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Full Length Research Paper

Evaluation of Engineering Properties of Tomato (cv. Cobra 26) Fruit, Necessary for its' Automated Harvesting and Processing

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ABSTRACT: Evaluating the influence of maturation on selected physical characteristics and mechanical properties of tomato (cv. Cobra 26) fruits were carried out in this study. These physical characteristics (mass, length, weight, thickness, volume, surface area, aspect ratio, geometric mean diameter, projected area, sphericity and density), and mechanical properties (failure force, failure energy, relative deformation and firmness) of the fruits were determined at two maturity stages (pink and red). All these parameters investigated are key factors in the design, programming and application of tomato fruits harvesting robots and machines. Results obtained from the study revealed that maturity significantly affected all the parameters investigated, apart from the fruit's volume, sphericity and aspect ratio. Furthermore, it was observed that all the physical parameters investigated increased during the maturation of the fruits. Regarding the mechanical properties, the results showed that the failure force, failure energy and firmness of the fruit decreased significantly ($p \leq 0.05$) from 81.80 N to 50.30 N, 367.55 N.mm to 296.68 N.mm, and 89 N to 56 N respectively, as the fruit matured. But in contrast, the relative deformation of the fruit increased significantly (from 9.60 mm to 19.32 mm) as the maturation of the fruit progressed from the pink stage to the red stage. The findings of this study will be useful in the design, construction, programming and application of tomato harvesting machines.

Keywords: Automation, Cobra 26, mechanical properties, physical characteristics, tomato

INTRODUCTION

Tomato (*Lycopersicon esculentum*) is one of the berry fruits widely cultivated in most parts of the world. It is one of the most nutritious fruits consumed globally, as its demand is increasing due to its medicinal values. Tomato fruits contain essential antioxidant compounds, which are associated with the treatment and management of many forms of cancers (Tilahun *et al*., 2017). Nour *et al*. (2015) and Loayza *et al*. (2020) stated that the concentration of antioxidants in tomato fruits is affected by the fruit maturation; and during storage antioxidants concentration is greatly affected by the level of mechanical damage done to the fruit, during the harvesting and handling operations.

Recently, there is a rapid growth in tomato production in Nigeria. According to information obtained from the official portal of Food Agriculture Organization (FAO), Nigeria tomato production has increased from 1,925,120 tonnes in 2013 to 3,913,993 tonnes in 2018, about 52% increment (FAOSTAT, 2018). This accounted for about 20% of Africa total tomato production.

Despite the increment, tomato production in Nigeria and most part of the world is still labour and time intensive (Feng *et al.,* 2018). This is because of the inadequate automation of tomato fruits' harvesting and handling operations. Tomato fruit has a short ripening period and it is highly perishable in nature. According to Jahanbakhshi and Kheiralipour (2019) and Shahroudi *et al*. (2018), product wastage in tomato fruits is very high, when compared with other fruits and vegetables, and about 40% of this wastage occurred during the harvesting operation. Hence, several researches are ongoing on how to fully automate tomato production, to avoid food wastage. Within the past two decades, many robotic specialists had developed tomato fruits harvesting robots, using the physical characteristics, mechanical properties and optical qualities of tomato fruits. Kondo *et al*. (2010) and Feng *et al*. (2018) used some mechanical and optical properties of cherry tomato fruits to design a harvesting robot. The tomato harvesting robot designed by Feng *et al*. (2018) recorded 83% efficiency. Furthermore, Feng et al. (2014) designed a tomato harvesting robot using a structured-light vision system. An Automated tomato fruits picking robot system with human interface, was design and constructed by Takahashi et al. (2001). In addition, Li et al. (2010) studied the relationship between mechanical property of tomato fruits, and mechanical damage done by a harvesting robot on the fruit. They reported that there is a strong correlation between the mechanical parameters and the mechanical damage done to the fruits. According to Li et al. (2009), tomato fruit's internal and physical structures, had a strong correlation with the mechanical damage, done to the fruit during automated harvesting.

