Physical and mechanical properties of locally cultivated tomatoes in Sunyani, Ghana

Article *in* Scientific African · November 2020

DOI: 10.1016/j.sciaf.2020.e00616

Donatus Zogho
University of Lorraine

Eric Essandoh
University of Energy and Natural Resources

Eric Gyimah Anokye
Kwame Nkrumah University Of Science and Technology

Scientific African 10 (2020) e00616

Contents lists available at ScienceDirect

Scientific African

journal homepage: www.elsevier.com/locate/sciaf

Physical and mechanical properties of locally cultivated tomatoes in Sunyani, Ghana

Felix Uba[a,*], Eric Osei Esandoh[a], Donatus Zogho[b], Eric Gyimah Anokye[a]

[a] *University of Energy and Natural Resources, Ghana*
[b] *Université de Lorraine- École Nationale d'ingénieurs de Metz, France*

ARTICLE INFO

Article history:
Received 11 May 2020
Revised 25 September 2020
Accepted 28 October 2020

Keywords:
Coefficient of friction
Physical properties
Mechanical properties
Firmness
Energy

ABSTRACT

The physical and mechanical properties of tomato fruits are very pertinent and crucial in the design of mechanised equipment for harvesting, cleaning, sorting, grading, storing and packaging for transportation from farms to processing plants or market centres. The concept of physical and mechanical properties can be applied to prevent the degradation of tomato fruits during harvesting and processing. The objective of this research is to establish the physical and mechanical properties of locally cultivated tomatoes (*Eva F1* variety) in the Bono Region of Ghana. The 3-Dimensional linear characteristics of the samples obtained from linear measurement lead to the conclusion that *Eva F1* is spherical and as a result it can undergo both sliding and rolling motions because of the aspect ratio which is between 77.54 to 95.18 and sphericity values above 83.00. The linear measurements also revealed that handling and sorting devices should have an aperture size between 34 and 77 mm for outlet or inlet dimension for mechanisation. An ELE compression machine was used to determine the firmness of different grades of *Eva F1* tomatoes (red and yellow). An average compressive force of 16.88 N was found to cause fracture to the cell wall of a ripe (red) tomato while the yellow grade experienced an average force of 21.77 N. An inclined plane was used to determine the coefficient of friction for two different wooden surfaces (smooth and rough wawa boards). Average coefficient of friction values higher than 0.22 are recommended for mechanised material handling equipment and 0.21 or lower for packing boxes suitable for transportation. The research also showed that the best stage for the transportation of tomato is when they are at the yellow stage with low coefficient of friction and can absorb more energy before rupture.

Introduction

The edible fruit of the Solanum Lycopersicum plant, the tomato, has wide range of applications including the preparation of soup, stew, ketchup, salad, drinks, pizza, etc., [14]. The health contributions of tomato cannot be undermined as it is a

* Corresponding author.
E-mail address: felix.uba@uenr.edu.gh (F. Uba).

https://doi.org/10.1016/j.sciaf.2020.e00616

rich source of vitamins, minerals, carbohydrates, fats, protein and about 74 kJ(18 kcal) of energy. There are several varieties of tomatoes including; Jaguar, Roma VFN, Rio Grande, Ada cocoa, Lindo, Pectomech VF, Derma and Tropimech [25].

Their colours range from deep crimson to orange, yellow, green and chocolate. The quality of both fresh and processed or canned tomato depends on its physical, mechanical and chemical properties [2–4,8]. This paper intends to look into the effect of physical and mechanical properties on the quality of tomato fruits. Physical properties are the characteristics of substances that do not influence the chemical composition or structure of the substance while mechanical properties are characteristics exhibited by substances when they are subjected to external forces. The physical and mechanical properties of tomato fruits are very pertinent in the design of equipment for, harvesting, cleaning, sorting, grading, storing and packaging for transportation from farms to processing plants or markets and even in the design of tomato processors (processing machines) [12,18,28]. They are as well important for preventing the degradation of agricultural produce including the tomato fruit.

Studies conducted by [28] reveal that the static and sliding friction coefficients on different surfaces such as steel and rubber range from 0.375 to 0.641 and 0.396 to 0.503, respectively. However, one of the commonest materials for tomatoes handling in Ghana is wood (of several species) so this research would determine the static and sliding friction coefficient of wood (specifically plywood).

The packaging aspect of tomato handling brings the fruits to interact with material surfaces such as paper, plastic, textile, wood and metal. Friction occurs when the tomato fruit comes into contact with any of these materials. The friction between the tomato fruit and the surface it is in contact with vary from material to material. Friction plays an important role in material handling. For instance, during fruits handling friction is needed on material handling equipment (wooden carton, conveyor) to prevent the fruit from slipping or sliding backward. On the other hand, surfaces with less friction are required at discharge points to prevent too much use of energy [22]. Furthermore, physical attributes such as size, shape, bulk density and porosity are major considerations in the design of hopper, driers and aeration systems, as these properties affect the resistance of the stored mass to airflow [23].

Physical and Mechanical properties are needed for texture analysis and better understanding of product quality. For example, firmness (a mechanical property) of horticulture products is frequently used to determine their maturity and ripeness, which is important in handling, storing and processing procedures [26].

Another mechanical property is compression which always occurs during transportation. This occurs to fruits at the bottom of containers. Fruits also undergo compression from adjacent/side containers [6,12,14,21,23,27,28]. Viscoelastic character of tissues of the fruits can get damaged by this forces and therefore needs to be considered when packing fruits.

Bruising occurs during multiple impacts due to positional changes following different handling sequences within the supply chain, e.g. packaging, this occurs in collisions between vegetables and the handling equipment or containers during mechanical handling, [11,13,21].

