International Journal of Scientific Engineering and Technology ISSN :2277-1581
Volume No.4 Issue No.9, pp: 466-471 01 Sept. 2015

Creep Properties of Local Variety of Lime (*Lemun tsami*) under Quasi-Static Loading

*** Dakogol, F.A; [1]Obetta, S.E and [1]Ijabo, O.J**
*Department of Agricultural and Bio-Environmental Engineering, Federal Polytechnic Nasarawa, Nasarawa State, Nigeria
[1] Department of Agricultural and Environmental Engineering, University of Agriculture, Makurdi, Benue State, Nigeria
*Corresponding author's Email: Dakogolaudu@gmail.com,

Abstract: Local variety of lime (Lemun tsami) was subjected to quasi-static compressive loading using Instron Universal Testing Machine at three levels of time after harvest; freshly harvested, one and two weeks after harvest. Creep parameters were determined by fitting the experimental data to the Burger's Model and the obtained model equation for freshly harvested was: $J(t) = 1.843 + 2.59[\,1 - e^{(-t/2.933)}\,] + \frac{t}{1160.093}$, $R^2 = 0.98$. The instantaneous creep compliance (J_o) was; 1.843, 3.137 and 4.116 1/MPa for freshly harvested, one and two weeks after harvest respectively while the corresponding instantaneous elasticity (E_o) was 0.543, 0.319 and 0.243 MPa respectively. Compliance increased with increase in time after harvest while elasticity decreased with time after harvest. The obtained free viscosity (η_o) was 1160.093, 808.407 and 808.859 MPas for freshly harvested, one and two weeks after harvest respectively. This was found to decrease with increase in time after harvest.

Keywords: ***Lime (Lemun tsami), Creep, compliance function, Retardation time, Instantaneous Viscosity***

I. Introduction

Lime (*Citrus aurantifolia*) is a citrus species with a globose fruit. It is the smallest as compared to other citrus species with a thinner rind. It has many uses; the juice is used to flavor food and cola drinks, preparation of pickles and sauces. Although the oil from its rind can irritate the skin because of its high acidic content, it has a lot of medicinal uses; it is antiseptic, antiviral, bactericidal and disinfectant (*Wikipedia, the free encyclopedia*) Despite the importance of lime, its production is said to be on the decline worldwide due to incidence of citrus canker (Hayley, 2014; Thomas, 2010). In Nigeria, there is little information on the engineering properties of the cultivar, this may be due to the fact that lime is used on a small scale as compared to other citrus cultivars as affirmed by Aiyelaagbe*, et al,*. (1996).

Lime is susceptible to injuries such as bruises, cuts, and puncture during harvesting, handling, packaging, transportation and storage. The situation is made worst by the transportation of this fruits in bulk in wagons under harsh environmental conditions and on bad roads. According to Nabil (2013), the knowledge of viscoelastic properties of fruits and vegetables do not only minimizing damage during harvesting, transportation and storage but also help in understanding physiological changes that take place in the fruit during growth, maturation, ripening and storage after harvest as well as assessment of product quality. Also, the knowledge of viscoelastic property of fruits is important in quality evaluation, equipment development and product processing.

Viscoelastic properties of fruits and vegetables are characterized by two distinctive phenomena; creep and stress relaxation. The major creep parameters include: Creep compliance function **J(t)**, a measure of relative ease with which a material can be deformed under a static load, retardation time (**T_{ret}**), the time taken for the material to deform to ($1 - \frac{1}{e}$) or about 63.2 % of the total deformation at rupture point under static load, and free viscosity (**η**).

The objectives of this work are to determine: (i) Creep compliance function **J(t)**, retardation time (**T_{ret}**), and Viscosity (**η**), at three levels of time after harvest (freshly harvested, 1 week and 2 weeks after harvest) respectively; and (ii) effects of time after harvest on these parameters.

