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*Research paper*

# Mechanical Behaviour of Groundnut (cv Kampala) Kernel under Compressive Loading as a Function of Loading Rate and Orientation

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Mechanical properties of groundnut are vital tools in the design and development of its threshing, handling and processing equipment. This present research was carried out to evaluate the fracture resistance (rupture force, rupture energy and deformation at rupture) of *Kampala* groundnut kernels as influenced by loading rate and orientation. The compression tests were carried out at three loading rates (15, 20 and 25 mm/min), under two orientations (axial and longitudinal). The results showed that the loading rate and orientation had significant ($p<0.05$) effect on all the three mechanical parameters investigated. Based on the results obtained from this present research, the force, energy and deformation at rupture point of the groundnut kernel declined as loading rate increase from 15 to 25 mm/min, in both orientations. The average rupture force decreased from 86.07 to 62.80 N, at axial orientation; and 42.40 to 19.53 N, at longitudinal orientation. While the rupture energy decreased from 0.065 to 0.031 Nm, at axial orientation; and 0.031 to 0.02 Nm at longitudinal orientation. The high correlation values ($r \geq \pm 0.90$) showed a strong regression relationship between the mechanical parameters studied, loading rate and kernel orientation. Data obtained from this study will help in the design and development of groundnut kernel (mostly Kampala) handling and processing equipment.

**Keywords:** *Kampala* kernel, rupture point, fracture resistance, loading rate, orientation

## INTRODUCTION

Groundnut (*Arachis hypogaea* L), is a significant subsistence and food crop in sub-Saharan Africa, grown in most countries, with the continent accounting for roughly a quarter of the world's production (Ajeigbe *et al.,* 2014). In Nigeria, groundnut is mostly cultivated in the northern region of the country, with most of the production going for local consumption and few for exportation. According to FAO data, total world groundnut production amounts to about 44 million in 2016, with Nigeria accounting for about 3 million (7%) of this production (FAO, 2018). Groundnut is a good source of protein, fat and oil, and vitamins. It is the 13$^{th}$ most important oil seed crop of the world. The haulms are a good source of feed for livestock, especially during the dry season when fresh green grasses are not available. Furthermore, it improves soil fertility through nitrogen fixation, thereby increasing the productivity of the land (Anyasor *et al*., 2009; Ajeigbe *et al.,* 2014). Groundnut performs best in a well-drained sandy loam or in sandy clay loam soils, with soil pH between 6.5 and 7.0.

Despite the nutritional and economic potentials of groundnut kernels, there is lack of machineries in its harvesting, handling and processing operations. These results in farmers using locally fabricated tools in groundnut harvesting and processing, which led to energy wastage, unhygienic processing conditions and high kernel breakage. The knowledge of mechanical properties of groundnut kernels, just like any other agricultural materials, are important in the design and development of equipment/machinery for handling, processing and packaging of groundnut kernels (Davies, 2009). One of the most critical processing and handling operations is nut shell cracking to extract the fragile whole kernel from the shell. Shelling operation could leads to damaged and broken kernels, if wrong mechanical forces were applied to the nut during the shelling operation. As stated by Ozdemir (1999), one of the most important factors for shelling is the mechanical force applied to the nut (hazelnut). Damaging the kernels during the shelling process greatly reduces their market value. Therefore, it is important to study the mechanical behaviour of kernels, nuts and pods for harvesting, conveying, storage, and shelling operation.

In previous studies, it was reported that the mechanical properties of seeds, kernels and grains are highly affected by the compression loading rate, loading orientation and moisture content. Saiedirad *et al.* (2008) studied the effects of loading rate and orientation on the force and energy required to fracture cumin seed under quasi-static loading. The results of the study showed that the force required for fracturing cumin seed decreased as the loading rates increase from 2 to 5 mm/min. Kang *et al*. (1995) reported that mean values of bio-yield strain and energy to bio-yield of wheat decreased as the moisture content increased at a loading rate of 1 to 25 mm/min. In addition, the rupture force of four peanut varieties (*Iraqi* 1, *Iraqi* 2, *Goli* and *Valencia*) pods in axial direction, at the loading rate of 25 mm/min were determined by Bagheri and his associates in 2011. Their results showed that *Iraqi* 1 had the highest rupture force (86 N), while *Iraqi* 2 had the lowest rupture force (61 N) (Bagheri *et al*., 2011). Braga *et al*., (1999) investigated force and energy required for the initial rupturing of macadamia nut shell under compression as a function of moisture content, nut size, and compression load position. They reported that there is a compression position for which force and energy values are minimal, independent of nut size and shell moisture. From literature review, there is no much research on the mechanical properties of *Kampala* groundnut kernels as influenced by loading rate and orientation. Therefore, the objective of this study was to determine the influence of loading rate on some mechanical properties of *Kampala* groundnut kernels, in axial and longitudinally orientations. The data obtained from this study would be useful in the design and development of *Kampala* groundnut processing equipment.

