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Original Research Article

Evaluation of the Influence of Soil Amendment and Maturity Stage on Mechanical Properties of Plantain Finger

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Abstract

Soil characteristics and crop maturation are some of the most important factor that determined the engineering properties of agricultural products. In this study, the mechanical properties of plantain (*Musa paradisiaca*) fingers were determined under two soil treatment conditions and five maturity stages. The plantain plants were cultivated under two soil treatment methods, which were organic and inorganic treatments. The results revealed that soil condition had significant ($P \leq 0.05$) effect on all the mechanical parameters investigated. The findings of the study revealed that the mechanical parameters of the organic produced plantain fingers were higher, when compared to the mechanical properties of fingers produced with inorganic soil treatment. The results further displayed that there were increment in the mechanical behaviours of the plantain fingers, as the maturation period increased from maturity stage 1 to maturity stage 3, before they started to decline to maturity stage, irrespective of the soil treatment applied. According to the results plantain fingers harvested matured but unripe (stage 3) can withstand the postharvest operations. Data obtain from this study will help engineers in designing and fabrication of systems for the mechanization of plantain production.

Keywords: Agricultural machines, maturity stage, mechanical properties, plantain finger, soil treatment.

INTRODUCTION

Plantain (*Musa paradisiaca*) is fast becoming a major staple crop, due to its low sugar content and fairly high vitamins and minerals content. These antioxidants and vitamins help to support the immune system, reduce the risk of cardiovascular diseases, and regulate the blood pressure (MNT, 2020). Plantain is widely cultivated in Africa, Asia and South America. Plantain has a great economic significance, as it generates considerable revenue for farmers, due to its high demand. About 41.58 million tons of plantain fingers were produced globally in 2019, out of which Nigeria accounted for 8% (3.18 million tons) of the world plantain production (FAOSTAT, 2020). Approximately 98% of the total plantain fingers produced globally in 2019 was consumed internally by the producing nations; hence, leaving about 2% (967, 215 tons) of the plantain fingers for produced for exportation (FAOSTAT, 2020).

Maturation and soils biochemical condition are vital pre-harvest criteria that affect the engineering properties of fruits and vegetables. The maturity stage of any fruit greatly influences its shelf life, the nutritional quality and physic-mechanical properties (Dadzie and Orchard, 1997; Eboibi and Uguru, 2018; Eboibi *et al*., 2018; Uguru *et al*., 2019). Fruits harvested at pre-mature stage are more susceptible to shriveling and mechanical damage (Dadzie and Orchard, 1997); while over-ripe fruits trend to be more susceptible to mechanical damage during long distance shipment (Harman, 1981; Kader, 1994). Uguru *et al*. (2019) reported that the compressive parameters of bean (cv. butter) seeds generally increases as the maturation of the bean seeds increased from 15 days after peak anthesis (DAPA) to 29 DAPA. Iweka and Uguru (2019) investigated the impact of maturity age on the physical characteristics of okra (*Abelmoschus esculentus*, cv. Kirikou) pods, and observed that moisture content declined non-linearly as the pods matured; while the dimensional properties tend to increase as the okra pods matured. According to Simson and Straus (2010), when agricultural products are harvested at the ideal maturity age, they tend to have longer shelf life, good nutritional and mechanical properties.

Furthermore, several researches had portrayed that soil characteristics had great influence on the engineering properties of agricultural products. Eboibi *et al*. (2018) reported that soil amendment had significant effect on the growth and development of common beans (*Phaseolus spp*). According to Eboibi *et al*. (2018), the alteration (in the positive order) of the soil chemical properties caused by the organic amendment, was responsible for the consequent improved in the morphological growth rate and performance of the bean plants. Liang *et al*. (2011) in their study observed that organic soil amendments, helps to reduce the soil pH, aids faster infiltration rate, and improve the soil biochemical properties; which will improve crop yield (Ouédraogo *et al*., 2001; Bratte and Uguru, 2021). Nwanze and Uguru (2020) examined the impact of organic and inorganic soil amendment on the mechanical properties of eggplant (*Solanum aethiopicum* L. cv. Djamba F1) fruits, and reported that both treatments had substantial effect on the fruits. But the fruits harvested from the plants cultivated in the soil amended with organic manure, were able to absorb higher compressive force, when compared to the fruits harvested from the plants cultivated in the soil amended with inorganic fertilizer. Likewise, Jaffery *et al*. (2003) stated that soil characteristics is one of the factors that can caused disparity in total flavonoids content of guava fruits.

