Journal of Soil Sciences and Agricultural Engineering

Journal homepage: www.jssae.mans.edu.eg
Available online at: www.jssae.journals.ekb.eg

Study on some Properties of Tomato Fruits for Natural Sun Drying

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ABESTRACT

The present study aimed to determine some physiochemical and mechanical properties of tomato fruits (commercial variety Jasmin 775), and regression models to estimate volume and mass based on diameters and projected area, which is considered as a database for designers and developer of machine or parts of agricultural smart mechanisms for harvesting, sorting, grading, handling, halving, and slicing. Physical properties were included the axial dimensions, arithmetic diameter, geometric diameter, mass, density, surface area, packing coefficient, sphericity, aspect ratio and draying rate of the tomato fruits. The mechanical properties were studied were the static coefficient of friction and firmness. The results indicated that the model for the prediction of volume based on dimension was $V_J = -199.4 + 2.456\, D_{max} + 2.791\, D_{min}$, while the model for the prediction of mass based on dimension was $M_J = -204.4 + 2.516\, D_{max} + 2.796\, D_{min}$ and model for the prediction of mass based on projected area was $M_J = -42.14 + 5.438\, P_a$. The model's equations obtained are important in predicting volume and mass of tomato fruits to designers of post-harvest machines that rely on vision technologies such as handling sorting and grading in food factories and agricultural harvest robots related to this variety.

***Keywords*: Tomato fruits, physical properties, volume modeling, mass modeling, sun drying.**

INTRODUCTION

The development of agricultural smart machine systems for harvesting, sorting, or grading tomato (*Solanum lycopersicum L.*) depend on knowing relationship between the physical properties and mass and volume of the fruits. Most tomato projects lack the mechanization and full information about the physical properties of the preferred tomato varieties to manufacturing. Egypt occupies the fifth center globally in the production of tomato, with an annual production volume of close to 7 million tons (FAO 2020), but the tomato crop is exposed to loss in the harvesting and production stages and during retail and wholesale operations, as well as a significant loss in the level of product quality. Therefore, study of the physical properties of tomato fruits has major role in development of mechanization for harvesting processes and post-harvest treatments. Therefore, the sun drying of tomatoes is one of the technical solutions to reduce the losses in this strategic crop (Bahaa 2020). The production of dried tomato is related to the climate condition in Egypt. It is produced in the winter season in Luxor and Aswan, As increase in solar radiation intensity and decrease in air humidity helps to process natural sun drying of tomato fruits. The shelf life of tomatoes is relatively short (Hoeberichts *et al.* 2002) due to different postharvest physiological, physical, and chemical changes that occur during storage (Fagundes *et al.*, 2015). These changes are triggered by the production of ripening hormones called ethylene (Carrari and Fernie 2006). The physical properties of tomato are important to design the equipment for processing, transportation, sorting, separation, and storing. Designing such equipment without consideration of these properties may yield poor results. Therefore, the determination and consideration of these properties have an important role (Taheri *et al.* 2009). The most valuable parts of the fruit with the highest content of dry mass are partitions and outer wall. Testing of mechanical properties is practical for the design of harvesting machines and all post-harvest operations: conveyors, sorting, grading, and packing machines, equipment for loading and unloading, storage structures, drying equipment (Kabas and Ozmerzi 2008). In the case of both mass and volume modeling, based on determined models for predicting mass and volume by using some geometric attributes (Khanali *et al.* 2007). Tabatabaeefar and Rajabipour (2005) used this method for predicting mass of apple fruits. According to the mechanical properties, a new method to grasp the tomato by the robot's fingers can be proposed to reduce the rupture probability of tomato fruit with symmetric internal structure during robot's harvesting (Li *et al.* 2011). The cost-effective grading system could be developed by constructing the relation between fruit physical properties and mass (Vivek *et al.* 2017). The determination of fruit mass based on easily measurable geometrical properties could decrease the grading time and avoid excessive workloads and labor costs in the industries (Demir *et al.* 2020). Fruit width and projected area perpendicular to width in the quadratic model and ellipsoidal volume in the linear model were found best based on the highest R^2 for predicting the mass of blood fruit (Sasikumarey al. 2021).

