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Effects of Temperature and Moisture Content on the Strength Properties of African Nutmeg (*Monodora Myristica*)

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Abstract

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The effects of temperature and moisture content of African nutmeg seedcoat 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 8.0, 11.2, 14.0, 17.4 and 28.7 percent (db) in an axial loading orientation. Investigations reveal that force needed to crack open the seedcoat decreased from 52.8N to 32.0N at temperatures of 60°C and 220°C respectively. A similar trend was also observed as compressive force decreased from 56.6N to 33.0N as moisture levels increased from 8.0 to 28.7 percent respectively. Deformation values were observed to increase from 0.64mm to 0.97mm for 60°C and 220°c respectively. These values of deformation varied from 1.07mm to 1.54mm at moisture content levels of 8.0 to 28.7 percent respectively. Failure stress, strain energy and young's modulus all tended to decrease with an increase in temperature. Also as moisture content increases, failure stress and modulus of elasticity decreased. However, an increase in strain energy was observed from 0.0201N.mm to 0.0341N.mm for an increase in moisture from 8.0 to 28.7 percent respectively. Based on these findings important recommendations are made.

Key words: 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

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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 particularly fruits and vegetables (Stroshine, 2005; Burubai, 2007). 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 reveals that it is one of the most important factors in the processing and handling of such materials (Misra and Young, 1981; Shelef and Mohsenin, 1969; Jackman and Stanley, 1994; Mamman and Umar, 2005).

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

Ramana et al. (1992) investigated cellular integrity during heating by microscopic examination. It was observed that the protoplasts were disrupted around 60^{o}C and the cells lost their integrity between 50^{o} and 65^{o}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 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 is used to prepare pepper soup as stimulant to relieve constipation and control passive uterine hemorrhage 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^oc and 90 % relative humidity for 48hours 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 60^o, 100^o, 140^o, 180^o and 220^o at 14% moisture content (db) and loading rate of 2.5mm/min were selected based upon those used by Vincent (1999) and Khazaei and Mann (2004). Prior to testing the samples were checked for possible cracks on their surfaces and those with cracks were discarded. The thermostat was preset 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 5 minutes. At the expiration of 5 minutes, 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 Standardes (ASAE S368.4, 2000). The effect of temperature on the strength properties were 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 8.0, 11.2, 14.0, 17.4 and 28.7% (db) as recommended by Oje (1993) and Aviara et al (2000) in investigating the moisture content of thevetia and shea nuts using the oven method. After drying each group of samples were sealed in a polyethylene bag and immediately placed in an insulated box to ensure slow cooling for 12hours 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 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 Discussion

The experimental results on the influence of both pre-heating temperature and moisture content on the five selected strength properties of African nutmeg are shown respectively in Tables 1 and 2.

Compressive force

The compressive load necessary to affect the desired seed coat rupture of African nutmeg was observed to decrease as pre-heating temperature of the Specimen increased (Table 1 and Figure 2). At 60^oC, a compressive force of 52.80N was recorded. This value decreased to 32.0N at a temperature of $220^o C$. This negative trend is in conformity with the findings of Reeve et al. (1977), Bourne (1982), Ramana et al. (1992) and Vincent (1999) as

