FAILURE BEHAVIOUR OF GROUNDNUT (SAMNUT 11) KERNEL AS AFFECTED BY KERNEL SIZE, LOADING RATE AND LOADING POSITION

*Uguru, H. and Nyorere, O.
Department of Agricultural and Bio-Environmental Engineering Technology, Delta State Polytechnic, Ozoro, Delta State, Nigeria
*Corresponding Author Email: erobo2011@gmail.com

ABSTRACT: *In this study, the failure bahaviour (failure force, failure energy, deformation at failure, and firmness) of SAMNUT 11 groundnut kernels were investigated, using the Universal Testing Machine. The quasi static compression tests were carried out at three loading rates (15, 20 and 25 mm/min), three kernel size categories (small, medium and large), and three loading positions (X -axis is in the plane containing the suture line; Y- axis is the plane perpendicular to the suture line, while Z-axis is the longitudinal axis through the suture). The results showed that loading rate, loading position, and kernel size had significant effect ($P \leq 0.05$) on all the parameters investigated. From the results, the failure force, failure energy, deformation at failure point and firmness increased as the kernel size increases from small to large. In addition, all the failure parameters investigated decreased linearly, as the loading rate increases from 15 mm/min to 25 mm/min. This research results further proved the significance of sorting and grading of groundnut kernels before storage, as larger kernels were able to withstand more static compression loading than the smaller kernels.*

Keywords: SAMNUT 11, mechanical properties, failure, deformation, energy, firmness,

INTRODUCTION

Groundnut (*Arachis hypogaea*) is a major leguminous crop cultivated in the arid and semi-arid regions of Nigeria, either grown for its oil, kernel, or the haulms (the vegetative residue). China (17.1 million tonnes) and India (9.8 million tonnes), which are the two highest groundnut production countries, account for about half of the world's production of 47.1 million tonnes. Other major world producing countries are: Nigeria (2.4 million tonnes), Senegal (915,000 tonnes), Ghana (420,000 million tonnes), Indonesia (480,000 tonnes), Myanmar (1.6 million tonnes) (FAOSTAT, 2019). Groundnut grows well in a well-drained, sandy loam soils, with soil pH range of 5.8 and 6.2. Groundnut contains high quality edible oil (50%), easily digestible protein (25%) and carbohydrates (20%) (FAO, 1994), therefore it is good in treating patients with protein related malnutrition sicknesses (Agriculturenigeria, 2019). Groundnut rosette epidemics and foliar diseases, aflatoxin contamination and lack of sufficient and consistent supply of improved seed varieties, are major setbacks of groundnut production in Nigeria (Bashir, 2012). To alleviate the problem of improve seeds facing Nigeria farmers, the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), has developed and tested over 15 new improved groundnut varieties, that are disease and pest resistant, within the last two decades (Ndjeunga et al., 2013). Groundnut harvesting can be done manually or mechanically. But due to lack of machines and financial difficulties, mechanical harvesting is not common in Nigeria. During manual harvesting, the groundnut plant is pulled up from the ground and left to dry for few days before threshing (Uys, 2016).

Kernel failure is a major problem facing groundnut kernel during handling and storage, operations. Failed groundnut kernel does not stored well, loss its viability, and susceptible to fungi attack. However, to reduce this problem, knowledge of the failure characteristics of groundnut kernel under compressive loading, is essential in the design and development of an efficient handling and packaging systems for groundnut kernel. During harvest and postharvest operations, fruits and kernels go through several static and dynamic pressures (e.g. high speed impacts), which caused bruises, crushes and cracks that increase their susceptibility to deterioration during storage (Bargale-Praveen *et al*., 1995; Altuntas *et al*., 2013). In the design of machines and equipment used in the handling, packaging and storage operations of agricultural materials, the knowledge of their strength behaviour under quasi-static compression loading is required. Harvested agricultural products have been damaged by the mechanical harvesting methods with exert load and breaking stress (Kuna-Broniowska *et al.*, 2012).

