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Research Article

Effects of Time after Harvest and Rate of Loading on Force Relaxation Behaviour of Local Variety of Grapefruit (*LemunTaba*)

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Abstract: Force relaxation properties of a local variety of grapefruit (*Lemuntaba*) was determined under quasi-static compression loading using Instron UTM at three levels of time after harvest (freshly harvested, 7 days and 14 days after harvest) and three rates of loading (10, 5, 1 mm/s) for freshly harvested and 10 mm/s for one and two weeks after harvest. Fitting the obtained data for freshly harvested, loaded at 10 mm/s to a three-term Maxwell model; the resulted model equation was of $F(t) = 743.521e^{-t/1.843}+592.817e^{-t/0.007}+474.254e^{-t/0.008}$, $R^2 = 0.97$. For freshly harvested loaded at 10 mm/s, the force relaxed (decayed) from an initial value of 2435.647 N to 743.521 N; about 69.473% in 1.834 s; Similar phenomenon was observed for other treatments. From the results, it can be deduced that when this cultivar is loaded with about 65% of the total force at rupture, about 69% of the imposed load will be dissipated upon removal of that in about 1.8 s; an evidence of high elasticity.

Keywords: Decay modulus, force, grapefruit (lemuntaba), relaxation, relaxation time

INTRODUCTION

Stress relaxation of food and biological material is a measure of the rate at which the same material dissipates stress after being subjected to a sudden load. The principle of stress relaxation is widely used in fruits and vegetable industries as well as food industries generally, the knowledge of stress relaxation parameters is used in the design of containers, i.e., the number of stack of fruits and the maximum depth of container to minimize mechanical damage due to dynamic or vibration loading while in transit and in store (Mohsenin, 1986).

Grapefruits (*citrus paradisi*) are a subtropical citrus fruits known for its bitter taste, it could be yellow-orange in colour when ripe; the flesh is segmented and is generally acidic. It ranges from 10-15 cm in diameter depending on the cultivar. The primary varieties include: Ruby Red, Pink, Thompson, Marsh and Duncan.

Grapefruit is an excellent source of many nutrients and phytochemicals that contribute to a healthy diet. It forms an essential part of a balanced diet as it is an important source of digestible carbohydrates, minerals and vitamins; particularly vitamins A and C. In addition, it provides roughage (indigestible carbohydrates) which is needed for normal healthy digestion. The juice helps lower cholesterol level in humans as well as assisting the body's metabolism to burn fats and is an antioxidant; the seed extract has strong anti-microbial properties against fungi and bacteria (*www/Grapefruit-Wikipedia*, *the free encyclopedia*).

Plate 1: Hand picking of grapefruits

Grapefruit, just as other fruits is essentially a perishable commodity, it begins to deteriorate as soon as it is harvested and is particularly prone to handling damage at all times. In general, the level of susceptibility of grapefruits to handling damage is greatly underestimated because the effects of mishandling do not appear until sometimes after the damage had occurred.

The physical and mechanical characteristics of grapefruit (*citrus paradisi*) for temperate regions are well documented (William, 1986) but the viscoelastic properties such as force relaxation and creep are rare if not completely absent for local varieties such as

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Lemuntaba (Plate 1) hence the near absence of handling and processing equipment and the huge losses of the variety that is often encountered. Given the growing economic and nutritional importance of this tropical local variety, it is imperative that viscoelastic properties of the variety be determined accurately so that handling, packaging and transportation systems are designed with utmost efficiency to minimize losses.

The objective of this study is to determine the relaxation parameters (force relaxation, decay modulus and relaxation time) of *Lemuntaba* at three levels of loading (10, 5 and 1 mm/s, respectively) and at three levels of time after harvest (freshly harvested, 7 and 14 days).

In stress relaxation, the test specimen is suddenly brought to a given deformation (strain) and the stress required to hold the deformation constant is measured as a function of time (Mohsenin, 1986; Anazodo, 1982; Golacki *et al*., 2007; Marco *et al*., 2007; Burubai *et al*., 2009a, 2009b).

