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Research Article

A Study on Rupture Resistance of Groundnut (cv. SAMNUT 22) Kernel

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ABSTRACT

This study was done to assess the influence of compression loading rate and kernel size on the rupture resistance of groundnut (cv. SAMNUT 22) kernel. These groundnut kernel mechanical parameters (rupture force, deformation at rupture, rupture power, firmness and toughness) were evaluated under three loading rates (15 mm min^{-1}, 20 mm min^{-1} and 25 mm min^{-1}), and three size categories (small, medium and large). The groundnut kernels were harvested at peak maturity stage, and tested in accordance to ASTM International standards. Results obtained from the tests showed that the rupture resistance of SAMNUT 22 kernel was highly dependent on its size and the loading rate. Generally, as the loading rate increases, the mechanical parameters values declined significantly ($p \leq 0.05$). Rupture force, deformation at rupture point, rupture power and the firmness increased as the kernel size increases; but in contrast, the kernel toughness decreases as its size increased. An average force of 57.96 N ruptured the large kernel, while a lower force of 27.35 N ruptured the small kernel. Moreover, the large kernel recorded the highest firmness (59.03 N mm^{-1}), when compared to the medium (51.69 N mm^{-1}) and small (44.98 N mm^{-1}) size kernel. In terms of rupture power, the small kernel power ranged from 0.1002 W (15 mm min^{-1}) to 0.084 W (25 mm min^{-1}); medium size kernel ranged from 0.115 W (15 mm min^{-1}) to 0.074 W (25 mm min^{-1}); while the large size kernel ranged from 0.135 W (15 mm min^{-1}) to 0.104 W (25 mm min^{-1}). These results portrayed importance of sorting of the groundnut kernels before processing unit operation, as it will help to conserve power and energy during the processing operation.

RESEARCH ARTICLE

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Keywords:

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- Loading rate,
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INTRODUCTION

Groundnut (*Arachis hypogea* L.), a leguminous oil crop comprises of two economical parts, which are the kernel and hull. The kernel contains large amount of edible oil (approximately 50%, depending on the cultivar) and protein (about 20%); while the hull can be processed into animal feed, insulation material, bio-fuel and manure (Bagheri *et al.*, 2011). It had been discovered that groundnut plant tolerates a wide range of soil pH, even though it does better in neutral and slightly acidic soils. Since groundnut plant just like other leguminous crops, can produce its own nitrogen through the nitrogen-fixing bacteria presents in its roots noodles, nitrogenous fertilizers are only useful to the plant during the early stage (within the first six weeks after germination), before the full establishment of the plant (Tsigbey *et al.*, 2003). Growing groundnut plants can improve the nitrogen content of the soil; at an approximate rate of 60 kg ha^{-1}. This is done by fixing the atmospheric nitrogen into the soil during lightning (Ndjeunga *et al.*, 2013; Uguru and Iweka, 2019).

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Institute for Agricultural Research and other seeds research centers have produced and registered about 20 disease resistant groundnut cultivars, within the past three decades. Some of these groundnut cultivars include are SAMNUT 10, SAMNUT 11, SAMNUT 22 etc.; which have high kernel and forage yields, and less susceptible to foliar diseases (Ndjeunga *et al.*, 2013; Uyeri and Uguru, 2018). According to the Food Agriculture Organization (FAO) data, Global groundnut total production in 2017 was about 48 million metric tons, with 2.4 million metric tons coming from Nigeria; while China and India were the two largest groundnut producing countries, producing 17.1 and 9.8 million metric tons respectively (FAOSTAT, 2019).

Agricultural products go through many static and dynamic pressures during harvest and post-harvest operations. This usually cause bruises, crushes and cracks to the products, thereby, increasing their susceptibility to deterioration during storage (Altuntas and Ozkan, 2008; Altuntas *et al.*, 2013; Uguru and Nyorere, 2019). Mechanical damage of agricultural products resulting from poor harvesting, handling or storage operations can caused physiological responses on the point of impact; causing complex physiological, metabolic, and enzymatic reactions; leading to unsuitable results (Pérez-López *et al.*, 2014; Akpokodje and Uguru, 2019; Umurhurhu and Uguru, 2019). The two main forces encountered by groundnut net/kernel during handling and storage operations are; compression force and impact force. These forces are experienced either by the whole nut/kernel or at a particular point of the nut/kernel. During the design of agricultural machines/equipment (with preference to groundnut), the knowledge of the mechanical parameters of the groundnut kernel, under quasi static compression are vital information needed by the engineers (Uguru and Iweka, 2019). Rupture force and energy are essential mechanical parameters required for the design and development of groundnut kernels' threshing, shelling and milling machines/equipment). Groundnuts are harvested and threshed to remove the pod, before shelled at lower moisture content to obtain the kernels. Groundnut shelling operation is a serious and delicate post-harvest unit operation, so that achieve high-quality groundnut kernels can be obtained (Bagheri *et al.*, 2011).