## MATERIALS AND METHODS

### Sample collection and preparation

The groundnut (cv Kampala) kernels used in this research were planted in the research farm of Delta State Polytechnic, Ozoro, Nigeria. The groundnut plants were harvested at full maturity stage (when about 80% of the kernels were plump and showed true colour of the *Kampala* variety), as recommended by Ajeigbe *et al.* (2014). After harvest, the plants were shaken to remove soil from the pods, and sun-dried on a platform for four days before threshing. The groundnut pods were shelled manually and carefully, to prevent damaging the kernels. After shelling, the kernels were again air-dried for seven days, for them to attain uniformed moisture content. Finally, the kernels were inspected thoroughly, and contaminants such as, premature, disease and pest infested, shriveled and moldy kernels, including foreign materials were discarded.

### Groundnut size determination

Big groundnut kernel size was only used for the mechanical test. To determine the average size of the groundnut kernel, 100 kernels were randomly selected, and the three major dimensions, length (L), width (W) and thickness (T), were measured using a digital vernier caliper with accuracy of 0.01 mm. From the major dimensions values obtained, the geometric mean diameter, also expressed as size (S), of the kernels was calculated by using equation 1 (Mohsenin, 1986; Eboibi and Uguru, 2017).

$$S = \sqrt[3]{L \times W \times T} \quad (1)$$

### Moisture content determination

The mechanical tests of the groundnut kernels were carried out at a moisture content of 20% wet basis The groundnut kernels moisture content was determined gravimetrically following the procedures of Nwakaudu *et al.* (2012), and calculated with equation 2 (Akpokodje *et al*., 2018).

$$\text{Moisture content} = \frac{\text{Weight of wet sample} - \text{weight of dry sample}}{\text{Weight of wet sample}} \times 100 \quad (2)$$

### Compression test

The mechanical properties of the *Kampala* groundnut kernels were determined at the National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria, using the Universal Testing Machine (Testometric model). During the test, individual groundnut kernel was placed under the flat compression tool of the Universal Testing Machine, as shown in (Figure 1), ensuring that the kernel was at alignment with the centre of the tool (Ozturk *et al*., 2009; Eboibi and Uguru, 2017). As compression of the kernel progressed, a force-deformation curve was plotted automatically by the machine in relation to the response of the kernel to compression. In addition, the test was done at three different loading rates (15, 20 and 25 mm/min). At the end of each compression, these mechanical parameters

**Figure 1**. A Kampala groundnut kernel undergoing quasi-static compression test, using Universal Testing Machine (Testometric model).

(rupture force, deformation at rupture, and rupture energy) of the kernel were calculated automatically by the testometric software of the Universal Testing Machine. The kernels were loaded into the machine in two orientations (longitudinal and axial). According to Steffe (1996), the rupture point of the material, correlates to the macroscopic failure (breaking point) of the sample. The tests were carried out at 15 replications, and the average value recorded.

### Statistical analysis

Analysis of variance was performed on the data obtained from this present research, using SPSS statistical software (version 20.0). The differences between the mean values of parameters were investigated using Duncan's multiple range tests at 95% confidence level.

## RESULTS AND DISCUSSION

Analysis of Variance (ANOVA) of the effect of loading rate and orientation on the mechanical behaviour of *Kampala* groundnut kernel is presented in (Table 1). As shown in (Table 1), loading rate and kernel loading orientation had significant ($P \leq 0.05$) effect on all the mechanical parameters (rupture force, rupture energy and relative deformation at rupture point) investigated. In addition, interaction effect of loading rate by kernel orientation on the rupture force was not significant ($P \leq 0.05$); whereas, it was significant on the rupture energy and deformation at rupture point. Regression equations representing relationships between the mechanical parameters, loading orientation, loading rate of *Kampala* groundnut kernels are presented in (Table 2). As showed in (Table 2), there is a strong linear relationship ($r \geq \pm 0.9$) between rupture force, rupture energy and deformation at rupture, and loading rate in the two orientations for *Kampala* groundnut kernels.

