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Research Article

MODELING THE LOAD-DEFORMATION BEHAVIOUR OF AFRICAN NUTMEG (*Monodora myristica*) SEEDS

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Abstract- The load-deformation behaviour of African nutmeg seed during cracking was modeled using dimensional analysis and other computational techniques; with the view of positively manipulating this energy-demanding and time-consuming unit operation in the design of African nutmeg cracking machine. The developed model shows that; compressive force, moisture content, heating temperature, pre-heating time, loading rate and duration of loading play a significant role in the deformation (cracking) process of African nutmeg seed. Results of the model predicted and measured deformation values were compared and an acceptable agreement was recorded at 95% confidence level. An analysis of variance indicates that the developed model has a low standard error of estimate (0.0018) and a high coefficient of determination (R^2 =0.902) which implies a good fit.

Keywords- Deformation, Compressive Force, Moisture Content, Loading Rate, Heating Time

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Introduction

African nutmeg (*Monodora myristica*) is one of the most important three crops in Nigeria. Although found almost everywhere in the southern part of the country, high concentrations of the trees are most prevalent in the south-south region [1]. It is a tree in the evergreen forest and almost every part of it has economic value. According to Falconer (1980) and Getahum (2000), the bark and roots are used to treat hermorrhoids, stomach-ache and fibrile pains [2,3]. But the most economically important part of the tree is the spherical seeds which are embedded in a white sweet-smelling pulp of the spherical fruit. The nuts are aromatic and are used after grinding as condiment in foods. It is used as stimulant to relieve constipation, and to control passive uterine hemorrhage in women immediately after child birth [4,5]. A further study indicated that compounds extracted or isolated from the Kernels lowered glucose levels in diabetic mice but contained 8.8% of protein, 29% fat and 50% carbohydrate [6].

Processing of the fruit involves allowing it to ferment for about 10 days and washing of the pulp to separate the nuts. The nuts are then sun-dried or smoke-dried for several days before cracking. However, the most demanding aspect of all the unit operations is the cracking of the nut to extract the kernel. The variability in shape and size of the nuts makes it impossible for uniform force application. Traditionally, the kernel is extracted by manually cracking the nut between stones. Thus, the cracking operation of African nutmeg is yet to be mechanized to reduce the drudgery associated with the activity as well as opening the avenue of large scale operation. This continued use of local cracking techniques in the absence of improved (modern) methods to crack the seed of African nutmeg is a serious encumbrance to large scale processing of this vital crop. This, of course, is due to a dearth of desirable information on the behaviour of the seeds (nuts) during processing. There is, therefore, the need for understanding the load-deformation behaviour of the seeds and this information is highly needed for proper design of processing machines. Specifically, the objective of this study is to develop a load-deformation model for African nutmeg cracking using dimensional analysis.

Materials and Methods

Bulk quantities of fresh African nutmeg (*Monodora myristica*) fruits were obtained from Sabagreia forest (Bayelsa State), on the 30th July, 2016. The fruits were processed and all foreign matter and damaged seeds removed. The seeds were stored at 10 ± 5°C and 90% relative humidity for 48hours. An Instron Universal Testing machine (Model 4400, Instron limited, England) controlled by a microcomputer was used for compression testing, and a Top-loading electronic balance (Model 6315, Osaw Industrial Products Limited, India) was used for weighing. Other equipment used includes convective-type oven with temperature controller (Model D25, Genlab, Widnes, UK), moisture meter (Model F 3, Dickey-John, UK) for moisture determination, and a heating rig (Model TL1, NCAM, Nig), a Mitutoyo Digital Caliper (Model CD-15CP-Mitutoyo, England), 200ml glass beaker, thermometer and thermal conductivity meter. The initial moisture content of the samples was then determined using the oven method.

Experimentation

The following experiments were then conducted and results used for model validation

(a) Five moisture content levels of 8.0, 11.2, 14.0, 17.4 and 20.7% (db) at which the seeds/nut could be easily cracked were determined using the oven method at 110°C. In the drying chamber, 50 kernels each were arranged in thin layers of five wire baskets. As drying proceeded, the samples were periodically withdrawn from the oven and tested with a moisture meter to determine if the desired final average moisture content had been attained. Upon completion of drying, each group of samples was sealed in a polyethylene bag and immediately placed in an insulated box to ensure slow cooling as recommended by ASAE standards [7]. After about 6 hrs of cooling, the samples were transferred to refrigerated storage. This procedure was repeated for moisture levels of 9.6, 12.2, 15.4, 19.5 and 20.7 percent for validation purposes.

It is necessary to indicate, at this point that the 20.7% (db) moisture content is the moisture content at harvest, while 14.0% (db) is what is obtainable in samples from the market. The rest were chosen based on the works of Oje (1993) and Aviara et al (2000) [8,9].

