
*Advances in Research*

*16(2): 1-6, 2018; Article no.AIR.43938*
*ISSN: 2348-0394, NLM ID: 101666096*

# Effect of Finger Size and Variety on Mechanical Properties of Intact Plantain (*Musa paradisiaca*) Finger under Quasi-static Loading

**O. Nyorere[1] and H. Uguru[1*]**

[1]*Department of Agricultural and Bio-environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria.*

***Authors' contributions***

*This work was carried out in collaboration between both authors. Author HU designed the study, performed the statistical analysis, wrote the protocol and first draft of the manuscript. Author ON managed the analyses of the study and literature searches. Both authors read and approved the final manuscript.*

***Article Information***

DOI: 10.9734/AIR/2018/43938
*Editor(s):*
(1) Dr. Siva Prasad Kondapalli, Department of Mechanical Engineering, Anil Neerukonda Institute of Technology & Sciences, India.
*Reviewers:*
(1) Okorie Ekwe Agwu, University of Uyo, Nigeria.
(2) Miguel Aguilar Cortes, Universidad Autónoma del Estado de Morelos, Mexico.
Complete Peer review History: http://www.sciencedomain.org/review-history/26144

***Original Research Article***

***Received 15th June 2018***
***Accepted 1st September 2018***
***Published 8th September 2018***

## ABSTRACT

The mechanical properties of two varieties of unripe plantain fruits (Fingers), namely, Dwarf hybrid and local, were evaluated in this study. Six mechanical parameters (bio-yield force, bio-yield energy, maximum compressive force, rupture force, rupture energy and relative deformation at rupture) of the plantain fingers were evaluated at two different finger sizes (small and large), under a compressive loading speed of 20 mm/min, using the Universal Testing Machine. The results obtained statistically showed that plantain variety significantly (P < 0.05) affected only the rupture energy and the relative deformation at rupture; whereas, plantain cultivar had no significantly influence on the remaining four parameters. In respite to the finger size, the all the six mechanical parameters studied increased from the small size to the large size. The results also show that for both varieties, the local plantain variety had higher values than in the improved variety. For the local variety, the bio-yield force and

**Corresponding author: E-mail: erobo2011@gmail.com;*

bio-yield energy increased by 13.8%, and 37.5%; 16% and 29.18% for the improved variety. Similarly, all the rupture parameters (rupture force, rupture energy, relative deformation at rupture) values increased by 11.9%, 11.14%, and 15.49% for the local variety; and 13.94%, 11.81% and 12.06% for the improved variety.

*Keywords: Plantain finger; mechanical properties; Quasi-static loading; bio-yield point; rupture point.*

## 1. INTRODUCTION

Plantain (*Musa paradisiaca*) is a large perennial herbaceous plant that originated in Southeast Asia [1], existing in the world are 68 species and two primary hybrids of plantain [2]. In the family of plantain *Musaseae* includes bananas (*Musa sapientum* and *Musa cavendishii*) which has the same growth pattern as plantain but are differentiated from one another by stem and leaf colour, fruit shape and storage of nutritional element, mainly carbohydrate in plantain finger and sugar in banana finger [3]. Plantain is generally grown in the tropical and temperate region of the world, and a good source of vitamins and dietary fibre. A plantain bunch consists of several fruits (expressed as fingers), each having a length range of 2.5–12 inches, and width range 0.75 to 2 inches [4]. Plantain production hits over thirty-five million tons in year 2016 [5], and presently, it is grown in over 130 countries of the world, with Cameroon the world leading producer (about 4.5 million tons). In Nigeria, for agro-climate reasons, plantain cultivation is concentrated in the southern region of the country. This crop also serves as source of income for rural farmers and substantial foreign exchange can be earned from export [6].