Mathematical Model

The rheological model to represent the creep behavior of food and biological materials are described by the four element Burger's model (Mohsenin, 1986 and Kelly, 2011). In fig. 1, when a static load is suddenly imposed on the material, spring E_o is stretched suddenly by an amount (O – A) which is $\varepsilon_o = \sigma_o/E_o$. After this initial strain, ε_o, creep starts at a high rate but gradually slows down due to dashpot η_o resulting in retarded elastic behavior (A-B). After time, t, (at the end of loading), when the imposed load is removed spring E_o snaps back to its original state but spring E_r cannot contract to its original state instantaneously because of η_1 and η_o but does so gradually.

When the load is removed, the spring E_r slowly forces the plunger of dashpot η_1 back to its original position; however, since no force is acting on the dashpot η_o upon load removal, this element retains a non-recoverable displacement representing a permanent deformation in the material (Mohsenin, 1986).

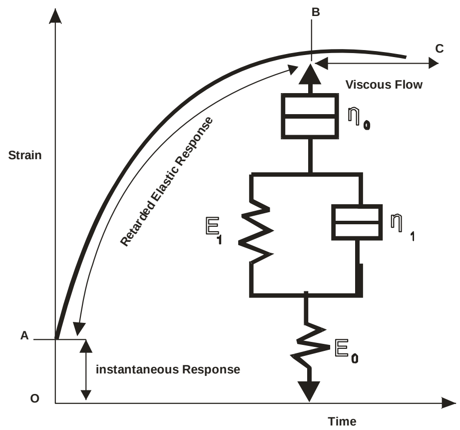

Fig.1: Mechanical Analogy of Four Element Burger's Model for a Typical Biological Material

The mathematical expression for Burger's Model is given by equation (1) (Mohsenin, 1986; Abd El-Maksoud, *et al.*, 2009; Kelly, 2011; Meyers, 2011)

$$\varepsilon(t) = \frac{\sigma}{E_o} + \frac{\sigma}{Er} + \frac{\sigma\, t}{\eta_o}\left[\, 1 - e^{(-t/Tret)}\right] + \frac{\sigma\, t}{\eta_o} \qquad .. \qquad (1)$$

II. Materials and Methodology

The local cultivar of lime (*Lemun tsami*) was obtained from Kaura Citrus Farm in Toto Local Government Area of Nasarawa State, North Central Nigeria. Four trees in plots of trees typical of the variety were selected from which fruits were harvested for the tests.

Some fruits were carefully handpicked from the trees while others were chipped off the three with a knife leaving a stalk 10 – 12 cm long and leaves removed (Coppock, *et al., 1969*); this is to maintain some level of physiological freshness for tests concerning freshly harvested. The fruits were kept cooled in a fruit shed by water spray while harvesting was going on; at the end of harvest (between 1.00 – 2.00 pm), they were then packed in cardboard boxes. The bottoms of these boxes were lined with foam to minimize mechanical injuries and sides perforated to reduce temperature and ethylene build up (Tabatabaekoloor, 2012).

They were transported the same day to Advanced Materials Laboratory of the Engineering Materials Development Institute (EMDI), KM 4, Ondo Road, Akure, Ondo State, Southwest Nigeria and stored in a cool room maintained at about 5 ^{o}C, and 87 % relative humidity immediately upon arrival at about 8.30 pm. Tests for freshly harvested was conducted at 7.30 am the following day (about 11 hours after harvest) while other tests were conducted after 7 and 14 days respectively.

Size and Shape

Dimensions of each specimen were determined on the three mutually perpendicular axes using a digital vernier caliper reading to 0.01mm. The fruits were characterized in terms of mean dimensions; major, intermediate and minor diameter were found to be 3.876 ± 0.409, 3.551 ± 0.291 and 3.512 ± cm respectively while geometric mean diameter and sphericity were respectively 3.640 ± 0.304 cm and 0.942 ± 0.042.

Creep Tests

Preliminary tests were first conducted on the samples to estimate the mean constant force that would produce deformation of about 63.2 % (equivalent of $1 - \frac{1}{e}$) of the total deformation at rupture point for each of the treatments (Mohsenin, 1986).

This was done by grouping the fruits into two, each group having nearly the same physical characteristics (size and sphericity). Surface moisture on the specimen was cleaned, and then placed axially in the Instron Universal Testing Machine (Model 3369, No. K334; 50 kN capacity) under parallel steel flat plate (Plate 1) and loaded to rupture point. Each test was replicated five times for each group at the rate of 1 mm/s and the mean force obtained. The same procedure was followed for all the treatments.

