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Influence of Mosture and Loading Velocity on the Force Relaxation Characteristics Ofafrican Nutmeg Seed

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Abstract: This paper presents the effects of moisture and loading velocity on the relaxation behaviour of African nutmeg seeds under uni-axial compression. The three-term Maxwell model with a maximum relative difference of ≤ 5% was used as the best fit equation to the force relaxation data. Results reveal that African nutmeg seeds had a time dependent behavoiur similar to other biomaterials. Generally, moisture had a negative trend with decay forces. Decay forces decreased from 823.3N to 5.3N as moisture increased from 8.0 percent to 28.7 percent. In the same vein, the relaxation times had a negative trend with loading velocity. At 2.5mm/min, relaxation times decreased from 296.7seconds to 0.6seconds. Similarly, relaxation times declined from 409.8seconds to 1.3 seconds at 4.0mm/min.

Key words: African nutmeg · Force relaxation · Moisture · Loading velocity

INTRODUCTION

One of the fundamental problems dictating the pace of design and development of food process machines, is the dearth of information on the rheological behaviour of biological materials under processing conditions. Generally, biological materials are viscoelastic in nature, thus their rheological characteristics depends on a lot of features such s moisture level, loading velocity and others [1-4]. Investigations reveal that the reaction of biomaterials to applied load can be closely related to their structure and pre-processing conditions like moisture and loading velocity, hence studies of rheological phenomena can be essential for identification of its state and viscoelastic changes during harvesting, transportation, processing and storage [5]. It is therefore necessary to study the viscoelastic properties of fruits. Conventionally, stress relaxation test is the most commonly used technique for analyzing such behaviours in fruits, grains and vegetables [6, 7]. The results of the relaxation tests are useful for estimating susceptibility to damage, since they measure the rate at which material dissipates stress after being subjected to a sudden force [8].

Inspite of the numerous scientific publications on the relaxation behaviour of various fruits and grains, information on force relaxation behaviour of African nutmeg is still insufficient. The objectives of this study, therefore, were to investigate the effects of moisture level and loading velocity on the relaxation behaviour of African nutmeg seed.

MATHEMATICAL FORMULATION

In modeling stress relaxation behaviour of most biological materials, a generalized Maxwell model with 2 or 3 elements is used. In the model, applied force, F(t), is used as the decaying parameter instead of stress. Thus the mathematical concept describing the force relaxation spectrum of viscoelastic materials is given as

$$F(t) = \sum_{i=i}^{N} Fi \left(e^{-\frac{t}{\lambda i}} \right) \qquad (1)$$

Where: F-initial force at time t=0, F_1 to F_N are the decaying forces and λ_1, λ_2 and λ_3 are the relaxation time

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constants corresponding to the different elements in the Maxwell model.

The non-linear regression procedure was applied to determine the number of Maxwell elements sufficient to represent the force relaxation behaviour of African nutmeg using XLstat software (2008).

MATERIALS AND METHODS

African nutmeg seeds were obtained from the sabagreia forest and processed. The seeds were stored at 10°C until time of testing.

To evaluate the effect of moisture, seeds were conditioned to three moisture levels of 8.0, 14.0 and 28.7% (db) respectively at a loading velocity of 2.5mm/min and 10% initial deformation. Similarly, the effect of loading velocity was investigated at 1.0, 2.5 and 4.0mm/min at 14% moisture level. Each test was replicated 10 times.

Relaxation tests were conducted at 10% step deformation using the Instron universal testing machine (model 4400, lnstron limited, England). Samples were compressed axially between two parallel plates and the relaxation data (force vs time) recorded from the integrator. These data were employed to determine the parameters of the generalized Maxwell model using XLstat software. Furthermore, the number of terms required in the model was chosen based on the maximum error (Maximum Relative Different, MRD) obtained from the experimental and model-predicted values. Therefore any model with MRD $\leq$ 5% was taken as the best fit model [4]. The maxim Error (MRD) values were obtained from the following equitation.

$$\text{Maximum error (MRD)} = \text{Max}\left[\frac{\text{measured - Calculated}}{\text{Measured}}\right] \times 100 \qquad (2)$$

RESULTS AND DISCUSSION

Influence of Moisture on Relaxation Characteristics: The effect of moisture content on the relaxation behaviour of African nutmeg seeds was studied. The experimental results were fit into the Maxwell model (equation 1) of one, two and three terms. A comparison based on R^2 and MRD values are shown in Table 1.

A comparison of results in Table 1 shows that the R^2 values increased as the number of terms in the model increases. This indicates that three-term model fits the data the best. Also comparison based on MRD values reveals that as the number of terms in the model increases, the MRD vales decreased. For the one-term model, the maximum and minimum values were 49.9 and 21.3 respectively; for the two-term model, MRD values ranged between 6.2 and 50.4. In the same vein, the MRD values for the three-term model spanned between 1.4 and 3.2. And since the MRD values of the three-term model are less than 5% maximum limit, it is chosen as the best fit equation for the force-relaxation data of African nutmeg. Thus the influence of moisture on the parameters of the three-term model at the three moisture levels was obtained from xlstat software as;

For MC = 8.0%

$$F(t) = 58.4\, e^{-t/87.2} + 823.2e^{-t/0.4} + 44.1e^{-t/2.5} \qquad R^2 = 0.956$$