Common mechanical properties of tomatoes are yield stress, hardness, rupture and penetration force, deformation at rupture and penetration, firmness, modulus of elasticity and Poisson's ratio and its components for different varieties at various stages of ripening [17]. The physical properties mainly include size, density, colour, shape (volume), mass and porosity of tomato fruit [4,11]. All the properties are necessary for the design of equipment for harvesting, transporting, cleaning, sorting, packing, storing, processing, etc. of fruits [13,12,14,15].

Tomato processing industries in Ghana are not progressing due to monetary issues and their seeming little knowledge on the physical and mechanical properties of their raw material, tomatoes. Straining tomatoes beyond the limit of its mechanical properties affects its appearance and quality thus causing both farmers and processors to incur losses. This has led to the collapse of several tomato processing industries in the country in the past. For instance, GIHOC cannery at Nsawam, Pwalugu Tomato Factory at Pwalugu, and the GIHOC Tomato Cannery-TOMACAN at Wenchi are all out of business because of economic losses due to massive decay or decomposition of their tomatoes [24].

The design of their system (processing technology) did not take these criteria into consideration and has led to production deficiencies. This resulted in reduction of work efficiency, product quality and increase in product loss. Therefore, determination and consideration of these criteria should play an important role in designing agricultural and processing equipment for tomatoes [20].

Also, much has to be done in the mechanization and automation of the processes involved in tomato production since most of the physical and mechanical properties of the tomatoes consumed in the country are degraded during the manual performance of these processes i.e. cultivation, harvesting, packaging, transportation, storage, etc. [24].

Ghana has a vast fertile land for tomato production but before the cultivation of the fruit can be felt in the country, mechanical and physical properties are needed to help in the mechanisation and automation of various stages to achieve quality product [5,24].

It is sad to know that Ghana which is used to be one of the major cultivators of tomatoes in the West African sub-region is now importing about 7 thousand metric tons of fresh tomatoes annually from neighbouring countries and 27 thousand metric tons of processed tomatoes from Europe, [5,25].

This therefore raises an alarm for an assessment of the physical and mechanical properties of locally cultivated tomatoes to determine the best handling practices to lure both farmers and processors to revamp the tomato industry [17].

The objective of this research is to determine the physical and mechanical properties of locally cultivated tomatoes in the Bono Region of Ghana with the aim of increasing the shelf life of tomatoes and hence improve the economy.

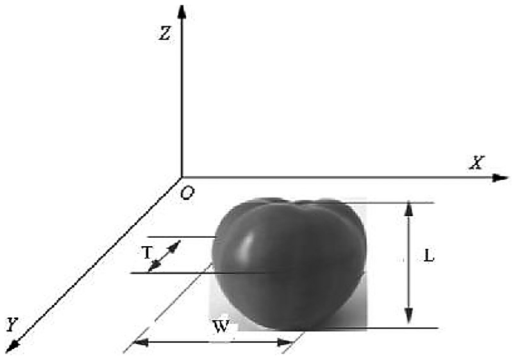

Fig. 1. Physical dimensions of tomatoes fruits, [13].

Fig. 2. A sample being prepared for planimeter test.

Every farmer in Ghana will be very delighted and proud of his or her work when their tomatoes end up in the market or other destinations with no or unnoticeable deformation or damage. Wholesalers, retailers, processors and consumers will also be delighted to have fresh tomatoes from the farms and markets, respectively without signs of damage or fracture on them, hence the need to undertake this research.

Materials and methods

The mechanical and physical properties of mature fresh tomato fruit of *Eva F1* variety were determined in all the experiments. Samples were obtained from Ministry of Food and Agriculture division in the Bono Region of Ghana. Samples of fruits were obtained as and when laboratory measurements were to be performed and the experiments were carried out under room conditions (averagely 25 °C). The physical properties estimated are arithmetic mean diameter (D_a), geometric mean diameter (D_g), aspect ratio, sphericity, surface area, porosity, true volume and true density.

The following physical properties (arithmetic mean diameter (D_a), geometric mean diameter (D_g) and aspect ratio (Ra)) were estimated from the linear dimensions of the fruits. The dimensions in a 3-Dimensional cartesian coordinate plane are length (L), width (W), and thickness (T) as shown in Fig. 1 and they were obtained by the use of Vernier Callipers.

Mathematical relations are available for determining the above-mentioned physical properties of tomatoes. The arithmetic mean diameter (D_a), geometric mean diameter (D_g) and aspect ratio (Ra) were calculated from Eqs. (1), (2) [18] and (3) [16,23]:

$$D_a = {}^{(L+W+T)}/_{3} \tag{1}$$

$$D_g = 3\sqrt{(LWT)} \tag{2}$$

$$\%R_a = \frac{W}{L} * 100 \tag{3}$$

Where L, W and T represent length, width and thickness of the fruits, respectively.

The true surface area was determined using a planimeter, whereas the total surface area of the fruit, S, was theoretically calculated as apparent surface area using two different equations [23], stated as Eqs. (4) and (5), respectively. The true surface area was determined using a planimeter (Fig. 2).

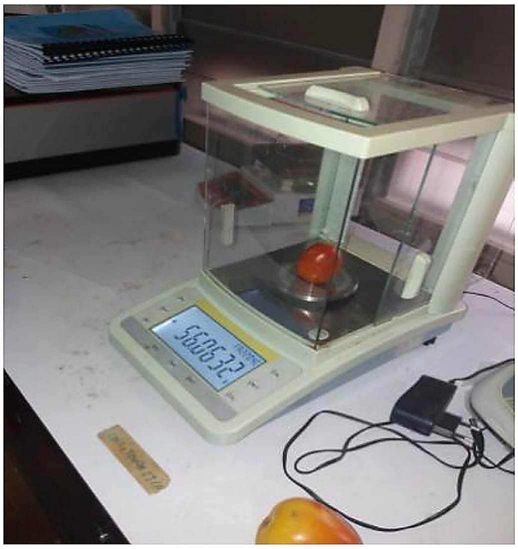

Fig. 3. Measurement of mass of a sample of tomato fruit.

$$S = \frac{\pi B L^2}{2L - B} \quad (4)$$

$$B = (WT)^{0.5} \quad (5)$$

where, B is a length given by the square root of the product of the width and thickness of the tomato fruit sample.

