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Effect of Moisture Content on Strength Properties of Okra Pod (Cv Kirenf) Necessary for Machine Design

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Abstract

In this study, compression tests were carried out on okra pods (cv Kirenf)to investigate moisture content's effect on seven mechanical parameters (failure force, failure energy, failure strain, maximum compressive force, rupture force, rupture energy, and deformation at the point of rupture). The tests were carried out at a deformation rate of 25 mm/min and five moisture content levels of 37.04, 44.20, 50.18, 56.19, and 61.06% (w.b), using the Testometric Universal Testing Machine (Testometric model, series 500-532). The results show that moisture content had significant (P≤ 0.05) effects on all the measured mechanical parameters. Failure force, failure energy, maximum compressive force, rupture force, and rupture energy decreased while failure strain and deformation at rupture increased with moisture content increases. Force and energy required to initiate the okra pod failure decreased by 58.52 and 61.57%, respectively; the maximum compressive force decreased by 61.47%; while force and energy and deformation required to initiate the okra pod rupture decreased by 61.37and 66.37%, respectively; whereas, failure strain and deformation at rupture increased by 28.72 and 40.57% respectively. The results provide useful data to be used by engineers in the design and development of suitable okra pod thresher and slicer.

Keywords — *Moisture content, okra pod, compressive force, mechanical properties*

I. INTRODUCTION

Okra (*Hibiscus esculentus*L.) is a tropical to subtropical plant widely distributed from Africa to Asia, Southern European, and America and belongs to Malvaceae[1]. The seeds of okra have been used as coffee substitutes, and edible oil also has been extracted from dried okra seeds. Vegetable curds prepared from the dried seed have been used as substitutes for cheese in recipes[2]. The seed's amino acid profile indicates that it could be used to complement other partially complete protein sources such as soybean [3].

Okra fiber is used as reinforced polymer (RP) materials, consisting of fibers embedded in polymer matrices. These materials are suitable for many diverse applications ranging from aerospace to sporting equipment [4]. **The** seeds of mature pods are sometimes used for chicken feed and used on a small scale to produce oil [1]; [5]. The roots and stems of okra are used to clarify sugarcane juice from which white or brown sugar is prepared [6]. The traditional threshing of dry okra pods involves manual rupturing of the pods and separating the seed from the chaff. The process is tedious and time-consuming; it also results in losses and low-quality products [2]. Therefore, the development of a mechanical okra thresher with a winnowing system would drastically reduce the drudgery of the okra pod's manual shelling to obtain the unbroken seeds.

The mechanical properties of biomaterials are important in designing machines for grinding, harvesting, cleaning, and separating okra pods and seeds. Mechanical properties data are useful in analyzing and determining a machine's efficiency or operation, developing new products and new equipment, and final quality of new products [7]; [8]. The moisture content of agro materials has been reported to influence processing equipment's adjustment and performance [9]. As a result, the moisture content's determination at which okra pods could be shelled with a combination of high whole seed yield and minimum seed damage is necessary. It would be of important consideration in the okra pod's design thresher and slicers.

Mechanical parameters are pre-requisite for the design and development of the processing of the okra pod. In recent years, mechanical properties have been studied for various crops such as cumin seed [10], macadamia nut [11], and shea nut [12]. According to [13], inadequate engineering data such as rupture force, rupture energy, and deformation energy on indigenous crops have greatly retarded indigenous technologies' development to process most crops. Reference [14] examined the rupture force, bio yield force, deformation, modulus of elasticity, and failure energy to examine the effects of moisture content and loading on the carob pod's mechanical properties.

Published literature on the mechanical properties of okra pod as a function of moisture content is scanty. Therefore, this study's objective was to investigate the effect of moisture content on the okra pod's selected mechanical properties, which will provide important data needed in the design and development of okra pod threshing and slicing machines.

II. MATERIALS AND METHODS

A. Sample Preparation

The okra pods, cultivar 'Kirenf' used for this research were collected from the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria. They were manually cleaned to remove all foreign materials such as dust, premature and damaged pods.

B. Moisture Content Determination

The moisture content of the okra pod was determined by using the microwave oven-drying method. A sample of the okra pod (5 g) was kept in a microwave oven (Samsung microwave oven model CE118 KF) and set at 270 W power level, as recommended by [15]. Moisture loss was measured after every 5 minutes until the stable weight is obtained. The sample was weighed again at the end of the period to determine its final weight. The experiments were replicated 5 times, and the average was recorded.

