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Mass modeling of pomegranate fruit using some physical properties

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A R T I C L E I N F O

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A B S T R A C T

Physical properties are the most important in the design of equipment and processing systems. Among the physical properties; dimensions, mass, volume, surface area and projected area are the most important parameters in processing systems. Grading fruit based on weight reduces packing and handling costs and also provides suitable packing patterns. In this study, physical properties of pomegranate were determined, and mass modeling with some physical properties was applied based on three classifications: (1) single or multiple variable regressions of pomegranate dimensions, (2) single variable regression of pomegranate surface area, and single or multiple variable regression of pomegranate projected area and (3) estimating pomegranate mass based on its volume. Results showed that mass modeling of pomegranate based on major diameter and first projected area are the most appropriate models in the first and second classifications, respectively. In the third classification, the highest R^2 was obtained for mass modeling based on the actual volume as $R^2 = 0.998$, whereas corresponding values were 0.942 and 0.918 for assumed pomegranate oblate spheroid and ellipsoid shapes, respectively. In an economical view, a suitable sizing and grading system of pomegranate mass was justified based on major diameter as linear relation $M = 8.7004a - 470.33$, $R^2 = 0.932$.

1. Introduction

Pomegranate is one of the major horticultural crops in the world used in many food industries. The edible portions of pomegranate are an excellent dietary source as they contain a significant proportion of organic acids, soluble solids, polysaccharides, vitamins, fatty acids, and mineral elements of nutritional significance (Fadavi et al., 2006). Pomegranate is a very promising and emerging crop for its refreshing arils, juice, and chemopreventive properties, which have medicinal value (Hertog et al., 1997). The pomegranate has been regarded as a food medicine of great importance for therapeutic purposes like colic, colitis-diarrhea, dysentery, leucorrhea, paralysis, and headache (Schubert et al., 1999; Sadeghi et al., 2009). Pomegranate fruit is also known for its anti-inflammatory and anti-atherosclerotic effect activity against osteoarthritis, prostate cancer, heart disease, and HIV-I (Malik et al., 2005; Sumner et al., 2005) .

There has been a remarkable increase in the commercial farming of pomegranates globally, due to the potential health benefits of the fruit, such as its high antioxidant, anti-mutagenic, and antihypertension activities and the ability to reduce liver injury (Du et al., 1975; Tsuda et al., 1994; Lansky et al., 1998; Gil et al., 1996). The annual world production of pomegranate exceeds 8.1 million Mg. India and China are the biggest pomegranate-producer countries in the world, followed by Iran, Turkey, Afghanistan, the U.S., Iraq, Pakistan, Syria and Spain (FAO, 2021). In Egypt, pomegranate is one of the important fruit crops that some farmers depend on as the main source of income, especially in Upper Egypt, which is an important export crop in Egypt. The total cultivated area, total production, and productivity

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of pomegranates in Egypt were 58319 fed, 219663 Mg, and 8.13Mg/fed, respectively (Agric. Statistics Economic Affairs Sector, 2016).

Consumers prefer fruits with equal weight and uniform shape. Mass grading of fruit can reduce packaging and transportation costs, and also may provide an optimum packaging configuration (Peleg, 1985). Stroshine and Hamann (1994) stated that fruits are often graded by size, but developing a machine that grades by weight may be more economical. Sizing by weighing mechanism is recommended for the irregular shape product. Therefore, the relationship between mass and dimensions (major, minor, and intermediate diameters) and projected areas may be useful and applicable. Electrical sizing mechanism is expensive, and the mechanical sizing mechanism reacts poorly. Therefore, determining relationships between mass and some physical properties may be useful .

Chakraverty (1972) stated that knowing the important physical properties such as shape, size, volume, surface, density, porosity, color, and other properties is necessary when designing different systems to separate, handling, sorting, and drying. Some physical properties of pomegranate fruit and its arils have been reported by several researchers (Akbarpour et al., 2009; Celik and Ercisli, 2009; Tehranifar et al., 2010; Riyahi et al., 2011; Badr, 2016; Jithender et al., 2017; Khodabakhshian et al., 2017; Patel et al., 2018; Dhake et al., 2023) and others.

