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Optimization of Crop Harvesting and Processing Machines, Through Modification of the Soil Biochemical Properties

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Abstract
This work investigated the influenceof soil's biochemical properties on the mechanical properties of okra (Abelmoschusesculentus) podsand groundnut (Arachishypogaea) kernels. The crops (Okra and groundnut) were cultivated under seven soil treatment programs, which were:T_1, the control; T_2, treated with composted manure ~2500 kg/ha; T_3, treated with composted manure~3500 kg/ha; T_4, treated with fertilizer ~100 kg/ha;T_5, treated with fertilizer ~200 kg/ha;T_6, treated with the combination of 1500 kg/ha of compost manure + 50 kg/ha of fertilizer; and T7, treated with the combination of2000 kg/ha of compost manure + 100 kg/ha of fertilizer. The two crops were collected (sampled) atpeak maturity stage, and were subjected to compressive test, by using the Universal Testing Machine. Findings gotten form the compression test depicted that okra pods and groundnut kernels produced with manure (T_2 and T_3) recorded higher failure force, failure energy, failure strain, rupture energy and rupture force, than the okra pods and groundnut kernels produced with fertilizer (T_4 and T_5). However, it was observed from the findings that combined treatment (T_6 and T_7) produced crops with better mechanical properties, than single individual treatments produced crops. The groundnut kernels' failure force and energy was from 67.5 N to 131.58 N and 0.044 Nm to 0.084 Nm respectively; while the okra pods' failure force and energy varied from 62.77 N and 112.88 N and 0.172 Nm to 0.324 Nm respectively. Additionally, the groundnut kernels' rupture force was between 62.89 N and 126.21 N, and the okra pods' rupture force was between 59.44 N and 108.22 N. Similarly, the groundnut kernel's failure strain ranged between 30.1% and 37.8%; while the okra pod's failure strain fluctuated between 20.1% and 31.3%, during on the treatment. The results of this research can be used to optimize the operation of harvesting and transportation of these crops' and the manufacturing of their processing machines; thus increasing food production.
Keywords: *Compost manure, compression test, fertilizer, groundnut kernel, okra pod*

INTRODUCTION

Agricultural materials'engineering properties are amongst the fundamental parameters must be taken into consideration when designing, fabricating and optimizing farm structures, machines and equipment. Hazbavi (2013) in their investigation into the activities of bio-materials stated that, the frictional parameters of roots fruits and seeds are essential elements needed, during the course of producing processing machines and storage systems. Likewise, Dursun and Dursun (2005) in their investigation intothe behaviours bio-materials, linked their physical characteristics, to the operation optimization of their processing and grading systems/ equipment. Enhancing the efficiency of farm machines is a vital step that helped to improve food security (Idama and Uguru, 2021). The agricultural material's coefficient of friction, has being recognized as a vital parameter that dictate,the type of material to be used for the machines' hopper production, while the dimensional attributes (size and shape) of agricultural material determinesthe capacity, slope and orientation of the machines' hopper (Iweka and Uguru, 2019). Similarly, moisture content, hardness, tensile parameters, compressive properties, flexural properties and tension properties of agricultural materials, are vital parameters that are used for the optimization of harvesting and processing machines (Ayman *et al*., 2012; Akpokodje and Uguru, 2019a; Idama and Uguru, 2021). Additionally, the aerodynamic properties of biomaterials are essential factors needed inthe sorting, handling, hydraulic transport operations of farm products, to minimize exposure of the crops to internal damage (Eboibi *et al*., 2018). Optimization of machine operations is vital for the reduction of carbon emissions, through the cutting down of fuel consumption and operation duration. Eboibi *et al.* (2017) stated that a reduction in fossil-fuel powered engines operation period, helps in reducing the amountof greenhouse gas emitted into the environment. Hence, helping in alleviating the negative consequences of climate change, experienced globally.

