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Full Length Research Paper

Fracture Resistances of Okra (*Abelmoschus esculentus*) Seeds Necessary for Processing Machine Design

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ABSTRACT: The fracture resistances of okra (*Abelmoschus esculentus*, cv. *Kirikou*) seeds were evaluated in this study. Okra pods were harvested at five maturity stages, and their seeds extracted. The five maturity stages at which the okra pods were harvested were; 12 days after peak anthesis (DAPA), 19 DAPA, 26 DAPA, 33 DAPA and 40 DAPA. These mechanical parameters (fracture force, fracture energy and deformation at fracture point) of the seeds were measured by using the Universal Testing machine, in accordance with ASTM procedures. The results revealed that fracture properties of okra seeds exhibited a strong dependence on the degree of maturation of the seeds. The fracture force and fracture energy of the okra seeds increased linearly as the okra seeds matured from 12 DAPA (maturity stage 1) to 40 DAPA (maturity stage 5). The okra seeds fracture force increased linearly from 19.04 N to 84.147 N; while the fracture energy increased from 0.021 Nm to 0.088 Nm. However, the relative deformation of the okra seeds at the fracture point decreased linearly as the seeds matured from the 1st stage to the 5th stage. These results will be useful to mechanical engineers during the design and construction of okra seeds shelling, crushing and milling machines.

Keywords: Compression, fracture resistance, maturity stage, okra seed, processing machine

INTRODUCTION

Okra (*Abelmoschus esculentus*) is grown as an annual flowering crop, and it belongs to the *Malvaceae* family. Okra plant parts (fresh leaves, buds, flowers, pods, stems, seeds, etc.) have industrial and nutritional uses. Fibers extracted from okra plant can be used as a reinforcement material in epoxy and polymer composites (Reddy and Reddy, 2016). Okra fibres reinforced composites are greatly utilized in the automobile and construction companies (Oghenerukevwe and Uguru, 2018). According to Akingbala *et al*. (2003), okra seeds contained appreciable amount protein and essential minerals. Oyelade *et al*. (2003) observed that okra seed had an average mass of 0.06 g, volume of 320 mm^3, density of 1.9 kg/m^2, surface area of 5465 mm^2, at a moisture content of 8%. Sahoo and Srivastava (2002) reported that okra seed at 8.16% moisture content (d.b), had static coefficient of 0.390 on aluminium surface, 0.345 on bakelite surface, 0.368 on galvanized iron surface and 0.389 on mild steel surface. Furthermore, Owolarafe and Shotonde (2004) stated that the modulus of elasticity, maximum compressive force, deformation at rupture point and hardness of okra fruit were 0.49 GPa, 136.41 N, 0.77 mm and 215.96 N/mm, respectively.

Basic knowledge of engineering properties of biomaterials is essential not only in the engineering field; but in other relevant field such as, plant breeding, food processors, etc. (Mohsenin, 1986). The values of the mechanical properties of biomaterials are used to analysis and determine the efficiency of a machine, develop new products and new equipment (Kang *et al*., 1995). Hazbavi (2013) investigated the effected of moisture content on some dependent physic-mechanical properties of okra seeds; and observed that their rupture force generally decreased from 13.75 to 9.44 N, as their moisture content increased from 7.1 to 20 (% d.b.). It was observed that some mechanical properties of *faba* bean

(*Vicia faba* L.) decreased as the moisture content increases from 9.89% to 25.08% (Altuntas and Yıldız, 2007). Pérez-Vicente *et al*. (2002) reported that seed/fruit orientation and loading speed affect the amount of force and energy a plum fruit can hold before failure. The maturity stage, size, shape, mechanical damage, and colour of fruits and vegetables are some essential factors considered by food processors and consumers. Several literatures have shown that maturation (maturity stage) greatly affects the engineering properties of crops (Demir *et al*., 2008).

