Characterization of Viscoelastic Behavior of Ripe Deseeded Tamarind Subjected to Uniaxial Compressive Loading

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Authors' contributions

This work was carried out in collaboration among all authors. Author MS designed the study, performed the experiment and graphs, wrote the protocol and wrote the first draft of the manuscript. Authors DKV and MS managed the analyses of the study. Author AKP managed the literature and corrections in writing format. All authors read and approved the final manuscript.

Original Research Article

ABSTRACT

The creep behavior a rheological property of tamarind (*Tamarandus indica L.*) was studied to characterize the effect of compressive stress and time on volumetric reduction in ripe deseeded tamarind and creep curve developed using Kelvin model. Five different compressive stresses 222.95, 445.90, 668.86, 891.81 and 1114.77 N/m^2 were used and deformation was observed at different time intervals 0+, 5, 10, 20, 30, 45, 60, 90, 120, 180, 240, 300 and 360 minutes. Creep curve were plotted to demonstrate the volumetric strain variance for various time intervals. The slope of curve is sharp at the beginning and then with the increase in duration of loading the slope of curve flattened down which shows that the rate of change of volumetric strain for a given sample at a given stress is large at the beginning and with increase in the time, the rate of change becomes less and less. The volumetric strain with respect to variation of loading is maximum in case of maximum stress that was 1114.77 N/m^2.

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1. INTRODUCTION

Tamarind (*Tamarindus indica* L.) is a type of tropical fruit and it has an important role in traditional medicine. Tamarind pulp has been used for many medicinal purpose such as reducing appetite, a gargle for sore throats, wound dressing [1,2] and also for the restoring sensation in paralysis cases. The unique sweet or sour flavor of the pulp is popular in cooking and flavoring. The product can also be stored for long periods due to its moderate water activity and continues to be used by many people in Africa, Asia and America [3].

Ripe deseeded tamarind is a biological material, not behave either as perfect elastic or perfect plastic material. They exhibit both viscous [4] and elastic [5] properties simultaneously. So they come under the category of viscoelastic materials [6]. It is not so firm yet strong enough to bear large compression without any failure due to surface rupture because the ripe deseeded tamarinds are very flexible in nature. Immediate deformation under load in a biological material is due to its elastic nature, whereas the continuous deformation over time is due to the viscous flow of intercellular fluid under pressure with time [7, 8,9]. Hence the elastic component in kelvin model represented by spring is comparatively high to any other biomaterial. Also looking to the short season tamarinds are deseeded stored, processed and again stored in small containers. Thus providing an opportunity to investigate the depth of container for long term storage of ripe deseeded tamarind.

If a constant and relatively large stresses applied to the biological materials, the material will get starts deform with time. This slow and continuous deformation with time under a constant stress is known as creep [10]. This type of behavior is typical of fruits and vegetables. Further it exposes the fact that the strain exhibited by the agricultural material under test is not independent of time. Such time- dependent activity can have a significant effect on the accuracy of predicted fruit and vegetable damage rates during harvesting, handling, transportation and storage [11].

In the creep experiment, the sample gets rapidly deformed when the load is suddenly applied to the sample, imposing a strain on the material that continues to increase at a decreasing rate as a function of time [12]. Regardless of the sample size, when the sample is deformed in compression, the strain produced can decrease the sample height and result in an increase in the sample diameter to a value depending on the bulk modulus of the material [13]. In many cases the transverse strain can be ignored due to the partly compressible nature of the most agricultural products, resulting in negligible lateral strain when compared to the uniaxial strain [14]. A plot of deformation as a function of time results in a curve known as creep curve [6]. Works have done to study some physical properties of tamarind concentration juice [15] and rheological characteristic of tamarind concentration juice [16] but no study have found on the deformation with respect to time of ripe deseeded tamarind. The present investigation was therefore carried out to study the effect of compressive stress and time on the reduction of volume of ripe deseeded tamarind.

