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Research Article

Impact of Soil Amendment on the Mechanical Strength Properties of Tomato Fruits

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Abstract

The production of high-quality food items is crucial for addressing food insecurity issues, which are related to food wastage resulting from mechanical damage. This research was aimed at producing tomato fruits with high mechanical strength through field management (soil treatment). The experimental field soil geotechnical conditions were analyzed through the American Society for Testing and Materials (ASTM) approved procedures. Tomato variety (Cobra 26) was cultivated under different treatment plans of organic manures (poultry manure "PM" and compost manure "CM", inorganic fertilizer "NPK 15:15:15", and combination of both organic manure and inorganic fertilizer. The tomato fruits were harvested at the pink maturity staged were subjected to compression test, following the approved recommendations from the American Society of Agricultural and Biological Engineers (ASABE) recommendations. Findings obtained from the mechanical testing of the tomato fruits shown that the fruits harvested from the Control, Treatments 1 "PM", Treatment 2 "CM", Treatment 3 "NKP fertilizer", Treatment 4 "PM + CM", Treatment 5 "PM + fertilizer" and Treatment 6 "CM + fertilizer' plans developed failure force of 137, 179.83, 167.33, 172.17, 180.67, 189.17 and 174.67 N, respectively; failure energy of 448, 637, 546, 592, 725, 810 and 614 Nm, respectively; and failure strain of 30.17, 38.12, 34.55, 36.91, 40.28, 41.05 and 37.66%, respectively. These results revealed that the combination of poultry manure and NPK 15:15:15 fertilizer (Treatment 5) is the most effective treatment plan for producing tomato fruit with the highest mechanical strength. The results achieved in this research will be helpful in the production of tomato harvesting and handling machines; however, further studies are required in more hybridization plans, tomato varieties and soil conditions to have robust data for automation of tomato fruits production.

Keywords: Food Security, Hybridization, Mechanical Properties, Shelf-Life, Geotechnical Properties

Introduction

Tomato (*Solanum lycopersicum L*) is one of the most extensively consumed fruits globally, and its production has increased from 154 to 190 million tons between 2010 and 2021 [1]. The increment observed in the tomato production can be attributed to anthropogenic factors, such as: improved agricultural practices and tomatoes varieties, technological advancement, increased in cultivation areas and high demand for tomato fruit and its derivatives [2]. In Nigeria tomato value chain has increased within the past decade, which is an indication of significant developments within the country's agricultural production sector, and aware of the medicinal and nutritional qualities of tomatoes. Tomato contains numerous phytochemicals and antioxidants compounds which have the ability of preventing and managing serious ailments such: cancers, kidney failure, liver problem and cardiovascular diseases [3-6].

Tomato fruit has complex internal structure which consists of the exocarp (skin), mesocarp, endocarp, seeds and locular gel tissues (gel) [7]. The gel which emanated from the placental cells embedded the seeds, is a vital part of the tomato fruit during maturation as it provide nutritional and structural support to the developing seeds [8]. Adequate understanding of the engineering properties of the fruit cellular structure plays a pivot role in the maintenance of its quality and characteristics, during harvesting and post-harvest operations. Micro-structural and macro-structural failures, which can be caused by poor harvesting and handling practices aid microbial invasion of the fruits; thus, lower their quality, quantity and shelf-life [9]. Rajeev stated that good knowledge of plants cellular structure helps to minimize the occurrence of mechanical damage, which is one of the major causes of food spoilage (food wastage) that is contributing to food insecurity [10].

To alleviate the challenges associated with mechanical damages and quality control of food items during field and post-field unit operations, researches have been intensified on the physical, mechanical and biochemical properties of plants, including seeds, fruits, nuts and vegetables [11-14]. In a study conducted by Akpokodje on the impact of field practices on the strength properties of eggplant *(Solanum melongena L)*, reported that calcium-based treatment had significantly increased the firmness of the eggplant fruits, regardless of the maturity stage [15]. In another experimental investigation, Wu reported that soil amendment involving cattle dung and inorganic fertilizer mixed at a ratio of 1:3 is most effective platform for tomato production, as it provides the tomato plants with the basic nutrients for necessary for growth and performance [16]. Similarly, Jahanbakhshi in their investigation into the influence of soil amendment on the engineering properties of agricultural materials reported that, vermicompost and sheep manure exhibited significant effect on the strength parameters of tomato fruits [17].

Though numerous investigations have been done on the influence of field practices on the biochemical and mechanical properties of tomatoes fruits, there is still information dearth on the effect of hybrid treatment on the mechanical (strength) properties of tomato fruits [16,18]. Sufficient knowledge of the strength behaviors of bio-materials is fundamental factor required for the production and optimization of agricultural machines and equipment [19]. Therefore, it has become paramount to establish the effect of combined treatment options on the mechanical properties of tomato fruits, as this will help in the design and development of tomatoes fruits handling and storage systems.