C. Moisture Conditioning of the Fruit

The conditioning of okra pods to different moisture levels was carried out using the method described by [16]. This involved the reduction of moisture by sun-drying the fruits for different periods. The pods were subjected to sun-drying (temperature) 30 ±5^{0}C by exposing them to the sunlight. After every 24 hours, a sample was taken from the pods and stored in a polyethylene bag for 20 hours to attain uniform moisture content [17]. The sun-drying exercise lasted for 96 hours, and five samples at different moisture levels were obtained. The initial moisture content (Mc) of the pods, at harvest, was found to be 61.06% w.b. (wet basis)

D. Determination of the Mechanical Properties of the Okra Pod

The seven mechanical parameters(failure forced, failure energy, maximum compressive force, rupture force, rupture energy, and deformation at rupture) of the okra pod were evaluated at five different moisture content levels (37.04, 44.20, 50.18, 56.19, and 61.06% (w.b)), by using the Universal Testing Machine (UTM) (Testometric model, series 500-532), equipped with a 50 N compression load cell and controlled by a microprocessor. The individual sample (okra pod) was placed between two parallel plates and compressed at a 25 mm/min compressive speed. The UTM. automatically generated test results and force-deformation curves until the curve arrived at to rupture point (point A in Figure 1), where the machine stops automatically.

According to [18], the bioyield point is related to a failure in the material's microstructure associated with an initial disruption of cellular structure. The rupture point of the material, which correlates to the macroscopic failure (breaking point) in the sample, the failure strength was taken as the stress at which the sample failed in its internal cellular structure. The failure point was taken as the point on the force-deformation curve at which the compressed fruit weakened and failed internally. At this point, an increase in deformation resulted from either a decrease or no change in force, and the fruit could be said to have failed in its internal cellular structure [7]; [19]; [20]. Rupture point was the point on the force-deformation curve at which the pod completely became ruptured, and deformation resulted from a decrease in force [7]; [19]. Rupture force is the minimum force needed to crack the individual okra pod. If the compression exceeds the rupture strength of the material, it will lead to cracks or breakage. The compression test was replicated ten times for each moisture content level, and the mean of each parameter obtained was recorded.

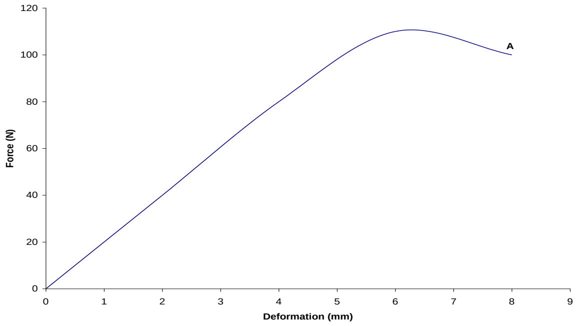

Figure 1: Force – deformation curve of cucumber fruit under compressive loading

E. Statistical Analysis

Ten replicas were taken for all the experiments, and average values are reported. The results of the seven mechanical parameters (failure forced, failure energy, maximum compressive force, rupture force, rupture energy, and deformation at rupture) were subjected to analysis of variance (ANOVA) to evaluate a statistical significance of observed differences among treatment means at ($p \leq 0.05$) using SPSS 20.0 software (IBM Corporation, USA). In contrast, regression analysis was performed using Microsoft Excel 2016 software.

III. RESULTS AND DISCUSSIONS

Table 1 gives the analysis of variance (ANOVA) for the effect of moisture on the mechanical parameters (failure forced, failure energy, maximum compressive force, rupture force, rupture energy, and deformation at rupture) of *Kirenf*cultivar of okra pod. As depicted from Table 1, moisture content ($P<0.05$) significantly affects all the okra pod's seven mechanical properties. Also, the regression relationships existing between the parameters and moisture content can be expressed using polynomial equations of the first and second-order, in the following forms:

$$y = a + bx \qquad (1)$$

$$y = a + bx + cx^2 \qquad (2)$$

Where:

y = Mechanical parameter

a, b, c = regression coefficients

x = moisture content (%, w.b.)