Having obtained the mean force and the corresponding deformation at rupture point for all the treatments, 63.2 % of the constant force obtained in the preliminary test was imputed in to the machine as static load for each group. Each specimen was loaded at 1 mm/s (with the 63.2 % mean load obtained in the preliminary test) for 920 s, the strain with time was automatically captured by the micro-computer of the machine (during loading only) and the corresponding constant stress (**σ_o**) of each specimen calculated using equation (2) according to Jatuphong, *et al.*, (2008)

$$\boldsymbol{\sigma_o} = \frac{Constant\ \ force\ \ (F_o)}{\text{Final Contact Area } (A_o)} \qquad .. \qquad .. \qquad (2)$$

Although the area of contact of test specimen varies during loading, the contact area registered by the machine at the end of loading was used (Jatuphong, *et al.*, 2008).

The test was replicated five times for each group for all the treatments and the mean strain at each time interval was obtained.

Creep Compliance.

Creep compliance (*J*) is the ratio of strain to stress ($\frac{\varepsilon}{\sigma}$) or the reciprocal of modulus ($\frac{1}{E}$), thus diving equation (1) by the calculated constant stress (**σ_o**) yields equation (3) which is the creep compliance function *J(t)*.

$$J(t) = J_o + Jr\left[\, 1 - e^{(-t/Tret)}\right] + \frac{t}{\eta_o} \qquad .. \qquad (3)$$

The mean creep compliance of each treatment is presented in Table 1.

III. Results and Discussions

ISSN :2277-1581
01 Sept. 2015

Table 1: Mean Creep Compliance (1/Mpa)

Time (s)	Time after Harvest (Days)		
	0	7	14
0	1.843	2.963	3.939
5	1.980	3.137	4.116
10	2.106	3.302	4.284
15	2.222	3.450	4.432
20	2.317	3.579	4.565
25	2.399	3.697	4.698
30	2.478	3.807	4.802
35	2.556	3.909	4.902
40	2.614	4.007	5.002
45	2.680	4.076	5.082
50	2.722	4.166	5.158
55	2.770	4.208	5.218
60	2.815	4.274	5.283
70	2.854	4.324	5.329
80	2.888	4.372	5.410
90	2.921	4.423	5.419
100	2.939	4.456	5.474
110	2.975	4.492	5.490
120	2.998	4.517	5.514
160	3.009	4.553	5.540
200	3.037	4.581	5.568
240	3.055	4.608	5.592
280	3.072	4.630	5.600
320	3.082	4.652	5.618
370	3.096	4.668	5.631
420	3.102	4.684	5.658
470	3.108	4.701	5.673
520	3.116	4.714	5.693
570	3.122	4.734	5.700
620	3.132	4.736	5.712
670	3.138	4.755	5.726
720	3.140	4.760	5.733
770	3.142	4.760	5.793
820	3.144	4.769	5.796
870	3.145	4.770	5.797
920	3.147	4.772	5.800

Creep Compliance – Time Curves

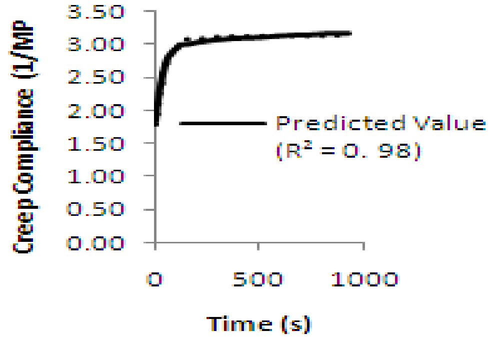

Fig.2: Creep Compliance of Freshly Harvested Lime

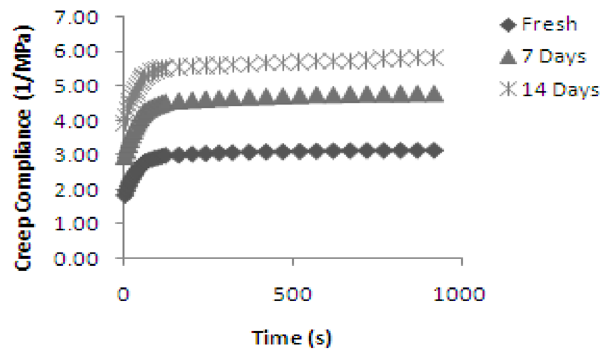

Fig.3: Variation of Creep compliance with time after harvest

Figs. 2 is the creep compliance – time curve of freshly harvested Lime while Fig. 3 is the variation of creep compliance with time after harvest.