Okra (*Abelmoschusesculentus*)a member of the Malvaceaefamilyisa popular crop, widely utilized in the industrial, pharmaceutical and nutritional sectors. Okra is among the agricultural materials which can be conveniently processed into, bio-flocculatingmaterialfor the treatment and management of industrial waste water (Anastasakis *et al.*, 2009), medicines used for curative treatment of severe aliments (Maramag, 2013), and eaten due to its' essential vitamins and minerals content (Oghenerukewve and Uguru, 2018; Liu *et al.,* 2019). Okra pods and leaves have relatively strong antibacterial potential; therefore, it is used in the management of acute inflammation of the body joints, pneumonia and sexual transmitted diseases such as gonorrhea (Habtemariam, 2019). Fibre obtained from okra plant hasappreciable environmental friendliness, mechanical and thermal properties; making it a suitable substitution material for artificial fibres in the composites production industries (Thakur *et al.*, 2014; Edafeadheand Uguru, 2020). Groundnut (*Arachishypogaea)*, a prominent member of the *leguminosae* family, contains high quality edible oil, protein, essential minerals and vitamins (Muhammad *et al.*, 2015). The Nigeria Institute for Agricultural Research (IAR) has developed several diseases and pests resistant groundnut varieties, within the last two decades (Uguru *et al.*, 2020).

Soil amendment, achieved by altering the soil's biochemical properties, has been confirmed as one of the principal causes of serious alterations in the mechanical, chemical and structural properties of agricultural products (Akpokodje and Uguru, 2019b; Nwanze and Uguru, 2020). The minerals(chemicals) composition of a soil considerably affects the biochemicalandstructuralpatternsoftheplantsgrowing in it. Improving the soil's biochemical composition provides favorable condition for micro organisms' performance, which will enhance the plant's growth, development, diseases and pests'resistance hormones activities (Alagöz *et al.*, 2020; Bratte and Uguru, 2021). Furthermore, Gorji *et al.* (2010) stated that soil biochemical properties are principal influencers of crops' physical characteristics, which will then affects the operations of the equipment/systems required for harvesting and post-harvest operations.According to Edafeadhe *et al.* (2020), nitrate tends to increase the cellulose concentration of plant fibres, which leads to the production of plants fibres with higher tensile properties.

Hazbavi (2013) reported that farming systems (e.g. soil amendments) affects fruits and vegetables water content (moisture content [MC]); and bio-materials with higher MC tends to have lower ability to absorb compressive and tensile loadings, when compared to bio-materials with lower water content. Amending the poor quality soil with substances with a large percentages of nitrogen, calcium and potassium can lead to increase in crops productivity. Additionally, some organic soil amending agents have appreciable potentials of increasing the most crops'tissues firmness and better storability (Akpokodje and Uguru, 2019a; Mazumder *et al.*, 2021). Kashem *et al.* (2015) and Ayito and Iren (2018) in their investigation into the impact of manure, fertilizer (inorganic manure), and the combination of manure and fertilizeron the physical, mechanical and thermal properties of crops, reported that crops produced with combined treatment therapies had advanced engineering properties, comparing the results to crops cultivated solely with fertilizer or manure. This was linked to the higher percentage of nitrogen, potassium, calcium, amino acids and phosphors in well formulated manure. Therefore, crops with enhanced engineering properties, tends to aid the production of farm machines that consume lower power; which can be sourced from the wind or other renewable energy sources. Though for adequate power reliability from wind during farming operations, an appropriate investigation into the local wind characteristic of the location is paramount action required to be taken (Eboibi *et al.*, 2017).

Appropriate application of combined therapies involving fertilizers and organic manure is not only helpful to crop management, but to the environment (Ayito and Iren, 2018; Idama, *et al.*, 2021).Past researches have investigated the impact of soil biochemical properties on several crops' structural behaviours; however, not much has been reported in literatures on the influence of hybridized soil amendments on the structural properties of okra pods and groundnut kernels. Thus, the aim of this work is to evaluate the influence of hybridized soil amendments on okra pods' and groundnut kernels'mechanical properties, as well as on the soil's biochemical characteristics. Knowledge (information) acquired from the study will provide reasonable assistance during the production and optimizing the operations of various machines for harvest and post-harvest operations, thus fighting the menace of global food insecurity.

MATERIALS AND METHODS

Research area

The research was embarked uponat the Faculty Engineering, Delta State University of Science and

Technology (DSUST), Ozoro, Nigeria. Ozoro is can be geographically categorized into two main seasons:t he rainy (April to October) season, and the dry (November to March) season. Ozoro community'st emperature varies between 21^{0}C and 28^{0}C, during the rainy season period; while the annual rainfall was about 1800 mm, according to information provided by the university's metrological station for the year 2021. Ozoro soil is basically alluvial, having high infiltration rate, according to information provided by the university's civil and water resources engineering department.