To date, many researches have been conducted on the effects of groundnut cultivar, kernel size, kernel orientation, and compression speed, on their physical characteristics and mechanical properties. Their influence on various mechanical properties of groundnut pods and kernels had been reviewed by several researchers. Bagheri *et al.* (2011) observed that the rupture force of groundnut pod was highly dependent on the groundnut cultivar. Rupture force of groundnut (cv. Iraqi 2) pod was 61 N; while the values for Iraq 1, Goli and Valencia groundnut cultivars were 86 N, 69 N and 66 N (Bagheri *et al.*, 2011). According to Ince *et al.* (2009), groundnut kernel firmness increased from 43.07 N mm^{-1} to 59.74 N mm^{-1}, as its size increased from small to large size. Ince *et al.* (2009), further observed that groundnut kernel had a higher firmness when it is loaded along the perpendicular orientation (49.49 N mm^{-1}), when compared with the value obtained when the kernel was loaded along the longitudinal orientation (48.47 N mm^{-1}). Furthermore, another study conducted by other researchers (Uguru and Nyorere, 2019) showed that loading rate/speed significantly influenced the failure force of groundnut (cv. SAMNUT 11) kernels. Uguru and Nyorere (2019) reported that the kernel failure force decreased linearly (61.10 N to 27.61 N) as the loading speed of the compression machine increase from 15 mm min^{-1} to 25 mm min^{-1}, which is also similar to the results we obtained for SAMNUT 22 kernel. Ijabo *et al.* (2016) recorded a cracking force of 45.13 N for a groundnut (local cultivar) kernel when it was compressed along the helium position (plane containing the helium line), at a moisture content of 5.5% (dry basis). It has been reported that groundnut kernel failure is a major problem facing groundnut processors during handling, packaging and storage unit operations. Food engineers' major concern is how to remove the fragile groundnut kernel undamaged from the groundnut pod, during the processing and handling operations. This is because damaged (failed) groundnut kernel does not store well, will lose its viability, and becomes susceptible to fungi/bacterial attacks (Braga *et al.*, 1999; Uguru and Nyorere, 2019).

From relevant literature review, there is no study on the rupture resistance of groundnut (cv. SAMNUT 22) kernels, when measured at different kernel size categories, and different loading rates. Therefore, this study was aimed to evaluate some mechanical behaviours (rupture force, deformation at rupture, rupture power, firmness and toughness) of SAMNUT 22 kernels, at three size categories (small, medium and large) and three loading rates (15 mm min^{-1}, 20 mm min^{-1} and 25 mm min^{-1}). Data obtained from this study will be useful during processing operation of groundnut kernels.

MATERIALS AND METHODS

Plant of interest

The SAMNUT 22 groundnut kernels used for this study were obtained from ICRISAT Kano State, Nigeria. SAMNUT 22 groundnut cultivar produces large kernel and high yields and rich oil quality. It was developed by ILRI- ICRISAT and registered in 2001, with the code NGAH 01-22.

Groundnut cultivation and pre-harvest maintenance

The study was carried out inside the Research Station of Delta State Polytechnic, Ozoro, Nigeria. The groundnut (SAMNUT 22) kernels were cultivated under organic farming method. Groundnut plants did not responds well to nitrogen fertilizers about five weeks after planting (Ajeigbe *et al.*, 2014; Uyeri and Uguru, 2018); therefore, the compost manure was mixed with the soil (at the rate of 3000 ton ha^{-1}), four weeks before the planting of the groundnut kernels. Compost manure releases its nutrients slowly into the soil; therefore, it is appropriate to incorporate it into the soil weeks before the propagation of crops (Akpokodje and Uguru, 2019).

Weeding was done manually, while sprinkler irrigation was employed to meet up with the groundnut water requirement. Any disease infested groundnut plant was uprooted and burnt outside the farm in a thrash pit. Insects were controlled with organic insecticide prepared from neem bark extract; while traps and nets were used to control pests' incursions.

Groundnut samples harvest and preparation

The groundnut plants from where the kernels used for this study were obtained were harvested at peak maturation period. This is when approximately 85% of the kernels physical appearance has showed their true colour, and the kernels were plumped (Ajeigbe *et al*., 2014; Uyeri and Uguru, 2018). The harvested groundnut plants were dried under the sun for six days on a platform at ambient temperature of 30 ± 4^0C during the day. Then they were threshed cautiously (to minimize mechanical damage been done to the pods and kernels) using a stick to remove the pods from the groundnut plants. The pods were physically shelled to obtain the kernels; and the kernels were sun-dried for another twelve days, to lower their moisture content. In order to obtain healthy kernels to be used for the study; the dried kernels were manually inspected. Foreign bodies, premature and damage groundnut kernels, etc. were discarded from the lot.

Methods

Gravimetrical method was employed to determine the kernel's moisture content; and Equation (1) was used to calculate the moisture content (Uyeri and Uguru, 2018; Akpokodje *et al*., 2018). The average moisture content of the kernels was 23% to 26% (wet basis).

$$Moisture\ content = \frac{Weight\ of\ wet\ sample - weight\ of\ dry\ sample}{Weight\ of\ wet\ sample} \times 100 \qquad (1)$$

Groundnut kernel size determination

The kernel's principal dimensions, namely; length (*L*), width (*W*) and thickness (*T*) were measured with the aid of a digital vernier caliper (Mitutoya, Japan), with 0.01 mm accuracy (Uyeri and Uguru, 2018). The kernel's geometric mean diameter (*GMD*) and sphericity (ϕ) were calculated by employing Equations 2 and 3 (Mohsenin, 1986; Öztekin *et al*., 2020). The size classifications of the kernels are presented in Table 1.

$$GMD = \sqrt[3]{L \times W \times T} \qquad (2)$$

$$\phi = \frac{GMD}{L} \times 100 \qquad (3)$$

Table 1. Size classification of the SAMNUT 22 groundnut kernels.

Size	Small	Medium	Large
L (mm)	L < 6.25	10.00 ≤ L ≤ 6.25	L >10.00
W (mm)	W < 5.55	8.55 ≤ W ≤ 5.55	W >8.55
T (mm)	T < 5.15	8.15 ≤ T ≤ 5.15	T >8.15
GMD (mm*)	5.04	6.03	7.14
Sphericity* (%)	59.16	65.18	83.81

* = Mean value of the groundnut kernels

Mechanical test on the groundnut kernel

The quasi-static compression test of the SAMNUT 22 groundnut kernel was done by using the Universal Testing Machine (Testometric model, manufactured in England), with accuracy of 0.001 N. During the test, each groundnut kernel was placed inside the machine, ensuring that it is in alignment with the loading cell (Uyeri and Uguru, 2018). Then the kernel was loaded at a preset loading rate (speed), as shown in Figure 1. As the loading progressed, a force-deflection curve of the groundnut kernel was plotted spontaneously by the microprocessor of the machine (Figure 2) relatively to the kernel's compressive reaction to the quasi-static compression (Eboibi and Uguru, 2017; Uyeri and Uguru, 2018).