According to Eboibi and Uguru, (2018) the maturation of honey bean (*Phaseolus vulgaris* L.) seeds significantly ($p \leq 0.05$) affect their physical characteristics, as the seeds true density increased from 774.25 to 1144 kg/m^3, while the bulk density increased from 544.75 to 867.66 kg/m^3. Iweka and Uguru (2019) reported that the thousand seeds mass and specific gravity of okra seeds generally increases as the okra seeds matured from stage 1 to stage 5. Seed development and maturation start after fertilization; as the seed matures, it accumulates fresh weight and its' engineering properties changes. These changes continue until the seed is harvested (Mehta *et al*., 1993; Nyorere and Uguru, 2018a). Threshing dry okra pods traditionally, is a difficult task, time consuming, and production of low quality okra seeds (unbroken seeds).

The knowledge of the mechanical properties (mostly fracture force and fracture energy) of okra seeds are considered during the design and fabrication of okra thresher with winnowing machines, that will produce high quality okra seeds (unbroken seeds) (Oghenerukevwe and Uguru, 2018).

Akani *et al*. (2000) and Oghenerukewve and Uguru (2017) reported that scarcity of information (e.g. rupture force, rupture energy, deformation, etc.) of indigenous crops, have greatly retarded the development of indigenous machines and equipment for the processing of most indigenous crops. Published literatures on the mechanical properties of okra seed as a function of maturation is scanty.

Therefore, the objective of this study was to evaluate the influence of maturity stage on some mechanical properties (fracture force, fracture energy and fracture power) of okra seeds. The results obtained from this study will be useful in the design and fabrication of okra pod threshing and winnowing machines.

MATERIALS AND METHODS

Materials

The dried okra (*Abelmoschus esculentus*, cv. *Kirikou*) seeds were obtained from the Department of Agricultural and Bio-environmental Engineering, Delta State Polytechnic, Ozoro, Nigeria.

Okra plant cultivation

This study was conducted between July and November, 2019. The okra plants were closely monitored to prevent human and pests interference up to the maturity point. The okra seeds were planted under organic farming methods, at the Research Farm of Delta State Polytechnic, Ozoro, Nigeria. They were observed daily during their flowering stage, and the okra flowers were coded according to their day of anthesis.

Okra seeds sampling procedure

Maturity stage of okra seeds can be determined based on their colour change, from white via green to brown. The first pods were harvest at 12 days after peak anthesis (DAPA). Subsequently, the pods were harvested at 7 days interval till 40 days after peak anthesis. A total of 5 groups of okra pods were harvested. After each harvest, the pods were manually inspected to remove all damage and pest infested pods. Then the pods were cut into two halves with a sharp knife, and the seeds carefully removed. The seeds were further inspected for damage seeds, before they were taken to the laboratory for compression testing.

Methods

Determination of moisture content

The moisture content of the harvested okra seeds at each maturity stage was determined using the gravimetric method. The fresh okra seeds were weigh using a digital electronic balance (with sensitivity of 0.01 g), and were put inside an electric laboratory oven, preset at a temperature of 115°C (±3°C). The weight of the okra seeds taken every one hour until a constant weight was achieved. Moisture content of the okra seeds was calculated with equation 1 (AOAC, 2000).

$$\text{Moisture content} = \frac{W_2 - W_3}{W_2 - W_1} \times 100 \qquad (1)$$

Where:
W1 = Weight of container, g;
W2 = Weight of wet sample + container, g
W3 = Weight of dry sample + container, g

Okra seed compression test

The compression test of the okra seeds was done by using the Universal Testing Machine (Testometric model, manufactured in England), with 500 N compression load cell, having accuracy of 0.001 N and controlled by a microcomputer. Each okra seed was tested with the following parameters: preload speed of 50 mm/min, test-speed of 20 mm/min and sensitivity of 4. During the test,

