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Uni-axial Compression of Pumpkin Seed as Influenced by Moisture Content

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Abstract: The knowledge of compressive strength is necessary to minimizing the mechanical damage to pumpkin seed during handling operation. It is equally important in the design of pumpkin seed crusher. The load, energy and deformation at yield and rupture points of pumpkin seed were investigated as factorial experiments; at three levels of moisture content (18.1, 22.2 and 26.03% d.b) and two levels of variety factors (*c. maxima* and *c. pepo*). Results were analyzed using ANOVA in accordance with the General Linear Model procedure of SPSS 17 at 5% level of probability. The effects of moisture content was significant on rupture force and deformation ($p < 0.05$), while the variety factor significantly affected rupture force and energy ($p < 0.05$). The rupture force, yield force, yield energy, rupture energy and rupture deformation at 18.1% d.b in *c. maxima* variety were 214N, 35.01N, 0.0209J, 0.445J and 0.868mm respectively. Correspondingly, these values were 266N, 37.14N, 0.246J, 1.05 and 1.10mm respectively in *c. pepo* variety.

Keywords: Cucurbitaceae, moisture content, yield point, rupture point, seed, Nigeria

I. Introduction

Pumpkin is a fruity vegetable belonging to the family of cucurbitaceae; it has been cultivated for more than 10,000 years in different locations of the world, [1]; it performs well in the tropical, subtropical and in temperate climates of the world [3]. The yield of pumpkin fruits and seeds varies with climate, variety/cultivar, production system, weed competition, plant diseases and management practices. Pumpkins have been cultivated for nutritional and medicinal/pharmacological applications; some of the pharmacological effects include antidiabetic, antihypertensive, antibacterial, antihypercholesterolemic, immunomodulation, intestinal antiparasitic, analgesic and antiinflammation effects have been reported, [3].

Despite the benefits of pumpkin seeds, its cultivation and utilization has been left to subsistent farmers in Nigeria as noted by reference [3]. Reference [3] and [4] investigated the effects of moisture content and variety factors on the axial dimensions, surface and projected areas, seed volume, true and bulk densities, coefficient of static friction, dynamic and static angles of repose, seed hardness and oil contents of *c. maxima* and *c. pepo* varieties of pumpkin seed. Reference [5] investigated the relationship between mechanical properties of pumpkin fruit and skin thickness, while reference [6] investigated the kinetics and temperature dependent moisture diffusivities of pumpkin seed during drying. Engineering data on pumpkin seed relevant to minimizing mechanical damage to pumpkin seed during material handling, and for the design of pumpkin seed packaging and storage facility is lacking, in view of which the research investigated the effects of moisture content and variety factors on the load and energy at yield and rupture points, and the deformation at rupture point of pumpkin seed.

Handling/mechanical damage could result from loading of agricultural materials during harvest, transportation, and storage; these loads are either compressive, tensile, shear, or impact in nature. The result of mechanical damage is generally to rupture or damage cells. Furthermore, greater damage to agricultural materials is done by the same absorbed energy when products are loaded slowly as observed in storage or during material handling [7].

Uni-axial compression tests have been conducted for a wide range of agricultural materials such as pine nut [8], cumin seed [9], corn seed [10], millet seed [11], desma seed [23], barley seed [12], jatropha [14], and on conophor nut [13]. Reference [14] investigated the effect of seed mass and loading orientation on the rupture properties of jatropha seed; results indicated that rupture force of seed and kernels increased with unit mass in all loading orientations, with the highest and the lowest rupture forces indicated by the vertical and the transversal loading orientations. Reference [15] found that for sunflower seed, the rupture force, deformation and energy increased polynomially with moisture content between 1.8 to 14.5% d.b, but decreased with further increase in moisture content between 14.5 and 20.3% d.b. Reference [13] differentiated between bioyield point and yield point of agricultural materials; the bioyield point is the "point on the force-deformation curve at

which the compressed nut shell weakened and failed internally without cracking outwardly” while the yield point is the “point on the force-deformation curve at which the visible failure of nut shell became initiated and the shell just began to tear”. Although the force-deformation curves of some agricultural materials exist without yield point [22]; typical force-deformations curve of pumpkin seed as reported by reference [25]. While the rupture point is the point on the force-deformation curve at which the shell or seed coat got completely broken and torn with kernels exposed [16].