Figure 1. SAMNUT 22 groundnut kernel undergoing compression loading.

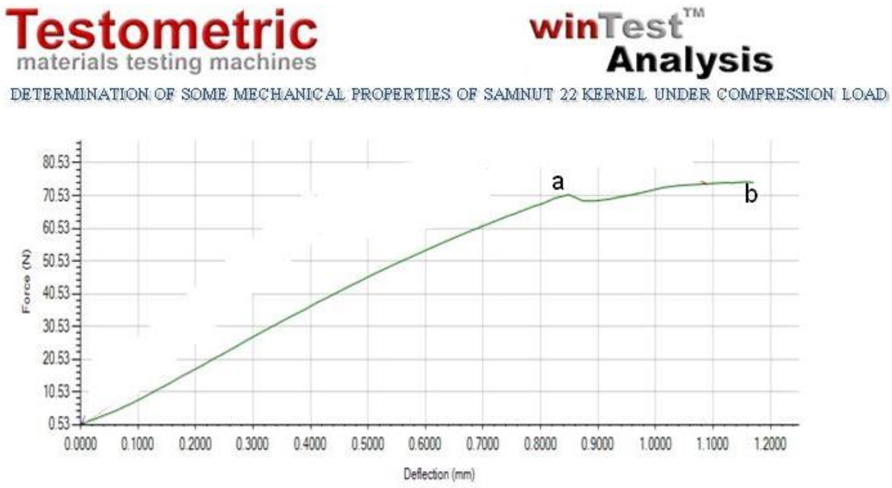

Figure 2. A force-deflection curve of SAMNUT 22 kernel under quasi compressive loading. a = Bio-yield point, also expressed as failure point (Steffe, 1996; Uyeri and Uguru, 2018)
b = Breaking point, also expressed as rupture point (Steffe, 1996; Uyeri and Uguru, 2018)

At the end of each test, the machine calculated these mechanical parameters (rupture force, deformation at rupture point, rupture energy) electronically. The tests were done at three loading rates (15, 20 and 25 mm min^{-1}), three kernel sizes (small, medium and large) at the kernel's *Y*-axis. The loading position was taken based on the orientation of the groundnut kernel. The line (axis) which parallel to the split plane was considered as the *X*-axis; the axis longitudinal to the split plane was considered as the *Y*-axis. Finally, the axis perpendicular to the split plane was considered as the *Z*-axis, as shown in Figure 3 (Uyeri and Uguru, 2018).

Groundnut kernel just like other biological materials has complex biomechanical behaviours; thereby, it is practically difficult to categorize it with simple constants (Lysiak, 2007; Uguru *et al.*, 2020). Bio-yield and rupture points are introduced, in order to calculate most of its mechanical properties (Uguru and Iweka, 2019). Bio-yield point (failure point) correlates to the microstructure failure of the sample, and it is linked to the initial disruption of the sample's cellular structure. Rupture point (breaking point) correlates to with macro-structural failure of the kernel, during compressional loading (Steffe, 1996; Eboibi and Uguru, 2017). Each test was replicated twenty times and the average value taken.

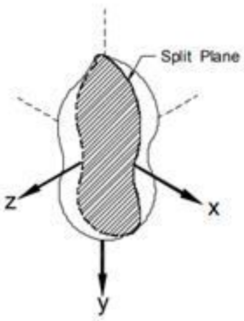

Figure 3. Graphical representation of groundnut kernel showing the three axes (Ince *et al.*, 2009).

Calculated parameters

The kernel's toughness, firmness and rupture power were calculated from the measured (rupture force, rupture energy and deformation at rupture point) values obtained from the Universal Testing Machine.

Groundnut kernel toughness is the energy the kernel can withstand before rupturing (Uguru and Iweka, 2019); it is calculated by dividing the rupture energy by the kernel's volume, as shown in Equation 4 (Umurhurhu and Uguru, 2019). Equations 5 and 6 were used to calculate the kernel's rupture power and volume (V). The kernel's firmness was taken as the ratio of its rupture force to deformation at its rupture point (Equation 7) (Khazaei *et al*., 2002; Eboibi and Uguru, 2017).

$$T_o = \frac{E}{V} \tag{4}$$

$$P = \left(\frac{E \times S}{6000D}\right) \tag{5}$$

$$V = \frac{\pi \times L \times W \times T}{6} \tag{6}$$

$$F_r = \frac{R_f}{D} \tag{7}$$

Where:
T_o = toughness (N m);
P = rupture power (W);
E = rupture energy (N m);
S = loading rate (mm min^{-1});
F_r = firmness (N mm^{-1});
R_f = rupture force;
D = deformation at rupture point (m)

Statistical analysis

Results obtained from this study were analyzed using the Statistical Package for Social Statistics (SPSS version 20.0); while Duncan's Multiple Range Test (DMRT) was used to compare the mean at 95% confidence level.