Land preparation

The research was embarked upon between March 2021 and July 2021. The land was cleared and tilled manually, and split into plots. Top soil (0 -20 cm deep) samples were sampled randomly, and taken instantly to the chemical engineering laboratory. All the soil analyses were done on the soil by using the ASTM International methods. This was required to ascertain the soil's biochemical status before application of soil amendments.

Material selection/procurement

Fertilizer, the NPK 15:15:15 brand, was purchased from an agro-allied shop in Ughelli, Delta State. While the poultry waste, empty oil palm fruit bunch waste, and the cassava root peelings were obtained from the university farm.

The okra seeds and groundnut kernels were collected from the seeds bank, located at the Department of Agricultural Engineering, DSUST. SAMNUT 11 groundnut cultivar and Kirikou okra cultivar were designated for this research. According to information from location farmers, SAMNUT 11 groundnut has a high resistance to rosette disease, and the kernel contains a high proportion of edible oil.

Compost (organic) manure production

The organic manure was produced through the mixture of used poultry beddings, cassava root peelings and residues from oil palm fruit, in the mix ratio 4:4:2 (weight to weight).After the composing period (90 days), compost samples were arbitrarily collected and sent to the laboratory for biochemical analysis, using procedures approved by the ASTM International methods.

Treatment options and application methods

Seven treatment therapies, as summarized in Table 1, were used for this study.

Table 1: The treatments and their application rates

Treatment code	Treatment used	Application rate
T_1	Control (no treatment was utilized)	Nil
T_2	Composted manure	2500 kg/ha
T_3	Composted manure	3500 kg/ha
T_4	Fertilizer	100 kg/ha
T_5	Fertilizer	200 kg/ha
T_6	Combination of compost manure and fertilizer	1500 kg/ha of compost manure + 50 kg/ha of fertilizer
T_7	Combination of compost manure and fertilizer	2000 kg/ha of compost manure + 100 kg/ha of fertilizer

The compost manure was mixed (through light tilling) with the soil – in the allocated plots-two weeks before crop planting. This allows leaching of the manure nutrients into the soil, which is necessary before planting of the experimental crops. The fertilizer was applied, employing the ring fertilizer application method;14 days after sprouting of the crops.

Sprinkler irrigation method was adopted for soil hydration, while weeding was done manually. Cases of insects attack were not recorded; hence, insecticide was not applied on the crops.

Sample collection and preparation

The okra pods were sampled (harvested) 14 days after flowering, while the groundnut pods were harvestedthree months after planting.

After harvesting, the okra pods were checked manually for deformed, pests infested and extra-large pods. The pods were washed with cool water to remove the dirt and field heat, and dried with tissue paper, before they were taken to the laboratory for mechanical properties evaluation.

The groundnut pods were sun-dried for two weeks before they were shelled to obtain the groundnut kernels. Then the kernels were inspected to remove all deformed, pests infested, and extra-large kernels.

Laboratory analyses

Determination of the biochemical properties of the soil and compost manure. The nitrogen percentage was determined usingthe recognized micro-kjeldahl procedure (Page *et al.*, 1982). The available phosphorus in the soil and manure was determined according to the procedure outlined by Menon (1993). The potassium proportion was determined by using the combination of 1N ammonium acetate (NH_4OAC) solution and flame emission spectroscopy as outlinedby Anderson and Ingram (1993). The nitrate was determined by using the procedures described by (Bundy and Sturgul. 1994). Then the sodium, lead, zinc, copper and copper values were measured in accordance with procedures approved by ASTM International.

Determination of the mechanical properties of the okra pods and groundnut kernels

The Universal Testing Machine "UTM" (Testometric model, manufactured in England), was employed to determine the compressibility resistance of the okra pod and groundnut kernel. During the test, each sample was compressed slowly (10 mm/min), until the sample attained its breaking (rupture) point. After each test, some essential mechanical parameters, such as; failure force, rupture force, failure energy, rupture energy and deformation at failure point, which are necessary for the performance optimization of handling and processing systems were determined.

Failure (bio-yield) point relates to the micro-structural failure of biomaterial; while rupture (breaking) point relates to the macro-structural failure of biomaterials (Mohsenin, 1986; Steffe, 1996).

Statistical Analysis

The raw data wasanalyzed by using the analysis of variance (ANOVA) tool, through the help of the IBM SPSS software (version 20); in orderto evaluate the effect of soil amendment of the mechanical properties of the crops. The "means" of the results were separated by using the Duncan Multiple Range Test (DMRT) at 95% confidence level.