Ten samples with each of the chosen moisture content levels were tested to determine the effect of moisture content on load – deformation behaviour. Quasi-static compression tests were performed with an Instron testing machine equipped with a 100KN compression load cell and having a precision of 0.001N and an integrator. A loading rate of 2.5mm/min was used as described in ASAE recommendations S368.4. Test deformation results were automatically generated from the integrator.

(b) Loading rate test were also conducted at 1.0, 2.5, 4.0, 5.5 and 7.0mm/min at 14% moisture as recommended by ASAE Standard (ASAE S368.4, 2000) and also applied by Khazaei and Mann (2004) in investigating the mechanical properties of sea buckthorn berries [10].

Quasi-static compression test was performed at the above stated loading rates with the individual seeds axially loaded between the two parallel plates of a universal testing machine. As the compression progressed, a load–deformation data was automatically generated in response of each seed to compressive load and was obtained from the recorder incorporated.

(c) The effect of temperature on crackability was also studied at 60^0, 100^0, 140^0, 180^0 and 220^0C at 14% moisture level and at a loading rate of 2.5mm/min. A temperature-controlled heating rig (Model TLI, NCAM, Nig), with a cylindrical barrel heating chamber was used for testing temperature effects on deformation. The thermostat was pre-set at the required temperature level and allowed to stabilize. Ten samples were then pre-heated at each of the temperature levels for a constant period of 5minutes. At the expiration of 5minutes, the pre-heated samples were immediately removed and compressed with an Instron universal testing machine at a loading rate of 2.5mm/min. This was done in conformity with ASAE standard (ASAE S368.4, 2000) to ascertain the effect of pre-heating temperature on the strength properties of the samples which has a direct relationship with the load-deformation behaviour. The load-deformation data were recorded by the Instron integrator until the specimen failed. This experiment was repeated for all temperature levels. A total of 50 samples were tested for the effect of temperature.

(d) The heating time-temperature relationships in the pre-heating process and how these can affect the mechanical behaviour of African nutmeg was investigated at a temperature of 180°C with the time intervals of 5, 10, 15, 20 and 25 minutes as used by Miruna (1999). Prior to testing, the samples were held at a moisture content of 14% (db) [11].

A temperature-controlled heating rig (Model TL1, NCAM, Nig) with a cylindrical barrel heating chamber was used. A pre-set temperature of 180°C was selected from the thermostat and allowed to stabilize before inserting the samples in the heating chamber. Ten samples were then pre-heated at each of the time intervals at the constant temperature of 180°C. At the expiration of every test-time, pre-heated samples were immediately removed and compressed with the universal testing machine at a loading rate of 2.5mm/min in accordance with the recommendations of ASAE S368.4 (2000) to obtain the effect of pre-heating time on the mechanical properties of the specimen. Test results on the load-deformation characteristics and other data were recorded by the integrator until the specimen failed.

Mathematical Formulation

Dimensional analysis was used to develop the predictive model for the load-deformation behaviour of African nutmeg in the cracking process as was also applied bySrivastava et al,(1990), Cakir and Alayunk (2001), Sefa and Kazim (2004), Sterling (1955) and Paolo (2005) [12-16].The development of the model is based on the Buckingham-Pi theorem which states that the number of dimensionless and independent quantities required to express a relationship among variables in any phenomenon is equal to the number of quantities involved, minus the number of dimensions in which those quantities may be measured [17,18].

Mathematically, π – theorem is

$$y = n - x$$

Where y is the number of π – terms; n is the total number of variables and *x* is the number of basic dimensions.

Literature indicates that the following pertinent variables have significant effect on the load-deformation behaviour of agricultural materials. They are:

(a) Dependent variable:
- Deformation, d = L

(b) Independent variable;
- Applied force, F = MLT^{-2}
- Modulus of elasticity, E = $ML^{-1}T^{-2}$
- Temperature, $\theta_T = \theta$
- Loading rate, R = LT^{-1}
- Time of pre-heating, τ = T
- Thermal conductivity, K = $MLT^{-3}\theta^{-1}$
- Moisture content, μ = π
- Duration of loading, t = T