Table 1
Effect of temperature on strength properties

Tempe-rature	Strength properties	N	Mean	Standard eviation	Range
			52.8	19.88	25.20 – 83.10
	Compressive force (N)		0.643	0.328	0.359 – 1.429
60°C	Deformation (mm)	10	5.587	2.1	2.667 – 8.794
	Failure stress (N/mm^2)		0.023	0.0217	0.0053 – 0.0742
	Strain energy (N.mm)		180.9	29.28	132.91 – 226.68
	Young's modulus (N/mm^2)				
	Compressive force (N)		42.9	20.39	13.10 – 79.90
100°C	Deformation (mm)	10	0.594	0.194	0.242 – 0.781
	Failure stress (N/mm^2)		4.54	2.158	1.386 – 8.455
	Strain energy (N.mm)		0.016	0.009	0.0018 – 0.0297
	Young's modulus (N/mm^2)		167.1	58.66	80.31 – 285.37
	Compressive force (N)		42.19	10.71	30.40 – 60.900
140°C	Deformation (mm)	10	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)		0.013	0.009	0.0049 – 0.0328
	Young's modulus (N/mm^2)		145.8	58.66	78.45 – 234.85
	Compressive force (N)		37.67	16.39	18.20 – 60.60
180°C	Deformation (mm)	10	0.88	0.279	0.310 – 1.290
	Failure stress (N/mm^2)		3.986	1.734	1.926 – 6.413
	Strain energy (N.mm)		0.013	0.0077	0.0030 – 0.0223
	Young's modulus (N/mm^2)		140.2	58.25	47.45 – 244.74
	Compressive force (N)		32	18.76	7.30 – 63.40
220°C	Deformation (mm)	10	0.97	0.281	0.22 – 1.01
	Failure stress (N/mm^2)		3.39	1.99	0.77 – 6.71
	Strain energy (N.mm)		0.013	0.0118	0.0016 – 0.0323
	Young's modulus (N/mm^2)		98.73	28.43	52.39 – 148.61

reported in this work and elsewhere. It was however, observed that between 180°C 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 100^0 C and 140^0 C is recommended.

On the other hand, the compressive force value varied from 56.60N to 33.0N

Table 2
Effect of moisture content on strength properties

Moisture content, %	Strength properties	N	Mean	Standard deviation	Range
			56.6	20.49	27.60 – 96.20
	Compressive force (N)		1.074	0.5177	0.494 – 2.312
8	Deformation (mm)	10	5.989	2.168	2.921 – 10.180
	Failure stress (N/mm^2)		0.0701	0.0308	0.0078 – 0.1168
	Strain energy (N.mm)		128.59	30.58	69.44 – 167.19
	Young's modulus (N/mm^2)				
	Compressive force (N)		53.82	21.53	20.50 – 88.70
11.2	Deformation (mm)	10	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)		121.5	20	112.3 – 270.90
	Compressive force (N)		41.55	19.4	14.80 – 84.30
14	Deformation (mm)	10	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
	Compressive force (N)		33.61	14.6	12.50 – 57.30
17.4	Deformation (mm)	10	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
	Compressive force (N)		33	11.2	10.20 – 53.00
	Deformation (mm)	10	1.5378	0.6814	0.6810 – 2.855
28.7	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)		40.3	30.55	15.62 – 105.26

for moisture content levels of 8.0 percent and 28.7 percent respectively. Though seedcoat rupture required a lower force at higher moisture contents (conserving energy), however product quality must be maintained by avoiding excessive kernel breakage to appeal to consumers. Thus a moisture content range of 11.2 to 14.0 percent (db) is recommended for optimum results. The correlation between compressive force and moisture content are shown in Table 2 and Figure 3. These results agree

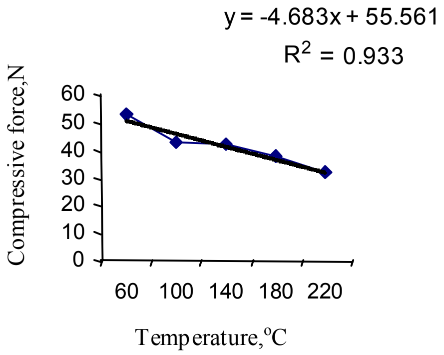

Fig. 2. Effect of temperature on compressive force

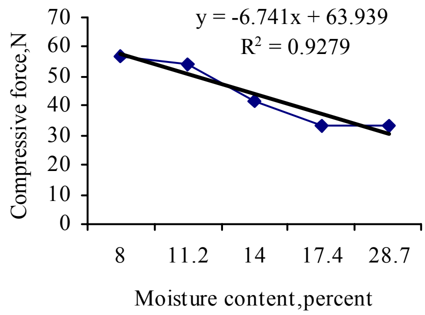

Fig. 3. Effect of moisture contents on compressive force

with that of Cenkwoski 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). Results reveal that deformation increased as temperature increases. At 60°C, a deformation of 0.643mm was noticed. This increased to 0.970mm at 220°C. This positive correlation (Figure 4) shows that at higher temperatures, lesser force is required to achieve the desired deformation. These results are consistent with that of Khazaei and Mann (2004).