RESULTS AND DISCUSSION

Soil and compost manure analysis

The results of the biochemical properties of the soil and compost manure used for the crops cultivation, are presented in Table 2. It was revealed in Table 2 that the compost manure contained appreciable amounts of nitrogen, potassium, phosphorus and calcium– the macro nutrients needed by plants for proper growth and development of their body systems.

Table 2: Biochemical properties of the compost manure and un-amended soil sample

Parameter	Soil	Compost manure
pH	6.4	7.75
Nitrogen (%)	0.19	0.74
Phosphorus (%)	0.27	0.52
Potassium (%)	0.21	0.49
Nitrate (mg/kg)	0.30	11.9
Sodium (mg/kg)	450.75	2120
Calcium (mg/kg)	1434.45	2359
Lead (mg/kg)	3.80	8.30
Copper (mg/kg)	4.30	15.80
Zinc (mg/kg)	18.50	41.40

Okra pod and groundnut kernel analysis

The result of the multivariate test of the raw laboratory tests is presented in Table 3. Table 3 portrayed that treatments application exhibited significant ($p \leq 0.05$) influence on all the selected mechanical parameter investigated in both the okra pods and groundnut kernels. This depicted the significance of soil treatments in influencing the mechanical behaviours of agricultural products. Similar outcomes were obtained by Ekruyota *et al*. (2021), when soil treatment and fruit maturation had substantial influence on the mechanical behavior of tomato fruits.

Table 3: multivariate tests test of the effect of treatment

Source	Parameter	df	Mean Square	F	p-value
Crop	Failure force	1	952.68	45.98	2.29E-07*
	Failure energy	1	0.364	2668.13	2.55E-29*
	Rupture energy	1	0.371	11576.89	3.39E-38*
	Rupture force	1	624.09	105.79	5.15E-11*
	Failure strain	1	575.72	745.84	1.00E-21*
Treat-ment	Failure force	6	2285.09	110.30	3.66E-18*
	Failure energy	6	0.006	47.05	2.39E-13*
	Rupture energy	6	0.007	203.14	9.54E-22*
	Rupture force	6	2106.84	357.15	4.13E-25*
	Failure strain	6	57.70	74.75	6.27E-16*
Crop x treatment	Failure force	6	60.39	2.92	0.0245*
	Failure energy	6	0.002	15.75	7.90E-08*
	Rupture energy	6	0.002	61.09	8.64E-15*
	Rupture force	6	45.78	7.76	5.62E-05*
	Failure strain	6	2.909	3.77	7.1E0-04*

x = interaction; * = significant at $p \leq 0.05$ and ns = not significant at $p \leq 0.05$ according to DMRT

Effect of soil treatment on the crops' failure force

The results of the failure forces for the crops are plotted in Figure 1. Figure 1 indicated that, soil's treatment conspicuously affected the failure force of the two crops examined in this work. It was observed that regardless of the soil's biochemical status, failure forcepoint of the SAMNUT 11kernels was significantly higher, comparing the result with the result recorded for the okra pods. Failure force recorded for the groundnut kernels'in this study was between 67.5 N and 131.58 N; and the control kernels (T_1) developed the least failure force point, while the T_7 (advanced combined treatment) kernels developed the highest failure force point. Likewise, the failure force of the okra pods was between 62.77 N and 112.88 N; and the control pods (T_1) developing the least failure force, while the combined treatment (T_7), developed the highest point at which the failure of the pods and kernels occurred.

Regarding single therapy, it was observed from the findings (Figure 1) that crops produced with organic manure (T_2 and T_3) were able to absorb compressive force before failure, when compared to the crops produced with fertilizer (T_4 and T_5). Similar results were obtained by Jahanbakhshi and Kheiralipour (2019), where the soil's biochemical properties substantially affected the engineering properties of tomato fruits. Failure force is a critical parameter needed to be considered when designing and operating crop's harvesting and handling machines, in order to reduce the incidence of mechanical damage.