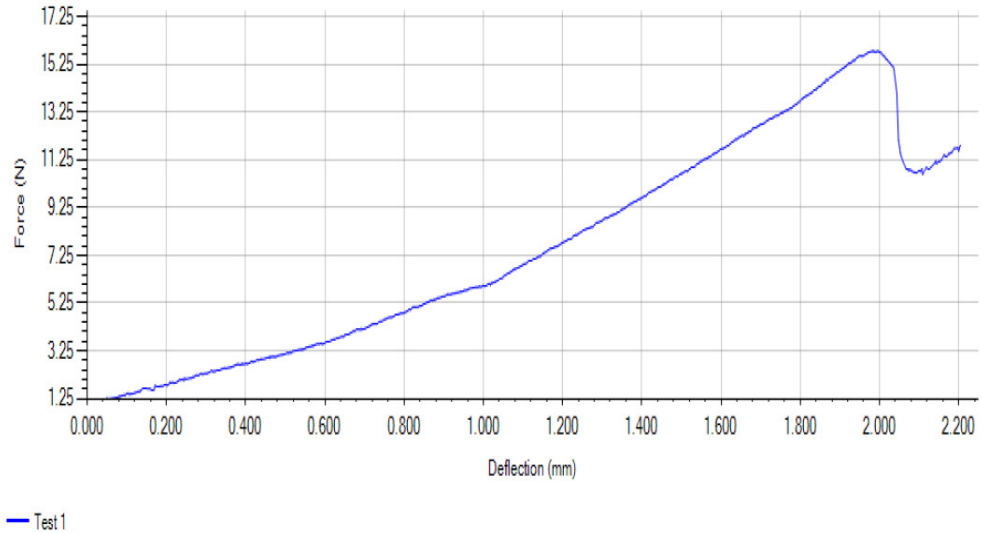

Figure 1: A force-deflection curve of the okra seed plotted by the machine.

each individual okra seed was placed in between the loading cells, making sure it was in alignment with the loading cells, and compressed quasi statically until the seed ruptured. During the compression, a force-deformation curve was plotted electronically by the machine in relation to the response of the okra seed to the uniaxial loading (Figure 1). Once the Universal Testing Machine detected the rupture point of the okra seed, it will stop compression automatically. Then the rupture force, rupture energy and deformation at rupture point of the okra seed will be calculated electronically, by the microprocessor of the machine, and the values read from the computer screen attached to the machine (Uguru *et al*., 2019).

Since Okra seed has complex non-isotropic system, it is basically difficult to characterize it by constant like stress. This is because its size and shape changes continually during loading until rupture point. Therefore, it is necessary to introduce some concepts such as failure and rupture points (Nyorere and Uguru, 2018b; Uguru *et al*., 2019). According to the American Society of Agricultural Engineers (ASAE), rupture point (also expressed as the fracture point) of a seed correlates to the macroscopic failure (breaking point) of the seed under compression loading (Steffe, 1996; Kilickan and Guner, 2008).

Calculated parameter

The okra seed's fracture power was calculated from the compressive parameters fracture force, fracture energy and deformation at fracture point) obtained from the Universal Testing Machine. The fracture power was calculated by applying equation 2.

$$P = \left(\frac{E \times S}{6000D}\right) \tag{2}$$

Where:
E = Rupture energy or energy absorbed by the seed (Nm),
P = Power (W),
S = Compression speed (mm/min),
D = deformation at rupture point (mm)

All the laboratory tests were carried out under ambient laboratory temperature (27±4°C).

Statistical analysis

All data obtained from this study were subjected to statistical analysis using the Statistical Package for Social Statistics (SPSS version 20.0) and Duncan's Multiple Range Test (DMRT) was used to compare the mean at 95% confidence level.

RESULTS AND DISCUSSION

The results of the effect of maturation on the fracture resistance of okra seeds are presented in (Figures 2 to 5). The study revealed that maturity stage had significant effects on the fracture resistance of okra seeds. Regression analysis (Equations 3 to 6) showed that there was strong correlation (r ≥0.91) between all the mechanical parameters (fracture force, fracture energy, deformation at fracture point, and fracture power), and the maturity stage of the okra seed.