Analysis of Creep Parameters from Creep Compliance – Time Curve

The Model parameters viz., instantaneous Compliance (J_o), instantaneous elasticity (E_o), Viscosity of the free dashpot (η_o), retarded compliance (***Jr***), retarded elasticity (***Er***), retarded viscosity (η_r), and retardation time (T_{ret}) were obtained from the Compliance data as illustrated by Fig. 4 following steps (i) – (vii)

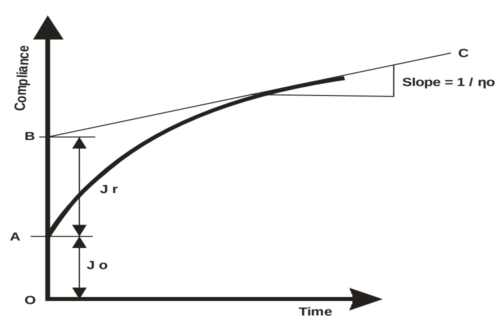

Fig.4: Graphical illustration for calculation of creep parameters

i) J_o = Instantaneous response (O - A). For freshly harvested, J_o = 1.843 MPa^{-1}

ISSN :2277-1581
01 Sept. 2015

ii) From $J_o = \frac{1}{E_o}$, $E_o = 0.543$ MPa

iii) The slope of the straight line portion of the curve (B - C) equals $\frac{1}{\eta_o}$ while the intercept gives ***Jr***. This was obtained by linear regression analysis using IBM ® SPSS ® Statistics, Version 20.0

For freshly harvested, the slope is 0.000862, therefore η_o= 1160.093MPas, the intercept is 2.592, therefore ***Jr*** = 2.592 MPa^{-1}

iv) From $J_r = \frac{1}{E_r}$, $E_r = 0.386$ MPa

v) However, retardation time (T_{ret}) was determined from the exponential portion of the curve (A – B) (Gorji, et al., 2010) whose equation is of the form:

$J(t) - J_o = Jr\,[\,1 - e^{(-t/Tret)}]$

Re-arranging and taking log on both sides gives equation (4) $Ln\left[1 - \frac{J(t) - Jo}{Jr}\right] = \frac{t}{Tret}$ .. ..(4)

Inserting appropriate values, T_{ret} = 2.933 sec.

vi) From $T_{ret} = \eta_r / E_r$, η_r = 0.113 MPas.

vii) Putting these model parameters in equation (3) gives equation (5) for freshly harvested cultivar

$J(t) = 1.843 + 2.59[\,1 - e^{(-t/2.933)}\,] + \frac{t}{1160.093}$, $R^2 = 0.98$ .. .. .. (5)

This procedure was followed and the parameters obtained for all the treatments are presented in Table 2.

Table 2: Creep parameters for Lime

Parameters	Time after Harvest		
	Fresh	1 week	2 weeks
Jo (1/MPa)	1.843	3.137	4.116
Eo (MPa)	0.543	0.319	0.243
Jr (1/MPa)	2.592	3.965	4.956
Er (MPa)	0.386	0.252	0.202
ηr (MPas)	0.113	0.189	0.886
Tret (s)	2.933	3.75	4.386
ηo (Mpas)	1160.093	808.407	808.859

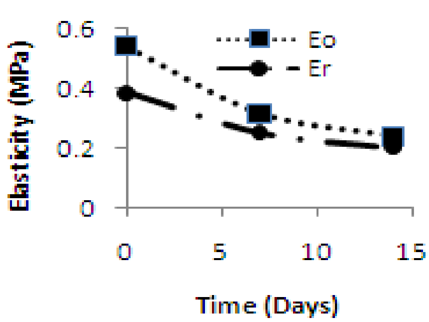

Fig. 5: Variation of Instantaneous and Retarded Elasticity with time after Harvest