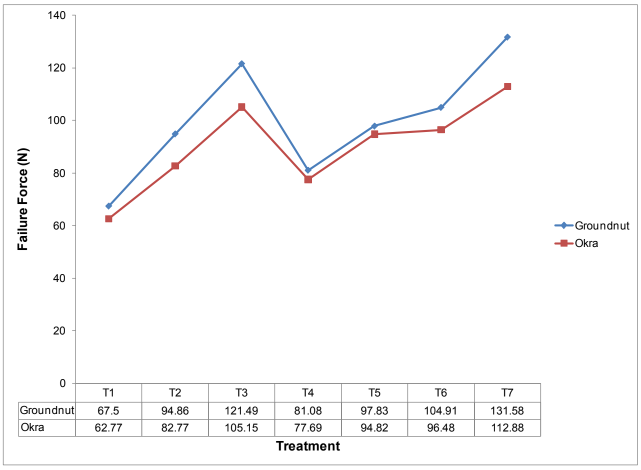

Figure 1: point of okra pods and groundnut kernels,under different soil treatment

Effect of soil treatment on the failure energy of the crops

The result of the effect of soil treatment on the failure energy for the crops examined in this work is presented in Figure 2. Figure 2 revealed thatregardless of the treatment option used for the crops cultivation, the failure energy of okra pods was significantly higher, compared to the failure energy recorded for groundnut kernels. The findings showed that the failure energy of the okra pods varied from 0.172 Nm to 0.324 Nm; with the control pods (T_1) having the lowest failure energy, and the combined treatment produced pods (T_7) developing the maximum failure energy. Similarly, the failure energy of the groundnut kernels ranged from 0.044 Nm to 0.084 Nm; with the control kernels (T_1) developing the minimum failure energy, and the combined treatment produced kernels (T_7) recording the maximum failure energy.

In terms of single treatment therapy, the findings depicted that the crops cultivated with organic manure (T_2 and T_3) absorbed higher compressive energy before failure, when compared to the crops cultivated with fertilizer (T_4 and T_5). Similar results were obtained by Jahanbakhshi and Kheiralipour (2019), where soil biochemical properties substantially affected the engineering properties of tomato fruits. Failure energy is a vital parameter that is considered by engineers, when designing and development of machines/ equipment for crops' harvesting and transportation. This is because, agricultural machines/equipment must be developed in manner that, they will minimize the rate at which crops are subjected to mechanical damage.

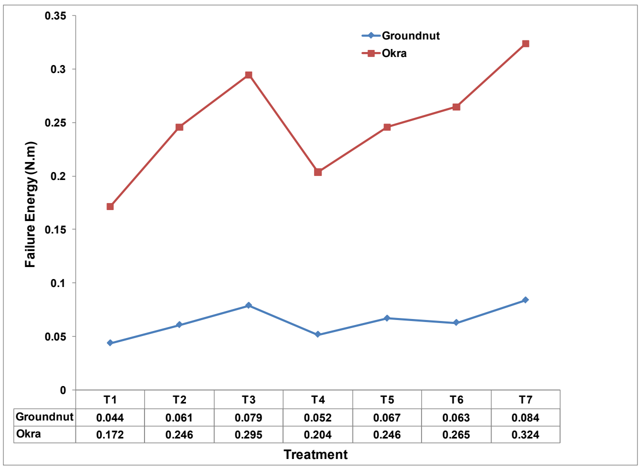

Figure 2: Failure energy of okra pods and groundnut kernels, under different soil treatment

Effect of soil treatment on the failure strain of the crops

The study's findings presented in Figure 3, revealed that soil treatment exhibited substantial influence on the failure strain of the two crops investigated. Observations made from Figure 3 revealed that regardless of the treatment option used for crop production, the failure strain of the groundnut kernels was significantly ($p \leq 0.05$) higher than the failure strain of the okra pods. According to the results, the failure strain of the groundnut kernels ranged between 30.1% and 37.8%; while the failure strain of the okra pods ranged between 20.1% and 31.3%. Furthermore, the study depicted that crops produced under the control program had the least failure strain, while the crops produced under the combined treatment program had the highest failure strain.

Similarly, the findings portrayed that the crops produced with organic manure treatment (T_2 and T_3) withstood higher compressive strain before failure, when compared to the crops cultivated through fertilizer treatment (T_4 and T_5). Failure strain is a vital parameterrequired for appropriate design and productionof crop harvesting and handling machines, to minimize the prevalence of mechanical damagehappening to the harvested crops.These findings are in conformity with the earlier observations reported by Truong and Wang (2015) and Kashem *et al.* (2015), on the impact of soil biochemical properties amending materialson the engineering behavioursof fruits,roots, seeds and vegetables.