The objectives of this study are to determine of some physiochemical and mechanical properties of tomato (Jasmin 775) variety, it is a new variety customed to natural sun drying, to obtain information that could contribute to database designing for development and design of machines or parts of smart mechanisms for harvesting, sorting, grading, handling, halving, and slicing.

MATERIALS AND METHODS

Fresh tomato fruits were used in this study of the commercial tomato Jasmin 775 variety (Importer Techno Green co., production Syngenta - Netherlands). The fruits were obtained from Agricultural Experiments and Research Center, Aswan University, Egypt in winter 2021 and there kept inside polyethylene bags in a refrigerator at 4°C prior to carrying out the measurements. The measurements and testing were carried out the day after the harvest in Agri., and

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DOI:10.21608/jssae.2021.102632.1036

Nat. Res. Aswan U., Egypt. Healthy, red ripe mature tomatoes were randomly selected by hand, then cleaned.

Tomato fruits physiochemical properties

Axial dimensions

One hundred fresh tomato fruits were randomly selected to measuring of three principal dimensions of height (H), the greatest diameter ($D_{max.}$) and smallest diameter ($D_{min.}$), where ($D_{max.}$ and $D_{min.}$) is a plane perpendicular to a polar axis as shown in Fig. (1). This method has been successfully used in other fruits by several researchers as (Ghaffari *et al*., 2015), These dimensions were measured with a digital Vernier-caliper with an accuracy of 0.01 mm.

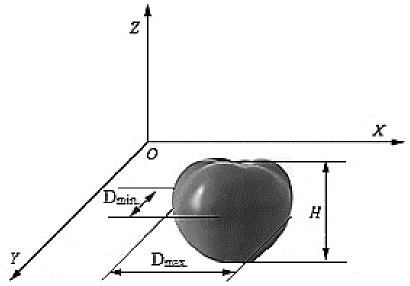

Fig. 1. Tomato fruit axial dimensions

Average diameter

The average diameter was calculated by the arithmetic mean and geometric mean methods of the axial dimensions. The arithmetic mean diameter (D_a, in mm.) and geometric mean diameter (D_g, in mm.) of the tomatoes fruit were calculated using the following equations according to, (Li *et al.* op. cit.):

$$\mathbf{D_a = (H + D_{max.} + D_{min.})/3} \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$\mathbf{D_g = (H \times D_{max.} \times D_{min.})^{\frac{1}{3}}} \ldots\ldots\ldots\ldots (2)$$

Surface area (S_A)

Surface area of tomato is outside total area of the fruit, it is very important characteristic in determining of heat transfer coefficient and useful for analyzing heat and moisture transfer during drying processes. Surface area of tomato fruits (S_A) in cm^2 was calculated by using the following equation according to (Moradi *et al*., 2017).

$$\mathbf{S_A = \pi(D_g)^2} \ldots\ldots\ldots\ldots\ldots (3)$$

Projected area (Pa)

Digital camera Canon EOS M50 EF-M (24.1 MP) was used to capture the image of fruits at the position to allow the greatest and lowest diameters to appear. Then, the pictures of fruits were exported to AutoCAD 2020 program to calculate the projected area (Mahmoud and Elkaoud, 2019).

Sphericity and aspect ratio

The sphericity (S_p, %) was calculated by using the values of the geometric mean diameter and high from equation (4), and the aspect ratio which relates the fruit greatest diameter to height of the fruits will be determined by equation (5) according to (Moradi *et al*. op. cit.).

$$\mathbf{S_p = (H \times D_{max.} \times D_{min.})^{\frac{1}{3}}/H \times 100} \ldots\ldots\ldots (4)$$

$$\mathbf{R_a = D_{max.}/H \times 100} \ldots\ldots\ldots\ldots\ldots (5)$$

Mass (M, g)

Determine a single tomatoes fruit mass (g) for separately using a digital electrical balance with an accuracy of 0.01 g.