The criterion used to describe the shape of the tomato fruit is sphericity. Thus, the sphericity (Φ) of samples was found according to the relationship given by [18] in Eq. (6);

$$\phi = 3\sqrt{(LWT)}/L \quad (6)$$

True volume and true density were determined by the liquid displacement method [18]. The true volume (V_t) and true density were calculated by Eqs. (7) and 8:

$$V_t = {(M_a - M_w)}/{\rho} \quad (7)$$

$$\rho_t = M_a/V_t \quad (8)$$

where M_w is mass of sample in water; M_a mass of sample in air and ρ, density of water.

Fig. 3 shows the mass of the tomatoes (in Air) using a top pan scale that gives readings with a precision 0.001 g.

The apparent volume was calculated using the following equation for volume of ellipsoidal materials:

$$V_a = \frac{4\pi LWT}{3} \quad (9)$$

The error of apparent volume and true volume was obtained using Eq. (10);

$$\%e_V = {(V_a - V_t) * 100}/{V_t} \quad (10)$$

A unit mass (M_f) of tomato fruit was measured using a digital or electronic balance with a sensitivity of 0.001 g. In order to obtain the bulk density of the tomato fruit, a container with known mass and volume was filled with the samples to the top. The fruits were poured into the container in similar way and at a constant rate. After filling the container, it was weighed and the bulk density (ρ_b) was calculated from the ratio of fruit mass in the container to its volume.

The porosity ($\% \varepsilon$) of bulk fruits was computed from the values of true and bulk densities using Eq. (11), [18];

$$\%\varepsilon = \left(1 - \frac{\rho_b}{\rho_t}\right) * 100 \quad (11)$$

Tests for the following mechanical properties were performed; static coefficient of friction, compression force test, impact test and firmness test.

A convenient device for measuring the coefficients of friction of tomato is the inclined plane (Fig. 4). In order to estimate static coefficient of friction, (μ_s), the angle of slope of a wooden (wawa board) inclined plane is increased gradually until

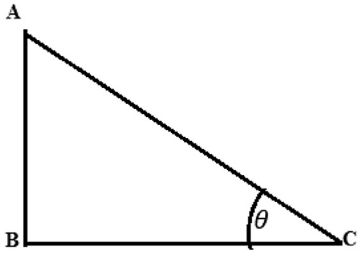

Fig. 4. Inclined Plane.

Fig. 5. Compression test being performed.

the tomato begins to slide down the plane. The choice of this material for constructing the inclined plane was based on the fact that the same material is used for carting tomatoes from farms to marketing centres. The coefficient of static friction is determined by the angle of the inclined plane, as expressed in Eq. (12). The quantity is dimensionless. The inclined plane was a two sided wooden hinged device which is set-up for use when the longest side (hypotenuse) is angularly displaced from the horizontal side till the fruit approaches the point it is about to slide as depicted in Fig. 4. The plane is assumed to be smooth and a level surface. The angle of inclination should be small to ensure accurate results. Also, fruits that are found to be in bad condition (ripped) are to be excluded from the experiment. The experiment was held on two kinds of surfaces of the wawa board (smooth and rough).

$$\mu_s = \tan\theta \tag{12}$$

A compression test was done using a compression test machine to understand the behaviour of tomato under compression loads. The ELE compression test machine in Fig. 5 was used to measure the load a fruit will withstand before rupture. The known load on the machine is 1.207 N/div with a calibration quoted in divisions (div). Each load (N) was estimated by multiplying the value of the known load by the recorded gauge reading and dividing it with 9.81 m/s^2 to calculate for the mass. This procedure was performed on 30 tomatoes for two grades of the fruits (i.e. red and yellow). The green fruits were not considered because in Ghana green fruits are not carted to the marketing centres.

To determine the amount of energy absorbed by tomato before rupture an impact test was carried out on the fruits using an impact test machine. Using ten tomatoes each of red and yellow fruits, the following were obtained from the experimental setup (Fig. 6). The Impact Test involves striking an impact specimen (V-notched) with a swinging weight. The instrument measured the energy absorbed in the process.

The firmness of the tomatoes under load was also determined over a period of four days. The Vernier Calliper was used to measure the mean diameter of the fruit and the measured diameters were recorded. The mean is recorded when a known weight is placed on the fruit on the first day. The procedure was repeated for four days and the firmness of the tomatoes over the days were calculated using Eq. (13);

$$firmness = \frac{constant\ load\ (L)}{area\ of\ tomatoes\ (A)} \tag{13}$$

Fig. 6. Impact testing machine being prepared for the experiment.

Table 1
Physical Properties of Red Fruits.

