DETERMINATION OF PHYSICO-MECHANICAL PROPERTIES OF TOMATO SEEDLINGS FOR DESIGN OF A TOMATO TRANSPLANTER

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ABSTRACT

Transplanting operation is an important phase in the production of Tomato. The process is carried out manually in Nigeria accounting for over 40% of the total working hours in its production. To address these problems, several mechanical transplanting machines have been developed to transplant various plants or crops in the developed countries. However, these transplanters were designed considering prevailing conditions and the plant or crop under study. These transplanters are expensive to procure by farmers in the developing countries. Therefore, there is need for engineers in the developing nations to develop transplanting machines that will suit the farming methods and bearing in mind materials availability, cost and operability. Though, in designing such machines for transplanting Tomato, the physical and mechanical properties of the Tomato seedling are required. In this work the physical and mechanical properties (stem thickness, height, weight, spread diameter, angle of friction, frictional coefficient, impact properties, compressive properties and tensile properties) of the seedling of the most commonly grown Tomato variety (Roma VF) in Nigeria were determined. The height, weight, stem thickness and spread diameter of the seedlings were found to be 243.35 ± 50 mm, 6.28 ± 3.42 g, 3.53 ± 1.07 mm and 70.08 ± 8 mm respectively while the impact energy was found to be 1.32 ± 0.38 J. The frictional angles and coefficient of friction when the seedlings were laid vertically on Mild steel, Aluminum and Galvanized sheets are 44.43 ± 5^o and 0.99 ± 0.18, 42.96 ± 4.85^o and 0.94 ± 0.16 and 43.73 ± 5.10^o and 0.96 ± 0.17 respectively and when laid horizontally on Mild steel, Aluminum and Galvanized sheets the values are 40.63 ± 3.50^{o}and 0.86 ± 0.11, 40.08 ± 2.75^o and 0.84 ± 0.09 and 39.58 ± 6.10^o and 0.83 ± 0.20 respectively. The Tensile force, stain, stress and Young’s Modulus in Tension for the seedlings were found to be 3.50 ± 1.00 N, 15.67 ± 5.13 %, 1.11 ± 0.32 N/mm^2 and 7.36 ± 2.80 N/mm^2. While the maximum applied force the seedling can withstand in compression is 11.64 ± 3.73 N with maximum deflection and strain of 0.69 ± 0.24 mm and 34.39 ± 12.23 % respectively

Key words: Tomato, Transplanter, Seedlings, Mechanical, Physical

1. INTRODUCTION

Tomato, (*Lycopersicon esculentum)* is a fruit vegetable consumed extensively in Nigeria; it is regarded as the most important vegetable after onions and pepper (Bankole and Abanigbe, 2012). Nigeria is the second largest producer of tomato in Africa; second only to Egypt and 13th in the world (Bankole and Abanigbe, 2012). Even with Nigerian's position in tomato production in Africa, the quantity of tomato produced in Nigeria is grossly inadequate (Orefi *et al.*, 2011). Nigeria produces 6 million tons of tomato annually prior to 1990 (UNCTAD, 2012). However, the scale of tomato production in 2008 - 2009 season was estimated to be between 1 and 2million tons (UNCTAD, 2012). In 2010 an estimated 1,860,600 tons of Tomato was produce in Nigeria, while the United States of America produces 12,858,700 tons (FAO, 2010; Ojo *et al.*, 2013). This low production of tomatoes in the developing countries in general and Nigeria in particular may be associated with low mechanization of the farm operations. Orefi *et al.*, (2011) stated that most of the tomatoes produced in Nigeria comes from small farms and gardens where the major tools applied are the traditional cutlass and hoe technology, which has been blamed for the low output levels. Umeh *et al.,* (2002) reported that Tomatoes are grown by an estimated 85% of Nigerian gardens each year all of which is produced by direct seedling or by manual transplanting.

