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Full Length Research Paper

Studies on the Physico-mechanical Properties of Okra (*Abelmoschus esculentus* L) Pods, in Relation to its Automated Harvesting

[1]Edafeadhe, G. O. I., and *[2]Uguru, H.

[1]Department of Mechanical Engineering Technology, Delta State Polytechnic, Otefe Oghara, Nigeria.
[2]Department of Agricultural and Bio-environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria.
*Corresponding Author E-mail: erobo2011@gmail.com

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ABSTRACT: This study evaluated the effect of farming method (organic and inorganic), on some physical characteristics and mechanical properties of okra pod. Two commonly cultivated okra varieties (Kirikou and Clemson) in Nigeria were used for this study. The two okra varieties were cultivated both under the organic and inorganic farming method. Under the organic farming, the soil was treated with organic manure at the rate of 2,000 kg/ha; while under the inorganic farming method, the soil was treated with NPK 15:15:15 fertilizer, at the rate of 200 kg/ha. The okra pods were harvested at the mature green maturity stage, and their physical characteristics and mechanical properties tested. The mechanical properties of the okra pods were determined through compression and shear tests, using standard recommended procedures. Results obtained revealed that the soil treatment significantly ($p \leq 0.05$) affected the physical characteristics and mechanical properties of the okra pods. Irrespective of the okra variety, the okra cultivated with organic manure recorded highest physical characteristics values; when compared with the okra cultivated with NPK 15:15:15 fertilizer and the control okra pod. Furthermore, the study revealed that the okra pod cultivated with organic manure recorded higher failure force and failure energy, when compared with the compared with the okra pods cultivated with NPK 15:15:15 fertilizer and the control okra pods. Regardless of the okra variety, the maximum shear force and energy were recorded in the control okra pod stalk; while the shear force and energy of the Kirikou okra pod was higher than the values obtained in the Clemson okra pod. Results obtained from this study will be useful in the design and optimization of automated okra pods harvesting and handling machines.

Keywords: Automated, Clemson, compression test, harvesting machine, okra pod, shear test

INTRODUCTION

Okra (*Abelmoschus esculentus* L.) is one of the most cultivated crops in Nigeria, and most parts of Africa and Asia countries. According to Food and Agricultural Organization (FAO), India is the leading okra producer (6.12 million tons), followed by Nigeria (2.04 million tons) out of the 9.87 million tons of okra produced globally in 2018 (FAOSTAT, 2018). Okra plant has strong tolerant to both acidic and alkali soil; and it is among the drought-tolerant crops cultivated globally (Bakre and Jaiyeoba, 2009). Its leaves and pods have a lot of nutritional, medicinal and industrial uses. Okra pod contains important compounds such as, D-galactose, L-rhamnose and L galacturonic acid (Agarwal *et al*., 2001). According to Zaharuddin *et al*. (2014) okra pods contain essential

polysaccharides which are useful both in the pharmaceutical and food processing industries. Apart from the nutritional and medicinal values of okra pod, it still has a lot of industrial applications. According to Jatav *et al*. (2016), okra is a natural coagulant, which can use for surface water treatment. Anastasakis *et al*. (2009) reported that okra mucilage has flocculation properties, and can be effectively used as wastewater treatment. According to Chadda, (2010) and Badgujar *et al*. (2018), okra seeds contain 13-22% oil, depending on the variety, which is used in the soap and industries.