Tomato fruit been very fragile, it is highly susceptible to mechanical damages during harvesting and post-harvest operation. This is a very serious challenge, during practical application of the tomato harvesting robot, in harvesting tomato fruits from the farm (Tanigaki *et al*., 2008; Wang *et al*., 2017). Therefore, the knowledge of the mechanical properties of tomato fruits is essential for the design and application of tomato harvesting robots. Li et al. (2011) evaluated some mechanical properties of Fenguan 906 and Jinguang 28 tomato fruits, which are related to automation of the tomato fruits harvesting operation. Thiagu et al. (2006) studied some mechanical properties of tomato (cv. Pusa Ruby and Vashali hybrid) fruits at various maturity stages, and reported that these parameters (firmness, rupture and deformation) greatly influenced the applications of harvesting robots. But data obtained by researchers in Europe, Americas and Asia, cannot be comfortably fitted into the design of robots for Nigeria grown tomato fruits. This is because, mechanical properties and physical characteristics of fruits and vegetable are greatly affected by climatic conditions, biotic factor, farming method, edaphic factor, crop genotype, etc. (Dixon et al., 1991; Eboibi and Uguru 2017).

From literature search, there is information dearth on the practical knowledge of engineering properties of many Nigeria grown tomato cultivars, which will aid the design and application of harvesting robots. Therefore, the aim of this paper was to evaluate some physical characteristics and mechanical properties of tomato (cv. Cobra 26) fruits, at two maturity stages. Results obtained from the study will be useful in the design and application of Nigeria grown tomato fruits harvesting robots.

MATERIALS AND METHODS

Material

The study was carried out between January 2019 and April 2019, jointly between the Department of Mechanical Engineering Technology, Delta State Polytechnic, Otefe, Nigeria, and Department of Agricultural and Bio-Environmental Engineering Technology, Delta State Polytechnic, Ozoro, Nigeria. The tomato was cultivated at the research farm of Delta state polytechnic, Ozoro; while the mechanical analysis of the fruits were carried out at the Laboratory of the Department of Mechanical Engineering Technology, Delta State Polytechnic, Otefe, Nigeria.

Tomato cultivation

Tomato (cv. Cobra 26) seeds used for this study were procured from Technisem seeds distribution centre, Ughelli, Delta state, Nigeria. The seed were cultivated at the research farm of Delta state polytechnic, Ozoro, under convectional farming method. Cobra 26 is a hybrid tomato cultivar, which produces fairly square fruit, with 4-5 locules, having excellent fruit's firmness. Furthermore, the tomato has a good vigour and productivity.

Tomato fruits harvesting and sample preparation

The fruits were harvested at two maturity stages, based on the colour maturity codes approved by the US Department of Agriculture (USDA, 1991). The maturity stages were the pink and red maturity stages. All the harvested fruits were manually inspected to remove all deformed and pests infested fruits. Furthermore, the fruits used for both the physical and mechanical properties determination were selected based on uniformity of size and shape. Extra large and small fruits were discarded.

Methods

Twenty (20) fruits were used to determine the physical characteristics and mechanical properties of the tomato

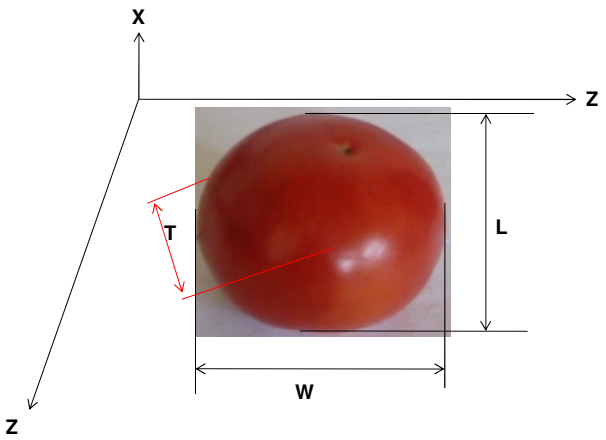

Figure 1: A tomato fruit showing the three axes.

fruit. The physical characteristics of the fruits were done at the Mechanical Engineering Laboratory of Delta State Polytechnic, Otefe, Nigeria. While the mechanical properties tests were carried out at the National Center for Agricultural Mechanization (NCAM), Ilorin, Kwara State, Nigeria. All the laboratory tests were carried out under ambient room temperature of 27±4°C.

Determination of physical parameters

Dimensional parameters

These dimensional parameters; length (L), width (W) and thickness (T), as shown in (Figure 1), of each tomato fruit were measured with a digital caliper, having a precision of 0.01 mm.

Geometrical parameters

The geometrical parameters (geometric mean diameter (Dg), surface area (S), projected area (P_a), volume (V), sphericity (φ) and aspect ratio (R_a)) were calculated from the values obtained from the dimensional parameters, using Equations 1 to 5. Then water displacement method was used to determine the volume of the tomato fruit (Mohsenin, 1986).