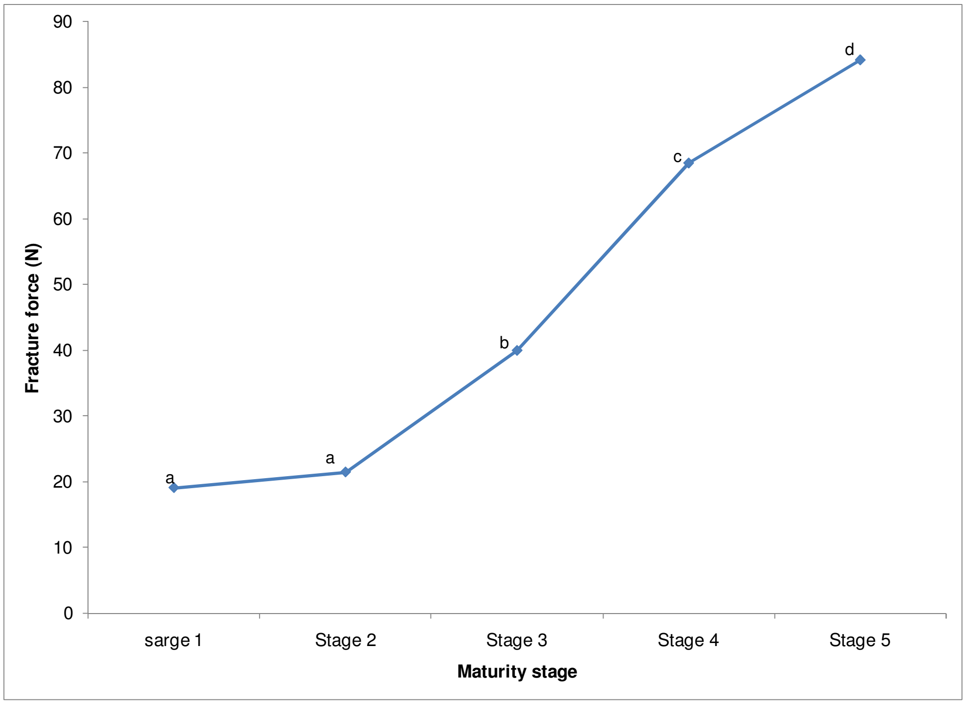

Figure 2: Fracture force of Okra seeds.

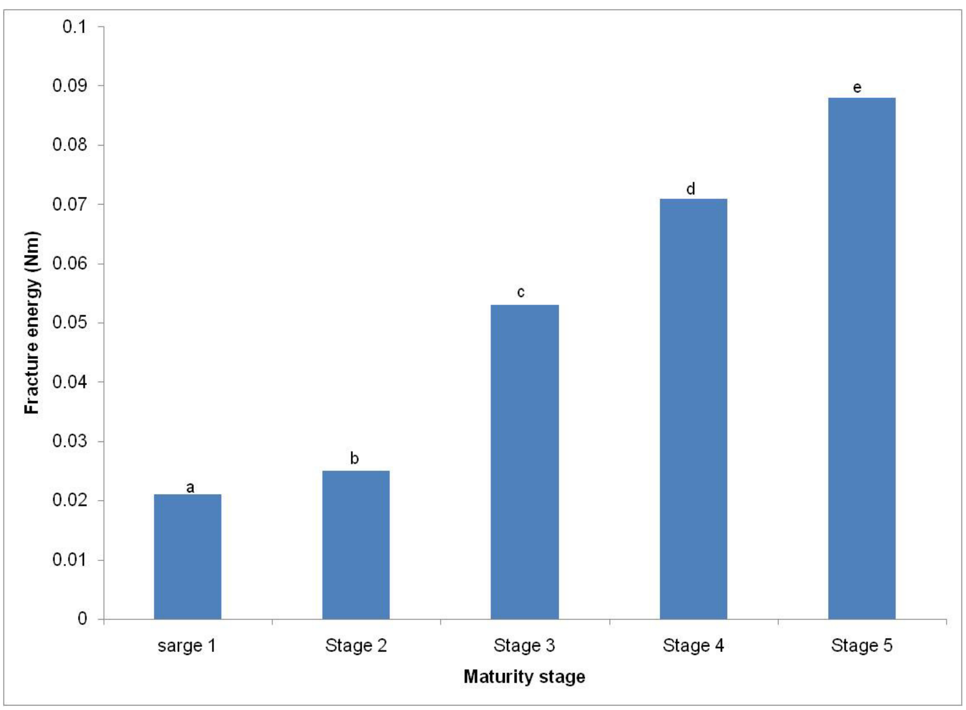

Figure 3: Fracture energy of okra seeds.