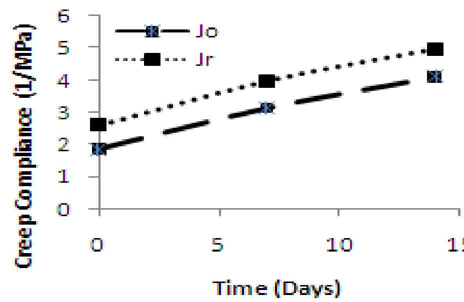

Fig. 6: Variation of Instantaneous and Retarded Compliance With Time After Harvest

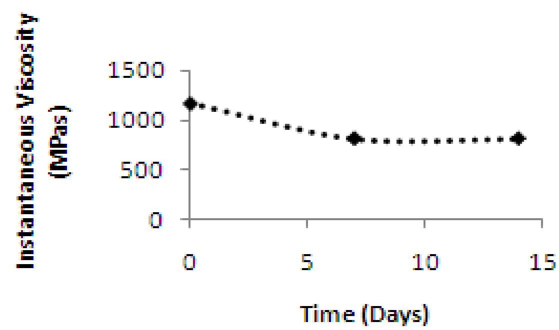

Fig. 7: Variation of Viscosity (η_o) with Time after Harvest

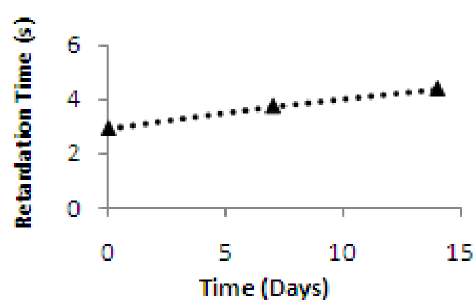

Fig. 8: Variation of Retardation Time (T_{ret}) With Time after Harvest

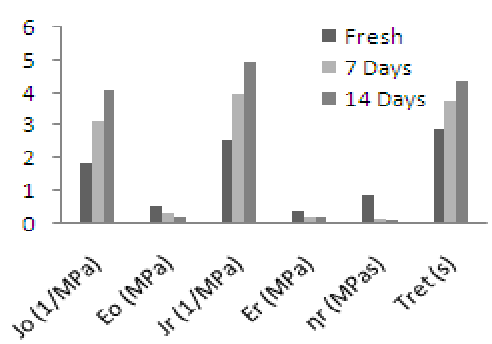

Fig. 9: Variation of Creep Parameters with time after harvest.

Fig.2 shows that creep compliance has an initial exponential increase with time but levels off as time increases to infinity. This means that as the static load is suddenly applied, it is initially borne by both the elastic and viscous components to a point where the elastic component ceases; where the viscous component dominates resulting in the curve leveling off as affirmed by Gorji *et al.*, (2010) for apple and Mohsenin (1986) for most fruits and vegetables. Fig. 3 shows the variation of compliance curve with time after harvest.

Instantaneous elasticity was found to be 0.543, 0.319 and 0.243 MPa for freshly harvested, 7 and 14 days after harvest respectively; while retarded elasticity was 0.386 0.252 and 0.202 MPa for the corresponding time after harvest. However, Gorji *et al.*, (2010) obtained from prepared samples of two varieties of Apple (*Golab* and *Shafi Abadi)* loaded at 25.4 mm/min an instantaneous elasticity of 714.28 and 400 MPa respectively, while the retarded elasticity was 7.7 and 7 MPa repectively.

The differences between the values of instantaneous elasticity obtained for Lime as compared to Apple may be due to the differences in the internal structures of the fruits. According to Panmanas and Charoonpong (2012), unlike most fruits whose internal structures are homogeneous, citrus fruits have high compartmentalized internal structure; juice sacs (which contain juice) are enclosed in a segment covered by a tough lamella, these segments are enclosed in a rind made up of *Albedo* (which has white spongy texture) and *Flavedo* (greenish part dotted with oil glands. These structures give the fruits its high elastic property.

