Int. Agrophysics, 2007, 21, 217-223

INTERNATIONAL
Agrophysics
www.international-agrophysics.org

Effects of temperature and moisture content on the strength properties of African nutmeg (*Monodora myristica*)

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Received August 2, 2007; accepted August 27, 2007

A b s t r a c t. The effect of temperature and moisture content of African nutmeg seed coat was studied as it affects compressive force, deformation, failure stress, strain energy and modulus of elasticity (firmness). Quasi-static compressive tests were conducted at sample temperatures of 60, 100, 140, 180 and 220°C. Similar tests were also performed at moisture content levels of 8, 11.2, 14, 17.4 and 28.7% (db) in an axial loading orientation. Investigations revealed that the force needed to crack open the seed coat decreased from 52.8 to 32 N at temperatures of 60 and 220°C, respectively. A similar trend was also observed as compressive force decreased from 56.6 to 33 N and as moisture levels increased from 8 to 28.7%, respectively. Deformation values were observed to increase from 0.64 to 0.97 mm for 60 and 220°C, respectively. These values of deformation varied from 1.07 to 1.54 mm at moisture content levels of 8 to 28.7%, respectively. Failure stress, strain energy and Young's modulus all tended to decrease with an increase in temperature. Also, as moisture content increased, failure stress and modulus of elasticity decreased. However, an increase in strain energy was observed from 0.0201 to 0.0341 N mm for an increase in moisture from 8 to 28.7%, respectively. Based on these findings important recommendations are made.

K e y w o r d s: African nutmeg, compressive force, deformation, failure stress, strain energy

INTRODUCTION

One of the most serious problems confronting the post-harvest processing of African nutmeg is the cracking of the seed coat to extract the kernel. This energy-demanding and time-consuming unit operation can be positively manipulated by varying the moisture content and pre-heating temperature to condition the seed for mechanical cracking.

Investigations reveal that the moisture content in agricultural materials significantly affects their mechanical properties such as modulus of elasticity, failure stress and rate of deformation of particular fruits and vegetables (Burubai, 2007; Stroshine, 2005). Cenkowski and Zhang (1995) studied the effect of moisture content on the mechanical behaviour of Canola and observed that the modulus of elasticity of the product decreased with increasing moisture content. Research results from investigation of the effect of moisture content on the strength properties of different agricultural materials reveal that it is one of the most important factors in the processing and handling of such materials (Jackman and Stanley, 1994; Mamman and Umar, 2005; Misra and Young, 1981; Shelef and Mohsenin, 1969).

On the other hand, the softening phenomenon that occurs in plant materials upon heating has been believed by some scientist to be a result of cell separation (Shomer, 1995). Others, however, observe that cell rupture generally accompanies the heating process (Reeve, 1977).

Ramana *et al*. (1992) investigated cellular integrity during heating by microscopic examination. They observed that the protoplasts were disrupted around 60°C and the cells lost their integrity between 50 and 65°C. Bourne (1982) observed also that the firmness of biomaterials varies with temperature. He observed that most biomaterials showed a slight linear softening with increasing temperature.

Morphologically, African nutmeg (*Monodora myristica*), belonging to the Anannacea family, is a climber tree. It is a berry that grows well in the evergreen forest of Africa. The seeds which are embedded in a white sweet-smelling

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pulp of the sub-spherical fruit (Fig. 1) are economically and medically important (Burubai, 2007). The kernel obtained from the seeds is a popular condiment used as a spicing agent. When ground to powder, it is used to prepare pepper soup as a stimulant to relieve constipation and control passive uterine haemorrhage in women immediately after child birth (Udeala, 2000). However, the most demanding unit operation is the cracking which is yet to be mechanized. This can only be achieved if information on the strength properties of this economically and medically viable crop is provided.

Fig. 1. Fruit and seeds of African nutmeg.

Therefore, the objective of this study was to investigate the effects of pre-heating temperature and moisture content on compressive force, deformation, failure stress, strain energy and Young's modulus of African nutmeg seed coat rupture under quasi-static loading.