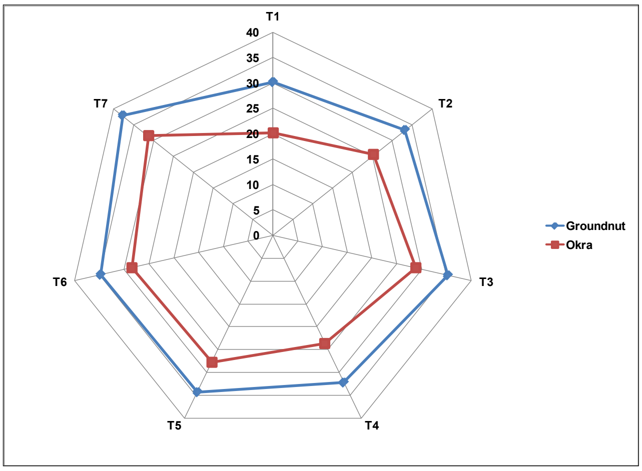

Figure 3: Failure strain of okra pods and groundnut kernels,under different soil treatment

Effect of soil treatment on the rupture force of the crops

Figure 4 shows the impact of soil biochemical properties on the investigated crops.The results shown in Figure 4 indicated that, soil treatment had substantial effect on the rapture force of the two crops investigated. Furthermore, Figure 4 showed that irrespective of the treatment option used for crop production, the rupture force for the groundnut kernel was significantly higher than the rupture force for the okra pods. The groundnut kernels' rupture force ranged between 62.89 N and 126.21 N; while the okra pod's rupture force ranged between 59.44 N and 108.22 N. Equally, it was observed that the groundnut kernels and okra pods produced without any soil treatment (T_1), developed the least rupture force, while the groundnut kernels and okra pods' produced through combined treatment (T_7) developed the highest rupture force.

Individually, the study revealed that the crops produced through organic manure treatment therapies (T_2 and T_3) were able to absorb larger compressive force before their macro-structural failure, when compared to the crops produced with fertilizer treatment therapies (T_4 and T_5). A similar trend on the effect of soils treatment on the mechanical behavioursof crops was reported by Uguru and Akpenyi-Aboh (2021) for bell pepper, cultivated in soil subjected to different biochemical treatments. Rupture force is an essential factor to be considered during the design and operation of crop processing machines, to minimize the power and energy wastage.

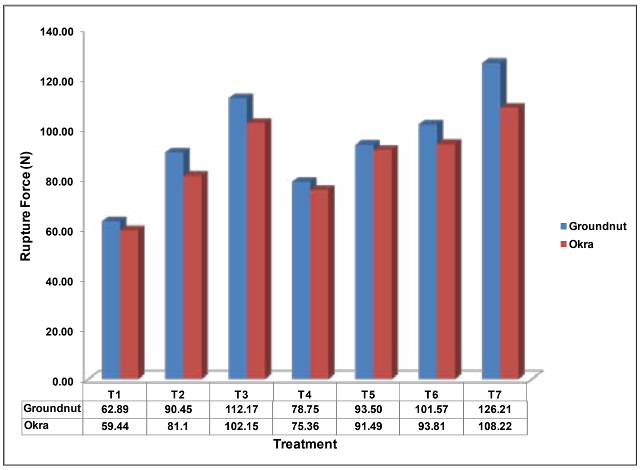

Figure 4: Ruptureforce of okra pods and groundnut kernels, under different soil treatment

Effect of soil treatment on the rupture energy of the crops

The results of the impact (mean rupture force) of the soil treatment on the crops are plotted in Figure 5. Figure 5 depicted that regardless of the treatment option utilized for the crop production, the rupture energy of the okra pods was significantly higher than the rupture energy of the groundnut kernel. It was observed from the processed results that, the rupture energy of the okra pods varied between 0.185 Nm to 0.330 Nm; with the control okra pods (T_1) recording the least rupture energy, while the okra pods cultivated through the combined treatment (T_7) therapy, developed the highest rupture energy. Likewise, the rupture energy of the groundnut kernels ranged from 0.050 Nm to 0.094 Nm; with the control groundnut kernels (T_1) having the lowest rupture energy, and the groundnut kernels produced through combined treatment (T_7),having the highest rupture energy.