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

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

$$Projected\ area = \frac{\pi LW}{4} \quad (3)$$

$$\text{sphericity } (\varphi) = \frac{D_g}{L} \times 100 \quad (4)$$

$$R_a = \frac{W}{L} \quad (5)$$

Gravimetric parameters

Fruit mass

The mass (M) of the fruit was measured by using a digital weighing balance (Figure 2) with sensitivity of 0.01 g.

Figure 2: Measuring the mass of a tomato.

Fruit density

Then the density (ρ) of the tomato fruit was determined by using the formula shown in Equation 6

$$\rho = \frac{M}{V} \quad (6)$$

Determination of mechanical parameters

The Universal Testing Machine (UTM) (Testometric model), equipped with 500 N loading cell and micro-processor, was used to measure the mechanical parameter of the tomato fruit. Two major mechanical tests, which were whole fruit compression test (WFCT) and Magnus -Taylor penetration test (MTPT), were carried on the fruits.

Whole fruit compression test

In the compression test, each tomato fruit was placed centrally the between two compression flat cells. The

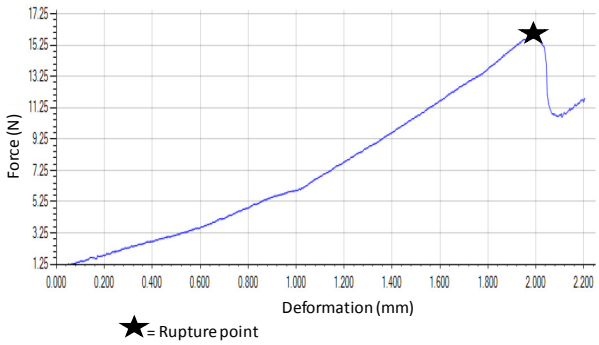

Figure 3: Force-deformation curve of tomato fruit under compression loading.

tomato fruit was then loaded uniaxial at a compression speed of 15 mm/min, until its' rupture point. As the loading continued before the rupture point, a force-deformation curve was plotted by the machine (Figure 3), from the data mined by the microprocessor of the machine. According to Steffe (1996) rupture point (also expressed as the breaking point) of the tomato fruit correlates to its macroscopic failure point. These compressive parameters; failure force, failure energy and deformation at failure point, were calculated electronically by the machine, and displayed on the computer screen attached to the machine. The compression test was done on the fruits along the length of the fruit (perpendicular to the Z axis).

Magnus Taylor penetration test

This test measured the fruit's resistance to penetration, which is a key indicator of its firmness (Mecmesin, 2018). A 6 mm diameter round end stainless steel probe, attached to the Universal Testing machine, was used to measure the fruit firmness. The machine was pre-set with the following information: preload speed, 200 mm/min; testing-speed, 105 mm/min; and post-test speed, 50 mm/min. During the test, the intact tomato fruit was placed into the machine and held firmly with one hand. Then the probe penetrated the fruit to a pre-set depth (40% of the fruit's diameter) and swiftly returned to its original position. A force-formation curve was plotted automatically by the UTM, in response of the fruit resistance to the penetration force. The fruit firmness was read from the curve.

Statistical evaluation

The results obtained from this study were analyzed using the SPSS (version 20.0) for Windows. The means were separated and compared using Duncan's Multiple Range Test (DMRT) at 5% significant level.

RESULTS AND DISCUSSION

Physical characteristic

The analysis of variance (ANOVA) and mean results presented in (Table 1), showed that maturity stage of the fruit, significantly ($p \leq 0.05$) affected most of its physical characteristics. The study revealed that the fruit's, mass, length, width, thickness, geometric mean diameter, surface area, projected area and density all increased significantly ($p \leq 0.05$), as the fruit matured from the pink stage to the red stage. In contrast, the fruit's volume, sphericity, and aspect ratio did not exhibited any significant ($p \leq 0.05$) difference as the fruit matured from the pink stage to the red stage. Geometrical parameters of fruits are essential parameters to be considered during the programming and evaluation of harvesting robots. Nalbandi *et al*. (2010) stated that physical characteristics of fruits are key factors during the design and application of machines for fruits harvesting and post-harvest operations. The size and shape of a robot's gripper are highly influenced by the fruit's geometric mean diameter, surface area, projected area and sphericity. According to Bamgboye and Sadilku (2015), fruit with high sphericity value tends to roll on any of its' three axes easily. Therefore, it must be taken into account during the design and application of transfer/transportation system. Li *et al* (2011) further stated that the probability of the robot gripper causing damage to a fruit, during automated harvesting operation will be highly reduced if the fruit was grabbed in in the right position. According to Roshanianfard *et al*. (2019), the mass and density of fruits are some of the key factors to be considered during the design of a robotic arm for harvesting operations. The size and capacity of the tomato collection point will be determined by the weight and density of the fruit. Although tomato harvesting robots uses optical properties of the fruit to determine its maturity; within adequate knowledge of the physical characteristics of the fruit, the field efficiency of the machine will be below average.