The moisture content (already dimensionless) will take no part in the dimensional analysis itself but will re-enter the procedure when describing and fitting the final model. Thus the deformation, d, will be expressed as a function of the other variables as

$$d = f(F, E, \theta_T, R, t, \tau, K) \qquad [1]$$

Therefore the number of variables is n = 8, But since there are 4 dimensions (M, L, T,θ) in the problem, the number of dimensionless π-terms becomes, y = 8 – 4 = 4.This may be expressed as;

$$\pi_1 = \Phi(\pi_2, \pi_3, \pi_4) \quad - \quad - \qquad (2)$$

Hence, four π-terms say π_1, π_2 ,π_3 and π_4 were obtained based on the principle of dimensional homogeneity as

$$\Rightarrow \quad \pi_1 = \frac{d}{Rt_2} \quad - \quad - \quad - \qquad (3)$$

$$\Rightarrow \quad \pi_2 = \frac{F}{R^2Et^2} \quad - \quad - \qquad (4)$$

$$\Rightarrow \quad \pi_3 = \frac{\theta_T K}{R^2Et} \quad - \quad - \qquad (5)$$

$$\Rightarrow \quad \pi_4 = \frac{\tau}{t} \quad ----- \qquad (6)$$

To ensure simplicity in the experimentation process, the present π-terms (π_2,π_3 andπ_4) can be adjusted to generate new π - terms by multiplying or dividing with each other [19], while maintaining the independency condition.

Thus:

$$\pi_2^1 = \frac{\pi_2}{\pi_3} = \frac{F}{R^2Et^2} \times \frac{R^2Et}{\theta_T K} = \frac{F}{\theta_T Kt}$$

Also, dividing the newly transformed π_2^1 by π_4 yields.

$$\pi_2 = \frac{\pi_2^1}{\pi_4} = \frac{F}{\theta_T Kt} \times \frac{t}{\tau}$$

$$\therefore \pi_2 \equiv \frac{F}{\theta_T K\tau}$$

Therefore, bringing in the reserved dimensionless and independent variable, moisture content to represent π_3 will give

$$\pi_3 = \mu$$

Hence a check to ensure the dimensionlessness of the terms is conducted for the present analysis as follows:

$$\pi_1 = \frac{d}{Rt} = \frac{[L]}{[LT^{-1}][T]} = 1$$

$$\pi_2 = \frac{F}{\theta_T K\tau} = \frac{MLT^{-2}}{[\theta][MLT^{-3}\theta^{-1}][T]} = 1$$

and

$$\pi_3 = \mu = M^o L^o T^o \theta^0 = 1$$

Thus, the dependence of the various π-terms can be mathematically described by a multivariable linear regression. In accordance with this, the General Linear Model (GLM) procedure of statistical Analysis System software (SAS, 2003) [20, 21] was employed to determine the dependence of π_1 on π_2 and $\pi_3$using the experimental data as given below.

Table-1 *Multiple regression analysis showing the dependence of π_1 on π_2 and π_3*

Dependent variable: π_1 analysis of variance

Source	DF	Sum of Square	Mean Square	F Value	Pr > F
Model	2	0.00074238	0.00037119	10.79	0.0848
Error	2	0.00006882	0.00003441		
Corrected Total	4	0.00081120			

Root MSE	0.00587	R-Square	0.9152
Dependent Mean	0.12789	Adj R-Sq	0.8303
Coeff Var	4.58656		

Parameter Estimate

Variable	DF	Parameter Estimate	Standard Error	t value	Pr>1t1
Intercept	1	0.14153	0.03138	4.51	0.0458
π_2	1	0.01904	0.02330	0.82	0.4997
π_3	1	0.00148	0.0018	0.94	0.4465

The multivariable regression equation obtained from the parameter estimate above is as follows:

$$\pi_1 = 0.01415 + 0.0190\pi_2 + 0.00148\pi_3 (7)$$

Therefore, substituting the values of the various πterms yields the load-deformation model as;

$$\frac{\mathrm{d}}{\mathrm{Rt}} = 0.1415 + 0.0190\ \frac{\mathrm{F}}{\theta_T K\tau} + 0.00148\mu \qquad [8]$$

The analysis of variance (Anova) in [Table-1] indicates that the model is statistically important as the coefficients of the proposed model are statistically different from zero [Table-1]; thus, deformation of Africa nutmeg can be successfully predicted using the model.

Results and Discussions

Load-deformation model

The effect of integrated functions of controlling variables on the deformation behaviour of African nutmeg during cracking has been investigated, and the relationship between these variables studied using dimensional analysis with a general prediction model developed as:

$$d = Rt\left(0.141 + \frac{0.019F}{\theta_T K\tau} + 0.00148\mu\right) ---- \qquad (9)$$

As revealed in the model; loading rate(*R*), duration of loading(*t*), compressive force(*F*), temperature(θ_T), heating time(τ) and moisture content(μ) contributes significantly to the deformation of the seed during cracking. It is also interesting to observe that the coefficient of determination (r^2 = 0.915) obtained from this model shows a better fit than the results of Srivastava *et al*, (1990) for the prediction of bruise diameter of three apple varieties (r^2 = 0.757) using dimensional analysis.