The relationship between moisture content and deformation is also presented in Table 2 and Figure 5. It is evident that values of deformation varied from 1.074 mm to 1.537 mm for moisture content levels of 8.0 percent and 28.7 percent respectively. However, these two extreme moisture content (8.0 and 28.7 percent) were accompanied with excessive kernel breakage. This is not good for quality control. Thus a moisture content range of 11.2 to 14.0 percent (db) is recommended for best

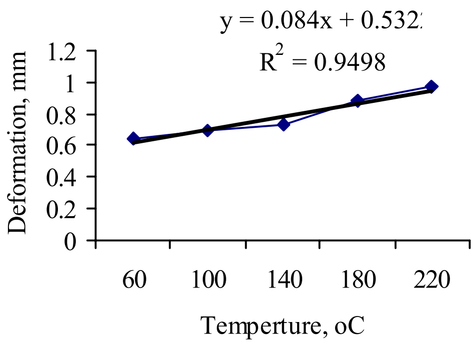

Fig. 4. Effect of temperature on deformation

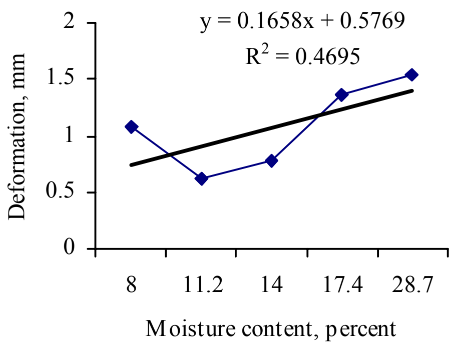

Fig. 5. Effect of moisture content on deformation

results. The results herein presented are in agreement with that 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 preheating 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 above.

Results from Table 1 shows that, generally failure stress responded negatively to an increase in temperature. At 60°C, a failure stress value of 5.587N/mm^2 was obtained. This value reduced to 3.39N/mm^2 at 220°C. The cause and effect between temperature and failure stress is presented in Figure 6. The results obtained confirm the fact that increases 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 5.989N/mm^2 at 8.0 percent moisture content and 3.583N/mm^2 at 28.7 percent moisture. The regressional relationship between failure stress and moisture content is shown in Figure 7. The findings here presented 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 is shown in Table 1 and Table 2. Generally, strain energy tended to decrease with increasing temperature as revealed in Table 1 and Figure 8. An average value of 0.0233N.mm was recorded at 60°C and 0.0125N.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 0.0201N.mm at 8.0 percent moisture, but increased to 0.0341N.mm at 28.7 percent moisture. This relationship is shown in Figure 9.