Seed moisture content

This study showed that the moisture content of the okra seeds decreased linearly during the maturation of the seeds. At maturity stage 1, an average moisture content of 81% (wb) was recorded, which declined to 24% (wb), at maturity stage 5 (Table 1). Similar results were obtained by Iweka and Uguru (2019); but this study

Table 1: Moisture content of okra seeds.

Maturity stage	Moisture content
Stage 1	81±3
Stage 2	75±2
Stage 3	62±3
Stage 4	35±1
Stage 5	24±2

Values are mean ± SD

results were slightly lower than the results recorded by Iweka and Uguru (2019). The discrepancies in the moisture content of the okra seeds, even though they are the same cultivar, could be attributed to the time of harvest, farming method and environmental conditions. According to Delouche (1980) and Eboibi *et al*. (2019), environmental conditions such as, temperature, rainfall, nutrients availability, diseases infection, and pest pressure greatly influenced crops engineering properties. Gonçalves *et al*. (2005) reported that the moisture content is an index of optimum harvest time of seeds and fruits; and the moisture content of seeds generally declined during the course of maturity. Moisture content of seeds and fruits greatly influences the adjustment and performance of crop processing machines.

Okra seed fracture force

The fracture force of the okra seed increased as the okra seed matured from stage I to stage 5 (Figure 2). For all cases, the lowest fracture force (19.04 N) was recorded at the first stage of maturation. As the seed matured to the fifth stage, the fracture force significantly ($p \leq 0.05$) increased to 84.147 N. This shows that the okra seeds were least resistance to compression loading at the younger age. Although significant difference occurred between the fracture force and maturity stage of the okra seed; there was no significant difference between the seed's fracture force at the 1st and 2nd maturity stages. The variation in the fracture force of the okra seed during maturation could be attributed to the changes in the seed's cellular structure as it matured. According to Kays and Paull (2004) and ASAE (2005), the fracture resistance of seed is a combination of factors inherent to its structure, morphological composition and maturity stage. Regression analysis (equation 3), revealed that a strong correlation relationship ($r = 0.971$) existed between the maturation of okra seed, and the force required to fracture the okra seed. Similar results were obtained by Uguru et al. (2019) for common bean (cv. *Butter*) seeds, where the fracture force of Butter bean seed increased from 54 N to 83 N, as the bean pods matured from 15 DAPA to 29 DAPA. Likewise, Romuli *et al.* (2019) reported that the force require to fracture *Jatropha curcas* L seeds increased from 99.6 N to 113.2 N and the seeds matured from the yellow stage to the black stage.

$$y = 17.72x - 6.577, \quad R^2 = 0.944 \tag{3}$$

Correlation (r) = 0.971

Fracture energy

The study showed that as the okra seed matured from stage 1 to stage 5, the fracture energy of the okra seed increased significantly (Figure 3). At the 1st maturity stage, the okra seed was able to resist fracture energy of 0.021 Nm; while at the 5th maturity stage, the amount of fracture energy the okra seed was able to resist increased to 0.088 Nm. The higher fracture energy absolved by the matured okra seeds can be ascribed to the differences in the seeds body mass, density and cellular structures (Uguru and Iweka, 2019). Similar results were obtained by Karaj and Müller (2010) for *Jatropha curcas* seeds, and Edafiadhe and Nyorere (2019) for okra (cv. *Kirenf*) Pods. According to Edafiadhe and Nyorere (2019), the failure energy of the okra pods increased significantly ($p \leq 0.05$) from 0.056 Nm to 0.313 Nm as the pods maturation processed from maturity stage 1 to maturity stage 5. The fracture energy of seeds is an important factor to be considered during the design and fabrication of okra, shelling, milling and crushing machines. Shelling of the seeds is an essential mechanical postharvest operation to provide kernels (shelled seeds) as the main product, along with fruit hulls and seed shells as byproducts (Contran *et al*., 2013; Lim et al., 2014). The following linear regression relationship (Equation 4) was developed for the fracture energy of the okra seeds, with respect to the maturity stages.