Density

The volume of each tomato fruit was determined by using the water displacement method. 700 milliliter of water was placed in a 1000 milliliter graduated measuring cylinder and fruit were immersed in that water. The amount of displaced water was recorded from the graduated scale of the cylinder. The density measurements were an average of ten replications. The ratio of mass to volume of displaced water gave the tomato density. Density of tomato fruits was calculated by using the following equation (Mohsenin, 1986):

$$\boldsymbol{\rho_d = \mathbf{M/1000 \times V_c}} \ldots\ldots\ldots (6)$$

Where: ρ_d= Relative density ؛ g/m^3, and V_c= volume of the fruit؛ cm^3.

Packing coefficient

The packing coefficient was defined by the ratio of the volume of fruits packed to the total and calculated by the equation (7) according to (Moradi *et al*. op. cit.).

$$\mathbf{P_c = V_c/V_0} \ldots\ldots\ldots\ldots (7)$$

Where: P_c = Packing coefficient, V_c = volume of the fruit (cm^3), V_0 = volume of the box containing fruit (cm^3).

Moisture content.

The moisture content of three varieties (Nesma, Masa and 2020) of tomatoes were determined by drying method in a hot air oven at 105°C for 24 hours. This test was repeated six times. The moisture content of the samples was determined by using the standard method of ASAE (ASAE Standard, 1999).

Moisture content M (d.b), (%):

$$\mathbf{M = (W_m/W_d) \times 100} \ldots\ldots\ldots\ldots (8)$$

Where:

W_m: Mass of moisture in sample, (g); and W_d: Mass of bone-dry material, (g).

Drying rate of fruits

The drying rate which was the quantity of moisture removed from halves of tomatoes (Aliyu *et al.* 2013) under natural sun drying to reach of required moisture content in least number of days possible. Tomatoes were placed on rack dryer under natural sun drying and were considered dried when they reached of 10 - 20 % moisture content (Bahaa op. cit.). Drying experimental using 100 kg tomato fruits and halving into two halves through the vertical axis manually by sharpen knife (Mahmoud 2021), at average initial moisture contents about 89.33 %, were conducted three times in condition of Aswan governorate, Egypt, with three period, first experiment was from 1 – 9, second was from 10 –18 and third from 20- 29 March 2021, this month is considered the peak production for this variety. To determine the residual solids percentage from the evaporation of water (Ringeisen *et al.* 2014), moisture content was determined at end of each day (using the same method mentioned previously) to random samples of natural sun-dried tomato fruit and determining of period required to dried.

Mechanical properties

Static coefficient of friction

Static coefficient of friction for fruits was determined with respect to each of the following four structural materials namely, stainless steel, plastic, rubber, and plywood with fruits parallel to the direction of motion. The fruits are placed as a group bonded together on a horizontal surface then the angle of inclination is gradually increased until the fruits begin sliding without rolling. For each fruit group of an average sample of (10), the friction was determined. The angle of inclination was read from a graduated scale and the coefficient of friction was taken as the tangent of this angle (Mahmoud and Elkaoud op. cit.).

$$\boldsymbol{\mu = \tan\beta} \ldots\ldots\ldots\ldots (9)$$

Where: μ = Static coefficient of friction, and β = angle of inclination.

Firmness

Penetrometer, made in Italy, with an accuracy of (0.01 N/cm²) was used to determine the firmness of tomato. Firmness was measured by applying pressure slowly in a direction perpendicular to the surface of the fresh fruit and then taking the indicator reading. The cylindrical probe with a circular edge, which had 0.6 cm diameter.

Regression Models

Fruit mass and volume can be predicted based on actual mass and volume, greatest diameter (D_{max}) and lowest diameter (D_{min}). The mass can be estimated as function of projected area (P_a) which depended on independent variables of projected area and actual mass was measured. The mass of tomato fruits can be predicted by the surface and projected area, which is obtained from the vision system of the harvesting robot (Li *et al.* op. cit.). Towards this end, MATLAB® 2019 (Math Works Inc.) software. The model obtained with variables for predicting the volume and mass of tomato fruits was:

- **The overall volume model is based on the following equation:**

$$V_J = a_1 + b_1 D_{max} + c_1 D_{min} \dots\dots\dots (10)$$

Where: V_J is volume of tomato fruits (cm^3). While a1, b1 and c1 are coefficients of regression, Dmax greatest diameter (mm) of fruits, and Dmin is lowest diameter (mm).

