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Full Length Research Paper

Fracture resistance of palm kernel seed to compressive loading

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Quasi-static compression tests were carried out on treated single palm kernel seeds to study the effects of temperature, moisture content and loading position on the rupture force, deformation and toughness of the kernels. The levels of moisture content and temperature considered were 5, 7 and 10% w.b and 70, 90 and 110°C each at the horizontal and vertical loading position. Twenty palm kernel seeds were tested at each moisture and temperature level in both horizontal and vertical loading positions making a total of 480 kernels that were individually measured and tested. The average compressive force required to rupture a palm kernel seed under compressive loading decreased as the moisture content of the seed increased from 7 to 10% (wb), while the corresponding deformation increased from 1.18 to 1.43 mm but decreases from 1.18 to 1.03 mm as the temperature increases. Maximum toughness occurred at 7% moisture content and 70°C temperature respectively, indicating the optimum moisture content and temperature for absorbing compressive energy. The value of toughness is an important indicator of the ability of the palm kernel to resist mechanical damage during loading. The loading position has significant effect on the rupture force and should be considered when palm kernel seeds are being loaded.

Key words: Resistance, compression loading, rupture, palm kernel, determination, toughness.

INTRODUCTION

During processes like planting, harvesting storage, processing and transportation, agricultural products are often subjected to mechanical forces. These forces most of the time results to deformation of the crops. Deformation may either sometimes be enough to result to cutting, pressing, crushing, tearing or just very small especially during harvesting and threshing to avoid a more severe damage. Thus, mechanical strength like compression tensile strength and shear strength of agricultural products plays an important role in harvesting, storage and processing of the crop. Sitkei (1986) reported that most agricultural products are visco-elastic in nature, they respond differently to tensile or compressive forces and also behave differently when they are subjected to vibration. Therefore, a fundamental knowledge of agricultural product behaviour under mechanical forces is essential in determining the power requirement for different operations like cutting, crushing, pressing, milling etc. It is generally agreed that the oil palm (*Elaeis guineensis*) originated in the tropical main forest of West Africa. The main belt runs through the southern latitudes of Cameroon, Cote d' Ivoire, Ghana, Liberia, Nigeria, Sierra Leone, Togo and into the equatorial region of Angola and the Congo (FAO, 1993). Because of its economic importance as a high-yielding source of edible and technical oils, the oil palm is now grown as a plantation crop in countries with high rainfall in tropical climates within 10° of the equator. The palm tree bears its fruits in bunches (Figure 1) which vary in weight from 10 to 40 kg. The individual fruit ranging from 6 to 70 g, is made up of an outer skin (the exocarp), a pulp (mesocarp) containing the palm oil in a fibrous matrix, a central nut consisting of a shell (endocarp) and the kernel, which itself contains an oil, quite different to palm oil, resembling coconut oil (FAO, 1993) (Figure 2).

Extraction of oil from palm kernels is generally different

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Figure 1. Fresh palm fruits in bunch.