Increasing demand for food, due to the world growing population, has directed engineers' interest in producing automated agricultural machines, which can replace human labour and other obsolete farm machines. Full mechanization crops' pre-harvest, harvest, and post-harvest operations is faced with many hurdles, due to the unique nature of agricultural materials. Material damage is one of the challenges facing mechanical harvesting of fruits, pod, roots and vegetables. This is because during mechanized harvesting of fruits, pods, seeds, etc., they are subjected to compression and tensile forces. These forces, if not well managed, can lead to bruises, punctures and cracks of the harvested product; thereby, increasing its susceptibility to spoilage during storage, and loss of nutritional values (Altuntas *et al*., 2013; Uguru and Nyorere, 2019). Therefore, physical characteristics such as; weight, density, volume and projected area, are key factors during the design of okra pod sorting, grading and transporting machines. Akani *et al*. (2010) stated that the knowledge of the mechanical properties of fruits/pods and vegetables is vital in the design and application of their harvesting and handling machines. According to Zhang *et al*. (2016), mechanical properties of agricultural products are key parameters to be considered, during the design and application of machines used for their harvesting and processing unit operations.

In the past two decades, scientists have intensified their efforts in investigating the engineering properties of agricultural materials. Ince *et al*. (2009) studied the mechanical properties (mean rupture force, deformation, firmness and toughness) of groundnut kernel, and observed that the mechanical properties were a function of the kernels' moisture content. Oghenerukewve and Uguru (2018) investigated the significant of moisture content, during the design and application of okra (cv. kirenf) processing and packaging machines. Badgujar *et al*. (2018) studied some engineering properties of two Iranian okra varieties (Pusa A4 and Punjab-8), which can be used during the design, construction, programming and application of okra harvesting and processing machines. Furthermore, Hazbavi (2013) investigated some physico-mechanical properties of another Iranian okra seeds, and observed that all the parameters (seed length, width, thickness, geometric diameter, mass, volume, surface area, sphericity and rupture force) were highly influenced by the seeds' moisture content. Some physical characteristics of okra (cv. Varsha Uphar) seeds were studied by Kumar *et al*. (2018a); and observed that the seeds bulk density of okra seed varied between 510 kg/m^3 and 570 kg/m^3, while the seeds length, width, thickness and geometrical diameter were 5.73 mm, 4.83 mm, 4.49 mm and 4.98 mm respectively. In addition, Kumar *et al*. (2018b) used some physico-mechanical properties of okra seeds to design and construct an okra planting machine, with total field efficiency of 86.79%.

Results (engineering data) obtained from okra cultivated in Asia countries, cannot be effectively used in the design, construction, programming and application of harvesting machines for Nigeria grown okra pods. This is because, differences in the farming methods, soil type, okra varieties and climatic conditions, greatly influenced the engineering properties of agricultural products (Eboibi *et al*., 2019). In addition Iweka and Uguru (2019) stated that environmental conditions and harvesting period, significantly affected the physical properties of okra (cv. Kirikou) seeds and pods. Although, some researchers have studied the engineering properties of some Nigeria grown okra varieties; none had worked on the effect of farming method on the physic-mechanical properties of okra pod. Therefore, the objective of this study was to investigate the effect of farming method (organic and inorganic) on the physical characteristics and mechanical properties of pod, harvested from two okra varieties (*Clemson* and *Kirikou*). The data obtain will be useful in the design and programming of automated okra harvesting and handling machines.

MATERIALS AND METHODS

Okra seeds

The study was carried out using two okra varieties; one local variety (*Kirikou*) and one hybrid variety (*Clemson* spinelsss 80). The two okra varieties seeds were obtained from the seeds centre of the Department of Agricultural and Bio-Environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria.

Organic manure

The organic manure used for this study was formulated from the combination of cattle dungs, pig dungs and poultry waste, mixed at the ratio of 5:3:2 (by weight). Passive aerated static composting method was used to produce the organic manure.

Methods

Experimental design

The randomized complete block design (RCBD)

experimental design with three replications was adopted for this study. The treatments for each okra variety included the control sample (0 kg fertilizer or organic manure); the organic manure was applied at the rate of 2,000 kg/ha; and the NPK 15:15:15 fertilizer was applied at the rate of 200 kg/ha. Each of the experimental plot measured 3 m x 2 m (6 m^2), and 1 m apart. The organic manure was uniformly incorporated into the soil, three week before the planting of the okra seeds; while the fertilizer was incorporated into the soil, one week before planting of the okra seeds. Other variables such as; irrigation, temperature, pests control, rain etc., were the same across for all the treatments during the okra growing period.

