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Robotization of Tomato Fruits Production to Enhance Food Security

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Authors' contributions

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

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ABSTRACT

The world is facing food insecurity problem due to shortage of workforce and growing world population. Robotization of crop production will help to boost food production, through effective labour conservation. This study was carried out to optimize the performance of tomato fruits' robotic harvesters, through field practices (pre-harvest treatments). Tomato (Cv. UC82B) was cultivated under four major field practices, which were: control, organic treatment, inorganic treatment using potassium nitrate (KNO_3), and combine treatment using the combination of compost manure and KNO_3. Tomato fruits were harvested at the pink maturity stage and were subjected to compression test, using the Universal Testing Machine, at three compression speeds of 15 mm/min, 20 mm/min and 25 mm/min. Results obtained from the study showed that, field practices and compression speed significantly ($p \leq 0.05$) affected the failure parameters (failure force, failure energy and deformation) of the tomato fruits. Regardless of the compression speed, the fruits produced with combined treatment had the highest failure parameters; while the control fruits developed the least failure parameters. Tomato fruit produced using the combined treatment developed failure force, failure energy and deformation of 87.60 N, 701.97 N.mm and 16.88 mm

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respectively. In the terms of the compression speed, the study revealed that the ability of the fruits to absolved compression force declined significantly, as the compression speed increased from 15 mm/min to 25 mm/min, across the four treatments regimes. These results will be useful during the programming and application of automatic tomato fruits harvesting robots, to optimize their efficiency, hence improving food security condition.

Keywords: Automation; compression; field practices; food insecurity; tomato; optimization.

1. INTRODUCTION

Tomato (*Solanum lycopersicum*) which belongs to *Solanaceae* family is an edible fruit, rich in minerals and vitamins. Tomato is cultivated in several countries in the world, as it can adapt to wide range of soil and climatic conditions. Numerous tomato varieties such as: Cobra 26, Roma VF, Ibadan Local, UC82B, Beske, Kelvin, etc., are widely cultivated across Nigeria. According to Food and Agricultural Organization (FAO) food production statistics, tomato is the most produced berry fruit in Nigeria, producing 4.1 million tons of tomato fruits in 2017 [1]. Tomato fruits consumption had increased recently, due to their nutritional and medicinal values. The fruit is rich in vitamins, minerals and other essential compounds. It is used to treat ailments cancer, high blood pressure and diabetes [2]. Bhowmik [3] reported that tomato fruit has essential antioxidants and compounds that helped to reduce lead toxicity in the body, decrease stroke risks, reduce heart diseases, facilitate healing of wounds and encourage glucose and insulin uptake in diabetic patients.

The rapid growing human population is creating serious food insecurity problem, despite the increment in food production [4]. The United Nations (UN) stated that food security is when all people, at all times, have to sufficient access to safe and nutritious food, at the right quantity and quality to meet their food preferences and dietary required for an active and healthy life [5]. According to the United Nations, about 820 million people in the world, about 10.7% of the world population is experiencing chronic malnourishment in 2016; the incidence is rising steadily globally [6]. According to FAO, irrespective of the level of economic and technical developments of a country, food insecurity should be kept to the barest minimum [4]. Food insecurity problem is mainly caused by shortage of workforce, lack of automated machines, obsolete agro-techniques, poor field practices, and food wastage [7]. Tomato fruits have very short repining duration; therefore, prolonging their harvesting lead to food wastage. About 40% of the tomatoes fruits produced globally are lost through improper harvesting, handling and processing operations, leading to decline in the quality and quantity of food available for human consumption [4;8]. Bac [9] reported that the application of advance intelligent machines (robots) in agricultural production, will not only increased food production but also their qualities values. Coren [10] reported that automation of agricultural operations reduced to the cost of the operations by about 80%, compared with manpower workforce. The operation cost and labour requirement of an automated machine, compared to manual machine is about 80% and 50% respectively, making automated machines cheaper to maintain and use, although their initial cost prices are higher than manual machines [11,12].

Robots have being designed and developed by several researchers [13-17] for several agricultural operations. Robotic engineers have discovered that the mechanical behaviours of the agricultural products, is one of the major obstacles, which hinder the performance of smart machines in the field. According to Tanigak [18] and Li [19], mechanical damage is still a major challenge encountered, during the design and application of robots for crops harvesting. Citing [20,21], during mechanized harvesting and handling operations of agricultural products, the products are exposed to numerous mechanical forces. These forces can cause irreparable damage (internal cellular failure), if they are above the bearing capacity of the products. This irreparable damage (also expressed as mechanical damage) makes the products susceptible to microbial attacks; therefore, lowering its viability, nutritional quality, and storability [22,23]. Therefore mechanical and robotic engineers must considered the mechanical properties of agricultural products, when designing and developing automated harvesting, handling and packaging machines. Additionally, plants breeders should develop crops that can withstand wider range of mechanical forces, during harvest and post-harvest operations [24,25].