It is worthy to note that the initial deformation of the material must be less than the deformation at failure of the test specimen; however, it should be high enough to impose considerable strain on the specimen. It should be at least 65% of the total deformation at failure (Anazodo, 1982).

The most important viscoelastic parameters which can be obtained from a stress relaxation test are decay stress (σ_d) or decay modulus (E_d), equilibrium stress (σ_e) or equilibrium modulus (E_e) and time of relaxation (T_{rel}) (Khazaei and Mann, 2004; Pallottino *et al*., 2010). Relaxation time is the time at which the stress in a body resembling a simple Maxwell model decays to 1/e of the initial stress (Mohsenin, 1986). It is a measure of the rate at which a material dissipates stress after receiving a sudden force.

Mathematical models: In modeling stress relaxation of biological materials, a generalized Maxwell model with two or three elements is often used. Although when using generalized Maxwell model to characterize food and biological materials, most researchers used 'stress' (Pallottino *et al*., 2010; Anazodo, 1982); however, because the actual contacting surface area of food material continually changes under applied load making it difficult to calculate exactly the 'true stress' values from the beginning of compression to rupture point, 'stress' can be replaced by any other decaying parameter such as force, modulus of elasticity, (Khazaei and Mann, 2004; Gorji *et al*., 2010); so generalized Maxwell's model for force relaxation can be represented by Eq. (1):

$$F(t) = \sum_{i=1}^{n} Fi\,(e^{-t/Ti}) \tag{1}$$

where, T_1, T_2, … T_n are the relaxation time constants corresponding to various Maxwell model elements, F_1, F_2. F_n are the decay forces and $F_{(t)}$ is the instantaneous force.

MATERIALS AND METHODS

Materials: Grapefruits used for this study were obtained from Kaura CitrusFarm 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 tree 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 packed in cardboard boxes at ambient temperature of 27°C and 78% relative humidity as shown in Plate 2. 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). In addition, the heat of respiration is removed through these perforations.

The fruits 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°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 h after harvest) while other tests were conducted after 7 and 14 days respectively.

Methods:

Dimensions: Dimensions of 100 freshly harvested fruits were determined on three mutually perpendicular axes using a digital vernier caliper reading to 0.01 mm and the results presented in Table 1.

Preliminary tests: Because of variations in sizes, the fruits were grouped into two based on geometric mean diameter (nearly the same physical characteristics): For freshly harvested for example, the range of the

Plate 2: Grapefruits to be loaded in to a cushioned perforated Carton

Plate 3: Grapefruit placed axially between parallel compression tools of the universal testing machine

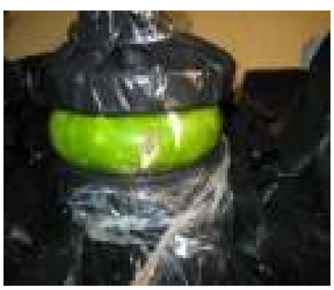

Plate 4: Grapefruit loaded to rupture

Table 1: Physical properties of grapefruit

Statistics	Major Dia. (cm)	Inter. Dia (cm)	Minor Dia (cm)	G.M Dia. (cm)	Sphericity (φ)
No. Samp.	100	100	100	100	100
Mean	10.382	10.068	9.363	9.924	0.957
Std Dev.	0.863	0.754	0.767	0.727	0.026
Min. Val.	8.745	8.645	7.400	8.240	0.891
Max. Val.	12.475	11.670	10.730	11.119	0.995

geometric mean diameter of the first and second group were 8.240-9.799 and 9.899-11. 119 cm, respectively. Five fruits from each group were randomly selected, cleaned of any surface moisture, placed centrally (axially) in the Instron Universal Testing Machine (Model 3369, No. K334; 50 kN capacity) under parallel steel flat plate (Plate 3); however, to avoid spillage of citrus juice (which is acidic) on the platform of the machine, it was covered with plastic sheet and loaded to rupture point (Plate 4). For freshly harvested, the samples were loaded at 10, 5 and 1 mm/s respectively while for 7 and 14 days after harvest, the samples were loaded at the rate of 10 mm/s. The mean load at rupture for each group was determined and 65% of this load used.