Validation of the developed model was done with selected tests and values of predictor variables substituted into the model and results of the predicted compared with the measured experimental results from the Instron Universal Testing Machine. A summary of this is shown below:

Table -2 *Predicted and measured deformation values.*

Predicted (mm)	Measured (mm)
0.585	0.5301
0.639	0.6989
0.7275	0.7784
0.8598	0.8709
0.9537	0.9951
1.1872	1.0738
1.3749	1.4521
1.4474	1.6274
1.4528	2.0173

An analysis of variance was therefore conducted using SAS software to show the deviation between the predicted and measure deformation values as follows.

Table-3 *Analysis of variance between predicted and measured deformation values*

Dependent variable: Measure Analysis of Variance

Source	DF	Sum of Square	Mean Square	F Value	Pr > F
Model	1	1.77780	1.77780	64.53	< . 0001
Error	7	0.19285	0.02755		
Corrected Total	8	1.97064			

Root MSE	0.16598	R – Square	0.9021
Dependent Mean	1.12711	Adj R – Sq	0.8882
Coeff Var	14.2613		

Parameter Estimate

Variable	DF	Parameter Estimate	Standard Error	t Value	Pr > I t I	Standardized Estimate
Intercept	1	-0.25828	0.18112	-1.43	0.1969	0
Predicted	1	1.35126	0.16821	8.03	< . 0001	0.94981

Statistical parameters in [Table-3] shows that there is no significant difference between the predicted and measured as revealed by the test of goodness of fit (r^2=0.902). Anova also revealed a correlation coefficient of 1.351. In general, the predicted and experimental results showed acceptable agreement at 95% confidence level and is regressed as

$$Measured = 1.351\,(predicted) - 0.258 \qquad (R^2 = 0.9021)$$

Conclusions

The present study was undertaken to investigate the load-deformation behaviour of African nutmeg during cracking using dimensional analysis and other computational techniques.

It was observed from the model that, loading rate, duration of loading, compressive force, temperature, heating time and moisture content play significant roles in the deformation (cracking) process of African nutmeg. Moreover, coefficient of determination (r^2 = 0.915) recorded from the model is relatively better than the one obtained by Srivastava et al (1990) for predicting bruise diameter of three apple varieties using dimensional analysis (r^2 = 0.757).

Validation of the model indicates that experimental observations were found to be in reasonable agreement with the theoretical predictions at 95% confidence level. Food processors Engineers should therefore take note of the effect of these important variables in the design of African nutmeg cracking machines.

Application of research:

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Conflict of Interest: None declared

Ethical approval: This article does not contain any studies with human participants or animals performed by any of the authors.

References

[1] Adegoke E. and Akinsanya A. (1970) *Journal of West African Science Association,* 13 (2), 13-33.
[2] Falconer T. (1990) *Unasylva,* 41,160.
[3] Getahun A. (2000) *Agro-ecosystems,* 1, 45-56.
[4] Iwu M.M. (2000) *J. Ethno-pharmacology,* 21,14-19.
[5] Udeala O.K. (2000) *Journal of Pharmacy and Pharmacology,* 32, 6-9.
[6] Omoti U. (2000) *J. Sci. Food and Agric.,* 38,67-72.
[7] ASAE Standard, 10th Ed.(2000) S3684.Compression Test of Food Materials of Converse Shapes. St. Joseph, Michigan: ASAE.
[8] Oje K. (1993) *Journal of Agricultural Engineering and Technology,* 1, 38-45.
[9] Aviara N.A., Haque M.A. and Izge A. (2000) *Agro-science,* 1(2, 19-34.
[10] Khazaei J. and Mann D. (2004) *Journal of Scientific Research,* 6(2), 50-30.
[11] Miruna T. (1999) *J. Food Sci.,* 45,827-830.
[12] Srivastava A.K., Mandhars S., and Singh D. (1990) Apple bruise prediction models using dimensional analysis. International Agricultural Engineering Conference and Exhibition. Asian Institute of Technology, Bangkok, Thailand 1-4 June, Pg. 30-38.
[13] Cakir E. and Alayunk F. (2001) *Journal of Biological Sciences,* 1 (10), 925-928.
[14] Sefa T. and Kazim C. (2004) *Mathematical and computational applications*, 9 (3), 427-434.
[15] Sterling C. (1955) *Food Res.,* 20, 474-479.
[16] Paolo P. (2005) *Applied Rheology,* 15(4), 218- 229.
[17] Barenblatt G.I. (1987) *Dimensional Analysis. 2nd ed. New York: Gordon and Breach Science Publisher.*
[18] Murphy G. (1950) *Similitude in Engineering. 2nd edition, Donald Press. New York.*
[19] Langhaar L.H. (1980) *Dimensional Analysis and Theory of Models. 2nd ed. Florida: Robert Krieger Publishing Company.*
[20] Misra R.N. and Young J.H. (1981) *Transaction of the ASAE,* 24 (5), 1338-1341.
[21] SAS (2002) *Statistical Analysis Software program package. SAS Institute, Version* 9.