RESULTS AND DISCUSSION

Rupture force

Results of the rupture force of the groundnut kernels are presented in Figure 4. With reference to the results (Figure 4), it can be seen that the average force require to initiate rupture of a kernel increased linearly as the kernel's size increases from the size to the large. The effects of loading rate and kernel size on the rupture force of the SAMNUT 22 groundnut kernel are shown in Tables 2 and 3. According to Table 2, the mean force required for the rupture of the kernel decreased significantly ($p \leq 0.05$) as the loading rate increase from 15 mm min^{-1} to 25 mm min^{-1}. With respect to the size of the kernel, the statistical analysis showed that the size of the kernel significantly ($p \leq 0.05$) influenced the kernel's rupture force (Table 3). Generally, the large kernels had maximum rupture force (57.96 N); while the small kernels recorded the least rupture force (27.35 N). As shown in Tables 2 and 3, the rupture force values of the kernels at different loading rate and size of kernel were different statistically. These results are in similar trend with those reported by Uguru *et al.* (2020) and Ince *et al.* (2009). Uguru *et al.* (2020) stated that, when SAMNUT 11 groundnut kernel compressed along the *X*-axis, at a speed of 15 mm min^{-1}, a rupture force of 94.31 N was observed. Similarly, when a groundnut kernel was compressed along the *X*-axis by Ince *et al.* (2009), a rupture force of 122.76 N, was recorded. In addition, Sosa *et al.* (2012) stated rupture force of groundnut kernel can be influenced the compression speed of the processing machine. The disparities in the rupture force values recorded by different authors could be attributed to soil condition, agricultural practices, environmental conditions, harvesting time, and groundnut variety. Sadowska *et al.* (2013) observed a clear increment in the fracture force of grass pea (*Lathyrus sativus* L.) seed, as the seed size increases; despite its variability, accessions and varieties (Sadowska *et al.*, 2013).

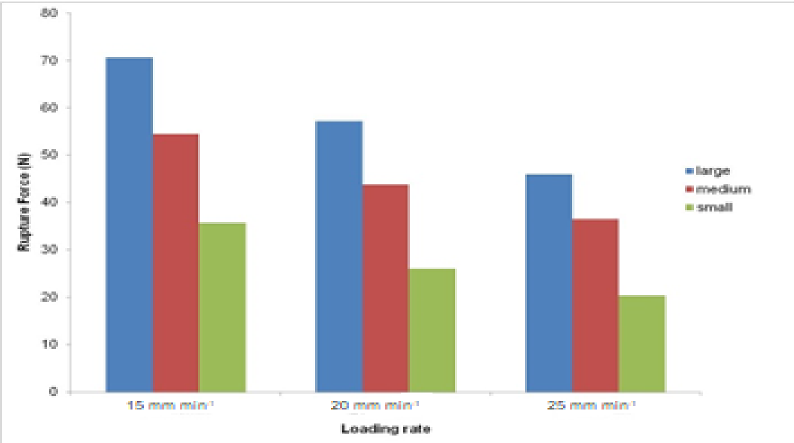

Figure 4. Effect loading rate and kernel size on the rupture force of groundnut kernel.

Table 2. Effect of loading rate on rupture force, deformation at rupture, rupture power, firmness and toughness of SAMNUT 22 groundnut kernel.

Loading rate	Rupture force (N)	Deformation at rupture (mm)	Rupture power (W)	Firmness (N mm^{-1})	Toughness (mJ mm^{-3})
15 mm min^{-1}	53.58^{c}	0.894^{c}	0.117^{c}	56.32^{c}	0.166^{c}
20 mm min^{-1}	42.36^{b}	0.824^{b}	0.103^{b}	51.53^{b}	0.116^{b}
25 mm min^{-1}	34.30^{a}	0.717^{a}	0.091^{a}	47.85^{a}	0.071^{a}

In each column, means with the same common letter (superscript) are not significantly different at $p \le 0.05$, Duncan's Multiple Range Test.

Table 3. Effect of kernel size on rupture force, deformation at rupture, rupture power, firmness and toughness of SAMNUT 22 groundnut kernel.

Loading rate	Rupture force (N)	Deformation at rupture (mm)	Rupture power (W)	Firmness (Nmm^{-1})	Toughness (mJ mm^{-3})
Small	27.35^{a}	0.653^{a}	0.091^{a}	44.98^{a}	0.146^{b}
Medium	44.94^{b}	0.808^{b}	0.101^{b}	51.69^{b}	0.121^{b}
Large	57.96^{c}	0.974^{c}	0.118^{c}	59.03^{c}	0.103^{a}

In each column, means with the same common letter (superscript) are not significantly different at $p \le 0.05$, Duncan's Multiple Range Test.

Deformation at rupture point

Figure 5 showed the deformation level of a groundnut kernel at rupture point. The study revealed that small kernel had lower relative deformation, when compared with the large kernel. This portrayed that, a large groundnut kernel has the capability of absorbing more force and energy during quasi static compressive loading, when compared with the small size kernel. The deformation rate experienced by a kernel was significantly ($p \leq 0.05$) influenced by its size and loading rate (Tables 2 and 3). At the speed (rate) of 15 mm min^{-1}, 0.894 mm deformation was recorded; when compared to when lower deformations, 0.824 mm and 0.717 mm recorded at higher loading rates of 20 mm min^{-1} and 25 mm min^{-1} respectively. From the results, the deformation obtained under quasi static compression loading for large and medium size groundnut kernel, was greater when compared to the value recorded for small size kernel. The mean deformation values recorded at rupture point in this study, varied significantly from 0.653 mm for the small size kernel, 0.808 mm for the medium size kernel, to 0.974 mm for the large size kernel (Table 3). These results affirmed the previous reports on *Gmelina arborea* fruits, where the larger fruits tend to possess larger elastic modulus and have the ability of absorbing more deformable power during compression loading, when compared to their smaller fruits counterparts (Oghenerukevwe and Uguru, 2018).

SAMNUT 10 and SAMNUT 11 groundnut kernels deformation patterns were similar to results obtained in this study. Uyeri and Uguru (2018) reported that the deformation of SAMNUT 10 groundnut kernel generally increases (0.687 mm to 1.399 mm), as its size increased from small to large; likewise, SAMNUT 11 groundnut kernel deformation also increases (from 0.599 mm to 1.156 mm), as its size increased from small to large. In addition, Khodabakhshian *et al.* (2010) stated that relative deformation of sunflower seed under quasi static compression loading, increase linearly with increased in its seed's size. But on the contrary, Ince *et al.* (2009) reported that the relative deformation of groundnut kernel under compression loading was greater in the small size kernel, when compared to the value obtained from the medium and large size groundnut kernels. In other words, Ince *et al.* (2009) stated categorically that the large size groundnut kernels were more fragile than their small size counterparts. Relative deformation is a vital mechanical parameter to be considered in the shelling of groundnut pods. The amount of deformation in the hull and kernel under compression force designates the splitting of the kernel during shelling (Uyeri and Uguru, 2018; Ince *et al.*, 2009).