In this paper, we have explored the viscoelastic behavior of ripe deseeded tamarind subjected to uniaxial compressive loading. The objective of the work to study the effect of compressive stress and time on the reduction of volume of ripe deseeded tamarind. Creep curve and kelvins model develop for ripe deseeded tamarind were also studied.

2. MATERIALS AND METHODS

The present research work on "Characterization of viscoelastic behavior of ripe deseeded tamarind subjected to uniaxial compressive loading" was undertaken in the Department of Post-Harvest process & Food Engineering, College of Agricultural Engineering, JNKVV, Jabalpur.

2.1 Experimental Unit

Experimental unit used into this study was developed in laboratory [17]. A equipment which was consisted of a PVC cylinder of 38 cm depth, 16.6 cm internal diameter and 7 mm thickness was used to determine the volumetric strain of ripe deseeded tamarind. The internal surface of the PVC cylinder was provided with mirror shine smooth finish. The PVC pipe was fixed on a circular flat plate at the bottom to provide it a suitable base. A circular cover plate of diameter 16 cm and thickness 8 mm was provided to transmit the load uniformly all over cross–

sectional area of the cylinder. The diameter of the cover plate was kept slightly less than the internal diameter of the PVC cylinder and cover plate was kept free to move inside the PVC cylinder. The weight of cover plate was 300 g. Five loads made up of steel i.e. 500 g, 1000 g, 1500 g, 2000 g and 2500 g each with diameter less than that of cover plate were used. The dial calipers was used for measuring depth of the ripe deseeded tamarind.

Fig. 1. Experimental set-up

2.2 Ripe Deseeded Tamarind

In this experiment it was decided to use ripe deseeded tamarind for uniaxial compressive loading. The ripe deseeded tamarinds are usually springy in nature not so resilient yet strong enough to bear large compression without any failure due to surface rupture. Deseeded tamarinds are also flexible in nature [18] so elastic component in kelvin model represented by spring, comparatively high as compare to any other biomaterial. Also looking to the short season, the tamarinds were deseeded stored, processed and again store in small containers. Thus providing an opportunity to study the depth of container for long term storage of ripe deseeded tamarind. In this experiment tamarind (irrespective of variety) was purchase from local market of Jabalpur (M.P.).

2.3 Loads

In this experiment five loads mainly 500, 1000, 1500, 2000 and 2500 g were used. Loads were

taken from the commercial weight box. The load applied was noted in terms of stress applied in N/m^2 over a cross sectional area (0.022 m^2). The loads used was converted to stress applied resulting in following five different stresses 708.44, 885.54, 1062.65, 1239.76 and 1416.87 N/m^2.

2.4 Methodology

In this experiment five stresses applied was 708.44, 885.54, 1062.65, 1239.76 and 1416.87 N/m^2. A sample of ripe deseeded tamarind weighed in a balance to determine the mass was placed in the cylinder and it was allowed to settle. Then these tamarinds were covered with the cover plate. The depth of the cover plate was measured from the top of the cylinder just before and after the application of load at the four previously marked (diametrically opposite) points on the cylinder. The reading was used to represent the depth of the cover plate. This depth plus the thickness of the cover plate, when subtracted from the total depth of the cylinder will give the height of the sample present in the cylinder. In this experiment PVC cylinder was used which had area 0.006 m^2. The volume of the sample was calculated for each time interval (0+, 5, 10, 20, 30, 45, 60, 90, 120,180, 240, 300 and 360 minutes, 0+ is time just after applying the load). The change in volume (ΔV) of the cylinder, at all time interval (0+, 5, 10, 20, 30, 45, 60, 90, 120,180, 240, 300 and 360 minutes) with respect to its original volume (V_0) was also calculated. After change in volume (ΔV) the corresponding volumetric strain may be calculated.

The volume of cylinder was calculated by using the following relationship:

$$Vo = \pi r^2 l$$

Where,

V_0 = original volume of the cylinder (cm^3).
r = radius of cylinder (cm).
l = depth of grain inside the cylinder (cm).

