased with increaseing the storage time under all levels of temperture.This increase in deformation led to a significant reduction in the values of (k_1).

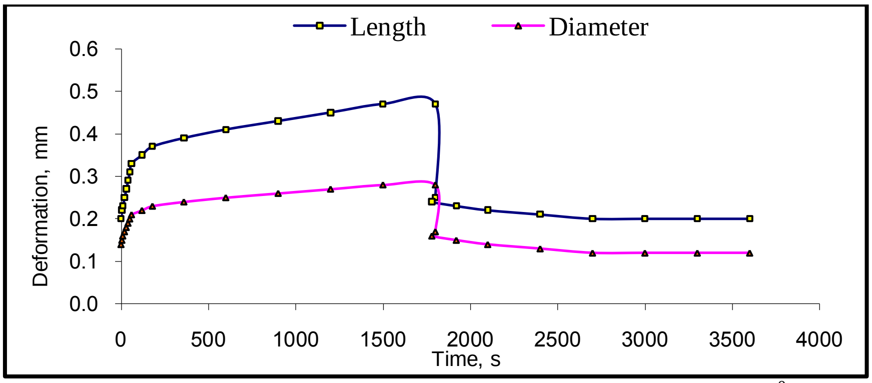
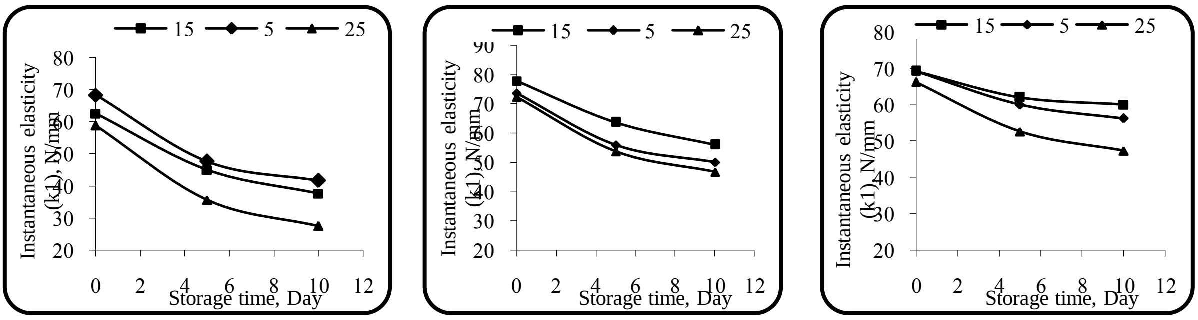


Fig.5. Typical curve of creep retardation test for fresh tomato at load 10N at 5 ^{0}C temperture.

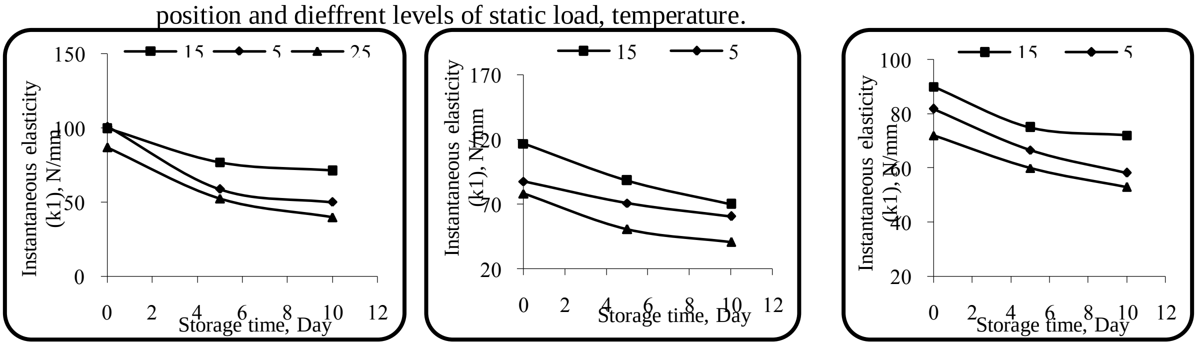
The average of the obtained Burger model constants for tomato.				
ITEM	*K_1 N/mm*	*K_2 N/mm*	*C_1 N.min/mm*	*C_2 N.min/mm*
L position	47.62	50	1500	609.75
D position	71.43	76.92	2500	821.21