Compression parameters

The results of study presented in (Table 2) revealed that maturity stage had significant ($p \leq 0.05$) effect on the failure force, failure energy and deformation at failure point of the tomato fruit. This study indicated that there is 95% confidence level between the maturity stages of the tomato fruits. Tomato fruit harvested at the pink maturity stage exhibited higher failure force, failure energy, but lower deformation at failure point; when compared with the fruits harvested at the red maturity stage. According to the results, the deformation of the fruit behaved in contrast to the failure force and failure energy. It increased from 9.60 mm at the pink stage to 19.32 mm at the red maturity stage. According to Bargel and Neinhuis

Table 1: Physical characteristics of tomato (cv. Cobra 26) fruit.

Parameter	Maturity stage		Mean	Sig
	Pink	Red		Duncan (p ≤0.05)
Mass (g)	52.25±7.59	58.21±9.91	55.23±9.22	0.0392*
Length (mm)	41.36±3.52	43.86±3.76	42.61±3.81	0.0362*
Width (mm)	52.42±2.02	54.62±3.81	53.52±3.21	0.0281*
Thickness (mm)	40.59±3.67	43.39±3.77	41.99±3.94	0.0225*
D_g (mm)	44.45±3.04	47.013.75	45.733.61	0.0224*
Area (mm^2)	6234.09±763.46	6986.12±1175.3	6610.10±1049.71	0.0214*
Projected area (mm^2)	1705.60±181.51	1891.81±305.03	1798.71±265.08	0.0243*
Volume (mm^3)	63385.00±7505.88	66150.00±9384.0	64767.50±8503.40	0.3100^{ns}
Sphericity (%)	84.77±4.72	86.04±1.69	85.41±3.56	0.2666^{ns}
Aspect ratio	1.34±0.19	1.25±0.03	1.29±0.14	0.0500^{ns}
Density (kg/m^3)	822.59±39.54	878.21±58.49	850.40±56.76	0.0011*

Mean± standard deviation; n=20; * = significant; ns = not significant rows at 95% confidence level according to DMRT

Table 2: Tomato fruits failure properties.

Maturity stage	Failure force (N)	Failure Energy (N.mm)	Deformation (mm)
Pink	81.80±6.14	367.55±17.01	9.60±1.24
Red	50.30±7.50	296.68±23.17	19.32±1.35
Mean	66.05±17.33	332.12±41.11	14.46±5.09
Duncan (p ≤0.05)	*	*	*

Mean± standard deviation; n=20; N = newton; * = significant (p ≤0.05) according to DMRT

Table 3: ANOVA results of the effect of maturity on the firmness of tomato fruit.

Source	Df	Mean square	F Stat	Sig
Within groups	1	11730.63	1078.42	1.67E-29*
Between groups	38	10.88		
Total	39			

* = significant (p ≤0.05) according to DMRT

(2004), the mechanical properties of tomato fruit is highly dependent on its maturity stage and development. These results are in line with those previously reported by Ciupak *et al*. (2012), when the compressive force and energy of tomato (cv. Admiro and Encore) fruits decreases as the fruits matured from the green stage to the red stage.

Failure point is the point where the fruit undergoes microstructural failure (Steffe, 1996), is vital point in fruits (mostly tomato) harvesting. This is because, at the point, there is disruption of cellular structure of the fruit, leading to rapid deterioration during storage, irrespective of the storage system adopted (Oghenerukevwe and Hilary Uguru, 2018). Therefore, during automated harvesting of fruits, the force exerted by the machine gripper, must be lower the mean failure force of the fruit to be harvested. According to the results displayed by the Cobra 26 tomato fruit, the robot gripper should exerted a force lower than 80 N on the fruits at the pink maturity stage, and 50 N at the red maturity stage. This is to lower the rate at which internal mechanical is being done to the fruits, during the harvesting operation; thus, preventing food wastage during storage. Tomato being a climacteric fruit, with a shorter shelf life is usually harvested at the pink maturity stage. Moneruzzaman *et al*. (2008) stated that proper plucking of tomato fruit enhanced its nutrients content retention during storage, and prolong the shelf life of the tomato fruit. According to Feng *et al.* (2018), tomato fruit harvesting robot are designed and programmed based on the fruit's and stalk's mechanical properties.