Tsuga (2000) reported that manual transplanting of vegetables accounts for approximately 40% of the total working hours in vegetable production. While Iya and Braide (1999) reported that the cost of transplanting tomatoes manually is high and adds up to the production cost of the crop. Ovidiu and Virgil (2013) reported that the manpower requirements for such operation is very high as it is up to130 – 140days-man/ha of the crop, and further stated that where the establishment is done by seedling culture is more added 30-50 days-man/ha for seedling preparation. Iya and Braide (1999) suggested that employing mechanical transplanting machines to carry out the transplanting operation will aid in reducing the cost of the operation and improve the timeliness in the production of such crops. While Ovidiu and Virgil (2013) reported that by automating the transplanting operations the use of manual work is reduced by 3 – 4times, increases productivity, allowing planting to be establish at the optimum time required for plant setting providing uniform distribution of plants per row.

To address these problems, several mechanical transplanting machines have been developed in the developed nations but Iya and Braide (1999) reported that such transplanters were designed according to the standards of the countries manufacturing them to suite the farming methods and devices used by their farmers and are also very expensive to acquire and operate by the farmers in the developing nations. Therefore, there is need for engineers in the developing nations to design transplanting machines that can suit the farming methods and considering available materials so that farmers can afford it.

But Ovidiu and Virgil (2013) reported that in the process of transplanting seedlings with mechanical transplanting machines, the seedlings are subject to various mechanical stresses such as compressive forces, tensile forces, impact forces etcetera, especially when in contact with the working bodies of the planting machines and thus the seedling can suffer severe injury which can slow down their development or even result in their wilting. To avoid these drawbacks, it becomes necessary to determine the maximum mechanical stress and other forces that the plant can withstand to be inculcated in the design of the transplanters so as to operate within acceptable error limits.

Several works have been done on the physical and mechanical properties of the stalk of various crops among which are the research conducted by Tavakoli *et al.* (2008) and O'Dogherty *et al.* (1995) on the mechanical properties of Wheat stalk and reported that the Tensile strength, Young's modulus, Sheer strength and Bending strength of the stalk ranges between 30.4 - 52.6MPa, 1.14-2.05GPa, 6.81-7.12 MPa and 13.70-19.31 MPa respectively. Zhao et al. (2009) and Galedar *et al*. (2008) reported that the tensile strength of the stalk of Alfalfa ranges between 16.8-36.0 MPa, while its Young's modulus ranges between 0.544-1.979GPa with a Sheer strength9.27MPa.Cao et al. (2011) worked on the physical and mechanical parameters of matured bottom stalk of the Reed for harvester design, they reported aTensile strength, Young's modulus, Compressive strength, Sheer strength and Bending strength of the stalk of118MPa, 0.321GPa, 26Mpa, 22 MPa and 152 MPa respectively. Xin *et al*. (2018) determined the physical and mechanical properties of the seedlings of Jinguan19 variety of Tomato to include seedling height of 121.8 mm, stem diameter of 2.1 mm, weight of 17.9 g compressive resistance of 4.2 N and adhesive force2.7 N. Ashutosh *et al*. (2015) worked on the biometric properties of onion seedlings relevant to the development of onion seedling using Pusa Red, Set-126 and Pusa Ridhi varieties of onion at 50, 60, 70 days old, the result obtained include: weight of seedlings without de-topping ranged from 0.53 to 3.05 g while with de-topping ranged from 0.47 to

1.68 g for all the three cultivars. The bulb and stem diameter for all varieties ranged from 3.13 to 5.76 g for bulb and 2.44 to 4.33 g for stem whereas height varied from 14.48 to 34.65 cm, the average coefficient of static friction for mild steel (MS), aluminium and galvanized iron (GI) varied from 0.63 to 0.79 while the compressive strength of bulb and stem of seedlings were 9.76 to 19.54 N for bulb and 4.08 to 8.17 N for stem respectively.

Although, there are tomato transplanters in other parts of the world. they are expensive for our farmers in Nigeria to procure (costing above 1 million naira as at 24 October, 2020) (Alibaba, 2020) and their characteristics may not be suitable for the varieties of the tomatoes we have in Nigeria (Iya and Braide, 1999).Furthermore, some important engineering properties (physical and mechanical) needed to design and fabricate transplanters that are affordable and adaptable to the varieties of tomato grown in Nigeria are not readily available. Hence, the need to conduct the current research.