Relaxation test: For each test, 65% of the value of force obtained in the preliminary test was imputed in to the machine and fruits in each group deformed at the set loading rates (10, 5 and 1 mm/s for freshly harvested and 10 mm/s for 7 and 14 days after harvest) (Khazaei and Mann, 2004). The machine automatically stopped when the set value of force is reached, then force decay with time was recorded at time intervals as in Table 2. The duration for each test was 300 sec (Pallottino *et al*., 2010; Jatuphong *et al*., 2008), though the duration of the test could be as long as possible since the

Table 2: Effect of time after harvest and rate of loading on force relaxation (N)

	Freshly harvested			1 Wk after harv.	2 Wks after harv.
Time (sec)	10 mm/s	5 mm/s	1 mm/s	10 mm/s	10 mm/s
0	2435.647	2433.459	2430.987	2215.033	1926.191
1	2428.071	2425.891	2423.419	2207.582	1918.866
2	2424.258	2422.109	2419.637	2203.859	1915.206
3	2421.762	2419.449	2416.968	2201.378	1912.767
4	2419.870	2417.559	2412.078	2199.517	1910.938
5	2418.356	2416.047	2410.566	2198.029	1909.475
6	2417.095	2414.787	2409.306	2196.789	1908.256
7	2416.014	2413.707	2409.104	2195.726	1907.211
8	2415.068	2412.762	2408.716	2194.796	1906.297
9	2414.227	2411.922	2408.414	2193.969	1905.485
10	2413.386	2411.166	2408.162	2193.225	1904.754
12	2412.630	2410.536	2407.946	2192.605	1904.145
14	2412.000	2409.996	2407.757	2192.074	1903.623
16	2411.460	2409.524	2407.589	2191.609	1903.166
18	2410.987	2409.104	2407.438	2191.196	1902.760
20	2410.567	2408.716	2407.301	2190.824	1902.395
25	2410.189	2408.414	2407.175	2190.527	1902.103
30	2409.886	2408.162	2407.067	2190.279	1901.859
35	2409.583	2407.946	2406.973	2190.067	1901.650
40	2409.331	2407.757	2406.889	2189.881	1901.467
45	2409.079	2407.589	2406.813	2189.716	1901.305
50	2408.863	2407.438	2406.744	2189.567	1901.159
55	2408.647	2407.301	2406.681	2189.432	1901.026
60	2408.446	2407.175	2406.623	2189.308	1900.904
70	2408.246	2407.067	2406.569	2189.202	1900.800
80	2408.057	2406.973	2406.519	2189.109	1900.709
90	2408.000	2406.889	2406.472	2189.026	1900.628
100	2407.832	2406.813	2406.428	2188.952	1900.555
110	2407.664	2406.744	2406.386	2188.884	1900.485
120	2407.508	2406.681	2406.346	2188.822	1900.424
130	2407.357	2406.623	2406.308	2188.765	1900.368
140	2407.206	2406.569	2406.274	2188.712	1900.316
150	2407.109	2406.519	2406.187	2188.662	1900.267
160	2406.961	2406.472	2406.089	2188.616	1900.221
170	2406.839	2406.428	2405.980	2188.572	1900.178
180	2406.719	2406.386	2405.780	2188.531	1900.137
190	2406.610	2406.346	2405.700	2188.492	1900.099
200	2406.503	2406.308	2405.612	2188.455	1900.062
220	2406.398	2406.274	2405.601	2188.421	1900.029
240	2406.298	2406.243	2405.589	2188.390	1899.999
260	2406.202	2406.214	2405.58	2188.361	1899.971
280	2406.111	2406.187	2405.565	2188.334	1899.945
300	2406.108	2406.162	2405.501	2188.309	1899.921

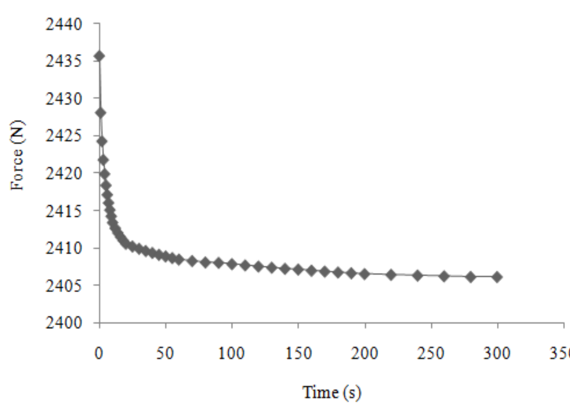

Fig. 1: A typical force relaxation curve of fresh grapeloaded at 10 mm/s

theoretical time is infinity (Mohsenin, 1986). Each test was replicated ten times and the mean value of the decay forces for each rate of loading are as presented in Table 2.