MATERIALS AND METHODS

Fresh African nutmeg fruits were collected from the Sabagreia forest, Nigeria, on the 30th July, 2006. The fruits were processed and all foreign matter and damaged seeds were removed. The seeds were then stored at 0°C and 90% relative humidity for 48 h as a conditioning measure before use.

For the effect of pre-heating temperature, the seeds moisture content was reduced to 14% (db) which represents the moisture content of samples obtainable in the market. A temperature controlled heating rig (Model TL1, NCAM, Nig) with a cylindrical barrel heating chamber was used for testing temperature effects. Temperatures of 60, 100, 140, 180, and 220°C at 14% moisture content (db) and loading rate of 2.5 mm min^{-1} were selected based upon those used by Vincent (1999) and Khazaei and Mann (2005). Prior to testing the samples were checked for possible cracks on their surfaces and those with cracks were discarded. The thermostat was preset to 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 5 min. At the expiration of 5 min, the samples were immediately removed and compressed with an Instron Universal testing machine (Model 4400, Instron Limited, England). This was done in conformity with ASAE Standards (ASAE, S368.4, 2000). The effect of temperature on the strength properties was recorded by the integrator until the specimen failed.

To ascertain the effects of moisture content, the seeds were conditioned to five moisture content levels of 8, 11.2, 14, 17.4 and 28.7% (db) as recommended by Oje (1993) and Aviara *et al*. (2000) in investigating the moisture content of the vetia and shea nuts using the oven method. After drying, each group of samples was sealed in a polyethylene bag and immediately placed in an insulated box to ensure slow cooling for 12 h before storage. Quasi-static compression was then performed using the Instron Universal testing machine as recommended by ASAE S368.4 (2000). Ten seeds were axially loaded at a rate of 2.5 mm min^{-1} in each of the moisture levels between two parallel plates. Strength properties data were automatically obtained from the recorder chart of the machine.

RESULTS AND DISCUSSIONS

Compressive force

The compressive load necessary to effect the desired seed coat rupture of African nutmeg was observed to decrease as pre-heating temperature of the specimen increased (Table 1 and Fig. 2a). At 60°C, a compressive force of 52.8 N was recorded. This value decreased to 32 N at a temperature of 220°C. This negative trend is in conformity with the findings of Reeve (1977), Bourne (1982), Ramana *et al.* (1992) and Vincent (1999), as reported in this work and elsewhere. It was, however, observed that between 180 and 220°C not only was the cellular integrity lost but a serious colour change was observed. This is an indication of a reduction in the quality of the product, hence a cracking temperature of between 100 and 140°C is recommended.

On the other hand, the compressive force value varied from 56.6 to 33 N for moisture content levels of 8 and 28.7%, respectively. Though seed coat rupture required a lower force at higher moisture content (conserving energy), product quality must be maintained by avoiding excessive kernel breakage to appeal to consumers. Thus a moisture content range of 11.2 to 14% (db) is recommended for optimum results. The correlation between compressive force and moisture content is shown in Table 2 and Fig. 2b. These results agree with those of Cenkowski and Zhang (1995) – high correlation.

Deformation

Data on deformation of African nutmeg seed coat rupture as a function of both temperature and moisture content were all obtained from the recorder chart of the Instron testing machines (Tables 1 and 2). The results reveal that deformation increased as temperature increased. At 60°, a deformation of 0.643 mm was noticed. This increased to 0.97 mm at 220°C. This positive correlation (Fig. 3a) shows

T a b l e 1. Effect of temperature on strength properties (number of observations = 10)