For the past two decades, numerous studies have been conducted on the mechanical properties of many agricultural materials. Braga *et al*. (1999) determined the force, deformation and energy to rupture macadamia nut under compression with respect to its nut size and loading position. In terms of force, deformation and energy to initiate rupture of the shell, macadamia nuts have a higher strength when compressed at perpendicular direction to the split plane. Additionally, Gupta and Das (2000) investigated the fracture resistance of both the sunflower seed and its kernel in terms of average compressive force, deformation and energy absorbed per unit volume at rupture. They found that the force required to rupture the seeds when loaded horizontally was lower when compared as the seeds were loaded vertically. Whereas, the opposite was true for the kernels, energy absorbed per unit volume at rupture was higher in vertical loading than in horizontal loading. In addition, Vursavus and Özgüven (2004) studied effect of loading orientation on the rupture force, deformation and toughness of apricot pit under compression load. According to their results, the higher values of all the dependent variables were obtained for apricot pit loaded along the longitudinal axis through the length. Furthermore, Ince *et al*. (2009) investigated the mechanical behaviour of hulled peanut and its kernel in a quasi-static compression tests. They reported that the force required at rupture point for large-size kernel was highest at the perpendicular loading position (59.86 N) compared with the parallel to the split plane position (50.45 N), and longitudinal position (31.90 N). Khazaei *et al*. (2004) studied required failure force and energy of three varieties of chickpea in two loading directions, they observed that variety and loading direction have significant effect on required force and energy to break the chickpea grain.

In spite of all the previous research works, there is lack of information on the failure behaviour of SAMNUT 11 kernels, under quasi static compression loading. Therefore, the objective of this study was to determine the effects of kernel size, loading rate, and loading position on the failure behaviour (failure force, failure energy, firmness, and deformation at failure) of SAMNUT 11 groundnut kernels. The data obtained from this research will provide necessary information for the modification of existing handling and storage systems for groundnut kernels

MATERIALS AND METHODS

Sample collection and preparation

The SAMNUT 11 groundnut kernels used in the experiments were obtained from the research farm of Delta State Polytechnic, Ozoro, Nigeria. The freshly harvested groundnut pods were sundried for seven days, to lower their moisture content before the quasi compression tests. After drying, the pods shelled manually, and the kernels were inspected to remove all foreign materials, immature and damage kernels.

Kernel Size Classification

The main dimensions; Length "L", Width "W", and Thickness "T" of the kernels were measured using a digital vernier caliper (accuracy of 0.01 mm). Afterwards, the size classifications of the kernels (small, medium and large) were done using the above-mentioned dimensional values. The size classifications of the SAMNUT 11 kernels are presented in Table 1.

Table 1: Size classifications of SAMNUT 11kernels

Variety	**Size (mm)**		
	Small	**Medium**	**Large**
SAMNUT 11	L <13.5	13.5 ≤ L ≤ 23.5	L >23.5
	W <8.5	8.5 ≤ W ≤ 13.5	W >13.5
	T < 7.5	7.5 ≤ T ≤ 10.5	T >10.5

Compression Properties Determination

The quasi static compression test of the SAMNUT 11 kernels was performed at the National Center for agricultural Mechanization (NCAM), Ilorin, Kwara state, Nigeria, using the Universal Testing Machine (Testometric model, series 500-532), having accuracy of 0.001 N, and equipped with a 50 N compression load cell and integrator. During the quasi static compression test, each sample was placed under the flat compression tool of the machine, and compressed a pre-determined speed. As the compression progresses, a force-deformation curve was plotted automatically by the machine in relation to the response of the sample to compression loading (Eboibi and Uguru, 2017). After each test, these failure bahaviour (failure force, failure energy, deformation at failure and firmness) of the sample were calculated automatically by the Universal Testing Machine. The tests were done at three loading rates (15, 20 and 25 mm/min), three kernel sizes (small, medium and large), and three loading positions (X, Y and Z axes), which were replicated fifteen times.

