Effect of Moisture Content on Strength Properties of Okra Pod (Cv Kirenf) Necessary for Machine Design

1Oghenerukevwe Prosper and 2Mr. Hilary Uguru*
1Department of Mechanical Engineering, Delta state polytechnic, Ozoro, Nigeria.
2Department of Agricultural and Bio-Environmental Engineering, Delta state polytechnic, Ozoro, Nigeria.

Abstract

In this study, compression tests were carried out on okra pods (cv Kirenf) to investigate the effect of moisture content on seven mechanical parameters (failure force, failure energy, failure strain, maximum compressive force, rupture force, rupture energy and deformation at the point of rupture). The tests were carried out at a deformation rate of 25 mm/min and five moisture content levels of 37.04, 44.20, 50.18, 56.19, and 61.06% (w.b), using the Testometric Universal Testing Machine (Testometric model, series 500-532). The results show that moisture content had significant (P≤ 0.05) effects on all the measured mechanical parameters. Failure force, failure energy, maximum compressive force, rupture force and rupture energy decreased while failure strain and deformation at rupture increased with increases in moisture content. Force and energy required to initiate the okra pod failure decreased by 58.52 and 61.57% respectively; the maximum compressive force decreased by 61.47%; while force and energy and deformation required to initiate the okra pod rupture decreased by 61.37 and 66.37% respectively; whereas, failure strain and deformation at rupture increased by 28.72 and 40.57% respectively. The results provide useful data to be used by engineers in the design and development of suitable okra pod thresher and slicer.

Keywords — Moisture content, okra pod, compressive force, mechanical properties

I. INTRODUCTION

Okra (Hibiscus esculentus L.), a tropical to subtropical plant that is widely distributed from Africa to Asia, Southern European and America, and belongs to the family Malvaceae[1]. The seeds of okra have been used as coffee substitutes and edible oil also has been extracted from dried okra seeds. Vegetable curds prepared from the dried seed have been used as substitutes for cheese in recipes[2]. The amino acid profile of the seed indicates that it could be used to complement other partially complete protein sources such as soybean [3].

Okra fiber are used as reinforced polymer (RP) materials, which are composites consisting of fibers embedded in polymer matrices. These materials are suitable for a large number of diverse applications ranging from aerospace to sporting equipment [4]. The seeds of mature pods are sometimes used for chicken feed and have been used on a small scale for the production of oil [1]; [5]. The roots and stems of okra are used for clarification of sugarcane juice from which white or brown sugar is prepared [6]. The traditional methods of threshing dry okra pods involve manual rupturing of the pods and the separation of the seed from the chaff. Process is tedious and time consuming; it also results in losses as well as low quality product [2]. The development of a mechanical okra thresher with winnowing system would, therefore, drastically reduce the drudgery of the manual shelling of okra pod to obtain the unbroken seeds.

The mechanical properties of biomaterials are important in the designing of machines for grinding, harvesting, cleaning and separation of okra pods and seeds. Mechanical properties data are useful in the analysis and determination of the efficiency of a machine or an operation, development of new products and new equipment and final quality of new products [7]; [8]. The moisture content of agro materials has been reported to have influence on the adjustment and performance of processing equipment [9]. As a result, the determination of the moisture content at which okra pods could be shelled with a combination of high whole seed yield and minimum seed damage is necessary, as it would be of important consideration in the design of the okra pod thresher and slicer.

Mechanical parameters are pre-requisite for the design and development of processing of okra pod. In recent years, mechanical properties have been studied for various crops such as cumin seed [10], macadamia nut [11] and shea nut [12]. According to [13] 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. Reference [14] examined the rupture force, bio yield force, deformation, modulus of elasticity and failure energy in examination of effects of moisture content and loading on mechanical properties of carob pod.
Published literature on the mechanical properties of okra pod as a function of moisture content is scanty. Therefore, the objective of this study was, therefore, to investigate the effect of moisture content on the selected mechanical properties of okra pod, which will provide important data needed in the design and development of okra pod threshing and slicing machines.

II. MATERIALS AND METHODS

A. Sample Preparation

The okra pods, cultivar 'Kirenf,' used for this research were collected from the research farm of National Centre for Agricultural Mechanization (NCAM), Ilorin, Kwara state, Nigeria. They were manually cleaned to remove all foreign materials such as dust, premature and damaged pods.