The fresh tomato exhibited a straight-line relationship, which is typical of elastic materials, whereas the stored tomato showed a curve linear relationship below that of fresh tomato indicating the loss of firmness. It has been reported that these changes in the mechanical properties of tomatos during storage are due to loss of turgor pressure and other biochemical reactions and returned to change in room temperture which affect the cell wall and middle lamella of the tissue. And it has been found that the values of k_1 determined at different storage time decreased with increase in compression levels. From these data, in general, the instantaneous elasticity (k_1) is inversely proportional with storage time,



10 N 14 N 18 N

Fig.6. Relationship between instantaneous elasticity with storage time for tomato at longitudinal loading position and dieffrent levels of static load, temperature.

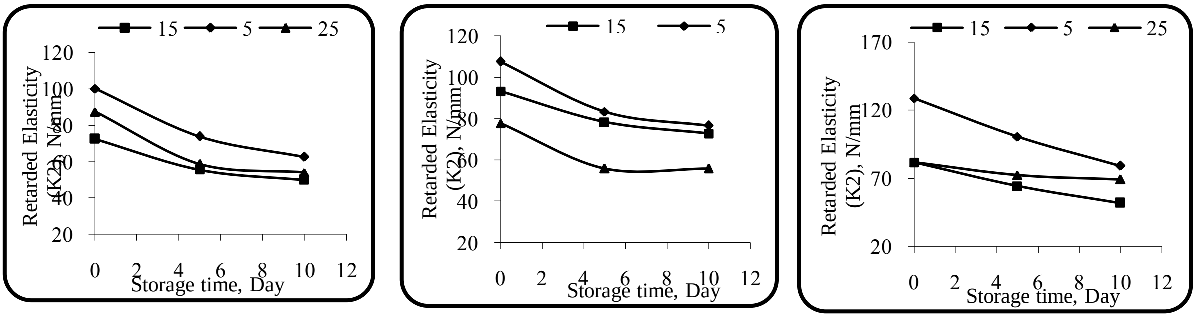


10 N 14 N 18 N

Fig.7. Relationship between instantaneous elasticity with storage time for tomato at diameter loading position and dieffrent levels of static load, temperature.

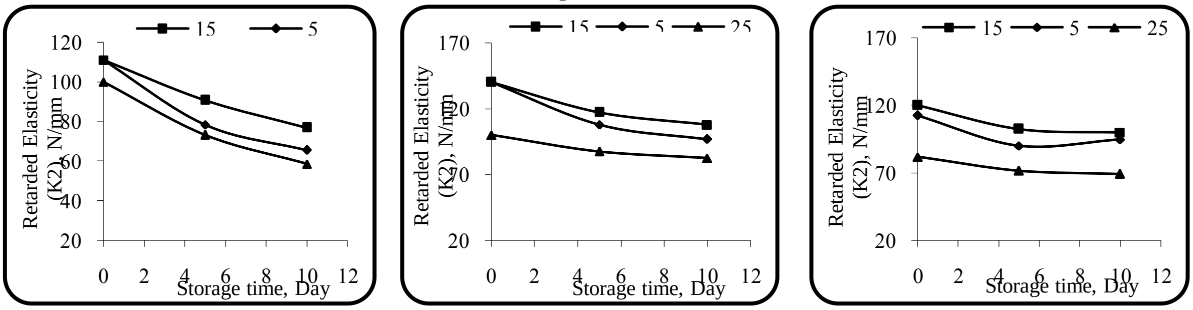
3.2. Retarded Elasticity (K_2), N/mm:

The results of the retarded elasticity (K_2) are presented in Figs. (8); (9). The results show that retarded elasticity (K_2) was decreased by increasing storage time at temperture levels. Its values increased as increasing temperture, its values increased as the static load increased from 10 N to 18 N. Significant differences between the retarded elasticity (K_2) values for all three levels of temperture were observed for all samples, and differences retarded elasticity as well as their interaction were significant in three loaded positions of fruit. In the same time, there were significant differences when using the three levels of load as affected by storage time. From these data, in general, the retarded elasticity (k_2) is inversely proportional with storage time.



10 N 14 N 18 N

Fig.(8) Relationship between retarded elasticity, with storage time for tomato at longitudinal loading position and dieffrent levels of static load, temperature.