Temperature (°C)	Strength properties	Mean	Standard deviation	Range
60	Compressive force (N)	52.80	19.88	25.20 - 83.10
	Deformation (mm)	0.643	0.328	0.359 - 1.429
	Failure stress (N mm^{-2})	5.587	2.10	2.667 - 8.794
	Strain energy (N mm)	0.0233	0.0217	0.0053 - 0.0742
	Young's modulus (N mm^{-2})	180.89	29.28	132.91 - 226.68
100	Compressive force (N)	42.90	20.39	13.10 - 79.90
	Deformation (mm)	0.594	0.194	0.242 - 0.781
	Failure stress (N mm^{-2})	4.540	2.158	1.386 - 8.455
	Strain energy (N mm)	0.0156	0.009	0.0018 - 0.0297
	Young's modulus (N mm^{-2})	167.12	58.66	80.31 - 285.37
140	Compressive force (N)	42.19	10.71	30.40 - 60.900
	Deformation (mm)	0.734	0.194	0.280 - 1.120
	Failure stress (N mm^{-2})	4.465	2.158	3.217 - 6.444
	Strain energy (N mm)	0.0134	0.009	0.0049 - 0.0328
	Young's modulus (N mm^{-2})	145.81	58.66	78.45 - 234.85
180	Compressive force (N)	37.67	16.39	18.20 - 60.60
	Deformation (mm)	0.880	0.279	0.310 - 1.290
	Failure stress (N mm^{-2})	3.986	1.734	1.926 - 6.413
	Strain energy (N mm)	0.0132	0.0077	0.0030 - 0.0223
	Young's modulus (N mm^{-2})	140.15	58.25	47.45 - 244.74
220	Compressive force (N)	32.00	18.76	7.30 - 63.40
	Deformation (mm)	0.970	0.281	0.22 - 1.01
	Failure stress (N mm^{-2})	3.39	1.99	0.77 - 6.71
	Strain energy (N mm)	0.0125	0.0118	0.0016 - 0.0323
	Young's modulus (N mm^{-2})	98.73	28.43	52.39 - 148.61

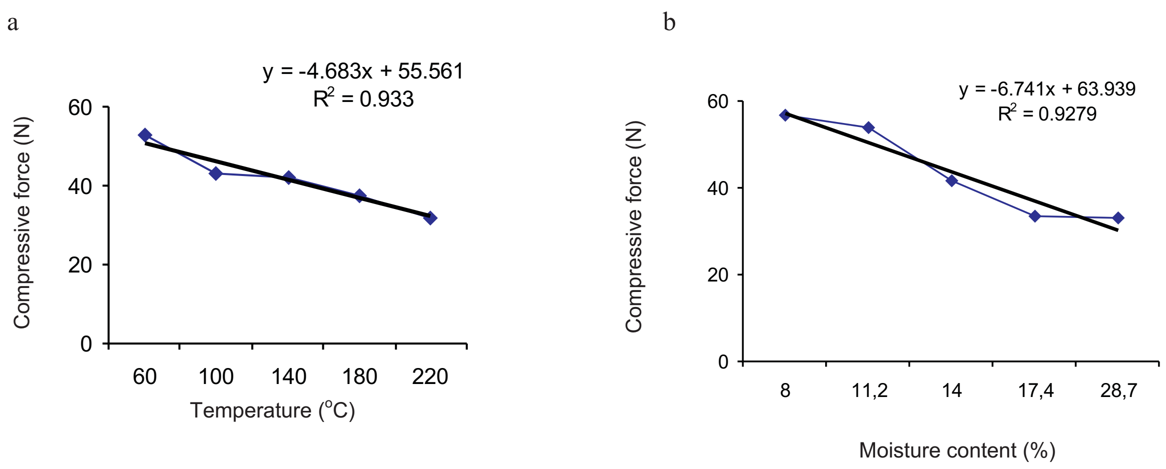

Fig. 2. Effect of temperature (a) and moisture content (b) on compressive force.

T a b l e 2. Effect of moisture content on strength properties (number of observations = 10)