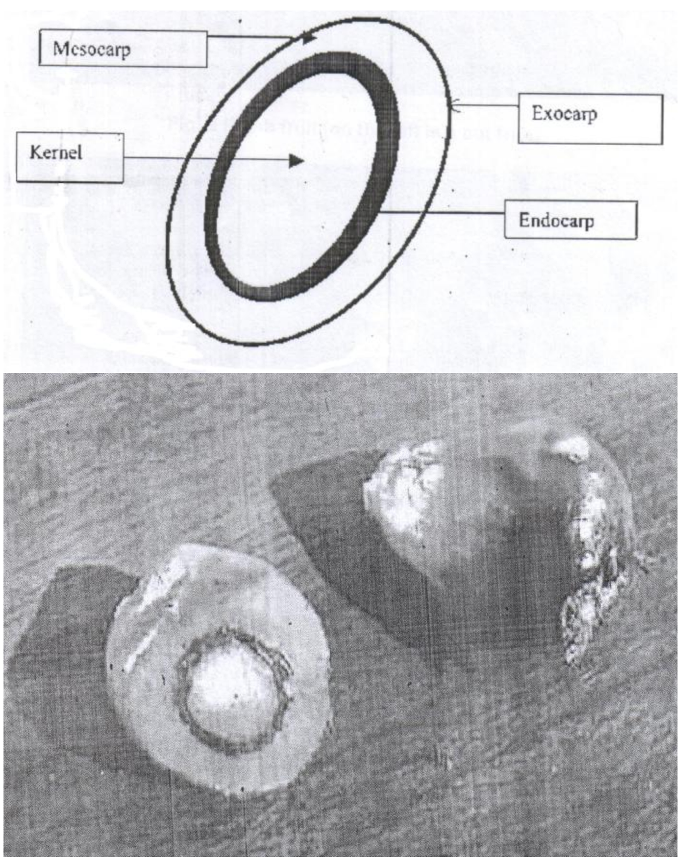

Figure 2. Cross –section of an individual palm fruit showing the main parts.

from palm oil extraction, and is often carried out in mills. The stages in this process comprise size reduction (that is grinding, the kernels into small particles), heating (cooking), and expression/extracting the oil using an oil seed expeller or petroleum derived solvent (FAO, 1993). Several researchers have investigated the physical and mechanical properties of some crops considered relevant to the design of suitable machines and equipment for their production and processing (Adebayo, 2004) carried out a compression test on Dura varieties of the palm nut in order to determine the force required for cracking the palm nuts. Dev et al. (1982) investigated the size and shape of sorghum as essential properties for the analysis of the behaviours of grains during handling, storage and processing. Paulsen (1978) studied the average compressive strength, deformation and toughness of soybean seed coat rupture under quasi-static loading. Ezeaku et al. (1998) studied the measurement of the resistance of Bambara groundnut seed to compressive loading, while Makanjuola (1972) carried out a study on some of the physical properties of melon seeds.

Such similar work appears not to have been done on palm kernel seeds. A similar information on some of its mechanical properties would be essential in the design of equipment and system for the loading and processing of palm kernel into palm kernel oil. Sequel to the aforementioned, a study of the resistance of palm kernel seeds to compressive loading was undertaken. The objectives of this study are:

i) To determine the average compressive force, deformation and toughness at palm kernel seed rupture under compressive loading; and
ii) To determine the effect of loading position, moisture content and temperature on the compressive force, deformation and toughness at palm kernel seed rupture.

MATERIALS AND METHODS

Samples of Dura variety of palm kernel at moisture content of 4.7% w.b was obtained from an open market at Okuku in Osun State,

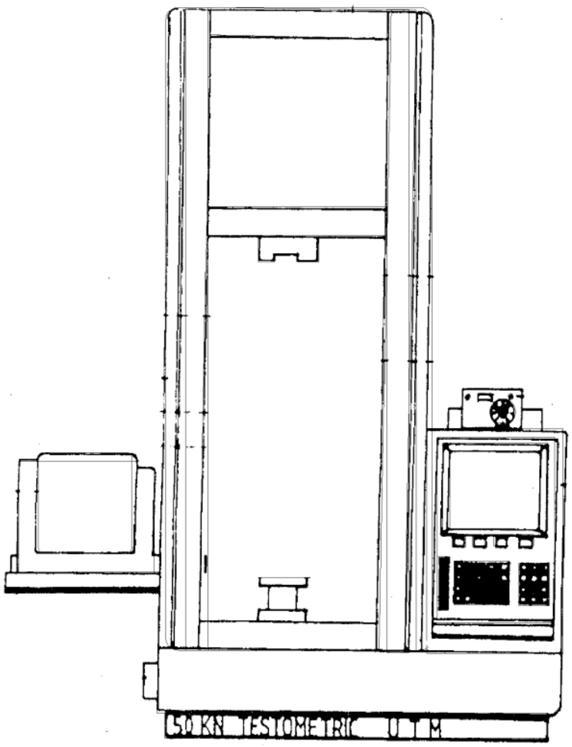

Figure 3. The instron universal testing machine (UTM).