The coefficients term in the equations and p-value for each parameter presented are presented in Table 2. The high coefficient of determination values ($R^2 \geq 0.96$) (Table 2), coupled with the p-values, indicates that the plots reasonably described the data points. There is a strong relationship between moisture levels and the mechanical properties tested in the okra pods. The regression equation results suggest that a Kirenf okra pod's mechanical properties can be predicted using either the linear or polynomial equations.

Table 1: Analysis of variance (ANOVA) of the Effect of Moisture Level on the Mechanical Parameters of Intact KirenfOkra Pod

Source of variation	Dependent Variable	df	F	Sig
Moisture content	Failure force	4	7.941	6.2E-05*
	F_{max}	4	6.867	2.1E-04*
	Rupture force	4	6.857	2.1E-04*
	Failure energy	4	2.920	3.1E-02*
	Failure strain	4	13.017	4.0E-07*
	Rupture energy	4	3.024	2.7E-02*
	Deformation at rupture	4	7.290	1.3E-04*

* =Significant at (P<0.05), ns= non-significant

Table 2: Regression relationships between mechanical properties and moisture content with their respective coefficient of determination (R^2) and p-value (p).

Parameter	**Linear equation**	**R^2**
Failure force	$y = -24.703x + 182.62$	0.973
Failure energy	$y = -0.0705x + 0.4899$	0.962
Failure strain	$y = 4.91x + 17.278$	0.985
F_{max}	$y = -26.969x + 197.04$	0.992
Rupture force	$y = -4.4461x + 335.08$	0.993
Rupture energy	$y = -0.0861x + 0.5868$	0.989
Def at Rupture	$y = 1.133x + 5.023$	0.990

Table 2 Continue

Parameter	**Polynomial equation**	**R^2**	**p-value**
Failure force	$y = 1.485x^2 - 33.613x + 193.01$	0.977	0.001265
Failure energy	$y = 0.0051x^2 - 0.1009x + 0.525$	0.969	0.002267
Failure strain	$y = -0.4714x^2 + 7.7386x + 13.98$	0.999	0.000127
F_{max}	$y = 0.9279x^2 - 32.536x + 203.53$	0.994	0.000156
Rupture force	$y = -0.0126x^2 - 3.2116x + 305.8$	0.993	0.000274
Rupture energy	$y = 0.0029x^2 - 0.1033x + 0.6069$	0.990	0.000524
Def at Rupture	$y = 0.0164x^2 + 1.0344x + 5.138$	0.990	0.000482

The detailed effect of the moisture content on the mechanical parameters studied is presented below.

A. Failure Force

The result of the statistical analysis on the effect of moisture on the failure force was significant ($P < 0.05$), as shown in Table 1. As shown in Figure 2, the force required to initiate okra pod failure was significantly higher at a lower moisture content level and decreased monotonically from 158.87 to 65.89 N (58.52% decreased), as the moisture content increased from 34.02 to 61 % (wb). This might be because the okra pod became softer at higher moisture content and required lesser force to fail. Also, from the result, the okra pod tends to be more ductile, with an increase in moisture content. This result was supported by the findings by [21] on chicken pea seeds.

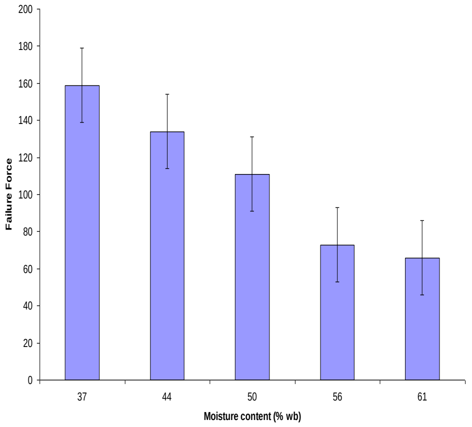

Figure 2: Correlation between failure force and moisture content of okra pod.

B. Failure Energy

According to the ANOVA table (Table 1), the Kirenf okra pod's Failure energy was significantly ($P \leq 0.05$) influenced by the moisture content level. The failure energy decreased from 0.419 to 0.161 Nm (61.57% decreased) as the moisture content increased from 37.04 to 61.06% w.b. as shown in Figure 3. Regression equations and p-value for failure energy with variations with the moisture level presented in Table 2 shows that failure energy is highly dependent on the moisture content of the pod. The above result implies that the energy needed in compression to initiate failure of the pod's intercellular structure is significantly dependent on the moisture content of the fruit. Our result is in good agreement with previous researchers [22] for cowpea.