Figures 2, 3 and 4 showed the effect of loading rate on the mechanical behviour of *Kampala* groundnut kernels. As shown in the plots in Figures 2, 3 and 4, the rupture force, rupture energy and deformation at rupture decreased as the loading rate increased from 15 to 25 mm/min. In addition, no significant difference existed among the rupture force and rupture energy, at the loading rate of 20 mm/min and 25 mm/min, but, significant ($P \leq 0.05$) difference existed, between loading rates 20 mm/min and 15 mm/min. The rupture force, rupture energy and deformation at rupture along the axial axis for all loading rate were always higher than the longitudinal axis. This indicated that greater force was necessary to rupture the kernel at lower loading rate than higher loading rate. The lower rupture force at higher loading rate could be attributed to the fact that the kernel tended to absorb more load during lower compressive loading. Furthermore, the results showed that groundnut kernels were more flexible in axial orientation than in the longitudinal orientation. This is could be attributed to the fact that during longitudinal loading, smaller kernel surface area is with contact with the compression plates of the Universal Testing Machine; the cellular structure and arrangement within the groundnut kernel.

These results were similar to the previous results reported by Bagheri *et al*. (2011) and Güner *et al*. (2003). According to Bagheri *et al*. (2011), the force required to rupture *Goli*, *Valencia, Iraqi* 1 and *Iraqi* 2 groundnut kernels were higher in the axial orientation 45, 44, 52 and 45%, than in the longitudinal orientation. Güner *et al*. (2003) reported that the highest rupture energy (812.90 Nmm) of hazelnut was obtained along the axial axis while the lowest (488.60 Nmm) was obtained along the longitudinal axis. In addition, results of a study conducted by (Singh and Goswami, 1998) reported that maximum energy absorbed by cumin grain was 14.8 and 20.4 mJ, in the horizontal and vertical orientations, respectively. Furthermore, Zareiforoush *et al*. (2012) investigated the effect of loading rate on rupture force and energy on rice grain. Their results showed that the rice grain rupture force declined from 84.38 to 69.15 N; while the rupture energy decreased from 23.38 to 18.56 mJ as the loading rate increased from 5 and 10 mm/min. according to Kang *et al*. (1995), the stress, strain, modulus of deformability,

**Table 1**. ANOVA of effect of loading rate and orientation on the mechanical behaviour of *Kampala* groundnut kernel.

| Source | df | Rupture force | Rupture energy | Deformation at rupture |
|---|---|---|---|---|
| O | 1 | 7.44E-09* | 1.98E-04* | 2.95E-06* |
| L | 2 | 2.19E-06* | 1.01E-03* | 6.36E-08* |
| O x L | 2 | $0.66012^{ns}$ | 0.01805* | 0.02183* |

O = orientation, L = loading rate, * =Significant at P ≤ 0.05, ns = not significant.

**Table 2**. The regression equations showing relationship between mechanical parameters of *Kampala* kernel, loading rate and orientation.

| Parameter | Loading orientation | | | | | |
|---|---|---|---|---|---|---|
| | Axial | | | Longitudinal | | |
| | Linear | $R^2$ | r | Linear | $R^2$ | r |
| Rupture force | y = -11.63 x + 95.39 | 0.894 | -0.945 | y = -11.43 x + 53.44 | 0.996 | -0.998 |
| Rupture energy | y = -0.017 x + 0.080 | 0.981 | -0.991 | y = -0.005 x + 0.035 | 0.935 | -0.967 |
| Def. at rupture | y = -0.43 x + 2.293 | 0.950 | -0.974 | y = -0.36 x + 1.76 | 0.945 | -0.972 |

x = loading rate, y = mechanical parameter, $R^2$ = coefficient of determination, r = correlation.