Samples collections and preparation

The okra pods were harvested for this study at the manure green maturity stage (Figure 1a). This is the maturity stage that okra pod are usually harvested for human consumption and medicinal uses. The harvested okra pods were inspected to remove deformed and pest infested pods, before they were immediately taken to the laboratory for physical and mechanical tests.

Figure 1a: A mature green *Kirikou* okra pod

Physical characteristics determination

Dimensional parameters

An electronic digital caliper, with an accuracy of 0.001 mm was used to measure the dimensional parameters (Length "L", Width "W", and Thickness "T") of the okra pods

Geometrical parameters

The aspect ratio (R_a), geometric mean diameter (Dg), surface area (S), projected area (P_a), volume (V), and sphericity (φ) of the okra pod were calculated using Equations 1 to 5. (Mohsenin, 1986).

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

$$surface\ area\ (S) = \pi D_g^2 \quad (2)$$

$$Projected\ area = \frac{\pi LW}{4} \quad (3)$$

$$\text{sphericity } (\varphi) = \frac{D_g}{L} \times 100 \quad (4)$$

$$R_a = \frac{W}{L} \quad (5)$$

The water displacement method was used to determine the volume of the okra pods, due to the shape of an okra pod.

Gravimetric parameters

Okra pod mass

The okra pod mass was measured with an electronic digital weighing balance, with an accuracy of 0.001 g.

Fruit density

Then the density (ρ) of the tomato fruit was determined by using the formula shown in Equation 6 (Mohsenin, 1986).

$$\rho = \frac{M}{V} \quad (6)$$

Mechanical parameters determination

All the mechanical tests were done at the material testing laboratory of the National Center for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria. In order to fully apply this study result into the design, programming and application of okra pods; two major tests were done on the okra pods. These were (i) Compression test of the intact pod itself, and (ii) the shear test on the pod stalk.

Compression test

The Universal Testing Machine (UTM), having an accuracy of 0.001 N, and equipped with 500 N loading

cell was used to determine the compression parameter (failure force, failure energy and deformation at failure point) of the okra pod. During the test each okra pod was loaded along the longitudinal axis, at a compression speed of 15 mm/min until okra pod ruptured. As the loading progresses before the rupture point, the failure force, failure energy and deformation at rupture point of the pod were determined automatically, by the micro-processor attached to the machine and displayed a screen. According to Steffe (1996), rupture failure point (also expressed as the yield point) of an agricultural material correlates to its microstructural failure point.

Shear test

This test was done only on the okra stalk, as shown in (Figure 1b). The Warnere Bratzler device attached to the Universal Testing Machine was used for the shear test. A 30^0 V-notch stainless steel, with 1 mm thickness, was used to shear the stalk into two parts, at a speed 1 mm/s. The test was done according to DIN 53294:1982 standard recommendations. At the end of each test, the shear force and energy are calculated electronically by the UTM and displayed on a screen.

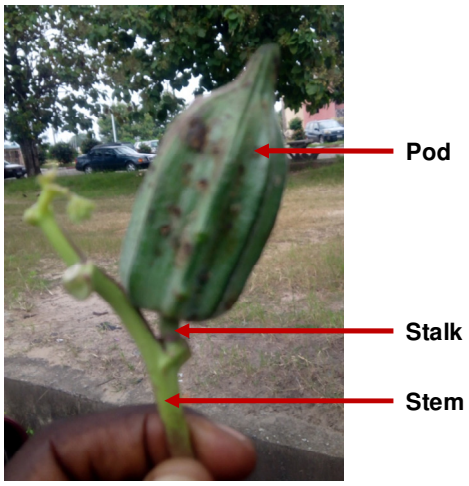

Figure 1b: A section of an okra showing the parts (pod, stalk and stem).