B. Moisture Content Determination

The moisture content of the okra pod was determined by using the microwave oven-drying method. A sample of the okra pod (5 g) was kept in a microwave oven (Samsung microwave oven model CE118 KF), and set at 270 W power level, as recommended by [15]. Moisture loss was measured after every 5 minutes, until stable weight is obtained. The sample was weighed again at the end of the period to determine its final weight. The experiments were replicated 5 times, and the average recorded.

C. Moisture Conditioning of the Fruit

The conditioning of okra pods to different moisture levels was carried out using the method described by [16]. This involved the reduction of moisture by sun drying the fruits for different periods of time. The pods were subjected to sun-drying (temperature) 30 ±5°C by exposing them to the sunlight. After every 24 hours, a sample was taken from the pods and stored in a polyethylene bag for 20 hours to attain uniform moisture content [17]. The sun-drying exercise lasted for 96 hours and five samples at different moisture levels were obtained. The initial moisture content (Mc) of the pods, at harvest, was found to be 61.06% w.b. (wet basis)

D. Determination of the Mechanical Properties of the Okra Pod

The seven mechanical parameters (failure forced, failure energy, maximum compressive force, rupture force, rupture energy and deformation at rupture) of the okra pod were evaluated at five different moisture content levels (37.04, 44.20, 50.18, 56.19, and 61.06% (w.b.)), by using the Universal Testing Machine (UTM) (Testometric model, series 500-532), equipped with a 50 N compression load cell and controlled by a micro-processor. Individual sample (okra pod) was placed between two parallel plates, and compressed at a compressive speed of 25 mm/min. Test results and force-deformation curves were automatically generated by the UTM., until the curve arrived to rupture point (point A in Figure 1), where the machine stops automatically.

According to [18], bioyield point is related to a failure in the microstructure of the material associated with an initial disruption of cellular structure; and the rupture point of the material which correlates to the macroscopic failure (breaking point) in the sample, the failure strength was taken as the stress at which the sample failed in its internal cellular structure. The failure point was taken as the point on the force-deformation curve at which the compressed fruit weakened and failed internally. At this point, an increase in deformation resulted from either a decrease or no change in force, and the fruit could be said to have failed in its internal cellular structure [7]; [19]; [20]. Rupture point was the point on the force-deformation curve at which the pod completely became ruptured and deformation resulted from a decrease in force [7]; [19]. Rupture force is the minimum force needed to crack the individual okra pod. If the compression exceeds the rupture strength of the material, it will lead to cracks or breakage. The compression test was replicated ten times for each moisture content level, and the mean of each parameter obtained was recorded.

E. Statistical Analysis

Ten replicas were taken for all the experiments, and average values are reported. The results of the seven mechanical parameters (failure forced, failure energy, maximum compressive force, rupture force, rupture energy and deformation at rupture) were subjected to analysis of variance (ANOVA) to evaluate a statistical significance of observed differences among treatment means at (p ≤ 0.05) using SPSS 20.0 software (IBM Corporation, USA), while regression analysis was performed using Microsoft Excel 2016 software.

III RESULTS AND DISCUSSIONS

Table 1 gives the results of analysis of variance (ANOVA) for the effect of moisture on the mechanical parameters (failure forced, failure energy, maximum compressive force, rupture force, rupture
energy and deformation at rupture) of Kirenf cultivar of okra pod. As depicted from Table 1, moisture content significantly (P<0.05) affect all the seven mechanical properties of the okra pod. Also, the regression relationships existing between the parameters and moisture content can also be expressed using polynomial equations of the first and second order, in the following forms:

\[ y = a + bx \]  
\[ y = a + bx + cx^2 \]

(1)
(2)

Where:
- \( y \) = Mechanical parameter
- \( a, b, c \) = regression coefficients
- \( x \) = moisture content (% w.b.)