Fruits engineering properties are the key factors to be considered during the design and development of agricultural machines (Idama *et al*., 2021). Although several researchers (Ramaswamy and Tung, 1989; Asoegwu *et al*., 1998; Nyorere and Uguru, 2018) had investigated some engineering of plantain and banana fingers, that could aid the design and production of modern machines. Literature review does not reveal much on the effect of soil treatment on the mechanical properties of plantain fingers. Therefore, this study was aimed at determining the mechanical properties of plantain fingers, with much prominence on the fingers' maturity age and the treatments applied to the soil.

MATERIALS AND METHODS

Materials

Plantain

The plantain plants were planted at the Department of Agricultural Engineering, Delta State University of Science and Technology, Ozoro, Nigeria research farm.

The plantain plants were subjected to two soil treatments

i. Compost manure applied at the rate of 3000 kg/ha
ii. NPK 15:15:15 fertilizer applied at the rate of 300 kg/ha

Methods

Compost manure preparation

The compost manure was prepared from poultry waste, cattle dung and cassava peelings and oil palm fruit bunch waste, mixed at the ratio of 2:5:2:1 (weight to weight).

The composting took a period of three months, adopting the passively aerated static pile composting procedure.

Soil and compost manure chemical analysis

Top soil samples were randomly collected from the growing area. Both the soil and compost manure samples were air-dried, ground and then sieved with a 2 mm mesh size. The nitrogen and available phosphorus content were determined by using macro-Kjeldahl and Bray-1 methods, as described by (Bremner, 1996; Kuo, 1996; Eboibi *et al*., 2021). The potassium content was determined by the flame emission spectroscopy as described by Anderson and Ingram (1993); while the sodium and copper concentrations were determined by the method as described by Chapman (1982). Results of the soil and compost manure chemical analysis are presented in Table 1.

Table-1: Physico-chemical properties of the soil and the compost manure

Parameters	Level	
	Soil sample	Compost manure
Particle size distribution (%)		
Sand	40.3	-
Silt	35.6	-
Clay	24.1	-
Chemical analysis		
Soil pH (H_20)	7.04	7.50
Total nitrogen (mg/kg)	0.224	0.424
Available Phosphorus (mg/kg)	0.337	0.492
Copper (mg/kg)	4.911	13.224
Nitrate (mg/kg)	0.303	15.820
Sodium (mg/kg)	280.748	953.614
Extractable Potassium (mg/kg)	687.585	8951

2.2 Sample Collection

Ten plantain plants were randomly selected during the flowering period. The plantain bunches were harvested in the following order.

10 weeks after flower emergence, and was coded Stage 1
11 weeks after flower emergence, and was coded Stage 2
12 weeks after flower emergence, and was coded Stage 3
13 weeks after flower emergence, and was coded Stage 4
14 weeks after flower emergence, and was coded Stage 5

At every experimental date, 2 bunches of were harvested and the fingers from the upper hands selected, as described by Nyorere and Uguru (2018). The selected fingers were taken immediately to the laboratory for compression test.

Mechanical Properties Determination

The Universal Testing Machine (Testometric model) was used to determine the mechanical properties of the intact plantain fingers. During the test, each plantain finger was placed in the machine under the flat compression tool (Eboibi and Uguru, 2017), and loaded at the rate of 20 mm/min until rupture point. Then the electronic computing unit of the machine determined and interprets the compression values of the fingers, and displayed the results on the screen attached to the machine.