As shown in Figure 1, the X -axis is in the plane containing the suture line; Y- axis is the plane perpendicular to the suture line, while Z-axis is the longitudinal axis through the suture (Braga *et al*., 1999; Bagheri *et al*., 2011). Failure point of the groundnut kernel correlates to the microscopic failure of the kernel Steffe (1996). Firmness is regarded as the ratio of failure force to deformation at the failure point of ground kernel.

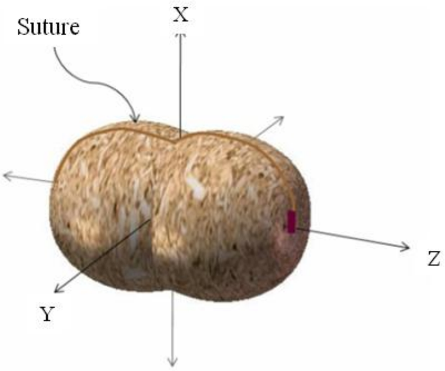

Figure 1: Representation of the Three Orientations of the Groundnut Kernel
Source: Bagheri *et al*. (2011)

Experimental Design and Statistical Analysis

A factorial experiment in a complete randomized block design was used to evaluate the effects of three loading rates, three sizes and three loading positions on failure behaviour (failure force, failure energy, deformation at failure and firmness) of SAMNUT 11 groundnut kernels. The data obtained from this research were statistically analyzed with SPSS (Statistical Package for the Social Sciences), while the means were separated by using Duncan's Multiple Range Test, at 95% confidence level.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of the failure behaviour of the SAMNUT 11 groundnut kernels are presented in Table 2. As shown in Table 2, loading position, loading rate and kernel size significantly influenced ($P \leq 0.05$) the four failure parameters (failure force, failure energy, deformation at failure point and firmness) investigated in this study. The interaction of loading rate and position only significantly influenced ($P \leq 0.05$) the failure force, failure energy, deformation at failure point, but does not significantly affects the firmness of the groundnut kernel. Furthermore, the interaction of loading rate and kernel size significantly influenced ($P \leq 0.05$) all the four parameter studied in this research. While the interaction of kernel size and loading position had significantly ($P \leq 0.05$) effect only on the failure force, failure energy and deformation at failure of the groundnut kernel. The mean values and standard deviation of the failure behaviour of SAMNUT 11 groundnut kernels, with respect to loading rates, kernel sizes and loading positions are given in Tables 3. Tables 4, 5, and 6 presented the separated means according to Duncan's multiple range test results for the groundnut kernels.

Table 2: ANOVA table of effects loading rate, kernel size and loading orientation on the mechanical behaviours of the groundnut kernels

Source of variation	**df**	**Failure force**	**Failure energy**	**Deformation at failure**	**Firmness**
L	2	2.56E-36*	1.12E-33*	1.69E-30*	7.89E-27*
P	2	2.01E-26*	1.21E-22*	4.83E-20*	8.17E-18*
S	2	1.35E-31*	2.76E-27*	3.42E-25*	5.21E-24*
L x P	4	2.54E-06*	4.17E-07*	1.15E-02*	0.41261^{ns}
L x S	4	4.44E-06*	1.46E-07*	4.22E-03*	1.08E-02*
S x P	4	6.46E-03*	3.21E-02*	0.10124^{ns}	0.64124^{ns}
L x P x S	8	0.15629^{ns}	6.03E-05*	0.29958^{ns}	2.05E-07*

L = loading rate; O = position; S = size; * = significant at $P \leq 0.05$; ns = non-significant

Table 3: Effects of loading rate, size and loading position on compression behaviour of SAMNUT 11 groundnut kernel

