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Research Paper

Failure Behaviour of Okra (cv *Kirenf*) Pod during Maturation

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Failure bahaviour (failure force, failure energy, and relative deformation at failure) of *Kirenf* okra pod at maturation (maturity stages) was investigated, using the Universal Testing Machine in the study. Quasi static compression tests were done upon the okra pods in five maturity stages. Pods were harvested at 10 Days after Peak Flowering (DAP) at the first maturity stage (stage 1), while okra pods harvested at 14 DAP, 18, DAP, 22 DAP and 26 DAP were considered as (stages 2, 3, 4 and 5) respectively. Results obtained from this study showed that maturity stage had significant effect ($P \leq 0.05$) on all the parameters investigated. From the results, the failure force and failure energy increased as the maturation of the okra pods increased from stage 1 to stage 5; whilst the deformation at failure decreased with increased in maturation of the okra pods. The okra pod failure force increased from 35.4 to 124.2 N during the maturity period; while the failure energy increased from 0.056 to 0.313 Nm at the pods matured from stage 1 to stage 5. This research proved the significance of maturity stage of okra during the packaging of okra pods.

Keywords: *Kirenf* okra, failure behaviour, failure force, deformation, failure energy

INTRODUCTION

Okra (*Hibiscus esculentus*L.), which belongs to the Malvaceae family is widely cultivated in Africa and Asia countries (Oyelade *et al.,* 2003). Okra seeds have been used as coffee substitutes; edible oil can be extracted from dried seeds, while vegetable curds prepared from the dried seed have been used as substitutes for cheese in recipes (Ajav and Adejumo, 2005). The amino acid profile of the seed indicates that it could be used to complement other partially complete protein sources such as soybean (Bryant *et al*., 1998). The roots and stems of okra are used for clarification of sugarcane juice from which white or brown sugar is prepared (Chauhan, 1972). Okra is used daily in households in different forms (fresh pods, grains, powder) due to its organoleptic qualities and it is a good wealth supplier. However, degradation of fresh okra is enhanced by its very high-water content (Grubben and Denton, 2004; Yao Firmin *et al*., 2018). Fruits and vegetable which are generally harvested at juvenile stage of maturity are mainly used in the preparation of sauces that are prepared with either their fresh or dried parts (Pineau *et al.,* 2004).

Material failure is one of the major problems facing agricultural materials during storage, packaging and handling operations. During harvest and postharvest operations, fruits, seeds and pods go through several static and dynamic pressures, which usually resulted in bruises, crushes and cracks, thereby increasing their susceptibility to deterioration during storage (Bargale-Praveen *et al*., 1995; Altuntas *et al*., 2013; Uguru and Nyorere, 2019). Mechanical parameters are pre-requisite for the design and development of processing of okra pod. Inadequate engineering data such as rupture force, rupture energy, and deformation energy on indigenous crops have greatly retarded the development of indigenous technologies for the processing of most crops (Akani *et al*., 2010; Oghenerukevwe and Uguru, 2018). According to Ince *et al*. (2009) the mechanical property of agricultural materials under compressive load is a function of failure force, deformation, firmness and toughness of the material. Ekinci et al. (2010) examined the some mechanical properties (rupture force, bio yield force, deformation, modulus of elasticity and failure energy) of carob pod, in relation to moisture content. Nyorere and Uguru, (2018) studied the effect of seed size on the mechanical properties of gmelina seed, and reported that the average compressive force required to

rupture the seed was significantly lower in the small seeds (475.8 N) than in the large seed (711.9 N). Other works done by previous researchers include; engineering properties of cumin seed (Singh and Goswami, 1998), design and performance evaluation of okra thresher (Ajav and Adejumo, 2005), and compressive behaviour of groundnut kernel (Uguru and Iweka, 2019).