The aim of this work therefore is to determine the physical and mechanical properties of tomato seedling most commonly grown Tomato variety (Roma VF) in Nigeria for the design of mechanical Tomato transplanting machines.

Roma VF variety of Tomato is a non-hybrid open pollinated cultivar that has gone through steady improvement (Joy et al., 2015). It is selected for this research work because it is the most widely grown non-hybrid variety of tomato in Nigeria, adaptable to different heat and moisture conditions (Seedaholic.com, Joy et al., 2015, Osim et al., 2010 and Ajayi, 2016).

2. MATERIALS AND METHOD

The following physical and Mechanical properties of four (4) weeks old seedling of Roma VF variety of Tomato were determined (stem thickness, height, weight, spread diameter, angle of friction, frictional coefficient, impact properties, compressive properties and tensile properties).

Seeds of the Tomato cultivar (Roma VF) were obtained from Yola market, they were sown in a nursery consisting of a perforated wooden box (45 X 60cm) filled with loamy sandy soil mixed with poultry droppings on 17 October, 2016 at the research farm of the department of Agricultural and Environmental Engineering, Modibbo Adama University of Technology Yola. located on latitude 9.23000N and longitude 12.46000 E (Nwankwor et al., 2018). The maximum and minimum temperatures during period of the experiment (17 October – 17 November 2016) were 37 ± 1^{o}C during the day and 19 ± 1^{o}C at night respectively with the relative humidity of33 – 35%. After 4 weeks of growth and development 50 samples of the seedlings were used to determine each of the physical and mechanical properties mentioned above.

2.1 Determination of Physical Properties

2.1.1 Stem thickness

The thickness of the stem was measured following the method prescribed by the ASNS (2014) with the aid of a Drappe micrometer screw gauge (with part no: 303 - 101,measuring range of 0 – 25 mm and accuracy of 0.01 mm), the middle portion of the stem of each of the seedling was placed between the anvil and the spindle of the micrometer and the stem thickness was read on the calibration on the sleeve and the thimble.

2.1.2 Spread diameter

The spread diameter of each of the sample of the tomato seedlings was determined following the method prescribed ASNS (2014) with the aid of a ruler with an accuracy of 1 mm. The seedling samples were placed in the field resting in its natural state and the spread diameter was measured with the aid of the ruler

2.1.3 Height

The measurement of seedling height of each of the sample was carried out following the method prescribed by the ASNS (2014) with little modification where the seedlings were laid on a table and the distance from the tip of the seedling to the end of its root was measure using a flexible Ningbo tape having an accuracy of 1 mm.

2.1.3 Weight

The seedling's weight was determined by placing it on a METLAR electronic balance which has an accuracy of 0.01 grams from where the weight of the seedling is read off, this was done for all 50 samples used.

2.2 Determination of Mechanical properties of the seedling

The mechanical properties (Angle of friction and Impact energy) were determined at the processing laboratory of the department of Agricultural and Environmental Engineering of Modibbo Adama University of Technology (MAUTECH), Yola, Nigeria. While the test for Tensile and Compression properties were carried out at the National Centre for Agricultural Mechanization (NCAM), Kwara State, Nigeria following ASTM D5035 and ASTM D4761-13standard respectively with a Testometric Material Universal Testing machine with a machine number 0500-10080.

2.2.1 Seedling Transportation

The seedlings were transported from the research farm of the department of Agricultural and Environmental Engineering MAUTECH, Yola to the laboratory of the National Center for Agricultural Mechanization (NCAM) following the guide line given by Balliu *et al.* (2017) and Thomas and Dumroese (2010). The seedlings were watered at the growing site on 12 November, 2016 then the seedling box was placed into a carton with its sides perforated for air circulation and light penetration which was then transported to Kaduna, on arrival the carton was then opened and the seedlings watered in the evening. The next morning (13 November, 2016) the seedlings were again watered and packed into the carton as before and transported to Ilorin were they were watered and monitored for 3 days before the test was carried out on the 17th November, 2016.

2.2.2 Angle of friction

The angle of sliding friction of tomato seedling on three surfaces (Mild Steel, Aluminum and Galvanize steel sheets) were determine using the tilting plane apparatus.