Materials and Methods

The Research Area

This research was carried in the research center of the Delta State University of Science and Technology, Ozoro, Nigeria. The region is located in the tropical forest vegetation and has bimodal rainfall distribution pattern, with mean annual rainfall of about 1800 mm. Generally, the area experienced high and wide variation of temperatures (27±80C) and humidity (41-85%), as reported by Uguru [20]. The soil samples were randomly taken from 10 spatial points within the field to the laboratory for geotechnical behaviors investigation.

Soil Geotechnical Properties Analysis

The sieve analysis of the soil was conducted in accordance with ASTM C136 approved procedures [21]. The natural moisture content of the soil was determined in agreement with ASTM D2216 guidelines, while the soil porosity was measured in harmony with modified ASTM D4404 procedures [22,23]. Furthermore, the soil specific gravity value was determined in accordance with ASTM D854 recommended guidelines [24].

Plant of Choice

Hybrid Tomato variety (Cobra 26 F1) was chosen as the tomato variety for this study.

Soil Treatment Materials

The treatment materials used in this study were animal-based organic manure - poultry manure; plants-based organic manure - Palm fruit waste manure; and synthetic fertilizer – NPK 15:15:15 fertilizer.

Organic Manure Formation

The poultry manure (PM) was formulated by composting poultry waste; while the compost manure (CM) was formulated from the combination of oil palm bunch and kitchen waste (mixed in ratio of 3:2 - by mass). The aerated static composting method was adopted for the organic manure production.

Experimental Setup

During the course of this research, the field was tilled and partitioned into smaller plots (2 m2 per each plot). The treatment (soil amendment) plans used in this experimentation are presented in Table 1, and in the case of the hybridized (combined) treatment, the organic manure and fertilizer were mixed in a ratio of 1:1 (by mass). The organic manures were incorporated into the soil at a rate of 2 kg/plot; the fertilizer was applied to the soil at the rate of 0.15 kg/plot; while the combined treatment was applied at a rate of 1.2 kg/plot. Apart from the soil amendments, all the other agronomy variables – irrigation, weeding, diseases and pests management and environmental conditions – were uniformly applied to all the plots.

Table 1: The research treatment plans

Treatment	Compositions
Treatment 1	Poultry manure (PM)
Treatment 2	Compost manure (CM)
Treatment 3	NPK 15:15:15 fertilizer
Treatment 4	PM + CM
Treatment 5	PM + NPK 15:15:15
Treatment 6	CM + NPK 15:15:15

Sample Preparation

The tomato fruits used in this research were harvested at pink color maturity stage through manual handpicking. Considering the perishability and climacteric nature of tomato fruits, they are mainly harvested at the pink color maturity stage to prolong their shelf life [30]. They (tomato fruits) were immediately washed with borehole water to remove the field heat, manually inspected to remove pests/diseases infested and deformed fruits. These procedures were followed in order to maintain consistency and reliability of results.

Tomato Fruit Mechanical Properties Determination

The strength properties of the tomato fruits were determined by using the Universal Testing Machine (Testometric model). Each tomato fruit was compressed at a speed of 15 mm/min in accordance with ASABE S368.4 recommendation as explained by Ekruyota [5,25]. At the end of each test the forced absorbed by the fruits against its deformation (Figure 1) by the machine's microcontroller; thereafter, the failure force, strain and energy were extracted and calculated from the graph. Twenty tomato fruits from each experimental treatment were tested based ASABE recommendations, and their mean value recorded.

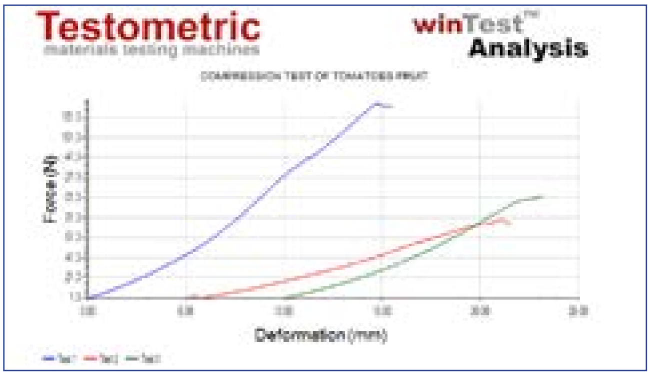

Figure 1: A force-formation plot

Statistical Evaluation

Descriptive statistics as carried on the results obtained from this study by using the Microsoft excel package.