Numerous studies had being done to determine the effect of field practices (pre-harvest treatment), on the mechanical properties of agricultural products, in order to minimize the problems of mechanical damages. Altuntas [26] observed that, field application of fruits growth enhancer such as methyl jasmonate, to the plum fruits significantly lowered (165.4 N to 129.6 N) their rupture force. Likewise, peach (*Prunus persica* L.) fruits treated in the field with calcium chloride foliar application, developed superior firmness, when compared with the untreated fruits [27]. In a study conducted by [28], they observed that foliar application of potassium solution, at a lower concentration, increased the weight and firmness of cherry tomato (*Solanum lycopersicum* Mill. cv. Unicorn) fruits. After studying the mechanical properties of apple (*Malus domestica* Borkh, cv. Fuji) fruit cultivated with potassium fertilization, Zhang [29] observed that apple fruit cultivated with potassium fertilization, developed superior mechanical properties than the control fruits, portraying the significant of potassium in fruits development. Although, researchers have worked exclusively on the mechanical properties of tomato fruits; there is paucity of information on the influence of field practices on the mechanical properties of many Nigeria grown tomatoes fruits. Hence, the objective of this study is to investigate the effect of field practices on the mechanical properties of tomato (cv. UC82B) fruits. The knowledge of these properties will be useful in optimizing tomato automated tomato fruits harvesting and handling machines, to prevent mechanical damages.

2. MATERIALS AND METHODS

2.1 Materials

2.1.1 Tomato seeds

The tomato (cv. UC82B) seeds used for this study were procured from the National Horticultural Research Institute (NIHORT), Ibadan, Nigeria. UC82B tomato has early maturity age, high productivity, and strong resistance to pests and diseases. The tomato fruits are square-shaped with very good firmness good keeping quality, making it one of the commonly cultivated tomato varieties in Nigeria [30].

2.1.2 Organic manure

The organic manure used for this study was compost from a mixture of cattle dung, poultry waste and groundnut shells; mixed at a ratio of 5:4:1 (by weight). The cattle dung and poultry waste were gotten from a livestock farm located at Ozoro, Nigeria; while the groundnut shells were gotten from local farmers in Delta State.

2.1.3 Potassium nitrate (KNO_3)

The KNO_3 fertilizer was procured from fertilizer deport located at Ughelli, Delta State, Nigeria.

2.2 Methods

2.2.1 Land preparation

The area used for this study was cleared, manually tilled and incorporated with preventive fungicide (Z-force: Active Ingredient, Mancozeb 80 % WP), was applied at the rate of 1 kg/ha. This is to prevent fungi attack during the tomato growing period.

2.2.2 Nursery of the tomato seedlings

The tomato seeds were nursed at the nursery section, of the Department of Agricultural and Bio-Environmental Engineering Technology research farm. During the nursery period, the seedlings were watered a knapsack sprayer at a low pressure. Weeding was done throughout the entire period by hand picking, while systemic insecticide was used to prevent insects' attack. After three weeks, the tomato seedlings were transplanted to the main experimental plots, at the rate of two seedlings per stand.

2.2.3 Experimental design

A randomized complete block design, with three replications was adopted for the study. Each plot grossly measured 2 m x 3 m. The organic manure was incorporated into the soil at the rate of 3 kg per plot; the KNO_3 fertilizer was mixed with the soil at the rate of 200 g per plot; then the combination of organic manure and KNO_3 was prepared by mixing the two treatments at the ratio of 5:5 (by weight), and mix with the soil at the rate of 2.9 kg per plot. At five weeks after transplanting, another batch of manure was applied to the organic plots at the rate of 2 kg per plot; while at the inorganic (KNO_3) plots, KNO_3 was applied through foliar application at a rate of 100 g per plot.

The field practices (pre-harvest treatments) were coded as follow:

T1 = Control (zero treatment)
T2 = Organic manure

T3 = Inorganic manure (Potassium nitrate)
T4 = Combination of organic manure and potassium nitrate

2.2.4 Tomato fruits collection and preparation

The tomato fruits were harvested manually at the pink maturity stage. Tomato being a climacteric fruit, continues its ripening process even after harvest. Therefore, it is usually harvested at the pink maturity stage, by farmers to reduce its deterioration, which results to great food wastage [31]. After harvested, the fruits were manually inspected to discard all deformed fruits, and sorted according to uniformity of size and weight. Their length ranged 50 – 80 mm; width ranged 50 – 70 mm; thickness ranged 45 – 70 mm; and weight ranged 80–120 g.