Other researchers determined the mass modeling of different fruits; orang (Shahbazi and Rahmati, 2013a), apple (Saikumar et al., 2023; Chakespari et al., 2010; Tabatabaeefar and Rajabipour, 2005), lemon (Baradaran et al., 2014), mango (Schulze et al., 2015; Spreer and Müller, 2011), cantaloupe (Seyedabadi et al., 2011), kiwi (Rashidi and Seyfi, 2008; Lorestani and Tabatabaeefar, 2006), apricot (Naderi et al., 2008), banana (Kamble et al., 2021), persimmon (Shahbazi and Rahmati, 2014), guava (Bibwe et al., 2022), cherry (Shahbazi and Rahmati, 2013b) and fig (Shahbazi and Rahmati, 2013c) .

Also, several researchers have investigated and reported the mass modeling of pomegranate fruit. Khoshnam et al. (2007) divided the models required into three classifications: the first classification depended on fruit dimensions, the second on projected areas, and the third on volumes. The recommended equation for calculating pomegranate mass based on minor diameter was nonlinear economically. They reported that each of the three projected areas can be used to estimate the mass, but there is a need to have three cameras, making the sizing mechanism more expensive. They suggested a mass model based on the first projected area as a nonlinear form. They also found there was a very strong relationship between mass and actual volume with the highest R^2 value among all models. The sizing mechanism based on measuring volume is more tedious, so they suggested a mass model of pomegranates based on estimated oblate spheroid volume as was the most appropriate. Mansouri et al. (2010) reported mass modeling of two pomegranate varieties (Malas saveh and Hondos yal abad). They recommended mass modeling based on all fruit dimensions and geometric mean diameter. The study showed that R^2 is too weak for mass modeling based on the projected area for the two pomegranate varieties. They also recommended mass models based on assumed elliptical and oblate spheroid volumes. Riyahi et al. (2011) reported that the nonlinear models, including quadratic and exponential, were not suitable for mass modeling based on the physical characteristics of pomegranate fruit, but linear models were more suitable. They recommended equations to calculate pomegranate fruit mass based on all axial dimensions, second projected area, and assumed elliptical volume of fruit .

No detailed studies concerning the mass modeling of pomegranate have been performed on Egyptian varieties up to now. The objectives of this research were to determine some physical properties of pomegranate fruit and determine an optimum pomegranate mass model based on its physical properties. This information is used to design and develop pomegranate processing systems, especially sizing and grading systems.

2. Materials and methods

2.1. Materials

2.1.1. Raw Materials

Measurements were carried out using a local Pomegranate fruit (*Punica granatum L.*) sweet variety, as shown in Fig. 1, purchased from the local market in Nasr City, Cairo, Egypt. A random sample of 30 fruits were used in this study.

Fig. 1. Pomegranate fruit, variety of '*Sweet*'.

2.1.2. Measuring instruments

A. Digital vernier caliper: A digital vernier caliper with 0.01 mm accuracy was used to check the dimensions of fruit samples.

B. Digital balance: The mass of each pomegranate fruit M and arils mass was measured by a digital balance with an accuracy of 0.01 g.

C. WinArea-Ut-06 modified system: WinArea-Ut-06 system developed by Mirasheh (2006) (Fig. 2) is modified by the authors to determined fruit axial dimensions and projected area in three perpendicular directions. Dimensional characteristics obtained from the system are based on image processing. Captured images from a Scanner, (Hp Scanjet G2410), are transmitted to a computer. Scanned images are then processed in the Auto CAD software and the desired user needs are determined (Dosoky, 2011). Fruit axial dimensions were taken in the scanner field were checked by vernier caliper, with accuracy of 0.01 and the total error was less than 1%.

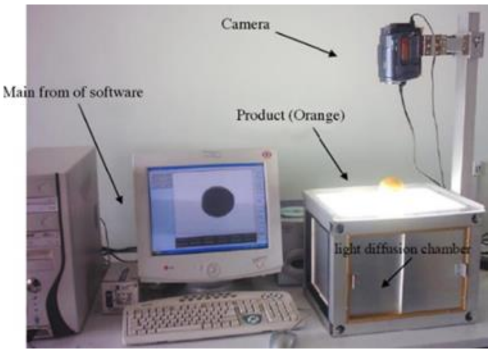


Fig. 2. Components of WinArea-Ut-06 system (Mirasheh, 2006; Keramat Jahromi et al., 2007; Khoshnam et al., 2007).