In fig. 5, both elasticity (E_o, and E_r,) decreased with time after harvest. This is similar with what Nabil (2013) and Ayman, *et al.*, (2012) observed in Tomato fruits and Pears respectively during storage; that both instantaneous and retarded elasticity of these fruits decreased with time of storage. Nabil (2013) stated that the obtained values of both instantaneous and retarded elasticity for Tomato fruits were found to be inversely proportional with storage time. This phenomenon may probably due to ripening process. According to Naoki and Donald (1997), elasticity in fruit tissues change as a function of fruit ripening; during ripening, the polysaccharide constituents (cellulose, pectin) in cell walls are degraded by wall hydrolyzing enzymes thus softening the textural properties of the fruits.

Instantaneous Creep Compliance (J_o) was found to be 1.843, 3.137, and 4.116 1/MPa for freshly harvested, 7 and 14 days after harvest respectively; while retarded Compliance (J_r) was 2.592, 3.965 and 4.956 1/MPa for the corresponding time after harvest.

I n Fig. 6, the following were observed: (i) the values of instantaneous compliance (J_o), was greater than that of retarded compliance (J_r) for the period under review. This is because the J_o represents the elastic component (with higher relative ease to deform and recover) while the J_r is a combination of viscous and elastic component. (ii) Both instantaneous and retarded compliance increased with time after harvest. This may probably be due to ripening process; according to Naoki and Donald (1997), the polysaccharide constituents (cellulose, pectin) in cell walls are degraded by wall hydrolyzing enzymes during ripening thus softening the textural properties of the fruits.

Instantaneous viscosity (η_o) was found to be 1160.093, 808.407 and 808.859 MPas for Freshly harvested, 7 and 14 days after harvest respectively. However, for two varieties of Apple (*Golab* and *Shafi Abadi*) loaded at 25.4 mm/min; Gorji *et al.*, (2010) obtained η_o = 2000 MPas for both varieties when freshly harvested while for Tomato fruits, Nabil (2013) obtained values of 1500 and 2500 N.min/mm for axial and longitudinal loading positions respectively. These differences in values of the three crops may not be unconnected with differences in their internal structures as earlier explained. In fig. 7, the instantaneous Viscosity (η_o) decreased with increase in time after harvest, this is in accordance with what Nabil (2013) obtained for Tomato fruits.

The retardation time were found to be 2.933, 3.750, 4.386 s for freshly harvested, 7 and 14 days after harvest respectively. However, Gorji *et al.*, (2010) obtained retardation values of 12 and 15 s for varieties of apple, *Golab* and *Shafi Abadi* respectively. This implies that *lemun tsami* has the ability to deform within a short time period and also recovers at the same time period upon removal of the imposed load. In comparison, *lemun tsami* is more elastic than Apple. In fig. 8, retardation time (T_{ret}) increased as time after harvest increases. Fig. 9 shows a graphical variation of creep parameters with time after harvest.

IV. Conclusion

From the results obtained, *Lemun tsami* is best handled when fresh; for at this state, it has relatively less tendency to deform under dead load (**Jo = 1.843** 1/MPa), more elastic (E_o = 0.543 MPa) and can dissipate internally imposed strain at a relatively short time (T_{ret} = 2. 933 s).

Acknowledgment

The authors wish to thank in a special way the Management of Engineering Materials Development Institute (EMDI) Akure, Ondo State, Nigeria for the use of their facilities and equipment most especially the Universal Testing Machine. Similarly, the co- operations and assistance received from staff of Advanced Materials Laboratory of the Institute are highly appreciated.

REFERENCES

i. *Abd El-Maksoud, M.A.; Gamea, G.R. and Abd El-Gawad, A.G (2009). Rheological Constants of the Four Elements Burgers Model for Potato Tubers Affected by Various Fixed Loads Under Different Storage Conditions. Misr Journal of Agric. Engineering; 26(1): 359-384.*

ii. *Abdullah, A.; Hussain, S.; Diaeldin, A and Mahmoud, Y (2014). Creep Behavior forEight Dates Cultivars at Two Different Maturity Stages. International Journal of Research in*