$$y = 0.018x - 0.002, \quad R^2 = 0.968 \tag{4}$$

Correlation (r) = 0.983

Relative deformation at fracture point

The influence of okra pod maturation on the deformation at fracture point of okra (cv. *Kirikou*) seeds is presented in (Figure 4). The results revealed that the relative deformation of the okra seeds decreased significantly ($p \leq 0.05$) as the seeds matured from 12 DAPA to 40 DAPA. At 12 DAPA, the seeds had a relative deformation of 2.208 mm; which decreased to 1.091 mm as the seeds approached 40 DAPA. This portrayed that the okra seeds harvested at the early maturity stages are more ductile, when compared to the seeds harvested at the late maturity stages. Lower deformation values of the okra seeds, recorded at the later maturity stages could be attributed to their lower moisture content of the seeds matured. According to Kang *et al*. (1995) seeds and fruits tends to be more flexible at higher moisture content, than in lower; this is because, the deformation of seeds and fruits is influenced by the structure of biological material and its cells' pores, and its resistance to deformation under applied forces.

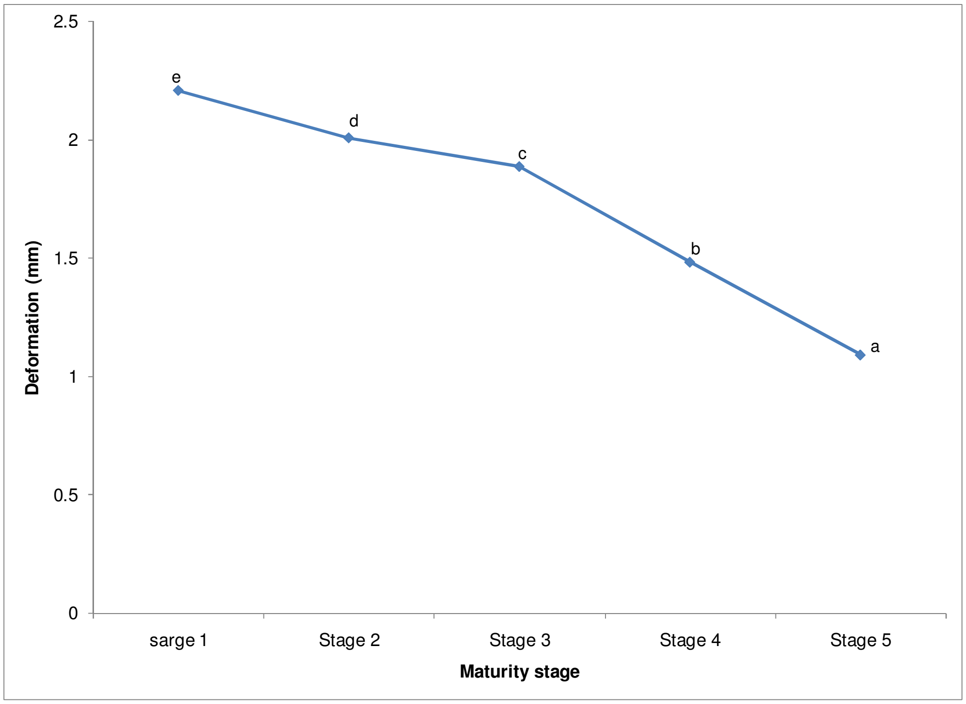

Figure 4: Relative deformation of okra seeds.