2.3 Mechanical Test

2.3.1 Compression (pressure) test

The pressure test of the tomato fruits was carried out by using the Universal Testing Machine (Testometric model, manufactured in England), with accuracy of 0.001 N. During the test, each tomato fruit was placed between the two compression plates, and quasi-static compressed until the rupture point. As the quasi-tomato fruit was plotted automatically by the microprocessor inside the machine, relatively to the fruit responses to the quasi-static compression [32]. At the end of the test, the failure parameters (failure force, failure energy and deformation) of the tomato fruit were mined by the microprocessor developed for the machine, and displayed on the screen attached to the machine. According to Steffe [33], bio-yield point, also expressed as failure point, relates to the microstructure failure of the tomato fruit. The pressure test was carried out at three compression speeds (15 mm/min, 20 mm/min and 25 mm/min), along the transverse section of the tomato fruit. The transverse loading position was taken, because that is the possible position that a robot grippers can gripped, during robotic harvesting of tomato fruits. Five fruits from each plot were used for the mechanical testing.

2.4 Statistical Analysis

Results obtained from the study were subjected to analysis of variance (ANOVA) using IBM SPSS software (version 20); to evaluate the effect of field practice and loading speed on the failure parameters of the tomato fruits. The means of the results were separated by Duncan Multiple Range Test at 95% confidence level.

3. RESULTS AND DISCUSSION

3.1 Pressure Test Results

The ANOVA results presented in Table 1 revealed that, field practices (pre-harvest treatments) and compression speeds had significant ($p \leq 0.05$) effect the pressure properties (failure force, failure energy and deformation) of the tomato fruits. Table 2 presented he mean values, and separated according to Duncan's Multiple Range Test at 95% confidence level. Generally, it was observed from the results that the fruits produced without using any treatment had the lowest failure parameters, while those fruits produced using the combination of organic manure and KNO_3 had the highest failure parameters.

Considering the field practices as a factor, the results presented in Table 3 revealed that regardless of the compression speed, the failure parameters of the fruits increased significantly ($p \leq 0.05$), as the fruits were treated with either organic manure or KNO_3. As shown in Table 3, the control fruits (fruits produced without using any soil amendment) had the lowest failure force, failure energy and deformation at failure point of 61.55 N, 302.48 N.mm and 11.75 mm respectively. Likewise, the study revealed the tomato fruits produced using the combination of organic and inorganic fertilizer developed the highest failure force, failure energy and deformation at failure point of 87.60N N, 701.97 N.mm, and 16.88 mm respectively. The results further portrayed that the tomato fruits produced with organic manure had superior pressure parameters, than the fruits produced with KNO_3. The study depicted that the failure force and failure energy of the tomato fruits produced using organic manure, were 11.34% and 13.59% higher than the failure force and failure energy of the fruits produced by using KNO_3. Although, field practices had significant effect on the pressure parameters of the tomato fruits; no significant difference existed between the failure parameters of the fruits produced with organic manure, and the fruits produced with the combination of organic manure and KNO_3 (Table 3). This could be attributed to the similarity in the essential (P, K, N, Ca, etc.) nutrients content in the two treatments options; since the concentration of the treatment was not significantly increased. Essential soil nutrients help to increase the mechanical qualities of tomato fruits; thereby, reducing mechanical damage during harvesting and handling unit operations [34]. The ability of biomaterials to withstand mechanical pressure is greatly influenced by the compression rate and the nature of the mechanical force applied [35,36].

Taking compression speed (Table 4) that is considered as the gripping speed of the robot grippers, as a factor. The study revealed that irrespective of the field treatment, the fruits failure parameters declined significantly ($p \leq 0.05$), as the compression speed increased from 15 mm/min to 25 mm/min (Table 4). The fruits compressed at the speed of 15 mm/min had the highest failure force, which was 9.32% higher than the failure force obtained at 20 mm/min, and 22.13% higher than the failure force recorded at the speed of 25 mm/min. The failure energy of the fruit was 633.24 N.mm at 15 mm/min, which later declined to 500.04 N.mm at 25 mm/min loading rate. This study results depicted that, the pressure to be exacted on a fruit, by the grippers should not exceed 70 N if the gripper has a speed of 20 mm/min (Table 4). But if the robot gripper is programmed to operate at a higher speed (≥ 25 mm/min), the force to be exerted on the tomato fruits should be lower than 60 N, to minimum the rate of mechanical damages occurring to the harvested fruits. Therefore, to prevent inflicting mechanical damages on the harvested fruits, the robot gripper slow gripping speed (≤15 mm/min if possible), because at a higher gripping speed (≥25 mm/min), the fruit will swiftly attained its failure point.