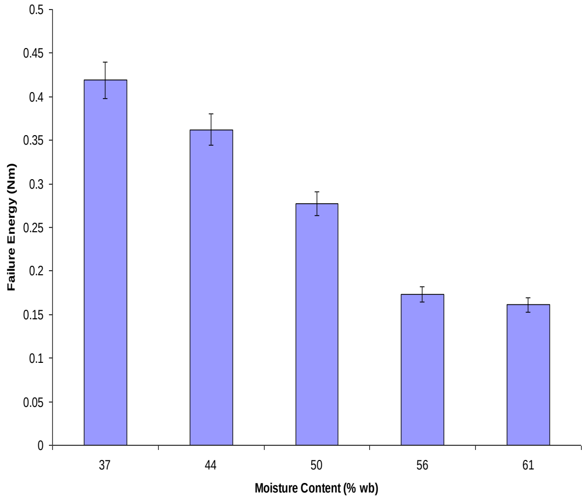

Figure 3: Effect of moisture content on the failure energy of okra pod

C. Failure Strain

The statistical analysis of moisture's effect on the failure strain was significant at ($P < 0.05$). The pod's deformation increased as the moisture content increases from 34.04 to 61.06 % wb (Figure 4), increasing from 43.63% to 61.21% (28.72% increased). According to [23], as the moisture content of fruit increases, the maximum compressive force decreased, but its position on the force-displacement curve increased, so the stress-strain curve's slope decreased. For this reason, the stress decreased, and the strain increased as time passing. A similar trend was observed by [24] in determining the physical and mechanical properties of hazelnut and its seed, who observed increasing deformation with increased moisture content.

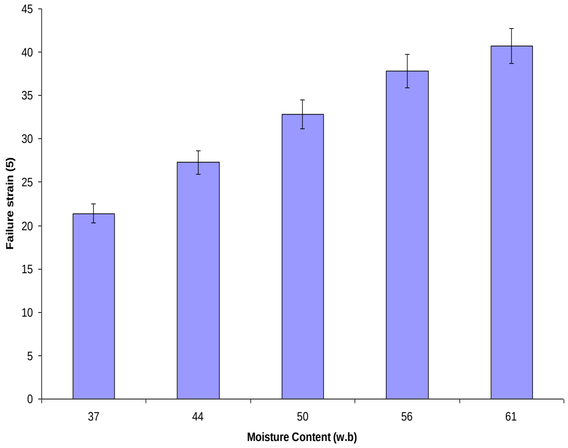

Figure 4: Correlation between failure strain and moisture content of okra pod.

D. Maximum Compressive Force (F_{max})

The measured Maximum compressive force from different moisture content was plotted in Figure 5. As shown in Figure 5, increasing the pod moisture content from 34.04% to 61.06% decreased the pod Maximum compressive force from 171.47 to 65.89 N (61.57% decreased). The decrease in maximum compressive force can be attributed to the okra pod becoming softer at increased moisture levels. A similar finding was reported by [8] for wheat and [25] for cumin seed.

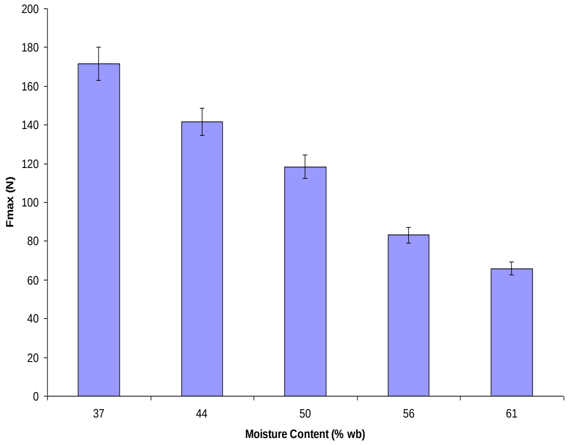

Figure 5: Correlation between maximum compressive force and moisture content of okra pod.