Loading rate	**size**	**Loading position**	**Failure force (N)**	**Failure energy (Nm)**	**Deformation at failure (mm)**	**Firmness (N/mm)**
15	Large	X-axis	75.37(3.42)	0.080(0.006)	2.27(0.07)	29.20(0.69)
		Y-axis	93.23(5.65)	0.103(0.009)	2.58(0.14)	30.51(0.58)
		Z-axis	61.97(2.93)	0.074(0.003)	3.05(0.13)	27.31(0.44)
	Medium	X-axis	60.86(4.05)	0.073(0.002)	1.94(0.15)	26.34(0.34)
		Y-axis	77.91(4.21)	0.086(0.006)	2.15(0.13)	29.86(0.31)
		Z-axis	45.04(3.79)	0.045(0.003)	2.61(0.12)	23.93(1.26)
	Small	X-axis	41.28(2.48)	0.042(0.002)	1.62(0.01)	22.59(0.17)
		Y-axis	57.86(3.87)	0.070(0.004)	1.83(0.10)	25.71(1.00)
		Z-axis	36.39(1.63)	0.036(0.003)	2.23(0.10)	22.46(0.89)
20	Large	X-axis	58.52(5.47)	0.070(0.006)	1.98(0.29)	27.20(1.34)
		Y-axis	75.90(5.59)	0.074(0.005)	2.15(0.15)	30.59(2.02)
		Z-axis	45.62(9.10)	0.050(0.013)	2.49(0.23)	22.75(2.07)
	Medium	X-axis	36.26(3.97)	0.035(0.005)	1.50(0.24)	22.85(1.24)
		Y-axis	54.47(4.22)	0.065(0.007)	1.60(0.10)	26.33(1.54)
		Z-axis	33.71(3.26)	0.033(0.005)	2.07(0.05)	22.68(1.71)
	Small	X-axis	27.89(2.30)	0.027(0.002)	1.15(0.01)	21.94(0.08)
		Y-axis	36.79(4.04)	0.037(0.007)	1.27(0.10)	22.16(0.60)
		Z-axis	22.66(1.36)	0.025(0.001)	1.66(0.14)	19.72(0.99)
25	Large	X-axis	34.42(2.53)	0.035(0.004)	1.39(0.09)	22.60(0.99)
		Y-axis	44.18(2.74)	0.045(0.002)	1.53(0.17)	22.52(1.36)
		Z-axis	30.35(2.37)	0.029(0.003)	1.97(0.20)	21.79(0.29)
	Medium	X-axis	28.64(1.50)	0.029(0.002)	1.15(0.01)	22.25(0.65)
		Y-axis	35.72(2.83)	0.035(0.006)	1.29(0.06)	21.99(0.44)
		Z-axis	21.95(2.50)	0.024(0.002)	1.62(0.10)	19.14(1.95)
	Small	X-axis	17.65(2.20)	0.020(0.002)	1.11(0.01)	15.64(1.86)
		Y-axis	23.13(1.07)	0.025(0.002)	1.13(0.01)	20.13(1.01)
		Z-axis	12.48(2.09)	0.017(0.002)	1.15(0.01)	11.25(1.80)

Values shown in parenthesis are the standard deviations for the respective mean

Table 4: Effect of kernel size on the failure behaviour of SAMNUT 11 groundnut kernels

Size	**Failure force**	**Failure energy**	**Def. at failure**	**Firmness**
Small	30.68^{a}	0.033^{a}	1.459^{a}	20.17^{a}
Medium	43.84^{b}	0.047^{b}	1.780^{b}	23.93^{b}
Large	57.73^{c}	0.062^{c}	2.156^{c}	26.05^{c}

Means with the same superscripts in the same column are not significantly different at 0.05 level of significance using Duncan's Multiple Range Test.

Table 5: Effect of loading rate on the failure behaviour of SAMNUT 11 groundnut kernels

Loading rate	**Failure force**	**Failure energy**	**Firmness**	**Def. at failure**
15	61.10^{c}	0.068^{c}	26.43^{c}	68.57^{c}
20	43.53^{b}	0.046^{b}	24.02^{b}	50.35^{b}
25	27.61^{a}	0.028^{a}	19.71^{a}	31.88^{a}

Means with the same superscripts in the same column are not significantly different at 0.05 level of significance using Duncan's Multiple Range Test.