Puncture parameter

Firmness

The analysis of variance (ANOVA) result presented in (Table 3), showed that maturity stage significantly affected the firmness of the tomato fruit. The results (Figure 4) revealed that the tomato firmness was greatly affected by the maturity stage of the fruit; as the fruit harvested at the pink maturity stage had a higher (89 N) firmness, when compared with the fruits harvested at the red maturity stage. Similar results were reported by Moneruzzaman *et al*. (2008), when the firmness of tomato

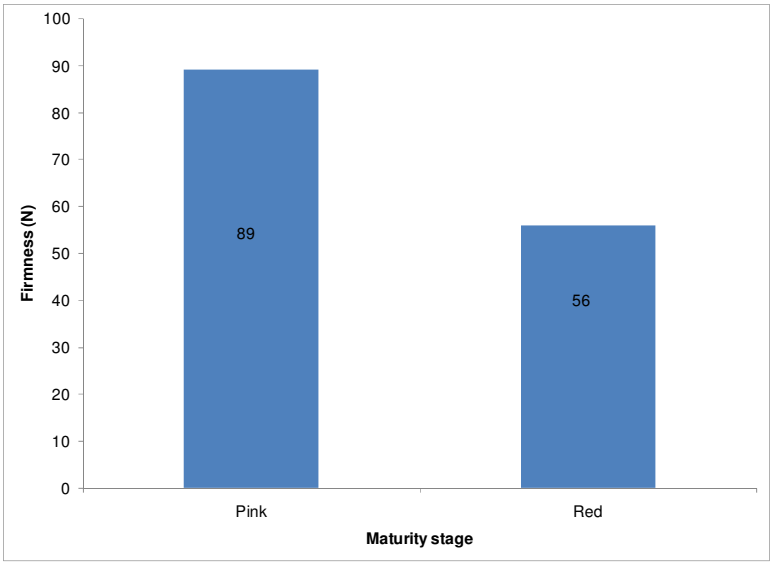

Figure 4: Firmness of Cobra 26 tomato fruit.

fruits decreased linearly, as the fruit ripen from the green stage to the red stage. Fruit firmness is another key factor to be considered using automated harvesting and processing of tomato fruits. The fruit firmness is essential during the design of robot algorithm; because according to Roshanianfard *et al*. (2019), robot harvesting of fruits involved four major steps; where are: grasping/picking the crop, stem/stalk cutting, lifting the fruit, and transportation of the fruit. Therefore, the firmness of the fruit will determine the pressure the fruit will be subjected to during the lifting and transportation sub-operations. Tomato fruit firmness influences consumer's preference, and its ability to be chopped or diced neatly during processing operation (Toivonen and Brummell, 2008). The compression and penetration results obtained from this study will be useful during the calibration of harvesting robot for Cobra 26 tomato fruit, which is widely cultivated in Nigeria. This is due to its high productivity, good fruit firmness and high resistant to diseases, according to information orally obtained from the farmers and the tomato seeds sales outlet.

Conclusion

This study investigated some physical characteristics and mechanical properties of tomato (cv. Cobra 26) fruits, with the sole aim of its mechanization. The findings revealed that maturity stage of the fruit significantly influenced most of its parameters evaluated in this study. The fruit's mass, length, width, thickness, surface area, projected area and density all increased significantly as the fruit matured from the pink stage to the red stage. It was observed that the fruit's volume, sphericity and aspect ratio did not increased significantly as the fruit matured. Rupture force and energy of the fruit significantly ($p \leq 0.05$) decreased from 81.80 N to 50.30 N and 367.55 N.mm to 296.68 N.mm as the fruit matured. In contrast, the relative deformation increased significantly ($p \leq 0.05$) from 9.60 to 19.32 N.mm as the fruit matured. Regarding the fruit's firmness, it was observed that the firmness significantly ($p \leq 0.05$) decreased from 89 N to 56 N as the fruit matured from the pink stage into the red stage. All these results obtained from this study are key factors to be considered during the design, programming and application tomato fruit harvesting robot and other automated post-harvest systems. This study was based on one commonly cultivated tomato cultivar in Nigeria. More researches need to be done on more commonly cultivated tomato cultivars in Nigeria, so that robust data can be made available to the mechanical and robotic engineers, for the design and production of tomato harvesting vehicles.

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