Statistical analysis

The results obtained from this study were subjected to analysis of variance (ANOVA) to using SPSS 20.0 software (IBM Corporation, USA), to determine if farming method have significant effects on the physico-mechanical properties of okra pods. Then Duncan's Multiple Range Test (DMRT) was used to separate and compare the mean at 95% confidence level.

RESULTS AND DISCUSSION

The results of the study presented in (Table 1), portrayed that farming method had significant ($p \leq 0.05$) effect, on all the physical characteristics on the pods of the two okra varieties investigated. As shown in (Table 1), the control pod had the lowest pod mass, length, width, thickness, surface area, projected area, volume, sphericity, density, but the highest aspect ratio values. Likewise, the organic okra pods recorded the highest pod mass, length, width, thickness, surface area, projected area, volume, sphericity, density, but the lowest aspect ratio values. Although, farming method significantly ($p \leq 0.05$) affected the physical characteristics of the pods, there was no significant differences existed between the mass, length, width, thickness, geometrical mean diameter, surface area, and projected area of the pods harvested from the control experiment and the pods harvested from the okra planted with NPK 15:15:15 fertilizer. In addition, it was observed in the study, that the most of the physical characteristics of the okra pods were significantly ($p \leq 0.05$) affected by the okra variety. Generally, it can be seen that physical parameters of the *Clemson* okra pods were significantly higher that the *Kirikou* okra pods. The length of the control *Clemson* okra pod was 162.14 mm, which was higher than the length of 80.97 mm recorded by the control *Kirikou* okra pod. Likewise, the width, mass, and surface area of the Clemson okra pod were 29.16 mm, 34.02 g and 8418.94 mm^2 respectively; while the control Kirikou okra pod had width, mass and surface area of 27.26 mm, 31.42 g and 4839.92 mm^2 respectively. Therefore, this study reveals the significant of the knowledge of the plant farming history, during the programming and application of automated okra harvesting machines. This is because, the physical characteristics values obtained for *Clemson* okra pods, cannot be completely into the application automated pod harvester for *Kirikou* okra pods. According to Jahanbakhshi (2018), the length, width, thickness, surface area, and density of fruits and pods play a vital role in the design, construction and application of special machines for agricultural mechanization. Furthermore, during the design and application of of okra pods conveying systems, grading and sorting; the pod's mass, density and sphericity are important parameters to be considered (Dursun and Dursun, 2005). If these factors are not taken into consideration, the machine/system will perform below expectation.

Mechanical properties

The ANOVA results of the effect of farming method on the compression parameters of the okra pod, presented in (Table 2), revealed that farming method significantly ($p \leq 0.05$) affected the compression parameters of the okra pod. But the interaction of okra variety and farming