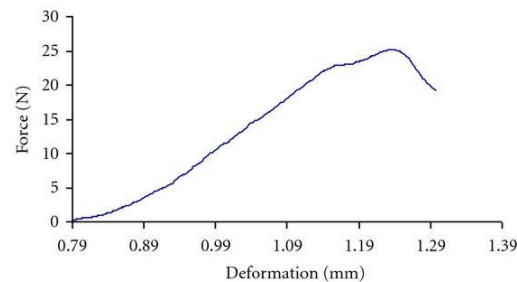


Figure 1; A Typical Force-Deformation Curve of Pumpkin Seed (Source, [25])

II. Materials and Methods

A) Sample preparation and seed rewetting procedures:

Dry pumpkin seeds were obtained from a local market in Mayo-Nguli, Maiha local government area of Adamawa state (located between latitude $10^{\circ}.02^{\circ}\text{N}$ and $10^{\circ}.15^{\circ}\text{N}$ and longitude $13^{\circ}.09^{\circ}\text{E}$ and $13^{\circ}.16^{\circ}\text{E}$).



Plate 2; *c. pepo* and *c. maxima* varieties of pumpkin respectively

The post harvest moisture content of 14.47%d.b and 12.13%db for the *c. maxima* and *c. pepo* varieties respectively were determined by oven drying method in accordance with the procedures of [3] and computed using equation (1).

$$MC_{db} = \frac{(m_2 - m_1) - (m_3 - m_4)}{m_3 - m_1} \quad (1)$$

Where; m_1 = mass of empty moisture can (g), m_2 = mass of air-dried sample + moisture can (g), m_3 = mass of oven dried sample + moisture can (g)

The desired moisture content of 18.1, 22.2 and 26.0% d.b were obtained by conditioning pumpkin seed (i.e. rewetting); this involved adding calculated quantity of distil water. The rewetting procedure adopted was equally employed by researchers in investigating the moisture dependent properties such as pistachio nut, cucurbit, cowpea, shea nut, and cotton seeds [17], [18], [19], [20], and [21] respectively.

$$Q = \frac{W_i(m_f - m_i)}{(100 - m_f)} \quad (2)$$

Q = The quantity of distil water needed to obtain the desired moisture content during the rewetting process, W_i = Weight of pumpkin seed before rewetting (g), m_f = final moisture content of pumpkin seed (% d.b), m_i = Initial moisture content of pumpkin seed (% d.b)

The rewetted pumpkin seed were packed in a low density polyethylene bags and stored in a refrigerator at 5°C for 72 hours [3]; this was done to create a favourable environment for the absorption of moisture by pumpkin seed and to prevent the action of microbes on the wet pumpkin seed.

B) Compression test:

The compression test was conducted with an Instron universal testing machine equipped with a 50kN compression load and an integrator at the Engineering Materials Development Institute Akure, Ondo state, Nigeria. The resolution of the testing machine was 1.0×10^{-5} N in load and 1.0×10^{-5} mm in deformation. The diameter of the indenter of 8mm used for the experiment was adopted from reference [22]. For each of the treatment combinations, forty randomly selected seeds were used; i.e. ten seeds at four replications and the mean values and standard deviation were noted. The individual seed was loaded laterally between the parallel plates of the machine (i.e. seed flat as shown in plate 2). The seed was compressed at a preset compression rate of 1.0mm/min until rupture occurred. As soon as seed rupture occurred, the machine automatically stopped and the values of force, energy, and deformation at yield and rupture points of pumpkin seed were read from the computer monitor.

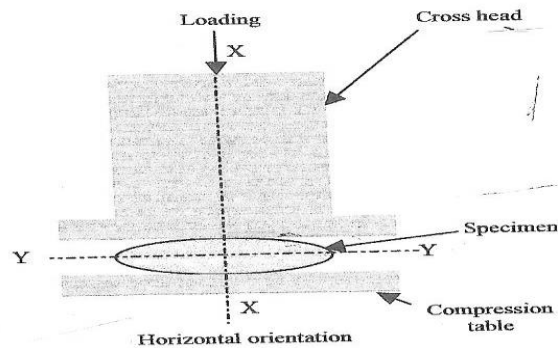


Plate 3; Compression axis of pumpkin seed

III. Results & Discussions

A) Results:

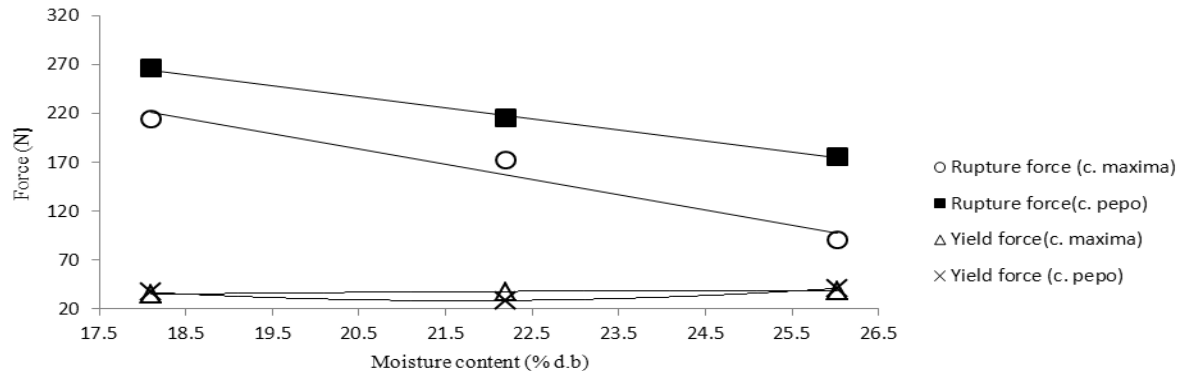


Figure 2 ; Rupture and yield forces of pumpkin seed at varying moisture contents

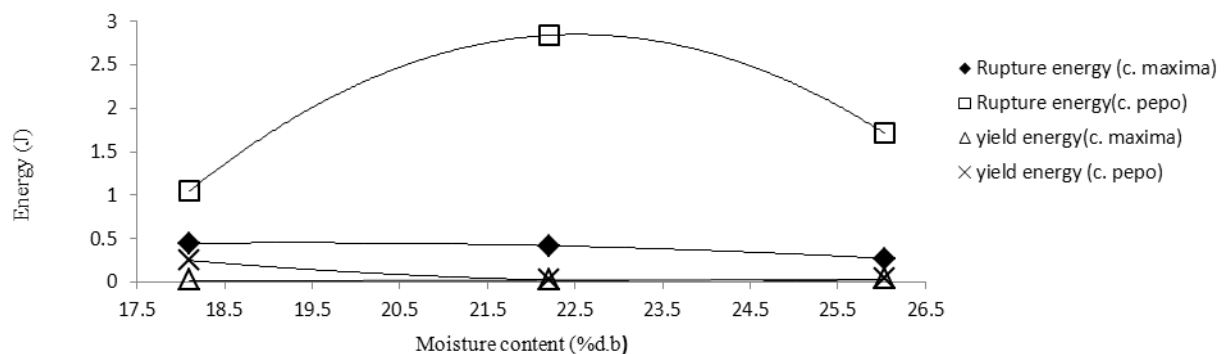


Figure 3; Yield and rupture energy of pumpkin seed at varying moisture content

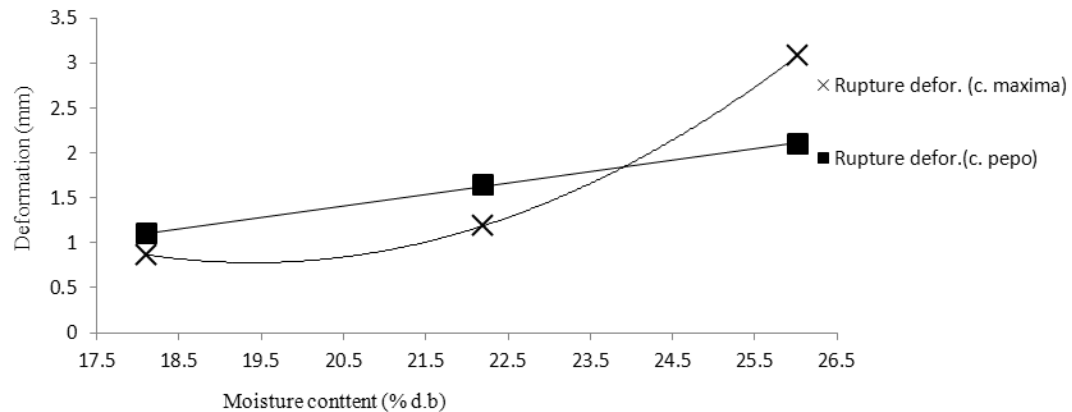


Figure 4: Rupture deformation of pumpkin seed at varying moisture content

Table 1; Coefficient of terms for the regressions equations of the yield and rupture properties of pumpkin seed

