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Determination of Poisson's ratio and elastic modulus of African nutmeg (*Monodora myristica*)

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A b s t r a c t. An investigation into the Poisson's ratio and elastic modulus of African nutmeg as a function of moisture content and loading rate was carried out. Quasi-static compressive tests were conducted at moisture levels of 8, 11.2, 14, 17.4 and 28.7% (d.b.) in an axial loading orientation. Both unit lateral extension and unit normal compression values were determined. Average values of 0.512 to 0.275 were obtained for moisture levels of 8 to 28.7%, respectively. Effects of loading rates were also investigated and results show that Poisson's ratio increased from 0.136 to 0.334 at loading rates of 1 and 7 mm min^{-1}, respectively. Elastic modulus was observed to decrease as moisture increased. Average values of 201.5 to 41.30 N mm^{-2} were noted for moisture levels of 8 to 28.7%, respectively. A similar negative trend was observed with loading rate. These finding could therefore be useful in predicting the load deformation behaviour of African nutmeg.

K e y w o r d s: African nutmeg, Poisson's ratio, elastic modulus, moisture content

INTRODUCTION

Knowledge of apparent elastic properties such as Poisson's ratio and elastic modulus of agricultural materials are important for the prediction of their load-deformation behaviour. These viscoelastic properties could be used to compare the relative strengths of different biomaterials and investigating these technological characteristics could aid in the design of process machines. This has led several investigators to study the Poisson's ratio and elastic modulus of various agricultural materials (Anold and Robert, 1969; Kang *et al.*, 1995). Research has shown that Poisson's ratio for biological materials depends basically on moisture content, stress magnitude and loading rate (Finney, 1963). Poisson's ratio only varies from 0 to 0.5 for most materials (Mohsenin, 1970; Peleg, 1987). For gels it is 0.3 to 0.5 (Yano *et al.*, 1987), and for apple, potato, and water, it is 0.23, 0.49 and 0.50, respectively (Mohsenin, 1970).

Fridley *et al.* (1968) determined the force-deformation curves for peaches and pears. They observed that values of modulus of elasticity were 1.03 and 5.3 MPa for peaches and pears, respectively. It was also observed that the Poisson's ratio of both fruits was between 0.2 and 0.5. Misra and Young (1981) also studied the elastic modulus of soybean, though at a loading rate of 5 mm min^{-1} and moisture content of 13% (w.b.). They observed that elastic modulus of soybean varied between 125 and 126 MPa.

African nutmeg, a berry that thrives well in the evergreen forests of Africa, is a condiment used in preparing both local and intercontinental cuisines. The seeds are both economically and medically important as they have been traditionally used to relieve constipation and to control passive uterine hemorrhage in women immediately after child birth (Udeala, 2006). However, there is paucity of information on viscoelastic properties, such as Poisson's ratio and modulus of elasticity, of African nutmeg to assist in the design of process machines.

Therefore the objective of this study was to determine the Poisson's ratio and elastic modulus as a function of moisture content and loading rate.

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MATERIALS AND METHODS

African nutmeg fruits were obtained from the Kalama gardens of Sabagreia, Nigeria, on August 3, 2006. They were manually processed and all unwanted and dama- ged seeds removed before storage.

The technique employed here for the determination of Poisson's ratio was that used by Sitkei (1986). Ten samples were investigated at each of the moisture content levels of 8, 11.2, 14, 17.4 and 28.7% (d.b.), and averages were taken for each moisture level. A similar experiment was conducted at loading rates of 1, 2.5, 4, 5.5, and 7 mm min^{-1} at a constant moisture level of 8%. Prior to testing, both the original length and diameter of specimens were recorded using a digital caliper (Model CD 15CP – Mitutoyo, England). The specimens were axially loaded in a Universal Testing Machine (Model 4400, Instron Ltd, England) and quasi-statically compressed until the material failed. Axial and lateral deflections of the sample at the cracking limit of axial load were recorded again with the digital caliper. Poisson's ratio was then calculated using the formula (Sitkei, 1986):

$$\mu = \frac{\left(\frac{D_1 - D_0}{2}\right) / D_0}{\left(L_0 - L_1\right) / L_0}, \quad (1)$$

were: μ – Poisson's ratio, D_0 – original diameter of specimen (mm), D_1 – diameter of specimen after deflection (mm), L_0 – original length of specimen (mm), L_1 – length of specimen after deflection (mm).