Item	Average	Min	Max	Standard Deviation, σ	Variance, σ^2
L(mm)	50.45	36.90	63.80	7.43	55.26
W(mm)	44.36	30.80	56.50	6.03	36.38
T(mm)	45.66	35.80	55.80	5.25	27.59
D_a(mm)	46.82	34.50	58.70	12.10	146.46
D_g(mm)	46.75	34.39	58.59	12.10	146.44
R_a	87.93	83.47	88.56	3.19	10.15
ϕ	92.68	93.21	91.84	0.70	0.49
S_a	6441.18	3500.52	10,053.06	3293.42	10,846,594.88
S_t	6407.60	3568.40	10,121.70	3305.72	10,927,797.73
$\%e_s$	0.01	0.02	0.01	0.01	0.00
M_a	118.70	80.00	190.40	57.61	3319.29
M_w	76.00	56.00	128.70	39.86	1588.65
V_t	42.83	24.07	61.89	18.91	357.49
ρ_t	2.77	3.32	3.08	0.45	0.20
ρ_b	1.63	1.04	2.41	0.69	0.48
$\%\varepsilon$	41.19	68.71	21.67	23.86	569.15

Results and discussion

Physical properties

The average linear dimensions for the various stages of *Eva F1* (red, green and yellow) taken from 60 samples each i.e. length (50.45 mm), width (44.36 mm) and thickness (45.66 mm) were measured using a digital Vernier Callipers and have been presented in Table 1–3.

The true surface area was determined using a planimeter (Fig. 3). The algebraic sum of the area of the peels of each tomato from the planimeter readings gave the total outer area of the fruit. The percentage error,$\%e_s$, between the apparent surface area, S_a and the true surface area, S_t was also calculated.

The smoothness/roughness of the fruit is related to the stage it is found in i.e. green, yellow and red [19]. This is found by physical examination were the ripe ones are smoother and less firm than the others this is because the unripe ones are found to have chlorophyll in their pericarp and turgid. Similarly, the stage of the fruit is determined by the colour which is also a physical property (green for unripe, yellow for transition and red for ripe) [7]. Table 4 shows the measured areas of the 10 pieces of peels obtained from the average sized tomato obtained from the sample size.

The masses of the tomatoes in water were used to estimate the bulk mass, bulk volume and bulk density, assuming a density of 0.997 g/cm^3 for water at room condition of 25 °C. The quantities were estimated from 12 samples of fruits. The porosity ($\%\varepsilon$) was also computed from the true and bulk densities using the relationship in Eq. (11) proposed by [18].

Mechanization of harvesting, handling and transportation need the parameters stated in the tables (Table 1–3) for effective operations. The average dimension of the various stages of tomatoes (red, yellow and green) selected as shown in the Tables (1 to 3) give the size of the aperture required for machines needed for separating and also for producing boxes meant for handling and transporting. An aperture size of 34 mm to 77 mm is required for the whole sample. This was obtained based on the average diameter of the various stages (green, yellow and red) of fruits considered. An average aperture of 47 mm for ripe/red tomatoes, 61 mm for yellow and 64 mm for unripe fruits (i.e. green) are recommended outlet or inlet

Table 2
Physical properties of yellow fruits.

Item	Average	Min	Max	Standard Deviation, σ	Variance, σ^2
L(mm)	70.73	45.60	90.40	13.71	188.04
W(mm)	56.84	43.40	70.10	8.00	64.07
T(mm)	55.54	39.40	66.30	7.44	55.39
D_a	61.03	42.80	75.60	16.50	272.32
D_g	60.66	42.72	74.90	16.19	262.25
R_a	80.36	95.18	77.54	10.67	113.76
ϕ	85.77	93.69	82.85	5.97	35.62
S_a	10,358.22	5421.21	15,546.65	5064.28	25,646,909.18
S_t	10,412.40	5319.50	16,549.70	5639.33	31,802,040.85
$\%e_s$	0.01	0.02	0.06	0.04	0.00
M_a	90.00	61.10	119.30	29.10	846.85
M_w	45.70	34.90	83.10	27.53	757.70
Vt	44.43	26.28	36.31	14.06	197.79
ρt	2.03	2.33	3.29	0.92	0.84
ρ_b	1.56	1.32	2.33	0.57	0.33
$\%\varepsilon$	22.98	43.23	29.09	14.95	223.56

Table 3
Physical properties of green fruits.

Item	Average	Min	Max	Standard Deviation, σ	Variance, σ^2
L(mm)	74.53	60.40	89.40	8.00	63.93
W(mm)	59.26	50.60	72.40	6.35	40.32
T(mm)	58.99	48.80	69.60	6.20	38.40
Da	64.26	53.27	77.13	11.97	143.28
Dg	63.87	53.03	76.66	11.85	140.51
Ra	79.52	83.77	80.98	3.18	10.13
ϕ	85.70	87.80	85.75	1.49	2.21
Sa	11,478.36	8012.43	16,538.62	4336.98	18,809,431.41
St	11,399.60	8066.70	16,345.80	4217.41	17,786,558.43
%es	0.01	0.01	0.01	0.00	0.00
M_a	117.00	82.10	170.30	45.05	2029.45
M_w	66.80	54.60	76.90	11.20	125.43
Vt	50.35	27.58	93.68	34.61	1197.94
ρt	2.32	2.98	1.82	0.58	0.34
ρ_b	1.08	1.11	1.33	0.18	0.03
$\%\varepsilon$	53.52	62.71	26.84	19.96	398.22

Table 4
Apparent surface area of average tomato of sample size.

Pieces	Area (mm^2)
1	7340.12
2	7900.43
3	4560.10
4	7131.36
5	7737.23
6	5853.23
7	9511.40
8	3234.32
9	5822.53
10	5321.11
Total	6441.183

dimensions for handling mechanisation/automation. These values also help manufacturers of tomatoes handling boxes to estimate the quantity of fruits that can be packed into the boxes at a time.

The density of the fruits ranges between 1.82 and 3.32 g/mm^3 showing that it will partially or completely sink when placed in water. This is an important parameter for separation of fruits using water and the various ways it could be handled and transported. With an average value ranging from 2.03 to 2.77 g/mm^3 it means it is less heavier than water and its movement can be relatively influenced by water.