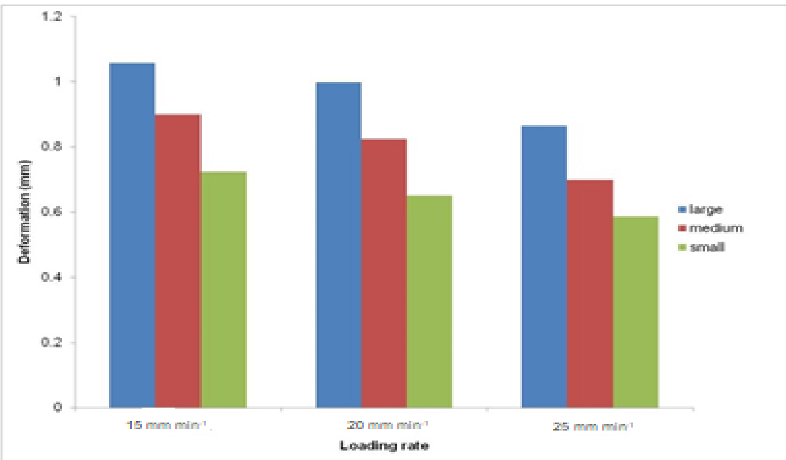

Figure 5. Influence of loading rate and size on the deformation of SAMNUT 22 kernel.

Firmness

From the results of this study as presented in Figure 6, a declined in the kernel's firmness was observed as its size decreases (from large size to the small size). Statistically, it can be seen that the loading rate and size of the kernel significantly ($p \leq 0.05$) influenced its firmness (Tables 2 and 3). Considering the loading rate, the highest value of firmness was recorded at 15 mm min^{-1}; while the lowest value of firmness was recorded at 25 mm min^{-1} (Table 2). According to Mohsenin (1986), kernel/seed firmness is highly dependent on the compressive force and the deformation. Therefore, these results portray that at higher loading rates, the rate at which the cellular structures of the kernel re-arranged themselves, following the distortion caused by the compression force dropped significantly. When plant tissue is subjected to mechanical test, it's (the tissue) anatomy greatly influenced the results obtained to a certain stress level (Niklas, 1992). Kutschera and Niklas (2007) reported that outer plants' tissues impose a strong mechanical restriction to the internal tissues expansion; therefore, this influences their mechanical properties during compression. Considering the plant's organs, tissue stresses that result from turgor, proliferation dynamics, structural variation of tissues, etc., create a tensional integrity within the organ (Kutschera and Niklas, 2007; Hernández-Hernández *et al.*, 2014). With respect to the size of the kernel, there was no significant (0.05 level of significance) similarity among the three kernel sizes, as shown in the Duncan's Multiple Range Test results of the mean separation presented in Table 3. From the results presented in Table 3, the large kernel recorded the highest average firmness (59.03 N mm^{-1}), when compared to the medium and small kernel sizes that recorded the average value of 51.69 N mm^{-1} and 44.98 N mm^{-1} respectively. Groundnut kernel being an agricultural product, its structure is heterogeneous and anisotropic; therefore, mechanical properties are dispersed inhomogeneous within its tissues (Li *et al.*, 2013; Uguru *et al.*, 2020). Similar trends were also observed for the *North Carolina*-7 groundnut variety (Ince *et al.*, 2009) and apricot pit (Vursavus and Özgüven, 2004). In the vase of the *North Carolina*-7 groundnut variety, the large groundnut kernel had the greatest firmness (54.77 N mm^{-1}), when compared to the firmness values 50.37 N mm^{-1} and 43.07N mm^{-1} obtained for the medium and small size groundnut kernels (Ince *et al.*, 2009). In addition, Uguru and Iweka studied the variation in the kernel firmness of two groundnut cultivars (SAMNUT 10 and SAMNUT 11), when they are subjected to compression loading at a rate of 20 mm min^{-1}. They reported a kernel firmness of 61.76 N mm^{-1} for the SAMNUT 10 (large kernel) and 53.71 N mm^{-1} for SAMNUT 11 (large kernel) (Uguru and Iweka, 2019). These results obtained by the various authors are similar, with little variations, which can be attributed to human error, processing and handling methods, etc.

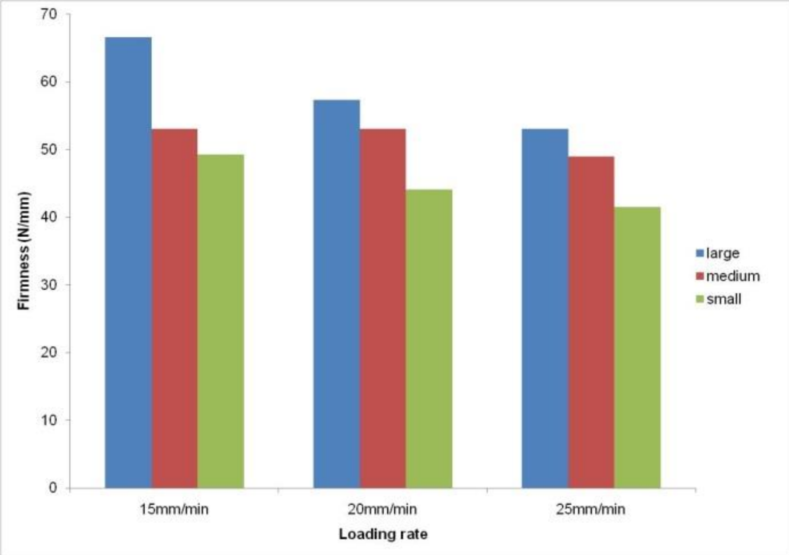

Figure 6. Influence of loading rate and size on the firmness of SAMNUT 22 kernel.