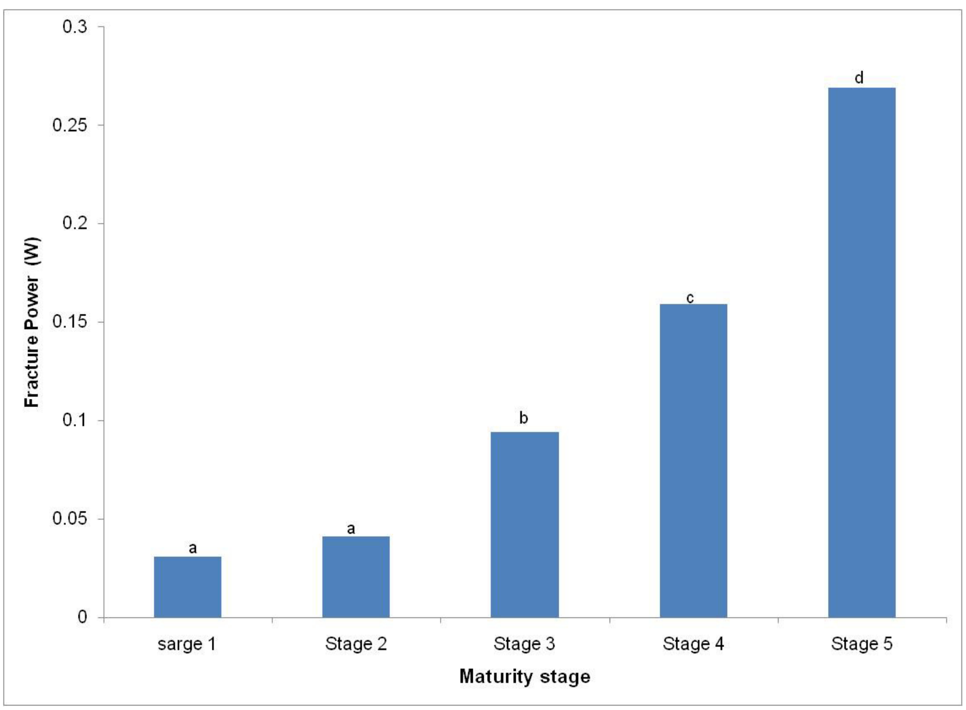

Figure 5: Fracture power of okra seeds.

These results are similar to those reported for plum fruits. According to Altuntas *et al.* (2013), the relative strain of plum fruits decreased from 28.13% to 16.84% as the fruits matured. Likewise, Eboibi *et al.* (2018) reported that deformation at rupture point of the cucumber fruit increased from 14.64 to 21.09 mm, as the moisture content of the cucumber fruits content increased from 72 to 87% (w.b).

The relative deformation highly influenced the adjustment and performance of crops processing and packaging equipment (Oghenerukevwe and Uguru, 2018). The regression relationship between the relative deformation and maturity stage of the okra seeds is presented in equation 5.

$$y = -0.275x + 2.563,\ R^2 = 0.952 \quad (5)$$

Correlation (r) = 0.971

Fracture power

The study revealed that the power require to fracture okra seeds was significantly ($p \leq 0.05$) influenced by the maturity period (Figure 5). The okra seeds harvested at 40 DAPA (stage 5) had the highest rupture power (0.269 W), compared to their counterparts harvested at other lower maturity stages (stages 1 to 4). Although, maturation of the okra seeds had significant ($p \leq 0.05$) effect on the power required to fracture the okra seeds. There was no significant difference between the required to fracture the okra seeds harvested at maturity stage 1, those harvested at maturity stage 2. Similar results were obtained by Altuntas *et al.* (2010) where the cracking power of almond (cv. *Nonpareil*), was observed to be of the ranged 0.20 and 0.73 W when loaded along the longitudinal orientation. The discrepancies in the fracture power of okra seeds used in this study, when compared to other results reported by previous authors. This could be attributed to the cellular structures of the different crops species used by the different authors and the maturity stages of the crops. Power is an essential factor to be considered during the design of machines; this is to avoid economic wastage and efficiency maximization. Regression relationship between the fracture power and the maturity stage of the okra seeds is presented in equation 6.

$$y = 0.059x - 0.059,\ R^2 = 0.915 \quad (6)$$

Correlation (r) = 0.956

Conclusion

The fracture resistances of okra (cv. *Kirikou*) seeds at different maturity stages were explored in this study. The results show a substantial difference of in these mechanical parameters (fracture force, fracture energy, deformation at fracture point and fracture power), as the seeds matured from stage 1 to stage 5. The fracture force increased linearly from 19.04 N to 84.147 N, as the seeds matured from stage 1 to stage 5. Fracture energy of 0.021 Nm was recorded at the 1^{st} maturity stage; which increased linearly to 0.088 Nm at the 5^{th} maturity stage. The maturity of okra seeds clearly influenced the relative deformation at fracture point, as the deformation decreased from 2.208 mm at the 1^{st} maturity stage to 1.091 mm at the 5^{th} maturity stage. The lower fracture force and fracture power of the younger okra seeds will lead to a low energy requirement during post-harvest unit operations. The results of this study will be useful in the design and construction of adequate equipment for okra seeds shelling, crushing and milling machines.

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