The materials (Mild Steel, Aluminum and Galvanize steel sheet) were placed on the apparatus plat form which was held firmly by nails on the plat form, a seedling was then placed on the surface of the materials in a vertical position, the plat form was then tilted with a screw mechanism of the apparatus until when the seedling starts to slide, at this point the tilting angle $\emptyset$ was then read from the protractor attached to the apparatus which is the static frictional angle of the seedling on the surface. This procedure is repeated with the seedling laid horizontally for all 50 samples.

The frictional angle obtained was used in equation (1) to calculate the coefficient of friction:

$$\mu = \tan\emptyset \quad (1)$$

Where: μis the coefficient of friction

∅is the angle of friction (degree)

2.2.3 Impact energy

Impact resistance signifies toughness of a material, which is the ability of the material to absorb energy during plastic deformation. It gives the maximum energy which will destroy the material under impact loading.

Procedure:

The test was carried out on an impact test apparatus developed by Maunde (2002) with a precision of ±1 mm. A seedling was held tightly by the specimen holder of the impact tester after which the knife is released from the 40^0 angle of the apparatus to impact the seedling held by the specimen holder, the height "h" reached by the knife after impacting the held seedling was recorded. This process was done for all the50 samples, after which the knife was released from the same position with no sample attached to the specimen holder, the height reached "H" was recorded, also the weight of the knife "m" was measured using 25 kg weighing balance. With the above results the impact energy "E" absorbed by the seedling was calculated using equation 2

$$E = m \times g \times (H - h) \quad (2)$$

Where: m is mass of Knife (kg)

g is acceleration due to gravity = $9.81 m/s^2$

H height reached by knife with no interruption (m)

h height reached by knife with seedling sample in specimen holder (m)

2.3.4 Tensile properties

Tensile properties are those mechanical properties obtained from a tensile test where the specimen is subjected to tensile force and the various points at which the specimen reaches it elastic limit, yield point and breakage point are recorded and using equations 3, 4 and 5 to calculate the stress, strain and young modulus respectively;

$$\sigma = \frac{F}{A} \tag{3}$$

$$\in = \frac{e}{L} \tag{4}$$

$$y = \frac{\sigma}{\in} \tag{5}$$

Where; σ is Stress on the seedling stem (N/mm^2)

$\in$ is strain on the seedling stem

F is Force applied on the seedling stem (N)

A is area of the seedling stem (mm^2)

e is extension of the seedling stem (mm)

L is original length of the seedling stem (mm)

y is Young modulus of the seedling stem (N/mm^2)

Procedure:

A 50 mm long stalk of the tomato seedling was attached to the jaws of the Universal testing machine and was operated at a speed of 5 mm/min to induce tension to the attach stalk, the forces and length at which the attached seedling reaches its elastic limit, yield point and breaking point in tension were automatically recorded by the machine and it also plots the result automatically, this process was done for all the 50 samples with an average diameter of2.00 mm.

2.3.5 Compression properties

Compression properties are those mechanical properties obtained from the compressive test where the specimen is subjected to compressive force and the various points at which the specimen reaches it elastic limit, yield point and breaking point in compression are recorded and using equations 3, 4 and 5 to calculate the stress, strain and young modulus respectively;

Procedure:

The stalk of the tomato seedling was laid on table of the universal testing machine and the machine was operated at a speed of 1 mm/min to induce the seedling to a compressive force, the forces and deflection at which the attached seedling reaches its elastic limit, yield point and breaking point in compression were automatically recorded by the machine and it also plots the result automatically, this process carried out for all the 50 samples.

3. RESULTS AND DISCUSSION

The results of the physical and mechanical properties of the 4 weeks old seedlings of Roma VF Tomato variety is presented on Tables 1 to 5.

3.1 Physical Properties of Roma VF Cultivar of Tomato

The average height of the seedling (Table 1) was found to be 243.36 mm which agrees with the recommended height of tomato seedling for transplanting by Shankara *et al*. (2005) while that of the stem thickness was found to be3.53 mm which is in agreement with the stem thickness of Tomato reported byLiang et al. (2015), Ilene (2013) and Iya and Braide (1999). The maximum mass of the seedling was 9.95g and the minimum was 3.12 g with an average of 6.28 g and the average spread diameter of the seedling was found to be 70.08 mm which agrees with the result of spread diameter of Tomato obtained by Mahesh *et al.* (2011).