- The overall mass model is based on the following equation:

$$M_J = a_1 + b_1 D_{max} + c_1 D_{min} \dots\dots\dots (11)$$

Where: M_J is mass of fruits, (g).

- The overall mass model is based on the following equation:

$$M_J = a_1 + b_1 P_a \dots\dots\dots\dots\dots\dots (12)$$

Where: P_a is projected are of fruits, (cm^2).

RESULTS AND DISCUSSION

Results of some physiochemical and mechanical properties of tomato were determined to sample size 100 fruits.

Physiochemical properties of the fruits

Axial dimensions

From Table (1) the values of maximum, minimum, and average height (H) ± SD of samples was 82.32, 63.60 and 73.34 ± 5.17 mm respectively.

As noted, the values of maximum, minimum, and average greatest diameter ($D_{max.}$) of samples were 80.88, 55.34 and 70.90 ± 4.40 mm respectively. While the values of maximum, minimum, and average lowest diameter ($D_{min.}$) of samples were 71.85, 47.70 and 62.98 ± 4.36 respectively.

Table 1. Physical properties of tomato Jasmin 775 variety (Sample size was 100 fruits)

Property		Range		Aver.	± SD	CV, %
		Max.	Min.			
	H	82.32	63.60	73.34	5.17	7.05
Axial dimensions, mm	D_{max}	80.88	55.34	70.90	4.40	6.20
	D_{min}	71.85	47.70	62.98	4.36	6.93
Arithmetic diameter, mm	D_a	76.11	58.15	69.07	3.50	5.07
Geometric diameter, mm	D_g	75.94	58.02	68.86	3.51	5.09
Equivalent diameter, mm	D_e	75.95	58.00	68.94	3.50	5.07
Aspect ratio	A_r.	124.18	79.30	96.02	7.22	7.44
Sphericity, %	S_p	101.01	82.67	94.10	4.36	4.63
Surface area, cm^2	S_a	181.08	105.71	149.27	15.01	10.06
Projected area, cm^2	P_a	45.62	26.78	35.34	4.30	7.50
Mass, g	M	185.3	107.1	150.06	23.75	15.71
Volume, cm^3	V	186.0	58.1	151.14	22.55	14.83
Density, g/cm^3	ρ	0.995	0.991	0.993	0.001	0.113
Packing coefficient	P_c	0.598	0.577	0.588	0.018	2.579

Fig. (2) showed that the frequency distribution curves of dimensions (H, $D_{max.}$, and $D_{min.}$). The highest frequencies of height fruits (H) of samples were 32% at (75 – 80 mm), the highest frequencies of greatest diameter ($D_{max.}$) were 39% at (70 – 75 mm) and the highest frequencies of lowest diameter ($D_{min.}$) were 43 % at (60 – 65 mm). The shape of curves is semi-normal distribution for high (H), left–skewed distribution for greatest diameter ($D_{max.}$) and lowest diameter ($D_{min.}$).

Average of arithmetic and geometric diameters

From Table (1) the values of arithmetic mean diameter (D_a) ± SD ranged from of 58.15 to 76.11 mm with average value of 69.07 ± 3.50 mm. While the values of the geometric mean diameter (D_g, ranged from 58.02 to 75.94 mm with average value of 68.86 ± 3.51 mm. The obtained results of the axial dimensions, arithmetic mean diameter and geometric mean diameter are important to justify of clearance or size handling mechanism and dimensions of cutting blade in cutting machines of tomato fruits.