The change in volume (ΔV) of the cylinder was calculated by using the following relations:

$$\Delta V = V_o - V_t$$

Where,

ΔV = change in volume of the cylinder (cm^3).
V_0 = original volume of the cylinder (cm^3).
V_t = volume at time t (cm^3).

Volumetric strain for all five sample for every time interval was calculated by using the relationship:

$$V_\delta = \Delta V/V_0$$

Where,

V_δ = volumetric strain.
ΔV = change in volume of the cylinder (cm³).
V_0 = original volume of the cylinder (cm³).

2.5 Statistical Analysis

Statistical analysis was performed to determine the correlation coefficient and polynomial equation using Microsoft Excel software. The graphical method was used to develop Kelvin model.

3. RESULTS AND DISSICUTION

It was found that the deformation of material was significant and hence, it could be measured at the time interval of 0+, 5, 10, 20, 30, 45, 60, 90, 120, 180, 240, 30 and 360 minutes after application of loads. Table 1 shows the observation of thus recorded at these time intervals.

The compressive stresses used were 222.95, 445.90, 668.86, 891.81 and 1114.77 N/m². Fig. 2 shows the graph between volumetric strain and duration of loading at different compressive stress ranging from 222.95 to 1114.77 N/m².

From the curve it was observed that the curve slope was steep at the beginning and then with the increase in the loading strain for a given sample at a given stress was high at the beginning and that as the time passes, the rate of change became less.

Also as the high value of the deformation coefficient (R^2= 0.838) indicates the relation between two variables i.e. change in volumetric strain with respect to time is strongly correlated. Initially the slope of the curve may be steep as the load is applied, the sample is rearranged and the air voids are reduced as well as the elastic deformation only initially takes place [18]. During later part of the stress application the curve slope flattened down, the explanation for the slope to flatten down with time can be due to the reduction of air voids and to the reduction of viscoelastic deformation with increasing time.

The equation for the Kelvin model [19] for biomaterials subjected to compressive load is given by:

$$\varepsilon = \frac{\sigma_0}{E} + (\varepsilon_0 - \frac{\sigma_0}{E})\, e^{\frac{-t}{\tau_{ret}}}$$

Where,

ε = strain at time t,
ε_0 = initial strain,
σ_0 = constant stress, N/m².
E = young modulus, N/m².
t = time, min.
τ_{ret} = retardation time, min.

Table 1. Average volumetric strain at different time interval for all five loading condition

Time(min)	Volumetric strain at differ stress				
	222.95 (N/m²)	445.90 (N/m²)	668.86 (N/m²)	891.81 (N/m²)	1114.77 (N/m²)
0.001	0.045	0.037	0.121	0.169	0.169
5	0.096	0.078	0.221	0.277	0.314
10	0.103	0.095	0.243	0.314	0.352
20	0.112	0.103	0.266	0.352	0.393
30	0.121	0.112	0.277	0.366	0.422
45	0.131	0.121	0.289	0.379	0.437
60	0.159	0.131	0.301	0.393	0.452
90	0.159	0.140	0.301	0.408	0.452
120	0.169	0.140	0.313	0.422	0.452
180	0.169	0.149	0.339	0.437	0.452
240	0.179	0.159	0.339	0.452	0.452
300	0.189	0.169	0.352	0.452	0.452
360	0.189	0.169	0.352	0.452	0.452

A tangent to the creep curve taken from the constant volumetric strain on the Y axis, as seen from (Fig. 3) gives the value of σ_0 /E as ''0.189''. Also as seen from initial strain at time 0+ that is just after the application of load the volumetric strain is 0.045. According to the definition the retardation time corresponds to the volumetric strain equal to sum of initial volumetric strain and 67% of difference of ε_0 and σ_0 /E which is '51 minutes'.