The aspect ratio and sphericity range from 77.54 to 95.18 and 82.85 to 93.69, respectively, with an average value of 87.93 and 92.68 for red respectively, 80.36 and 86.77 for yellow respectively whiles 79.52 and 85.70 for green, respectively and all these data were obtained from Tables 1–3. These quantities describe the shape of the fruits. The values displayed show the

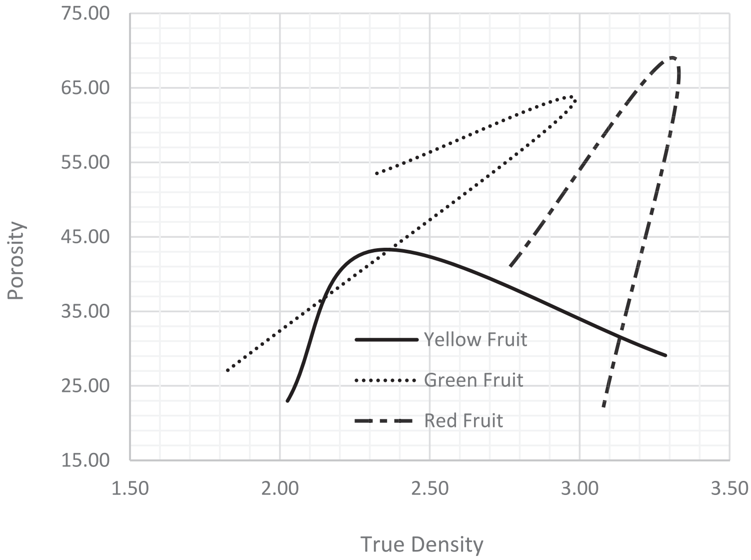

Fig. 7. Variation of porosity with true density.

tendency of describing the fruits as a sphere as compared to averages of 98.0% and 92.5% obtained from the works carried out by [9] and [13] respectively. This information helps to describe the type of movement that the fruits can undergo. The fruits can be considered to undergo both rolling and sliding when placed on a flat surface because spherical objects have been established to roll easily on surfaces while most have the tendency to slide on any surface. These is possible because of the aspect ratio which is between 77.54 to 95.18 and sphericity values above 83.00. This information also helps in the design of handling and sorting devices.

Porosity measures the fractional volume of the pores or air space in the fruit as compared to the total volume of the fruit. An average value of 41.19% for red fruit means about 41.19% of the volume is occupied by void space and the rest gelatinous matter and water. These parameters have a direct influence on the density. Fig. 7 shows how porosity varies with true density. It reveals that there is a critical value for porosity that when density reaches porosity will fall and all the graphs shown this characteristic. It will then be advantageous to determine the critical value for each fruit as it will help in the design of separation devices. The critical value relates to the mass and size which is an important parameter when mechanising fruit handling and transportation. It gives the range for porosity, that will allow the fruit to sink as air space influences floatation; a good information in sorting of fruits. The average porosity ranged from 22.98 to 53.52 which mean the fruits will not fully sink when placed in water which is an important information when formulating ways for transporting fruits by water.

Mechanical properties

Table 5 shows the average time and mass of weight. Some of the values for the yellow fruits were rounded off to zeros because they were found to be ripped during the experiment which rendered their values to be excluded from the analysis. The compression test was done purposely to determine the time it takes to break the cell wall by a load. From the table, smaller times and loads were taken to break the cell walls of the red tomatoes compared to the yellow tomatoes. This means, the red tomatoes have a weak cell wall as compared to the yellow fruits. This information will help in the packing of fruits during transportation. The packing levels for the red tomatoes should not be higher than the yellow tomatoes as the top tomatoes will exert their weight on the bottom ones (red tomatoes) causing them to fracture. It also gives the stage at which tomatoes should be transported to minimise damage to the fruits; the ideal stage of tomatoes recommended for transportation is the yellow fruits since they require more load and time to get fractured according to the results obtained by this research (i.e. the Red fruit needs an average of 1.720 kg of weight to rupture it in 7.3 s whiles the yellow requires 2.20 kg of weight in 15.8 s for rupture to take place). Similarly, compression values were also obtained for different varieties (Zucchero, Mosaica and 1018 F1; [10]) of tomatoes and values (2.309 kg, 1.624 kg and 2.427, respectively) fell within these values obtained.

Table 6 displays the results for the impact test. It was observed that the red tomatoes absorbed less mechanical energy during the impact test since its cell wall is softer than that of the yellow tomatoes. It means that higher energies are absorbed before the cell wall of the yellow tomatoes rupture. This information should enable farmers and packers to optimize the condition of the fruits for minimal bruising or damage during handling operations. Substantial amount of energy was absorbed by both red and yellow tomatoes before rupture under the impact test. The yellow tomatoes however absorbed more energy before rupture as compared to the red tomatoes, (energy absorbed for red fruit is 28.97 J whiles that of the

Table 5
Compression test results.