From literature review, information on the effect of maturation on the mechanical properties of okra pods, grown in Southern Nigeria is scanty. Therefore, the objective of this study was, to investigate the effect of maturation (stage 1 to stage 5) on the failure behaviour of *Kirenf* okra pod. The data obtained from this study will be helpful in designing storage and packaging systems for okra pods.

MATERIALS AND METHODS

Sample preparation

The *Kirenf* okra pods used for this study were harvested from the research farm of Delta State Polytechnic, Ozoro, Nigeria. They were harvested at five different maturity stages. After peak flowering, the okra pods were coded. The first harvest (stage 1) was done at 10 Days after Peak Flowering (DAP), while 14 DAP, 18, DAP, 22 DAP and 26 DAP were considered as Stage 2, 3, 4 and 5 respectively. All the harvested pods were cleaned manually inspected to remove all pest infested and damaged pods.

Mechanical properties determination

The mechanical properties (failure force and failure energy) of the okra pods were tested using Universal Testing Machine (Testometric model), equipped with a 50 N compression load cell and controlled by a micro-processor.

During the quasi compressive test, each okra pod (sample) was loaded in axial orientation (horizontal position) between the loading cells, and compressed at a loading speed of 25 mm/min until rupture point, as recommended by (Oghenerukevwe and Uguru, 2018). At the end of each test, the failure force and failure energy of each okra pod were calculated automatically by micro-processor of machine and displayed on the screen. At each maturity stage, ten okra pods were tested and the average value recorded for data analysis.

According to Steffe, (1996), bioyield point (also expressed as the failure) of a material is related to a failure in its microstructure, and it is associated with an initial disruption of cellular structure.

At failure point, an increased in deformation resulted either a decrease or no change in force (Mohsenin, 1986; Oghenerukevwe and Uguru, 2018).

Statistical analysis

The results of the failure behaviour recorded from this study were subjected to analysis of variance (ANOVA) to evaluate a statistical significance of observed differences among treatment means at using SPSS 20.0 software (IBM Corporation, USA). Duncan's Multiple Range Test (DMRT) was used to compare the mean at ($P \leq 0.05$). Regression analysis was performed on the results using Microsoft Excel 2016 software.

RESULTS AND DISCUSSION

The analysis of variance (ANOVA) of the failure behaviour of the *Kirenf* okra pod is presented in (Table 1). As shown in (Table 1), maturity stage significantly influenced ($P \leq 0.05$) in all the three mechanical parameters (failure force, failure energy and deformation at failure point). The regression relationships existing between maturity stage of the okra pod and the failure parameters can be expressed using polynomial equations of the first order, as shown in equation 1. The high correlation values ($r \geq \pm 0.90$) (Table 2) indicates strong relationship between maturation and the mechanical parameters tested for in the okra pods.

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

Where:
y = Mechanical parameter
a, b= regression coefficients
x = maturity stage

Failure force

The results of the effect of maturity stage on the failure force of *Kirenf* okra pod are resented in (Figure 1). From (Figure 1), the failure force of the pods increased with increase in the maturation of the pods. From the results, no significant difference occurred in the failure force of the okra pod between stage 1 and stage 2, and between stage 4 and stage 5. The results further showed that *Kirenf* okra pods harvested at younger stages (1 and 2) were not able to withstand much compressive force before failure. Failed okra pod does not stored well, loss its viability, susceptible to disease attack, and declined in its nutritional value (Uguru and Nyorere, 2019). 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 (Kuna-Broniowska *et al*., 2012).

Failure Energy

Figure 2 shows the Failure energy of the *Kirenf* okra pod was significantly ($P \leq 0.05$) influenced by the maturity

Table1 . Analysis of variance (ANOVA) of effect of maturity stage on the Mechanical Parameters of Intact *Kirenf* Okra Pod.

Source of variation	Dependent variable	Sig.
Maturity stage	Failure force	5.38E-08*
	Failure energy	6.31E-08*
	Deformation at failure	4.65E-08*

* =Significant at (P ≤0.05).

Table 2. Regression relationships between mechanical parameters and maturity stage of *Kirenf* okra pod.