Aspect ratio

From Table (1) the values of aspect ratio (R_a) ± SD ranged from of 79.30 to 124.18 % with average value of 96.02 ± 7.22 based on the average's greatest diameter. Taken along with the high aspect ratio, it may be deduced that the tomato fruit will rather roll than slide on their flat surfaces (Ghaffari, *et al.* op. cit.). However, the aspect ratio value is being close to the sphericity values may also average tomato fruit will undergo a combination of rolling and sliding action on their surfaces (Oyelade, *et al.*, 2005).

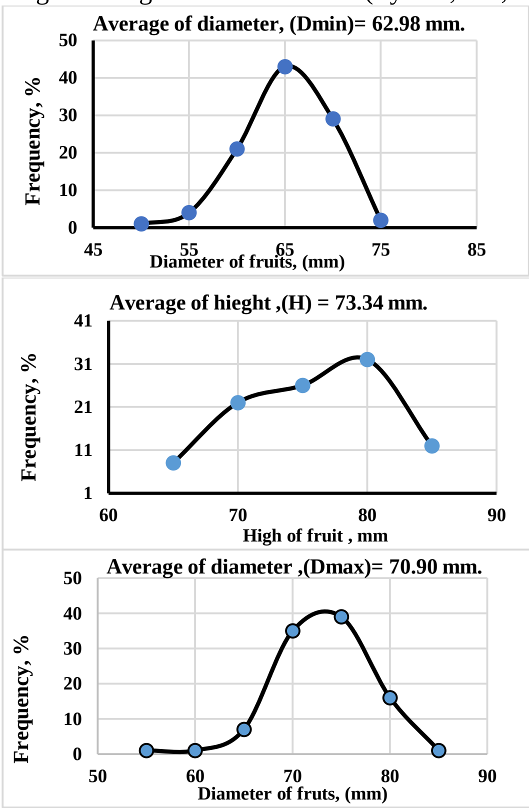

Fig. 2. Frequency distribution curves of dimensions (H, $D_{max.}$, and $D_{min.}$) for tomato fruits

Sphericity

The high sphericity of tomato fruit is indicative of the tendency of the tomato shape towards sphere. Largest, lower, and average values of sphericity was 101.01, 82.67 and 94.10 ± 4.36 % respectively as shown in Table (1). And Fig. (3) indicates that the most frequent percent 41% for tomatoes fruits in the sample were at range of sphericity 90 – 95 % and followed by values frequent percent 35% at range of sphericity 95 – 100 %. These results indicate that the tomato fruits tend to have a spherical shape with high percentage. If sphericity was greater than 1.1, it belongs to the oblong group, if sphericity was less than 0.9, the fruit belongs to the oblate group. The remaining fruits with intermediate index values are round (Buyanov and Voronyuk, 1985).

Surface area

From Table (1), the fruit surface area of the sample ranges from 181.08to 105.71with average value 149.27 ± 15.01.

Projected area

From Table (1), the fruit projected area of the sample ranges from 45.62 to 26.78 with average value 35.34 ± 4.30.

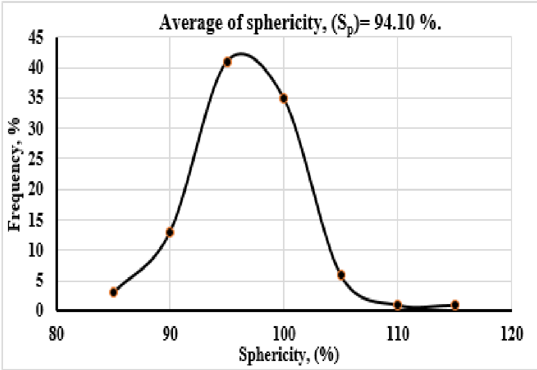

Fig. 3. Frequency distribution curves of sphericity, % for tomato fruits

Mass of fruits

In Table (1) and Fig. (4), these results showed that the values of individual fruits masses ranged from 107.1 to 185.3 g with an average value of 150.06 ± 23.75 g. The most frequent percent 31 % of tomatoes fruits in the sample had from 160 – 180 g mass and followed by values frequent percent 25% at range of s mass from 120 – 140 g.