A simple flowchart of how a tomato fruit harvesting robot, can utilized field practices and compression speed to harvest tomato fruits with intense care, to minimize food wastage is presented in Fig. 1. As presented in the flowchart, even though the fruit is considered matured through the digital imaging system, if the compression speed and force conditions are not, the gripper will not harvest. Failure point of the tomato fruits is a crucial factor to be considered, during their automated harvesting operations. Therefore, the appropriate force must be applied by the grippers. As presented in Table 2, the significant improvement in failure parameters of the tomato fruits, caused different field practices will enhance the efficiency of harvesting robots. Onishi [37,38] stated that one of the key aims of robotic fruits harvester, is programming the robot with accurate information to minimize the rate at which the robot inflicts damages on the targeted fruits to be harvested. Likewise, Li [19] stated that the nature and rate of mechanical forces, that a robot gripper with exert on targeted fruits, is a crucial factor to be considered during robotic harvesting of fruits.

As revealed in this study, robot engineers and computer programmers must have adequate knowledge of the field practices of tomato fruits, before the application of the robotic machines in the field, to enhance their optimization. The pressure applied by robot grippers during the process of fruits harvesting and handling operations, must be lower the failure force of the fruits. This study further affirmed the earlier report of Hua [39], which stated that effective robotization of tomato production, required the effective collaboration of agricultural engineers, computer engineers, plant breeders, sensors and instrumentations experts, software developers and system integration specialists. The knowledge of the mechanical properties of the UC82B tomato fruits as captured in this study will be very useful in optimizing the operation of tomato fruits automated harvester; thereby increasing tomato production with little workforce.

Table 1. ANOVA results of the pressure test

Source of variation	Dependent variable	Df	Mean square	F	P value
Treatment	Failure force	3	1966.554	184.76	2.32E-26*
	Failure energy	3	499607.20	493.09	4.76E-36*
	Deformation	3	78.754	271.37	4.30E-30*
Speed	Failure force	2	1785.16	167.73	2.19E-22*
	Failure energy	2	88814.35	87.67	9.45E-17*
	Deformation	2	54.741	188.63	1.82E-23*
Treatment x Speed	Failure force	6	27.785	2.61	2.85E-02*
	Failure energy	6	4980.59	4.92	5.45E-04*
	Deformation	6	1.21	4.16	1.91E-03*