Parameter	Linear equation	R^2	r
Failure force	y = 25.09 x + 5.43	0.938	0.968
Failure Energy	y = 0.068 x - 0.009	0.960	0.979
Deformation at failure	y = -0.861 x + 7.463	0.924	-0.961

R^2 = coefficient of determination, r = correlation, x maturity stage.

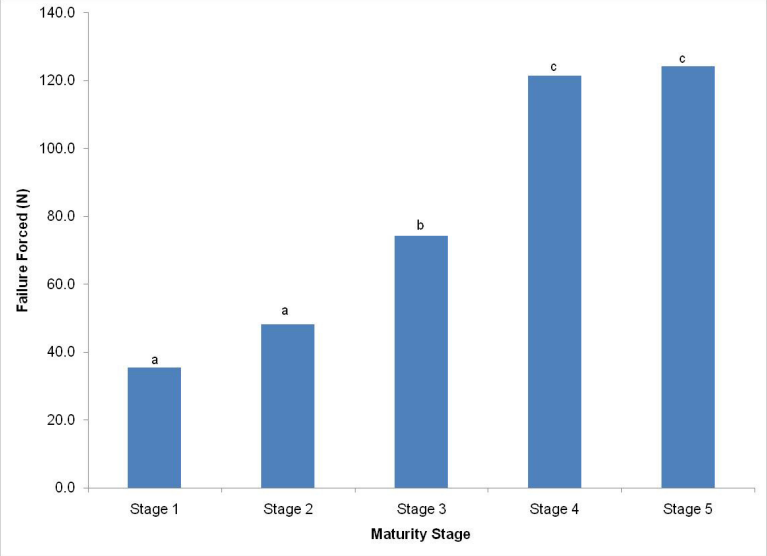

Figure 1. Effect of maturity stage on the failure force of *Kirenf* okra pod. Columns with the same common letters means that they are not significant different at (P ≤0.05).

stage. The Failure energy increased from 0.056 Nm to 0.313 Nm (82.17% increment) as the pod matured from stage 1 to stage 5, but significant difference was observed between maturity stages 1, 2 and 3. From the results, there was drastic increased in the failure energy between stage 3 and 4, signifying significant intercellular structure development of the okra pod within these stages. The regression equations presented in (Table 2) shows that failure energy is highly dependent on the maturation of the okra pod.

Deformation at failure

The effect of maturity stage on the deformation at rupture of the *Kirenf* okra pod is shown in (Figure 3). As seen in (Figure 3), the deformation at failure point of the okra pod was highly dependent on the maturation of the okra pod, as the deformation values decreased with increase in the maturity stages. The decreased in the relative deformation of the pod as maturation increase from stage 1 to stage 5, could be attributed to the declining moisture content of the okra pods during maturity. Fruits and pods are more flexible at higher moisture content, than in lower moisture content. Deformation of biological material is dependent on the structure of biological material and its cells' pores (Persson, 1987), and its resistance to deformation under applied forces (Kang *et al*., 1995). This research proved the significance of maturity stage of okra pod with their packaging system. Okra pods met for