Toughness

The toughness of the groundnut kernel is presented in Figure 7. The study revealed that the toughness of the kernel, declined linearly as the kernel size and loading rate increases (Figure 7). Additionally, the kernel toughness statistical decreased significantly ($p \leq 0.05$) with an increase in kernels size (Table 3). No significant ($p \leq 0.05$) difference existed between the toughness of the small and medium size kernels (Table 3); whereas, the toughness of the medium kernel was significantly ($p \leq 0.05$) different from the toughness of the large kernel. Kernels/seeds density, cellular structure, and body mass highly influenced their toughness during compression (Uguru and Iweka, 2019; Fricke and Wright, 2016). Fricke and Wright (2016) reported that smaller seed tends to have greater tissues densities, when compared to larger seeds; therefore, seed toughness is strongly directly proportional to its mass and volume. Seed toughness, is highly influenced by its size, variety and microstructure (Khazaei *et al.*, 2002).

In reference to the loading rate, the toughness differ significantly ($p \leq 0.05$) across the three loading rates (Table 2). Taking loading rate as a factor, at 15 mm min^{-1}, toughness of 0.166 mJ mm^{-3} was recorded; which later declined to 0.071 mJ mm^{-3} at 25 mm min^{-1} loading rate. The mechanical resistance of plant's tissues is greatly affected the nature the stress and the rate at which it was applied to the plant's tissues (Niklas, 1992; Uguru *et al.*, 2019). This study confirmed earlier studies of (Uguru and Iweka, 2019; Ince *et al.*, 2009; Uguru *et al.*, 2020) for other groundnut cultivars, planted under similar field practices. The toughness of groundnut (cv. North Carolina-7) kernel decreased from 0.032 mJ mm^{-3} to 0.022 mJ mm^{-3}, as the kernel's size increased from small to large (Ince *et al.*, 2009). In addition, Uguru and Iweka (2019) stated that small size groundnut (cv. SAMNUT 10) kernel had higher toughness (0.091 mJ mm^{-3}); when compared with large size kernel (0.041 mJ mm^{-3} toughness). Furthermore, Uguru *et al.* (2020) reported that the toughness of groundnut (cv. SAMNUT 11) kernel increased linearly (0.041 mJ mm^{-3} to 0.083 mJ mm^{-3}), as the loading rate increases (15 mm min^{-1} to 25 mm min^{-1}). Seed toughness highly influences its milling energy and ability to withstand mechanical damage, during post-harvest units operations (Khazaei *et al.*, 2002; Nyorere and Uguru, 2018). The minor differences recorded in the kernel's toughness (when compared other authors' results to our own) can be attributed to the different groundnut cultivars used by the various researchers, soil and environmental conditions. Plant cultivar, maturity stage, genetic modification, farming methods, environmental conditions (mostly sunlight and rainfall), soil condition, diseases and pests attacks, processing and storage conditions affect engineering properties agricultural materials (Radzevičius *et al.*, 2012; Eboibi *et al.*, 2019).

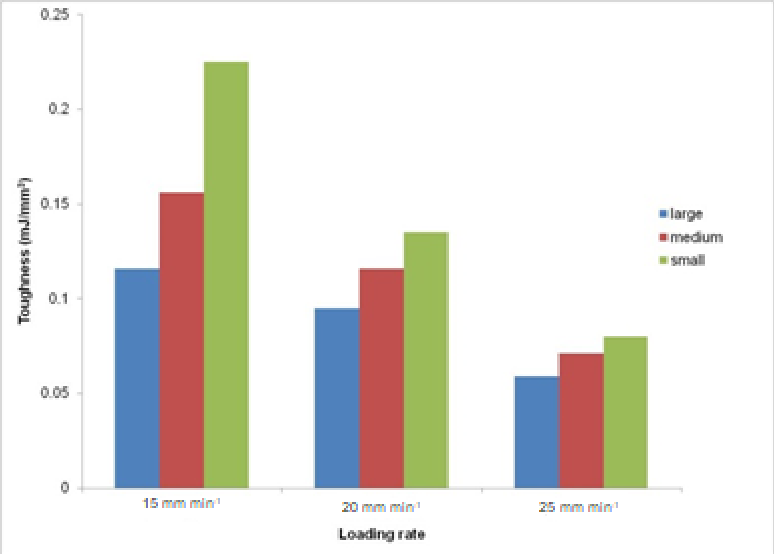

Figure 7. Influence of loading rate and size on the toughness of SAMNUT 22 kernel.

Rupture power

Rupture power of the groundnut kernels, when compressed at the various loading rates is presented in Figure 8. As shown in Figure 8, the rupture power value obtained for the large kernels was higher than those obtained for both the small and medium groundnut kernels. From the statistics results (Tables 2 and 3), the kernel size and loading rate significantly ($p \leq 0.05$) affected the rupture power of the kernel. The small kernel's rupture power ranged from 0.1002 W to 0.084 W, as the loading rate increased from 15 mm min^{-1} to 25 mm min^{-1}; while the medium kernel rupture power ranged from 0.115 W to 0.074 W, as the loading rate increased from 15 mm min^{-1} to 25 mm min^{-1}; lastly, the large kernel rupture power ranged from 0.135 W to 0.104 W, as the loading rate increased from 15 mm min^{-1} to 25 mm min^{-1}. There was no statistical significant ($p \leq 0.05$) similarity between the mean rupture power of the kernels calculated for the three loading rates, across the three kernel size categories. Similar results were reported by Khazaei *et al.* (2002) for almond kernel, and Uguru and Iweka (2019) for groundnut (cv. SAMNUT 10) kernels. According to Khazaei *et al.* (2002), the rupture power of the kernel generally increases with an increased in the size, but no significant ($p \leq 0.05$) difference existed between the rupture powers of the medium and big kernels. Citing Uguru and Iweka (2019), SAMNUT 10 kernel rupture power, when compressed at 20 mm min^{-1} ranged from 0.122 W (small kernel) to 0.193 W (large kernel). In addition, Altuntas *et al.* (2008), observed that the rupture power of almond (cv. *Nonpareil*) nut, when compressed along the X- axis, ranged from 0.20 W to 0.73 W. This study in collaboration with similar studies, revealed that lesser power will be consumed if the groundnut kernels are milled at a higher compression speed. Since high loading rates can lead to high temperature, which can burn the groundnut oil, care should be taken when selecting the loading rate of kernel during groundnut oil production. The results from this study further portrayed that before milling or other processing operations of groundnut kernels is to be carried out, sorting should be done to save power and energy during the processing unit operations.