Table 1: Physical characteristics of okra pod

Parameter	Variety	Treatment			Sig (p ≤0.05)
		Control	Manure	Fertilizer	
Mass (g)	Kirikou	31.42^{a}±3.50	40.32^{c}±5.56	35.42^{b}±4.19	*
	Clemson	34.02^{a}±3.03	43.32^{c}±6.04	37.52^{b}±3.99	*
Length (mm)	Kirikou	80.97^{a}±6.71	88.92^{c}±4.45	83.29^{b}±4.30	*
	Clemson	162.14^{a}±9.67	175.74^{c}±10.31	167.24^{b}±8.49	*
Width (mm)	Kirikou	27.26^{a}±2.69	32.31^{b}±3.45	29.28^{a}±3.28	*
	Clemson	29.16^{a}±2.47	31.61^{b}±3.34	29.37^{a}±2.47	*
Thickness (mm)	Kirikou	27.17^{a}±2.75	32.25^{b}±3.51	29.38^{a}±3.24	*
	Clemson	29.16^{a}±2.48	35.71^{b}±3.50	30.87^{a}±3.04	*
Dg (mm)	Kirikou	39.11^{a}±3.37	45.22^{b}±3.76	41.37^{a}±4.44	*
	Clemson	51.64^{a}±3.70	56.01^{b}±4.71	52.09^{a}±3.71	*
Surface area (mm^2)	Kirikou	4839.92^{a}±819.37	6466.13^{b}±1079.97	5436.26^{a}±1128.2	*
	Clemson	8418.94^{a}±1181.24	9922.48^{b}±1667.22	8567.46^{a}±1234.2	*
Projected area (mm^2)	Kirikou	1741.97^{a}±279.26	2263.45^{b}±326.38	1919.71^{a}±272.30	*
	Clemson	3726.39^{a}±486.02	4377.42^{b}±637.36	3868.82^{a}±486.12	*
Volume (mm^3)	Kirikou	45555.0^{a}±6937.12	54905.0^{c}±7726.00	49475.0^{b}±5793.5	*
	Clemson	51355.0^{a}±5425.52	61150.0^{c}±8369.90	53925.0^{b}±5277.3	*
Sphericity (%)	Kirikou	48.36^{a}±2.68	50.83^{b}±3.01	49.83^{ab}±3.39	*
	Clemson	31.85^{a}±1.32	31.87^{b}±1.95	31.14^{ab}±1.39	*
Aspect ratio	Kirikou	2.98^{a}±0.23	2.77^{a}±0.25	2.87^{a}±0.30	*
	Clemson	5.58^{a}±0.33	5.60^{a}±0.52	5.72^{a}±0.36	*
Density (kg/m^3)	Kirikou	695.34^{a}±60.84	737.55^{b}±66.89	716.68^{b}±33.83	*
	Clemson	666.04^{a}±57.83	708.87^{b}±38.80	695.85^{b}±31.64	*

Mean± standard deviation; n=20; Sig = Duncan p ≤0.05**;** * = not significant; columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05).

Table 2: ANOVA results of the effect of farming method and variety on the mechanical properties of okra pod.

Source of variation	Dependent variable	df	Sig
V	Failure force	1	6.5E-03*
	Failure energy	1	1.06E-02*
	Deformation	1	9.82E-10*
FM	Failure force	2	1.34E-03*
	Failure energy	2	6.21E-04*
	Deformation	2	2.80E-03*
V x FM	Failure force	2	0.6992^{ns}
	Failure energy	2	0.7947^{ns}
	Deformation	2	0.5511^{ns}

V = variety; FM = farming method; * = significant; ns = non-significant at 95% confidence level using DMRT

Table 3: mechanical properties of okra pod

Farming method	Failure force (N)		Failure energy (N.m)		Deformation (mm)	
	kirikou	Clemson	kirikou	Clemson	kirikou	Clemson
Control	87.33^{a}±4.1	78.67^{a}±4.1	0.223^{a}±0.03	0.193^{a}±0.02	6.2^{a}±0.2	9.6^{a}±0.4
Manure	99.67^{b}±3.8	89.00^{b}±4.5	0.303^{b}±0.04	0.250^{b}±0.04	7.5^{c}±0.3	11.5^{c}±0.9
Fertilizer	93.33^{b}±3.7	86.67^{b}±3.7	0.267^{b}±0.02	0.223^{b}±0.02	6.7^{b}±0.2	10.4^{b}±0.5

Mean± standard deviation; n=20; Sig = Duncan p ≤0.05**;** * = not significant; columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05).

method, did not exhibit any significant (p ≤0.05) effect on the compression parameters of the okra pods. The separated means of the compression parameters are presented in (Table 3). As shown in (Table 3), the failure force and failure energy of the *kirikou* okra pod was insignificantly higher the failure force and failure energy of the *Clemson* okra pod. But the deformation recorded in the *Clemson* okra pod, was higher than the deformation