Moisture content (%)	Strength properties	Mean	Standard deviation	Range
8.0	Compressive force (N)	56.60	20.49	27.60 – 96.20
	Deformation (mm)	1.074	0.5177	0.494 – 2.312
	Failure stress (N mm^{-2})	5.989	2.168	2.921 – 10.180
	Strain energy (N mm)	0.0701	0.0308	0.0078 – 0.1168
	Young's modulus (N mm^{-2})	128.59	30.58	69.44 – 167.19
11.2	Compressive force (N)	53.82	21.53	20.50 – 88.70
	Deformation (mm)	0.628	0.178	0.388 – 0.911
	Failure stress (N mm^{-2})	5.695	2.279	2.169 – 9.386
	Strain energy (N mm)	0.0216	0.0161	0.0053 – 0058
	Young's modulus (N mm^{-2})	121.50	20.0	112.3 – 270.90
14.0	Compressive force (N)	41.55	19.40	14.80 – 84.30
	Deformation (mm)	0.773	0.432	0.256 – 1.675
	Failure stress (N mm^{-2})	4.397	2.053	1.566 – 8.921
	Strain energy (N mm)	0.0225	0.0242	0.0027 – 0.0875
	Young's modulus (N mm^{-2})	108.37	108.37	60.40 – 275.87
17.4	Compressive force (N)	33.61	14.60	12.50 – 57.30
	Deformation (mm)	1.358	0.521	0.568 – 2.286
	Failure stress (N mm^{-2})	3.557	1.545	1.323 – 6.064
	Strain energy (N mm)	0.0271	0.0172	0.0037 – 0.0564
	Young's modulus (N mm^{-2})	45.38	18.03	15.08 – 84.14
28.7	Compressive force (N)	33.00	11.20	10.20 – 53.00
	Deformation (mm)	1.5378	0.6814	0.6810 – 2.855
	Failure stress (N mm^{-2})	3.583	1.235	1.714 – 5.503
	Strain energy (N mm)	0.0341	0.0247	0.0087 – 0.0788
	Young's modulus (N mm^{-2})	40.30	30.55	15.62 – 105.26

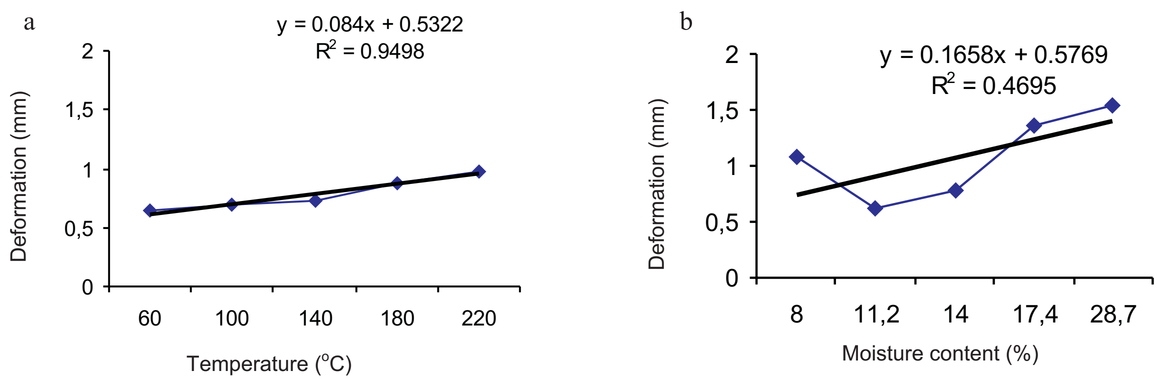

Fig. 3. Effect of temperature (a) and moisture content (b) on deformation.

that at higher temperatures lesser force is required to achieve the desired deformation. These results are consistent with those of Khazaei and Mann (2005).

The relationship between moisture content and deformation is also presented in Table 2 and Fig. 3b. It is evident that values of deformation varied from 1.074 to 1.537 mm for moisture content levels of 8 and 28.7%, respectively. However, these two extreme moisture content levels (8 and 28.7%) were accompanied with excessive kernel breakage. This is not good for quality control. Thus a moisture content range of 11.2 to 14% (db) is recommended for best results. The results presented herein are in agreement with those of Jackman and Stanley (1994).

Failure stress

This is the yield stress at which the seed coat fails under the applied compressive force. Data on the effect of both pre-heating temperature and moisture content on the failure stress of African nutmeg were obtained directly from the recorder chart as shown in Tables 1 and 2.

Results from Table 1 show that, generally, failure stress responded negatively to an increase in temperature. At 60°C, a failure stress value of 5.587 N mm^{-2} was obtained. This value reduced to 3.39 N mm^{-2} at 220°C. The cause and effect between temperature and failure stress is presented in Fig. 4a. The results obtained confirm the fact that increase in temperature reduces the cellular integrity of biomaterials (Ramana *et al.*, 1992).