Table 1: Physical Properties of 4 weeks old Tomato Seedling

	Height (mm)	Weight (g)	Stem Thickness (mm)	Spread Diameter (mm)
Maximum	284.00	9.95	4.43	78.00
Minimum	183.00	3.12	2.29	62.00
Average ($\bar{x}$)	243.36	6.28	3.53	70.08
standard deviation (δ)	33.50	1.87	0.65	4.68
Coefficient of Variation (CV)	13.77	29.72	18.44	6.68

All results are obtained from 50 samples

3.2 Mechanical Properties of Roma VF Cultivar of Tomato

3.2.1 Impact Test

Table 2 presents the results of the impact energy test, the maximum height reached by the knife after impacting and cutting the stalk of the seedling was found to be 61.00 mm as against 97 mm reached when the knife was released without anything on its pact implying that the seedling absorbs about 1.79 J of the knife’s energy while the minimum height reached was 35 mm with the seedling absorbing a minimum of 1.04 J of the knife energy. The coefficients of variation of the impact height and impact energy are 16.17 % and 18.32%.

Table 2: Impact test result of 4 weeks old tomato

H = 97 mm, m = 2.948 kg and g = 9.81m/s^2		
	Impact Height (mm)	Impact Energy (J)
Maximum	61.00	1.79
Minimum	35.00	1.04
Average ($\bar{x}$)	51.52	1.32
Standard Deviation (δ)	8.33	0.24
Coefficient of Variation(CV)	16.17	18.32

All results are obtained from 50 samples

3.2.2 Frictional Angle

The results of the frictional angle and coefficient of friction of the seedlingson all three surfaces (Mild Steel Sheet, Aluminum sheet and Galvanize steel sheet) are presented on Table 3. The average frictional angle of the seedling when laid horizontally on Mild steel sheet, Aluminum sheet and Galvanized Sheet are44.43^o,42.96^o and 43.73^o respectively with frictional coefficients of 0.99, 0.94 and 0.96 respectively which are similar to those obtained by Ashutosh et al., (2015) for onions on the same surfaces (Mild Steel, Aluminum and Galvanize steel sheets)when vertically laid, the frictional angles were found to be 40.63^o on Mild steel with frictional coefficient of 0.86, 40.08^o with a frictional coefficient of 0.84 on Aluminum and 39.58^o with a frictional coefficient of 0.83 on Galvanized steel sheet.

Table 3: Frictional Properties of 4 weeks old Tomato seedling

	Vertical frictional angle (^{o})	Horizontal Frictional angle (^{o})	Vertical frictional coefficient	Horizontal Frictional coefficient
		Mild Steel Sheet		
Maximum	49.50	43.50	1.17	0.95
Minimum	39.50	36.50	0.82	0.74
Average ($\bar{x}$)	44.43	40.63	0.99	0.86
Standard Deviation (δ)	3.36	1.56	0.12	0.05
Coefficient Of Variation (CV)	7.56	3.83	11.71	5.47
		Aluminum		
Maximum	48.00	42.50	1.11	0.92
Minimum	38.30	37.00	0.79	0.75
Average ($\bar{x}$)	42.96	40.08	0.94	0.84
Standard Deviation (δ)	3.34	1.59	0.11	0.05
Coefficient Of Variation (CV)	7.77	3.96	11.73	5.58

	Vertical frictional angle (°)	Horizontal Frictional angle (°)	Vertical frictional coefficient	Horizontal Frictional coefficient
		Galvanized Steel		
Maximum	48.70	47.60	1.14	1.10
Minimum	38.50	35.40	0.80	0.71
Average ($\bar{x}$)	43.73	39.58	0.96	0.83
Standard Deviation (δ)	3.14	1.88	0.11	0.06
Coefficient Of Variation (CV)	7.18	4.74	10.94	6.95