2.2. Methods

2.2.1. Physical properties of Pomegranate fruit

- Geometric mean diameter (D_g) was obtained using the following equation (Mohsenin, 1970):

$$D_g = \sqrt[3]{abc}$$

Where:

a = Major diameter in mm.

b = Intermediate diameter in mm.

c = Minor diameter in mm.

- Roundness percent (R_n) is obtained using the following equation (Mohsenin, 1970):

$$R_n = \frac{A_p}{A_c}$$

Where:

A_p = Largest projected area of pomegranate in natural rest position in mm².

A_c = Area of smallest circumscribed circle in mm².

Roundness percent was measured in the three cartesian directions, R_{n1}, R_{n2} and R_{n3}, and then the Criteria roundness CR_n was calculated as follows:

$$CR_n = \frac{R_{n1} + R_{n2} + R_{n3}}{3}$$

- Sphericity (S_{ph}):

Sphericity was obtained using the following equation (Mohsenin, 1970):

$$S_{ph} = \frac{Dg}{a} \times 100$$

- Actual volume (V): The actual Volumes of the individual pomegranates were determined using the water displacement method. Pomegranate was placed with a metal sponge sinker into a measuring cylinder containing known water volume such that the fruit did not float during water immersion; the weight of water displaced by the fruit was recorded. The actual volume of each fruit was calculated by the following equation (Mohsenin, 1986):

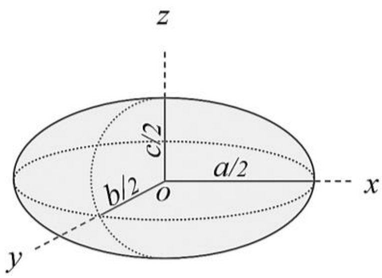
$$V = \frac{W}{\gamma}$$

Where:

W = Weight of displaced water in Dyne.

γ = Weight density of water in Dyne/cm³.

- The volume of regularly geometrical shape: The pomegranate shape was assumed as a regularly geometrical shape, i.e., oblate spheroid shape and ellipsoid shape as shown in Fig. 3; thus, their volumes were calculated as following equations:



Oblate spheroid — $a = b \neq c;\ c < a$

$$V_{osh} = \frac{4}{3}\pi\left(\frac{a}{2}\right)^2\left(\frac{c}{2}\right)$$

Ellipsoid — $a \neq b \neq c$

$$V_{ellip} = \frac{4}{3}\pi\left(\frac{a}{2}\right)\left(\frac{b}{2}\right)\left(\frac{c}{2}\right)$$

Fig. 3. Oblate spheroid and ellipsoid shapes.

- Bulk density (ρ_b): The bulk density is the ratio of the mass of the sample to the total volume. It was determined by filling a 3000 ml container with a sample from a height of about 15 cm and then weighing the contents (Deshpande et al., 1993).
- True density (ρ_t): Random samples of pomegranate fruits were used to calculate the density using the following equation:

$$\rho_t = \frac{M}{V}$$

Where:

M = Mass of the individual pomegranates in g.

V = Volume of the individual pomegranates in cm^3.

- Void percent (ε): Void percent was calculated by the following equation (Mohsenin, 1970):

$$\varepsilon = 1 - \frac{\rho_b}{\rho_t}$$

Where:

ε = Void percent in %.

ρ_b = The bulk density in g/cm^3.

ρ_t = The true density in g/cm^3.

- Surface Area (S_A): Surface area was obtained from the following equation (Fathollahzadeh et al., 2008):

$$S_A = \pi \times Dg^2$$

Criteria Projected Area (CA_p): Projected sample area was plotted to measure using a scanner, and the sample pictures were exported to Auto CAD program to calculate the area. Projected area was measured in the three cartesian directions: A_{p1}, A_{p2} and A_{p3}. The criteria projected area CA_p calculated as follows:

$$CA_p = \frac{A_{p1} + A_{p2} + A_{p3}}{3}$$

Where:

A_{p1}, A_{p2}, and A_{p3} are the projected areas in *ac*, *bc* and *ab* levels, respectively.