Plantain finger, like other agricultural materials, has complex mechanical behaviours (Mohsenin, 1986); hence it is essential to introduce some basic concepts (e.g. bio-yield and rupture points) to analysis its mechanical properties (Uguru and Iweka, 2019). Bio-yield point of agricultural products correlates, to its microstructural failure point, and is a key criterion to be evaluated during the design and production of agricultural machines in order to reduce (Edafeadhe and Uguru, 2019; Ekruyota and Uguru, 2021). Steffe, J.F. (1996) reported that rupture point of agricultural material is related to the macroscopic disruption of the material, and it is also expressed as the breaking point of the material (Uyeri and Uguru, 2018).

STATISTICAL ANALYSIS

Results obtained from this study were subjected to Analysis of variance (ANOVA), using the SPSS statistical software. While the mean were separated using Duncan's Multiple Range Test (DMRT) at 5% significance level.

RESULTS AND DISCUSSION

The ANOVA result of the effect of maturation and soil treatment, on the mechanical properties of the plantain finger, is presented in Table 2. As showed in Table 2, maturity stage and soil treatment had significantly ($P \leq 0.05$) effect on all the parameters investigated in this study. Whereas, the interaction of maturity stage and soil treatment did not significantly ($P \leq 0.05$) affects the parameters investigated in this study.

Table-2: The ANOVA of effect of maturity stage and soil treatment on the mechanical parameters of the plantain finger

Source	df	Failure Force	Rupture force	Failure energy	Rupture energy	Deformation at rupture
P	1	4.26E-04*	2.65E-04*	1.01E-02*	5.31E-03*	5.27E-02*
S	4	2.22E-06*	3.69E-06*	9.13E-08*	4.54E-08*	6.35E-06*
P x S	4	0.9256^{ns}	0.8712^{ns}	0.9431^{ns}	0.7083^{ns}	0.8998^{ns}

* Significant at $P \leq 0.05$, ns non-significant, S = Maturity stage, P = Treatment

The mean values of the mechanical parameters of the plantain fingers investigated in this study are given in Table 3. As revealed by Table 3, all the mechanical parameters investigated, generally increased as the plantain fingers matured from stage 1 to stage 5. In addition, it was observed from the findings of this study that the mechanical properties of the plantain fingers produced with organic (compost) manure were higher, when compared to the plantain fingers produced with inorganic fertilizer. These findings were similar to the ones previously reported by Ekruyota *et al*. (2021), when the mechanical properties of Roma tomato (*Solanum lycopersicum*) fruits cultivated with compost manure had better (higher) compressive properties, when compared to the values obtained from Roma tomato fruits cultivated with NPK 15:15:15 fertilizer. Likewise, Idama and Uguru (2021), in their study into the optimization of tomato fruits producing machines, observed that the mechanical properties of tomato (Cv. UC82B) fruits produced by compost manure were higher, when compared to the tomato fruits produced with inorganic fertilizer (KNO_3).

Table-3: Effect of maturity stage and treatment on the mechanical properties of plantain finger