For the elastic modulus, tests were conducted at moisture levels of 8, 11.2, 14, 17.4 and 28.7% (d.b.). Also effects of loading rates on elastic modulus were performed at 1, 2.5, 4, 5.5 and 7 mm min^{-1} as recommended by ASAE Standard S368.4 (2000) and as employed by Khazaei and Mann (2004) in investigating the elastic modulus of sea buckthorn berries. Ten samples were tested in the universal testing machine at each of the moisture levels and loading rates. Seeds were axially loaded and quasi-statically compressed. Data on the strength properties were automatically obtained from the integrator.

RESULTS AND DISCUSSION

Poisson's ratio

This property is the ratio of the unit lateral extension to unit normal compression. Poisson's ratio for biological materials has been believed to depend basically on moisture content and loading rate (Finney, 1963). Results on the Poisson's ratio of African nutmeg as a function of moisture content and loading rate is given in Tables 1 and 2. Generally, Poisson's ratio was observed to decrease as moisture level increased. An average value of 0.512 was obtained at 8% of moisture. This value then decreased to 0.275 at 28.7% moisture. Ultimately, an overall average of 0.301 was

Table 1. Values of Poisson's ratio as a function of moisture content

Original diameter D_0 (mm)	Diameter after D_1 (mm)	Original length L_0 (mm)	Length after L_1 (mm)	Poisson's ratio, μ	μ_{av}
Moisture content 8%					
12.70	12.95	21.62	20.73	0.246	
12.74	12.75	19.86	19.51	0.018	
12.12	12.16	19.99	18.80	0.029	
12.83	13.07	17.60	16.82	0.211	
12.65	12.90	17.67	17.10	0.306	0.512
10.87	11.00	16.83	16.28	0.183	
11.42	11.45	17.85	17.11	0.032	
12.32	12.83	17.48	16.81	0.038	
11.30	11.32	17.38	16.80	0.027	
12.50	12.88	15.62	14.75	0.273	
Moisture content 11.2%					
13.02	13.42	19.74	19.06	0.446	
11.44	12.07	18.19	17.04	0.436	
12.53	12.62	17.61	17.28	0.064	
11.36	11.92	18.40	17.87	0.965	
12.45	12.86	18.24	17.42	0.366	0.412
12.50	12.89	18.39	17.93	0.624	
13.59	14.18	17.72	16.78	0.409	
11.54	11.98	15.96	15.07	0.342	
10.69	11.23	15.45	13.62	0.213	
12.47	12.89	15.21	14.20	0.254	
Moisture content 14%					
11.60	11.87	17.88	16.75	0.184	
12.21	12.67	16.64	14.80	0.703	
11.42	11.64	13.67	13.08	0.223	
11.60	11.69	19.46	18.46	0.076	
11.76	12.51	19.91	18.62	0.492	0.374
12.15	19.97	18.85	16.53	0.620	
12.40	12.64	16.14	15.13	0.155	
11.60	12.16	15.73	14.65	0.352	
12.89	13.31	15.95	15.30	0.340	
11.46	12.22	17.12	16.17	0.598	
Moisture content 17.4%					
13.19	14.22	18.98	17.61	0.552	
12.35	13.34	17.22	15.59	0.423	
11.71	12.39	17.49	16.09	0.363	
11.75	11.87	17.42	16.58	0.106	
13.66	13.88	19.23	18.58	0.238	0.309
11.31	11.56	18.43	16.70	0.118	
11.37	11.78	16.55	14.56	0.150	
11.72	12.45	17.04	15.75	0.411	
11.12	11.58	16.14	14.69	0.229	
10.20	11.51	18.45	16.10	0.504	
Moisture content 28.7%					
11.66	12.46	19.55	18.15	0.479	
10.95	11.95	19.90	17.88	0.585	
12.94	13.37	16.76	15.89	0.320	
11.92	12.78	18.66	15.71	0.228	
12.80	12.84	19.81	18.39	0.022	0.275
11.54	11.85	18.41	16.54	0.104	
11.98	12.57	16.15	14.95	0.331	
12.35	13.11	17.38	16.24	0.469	
12.55	12.79	17.49	15.81	0.099	
11.55	11.80	19.87	18.09	0.115	