In terms of single soil treatment therapy, it was observed that groundnut kernels and okra pods cultivated throughorganic manure management (T_2 and

T_3) developed higher rupture energy, when compared to groundnut kernels and okra pods produced through fertilizer treatment (T_4 and T_5). These observations are in conformity with earlier results obtained by Ahmad Abadi *et al*. (2011) and Jahanbakhshi and Kheiralipour (2019) on the impact of soil biochemical properties on the biomechanical behaviours of agricultural materials. Rupture energy is a crucial criterion that must be taken into account during the design and operation of crop processing machines/equipment, to minimize the occurrence rate of mechanical damage.

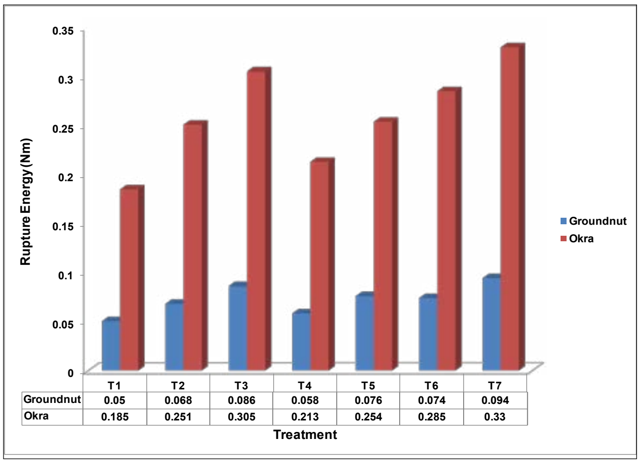

Figure 5: Effect of soil treatment on the rupture energy of okra pods and groundnut kernels

The results of this study had proved that organic manure, though bulky, when well-formulated gave better results than inorganic fertilizer. However, problems of bulkiness and poor nutrients content associated with most organic manures can be overcome through substitution with fertilizers. Makinde *et al.* (2010) reported that substituting fertilizer with organic manure had duel effects; it helps to alleviate the serious consequences of fertilizers on the environment, and also reduce the large quantity of organic manure required for maximize crop yield.

The observation made from from this study portrayed that crops cultivated using the combined (organic-inorganic) treatment, were able to withstand a wider range of compression forces. Thus, they are able to absorb larger mechanical stresses, when compared to products of single treatment; during mechanized harvesting and handling operations. Crops produced under combined treatment will lower the optimization of the crops' processing machines, as a higher compressive force and compressive energy will be required to mill or fracture the groundnut kernels and okra pods.

Shahedy (2007) reported that compression forces are the leading causes of micro-structural damage to crops, during the harvesting and handling operations of the crops; thus lowering the efficiency of most farm machines. In a situation that the compression forces of an agricultural product, rises above the maximum force it can conveniently absorbed, the extra forces can cause permanent disorder to the microstructural architecture of the product; thereby subjecting the product to microbial invasion (Linden *et al.*, 2006). The results of this study will be beneficial for optimization ofokra pods and groundnuts kernels during harvesting, handling and processing operations. Citing Gongal *et al.* (2015), adequate information of physical and mechanical properties of fruits, roots and seeds play a great deal in optimizing the productivity of automated agricultural machines.

CONCLUSIONS

This study examined the impact of soil biochemical properties on some essential engineering properties of different types of crops. Selected mechanical behaviours of SAMNUT 11 groundnut cultivar and Kirikou okra cultivar produced using different quantities of manure, fertilizer (NPK 15:15:15) and combinationsof manure and fertilizer, were determined accordingly. Findings of the study portrayed that the compression properties of okra pods or groundnut kernels, cultivated using combined treatment were higher, compared to the results recorded for the crops grown with single treatment. Similarly, the results depicted that okra pods and groundnut kernels produced with compost manure developed a higher resistance to compressive loading, when equated to okra pods and groundnut kernels cultivated with fertilizer. The study showed that combined treatment will help in optimizing the productivity of okra pods and groundnut kernels production automated machines. This is, due to the high resistivity of the okra pods and groundnut kernels to mechanical damage. Whereas, combined treatment will be detrimental to the performance of processing machines, due to the high power and energy requirement to fracture or mill the pods and kernels. Nevertheless, it can be established that using fertilizers as substitute for organic manure, will reduced the large quantity of organic manure required for enhanced crop productivity; and at the same time, improve the mechanical properties of agricultural materials, leading to reduction in food wastage resulting from mechanical damage of the crops.

Conflict of Interest

The authors declared no conflict of interest

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