E. Rupture Force

It can be observed from the ANOVA table (Table 1) that the force required to initiate seed rupture decreased significantly ($P < 0.05$) as the moisture content increased from 37.04 to 61.06% w.b. The rupture force was found to increase from 65.35 to 169.18 N (61.37% increases), as the moisture content decreased from 61 to 37 % w.b. (Figure 6). The decrease in the rupture force with moisture content may be attributed to a decrease in the seed's strength at higher moisture contents. The result's trend agrees with the report of [26] for lentil seed and [27] for pine nuts. Reference [28] researched the effects of moisture content on some physical and mechanical properties of faba bean (*Viciafaba* L.), reported that as the moisture content increased from 9.89% to 25.08%, the rupture force values ranged from 314.17 N to 185.10 N. The relationship between moisture content and rupture force is presented in the regression equations in Table 2.

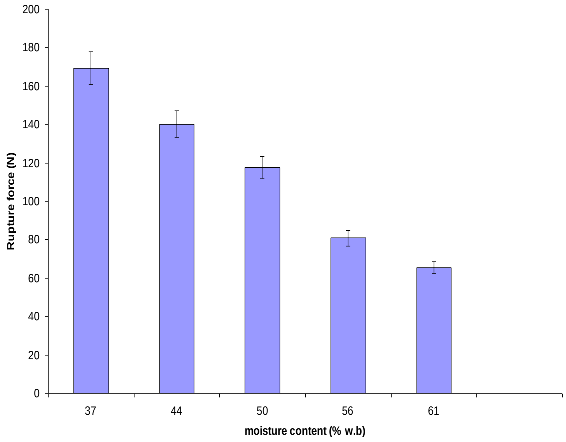

Figure 6: Correlation between failure strain and moisture content of okra pod.

F. Rupture Energy

From the ANOVA table (Table 1), the decrease in rupture energy (which is the same as the energy absorbed at rupture point) with moisture content was found to be statistically significant (P≤ 0.05). The rupture energy decreased from 0.498 to 0.167 Nm with the increase in moisture content from 37.04 to 61.06%w.b. (66.37% decreased), as shown in Figure7. The decrease in the rupture energy with the okra pod's increasing moisture content may be attributed to the pod's softening at higher moisture contents. This result agrees with [10], who reported a decrease in energy absorbed by cumin seed with an increase in moisture content. The relationship between moisture content and the rupture energy of the okra pod is presented in Table 2.

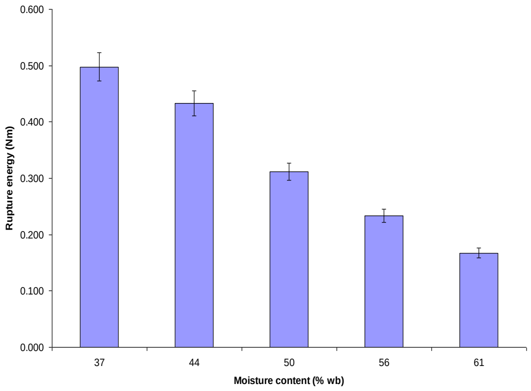

Figure 7: Effect of moisture content on the rupture energy of okra pod

G. Deformation at Rupture

The deformation at rupture was significantly (P≤ 0.05) affected by the moisture content of the okra pod (Table 1). The deformation of the okra pod at the rupture point as a moisture content function is presented in Figure 8, which slowly increased from 6.31 to 10.62 mm (40.57% increased) as the moisture content increased from 37.04 to 61.06% w.b. Reference [29] studied the force required to cause deformation and subsequent rupture in pumpkin seed and reported that the hull breaking load varied from 30 to 50 N for dry seeds and 14 to 36 N for wet seeds quasi-static compression with horizontal and vertical orientations of the seed. Our result is similar to the results obtained for barber by [30], where the deformation at rupture increased as the moisture content increased from 53.11 to 89.23% w.b. This could be attributed to the okra pod's viscoelastic property, which causes higher deformation of the fruit under compression at a lower moisture level. Rupture deformation changes based on the properties of biological materials. It depends on the structure of biological material and the cells' pores [31]. Hardness is the resistance of the individual pod to deformation under applied forces [8]. The regressional relationship between moisture content and deformation at the okra pod's rupture is presented in Table 2.