All results are obtained from 50 samples

3.3.3 Tensile Test

The result obtained from tensile test of the stalk of Tomato seedling are presented on Table 4, maximum force applied which elongated the seedling to its maximum yield point by 11.31 mm is 4.26 N with the maximum stress and strains of 1.36 N/mm^2 and 22.61 % respectively with a Young's Modulus of 9.69 N/mm^2 while the minimum force that yielded the seedling at an elongation of 6.17 % is 2.26 N with a minimum stress, strain and Young's Modulus of 0.72 N/mm^2 12.36 % and 4.10 N/mm^2 respectively. The mean values of the stress, strain and Young's Modulus are 1.11 N/mm^2, 15.67 % and 7.36 N/mm^2 respectively which are lower than those reported by Dongdong and Jun (2016) for Wheat, Corn, Alfalfa and Coronilla.

Table 4: Tensile test result of 4 weeks old tomato seedling

	Force applied (N)	Elongation (mm)	Strain (%)	Stress (N/mm²)	Young's Modulus (N/mm²)
Maximum	4.26	11.31	22.61	1.36	9.69
Minimum	2.26	6.17	12.36	0.72	4.10
Average ($\bar{x}$)	3.50	7.83	15.67	1.11	7.36
Standard Deviation (δ)	0.65	1.79	3.58	0.21	1.84
Coefficient of Variation (CV)	18.54	22.84	22.84	18.54	24.96

All results are obtained from 50 samples

3.3.4 Tensile Test

The result of the compression test of the stalk of the Tomato seedling is presented on Table 5. The average compressive force that strains the seedling by 34.39 % is 11.64 N which is lower than those reported by Momtaz *et al*. (2019) for sweet corn stalk. The maximum and minimum strains are 47.85 % and 23.95 % respectively while those of the applied force are 16.7 N and 9.25 N respectively with Coefficient of Variation (CV) of 18.39 % and 20.01%.

Table 5: Compressive test result of 4 weeks old tomato seedling

Test No	Force Applied (N)	Deflection (mm)	Strain (%)
Maximum	16.70	0.96	47.85
Minimum	9.25	0.48	23.95
Average ($\bar{x}$)	11.64	0.69	34.39
Standard Deviation (δ)	2.33	0.13	6.32
Coefficient of Variation (CV)	20.01	18.39	18.39

All results are obtained from 50 samples

4. CONCLUSION

Physical and mechanical properties of the plant are the most important properties in designing agriculture machine. In the operations of transplanting machines, the seedlings are subjected to various forces which are liable to damage the seedling if proper design is not adhered to. This work mainly concentrated on the determination of the physical and mechanical properties (stem thickness, height, weight, spread diameter, angle of friction, frictional coefficient, impact properties, compressive properties and tensile properties) of four weeks old seedling of the most widely grown variety of tomato in Nigeria (Roma VF). The physical properties of the seedlings were found to include maximum and minimum heights of 284 and 183 mm respectively, maximum weight of 9.95 g and 3.12 g minimum weight, maximum stem thickness of 4.43 mm and minimum of 2.29 mm with maximum and minimum spread diameters of 78 and 62 mm respectively. The mechanical properties include maximum and minimum Impact energies of 1.79 and 1.04 J, the maximum and minimum frictional coefficients of the seedlings on Mild steel sheet, Aluminum sheet and Galvanized sheets when the seedlings are laid horizontally were found to be 0.95, 0.74, 0.92, 0.75, 1.10 and 0.71 respectively with corresponding static frictional angles of 43.5, 36.5, 42.5, 37.0, 47.6 and 35.4 degrees respectively, while that of the vertically oriented seedlings are 1.17, 0.83, 1.11, 0.79, 1.14 and 0.8 respectively with corresponding angle of frictions of 49.5, 39.5, 48.0, 38.3, 48.7 and 38.5 respectively. The maximum and minimum forces resisted by the seedlings in tension were found to be 4.26 and 2.26 N respectively with corresponding strain, stress and Young's Modulus of 22.26 and 12.36 %, 1.36 and 0.72 N/mm^2 and 9.69 and 4.10 N/mm^2 respectively. While the seedlings were able to with stand a maximum force of 16.7N and a minimum of 9.25 N in compression with maximum deflection of 0.96 mm and a minimum of 0.48 mm with a maximum strain of 47.85 % and a minimum of 23.95 %.

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