Mature plantain fingers (ripe or unripe) are consumed boiled, steamed, baked, pounded, roasted, or sliced and fried into chips. Overripe plantain fingers are processed into beer or spiced with chili pepper, fried with palm oil and served as snacks (*dodo-ikire*). Industrially, plantain fingers serve as composite in the making of baby food (*Babena* and *Soyamusa*), bread, biscuit, etc [7-8]. According to Treche [9], 69.4 percent of plantains and other cooking bananas are used for human consumption while 8.0 percent are used for animal feed. Post-harvest losses and transformed quantities in the world are 11.5 percent and 11 percent, respectively. Plantain finger contained significant amount of calcium when compared to cocoyam, sweet potato, maize and sorghum [10]; and it is considered to help in the management of high blood pressure and heart diseases. Plantain's finger low level of toxic and anti-nutrient substance namely, cyanogenic glucosides and gluco alkaloides made it safe for human consumption [1].

Knowledge of the engineering properties of fruits is an important attribute in the design of their harvesting, processing, handling and packaging systems. Many studies have been reported on the physical and mechanical properties of fruits; such as date fruit [11], melon [12], and citrus fruits [13]. In addition, [25] conciliated the temperature effect of ripening treatment on properties of banana finger. Salvador [14] studied the changes in color and texture of banana during storage at 10 ºC and 20 ºC, and reported that during storage, the peel colour change (from green to yellow) was gradual in the M. *Cavendish* samples, whereas the M. *Paradisiacal* variety remained green for the first 8 days and then changing rapidly to a yellow from day 12 onwards. In the study of Johnson and Dover [16], apple fruits from 24 commercial orchards were mechanically tested during six seasons, and it was observed that bruising susceptibility varied in a greater measure within a season than between seasons. According to Asoegwu [15], reduction in losses of plantain finger during harvesting, transportation, packaging and storage, requires the understanding of its physical and mechanical properties.

Even though some researches have been done on the mechanical properties of cut plantain finger [15], but there is dearth information on the mechanical properties of intact plantain finger, necessary for the design and development packaging and storage system. Hence, the main aim of this study is to determine the mechanical properties namely, bio-yield force, maximum compressive force, rupture force, bio-yield energy, rupture energy and relative deformation at rupture, of intact plantain finger with respect to its different finger sizes; which will provide relevant data for the design and development of packaging and storage systems.

## 2. MATERIALS AND METHODS

### 2.1 Samples Collection

The matured plantain bunches, improved (*Dwarf* hybrid) and local varieties, were harvested from a research farm located at Ozoro, Delta state, Nigeria. They were all harvested at a stage of maximal maturity when at least one ripe finger appears on the bunch [17]. The plantain fingers from the upper region of the bunches were cleaned and selected based on uniformity in size, cylindrical shape and freedom from mechanical damage.

### 2.2 Plantain Finger Size Determination

To determine the average size of the finger, samples (plantain fingers) from each variety were randomly selected. The two linear dimensions of the finger, namely length (L) and diameter (W) were carefully measured using digital vernier caliper reading to 0.01 mm. The geometric mean diameter ($D_g$) and total surface area (S) were computed using the following equations (1 and 2) [18].

**Geometric mean diameter**

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

**Surface area**

The surface area of the finger was determined according to the following equation.

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

### 2.3 Mechanical Properties Determination

The mechanical test of the intact plantain finger was done at the Material Testing Laboratory of the National Center for agricultural Mechanization, (NCAM), Ilorin, Kwara state, Nigeria, using a Universal Testing Machine (Testometric model, series 500-532) equipped with a 50 N compression load cell and integrator, with measurement accuracy of 0.001 N. Each sample was placed in the machine under the flat compression tool (Fig. 1), ensuring that the centre of the tool was in alignment with the sample, and compressed at the speed of 20 mm/min. As the compression progressed, a load-deformation curve was plotted automatically in relation to the response of the sample to the compression. The electronic computing unit of the machine measured the selected parameters (force, energy, deformation and strain) at bio-yield and rupture point of the plantain finger automatically, and the following parameters were interpreted by the testometric software of the Universal Testing Machine.

i. Bio-yield force
ii. Maximum compressive force ($F_{max}$)
iii. Rupture force
iv. Bio-yield energy
v. Rupture energy
vi. Relative deformation at rupture

The surface of contact between the sample and the compression plate changes during compression, making compression stress, the most popular and univocal physical parameter, difficult to use [19]. Fifteen replications were used for the experiment.