For MC = 14.0%

$$F(t) = 19.5e^{-t/446.4} + 22.2e^{-t/20.8} + 130.3e^{-t/0.8} \qquad R^2 = 0.986$$

For MC = 28.7%

$$F(t) = 107.1\, e^{-/0.8} + 16.9e^{-t/943.3} + 5.3e^{-t/9.1} \qquad R^2 = 0.980$$

At 8.0% moisture level, the decay force was greater in the second term with a relaxation time of 0.4 seconds. However, at 28.7% moisture, the decay force was highest in the third-term with a relaxation time of 0.8 seconds. These decay forces are representations of the elastic components in the Maxwell elements and indirectly, they are the measures of elasticity of the material tested [6, 9]. Further more, the decay forces decreased with increase in moisture level. This behaviour may be attributed to be fact that moisture reduces the firmness of biomaterials [10] and African nutmeg tissue being fibrous in nature tend to soften and becomes more viscous with increase in moisture level. The goodness of fit statistics for the three-term model for the three moisture levels are given below.

Influence of Loading Velocity on Relaxation Characteristics: The effect of loading velocity on the stress relaxation behaviour of African nutmeg is shown in Table 3.

A comparison based on the R^2 values from Table 3 reveals that, as the number of terms in the Maxwell model increased from one-term to three-terms, the R^2 values correspondingly increases. This behaviour points to the fact that the three-term model fits the data the best. A similar comparison based on the MRD values shows that, as the number of terms in the model increased from one to

Table 1: Comparison of Maxwell models with one, two and three terms at different moisture levels

Moisture (%)	One-term modelMRD (%)	R^2	Two-term modelMRD (%)	R^2	Three-term modelMRD (%)	R^2
8.0	21.3	0.888	6.2	0.935	3.2	0.956
14.0	27.1	0.721	23.7	0.946	1.4	0.986
28.7	49.9	0.300	50.4	0.294	2.8	0.980

Table 2: Goodness of Fit statistics

	MC = 8.0%	MC = 14.0%	MC = 28.7%
Observations	18.00	18.00	18.00
DF	12.00	12.00	12.00
R^2	0.956	0.956	0.956
SSE	769.38	39.83	19.38
MSE	64.12	3.32	1.62
RMSE	8.01	1.82	1.27
Iterations	200.00	200.00	200.00

Table 3: Comparison of Maxwell models of one, two and three terms at different loading velocities (equation 1)

Loading velocity (mm/min)	One-term modelMRD (%)	R^2	Two-term modelMRD (%)	R^2	Three-term modelMRD (%)	R^2
1.0	19.9	0.742	8.1	0.982	4.9	0.989
2.5	26.4	0.784	23.7	0.973	5.0	0.990
4.0	99.0	0.896	99.6	0.902	4.3	0.990

Table 4:

	LV=1.0mm/min	LV=2.5mm/min	LV=4.0mm/min
Observations	18.00	18.00	18.00
DF	12.00	12.00	12.00
R^2	0.989	0.99	0.990
SSE	32.64	43.23	86.98
MSE	2.72	3.60	7.25
RMSE	1.65	1.89	2.69
Iterations	81.00	200.00	200.00

three, the MRD values decreased. For one-term model MRD values ranged between 19.4 and 99.0; for the two-term model values were in the range of 8.1 to 99.6 and the three-term model had values between 4.3 and 5.0. This further confirms that the three-term model is the best and was chosen.

Therefore the parameters of the three-term models developed from XLstat software (Non-linear regression) for the three loading velocities are;

For loading velocity = 1.0mm/min.

$$F(t) = 30.7e^{-t/724.6} + 21.7e^{-t/12.1} – 10.8e^{-t/2237.1} \qquad R^2 = 0.989$$

For loading velocity = 2.5mm/min

$$F(t) = 31.8e^{-t/296.7} + 19.9e^{-t/22,9} + 443.1e^{-t/0.6} \qquad R^2 = 0.990$$

For loading velocity = 4.0mm/min

$$F(t) = 30.1e^{-t/409.8} + 74.3e^{-t/2.0} + 136.9e^{-t/1.3} \qquad R^2 = 0.990$$

As shown in the above models, the relaxation times had negative trends for loading velocities of 2.5 and 4.0 mm/min. At 2.5 mm/min, relaxation time decreased from 296.7 seconds to 0.6 seconds respectively. Similarly, at 4.0 mm/min, relaxation time declined from 409.8 s to 1.3 s. However, at 1.0 mm/min of loading, the relaxation time had no trend. These results are in good agreement with those reported by Bargale and Irudayaraj [11], that the effect of loading velocity on relaxation time of some biomaterials did not show a clear trend.

The decay forces also did not show a clear trend as evidenced from the models. This could be attributable to the cellulose micro-fibrils embedded in the amorphous matrix of hemicellulose and pectic substances which give rigidity and resistance to tearing of the cell walls and also the ability to stretch.

The goodness of fit statistics for the above models is shown in Table 4.

CONCLUSIONS

Based on the results obtained from this investigation, the following conclusions are drawn for African nutmeg seeds:

- That African nutmeg seeds had a time dependent behaviour similar to other viscoelastic materials
- That the three-term Maxwell model with maximum relative difference $\leq$ 5% was used to develop equations for the force relaxation data.
- That the decay forces decreased from 823.2N to 53N as moisture level increased from 8.0 percent to 28.7 percent respectively.
- That decay forces did not show a clear trend with loading velocity as evidenced in the models above.

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