Parameter	Treatment	Stage 1	Stage 2	Stage 3	Stage 4	Stage 5
Failure force	Organic	$595^{a}\pm33$	$726^{b}\pm34$	$846^{c}\pm42$	$744^{bc}\pm72$	$651^{a}\pm62$
(N)	Inorganic	$543^{a}\pm28$	$644^{b}\pm21$	$722^{c}\pm34$	$681^{bc}\pm44$	$551^{a}\pm31$
Rupture force	Organic	$640^{a}\pm21$	$795^{b}\pm45$	$892^{c}\pm29$	$812^{bc}\pm52$	$639^{a}\pm24$
(N)	Inorganic	$587^{a}\pm52$	$655^{b}\pm22$	$735^{c}\pm22$	$699^{bc}\pm34$	$601^{a}\pm42$
Failure energy	Organic	$6.13^{a}\pm0.4$	$6.94^{b}\pm0.6$	$9.19^{c}\pm0.5$	$7.52^{b}\pm0.9$	$6.05^{a}\pm0.2$
(Nm)	Inorganic	$5.81^{a}\pm0.3$	$6.22^{b}\pm0.3$	$8.12^{c}\pm0.4$	$6.90^{b}\pm0.8$	$5.58^{a}\pm0.2$
Rupture energy	Organic	$7.05^{a}\pm0.3$	$8.32^{b}\pm0.5$	$9.98^{c}\pm0.4$	$8.08^{b}\pm0.8$	$7.23^{a}\pm0.2$
(Nm)	Inorganic	$6.14^{a}\pm0.5$	$6.88^{b}\pm0.4$	$9.12^{c}\pm0.5$	$7.45^{b}\pm0.9$	$6.29^{a}\pm0.4$
Deform at rupture	Organic	$25.4^{c}\pm2.1$	$20.3^{b}\pm2.2$	$15.8^{a}\pm1.6$	$19.3^{b}\pm2.7$	$23.8^{c}\pm3.2$
(mm)	Inorganic	$24.7^{c}\pm2.4$	$19.5^{b}\pm2.2$	$15.2^{a}\pm1.7$	$18.5^{b}\pm2.4$	$22.0^{c}\pm2.1$

Values are mean ± SD, Means with similar common letter superscript in the same row did not differ significantly ($p \leq 0.05$).

This study finding depicted that as the maturation of the plantain fingers progresses, the mechanical properties generally increases. It was observed from the results that as the fingers matured from stage 1 to maturity stage 3, all the mechanical parameters investigated increases significantly ($p \leq 0.05$); but as the maturation of the fingers increased from stage 3 to stage 5, mechanical parameters investigated shown significant ($p \leq 0.05$) decrement. Regardless of the treatment applied, the failure force, rupture force, failure energy and rupture energy were significantly at maturity stage 1. The decline observed as the plantain fingers matured from stage 3 to stage 5, could be attributed to the repining and weaken of the plantain fingers. These findings are in conformity with the previous findings of Thompson (1996), which stated that the softening of banana finger during ripening is associated with the conversion of starch to sugar, the breakdown of pectin substances and the movement of water from the rind of the banana to pulp during ripening.

Similar results were reported by Soltani *et al*. (2011), where the firmness of banana fingers declined from 75.1 N to 27 N, and the fingers hardness decreased from 12.6 $J.mm^{-1}$ to 3.9 $J.mm^{-1}$, as the fingers matured from stage 1 to stage 7. Correspondingly, Tapre and Jain (2012) examined the effect of maturation on the textural qualities of banana fingers, and observed that, the fingers cohesiveness, chewiness, fracture force and stiffness decreased significantly, as the fingers matured from stage 5 to stage 7.

Results obtained from this study, will be helpful in plantain production, as enhancing the mechanical properties of the fingers will reduced the susceptibility of the fingers to mechanical damage. Mechanical damage is one of the major causes of food spoilage, and is still a major challenge encountered, during crop harvesting, handling and storage operations (Li *et al*., 2011; Uguru and Nyorere, 2019). Maturity at harvest is an important factor affecting quality perception and the rate of change of quality during post-harvest handling. Most currently used maturity indices are based on a compromise between those indices that would ensure the best eating quality to the consumer and those that provide the needed flexibility in marketing (Kader, 1994).

CONCLUSION

The study examined the influence of maturity stage and soil treatment on selected properties of plantain finger. The plantain plants were cultivated under two farming methods (organic and inorganic). The plantain fingers were harvested at five maturity stages (stage 1 to stage 5), and their mechanical properties, tested according to standard procedures. Findings of this study revealed that, the mechanical properties of plantain finger were highly dependent on its maturity stage, and the soil treatment applied. Generally, the plantain fingers produced with compost manure had higher mechanical properties, than the plantain fingers produced with inorganic fertilizer. The failure force, rupture force, failure energy and rupture energy of the finger increased from maturity stage 1 to maturity stage 3, before it declined in the advanced stages of maturity of 4 and 5. Results obtained from this study will be useful in the design and construction of machines for plantain fingers harvesting and post-harvest operations.

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