** = significant at p ≤0.05, according to Duncan's Multiple Range Test*

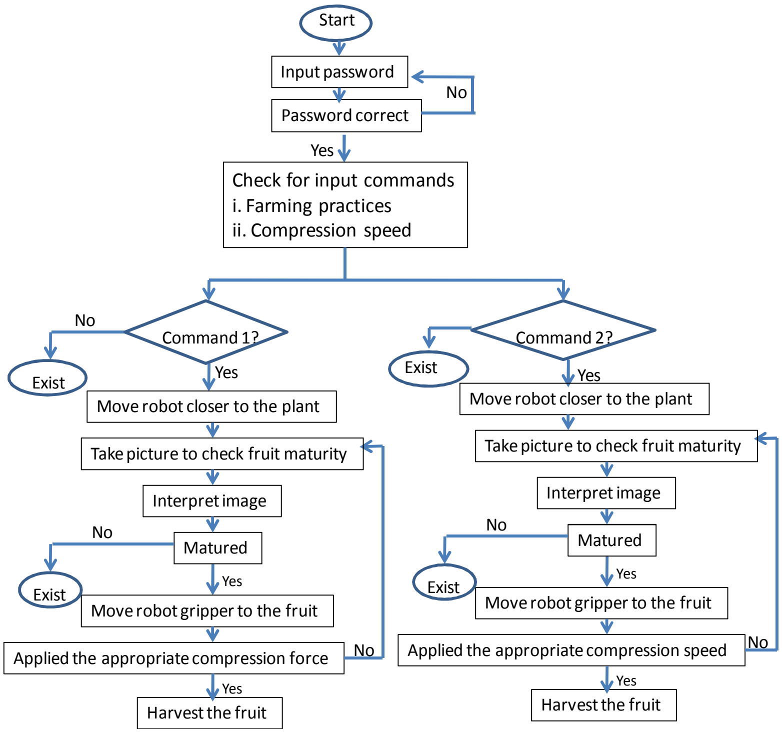

Fig. 1. A simple flowchart of tomato harvesting robot

Table 2. Separated means of the failure parameters

Parameter	Treatment	Compression speed			P value
		15 mm/min	20 mm/min	25 mm/min	
Failure force (N)	T1	69.87^{a}±3.29	61.18^{d}±1.99	53.46^{g}±3.92	7.23E-23*
	T2	90.99^{c}±2.46	85.48^{f}±2.37	70.28^{i}±3.87	
	T3	84.63^{b}±2.02	72.10^{e}±4.56	62.04^{h}±3.87	
	T4	94.44^{c}±3.46	89.48^{f}±1.75	78.88^{i}±4.01	
Failure energy (N.mm)	T1	332.73^{a}±18.6	308.10^{d}±9.9	266.61^{g}±15.3	2.67E-48*
	T2	726.30^{c}±36.6	690.63^{f}±24.6	605.83^{i}±24.3	
	T3	686.97^{b}±26.3	549.53^{e}±23.5	511.25^{h}±23.5	
	T4	786.96^{c}±22.5	702.47^{f}±34.3	616.47^{i}±24.6	
Deformation (mm)	T1	12.80^{a}±0.78	11.85^{e}±0.46	10.60^{i}±0.53	6.82E-26*
	T2	18.00^{b}±0.43	16.69^{f}±0.32	13.89^{j}±0.67	
	T3	16.20^{c}±0.39	14.42^{g}±0.44	12.43^{k}±0.40	
	T4	18.05^{d}±0.77	17.50^{h}±0.44	15.08^{l}±0.59	

In each column, means with the same common letter (superscript) are not significantly different at p ≤0.05, according to Duncan's Multiple Range Test

Table 3. Effect of field practices on the failure force, failure energy and deformation of tomato (cv. UC82B) fruit

Treatment	Failure force (N)	Failure energy (N.mm)	Deformation (mm)
T1	61.50^{a}	302.48^{a}	11.75^{a}
T2	84.25^{c}	674.25^{c}	16.19^{c}
T3	72.92^{b}	582.58^{b}	14.35^{b}
T4	87.60^{c}	701.97^{c}	16.88^{c}

In each column, means with the same common letter (superscript) are not significantly different at p ≤0.05, according to Duncan's Multiple Range Test

Table 4. Effect of compression speed on the failure force, failure energy and deformation of tomato (cv. UC82B) fruit

Compression speed	Failure force (N)	Failure energy (N.mm)	Deformation (mm)
15 mm/min	84.98^{c}	633.24^{b}	16.26^{b}
20 mm/min	77.06^{b}	562.68^{bc}	15.11^{b}
25 mm/min	66.17^{a}	500.04^{a}	13.00^{a}

In each column, means with the same common letter (superscript) are not significantly different at p ≤0.05, according to Duncan's Multiple Range Test

4. CONCLUSION

This study was carried out on how to optimize robotization of tomato fruits production. Tomato (UC82B) was cultivated by using organic manure, potassium nitrate, and combination of organic manure and potassium nitrate. Fruits harvested from each experimental plot were subjected to compression loading, at three compression speeds (15 mm/min, 20 mm/min and 25 mm/min). Results obtained from the compression test, revealed that both field practices and compression speed significantly ($p \leq 0.05$) affect the failure force, failure energy and deformation of the tomato fruits. The fruits harvested from the control plot had the lowest failure force and failure energy, regardless of the compression speed. Likewise, the tomato fruits produced with the combination of organic manure and KNO_3 developed the best failure force, failure energy, and deformation at failure point. Considering the compression speed, the study revealed that the tomato fruits were able to absolve more force and energy, when compressed at a lower compression speed (15 mm/min). It was observed that the tomato fruits swiftly attained their failure point, when the fruits were compressed at a higher compression speed of 25 mm/min. The showed the maximum pressure the robot grippers should exacted on tomato fruits, should be lower than the failure force, to avoid mechanical damage, which can lead to food wastage. If this study results are adequately into the design and programming of automated tomato fruits harvesters, it will optimize their field efficiency.

DISCLAIMER

The products used for this research are commonly and predominantly use products in our area of research and country. There is absolutely no conflict of interest between the authors and producers of the products because we do not intend to use these products as an avenue for any litigation but for the advancement of knowledge. Also, the research was not funded by the producing company rather it was funded by personal efforts of the authors.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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