The coefficients term in the equations and p-value for each parameter presented are in Table 2. The high coefficient of determination values (\( R^2 \)) ≥ 0.96) (Table 2) couple with the p-value indicates that the plots described the data points reasonably, and there is strong relationship between moisture levels and the mechanical properties tested in the okra pods. The regression equation results suggest that the mechanical properties of a Kirenf okra pod can be predicted using either the linear or polynomial equations.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Linear equation</th>
<th>( R^2 )</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Failure force</td>
<td>( y = -24.703x + 182.62 )</td>
<td>0.973</td>
<td></td>
</tr>
<tr>
<td>Failure energy</td>
<td>( y = -0.0705x + 0.4899 )</td>
<td>0.962</td>
<td></td>
</tr>
<tr>
<td>Failure strain</td>
<td>( y = 4.91x + 17.278 )</td>
<td>0.985</td>
<td></td>
</tr>
<tr>
<td>( F_{\text{max}} )</td>
<td>( y = -26.969x + 197.04 )</td>
<td>0.992</td>
<td></td>
</tr>
<tr>
<td>Rupture force</td>
<td>( y = -4.4461x + 335.08 )</td>
<td>0.993</td>
<td></td>
</tr>
<tr>
<td>Rupture energy</td>
<td>( y = -0.0861x + 0.5868 )</td>
<td>0.989</td>
<td></td>
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<tr>
<td>Def at Rupture</td>
<td>( y = 1.133x + 5.023 )</td>
<td>0.990</td>
<td></td>
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</table>

Table 2 Continue

<table>
<thead>
<tr>
<th>Parameter</th>
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<tr>
<td>Failure force</td>
<td>( y = 1.485x^2 - 33.613 )</td>
<td>0.977</td>
<td>0.001265</td>
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<tr>
<td>Failure energy</td>
<td>( y = 0.0051x^2 - 0.1009 )</td>
<td>0.969</td>
<td>0.002267</td>
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<td>Rupture force</td>
<td>( y = -0.4714x^2 + 0.999 )</td>
<td>0.999</td>
<td>0.000127</td>
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<td>Rupture energy</td>
<td>( y = 7.7386x + 13.98 )</td>
<td>0.994</td>
<td>0.000156</td>
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<tr>
<td>Def at Rupture</td>
<td>( y = 0.9279x^2 - 32.536 )</td>
<td>0.990</td>
<td>0.000274</td>
</tr>
<tr>
<td>Rupture force (( x + 203.53 ))</td>
<td>( y = 0.0029x^2 - 0.1033 )</td>
<td>0.990</td>
<td>0.000524</td>
</tr>
<tr>
<td>Rupture energy (( x + 0.6069 ))</td>
<td>( y = 0.0164x^2 + 1.0344 )</td>
<td>0.990</td>
<td>0.000482</td>
</tr>
</tbody>
</table>

The detail effect of the moisture content on the mechanical parameters studied are presented below.

A. Failure Force

The result of the statistical analysis on the effect of moisture on the failure force was significant (P < 0.05), as shown in Table 1. As shown in Figure 2, the force required to initiate okra pod failure was significantly higher at lower moisture content level and decreased monotonically from 158.87 to 65.89 N (58.52% decreased), as the moisture content increased from 34.02 to 61 % (wb). This might be due to the fact that at higher moisture content, the okra pod became softer and required lesser force to fail. Also from the result, the okra pod tends to be more ductile, with increased in moisture content. This result was supported with the findings by [21] on chicken pea seeds.

Figure 2: Correlation between failure force and moisture content of okra pod.
B. Failure Energy

According to the ANOVA table (Table 1), the Failure energy of the Kirenf okra pod was significantly (P≤ 0.05) influenced by the moisture content level. The failure energy decreased from 0.419 to 0.161 Nm (61.57% decreased) as the moisture content increased from 37.04 to 61.06% w.b. as shown in Figure 3. Regression equations and p-value for failure energy with variations with the moisture level presented in Table 2, shows that failure energy is highly dependent on moisture content of the pod. The implication of the above result is that the energy needed in compression to initiate failure of the pod’s intercellular structure is significantly dependent on the moisture content of the fruit. Our result is in good agreement with previous researcher [22] for cowpea.