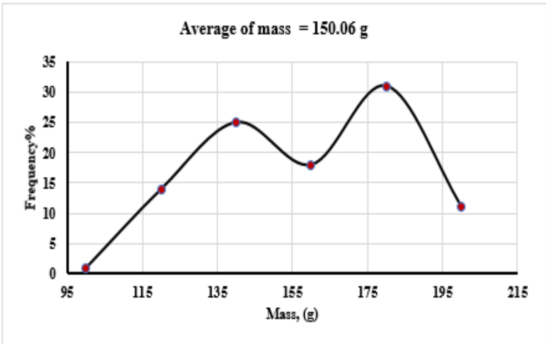

Fig. 4. Frequency distribution curves of mass (g) for tomato fruits

Density of fruits

Table (1) shows the average values of the density fruits, it has been observed that the density of tomato fruits approaches the density of water. Averages value of density for tomato Jasmin 775 commercial variety was about 0.993 ± 0.001 g/cm^3.

Packing coefficient

In Table (1) the results shown that the average of packing coefficient for tomato fruits was 0.588 ± 0.018.

Moisture content

All properties were measured at a constant moisture content to fresh tomato fruits. The average moisture content of the tomato fruits was determined 89.33% on a dry basis.

Effect of natural sun drying on drying rate

Increasing in percentage of residual solids is determinant of selecting the fruits of tomato variety in natural sun drying projects and the period required for drying is very important in determining the productivity of the variety. From Fig. (5) showed that the moisture content percentage (under climatic conditions of the experiment) reached to 26.80, 15.71, and 10.04 %, 25.80, 14.20 and 10.01 % and 23.30, 13.30 and 9.81 % at end of the seventh, eighth, and ninth days for first, second and third experiments, respectively.

Mechanical properties

Coefficient of friction

Table (2) show values of the coefficient of friction ranged from 0.26 to 0.33 with average value of 0.30 ± 0.017 for stainless steel (304) structural surfaces. While values of the coefficient of friction ranged from 0.31 to 0.39 with average value of 0.35 ± 0.05 for rubber structural surfaces. Values ranged from 0.29 to 0.32 with average value of 0.308 ± 0.02 for plywood structural surfaces.

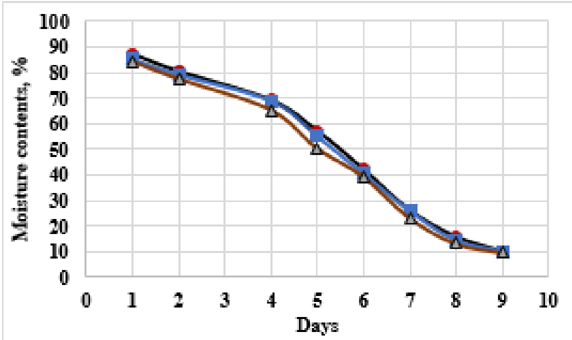

Fig. 5. Moisture contents under natural sun drying via days

Firmness

The results indicated that the maximum and minimum values of firmness was 6.66 and 5.65 N/cm^2, respectively with average values of 6.13 ± 0.71 N/cm^2.

Table 2. Mechanical properties of tomato Jasmin 775 variety (Sample size 100 fruits)

Property		Max.	Min	Aver.	± SD	CV, %
Coefficient of friction	S.S (304)	0.33	0.28	0.31	0.017	3.0
	Rubber	0.39	0.31	0.35	0.05	5.14
	Plywood	0.32	0.29	0.308	0.02	6.9
Firmness, (N/cm^2)	F_a	6.66	5.65	6.13	0.71	5.80

Evaluation of the regression models

The equations were predicted using the stepwise method and based on independence. Mass and diameters are the two independent variables that estimate fruit volume and mass of the commercial tomato (variety Jasmin 775), and projected area independent variables that estimate fruit mass:

- The volume model of tomato fruits based on measured mass, greatest diameter (D_{max}) and lowest diameter (D_{min}) was given as a linear form the following equation:

$$\mathbf{V_J = -199.4 + 2.456\,D_{max} + 2.791\,D_{min}}$$
$$\mathbf{R^2 = 0.9341 \ldots\ldots.(13)}$$