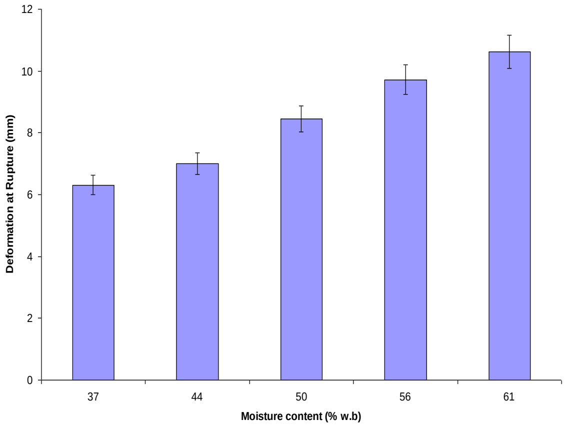

Figure 8: Correlation between rupture deformation force and moisture content of okra pod.

IV. CONCLUSIONS

In conclusion, the strength properties of the okra pod had a strong relationship with moisture content. Okra pods at low moisture content conditions are less susceptible to breakage losses during the post-handling and processing operations. The results of the analysis of variance (ANOVA) show that moisture content had a significant ($P \leq 0.05$) effect on the mechanical parameters (failure forced, failure energy, maximum compressive force, rupture force, rupture energy, and deformation at rupture) of *Kirenf* cultivar of okra pod.

The deformation at pod rupture increased with increasing moisture content. The force and energy required to initiate the okra pod failure decreased by

58.52 and 61.57%, respectively; the maximum compressive force decreased by 61.47%; while force and energy and deformation required to initiate the okra pod rupture decreased by 61.37and 66.37%, respectively; whereas, failure strain and deformation at rupture increased by 28.72 and 40.57% respectively. The results obtained from this research will provide useful data for mechanical engineers in the design and development of suitable okra pod thresher and slicer.

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REFERENCES

[1] O.J. Oyelade, B.I.O. Ade-Omowaye, V.F. Adeomi. "*Influence of variety on protein, fat contents, and some physical characteristics of okra seeds." Journal of Food Engineering*. 57, 111-114. 2003.

[2] E.A. Ajav, and BA. Adejumo. *"Performance Evaluation of an Okra Thresher." Agricultural Engineering International: the CIGR Ejournal*. Manuscript PM 04 006 Vol. VII. 2005.

[3] L. A. Bryant, J.R. Montecalvo, K.S. Morey, and B. Loy. Processing, Functional and Nutritional Properties of Okra Seed Products. *Journal of Food Science* 53-(3): 810-816. 1988.

[4] S.P. Reddy and A.C. Reddy. Tensile and flexural strength of okra Fiber-reinforced polymer composites. *International Journal of Engineering and Management Research*. 491-495.2016.

[5] F.W. Martin and R. Ruberte, R. Milling and use of okra seed meal at the household level. *Journal of Agriculture of the University of Puerto Rico*, 63:1-7. 1979.

[6] DVS.Chauhan. *Vegetable Production in India*. 3rd ed. Ram Prasad and Sons. Agra. 1972.

[7] NN. Mohsenin. "*Physical Properties of Plant and Animal Materials*." Gordon and Breach Science Publishers, New York pp 8-11, Books Ltd London 487 – 492. 1986.

[8] YS. Kang, C.K. Spillman, J.L. Steele, and DS. Chung. Mechanical Properties of Wheat. "*Transactions of the ASAE,"* 38(2), 573-578. 1995.

[9] NA. Aviara, M.I. Gwandzang, and M.A. Haque. "*Physical properties of guna seeds*." *Journal of Agricultural Engineering Research* 73: 105-111. 1999.

[10] KK. Singh and TK. Goswami. *"Mechanical properties of cumin seed (CuminumcyminumLinn.) under compressive loading", Journal of Food Engineering*, 36: 311-321.1998.

[11] G.C. Braga, S.M. Couto, T. Hara, and C.T. Neto. *"Mechanical behavior of macadamia nut under compression loading."Journal of Agricultural Engineering Research* 72: 239-245. 1999.

[12] A.M. Olaniyanand K. Oje. *"Some aspect of the mechanical properties of the shea nut." Biosystem Engineering.,* 81: 413-420. 2002.