Table 4: Shear properties of okra pod stalk

	Shear force (N)		Shear energy (Nm)	
	Kirikou	**Clemson**	**Kirikou**	**Clemson**
Control	784.15^{b}±27.92	677^{b} ±34.33	$1.386.91^{b}$±41.58	1.048^{b} ±30.71
Manure	627.94^{a}±33.01	535^{a} ±31.11	$0.984.14^{a}$±39.45	0.897^{a} ±21.33
Fertilizer	695.97^{a}±32.41	544^{a} ±28.09	$1.025.45^{a}$±35.91	0.922^{a} ±25.62
Sig.	*	*	*	*

Mean± standard deviation; n=10; Sig = Duncan p ≤0.05**;** * = not significant; columns with the same common letters (superscript) for each parameter are not statistical different (p ≤0.05).

of the *Kirikou* pod. This portrayed that the *Clemson* okra pod was more flexible under compression loading direction than the *Kirikou* okra pod. Likewise, the force and energy absolved by the okra pod produced by both the NPK 15:15:15 fertilizer and organic manure were significantly higher than that of the control okra pod. Furthermore, it was observed that pods produced with organic manure exhibited higher failure force (99.67 N) and failure energy (0.303 Nm), than the pods produced with NPK 15:15:15 fertilizer that recorded failure force and energy of 99.33 N and 267 Nm respectively. This portrayed that the manure contained more essential nutrients than the NPK fertilizer. According to Truong and Wang (2015), essential nutrients such as potassium, calcium, nitrogen and phosphorus help to improve crops yields and their engineering properties.

The failure force, failure energy and deformation at failure point of agricultural products are critical factors to be considered during the designing, construction and application of crops harvesting machines (automated or not). This is because; any force and energy beyond this point will lead to yielding (failing) of the harvested product. Oghenerukewve and Uguru (2018) stated that once an agricultural material had failed, it ability to store well will drop significantly, which will then leads to shorter shelf life and high food wastage. The study had revealed the range of failure force, failure energy and deformation at failure point, the okra pods can withstand, under differ farming method. Mohsenin NN (1996) reported that mechanical properties of agricultural products are very important during the analysis and determination of the efficiency of any machine and its operation.

Shear properties

The study revealed through the results presented in (Table 4), that farming method significantly (p ≤0.05) affect the shear force and shear energy of okra pod stalk. Regardless of the okra variety, the minimum shear force required to cut an okra pod stalk was recorded in the okra cultivated with organic manure; while the control pod stalk recorded the maximum shear force. This portrayed the significant of farming method in the shear properties of agricultural materials. These results are in conformity with those earlier obtained by Jahanbakhshi and Kheiralipour (2019) for tomato fruit. Jahanbakhshi et al. (2019) reported that the shear force of tomato fruit planted with Vermicompost was 58.60 N, which was significantly lower than control tomato fruit shear force of 93.26 N. Furthermore, the study portrayed that the *Kirikou* okra had insignificant higher shear force and shear energy, than the *Clemson* okra pod stalk. Shear force of an okra pod stalk is an important criterion to be considered, during the design and application of okra pod harvesting machines. This is because, due to the strong anchorage between the stalk and the okra stem, it had to be cut before the pod can be harvested. The results obtained from this study will further provide some vital information for the design and development of harvesting and handling systems okra pods. Nowadays, farmers use both organic manure and inorganic fertilizer to improve their crops' yield and quality.

Conclusion

The effect of farming method, on some physical characteristics and mechanical properties of okra pod, which are necessary for its automated harvesting and handling were evaluated in this study. The ANOVA results showed that farming method significantly affected the physico-mechanical properties of the okra pods. Results obtained from the laboratory test revealed that the okra pods mass, length, width, thickness, surface area, projected area, volume, sphericity, and density, were significantly higher in the organic farming, when compared with the inorganic farming and the control. The failure force and failure energy of the pods were higher in the okra cultivated with organic manure, when compared with the control and the inorganic okra pods. Furthermore, the shear test results showed that the organic okra pod had the lowest shear force and shear energy, regardless of the okra variety. The results obtained from this study will be useful in the design, construction and application of okra pod harvesting and handling machines. This is because failure parameters are important criteria during the design and application of

crops harvesting and handling machines.

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