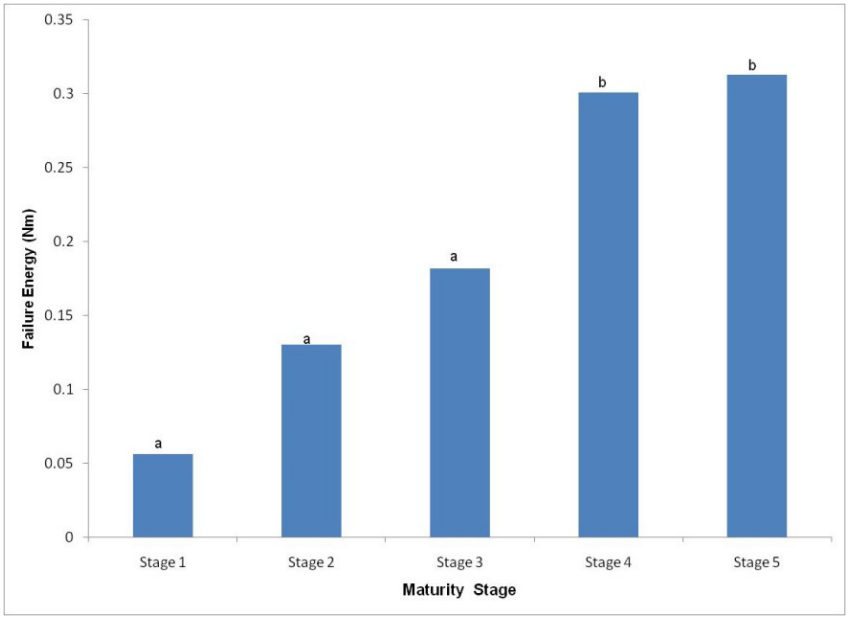

Figure 2. Effect of maturity stage on the failure energy of *Kirenf* okra pod. Columns with the same common letters means that they are not significant different at (P ≤0.05).

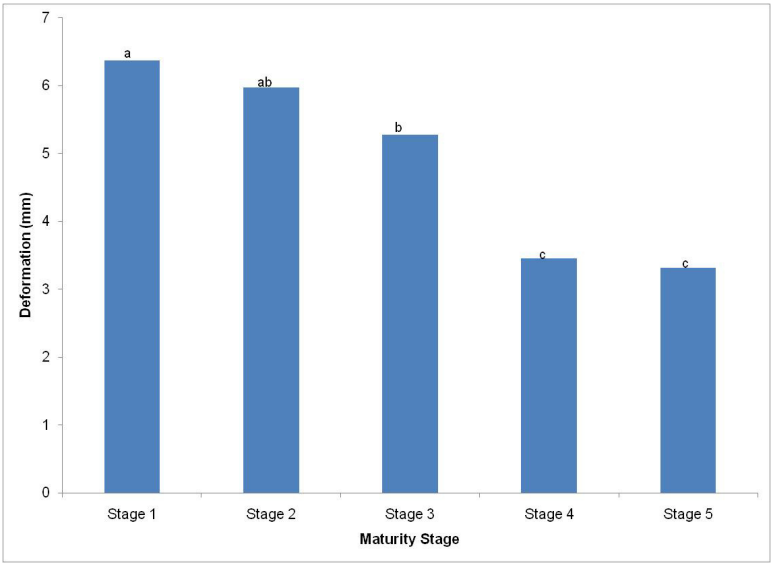

Figure 3. Effect of maturity stage on the deformation at failure of *Kirenf* okra pod. Columns with the same common letters means that they are not significant different at (P ≤0.05).

cooking are usually harvested at the earlier stages, while those met for planting and other industrial applications are harvested at the later stage. This is because okra pods harvested at late maturity stages (4 and 5) will be less susceptibility to failure losses during the harvest, post-harvest and handling operations.

Conclusion

The results of the study shown that the failure behaviour of *Kirenf* okra pod had strong relationship with its maturity stage. The result of analysis of variance (ANOVA) shows that maturity stage had significant (P ≤ 0.05) effect on the

mechanical parameters (failure forced, failure energy, and deformation at failure) of the *Kirenf* okra pod. The results showed that failure force and failure energy of the okra pod increased with increase in the maturity stage. The Failure energy increased from 0.056 Nm to 0.313 Nm; while the failure force increased from 35.4 to 124.2 N over the course of maturity. The deformation at failure of the pod decreased with increasing maturity of the pod. This research proved the significance of maturity stage of okra which their containerization, because okra pods harvested at late maturity stages (4 and 5) will be less susceptibility to failure losses during the harvest, post-harvest and handling operations.

Authors` Declaration

We declare that this study is an original research by our research team and we agree to publish it in the journal.

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