Item(s)	RED				YELLOW			
	Time(s)	Force, N	Mass, kg	Mass, g	Time(s)	Force, N	Mass, kg	Mass, g
1	6.1	20	2.038736	0.002039	18.5	24.23	2.469929	0.00247
2	8.3	15	1.529052	0.001529	12.6	19.45	1.982671	0.001983
3	7.5	16	1.630989	0.001631	17.5	25.21	2.569827	0.00257
4	6.4	18.3	1.865443	0.001865	18.5	25.32	2.58104	0.002581
5	8.2	12.9	1.314985	0.001315	13.2	17.32	1.765545	0.001766
6	7.2	16.98	1.730887	0.001731	20	19.45	1.982671	0.001983
7	6.2	19.2	1.957187	0.001957	15.2	19.43	1.980632	0.001981
8	8	17.8	1.814475	0.001814	18.3	18.99	1.93578	0.001936
9	7	12.9	1.314985	0.001315	14.3	19.92	2.030581	0.002031
10	6.5	15.32	1.561672	0.001562	15	21.34	2.175331	0.002175
11	6.5	17.3	1.763507	0.001764	20.9	21.25	2.166157	0.002166
12	8.1	18.2	1.85525	0.001855	12.3	16.34	1.665647	0.001666
13	7.8	12.2	1.243629	0.001244	17	19.34	1.971458	0.001971
14	8	16.4	1.671764	0.001672	18.2	20.36	2.075433	0.002075
15	6.4	16.3	1.66157	0.001662	13	19.93	2.0316	0.002032
16	6.7	15.9	1.620795	0.001621	13.2	21.39	2.180428	0.00218
17	7	18.4	1.875637	0.001876	13	23.88	2.434251	0.002434
18	7	13.5	1.376147	0.001376	16.7	25.12	2.560652	0.002561
19	6	13.2	1.345566	0.001346	16.6	27.83	2.836901	0.002837
20	6	16.2	1.651376	0.001651	12.9	29.31	2.987768	0.002988
21	8.2	18.3	1.865443	0.001865	0	0	0	0
22	6.3	18.3	1.865443	0.001865	0	0	0	0
23	8.2	16.45	1.67686	0.001677	0	0	0	0
24	8.3	12.45	1.269113	0.001269	0	0	0	0
25	8.2	16.43	1.674822	0.001675	0	0	0	0
26	8	19.34	1.971458	0.001971	0	0	0	0
27	8.1	19.32	1.969419	0.001969	0	0	0	0
28	6.5	21.43	2.184506	0.002185	0	0	0	0
29	7.9	19.43	1.980632	0.001981	0	0	0	0
30	7.3	23	2.344546	0.002345	0	0	0	0
Average	7.263333	16.88167	1.720863	0.001721	15.845	21.7705	2.219215	0.002219
Standard Deviation of mass(g)				0.000274				0.000353

Table 6
Impact test results.

Items	Energy absorbed (joules)			
	Red	σ	Yellow	σ
1	30.2	1.5129	28.8	0.4489
2	28	0.9409	28.9	0.3249
3	28.5	0.2209	29	0.2209
4	29.1	0.0169	29.5	0.0009
5	28.3	0.4489	30.4	0.8649
6	29	0.0009	30.2	0.5329
7	28	0.9409	30	0.2809
8	28.6	0.1369	29.3	0.0289
9	30.1	1.2769	29.8	0.1089
10	29.9	0.8649	28.8	0.4489
Average	28.97	0.7975588	29.47	0.571052

yellow is 29.47 J). This implies that, during harvest even if the fruits would be allowed to fall down or into a receptacle, both should not be allowed to fall at the same height. Low falling heights for the red fruits should be selected because they are more susceptible to damage than the yellow ones. This information allows much care to be taken especially when harvesting ripe (red) tomatoes or preferably the fruits should be harvested before they ripe.

The tomatoes were assumed to be spherical in shape to help estimate its surface area. From the results in both Table 7 and Fig. 8, it can be observed that firmness increased and then decreased after some time and fell within 0.33 to 0.55 N/mm^2. During the first day, the tomatoes contained more water and also a strong cell wall which made them tough. However, at that stage, they were more susceptible to puncture due to its turgidity. During the second day after the first impact, the tomatoes lost water through evaporation due to the impact of the imposable load. The fruit walls of the Tomatoes became tougher due to the loss of water. On the third day, the firmness decreases lower than that of the second day but a bit higher than that of the first day. This implies that, though the tomatoes lost water through the cell wall making

Table 7
Firmness test results.

Item	Diameter				
	Day 1	Day 2	Day 3	Day 4	Day 5
Sample 1	38.3	37.5	31.5	34.5	36.8
Sample 2	36.2	35.6	29.5	32.6	34.9
Sample 3	36.9	35.9	29.8	32.8	35.1
	Area				
Sample 1	4610.2	4419.6	3118.5	3740.8	4256.2
Sample 2	4118.5	3983.1	2735.1	3340.1	3828.0
Sample 3	4279.3	4050.5	2791.0	3381.2	3872.0
	Firmness				
Sample 1	0.33	0.34	0.48	0.40	0.35
Sample 2	0.36	0.38	0.55	0.45	0.39
Sample 3	0.35	0.37	0.54	0.44	0.39

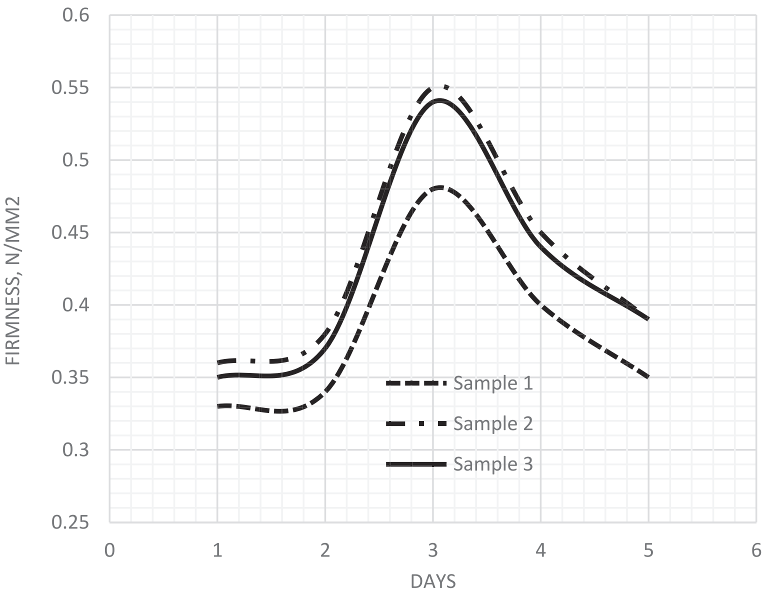

Fig. 8. Firmness variation with time.