The decay force versus time was then plotted. Figure 1 shows a plot of Force versus time of freshly harvested, loaded at 10 mm/s; Fig. 2 are plots of the experimental and predicted values, while Fig. 3 and 4 are Force-Relaxation curves at different rates of loading and times after harvest respectively.

Coefficients of maxwell model: There are a number of methods for estimating the Maxwell coefficients (decay stress, modulus, force and relaxation times) some of which include; Successive Residual method (Anazodo, 1982; Mohsenin, 1986), Gussian or Normalized Distribution Method (Mohsenin, 1986; Burubai *et al*., 2009a) and the use of soft ware computer packages such as: SIGMAPLOT (Khazaei and Mann, 2004); TableCurve^{TM}2D v4.0 (Marco *et al*., 2007; Gorji *et al*., 2010); X-port^{R}-2009 (Pallottino *et al*.,

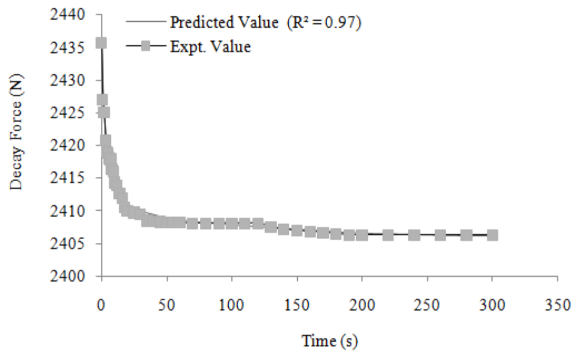

Fig. 2: Experimental and predicted force relaxation curve for fresh fruit loaded at 10 mm/s

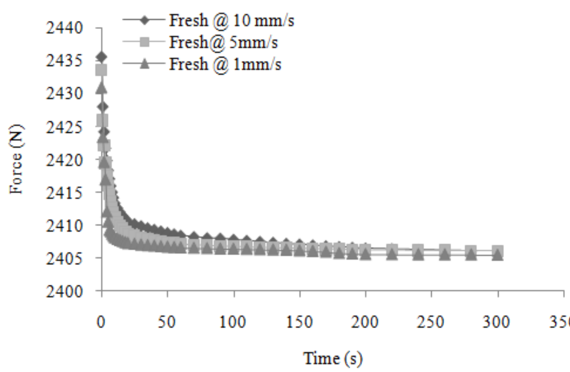

Fig. 3: Force-relaxation curve at different rate of loading for fresh grapefruit

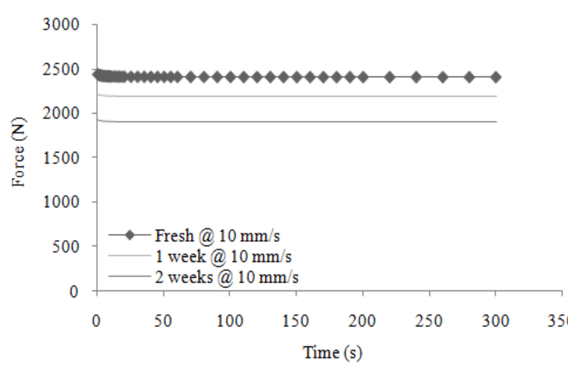

Fig. 4: Force-relaxation curve for different time after harvest

2010) and written computer algorithms (Mohsenin, 1986; Golacki *et al*., 2007).