- The mass model of tomato fruits based on measured of greatest diameter (D_{max}) and lowest diameter (D_{min}) was given as a linear form the following equation:

$$\mathbf{M_J = -204.4 + 2.516\,D_{max} + 2.796\,D_{min}}$$
$$\mathbf{R^2 = 0.9434 \ldots\ldots\ldots(14)}$$

- The mass model of tomato fruits based on measured of projected area was given as a linear form the following equation:

$$\boldsymbol{M_J = -42.14 + 5.438\,P_a}$$
$$\mathbf{R^2 = 0.9524 \ldots\ldots\ldots (15)}$$

The model equations obtained have been validated, these models are important to designers of post-harvest machines that rely on vision technologies such as handling sorting and grading in food factories and agricultural harvest robots.

CONCLUSION

It can be pointed out that the physical properties were studied of tomato fruit (Jasmine 775 variety). The results showed that:

- Maximum, minimum, and average of height tomato fruits (H) were 82.32, 63.60 and 73.43 mm, respectively.
- Maximum, minimum and average of greatest diameter (D_{max}.) were 80.88, 55.34 and 70.90 mm, respectively.
- Maximum, minimum and average of greatest diameter (D_{min}.) were 71.85, 47.70 and 62.98 mm, respectively.
- Fruits sphericity, mass, density, and firmness with averages value of 94.10 %,150.06 g, 0.993 g/cm^3 and 6.13 N/cm^2, respectively.

- There was a very good relationship between measured greatest and lowest diameters of tomato fruits and between volume (as R^2 = 0.9341) and mass (as R^2 = 0.9434), also between measured projected area and mass (as R^2 = 0.9524).
- The model's equations obtained are important in predicting volume and mass of tomato fruits to designers of post-harvest machines that rely on vision technologies such as handling sorting and grading in food factories and agricultural harvest robots related to this variety.

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دراسة بعض خصائص ثمار الطماطم المخصصة للتجفيف الشمسي

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يهدف هذا البحث إلى دراسة بعض الخصائص لثمار الطماطم (الصنف التجاري ياسمين 775) كصنف جديد من أصناف التجفيف، لاستخدامها في نمذجة حجم وكتلة الثمار بناءً على الأقطار والمساحة المعرضة، والتي تعتبر قاعدة بيانات لمصممي ومطوري الآلات أو أجزاء من الآليات الزراعية الذكية للحصاد والفرز والتدريج والمناولة والشطر الى نصفين والتقطيع. الخواص الطبيعية شملت كل من الأبعاد المحورية، القطر الحسابي، القطر الهندسي، الكتلة، الكثافة، المساحة السطحية، معامل التعبئة، الكروية، ونسبة الارتفاع الى العرض لثمار الطماطم. الخواص الميكانيكية شملت معامل الاحتكاك والصلابة. أشارت النتائج إلى أن معادلة نموذج التنبؤ بالحجم بناءً على الأقطار كانت $V_J = -199.4 + 2.456\ D_{max} + 2.791\ D_{min}$، بينما كان نموذج التنبؤ بالكتلة بناءً على الأقطار $M_J = -204.4 + 2.516\ D_{max} + 2.796\ D_{min}$ في حين كان نموذج التنبؤ بالكتلة بناءً على المساحة المعرضة $M_J = -42.14 + 5.438\ P_a$. كانت هناك علاقة جيدة جدًا بين القطر الأكبر والأقل المقاسان لثمار الطماطم وبين الحجم (حيث كانت قيمة $R^2 = 0.9341$) وأيضا الكتلة (حيث كانت قيمة $R^2 = 0.9434$)، وبين المساحة المعرضة والكتلة (حيث كانت قيمة $R^2 = 0.9524$). تعتبر معادلات النمذجة التي تم الحصول عليها والتحقق منها مهمة لمصممي آلات ما بعد الحصاد التي تعتمد على تقنيات الرؤية مثل الفرز والتدريج في مصانع الأغذية وروبوتات الحصاد الزراعي المتعلقة بهذا الصنف.