Nigeria. The kernel was manually cleaned to remove dirt and other foreign materials in compliance with Nigeria Industrial Standard. Moisture contents were determined by oven drying respective ground samples (100 g) at 103°C for 6 h, as recommended for oil crops by Young et al. (1982). While the samples were conditioned to desired moisture levels 5, 7 and 10% (w.b) by adding distilled water as calculated from Equation (1) according to Hammond et al. (1997) as follows:

$$water\ \text{to be added} = \left(\frac{100 - M_p}{100 - M_g} - 1\right) \text{x } W_s \qquad (1)$$

Where M_p = present moisture content, M_g = required moisture content, W_s = weight of samples in grammes.

After adding water, each sample was sealed in separate polyethylene bag and kept at 5°C in a refrigerator for a week to enable the moisture distribute uniformity throughout the samples. The seeds were weighted using an electronic weighing balance, while a vernier calliper was used in measuring the dimensions of the seed. The average minor diameter, intermediate diameter and major diameter of palm kernel seeds used for this investigation were 11.16, 13.4 and 21.11 mm respectively. Heating of the samples to the desired temperatures of 70, 90 and 110°C was achieved by spreading the kernel seeds in a closed container in a preset temperature controlled Gallenkamp or 440 oven at the different temperatures for 30 min in line with Olaniyan (2006). All ranges of temperature and moisture content were selected based on findings from literature review and preliminary tests.

All laboratory quasi-static compression tests were performed using the Instron Universal Testing Machine (UTM) equipped with a 50 kN load beam available at the National Centre for Agricultural mechanization Ilorin, Nigeria (Figure 3). The loading rate adopted throughout the test was 2.5 mm/min as recommended by Olaniyan (2006) for oil-bearing seeds. Each palm kernel seed was loaded by hand between two circular seated nosepieces by chuck attachment pins. The force at bio-yield point and the corresponding deformation for each seed sample were read off from the force deformation curve. The effect of the palm kernel seed position was determined by loading the seed in either the horizontal or vertical loading position. Before loading, the palm kernel seeds were visually inspected. Those with visible cracks were not tested, thus results from the tests should be considered as the maximum force or toughness that a palm kernel seed sample could withstand and prior to rupture. The average room temperature throughout the duration of the test was 30°C.

A 3 x 4 x 2 factorial experiment in a randomized complete block design (RCBD) (Cox, 1952; Montgomery, 1976) was used to evaluate the effects of moisture content, temperature and loading position on rupture force, deformation and toughness of palm kernel seed under compressive loading. The factors included in the design were moisture content, temperature and loading position, with moisture content being blocked. The range of each factor was selected based on findings from literature review and preliminary investigations. Twenty palm kernel seeds were tested at each moisture level and each temperature level in each loading position, making a total of 480 seeds that were individually measured and tested. The volume of individual palm kernel was calculated from the principal dimensions earlier measured. Assuming ellipsoidal shaped material, the volume as given by Mohsenin (1978) and Sitkei (1986) is:

$$V = \frac{\pi}{6}(abc) \qquad (2)$$

Where a = major diameter (mm), b = intermediate diameter (mm), c = minor diameter (mm), and v = volume of palm kernel seed (mm^3).

Toughness is regarded as the energy absorbed by palm kernel up to the rupture point per unit of the kernel volume. The energy absorbed during compression was indicated by the data from the UTM as energy at break (rupture). Toughness was then calculated by using the formula according to Mohsenin (1978) as:

$$P = \frac{E}{V} \qquad (3)$$

Where p = toughness (J/mm^3), E = energy (J), V = volume of kernel (mm^3).

The data recorded as means of twenty test samples in each test condition were subjected to analysis of variance test and Duncan's New Multiple Range Test was used to compare the means.

RESULTS AND DISCUSSION

All palm kernel seeds tested typically exhibited a force – deformation curve as shown in Figures 4 and 5. The bio-yield point in the force – deformation curves indicates the seed rupture point and this point was determined by a visual decrease in force as deformation increased. The force-deformation curves obtained in this investigation are similar to those obtained by previous researchers on different agricultural products (Ezeaku et al., 1998; Paulsen, 1978; and those reported in ASAE Standards ASAE S368.1 (1980). Tables 1 and 2 show a summary of the raw data obtained while the effects of temperature, moisture content and loading position on the average