Putting all the values in above equation the Kelvin model obtained for compressive loading of ripe deseeded tamarind for stress of 222.95 N/m^2 is:

$$\varepsilon_{(222.95)} = 0.189 - 0.096 \cdot e^{\frac{-t}{51}}$$

From the above equation it is noted that for compressive stress of 222.95 N/m^2 the retarded deformation starts 51 minutes after the application of the stress. Similarly proceeding with the graphical method the Kelvin model was developed for all the remaining four stresses namely 445.90, 668.86, 891.81 and 1114.77 N/m^2.
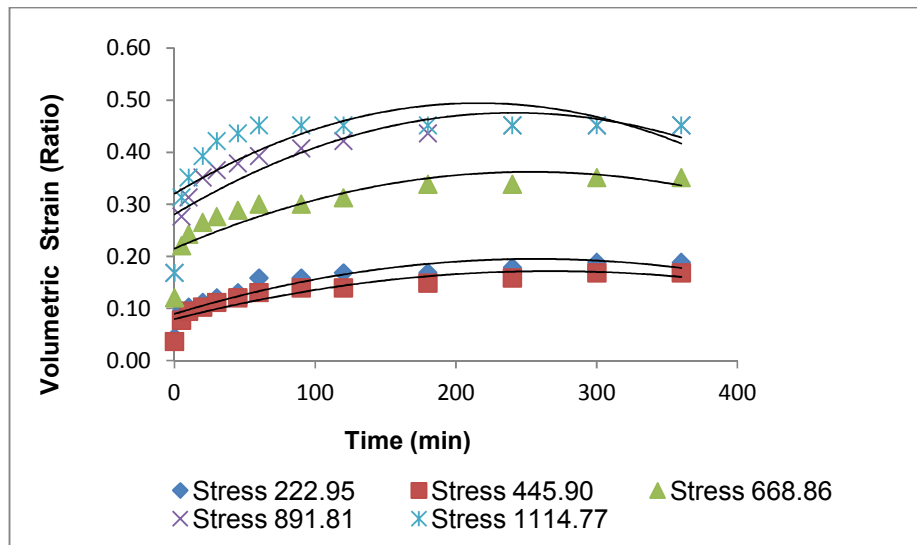

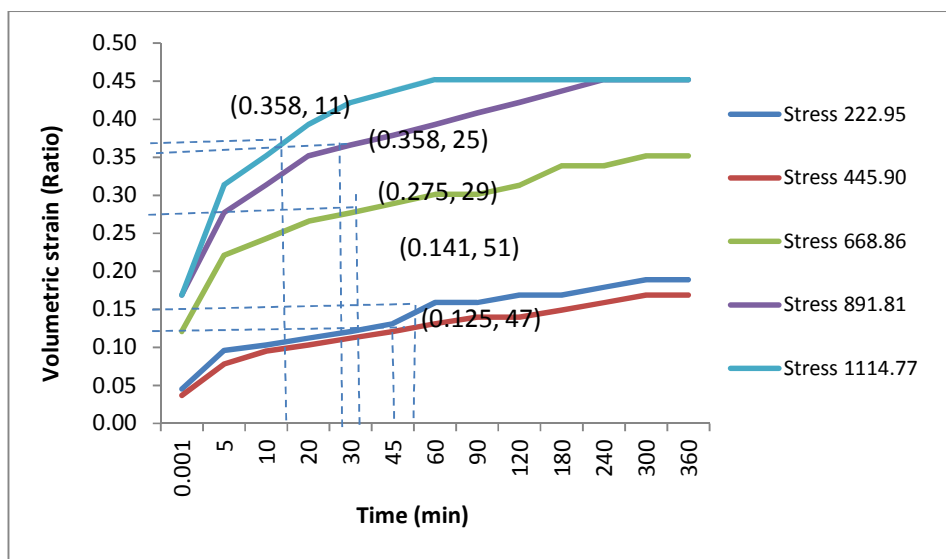**Fig. 2. Curve between volumetric strain and time**