As noted by Khazaei and Mann (2004), a three-term Maxwell model involving six constants are sufficient for many biological materials, thus a three-term Maxwell model expressed by Eq. (2) was used:

$$F(t) = F_1 e^{-t/T1} + F_2 e^{-t/T2} + F_3 e^{-t/T3} \quad (2)$$

where, F_1, F_2, F_3 are decaying forces; T_1, T_2, T_3 are the relaxation time constants and $F(t)$ is the instantaneous force at any time, t.

The Coefficients F_1, F_2, F_3; and T_1, T_2, T_3 were obtained by non-linear regression analysis by iteration method using IBM © SPSS ® Statistics, Version 20.0. The following procedures were followed:

- A scatter plot diagram of Force versus Time for each condition was plotted as in Fig. 1
- The curve was segmented into three based on change in shape
- Linear regression analysis of force-time data of each segment was run to obtain intercepts and slopes which act as the starting values for iteration
- Using the Model equation: $F_1 * e^{-t/XI} + F_2 * e^{-t/X2} + F_3 * e^{-t/X3}$ and fixing constraints; F_1, F_2, $F_3 > 0$; and X_1, X_2, $X_3 < 0$; the data was then iterated
- The values of the intercepts, F_1, F_2, F_3 give the 1st, 2nd and 3rd exponential coefficients of the three-term Maxwell model while the slopes; X_1, X_2, X_3 equal to $\frac{-1}{T1}$, $\frac{-1}{T2}$, $\frac{-1}{T3}$ respectively. The values obtained are presented in Table 3

RESULTS AND DISCUSSION

Force relaxation curve: The force relaxation curves (Fig. 1 to 4) have asymptotically decaying trend, typical of stress relaxation curves of most viscoelastic agricultural materials (Mohsenin, 1986; Khazaei and Mann, 2004; Pallottino *et al*., 2010).

Coefficients of maxwell model for grapefruit: From Table 3, considering freshly harvested, loaded at 10 mm/s; inserting the coefficients in Eq. (2) yields:

$$F(t) = 743.521 e^{-t/1.843} + 592.817 e^{-t/0.007} + 474.254 e^{-t/0.008}, \ R^2 = 0.97$$

Table 3, the first terms of the three-term Maxwell mode (F_1) made major contributions to the total decay forces. For freshly harvested at 10 mm/s for instance, the force relaxes from an initial value (F_o) of 2435.647 N (Table 1) to 743.521 N; about 69.473% in 1.834 s after which it slows down. Khazaei and Mann (2004) observed a similar trend with Sea buckthorn berries (*Hippophaerhamnoides* L.) using three-term Maxwell model where about 80% of the induced force was dissipated at the initial stage though at relatively long period of 370 s.

However, using a dimensionless relaxation modulus (G*) defined as:

$$G^*(t) = Ao + \sum_{i=1}^{n} Ai \, (e^{-t/Ti}) \quad (3)$$

where, $A_o = \frac{F(t)}{F(o)}$, $F(t)$ = force at time (t), $F(o)$ = initial time.

For Tarrocco orange, Pallottino *et al*. (2010) fitted the mean values to a three-term Maxwell model and obtained initial dimensionless decay parameter of 0.59±0.04 with initial relaxation time (T_{rel}) of 5.1 sec.

Table 3: Maxwell three-term coefficients

Treatments	Maxwell coefficients					
	F1	T1	F2	T2	F3	T3
Fresh @ 10 mm/s	743.521	1.854	592.817	0.007	474.254	0.008
Fresh @ 5 mm/s	730.038	1.834	584.030	0.069	467.224	0.007
Fresh @ 1 mm/s	729.296	1.727	583.434	0.067	466.747	0.006
1 wk @ 10 mm/s	664.510	1.606	531.608	0.059	425.286	0.007
2 wk @ 10 mm/s	577.857	1.589	462.286	0.053	369.829	0.009

Although this value is higher than the 1.854 s, this may be due to factors such as variations in cultivar, environmental factors, testing equipment and procedures as well as method of analysis used. For example, Mohsenin (1986) obtained a three-term Maxwell model for wheat dough using successive residual method as: $\sigma(t) = 372e^{-t/76}+230e^{-t/3.2}+100e^{-t/0.5}$ while Rudra (1987) got $\sigma(t) = 385.82e^{-t/65.469}+262.29e^{-t/3.4464}+82.21e^{-t/1.4186}$ for the same data but using a curve fitting program (the spline function) of the IMSL package.