Furthermore, Table 2 reveals that, as moisture content increases, failure stress decreases. The average failure stress was 5.989 N mm^{-2} at 8% moisture content and 3.583 N mm^{-2} at 28.7% moisture. The regression-type relationship between failure stress and moisture content is shown in Fig. 4b. The findings presented here are consistent with the investigations of Misra and Young (1981) and Mamman and Umar (2005).

Strain energy (Toughness)

This is the energy absorbed by the seeds prior to seed coat rupture per unit of seed volume. Data on strain energy of the specimen as a function of temperature and moisture are shown in Tables 1 and 2. Generally, strain energy tended to decrease with increasing temperature as revealed in Table 1 and Fig. 5a. An average value of 0.0233 N mm was recorded at 60°C and 0.0125 N mm at 220°C. This trend reveals the inability of African nutmeg seeds to absorb energy at higher temperatures, thereby confirming the work of Shomer (1995) on potatoes.

Table 2, however, reveals that increase in moisture content has a positive effect on strain energy. The seeds had an average strain energy value of 0.0201 N mm at 8% moisture, but increased to 0.0341 N mm at 28.7% moisture. This relationship is shown in Fig. 5b.

Young's modulus

Young's modulus, otherwise called firmness, is a measure of how easily the seed coat can be ruptured. The effect of this fundamental strength property as a function of temperature and moisture content was shown in Tables 1 and 2.

The effect of temperature, as shown in Table 1, reveals that as temperature increases, Young's modulus tends to decrease. At 60°C, an average Young's modulus value of 180.89 N mm^{-2} was obtained, but declined to 98.73 N mm^{-2} at 220°C. This implies that as temperature increase cellular integrity is lost, confirming the investigations of Ramana *et al.* (1992). However, the regression relationship between Young's modulus and temperature is revealed in Fig. 6a.

Results in Table 2 also indicate that, generally, moisture content has a negative effect on the firmness of African nutmeg seed coat. Average values of Young's modulus varied between 128.59 and 40.3 N mm^{-2} for moisture levels of 8 and 28.7%, respectively. This decline in resistance of the seed coat to applied load as a result of moisture increase

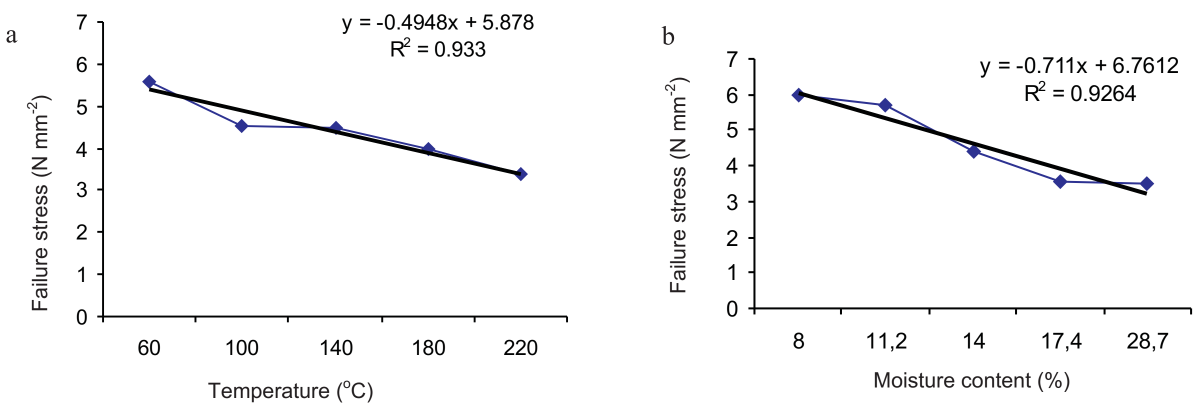

Fig. 4. Effect of temperature (a) and moisture content (b) on failure stress.