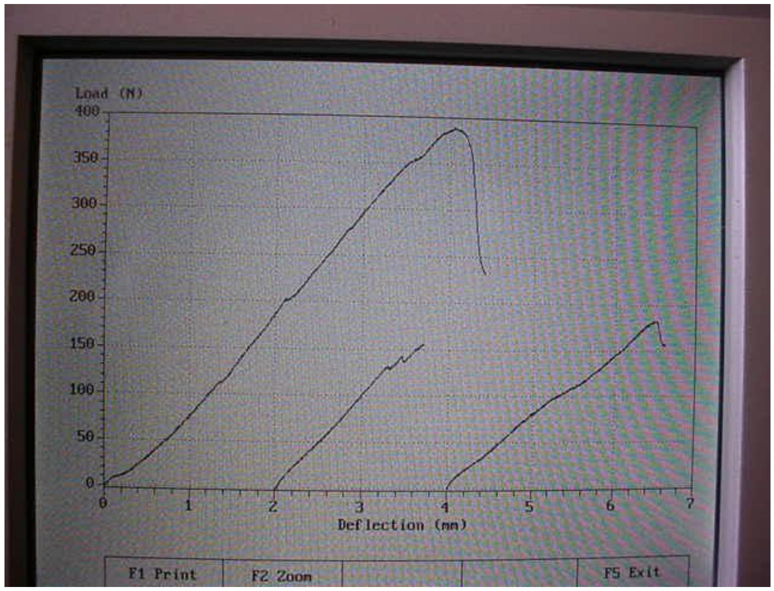

Figure 4. A typical load-deformation curve of palm kernel under horizontal compressive loading.

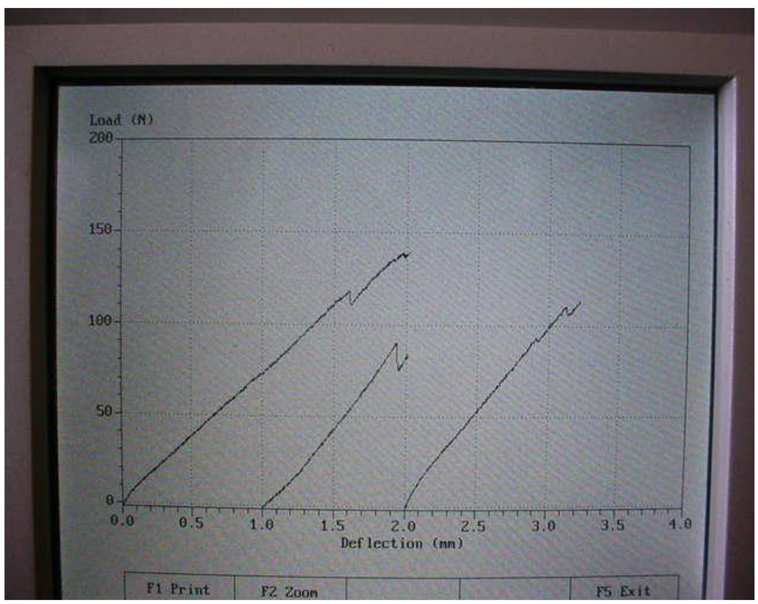

Figure 5. A typical load-deformation curve of palm kernel under vertical compressive loading.

force, deformation and toughness are shown in Tables 3, 4 and 5. These effects are thus discussed hereunder:

Effect of temperature

The effects of temperature on the average rupture force, deformation and toughness at palm kernel seed rupture are presented in Table 3. The table shows that average rupture force and deformation at seed rupture are significantly affected by the seed temperature at P (0.05) level, while the seed temperature does not significantly affect the toughness. However, the table also shows that as the temperature increases, the deformation and toughness decreases respectively. This may be attributed to the weakening of the cell walls of the kernel as a result of high temperature, thus yielding easily to pressure.

Table 1. Summary of mechanical properties of palm kernel seed at rupture for three moisture levels and two loading positions.