T a b l e 2. Values of Poisson's ratio as a function of loading rates

Original diameter D_0 (mm)	Diameter after D_1 (mm)	Original length L_0 (mm)	Length after L_1 (mm)	Poisson's ratio, μ	μ_{av}
Loading rate 1 mm min^{-1}					
11.34	11.43	15.94	15.55	0.162	
12.45	12.55	17.01	16.51	0.137	
12.35	13.33	15.87	15.38	0.285	
12.26	12.31	16.14	15.49	0.051	
11.40	11.55	15.91	15.61	0.349	
11.22	11.50	16.76	16.38	0.550	0.136
11.05	11.34	18.67	17.86	0.303	
13.14	13.27	18.00	17.60	0.223	
10.70	10.97	18.52	18.22	0.779	
11.46	11.56	16.84	16.03	0.094	
Loading rate 2.5 mm min^{-1}					
12.70	12.97	21.62	20.72	0.246	
12.74	12.75	19.96	19.51	0.018	
12.12	12.16	19.99	18.80	0.029	
12.83	13.07	17.60	16.82	0.211	
12.65	12.90	17.67	17.10	0.306	
10.87	11.00	16.83	16.28	0.183	0.263
11.42	11.45	17.85	17.11	0.032	
12.32	12.83	17.48	16.81	0.038	
11.30	11.32	17.38	16.80	0.027	
12.50	12.88	15.62	14.75	0.273	
Loading rate 4 mm min^{-1}					
11.96	12.06	17.04	16.67	0.193	
11.73	12.52	18.43	17.13	0.477	
11.57	11.96	17.84	16.31	0.197	
11.08	11.20	17.73	16.81	0.104	
11.20	12.00	18.50	17.84	0.901	
12.01	12.14	17.24	16.48	0.123	0.293
13.04	13.31	17.09	16.52	0.183	
12.21	12.96	17.01	15.49	0.344	
12.58	12.62	16.06	15.68	0.067	
13.34	13.42	16.39	15.26	0.044	
Loading rate 5.5 mm min^{-1}					
13.51	13.84	16.59	15.58	0.201	
11.42	11.57	16.06	15.66	0.264	
12.84	13.10	17.94	16.76	0.154	
10.90	11.09	18.07	16.49	0.100	
11.97	12.07	18.60	17.65	0.082	
11.99	12.40	19.92	18.88	0.328	0.297
11.68	11.97	15.67	14.94	0.267	
11.81	12.37	16.90	16.29	0.657	
12.59	13.05	18.42	17.51	0.370	
12.41	12.79	19.21	18.67	0.545	
Loading rate 7 mm min^{-1}					
10.59	10.78	18.85	18.16	0.245	
11.58	12.11	17.79	17.18	0.667	
11.24	11.45	18.20	17.38	0.207	
10.93	11.46	17.34	16.39	0.443	
12.20	12.79	16.93	15.44	0.275	
12.04	12.75	20.70	19.27	0.427	0.334
12.10	12.15	15.40	14.92	0.066	
11.33	11.65	16.69	16.17	0.453	
11.97	12.45	16.11	14.68	0.226	
11.89	12.18	17.40	16.76	0.332	

obtained. This confirms the investigations of Mohsenin (1970) and Peleg (1987), and a regression relation between Poisson's ratio and moisture content of African nutmeg is shown in Fig. 1.

From Table 2, average Poisson's ratio values of 0.136 and 0.334 were obtained at loading rates of 1 and 7 mm min^{-1}, respectively. Results reveal that the Poisson's ratio increased with increase in loading rate. However, an overall average of 0.265 was obtained. For prediction purposes, a regression equation between Poisson's ratio and loading rate is given in Fig. 2.