ISSN :2277-1581
01 Sept. 2015

Engineering and Technology (IMPACT: IJRET) 2(3): 2347 – 4599. www.impactjournals.us

iii. Abdullah, M.H.R.O; Ch'ng, P.E; and Yunus, N.A (2009). Some Physical Properties of Musk Lime (Citrus Microcarpa). World Academy of Science, Engineering and Technology. Pp 1079 - 1082. http://www. Retrieved: 22/6/2013.

iv. Aiyelaagbe, I. O.O.; Afolayan, S.O; Odeleye, O.O; Ogungbayigbe, l.O and Olufolaji, A.O (1996). Citrus Production in the Savannah of Western Nigeria: Current Status and Opportunities for Research Input. http://www.citrus_production in Nigeria.org. Retrieved: 08/05/2014.

v. Ayman, H. A. E; Abdul, R. O. A; and Mostafa, M. A (2021). Mathematical Evaluation Changes in Rheological and Mechanical Properties of Pears During Storage Under Variable Conditions. Journal of Food Science and Engineering. 2(2012) 564 – 575.

vi. Coppock, G.E; Hedden, S.L and Lenker, D.H (1969). Biophysical Properties of Citrus Fruit Related to Mechanical Harvesting. Transactions of the ASAE. Vol. 12(4): 561-563.

vii. Gorji, A. C.; Rajabipour, A. and Mobil, H. (2010). An isotropic Relaxation and Creep Properties of Apples. Advance Journal of Food Science and Technology. 2(4): 200-205.

viii. Hayley, B (2014). Citrus Profile: Agricultural Marketing Resource Centre (Ag MRC), a National Information Resource for Value Added Agriculture. http://en.wikipedia.org/wiki/citrus_production. cfm.htm. Retrieved: 08/05/2012.

ix. Jatuphong, V.; Chanisara, N.; Tipaporn, K. and Adisorn, P. (2008). Changes in Viscoelastic Properties of Longan During Hot-air Drying in Relation to its Indentation. http://www .oaae.go.th/statistic/export/130ILOD. Retrieved 13/07/2011.

x. Kelly,S.A(2011).RheologicalModels.http://en.wikipedia.org/wiki/rheological models/. Retrieved: 14/6/2012

xi. Meyers,C.(2011).KelvinVoight Material. http.//en.wikipedia.org/kelvina voight_material. Retrieved: 30/05/2011.

xii. Mohsenin, N.N. (1984). Physical Properties of Food and Agricultural Materials: A Teaching Manual. Gordon and Breach Science Publishers, INC. New York.

xiii. Mohsenin, N.N. (1986). Physical Properties of Plant and Animal Materials. Gordon and Breach Press, NewYork.

xiv. Nabil, S. A. (2013). Rheological Behavior of Tomato Fruits Affected by Various Loads Under Storage Conditions. American Journal of Engineering Research (AJER) 02(03): 36 – 43.

xv. Naoki, S and Donald, J. N (1997). Relationship Between Fruit Softening and Wall Polysaccharides in Avocado (Persea Americana Mill) Mesocarp Tissues. Journal of Plant Cell Physiology. 38(5): 603 – 610. http://pcp.oxfordjournals.org/by guest on June 18,2015.

xvi. Panmanas, S and Charoonpong, T (2012). Physicochemical and Textural Properties of Pomelo (Citrus Maxima. Merr. Cv. Kao Nam Pueng) Fruit at Pre-harvest, Postharvest and During the Commercial Harvest Period. The Philippine Agricultural Scientist. Vol. 95(1), 43-52.

xvii. Tabatabaekoloor, R (2012). Orange Responses to Storage Conditions and Polyethylene Wrapped Liner. Agric. Eng. Int: CIGR Journal Vol. 14(2): 127-130. Open Access: http.//www.cigrjournal.org. Retrieved: 22/6/2013.

xviii. Thomas, H.S (2010). Projections of World Production and Consumption of Citrus to 2010. http://en.wikipedia.org/wiki/citrus_production. Retrieved: 08/05/2014.

xix. Wikipedia,Lime(fruit),thefree encyclopedia. https://en.m.wikipedia.org/ Retrieved June, 17 2015.

Fig. 1: Lime undergoing quasi-static compression