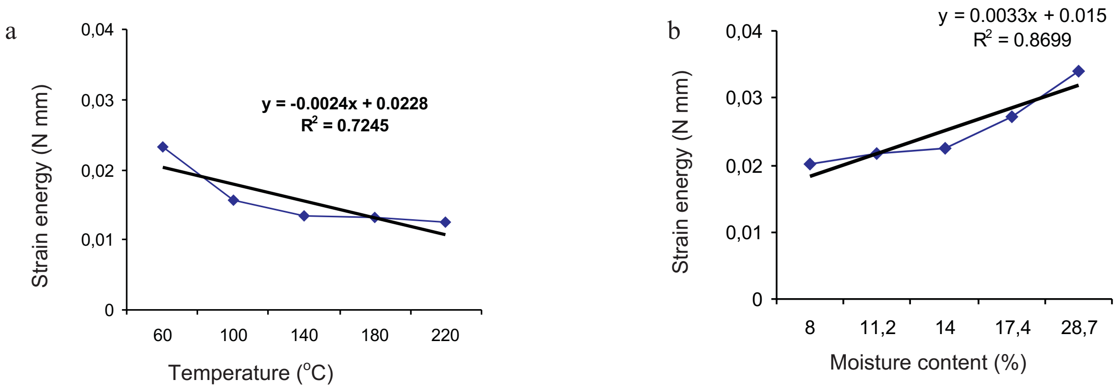

Fig. 5. Effect of temperature (a) and moisture content (b) on strain energy.

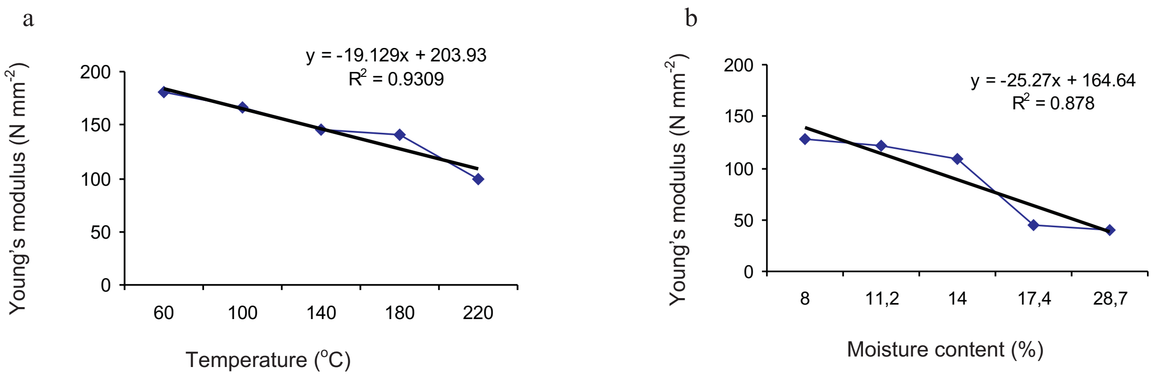

Fig. 6. Effect of temperature (a) and moisture content (b) on Young's modulus.

could be used to conserve force. However, to avoid excessive kernel breakage (quality control), cracking should be conducted within the range of 11.2 and 14% moisture content. These results are consistent with those of Shelef and Mohsenin (1969) and are displayed in Fig. 6b.

Engineering implications

In a bid to mechanize the various unit operations involved in the post-harvest processing of African nutmeg seeds, information and data on the behaviour of these strength properties as a function of temperature and moisture content is needed. These data – when fully used – will not only save energy but will promote the design and development of effective and efficient process machines.

CONCLUSIONS

1. From the study it can be concluded that the compressive force needed to initiate seed coat rupture of African nutmeg decreased with an increase in both pre-heating temperature and moisture content. Compressive force values of 52.8 and 32 N were obtained at 60 and 220°C, respectively. Also, 56.6 and 33 N were recorded for 8 and 28.7% moisture contents, respectively.

2. However, deformation – which is the desired parameter – increased positively with an increase in both temperature and moisture.

3. The other properties, such as failure stress and Young's modulus, decreased with increase in both temperature and moisture content, thereby confirming the works by Shelef and Mohsenin (1969) and Ramana *et al*. (1992).

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