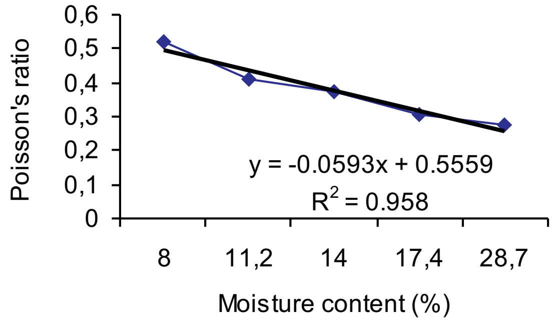

Fig. 1. Change of Poisson's ratio with moisture content.

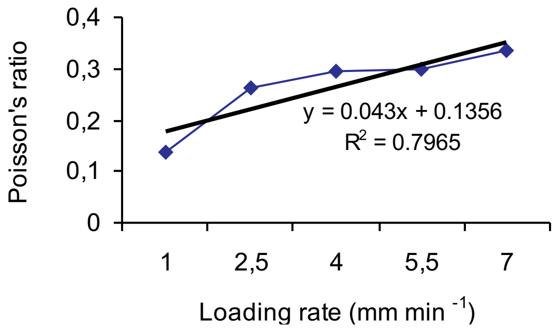

Fig. 2. Change of Poisson's ratio with loading rate.

Elastic modulus

Data on this fundamental mechanical property as a function of moisture content and loading rates is shown in Tables 3 and 4. Table 3 reveals that, generally, elastic modulus of African nutmeg decreased with an increase in moisture level. An average value of 201.5 N mm^{-2} was noted at a moisture level of 8%. It then decreased to 41.30 N mm^{-2} at 28.7% moisture. A trend between elastic modulus and moisture is therefore given in Fig 3.

Similarly, a negative trend existed between elastic modulus and loading rate as depicted in Table 4. Results reveal that at 1 and 7 mm min^{-1} average values of 135.51 and 120.46 N mm^{-2} were respectively recorded. These results agree with the findings of Finney (1963). The correlation between both variables is shown in Fig. 4.

Table 3. Elastic modulus as a function of moisture content

Moisture level (%)	Average elastic modulus (N mm^{-2})	Standard deviation
8.0	201.50	4.03
11.2	148.37	3.61
14.0	128.59	5.82
17.4	45.38	2.87
28.7	41.30	1.95

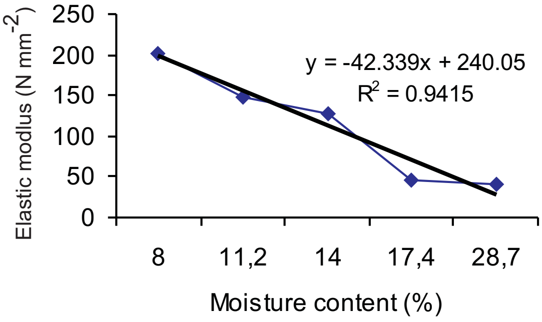

Fig. 3. Change of elastic modulus with moisture content.

Table 4. Elastic modulus as a function of loading rate

Moisture level (%)	Average elastic modulus (N mm^{-2})	Standard deviation
1.0	135.51	6.30
2.5	128.59	1.08
4.0	125.21	8.63
5.5	122.13	4.59
7.0	120.46	3.51

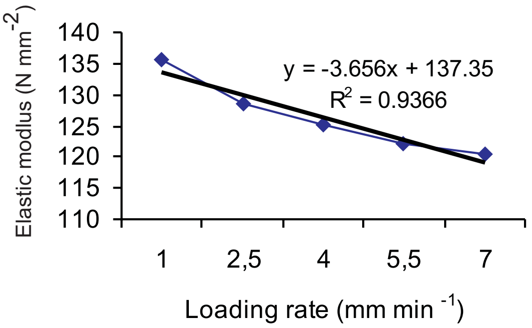

Fig. 4. Change of elastic modulus with loading rate.

CONCLUSIONS

1. It can be concluded that for African nutmeg Poisson's ratio has a negative trend with moisture increase. Poisson's ratio values of 0.512 to 0.275 were observed at 8 and 28.7% of moisture, respectively.

2. A positive correlation was observed between Poisson's ratio and loading rate. Average values of 0.136 to 0.334 were also obtained at loading rates of 1 and 7 mm min^{-1}, respectively.

3. Elastic modulus decreased generally with increase in both moisture content and loading rates, thereby confirming the works of Shelef and Mohsenin (1969).

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