**Fig. 1. Plantain finger undergoing quasi compression testing**

Plantain finger like other biological materials has complex biomechanical systems of very complex behaviour and cannot be characterized by simple constants [18], it is therefore necessary to introduce some concepts such as bio-yield and rupture points. Bio-yield point indicated the initial cell rupture in the whole finger and is used as a criterion for maximum allowable load that the finger can sustained without showing any visible damage [20]. The rupture point dictated failure over a significant volume of material causing fracture planes or cracks in the macrostructure of the plantain finger. The rupture energy

(Toughness) is the work required to initiate rupture of the finger, which is the area under the force-deformation curve up to the rupture point; while the bio-yield energy (firmness) of the plantain finger is its ability to store energy within its elasticity range [15].

### 2.4 Statistical Analysis

The experiments were conducted with ten replications for each plantain finger size. The analysis of variance (ANOVA) was carried out using SPSS 20.0 software. The significant differences of means were compared by using the Duncan's multiple ranges test at 5% significant level.

## 3. RESULTS AND DISCUSSION

The ANOVA of the mechanical parameters of the plantain finger are presented in Table 1. The ANOVA results indicated that plantain finger size did not significantly affects the bio-yield force, bio-yield energy, maximum compressive force, rupture force, rupture energy; while the plantain variety significantly ($P < .05$) influenced only the rupture energy and relative deformation at rupture of the plantain fingers. Finally, the interaction effect of plantain variety and plantain finger size did not significantly ($P < .05$) influenced the six mechanical parameters investigated.

In reference to the mean separation table (Table 2), the local plantain variety showed higher values of failure force, rupture force, maximum compressive force, failure energy rupture energy and relative deformation at rupture than the improved variety sample, which could be attributed to the differences in the microstructure of the two plantain varieties. The force and energy required to initiate the plantain finger bio-yielding, in both plantain varieties, increased with increase in the finger size (Table 2). This may be attributed to the fact that increment in the finger size led to its more resistance to failure; also, larger finger possessed larger modulus of elasticity and capable of being more deformable under compressive loading [21]. A similar trend was reported for cut plantain fingers, where the energy required to rupture a cut-out section of the finger increased from 0.259 J to 0.410 J as the cut size section increased from 5.45 $cm^3$ to 9.45 $cm^3$ [15]. According to Sadowska [19], despite variability of the size and the fracture force of seeds representing different accessions and varieties, there was a clear tendency towards an increase in fracture force along with an increase in seed size.

**Table 1. Analysis of variance (ANOVA) of size and variety on the mechanical parameters of plantain finger**

| Source of variation | df | Bio-yield force | $F_{Max}$ | Rupture Force | Bio-yield energy | Rupture energy | Relative deformation at rupture |
|---|---|---|---|---|---|---|---|
| C | 1 | $0.2414^{ns}$ | $0.0896^{ns}$ | $0.0979^{ns}$ | $0.0933^{ns}$ | 0.0021* | 0.0019* |
| S | 1 | $0.2685^{ns}$ | $0.8497^{ns}$ | $0.0717^{ns}$ | $0.2941^{ns}$ | $0.1533^{ns}$ | 0.0383* |
| C x S | 1 | 0.9949 | 0.3162 | 0.9641 | 0.6245 | 0.8283 | 0.5271 |