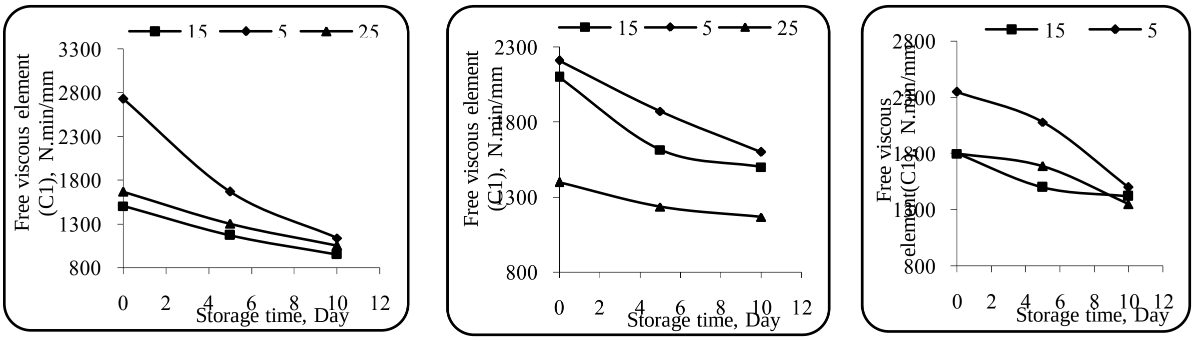


10 N 14 N 18 N

Fig.9. Relationship between retarded elasticity with storage time for tomato at diameter loading position and dieffrent levels of static load, temperature.

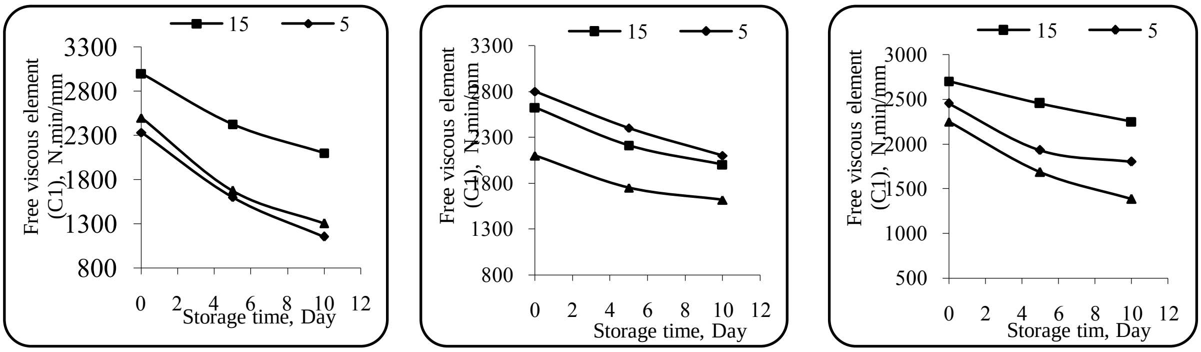
3.3. Free viscous element (C_1), N.min/mm:

The results of the free viscous element (C_1) are presented in Figs. (10); and (11). The results show that free viscous element (C_1) decreased by increasing storage time for tomato tested at levels of temperture. The free viscous element (C_1) values increased as incresing temperture, its values increased as the static load increased from 10 N to 18 N. Significant differences between free viscous element (C_1) values for all differenet temperture levels were shown for all fruits. Significan differences between free viscous element and the three positions of sample load. From these data, in general, the Free viscous element (C_1) is inversely proportional with storage time.



10 N 14 N 18 N

Fig.10. Relationship between Free viscous element with storage time for tomato at longitudinal loading position and dieffrent levels of static load, temperature.