Young's modulus

Otherwise called firmness or rigidity,

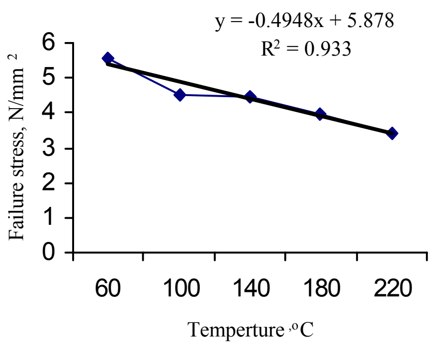

Fig. 6. Effect of temperature on failure stress

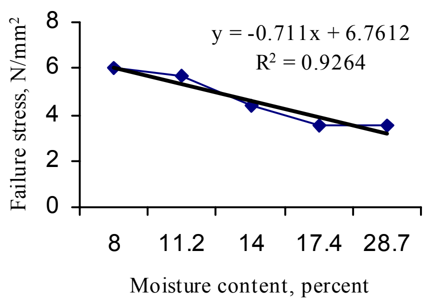

Fig. 7. Effect of moisture content of failure stress

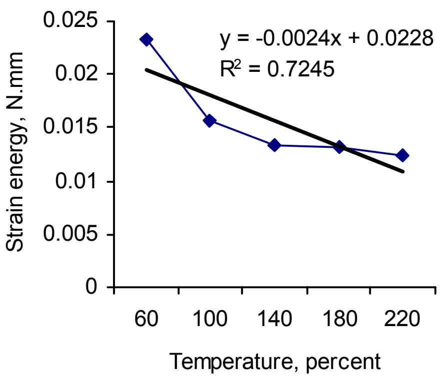

Fig. 8. Wffect of temperature on Strain energy

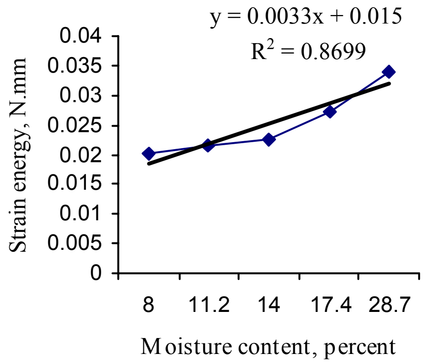

Fig. 9. Effect of moisture content on strain energy

Young's modulus 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 are shown in Tables 1 and 2 above. The effect of temperature as shown in Table 1 reveals that as temperature increases, Young's modulus tends to decrease. At 60^{o}C, an average young's modulus value of 180.89N/mm^2 was obtained, but declined to 98.73N/mm^2 at 220^{o}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 Figure 10.

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 128.59N/mm^2 and 40.30N/mm^2 for moisture levels of 8.0 percent and 28.7 percent respectively. This decline in resistance of the seed coat to applied load as a result of moisture increase could be used to conserve force. However, to avoid excessive kernel break-

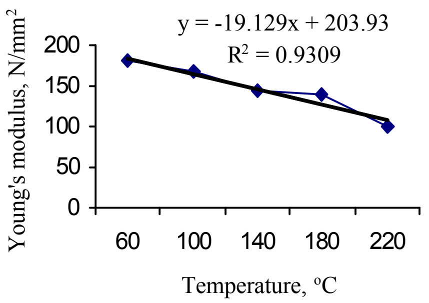

Fig. 10. Effect of temperature on Young's moduls

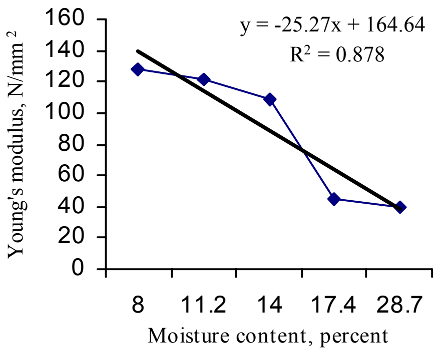

Fig. 11. Effect of moisture content on Young's moduls

age (quality control), cracking should be conducted within the range of 11.2 percent and 14.0 percent moisture content. These results are consistent with that of Shelef and Mohsenin (1969) and are displayed in Figure 11.

Engineering Implication

In a bid to mechanize the various unit operations involved in the post-harvest processing of African nutmeg seeds, information and data on the behavior 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.

Conclusion

From the study it can be concluded that, the compressive force needed to initiate seedcoat rupture of African nutmeg decreased with an increase in both pre-heating temperature and moisture content.Compressive force values of 52.8N and 32.0N were obtained at 60°C and 220°C respectively. Also 56.6N and 33.0N were recorded for 8.0 percent and 28.7 percent moisture contents respec-tively.

However, deformation which is the desired parameter increased positively with an increase in both temperature and moisture. But other properties such as failure stress, and young's modulus decreased with increase in both temperature and moisture content, thereby confirming the works of Shelef and Mohsenin (1969) and Ramana et al. (1992).

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