Fig. 3. Curve between volumetric strain and time

Table 2. Kelvin model derived for all the five compressive stresses

SI .No.	Stress N/m^2	Kelvin model	Retardation time (τ_{ret}), min
1.	222.95	$\varepsilon_{(222.95)}=0.189\text{-}0.096.e^{\frac{-t}{51}}$	51
2.	445.90	$\varepsilon_{(445.90)}=0.169\text{-}0.088.e^{\frac{-t}{47}}$	47
3.	668.86	$\varepsilon_{(668.86)}=0.352\text{-}0.154.e^{\frac{-t}{29}}$	29
4.	891.81	$\varepsilon_{(891.81)}=0.452\text{-}0.189.e^{\frac{-t}{25}}$	25
5.	1114.77	$\varepsilon_{(1144.77)}=0.452\text{-}0.189.e^{\frac{-t}{11}}$	11
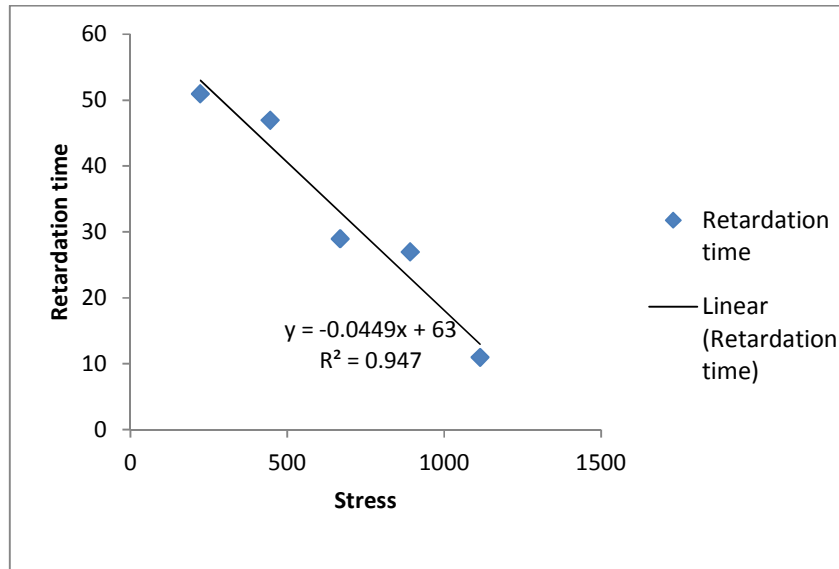
Fig. 4. Variation in time of retardation with different compressive stresses

From the Table 2 we can conclude that the retardation time decreases with increase in compressive stress and the delay time decreases with an increase in compressive stress. It is noted that the maximum retardation time of 51 minute corresponds to minimum compressive stress of 222.95 N/m^2, whereas the minimum retardation time of 11minutes corresponds to the maximum compressive stress of 1114.77 N/m^2. Also as seen from Fig. 4 the decrease in retardation time follows a straight line relationship with negative correlated coefficient with decreasing compressive stress. The straight line relationship is given by:

Y= -0.044x+63

The negative correlated coefficient value of (R^2 = 0.947) shows a strong association between retardation time and compressive stress.

The decrease in retardation time with increase in compressive stress may be because for higher value of compressive stresses, the elastic phase of deformation in ripe deseeded tamarind reduces faster as compared to that for smaller value of compressive stress which means for higher compressive stresses the viscous phase in deformation of ripe deseeded tamarind starts earlier.

4. CONCLUSION

The creep behavior of ripe deseeded tamarind was well represented by kelvin model. From the curve it was found that the slope is steep at the beginning and then with the increase in the loading period the curve slope flattened down which indicates that the rate of change of volumetric strain for a given sample at a given stress is high at the beginning and that as the time passes, the rate of change become less and less. It was noted from the Kelvin models the retardation time decreased from 51 minutes for 222. 95 N/m^2 to 11 minutes for 1114.77 N/m^2 and decrease in retardation time was found to have a

straight line relationship with a strong but negative correlation coefficient**.**

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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