Results and Discussion

Geotechnical Properties of the Soil

These properties are essential as they aid the understanding and behaviors of the soil in various constructional and agricultural projects. Table 2 and Figure 2 reveal the results of the soil particle size grading. The findings of the soil grain size distribution revealed that the soil contains 21% fine particles and 0% gravel. The presence of considerable amount of fine particles in the soil will enhance (lower) the soil's permeability and increased the soil's cohesion, which are essential soil parameters required for most agricultural production. Soils with high fine particle content tend to have high water-retaining capacity which helps in water conservation, which is beneficial during dry season farming [26].

Furthermore, the results of the soil's natural moisture content, specific gravity and porosity are presented in Tables 3. It was observed that the soil specific gravity, moisture content and porosity ranged from 2.06 – 2.1 (mean ~2.11), 22 – 27% (mean ~24.00%) and 46.00 – 50.00% (mean ~46.47%), respectively. This depicted that the soil has reasonable natural moisture level and porosity that can support plants growth. According to Villagra-Mendoza report on tomato production, tomato plants normally thrive better in soils with appreciable natural moisture level and porosity [27].

Table 2: The table of readings of the soil sieve analysis

Sieve size (mm)	Weight retained (g)	Percentage retained (%)	Percentage Passing through (%)
2.36	0	0	100
1.25	0	0	100
1	11	2.2	97.8
0.850	10	2	95.8
0.600	41	8.2	87.6
0.425	43	8.6	79
0.300	45	9	70
0.150	113	22.6	47.4
0.075	131	26.2	21.2

Table 3: The descriptive summary of the soil geotechnical properties

	Specific gravity	Moisture content (%)	Porosity (%)
Mean	2.11	24.00	46.47
Standard deviation	0.05	2.65	2.08
Minimum	2.06	22.00	46.00
Maximum	2.15	27.00	50.00
Count	3	3	3

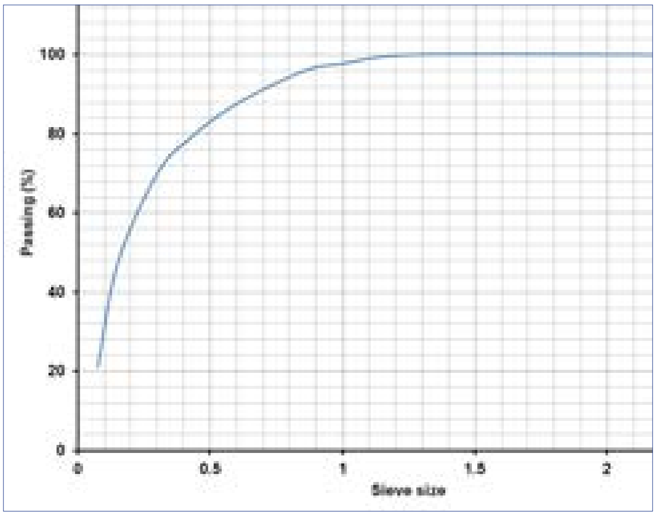

Figure 2: The plot of soil particle size grading of soil sample

Mechanical Properties of the Tomato Fruit

The results of the mechanical properties of the tomato fruits at harvest day are presented in Figures 3, 4 and 5. Figure 3 revealed the failure point of the tomato fruits based on the six treatment plans and the control unit. It was observed that the Control, Treatments 1, 2, 3, 4, 5 and 6 produced fruits developed failure force of 137, 179.83, 167.33, 172.17, 180.67, 189.17 and 174.67 N, respectively. Similarly, it was shown in Figure 4 that failure energy of the fruits cultivated under the control, Treatments 1, 2, 3, 4, 5 and 6 plans was 448, 637, 546, 592, 725, 810 and 614 Nm, respectively. Likewise, the results obtained from this study presented in Figure 5 revealed that the fruits collected from the Control, Treatments 1, 2, 3, 4, 5 and 6 experimental plots developed failure strain of 30.17, 38.12, 34.55, 36.91, 40.28, 41.05 and 37.66%, respectively. These findings are strong indication that the various treatment regimes had substantial effect on the compressive strength properties of the tomato fruits. These observations are similar to the reports of Ref [5] which stated that appropriate pre-harvest treatments contribute to an increase in the failure point of tomato (cv. Roma) fruits.

Generally, the fruits produced through the combined therapies (Treatments 4, 5 and 6) had better ability to absorb compression force (higher failure force), when compared to the fruits produced through single therapy (Treatments 1, 2 and 3). This signified that the combined treatments optimized the tomato growing condition and robust fruit development, thereby contributing immensely to the fruits' ability to resist compression force. Bio-materials with high failure points are more resistant to deterioration occurring through internal mechanical damage, as they have an ability of withstanding higher compressive force before undergoing microscopic failure [28].