C. Failure Strain

The result of the statistical analysis on the effect of moisture on the failure strain was significant at (P < 0.05). The deformation of the pod increased as the moisture content increases from 34.04 to 61.06 % wb (Figure 4), increasing from 43.63% to 61.21% (28.72% increased). According to [23], as the moisture content of fruit increases, the maximum compressive force decreased but its position on force–displacement curve increased so the slope of stress–strain curve decreased for this reason the stress decreased and the strain in creased by time passing. A similar trend was observed by [24] in determining physical and mechanical properties of hazelnut and its seed, who observed increasing deformation with increased in moisture content.

D. Maximum Compressive Force (Fmax)

The measured Maximum compressive force from different moisture content was plotted in Figure 5. As shown in Figure 5, increasing the pod moisture content from 34.04% to 61.06%, decreased the pod Maximum compressive force from 171.47 to 65.89 N (61.57% decreased). The decrease in maximum compressive force can be attributed to the okra pod becoming softer at increased moisture levels. Similar finding was reported by [8] for wheat and [25] for cumin seed.

E. Rupture Force

It can be observed from the ANOVA table (Table 1) that the force required to initiate seed rupture decreased significantly (P < 0.05) as the moisture content increased from 37.04 to 61.06% w.b. The rupture force was found to increase from 65.35 to 169.18 N (61.37% increases), as the moisture content decreased from 61 to 37 % w.b. (Figure 6). The decrease in the rupture force with moisture content may be attributed to a decrease in the strength of the seed at higher moisture contents. The trend of the
result is in agreement with the report of [26] for lentil seed, and [27] for pine nut. Reference [28] conducted a research on the effects of moisture content on some physical and mechanical properties of faba bean (Viciafaba L.), reported that as the moisture content increased from 9.89% to 25.08%, the rupture force values ranged from 314.17 N to 185.10 N. The relationship between moisture content and rupture force is presented in the regression equations in Table 2.

\[ \text{Deformation at Rupture} \]

\[ \text{Rupture Force} \]

\[ \text{Rupture Energy} \]

\[ \text{Moisture Content} \]

\[ \text{Table 1: Correlation between failure strain and moisture content of okra pod.} \]

\[ \text{Figure 6: Correlation between failure strain and moisture content of okra pod.} \]

G. Deformation at Rupture

The deformation at rupture was significantly (P ≤ 0.05) affected by the moisture content if the okra pod (Table 1). The deformation of okra pod at the rupture point as a function of moisture content is presented in Figure 8, which slowly increased from 6.31 to 10.62 mm (40.57% increased) as the moisture content increased from 37.04 to 61.06% w.b. Reference [29] studied the force required to cause deformation and subsequent rupture in pumpkin seed, and reported that the hull breaking load varied from 30 to 50 N for dry seeds and 14 to 36 N for wet seeds, following quasi-static compression with horizontal and vertical orientations of the seed. In addition, our result is similar to the results obtained for barberry by [30], where the deformation at rupture increased as the moisture content increased from 53.11 to 89.23% w.b. This could be attributed to the viscoelastic property of the okra pod which causes higher deformation of the fruit under compression, at lower moisture level. Rupture deformation changes based on the properties of biological materials. It depends on structure of biological material and cells’ pores [31]. Hardness is the resistance of the individual pod to deformation under applied forces [8]. The regressive relationship between moisture content and deformation at rupture of the okra pod is presented in Table 2.

\[ \text{Figure 7: Effect of moisture content on the rupture energy of okra pod.} \]

IV CONCLUSIONS

In conclusion, the strength properties of the okra pod had strong relationship with moisture content. okra pods at low moisture content conditions are less susceptibility to breakage losses during the post-handling and processing operations. The results of analysis of variance (ANOVA) shows that moisture content had significant (P ≤ 0.05) effect on the mechanical parameters (failure force, failure energy, maximum compressive force, rupture force, rupture energy and deformation at rupture) of Kirenf cultivar of okra pod.
The deformation at pod rupture increased with increasing moisture content. The force and energy required to initiate the okra pod failure decreased by 58.52 and 61.57% respectively; the maximum compressive force decreased by 61.47%; while force and energy and deformation required to initiate the okra pod rupture decreased by 28.72 and 40.57% respectively. The results gotten from this research will provide useful data for mechanical engineers in the design and development of suitable okra pod thresher and slicer.

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