[13] A.O. Akani, C.N. Ohanweand I.O. Omoniyi. *"Determination of optimum impact for decortication of Bambara groundnut." Proceedings of the Nigerian Institution of Agricultural Engineers,* 22: 87 – 89. 2000.

[14] K. Ekinci, D. Yilmaz, and C. Ertekin. Effects of moisture content and compression positions on mechanical properties of carob pod (*Ceratonia siliqua* L.). *African Journal of Agricultural Research,* 5(10): 1015-1021. 2010

[15] MR Becwar, NS. Msnsour and G.W. Varseveld. "*Microwave drying: A rapid method for determining sweet corn moisture*." *Hort Science*, 12(b): 562-563. 1977.

[16] S.N. Asoegwu. "*Some physical properties and cracking energy of conophor nuts at different moisture content*." *International Agrophysics*, 9,131-142. 1995.

[17] [F. Oluwole, N. Aviara, and M. Haque. *"Effect of moisture content and impact energy on the crackability of the shea nut."Agricultural Engineering International: CIGR Journal*, Manuscript FP 07 002 Vol. IX., www.cigrjournal.org. 2007.

[18] Steffe, J. F., 1996. *Rheological Methods in Food Process Engineering*. (Second Edition). Freeman Press, USA. Pp 72-90.

[19] U.G.N. Anazodo. *"Elastic and viscoelastic properties of agricultural products in relation to harvesting and postharvest processes." Agricultural Mechanization in Asia, Africa, and Latin America*, 13: 59–65, 70. 1982.

[20] E. Mamman, N.A. Aviara and O.A. Ogunjirin. "*Effects of heating temperature and time on some mechanical properties of Balanitesaegyptiaca nut."Agricultural Engineering International: CIGR Journal*, 14(2): 77－85. 2012.

[21] M. Konak, K. Carman andC. Aydin C. *"Physical properties of chickpea seeds."Biosystem Engineering,* 82: 73–78. 2002.

[22] A.W. Cecil and K.C. Watts. *"Properties of cowpea (var. Minica Beans)." Journal of Agricultural Engineering Research*, 68:159 – 167. 1997

[23] A. Zdunek, J. Cybulska, D. Konopacka, and K. Rutkowski. "*New contact acoustic emission detector for texture evaluation of apples.*" Journal of Food Engineering, 99(1): 83-91. 2010.

[24] A.M. Kermani, A. M. *"Some Physical and Mechanical Properties of Hazelnut."* The 5th National Conference on Agricultural Machinery Engineering and Mechanization, Mashhad, Iran: Ferdowsi University. 2008

[25] S.H Saiedirad, A. Tabatabaeefar, A. Borghei, M. Mirsalehi, F. Badii, M. GhasemiVarnamkhasti. *"Effects of moisture content, seed size, loading rate and seed orientation on force and energy required for fracturing cumin seed (Cuminumcyminum Linn.)"* under quasi-static loading. Journal of Food Engineering, 86 565–572. 2008.

[26] H. Bagherpour, S. Minaei. and MH *"Khoshtaghaza Selected physicomechanical properties of lentil seed." Int. Agrophysics*. 24:81-84. 2010.

[27] Vursavus, K., and Ozguven, F. (2005). *"Fracture resistance of pine nut to compressive loading."Biosystem Engineering*. 90(2):185-191.

[28] E. Altuntas, and. Yıldız. *"Effect of Moisture Content on Some Physical and Mechanical Properties of Faba Bean (Viciafaba L.) Grains." Journal of Food Engineering* 78, 174-183. 2007.

[29] M.S. Teotia, P. Ramakrishna, SK. Berry and S. Kaur. Some engineering properties of pumpkin seeds. *Journal of Food Engineering*, 9(l), 153- 162. 1989.

[30] H. Fathollahzadehand A. Rajabipour. "*Some mechanical properties of barberry*." *International Agrophysics journal* 22, 299-302. 2008.

[31] S. Persson. "*Mechanics of cutting plant material" l.* Michigan: *ASAE Publications*., 1987.

[32] Rajasekar S, Arvind B, Meyyappan N, *"Drying of Chickpeas (Cicer arietinum) and Black-eyed Peas (Vigna unguiculata)"* SSRG International Journal of Chemical Engineering Research 4.1 (2017): 14-21.