Remarkably, the plants treated with animal based manure had better (higher) failure force, when compared to the plants treated with artificial fertilizer. This confers Jahanbakhshi reports which stated that organic manure has the potential of enhancing the mechanical properties of tomato fruits [29]. Failure point of agricultural materials is the point of microstructural rupture of the material that can lead to internal deterioration during storage; hence, this one of the crucial factor evaluated during the design of food handling and storage systems. Internal deterioration of agricultural products encourages pathogen microorganisms' invasion, which may results to food spoilage, loss of nutritional quality and potential food poison [30].

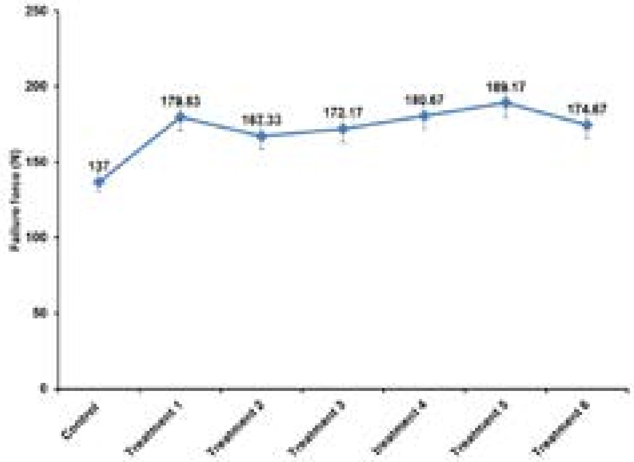

Figure 3: The failure force of the fruits

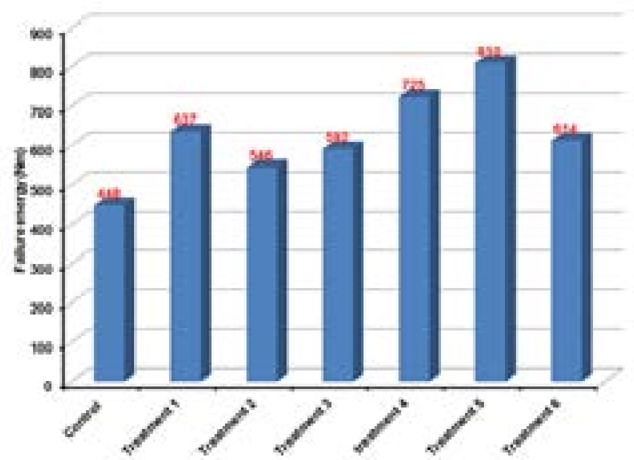

Figure 4: The tomato fruits failure energy

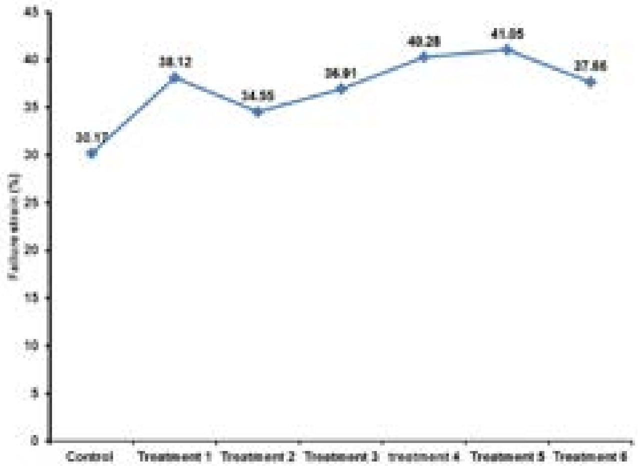

Figure 5: Failure strain values of the tomato fruits

Conclusion

Production of crops with better mechanical properties is paramount for the sustainability of agricultural production mechanization and automation. This research was embarked upon to evaluate the effect of crops pre-harvest treatment on the mechanical behavior of tomato fruits, through appropriate experimental design. The strength parameters of tomato fruits produced under different soil amendment plans - poultry manure and compost manure, inorganic fertilizer, and combination of both organic manure and inorganic fertilizer, were determined through standard ASABE procedures. The results revealed that the hybridized (organic manure and inorganic fertilizer) treatment plans yielded the tomato fruits with the best compressive strength characteristics. These findings will facilitate the design and development of suitable harvesting, handling and storage equipment for tomato fruits production; hence reducing post-harvest losses and enhancing tomato fruits security. However, further researches are required in more hybridization plans, cultivation practices, and tomato varieties to have robust data for development of smart systems for tomato fruits production.

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