Table 8
Dynamic coefficient of friction for fruits.

Sample	Coefficient of friction	
	Smooth	Rough
1	0.21	0.22
2	0.19	0.22
3	0.23	0.23
Average	0.21	0.22

their pericarp shrink it became tougher than the first day as a result of excessive loss of water through evaporation. From this point the cell wall started deteriorating leading to the decrease in the firmness of the tomato fruit as shown in Fig. 8. This trend (decrease in firmness with time) was also observed in [1] with values ranging from 0.2 N/mm^2 to 3.30 N/mm^2.

Hence, it will be better to transport the tomatoes during the first and second day after harvesting when the firmness is good with good percentage of water or moisture content.

To determine the coefficient of friction the ripening stages were divided into three and the coefficient of dynamic friction were determined for the various stages on both rough and smooth wooden surfaces. Table 8 and Fig. 9 show the results for the stages. It was observed that the average coefficient of friction value is higher for the rough surface, (i.e. an average value of 0.21 for smooth surface and 0.22 for rough surface). Hence, in order to reduce shear on the tomatoes during

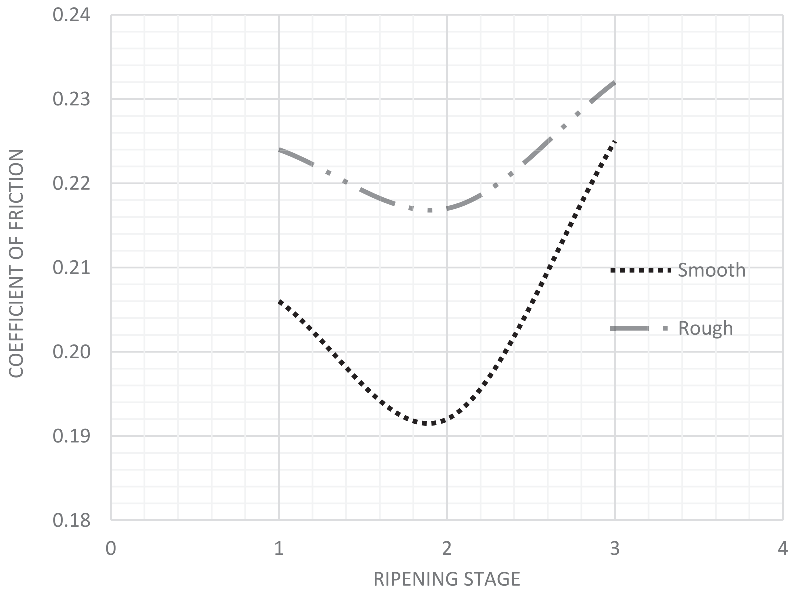

Fig. 9. Ripening stage against coefficient of friction.

transportation, boxes made from smoother wood should be used. The figure displays the effect of friction on the ripeness of tomatoes as it can be seen that the riper the tomatoes, the more susceptible it is to shear deformation due to the rise in friction. The tomato fruit begins to lose water and the pericarp begins to collapse reducing its smoothness when its ripeness is increased. It is observed that the coefficient of friction values of rougher boards are higher than those of smoother boards. Since higher friction favours shear deformation, using rougher boards to construct boxes or containers for conveying tomatoes during transportation, poses more danger to the produce thus causing it to reduce its wholesomeness. It was also observed by this study that boxes with coefficient of friction lower than 0.21 should be used for holding tomatoes prior to its transportation from the farm to processing plants or markets. However, in tomatoes processing factory conveyers are used to transport tomatoes during processing. The conveyor belt needs to be rough to some extent, in order to hold the tomato whiles it is being conveyed without rolling and sliding. In this case belt with coefficient of friction higher than 0.22 should be employed. A value of such magnitude is acceptable because from [9] and [10] coefficient values of 0.3 and between 0.157 to 0.184 were obtained for wood and plywood specifically which form one of their handling materials, respectively.

Conclusion

The water displacement method was used to determine the true average volume and density of red tomato (42.83 mm^3 and 2.77 g/mm^3), yellow tomato (44.43 mm^3 and 2.03 g/mm^3) and green tomato (50.35 mm^3 and 2.32 g/mm^3). Red and Yellow were placed in a compression test machine and yielded under an average weight of 1.72 kg (16.88 N) to cause fracture to the cell of the red tomato fruit whiles that of the yellow fruit was 2.2 kg (21.77 N). Also, an average coefficient of friction higher than 0.22 are recommended for conveyors belts and boxes of 0.21 coefficient or lower are suitable for transportation. Handling and sorting devices should also have an aperture size of 34 to 77 mm for the whole sample considered. An average aperture of 47 mm for ripe/red tomatoes, 61 for yellow and 64 for unripe fruits (i.e. green) are recommended outlet or inlet dimension for mechanisation. The fruits can be considered to undergo both rolling and sliding when placed on a flat surface and these are possible because of the aspect ratio which is between 77.54 to 95.18 and sphericity values above 83.00. This information also helps in the design of handling and sorting devices. The research also shows that the best stage for the transport of tomato is when they are at the yellow stage when the coefficient of friction is low.

Declaration of Competing Interest

None.

Acknowledgments

The authors will like to thank all technicians that helped in any form to bring out this findings, especially technicians at KNUST, Kumasi. The authors will also like to declare that the research was conducted using the physical facilities of Kwame Nkrumah University of Science and Technology, Kumasi, Twene Amanfo Senior Secondary School, Sunyani and Notre Dame Girls Senior Secondary School, Fiapre and it was financially supported by the authors.