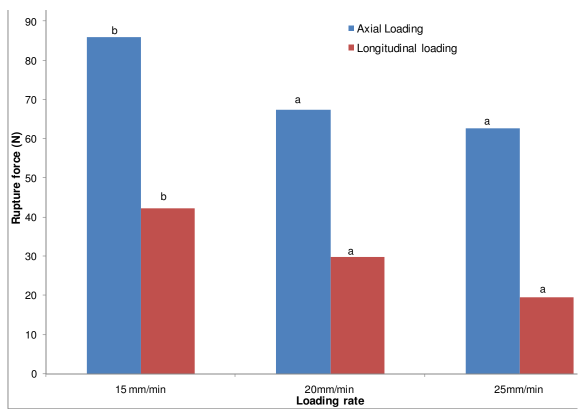


**Figure 2**. Effect of loading rate and kernel orientation on the rupture force of *Kampala* groundnut kernel. Bars with the same common letters means that they are not significant different at (P ≤0.05).

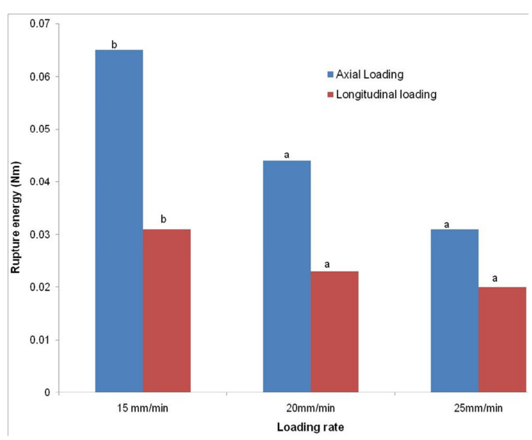


**Figure 3**. Effect of loading rate and kernel orientation on the rupture energy of *Kampala* groundnut kernel. Bars with the same common letters means that they are not significant different at (P ≤0.05).

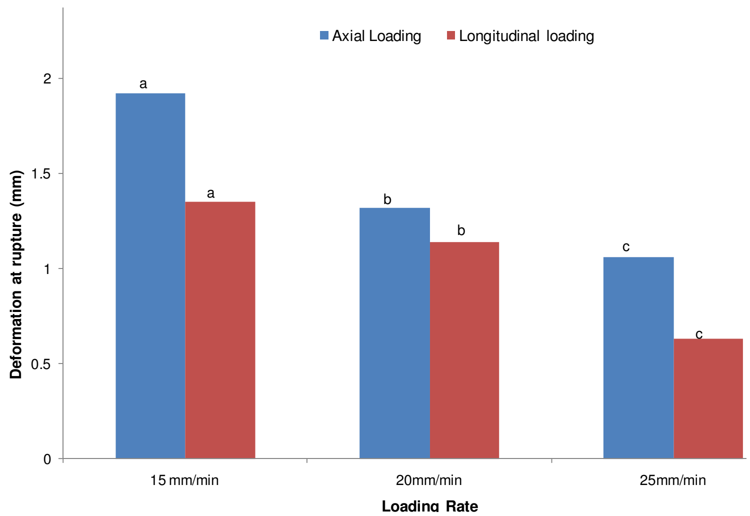


**Figure 4**. Effect of loading rate and kernel orientation on the deformation at rupture of *Kampala* groundnut kernel. Bars with the same common letters means that they are not significant different at (P ≤0.05).

and energy to yield point of kernel and grains are function of loading rate and moisture content.

Poor knowledge of the mechanical properties of groundnut kernels can result in their mechanical damage, during processing and handling operations. This could lead to drastic reduction in the kernels viability and nutritional quality. In addition, it could facilitate the chances of insect and pest infestation of the kernels, and lowered their storage ability. These mechanical parameters and the direction of minimum rupture are vital parameters to be considered in the design and development of harvesting, handling, storage, transportation equipment and machineries.

## Conclusion

Data obtained from this research showed that compressive loading rate, and groundnut kernel orientation had significant effect on all the mechanical parameters studied. The results showed that as the compressive loading rate of the *Kampala* groundnut kernel increased from 15 to 25 mm/min, the kernel rupture force decreased from 86.07 to 62.80 N, at axial orientation; and 42.40 to 19.53 N, at longitudinal orientation. Furthermore, the rupture energy decreased from 0.065 to 0.031 Nm, at axial orientation; and 0.031 to 0.02 Nm at longitudinal orientation respectively. In addition, from the results obtained, it can be seen that the groundnut kernels more flexible in the axial orientation than in the longitudinal orientation. Finally, results obtained from this research are vital information to be considered in the design and development of groundnut harvesting, handling and storage systems.

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