Mechanical Property, (unit)	Pumpkin Variety	Coefficients of regression: a, b, c; ($Y = a + bK + cK^2$)			Coefficient R^2
		a	b	c	
R_d (mm)	<i>c. maxima</i>	20.604	-2.043	0.0530	1
R_d (mm)	<i>c. pepo</i>	11.694	-1.087	0.0260	1
R_e (J)	<i>c. pepo</i>	-43.871	4.149	-0.0920	1
Y_e (J)	<i>c. pepo</i>	4.1890	-0.351	0.0073	1
R_e (J)	<i>c. maxima</i>	-1.0169	0.152	-0.0039	1
Y_f (N)	<i>c. pepo</i>	-8.175	3.727	-0.0741	1

Coefficients of regression: a, b ($Y = a + bK$)					
Y_e (J)	<i>c. maxima</i>	0.0018	-0.013		0.972
R_f (N)	<i>c. pepo</i>	-11.362	470.22		0.997
R_f (N)	<i>c. maxima</i>	-15.511	501.79		0.959
Y_f (N)	<i>c. pepo</i>	0.461	27.039		0.882

Y_f = yield force, R_f = rupture force, Y_e = yield energy, R_e = rupture energy, R_d = rupture deformation, K = Moisture content

Table 2; F- ratios for the rupture and yield properties of pumpkin seed

Sources of variation	DF	R_f	Y_f	R_e	Y_e	R_d
Moisture content (MC)	2	4.83*	1.04 ^{ns}	2.43 ^{ns}	0.96 ^{ns}	9.93*
Variety	1	5.43*	0.17 ^{ns}	19.54*	1.07 ^{ns}	0.10 ^{ns}
MC x Variety	2	0.11*	1.09 ^{ns}	2.44 ^{ns}	1.15 ^{ns}	2.12 ^{ns}

Y_f = yield force, R_f = rupture force, Y_e = yield energy, R_e = rupture energy, R_d = rupture deformation, * Significant ($p < 0.05$), ^{ns} Not significant ($p > 0.05$)

B) Discussions:

The force required to initiate seed coat rupture decreased linearly with increase in moisture content from 18.1 to 26.03% d.b (figure, 2); rupture force of 214N and 266N decreased to 90.5N and 176N in *c. maxima* and *c. pepo* varieties respectively. The relationship between rupture force and moisture content was described using linear regression equation in the form as presented in equation (3).

$$Y = a + bK \quad (3)$$

Where; Y = mechanical property; a, b = regression coefficient, K = moisture content (% d.b)

The coefficients of terms in equation (3) are presented in table (1). Reference [8] reported a linear decrease in rupture force of pine nut from 0.49KN at 1.38% d.b to 0.25KN at 25.48%d.b. Similarly, the rupture force of cumin seed decreased linearly from 83.74 to 56.17N and from 132.95 to 84.47N in the longitudinal and lateral orientations as the moisture content was raised from 7.24 to 21.38%d.b [9]; this trend was true for the rupture force of pumpkin seed in this study, although the values reported for cumin seed were lower in comparison to the rupture force of pumpkin seed. Reference [11] reported a decrease in the rupture force of millet seed (45.67 - 36N), millet kernel (25.2 - 17.8N) in the moisture content range between 0.065 to 0.265 d.b; nevertheless, the relation between rupture force and moisture content in millet seed was polynomial. The low values of rupture force at higher moisture content could be attributed to the fact that at higher moisture content pumpkin seed became softer; thus, lower force was required to initiate seed coat rupture [10], [12]. Though, [15] reported an increase in the rupture force of sunflower seed with increase in moisture content between 1.8 and 14.5 % d.b,

nevertheless, it decreased with further increase in moisture content between 14.5 and 20.3% d.b. The lowest value of rupture force in this study was higher than the rupture force of cumin seed (56.17 – 83.74N) [9], millet seed (36 – 45.67N) [11], and the rupture force of kavir variety of barley (9.98 – 85.74N) [12]. The rupture force of pumpkin seed were statistically different between moisture content levels ($p < 0.05$), as well as between varieties studied ($p < 0.05$) (Table, 2).

Compatibly, the force at yield point of pumpkin seed varied with moisture content between 18.1 and 26.03% d.b, nevertheless moisture content had an increasing effect on the force at yield point of pumpkin seed (figure, 2); the yield force in *c. maxima* increased linearly from 35.01 to 38.64N between 18.1 to 26.06% d.b, while in *c. pepo* the yield force initially decreased from 37.14 to 28.79N as the moisture content was increased from 18.1 to 22.2 %d.b, however, further increase in moisture content to 26.03% d.b resulted in the increase in yield force from 28.79 to 41.22 N. Reference [13] investigated the effect of moisture content and loading orientation on some strength properties of conophor nut. Their result indicated a polynomial decrease in the yield point from 41.2N to a minimum of 12.5N in the moisture content range between 14.9 and 26.03%d.b, after which the yield point increased polynomially in the lateral orientation. Their findings were true for the yield point in this study. Moreover, a slightly different behaviour was reported by reference [23]. The force at yield point of pumpkin seed in this study compared lower to the yield force of pine nut (0.116 – 0.121kN) [8], and desma seed (62.6 – 63.6N) [23].