References

[1] N. S. N. Albaloushi, M.M. Azam, A.H. Eissa, Mechanical properties of tomato fruits under storage conditions, J. Appl. Sci. Res. 8 (6) (2012) 3053–3064.
[2] N.N. Albaloushi, M.M. Azam, E.A. Amer, Mechanical properties of tomato fruits under storage conditions, J. Appl. Sci. Res. 8 (2012) 3053–3064.
[3] E. Altuntas, M. Erkol, The effects of moisture content, compression speeds, and axes on mechanical properties of walnut cultivars, Food Bioproc. Tech. 4 (7) (2011) 1288–1295.
[4] S. Arazuri, C. Jaren, J. Arana, J. Perez de Ciriza, Influence of mechanical harvest on the physical properties of processing tomato, J. Food Eng. 80 (2007) 190–198.
[5] S. Asuming-Brempong, A.A. Boakye, Socio-economic Analysis of Tomato Production in Ghana, Technical report Prepared For the Ghana trade and Livelihood coalition. July, University of Ghana Affiliates, Accra, Ghana. Mimeo, 2008.
[6] A. Baltazar, J. Espina-Lureco, I. Ramos-Torres, G. Gonzalez-Aguilar, Effect of methyl jasmonate on properties of intact tomato fruit monitored with destructive and nondestructive tests, J. Food Eng. 80 (2007) 1086–1095.
[7] H.T. Bui, J. Makhlouf, C. Ratti, Postharvest ripening characterization of greenhouse tomatoes, Int. J. Food Properties 13 (4) (2010) 830–846.
[8] FAOSTAT. 2011. Retrieved August 25th, 2018 from http://faostat.fao.org/site/339/default.aspx
[9] A. Jahanbakhshi, V.R. Sharabiani, K. Heidarbeigi, M. Kaveh, E. Taghinezhad, Evaluation of engineering properties for waste control of tomato during harvesting and postharvesting, Food Sci. Nutr. 7 (2019) 1473–1481.
[10] O. Kabas, A. Ozmerzi, Determining the mechanical properties of cherry tomato varieties for handling, J. Texture Stud. 39 (2008) 199–209.
[11] A. Kilickan, M. Guner, Physical properties and mechanical behaviour of olive fruits under compression loading, J. Food Eng. 87 (2) (2008) 222–228.
[12] Z. Li, P. Li, J. Liu, Effect of tomato internal structure on its mechanical properties and degree of mechanical damage, Afr. J. Biotechnol. 9 (12) (2010) 1816–1826.
[13] Z. Li, P. Li, J. Liu, Physical and mechanical properties of tomato fruits as related to robot's harvesting, J. Food Eng. 103 (2011) 170–178.
[14] Zhiguo Li, The effect of compressibility, loading position and probe shape on the rupture probability of tomato fruits, J. Food Eng. 119 (2013) 471–476.
[15] A.N. Lorestani, A. Tabatabaeefar, Modelling the mass of kiwifruit geometrical attributes, Int. Agrophysics 20 (2006) 135–139.
[16] I.N. Maduko, M.O. Faborode, Some physical properties of cocoa pods in relation to primary processing, Iƒe J. Technol. 2 (1990) 1–7.
[17] A.J. Matas, G. Lopez-Casado, J. Cuartero, A. Heredia, Relative humidity and temperature modify the mechanical properties of isolated tomato fruit cuticles, Am. J. Bot. 92 (3) (2005) 462–468.
[18] N.N. Mohsenin, Physical Properties of Plant and Animal Materials, Gorden and Breach Science Publisher, New York, 1978.
[19] K.M. Moneruzzaman, A.B. Hossain, W. Sani, M. Saifuddin, Effect of stages of maturity and ripening conditions on the physical characteristics of tomato, Am. J. Biochem. Biotechnol. 4 (4) (2008) 329–335.
[20] J.E. Orchard, E.K. Suglo, Integrated Food Crops Systems projects: Enhancing Smallholder Livelihood Through Reducing Costs and Adding Value to Agricultural production. Final Technical Report, Organization, City, 1999.
[21] R. Polat, T. Aktas, A. Ikinci, Selected mechanical properties and bruise susceptibility of nectarine fruit, Int. J. Food Properties 15 (2012) 1369–1380.
[22] S.M. Razavi, R. Akbari, Biophysical Properties of Agricultural & Food Materials, Ferdowsi University of Mashhad press, 2006.
[23] S.M. Razavi, M. BahramParvar, Some physical and mechanical properties of kiwifruit, Int. J. Food Eng. 3 (6) (2007) 1–14, doi:10.2202/1556-3758.1276.
[24] E.J. Robinson, S.L. Kolavalli, The Case of Tomato in Ghana: Productivity (No. 19), International Food Policy Research Institute (IFPRI), 2010.
[25] N.Y. Sarfo, Importance, Source and Control of Bacteria Wilt Disease in Greenhouse Tomato (Solanum Lycopersicum L.) in Southern Ghana, Master's Thesis, University of Ghana, Legon, 2018.
[26] J.F. Thompson, C. Crisosto, Handling at destination markets, in: A.A. Kader (Ed.), Postharvest Technology of Horticultural Crops, DANAR Publication, 2002.
[27] C. Valero, C.H. Crisosto, D. Slaughter, Relationship between nondestructive firmness measurements and commercially important ripening fruit stages for peaches, nectarines and plums, Postharvest Biol. Technol. 44 (2007) 248–253.
[28] L. Zhiguo, L. Pingping, L. Jizhan, Effect of mechanical damage on mass loss and water content in tomato fruits, Int. Agrophys. 25 (2011) 77–83.