** =Significant at (P<0.05), ns= non-significant, C = plantain variety, S = plantain finger size*

**Table 2. Mean comparison of the six mechanical parameters of plantain finger at different finger size categories and plantain variety**

| Parameters | Plantain finger size | | | |
|---|---|---|---|---|
| | Small (1521 $mm^2$) | | Large (2124 $mm^2$) | |
| | Improved variety | Local variety | Improved variety | Local variety |
| Bio-yield Force (N) | $1659.14^a$ | $1995.36^a$ | $1975.43^a$ | $2315.3^a$ |
| $F_{Max}$ (N) | $2313.80^a$ | $1792.04^a$ | $2669.23^a$ | $3029.51^a$ |
| Rupture Force (N) | $2313.80^a$ | $2688.71^a$ | $2653.13^a$ | $3011.64^a$ |
| Bio-yield Energy (Nm) | $5.12^a$ | $6.05^a$ | $7.23^a$ | $9.69^a$ |
| Rupture Energy (Nm) | $15.31^a$ | $17.36^b$ | $21.69^a$ | $24.41^b$ |
| Relative Deformation at Rupture (mm) | $14.15^a$ | $16.09^b$ | $18.28^a$ | $21.63^b$ |

*Means with the same common letter in the same row are not significantly different (P < 0.05) according to Duncan's multiple ranges test*

Like the bio-yield parameters, all the rupture parameters (force, energy and relative deformation) increased with increase in the finger's size, but higher in the local variety. This behavioral trend agreed with the theory of normal behavior of viscoelastic materials like processed apple [22]. Similar trend was reported on cumin seed, where the force and energy required to initiate rupture increased as the fruit size increased from small to large [23]. In addition, for cut out section of plantain fingers, all rupture parameters (strength, strain, and energy) increased with increased in cross-sectional area [15]. Rupture energy is a popular measure of mechanical resistance, and from the rupture energy values (Table 2), the most mechanically resistant plantain fingers were the local variety. The result of this research confirms the sensitivity of many agricultural products to mechanical damage due to variation in their sizes and varieties. Plantain finger firmness and toughness which is affected by size and microstructure, are important factor that influenced plantain's finger damage during transportation and storage. On a research on seeds of the Boomer variety, it was found that the larger seeds required a higher fracture force than smaller seeds [24]. The mechanical properties of intact plantain finger are vital attributes in the design of its harvesting, handling and packaging system.

## 4. CONCLUSION

From the results of the research, it can be concluded that the variety of plantain markedly influences its properties. Rupture energy, an important parameter of the mechanical resistance of fruits and seeds, was significantly affected by the plantain variety. Like the rupture parameters, all the bio-yield parameters (force, and energy) increased with the finger size, higher in the local variety than in the improved variety. As the average size of the finger increased from small (1521 $mm^2$), to large (2124 $mm^2$), the bio-yield force and bio-yield energy increase from 1995.76 to 2315.3 N, and 6.05 to 9.69 Nm for the local variety; and 1659.41 to 1975.43 N, and 5.12 to 7.23 Nm for the improved variety. Similarly, all the rupture parameters (rupture force, rupture energy, relative deformation at rupture) values increased from 2653.13 to 3011.64 N, 21.69 to 24.41 Nm, and 18.28 to 21.63 mm for the local variety; and 2313.80 to 2688.71 N, 15.31 to 17.36 Nm and 14.15 to 16.09 mm in the improved variety. The results obtained from this research will provide useful data for mechanical engineers in the design and development of suitable plantain fingers handling, storage and processing systems.

## COMPETING INTERESTS

Authors have declared that no competing interests exist.