However, for two varieties of Apples (*Golab kohanz* and *shafi abadi*), Gorji *et al*. (2010) obtained initial relaxation times of 1.30 and 1.50, respectively.

Relaxation time may be considered as a measure of the rate at which the material dissipates internally imposed stress, thus the shorter the relaxation time the quicker the imposed stress is being dissipated.

CONCLUSION

It has been asserted that high relaxation times are associated with viscous materials while low relaxation times are associated with elastic materials (Mohsenin, 1986). Thus from the initial relaxation times of 1.854, 1.834, 1.727 s for freshly harvested loaded at 10, 5, 1 mm/s; 1.605 and 1.589 s for one-and two weeks after harvest respectively, it can be deduced that grapefruit can dissipate internally imposed stress rapidly resulting in less deterioration as a result of imposed load.

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REFERENCES

Anazodo, U.G.N., 1982. Experimental viscoelastic characterization of corn cob composited under radial compression. Nigerian J. Technol., 6(1): 75-85.

Burubai, W., I. Amula, G.W. Etekpe, K.J. Alagoa, N. Preye and T. Suoware, 2009a. Influence of moisture and loading velocity on the force relaxation characteristics of African nutmeg seed. Am. Eurasian J. Agron., 2(1): 13-16.

Burubai, W., E. Amula, E. Ambah, P. Nimame, G.W. Etekpe and S.P. Daworiye, 2009b. Viscoelastic properties of African nutmeg. Am. Eurasian J. Agron., 2(1): 17-20.

Coppock, G.E., S.L. Hedden and D.H. Lenker, 1969. Biophysical properties of citrus fruit related to mechanical harvesting. T. ASAE, 12(4): 561-563.

Golacki, K., A. Stankiewicz and Z. Stropek, 2007. Elasticity and viscosity of carrot root tissue at different rate of deformation. Pol. J. Food Nutr. Sci., 57(2A): 63-66.

Gorji, A.C., A. Rajabipour and H. Mobil, 2010. An isotropic relaxation and creep properties of apples. Adv. J. Food Sci. Technol., 2(4): 200-205.

Jatuphong, V., N. Chanisara, K. Tipaporn and P. Adisorn, 2008. Changes in Viscoelastic Properties of Longan during Hot-air drying in Relation to its Indentation. Retrieved form: http://www.oaae.go.th/statistic/export/130ILOD. (Accessed on: July 13, 2011)

Khazaei, J. and D.D. Mann, 2004. Effects of temperature and loading characteristics on mechanical and stress-relaxation behavior of sea buclethorn berries part 3. Relaxation Behaviour. Agric. Eng. Int. CIGR J. Sci. Res. Dev., Manuscript FP03 014, Vol. 6, December, 2004.

Marco, C., B. Giulia, M. Monica, G. Roberto, B. Luigi and F.P. Giovanni, 2007. Stress relaxation test for the characterization of the viscoelasticity of pellets. Eur. J. Pharm. Biopharm., 67: 476-484.

Mohsenin, N.N., 1986. Physical Properties of Plant and Animal Materials. Gordon and Breach, New York.

Pallottino, F., M. Moresi, S. Giorgi and P. Menesatti, 2010. Orange fruit rheometrical characterization using stress-relaxation tests. Proceeding of the 17th Congress of the International Commission of Agricoltural and Biosystem Engineering (CIGR). Quebéc City, Canada, June 13-17, pp: 256.

Rudra, R.P., 1987. A curve fitting program to stress relaxation data. Can. Agr. Eng., 29(2): 209-211.

Tabatabaekoloor, R., 2012. Orange responses to storage conditions and polyethylene wrapped liner. Agric. Eng. Int. CIGR J., 14(2): 127-130.

William, M.M.., 1986. Mechanical and physical properties for postharvest handling of Florida citrus. P. Fl. St. Hortic. Soc., 99: 122-127.