Moisture content (%)	Loading position	Mechanical Properties		Toughness × 10^{-4} J/mm^3
		Rupture force (N)	Deformation at rupture (mm)	
5	Horizontal	256.05 (38.46)	1.48 (0.38)	2.7938
	Vertical	181.23 (30.21)	1.310 (0.35)	2.4290
7	Horizontal	475.79 (78.12) 80	1.24) (0.32)	4.2409
	Vertical	192.52 (31.64)	1.12 (0.30)	2.8034
10	Horizontal	323.56 (58.44)	1.23 (0.32)	2.4678
	Vertical	208.60 (46.26)	1.63 (0.40)	1.8171

SD Values in parenthesis are standard deviations, *each value is the means of 20 test samples.

Table 2. Summary of mechanical properties of palm kernel at seed rupture for three temperature levels and two loading position.

Temperature (°C)	Loading position	Mechanical Properties		Toughness × 10^{-4} J/mm^3
		Rupture force (N)	Deformation at rupture (mm)	
70	Horizontal	252.49	1.22	1.33
	Vertical	159.57	1.13	1.12
90	Horizontal	599.18	1.14	1.2 8
	Vertical	217.53	1.02	1.06
110	Horizontal	210.33	1.07	1.136
	Vertical	205.25	0.98	1.072

* Each value is the means of 20 test samples.

Table 3. Effect of temperature on average rupture force, deformation and toughness of palm kernel seed

Temperature (°C)	Rupture force (N)	Deformation at rupture (mm)	Toughness at rupture × 10^{-4} J/mm^3
70	206.03(a)*	1.18(c)	1.23(b)
90	408.36(b)	1.08(c)	1.17(a)
110	207.79(a)	1.03(c)	1.10(c)

*In each column, means with the same letters are not significantly different at P (0.05) based on Duncan's new multiple range test.

Effect of moisture content

The effect of moisture content on average rupture force, deformation and toughness is presented in Table 4. The table shows that the average rupture force, deformation and toughness are significantly affected by the moisture content of the palm kernel seed at P (0.05) level. The force required to initiate seed rupture increased when moisture content increased from 5 to 7% and later begins to decrease as the moisture content approaches 10%. This may be attributed to the fact that as the seed absorbs more moisture; it softens and tends to yield easily under pressure. Also, it may be indicated, within the range of moisture contents tested that palm kernel with lower moisture contents are generally more resistant to rupture, under compressive loading than those with higher moisture content.

Effect of loading position

The effect of loading position on average rupture force,

Table 4. Effect of moisture content on average rupture force, deformation and toughness of palm kernel seed.

Moisture content	Rupture force (N)	Deformation and rupture (mm)	Toughness $\times 10^{-4}$ J/mm^3
5	218.64(a)*	1.409	2.61(a)
7	33.4.16(b)	1.18(b)	3.52(b)
10	266.08(a)	1.43(a)	2.15(c)

*In each column, means with the same letters are not significantly different at P (0.05) based on Duncan's new multiple range test.

Table 5. The effect of loading position on the average rupture force, deformation and toughness of palm kernel seed.

Loading position	Rupture force (N)	Deformation at rupture (mm)	Toughness $\times 10^{-4}$ J/mm^3
Horizontal	352.90(a)*	1.23(a)	2.04(a)
Vertical	194.12(b)	1.20(a)	1.55(b)

*In each column, means with the same letters are not significantly different at P(0.05) based on Duncan's new multiple range test.

deformation and toughness is presented in Table 5. The table shows that rupture force and toughness are significantly affected by the loading positions, while the deformation is not significantly affected. This suggests that when palm kernel seeds are compressed, they absorb more energy at the horizontal position than at the vertical position. Thus, consideration should be given to the manner in which palm kernel seeds are loaded with respect to compression surfaces since loading position has significant influence on the rupture force.

Conclusions

The average compressive force required to cause palm kernel seed to rupture decreases as moisture content of the seed increased from 7 to 10% (w.b). Consideration should be given to the manner in which palm kernel seeds are loaded since loading position has significant influence on the rupture force. Deformation of palm kernel seed generally decreases as temperature increased and increases as moisture content decreases, suggesting that palm kernel seeds at lower moisture content are harder and less susceptive to rupture than palm kernel at higher moisture contents. Toughness is significantly different at all temperatures, suggesting that increase in temperature weakens the cell walls of the kernel, thus making it yield easily to pressure and consequently reducing the toughness of the kernel. However, the lower the moisture content of the kernel, the higher the toughness.

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