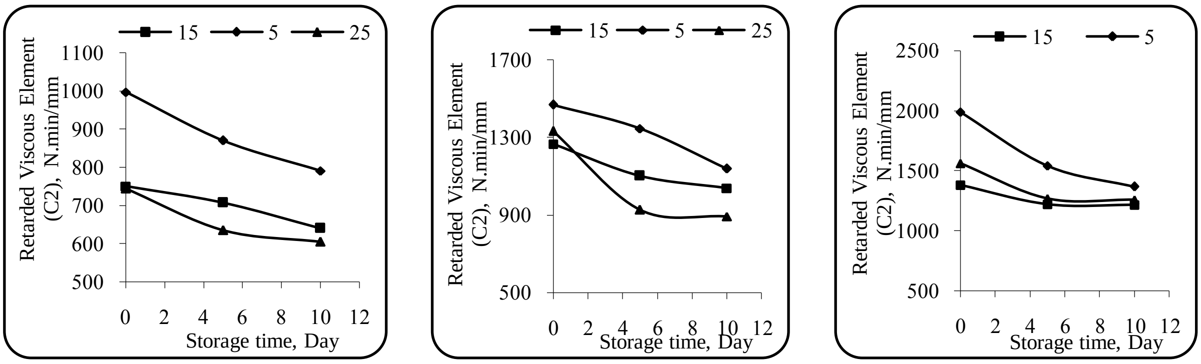


10 N 14 N 18 N

Fig.11. Relationship between Free viscous element with storage time for tomato at diameter loading position and dieffrent levels of static load, temperature.

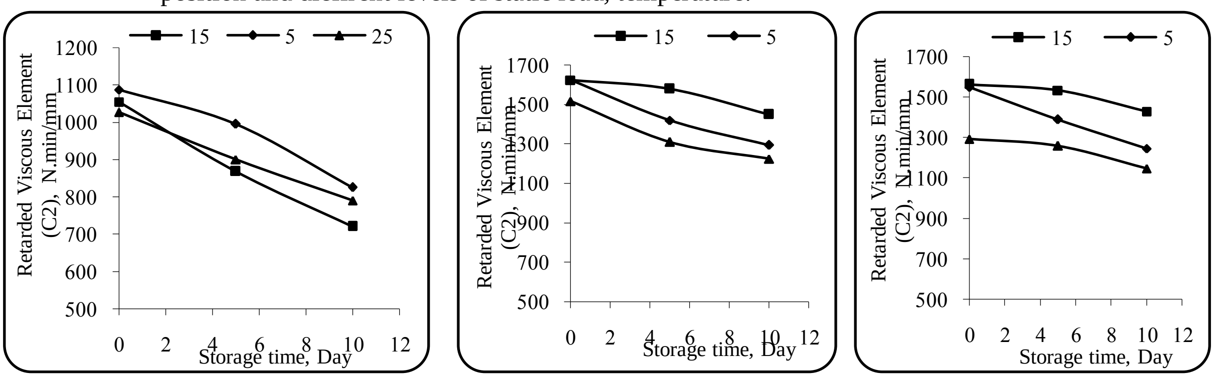
3.4. Retarded Viscous Element (C_2), N.min/mm:

The results of the retarded viscous element (C_2) are presented in Figs. (12) and (13). It is cleared that retarded viscous element (C_2) decreased by increasing storage time at temperture levels. The retarded viscous element at room temperture are highely than low room temperure than high room temperture . The retarded viscous element magnitudes increased by increasing the static load from 10 N to 18 N. Significant differences were shown among differenet at room temperture levels for all fruits. And differences in retarded viscous element as well as their interaction were significant in three loaded positions of fruit. From these data, in general, the retarded viscous element (C_2) is inversely proportional with storage time.



10 N 14 N 18 N

Fig.12. Relationship between retarded viscous element with storage time for tomato at longitudinal loading position and dieffrent levels of static load, temperature.



10 N 14 N 18 N

Fig.13. Relationship between retarded viscous element with storage time for tomato at diameter loading position and dieffrent levels of static load, temperature.

IV. CONCLUSIONS

A modified exponential model successfully represented the changes in the rheological properties of tomatoes due to storage under constant condition using creep tests. The changes in the rheological properties of tomatoes under fluctuating storage condition could be adequately described as a storage time. It is recommended to put the tomatoes in the packages on longitudinal position (L) so that it leads to less deformation under loads. Concerning temperature, the mean values of the rheological model constants were higher in magnitude when storing tomatoes in higher storage temperature than lower storage temperature. It was observed from the creep and retardation test for tomatoes that, the instantaneous deformation of the tested tomatoes when subjected to the constant load increased with time and also with storage time under all storage conditions in the investigation. When the tomato unloaded, the deflection happened due to the effect of the static load divided to two portions .One is not recoverable due to the fluid which has moved out of the cells .The other is recoverable which is probably due to the elasticity of the cell walls of the tomato.

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