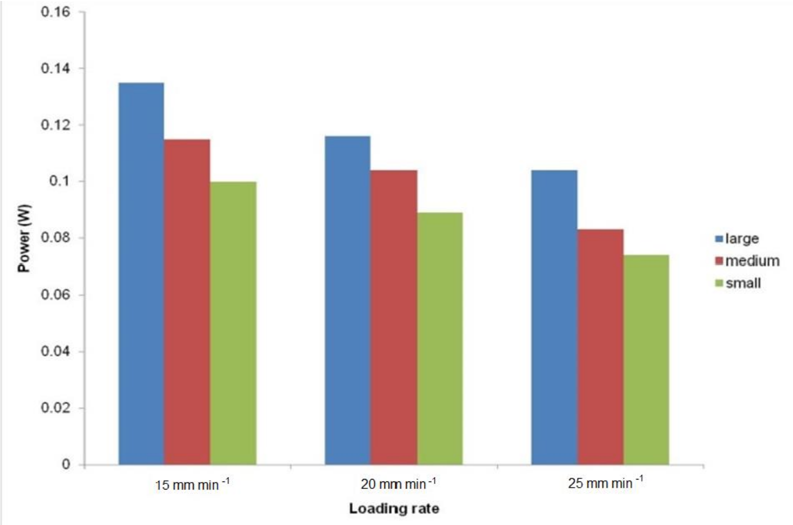

Figure 8. Influence of loading rate and size on the rupture power of SAMNUT 22 kernel.

CONCLUSION

This study evaluated the influence of loading rate and size on some mechanical behaviour of groundnut (cv. SAMNUT 22) kernel. The size categorizes were small, medium and large; while the loading rates categories were 15 mm min^{-1}, 20 mm min^{-1}, and 25 mm min^{-1}. The groundnut kernels were harvested at peak maturity stage, and tested in accordance to ASTM International Standard. Results obtained from this study specified that all the mechanical parameters (rupture force, deformation at rupture point, toughness, firmness and rupture power) were significantly ($p \leq 0.05$) dependent on the kernel size and loading rate. In terms of the loading rate, the large-size kernel recorded the highest force and deformation values at the rupture point; when compared with the results recorded for the medium and small size kernel. In addition, the results showed that the small-size kernel recorded significant ($p \leq 0.05$) highest toughness; when compared with the values recorded for the medium and large-size kernels. Furthermore, the study revealed that the firmness of the kernels increases with size; but decreases with loading rate. In addition, highest rupture power was recorded when the kernel was compressed at speed of 15 mm min^{-1}, when compared with the power values recorded from the loading rates of 20 mm min^{-1} and 25 mm min^{-1}. Therefore, it is important to consider kernel size and loading rate during the design of groundnut processing machine/equipment in order to minimize power and energy consumption, and maximized throughput capacity.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no conflict of interest

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.
Hilary Uguru: Design the research and writing the original draft.
Ovie Isaac Akpokodje: Data analysis and review of the original draft.
Ebubekir Altuntas: Editing of the manuscript.

REFERENCES

Ajeigbe HA, Waliyar F, Echekwu CA, Ayuba K, Motagi BN, Eniayeju D and Inuwa A (2014). A farmer's guide to groundnut production in Nigeria. Patancheru, 502 324, Telangana, India: *International Crops Research Institute for the Semi-Arid Tropics. p.28.*

Akpokodje OI, Uguru H and Esegbuyota D (2018). Remediation of cassava effluent contaminated soil using organic soap solution: Case study of soil physical properties and plant growth performance. *Journal of Scientific Research and Reports, 21(3): 1-11.*

Akpokodje OI and Uguru H (2019). Impact of farming methods on some anti-nutrients, nutrients and toxic substances of cassava roots. *International Journal of Scientific Research in Science, Engineering and Technology, 6(4): 275-284.*

Altuntas E and Ozkan Y (2008). Physical and mechanical properties of some walnut (*Juglans regia* L.) cultivars*. International Journal of Food Engineering, 4: Article 10.*

Altuntas E, Somuncu C and Ozturk B (2013). Mechanical behaviour of plum fruits as affected by pre-harvest methyl jasmonate applications. *Agricultural Engineering International: CIGR Journal, 15(2): 266-274.*

Bagheri I, Payman SH and Rahimi-Ajdadi F (2011). Mechanical behavior of peanut kernel under compression loading as a function of moisture contents. *Elixir Agriculture, 36: 3552-3557.*

Braga GC, Couto SM, Hara T and Almeida Neto JTP (1999). Mechanical Behaviour of Macadamia Nut under Compression Loading. *Journal of Agricultural Engineering Research, 72: 239-45.*

Eboibi O and Uguru H (2017). Storage conditions effect on physic-mechanical properties of *Nandini* cucumber. *International Journal of Engineering and Technical Research, 7(10): 75-82.*

Eboibi O, Akpokodje OI, Nyorere O, Oghenerukevwe P and Uguru H (2019). Evaluation of textural qualities and chemical properties of some tomato cultivars. *Direct Research Journal of Agriculture and Food Science, 7(6): 147-157.*

Food and Agriculture Organization of the United Nations (2019). FAOSTAT [online]. Website: http://www.fao.org/faostat/en/#data/QC. (01/08/2019).