## REFERENCES

1. Ogidi IA, Wariboko C, Alamene A. Investigation of some nutritional properties of plantain (*Musa paradisiaca*) cultivars in Bayelsa state. European Journal of Food Science and Technology. 2017;3:15-35.
2. FAO. Food and Agriculture Organization of the United Nations. Crop yield; 2013. Available:http://faostat.fao.org/site/567/DesktopDefault.aspx? Page 10 = 567 ₦ ancor
3. Phillips TA. An agricultural notebook. Longman, Nigeria LTD, Ikeja. 1976;125-129.
4. CRFG. Banana Fruit Fact. Available:http://www.crfg.org/pubs/ff/banana.html (Accessed July, 2018)
5. FAOSTAT. Plantain Production; 2018. Available:http://www.fao.org/faostat/en/#data/QC (Accessed: July, 2018)
6. Obayopo SO, Taiwo KA, Owolarafe OK, Adio SA. Development of a plantain slicing device. J Food Sci Technol. 2014:51(7): 1310–1317.
7. Ogazi PO. Plantain: Production, processing and utilization. Paman and Associates Limited, Uku-Okigwe; 1996.
8. Akyeampong E. Plantain production, marketing and consumption in West and Central Africa. Proc. International Symposium on Banana and Food Security. Douala, Cameroon 10–14, November. 1999;353–359 .
9. Treche, S. Importance de l'utilisation des racines, tubercules et bananes à cuire en alimentation humaine dans le monde. Les Cahiers de la Recherche Développement. 1997;43:95-109.
10. Tilahun A, Ann S, Jens A. Advancing human nutrition without degrading land resources through modeling cropping systems in the Ethiopian highlands. Food and Nutrition Bulletin. 2004;25:344-353.
11. Keramat Jahromi M, Rafiee S, Jafari A, Ghasemi BMR, Mirasheh R, Mohtasebi, SS. Some physical properties of date fruit

(cv. Dairi). Int. Agrophysics. 2008;22:221-224.
12. Emadi B, Abbaspour-Fard MH, Yarlagadda P. Mechanical properties of melon measured by compression, shear, and cutting modes. International Journal of Food Properties. 2009;12(4):780-790.
13. Omid M, Khojastehnazhand M, Tabatabaeefar A. Estimating volume and mass of citrus fruits by image processing technique. Journal of Food Engineering. 2010;100(2):315-321.
14. Salvador A, Sanz T, Fiszman SM. Changes in color and texture and their relationship with eating quality during storage of two different dessert bananas. Postharvest Biology and Technology. 2007;43:319–325
15. Asoegwu S, Nwandikom GI, Nwammuo OP. Some mechanical properties of plantain fruit. International Agrophysics. 1998;12(2):67-77.
16. Johnson DS, Dover CJ. Factors influencing the bruise susceptibility of Bramley's seedling apples. Proceedings of the European Workshop on Impact Damage of Fruits and Vegetables (EWIDF), Zaragoza (Spain). 1990;27-29.
17. Mitra SK. Postharvest physiology and storage of tropical and subtropical fruits. CAB International, Wallingford, United Kingdom. 1997;423
18. Mohsenin NN. Physical properties of plant and animal materials. Gordon and Breach Science Publishers, New York pp 8-11, Books Ltd London. 1986; 487–492.
19. Sadowska J, Jeliński T, Błaszczak W, Konopka S, Fornal J, Rybiński W. The effect of seed size and microstructure on their mechanical properties and frictional behavior. International Journal of Food Properties. 2013;16:814-825.
20. Mohsenin NN, Morrow CT, Tukey LD. The "Yield -Point" non-destructive technique for pending firmness of golden delicious apples. Proc Am, Soc Hort. Sci. 1965; 86(1):70–80.
21. Oghenerukevwe PO, Uguru H. Effect of fruit size and orientation on mechanical properties of *gmelina* fruit (*Gmelina arborea*) under quasi-Static loading. International Journal of Engineering and Technical Research. 2018;8:47- 51.
22. Fletcher SW. Mechanical behaviour of processed apples. Trans. ASAE. 1971;14(1):14 - 19.
23. Saiedirad MH, Tabatabaeefar A, Borghei A, Mirsalehi M, Badii F, Ghasemi Varnamkhasti M. Effects of moisture content, seed size, loading rate and seed orientation on force and energy required for fracturing cumin seed (*Cuminum cyminum* Linn.) under quasi-static loading. Journal of Food Engineering. 2008;86: 565–572.
24. Joshi M, Adhikari B, Panozzo J, Aldred P. Water uptake and its impact on the texture of lentils (Lens *culinaris*). Journal of Food Engineering. 2010;100:61–69.



*Peer-review history:*
*The peer review history for this paper can be accessed here:*
*http://www.sciencedomain.org/review-history/26144*