Table 6: Effect of loading position on failure behaviour of SAMNUT 11 groundnut kernels

Loading rate	**Failure force**	**Failure energy**	**Firmness**	**Def. at failure**
X-axis	42.32^{a}	0.045^{a}	21.22^{a}	1.567^{a}
Y-axis	55.46^{c}	0.060^{c}	25.53^{c}	1.735^{b}
Z-axis	34.46^{b}	0.037^{b}	23.40^{b}	2.094^{c}

Means with the same superscripts in the same column are not significantly different at 0.05 level of significance using Duncan's Multiple Range Test.

From the results presented in Table 3, the compression force the groundnut kernels can withstand before failure point increased with an increase in kernel size; but decreased with increase in the loading rate. This relationship could be attributed to the changes in the cellular structure of the kernels, as their sizes increases. According to Westoby *et al*. (2002) seed size underlies a strategic axis of variation in plant mechanical defense. As presented in Table 6, the force, energy and firmness of the kernels at failure point were highest when loaded perpendicular to the split plane (Y-axis), when compared with kernels loaded at the X-axis and Z-axis. This shown that the groundnut kernels were more resistant to compression loading at the Y-axis, than in the other two axes. This shows that it is appropriate to store the groundnut kernels in the horizontal position (Y-axis), as they are able to withstand more compression loading in that horizontal position (Y-axis) than in the vertical position (Z-axis). Similar trends were observed by Olaniyan and Oje (2002) for shea nut, Vursavus and Özgüven (2004) for apricot pit, and Ince *et al*.(2009) for peanut kernel. In the study of Ince *et al*.(2009) on the mechanical behaviour of peanut kernel, they recorded the highest deformation when the kernel was loaded in the Y-axis. Kermani (2008) determined the physical and mechanical properties of hazelnut and its seed, and observed the highest failure force at the longest diameter and the lowest failure force along the smallest diameter.

The absorbed energy by the kernels and the kernels firmness decreased in increase in loading rate, and decrease in kernel size, throughout the three axes measured. This means the kernel becomes more susceptible to bruising as the kernel size decreases. Ince *et al*. (2009) reported that the firmness of peanut statistically ($P \leq 0.01$ level of significance) increased with an increase in kernel size, at its three different axes. According to their results, the firmness of peanut kernels increased 43.07 N/mm (small size) to 59.74 N/mm (large size). Large seeds are generally considered more stress resistant (Muller-Landau 2010). Furthermore, Ince *et al*. (2009) repotted from this findings that the peanut kernel firmness was highest at the perpendicular loading position to the split plane (49.49 N/mm), compared with the parallel to split plane position (45.42 N/mm), and longitudinal position (48.47 N/mm). Similar observations were also reported by Olaniyan and Oje (2002). Sadrnia *et al*. (2009) studied mechanical failure of two types of watermelon in Quasi-Static loading. Their results show that the loading direction affects the failure force, as the force recorded in the longitudinal direction was significantly less than in the transverse direction. This research results show the significance of sorting and grading before packaging and storage of groundnut kernels. This is because it can be seen from the results that the larger kernels were able to withstand more static compressive loading than the smaller kernels.

CONCLUSIONS

The results obtained from this study showed that loading rate, loading position, and kernel size had significant effect on the failure behaviour of SAMNUT 11 groundnut kernels. Failure force, failure energy and firmness of the kernels were highest in the Y-axis loading position and lowest in Z-axis loading position. From the results, the failure behaviour of the groundnut kernels decreased with an increase in quasi static compressive loading rate. According to the results lower failure parameters were obtained in the smaller kernels than larger kernels, signifying the importance of sorting and grading before packaging of groundnut kernels.

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