Fricke EC and Wright SJ (2016). The mechanical defence advantage of small seeds. *Ecology Letters, 1-5.*

Hernández-Hernández V, Rueda D, Caballero L, Alvarez-Buylla ER and Benítez M (2014). Mechanical forces as information: an integrated approach to plant and animal development. *Frontiers in Plant Science, 5: 1-16.*

Ijabo OJ, Orwua JT and Omale PA (2016). Determination of quasi-static behaviour of bambara nut, ground nut and African yam beans pods and seeds. *Journal of Environmental Science, Computer Science and Engineering & Technology, 5(3): 369-378.*

Ince A, Ugurluay S, Güzel E and Özcan MT (2009). Mechanical behavior of hulled peanut and its kernel during the shelling process. *Philippine Agricultural Scientist, 92(1): 92-99.*

Khazaei J, Rasekh M and Borghei AM (2002). Physical and mechanical properties of almond and its kernel related to cracking and peeling. An ASAE Meeting Presentation, Paper No 026153.

Khodabakhshian R, Emadi B, Fard MH A and Saiedirad MH (2010). Mechanical properties of sunflower seed and its kernel, azargol variety as a case study, under compressive loading. *Journal of Agricultural Science and Technology, 4(2): 34-40.*

Kutschera U and Niklas KJ (2007). The epidermal-growth-control theory of stem elongation: an old and a new perspective. *Journal of Plant Physiology, 164: 1395–1409.*

Li Z, Yang H, Li P, Liu J, Wang J and Xu Y (2013). Fruit biomechanics based on anatomy: A Review. *International Agrophysics, 27: 97-106.*

Lysiak G (2007). Fracture toughness of pea: Weibull Analysis. *Journal of Food Engineering 83: 436-443.*

Mohsenin NN (1986). Physical properties of plant and animal materials. *Gordon Breach Science Publishers,* New York, USA.

Ndjeunga J, Ntare BR, Ajeigbe H, Echekwu CA, Ibro A and Amadou A (2013). Adoption and impacts of modern groundnut varieties in Nigeria. http://grainlegumes.cgiar.org/wpcontent/uploads/2016/08/2013_Groundnut_Nigeria_Early-adoption-of-groundnut.pdf. (01/05/2019).

Niklas KJ (1992). Plant biomechanics: An engineering approach to plant form and function. *The University of Chicago Press, Chicago*, United States of America.

Nyorere O and Uguru H (2018). Effect of seed size on the mechanical properties of *gmelina* seed. *International Journal of Scientific & Engineering Research, 9(8): 853-856.*

Oghenerukevwe P O and Uguru H (2018). Effect of fruit size and orientation on mechanical properties of gmelina fruit (*Gmelina arborea*) under quasi-Static loading. *International Journal of Engineering and Technical Research, 8: 47-51.*

Öztekin YB, Taner A and Duran H (2020). Chestnut (*Castanea sativa* Mill.) cultivar classification: An artificial neural network approach. *Natulae Botanicae Horti Agrobotanici Cluj-Napoca, 48(1): 366-377*

Pérez-López A, Chávez-Franco SH, Villaseñor-Perea CA, Espinosa- Solares T, Hernández-Gómez LH and Lobato-Calleros C (2014). Respiration rate and mechanical properties of peach fruit during storage at three maturity stages. *Journal of Food Engineering, 142: 111–117.*

Radzevičius A, Viškelis P, Karklelienė R, Viškelis J, Bobinas Č, Dambrauskienė E and Sakalauskienė S (2012). Tomato ripeness influence on fruit quality. *World Academy of Science, Engineering and Technology, 64: 594-597.*

Sadowska J, Jeliński T, Błaszczak W, Konopka S, Fornal J and Rybiński W (2013). The effect of seed size and microstructure on their mechanical properties and frictional behavior. *International Journal of Food Properties, 16(4): 814-825.*

Sosa N, Salvatori DM and Schebor C (2012). Physico-chemical and mechanical properties of apple disks subjected to osmotic dehydration and different drying methods. *Food and Bioprocess Technology, 5(5): 1790-1802.*

Steffe JF (1996). Rheological methods in food process engineering. (Second Edition). Freeman Press, USA.

Tsigbey FK, Brandenburg RL and Clottey VA (2003). Peanut production methods in Northern Ghana and some disease perspectives. *Online Journal of Agronomy, 34(2): 36- 47.*

Uguru H and Iweka C (2019). The Influence of size and variety on the compressive behaviour of groundnut kernel. *Direct Research Journal of Agriculture and Food Science, 7(3): 62-69.*

Uguru H and Nyorere O (2019). Failure behaviour of groundnut (SAMNUT 11) kernel as affected by kernel size, loading rate and loading position. *International Journal of Scientific & Engineering Research, 10(2): 1209-1217.*

Uguru H, Nyorere O and Omotor DO (2019). Evaluation of fracture resistance of honey bean seed under quasi compressive loading. *Direct Research Journal of Agriculture and Food Science, 7(5): 86-92.*

Uguru H, Akpokodje OI and Ijabo OJ (2020). Fracture resistance of groundnut (cv. SAMNUT 11) kernel under quasi-static compression loading. *Scholars Journal of Engineering and Technology, 8(1): 1-8.*

Umurhurhu B and Uguru H (2019). Effect of storage duration on mechanical properties of *Bello* eggplant fruit under quasi compression loading. *International Journal of Research-Granthaalayah 7(5): 311-320.*

Uyeri C and Uguru H (2018). Compressive resistance of groundnut kernels as influenced by kernel size. *Journal of Engineering Research and Reports, 3(4): 1-7.*

Vursavus K and Özgüven F (2004). Mechanical behaviour of apricot pit under compression loading. *Journal of Food Engineering, 65: 255-26.*