The energy of pumpkin seed at yield and rupture points are presented in in figure (3). It shows that rupture energy varied polynomially between 18.1 and 26.03% d.b; the rupture energy in *c. pepo* increased polynomially from 1.05J at 18.1 %d.b to a maximum of 2.84J at 22.2 %d.b, however, further increase in moisture content to 26.03% d.b resulted in the progressive decline in rupture energy ($p > 0.05$) (Table, 2). While in *c. maxima* it decreased polynomially from 18.1 to 26.03% d.b; the relationship between rupture energy and moisture content was best described using polynomial regression equation of the second order presented in equation (4)

$$Y = a + bK + cK^2 \quad (4)$$

Where; Y = mechanical property; a, b, c = regression coefficients, K = moisture content

The coefficients of terms in equation (4) are presented in table (1). The rupture energy at each moisture content of pumpkin seed at each moisture content level were different between *c. maxima* and *c. pepo* varieties ($p < 0.05$) (Table, 2). The energy at rupture point in this study was consistent with the findings of reference [15] on sunflower seeds between 5.0 and 20.3%w.b. In a similar study, the energy absorbed at rupture increased with moisture content up to 14.5% w.b, while decreased with further increase in moisture content from 14.5 to 20.3%w.b in both vertical and horizontal orientations. It was further found that the effect of loading orientation was not significant on the energy absorbed at rupture point of sunflower seed [15]. Increasing effect of moisture content on rupture energy was reported for pine nut (0.159 – 0.214J), [8], Dc 370 variety of corn seed (72.71 – 80.33Nmm) [10], and millet grain (5.03 – 9.50Nmm) [11]. However, the decreasing effect of moisture content on the energy absorbed at rupture point have been reported for cumin seed (50.62 – 27.52) [9], and desma seed (0.21 – 0.20Nm) [23].

The energy at yield point between 18.1 and 26.03%d.b were lower in comparison to the rupture energy of pumpkin seed (figure, 3). The yield energy of pumpkin seed decreased polynomially from a maximum value of 0.246J at 18.1% d.b to 0.0352J at 26.03% d.b. While in *c. maxima* a slight increase in from a maximum value of 0.246mJ at 18.1 %d.b to 0.035J at 26.03%d.b ($p > 0.05$) was observed (Table, 2). The linear and polynomial relationships between moisture content and yield energy in *c. maxima* and *c. pepo* varieties respectively were best described using regression equation with coefficient of terms presented in Table (1). None of the investigated factors (moisture content, variety, and the interaction effects of moisture content x variety factors) were significant on the energy at yield point of pumpkin seed ($p > 0.05$). Reference [23] reported an increasing effect of moisture content on the energy at yield point of desma seed; yield energy increased from 0.10Nm at 9.2% w.b to 0.20Nm at 13.8% w.b. The result of the trend between moisture content and the yield energy of desma seed was similar to the one in this study, though, further increase in the moisture content of desma seed to 17.8%w.b resulted in the decline of yield energy from 0.2Nm to 0.15Nm.

The variation of the deformation at rupture and yield points of pumpkin seed are presented in figure (3). It shows that the deformation at rupture in both varieties were higher than the deformation at yield point. Moisture content had increasing effect on the rupture point of pumpkin seed between 18.1 and 26.03%d.b ($p < 0.05$); the values of rupture deformation were higher for *c. pepo* at each moisture content investigated except at 26.03% d.b where *c. maxima* indicated greater rupture deformation ($p > 0.05$) (Table, 2). The higher deformation shown by pumpkin seed may have resulted from the fact that at higher moisture content pumpkin seeds were softer; thus, it gave lesser resistance to deformation. This result was consistent with the result of the effect of moisture content on pine nut (0.92 – 1.81mm) [8], and desma seed (0.91- 1.08mm) [23]. However, a decreasing effect of moisture content was reported for apricot (4.19 – 2.68mm) [24]. Reference [24] attributed the decrease in rupture deformation of apricot nut to the absence of enough clearance between shell and kernel

upon increase in moisture content due to which it behaved structurally turgid, hence a decline in the rupture deformation.

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