2.2.2. Fruit mass modeling with some physical properties

In order to estimate the pomegranate mass from dimensional characteristics, projected areas, and volume, three classifications of models were considered as follows:

A. Single or multiple variable regressions of pomegranate dimensional characteristics: major diameter (*a*), intermediate diameter (*b*), and minor diameter (*c*).

B. Single regression of pomegranate surface area (S_A), and single or multiple variable regressions of pomegranate projected areas: A_{p1}, A_{p2}, and A_{p3}.

C. Single regression of pomegranate volumes: actual volume, volume of the fruit assumed as an oblate spheroid, and ellipsoid shapes.

In the case of the first classification, mass modeling was accomplished concerning major, intermediate, and minor diameters. The model obtained with three variables for predicting pomegranate mass was:

$$M = \beta_1 a + \beta_2 b + \beta_3 c + \beta_4$$

In this classification, the mass can be estimated as a function of one, two, and three dimensions.

In the second classification model, the mass of the pomegranate was estimated based on the surface area, and mutually perpendicular projected areas as follows:

$$M = \beta_1 (S_A) + \beta_2$$

$$M = \beta_1 (A_{p1}) + \beta_2 (A_{p2}) + \beta_3 (A_{p3}) + \beta_4$$

In this classification modeling based on projected area, the mass can be estimated as a function of one, two, or three projected areas.

In the case of the third classification, three volume values were measured or calculated to achieve the models which can predict the pomegranate mass based on volume. At first, actual volume *V*, as stated earlier, was measured; then, the pomegranate shape was assumed to be regularly geometrical, i.e., oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) shapes. In this classification, the mass can be estimated as either a function of the volume of supposed shapes or the measured actual volume as represented in the following expressions:

$$M = \beta_1 V + \beta_2$$

$$M = \beta_1 (V_{osp}) + \beta_2$$

$$M = \beta_1 (V_{ellip}) + \beta_2$$

3. Results and discussions

3.1. Physical properties of Pomegranate fruit

A summary of some selected physical characteristics of the pomegranate fruit is presented in Table 1.

3.2. Fruit mass modeling with some physical properties

A summary of linear regression models based on the selected independent variables has been represented in Table 2. The results showed that all selected models had a high significance ($p < 0.05$). Among the first classification models No. 1, 2, 3, and 4, model 4, where all three dimensions were considered had the highest R^2 value, and regression standard error R.S.E. was also the lowest for all the three regions. However, all three diameters must be measured for model 4, which makes the sizing mechanism more tedious and expensive. Among models 1, 2, and 3, model 3 had the highest R^2 value and the lowest R.S.E. for the entire regions. Therefore, model 3, among the one-dimensional models, was selected as the best pomegranate mass model with the major diameter, as shown in Fig. 4.

Mansouri et al. (2010) recommended equations to calculate mass based on geometric mean diameter for two varieties of pomegranate. In another study, Khoshnam et al. (2007) recommended an equation calculating pomegranate mass based on minor diameter as $M = 0.06c^2 - 4.11c + 143.56$, $R^2 = 0.91$. For the entire regions, the best equation to calculate the mass of pomegranate based on the major diameter was given in linear form as follows:

$$M = 8.7004a - 470.33 \text{ , } R^2 = 0.932$$

Among the second classification models, Nos. 5, 6, 7, 8, and 9, shown in Table 2, based on surface and projected area, model 9 for the entire regions had maximum R^2 value and minimum R.S.E. The overall mass model based on three projected areas (model 9) for the entire regions, was given as follows:

$$M = 4.355A_{p1} + 2.226A_{p2} + 0.256A_{p3} + 110.653 \text{ , } R^2 = 0.978$$

Table 1

Physical characteristics of pomegranate fruit.

Property	Range Min.	Range Max.	Mean*	S.D.	C.V. (%)
Major Dia. *(a)*, mm	73.24	101.70	90.13	7.45	8.27
Intermediate Dia. *(b)*, mm	69.70	99.88	86.86	7.58	8.73
Minor Dia *(c)*, mm	61.00	85.40	75.13	5.84	7.78
Geometric Mean Dia. (D_g), mm	67.78	94.20	83.77	6.67	7.96
1st Roundness (R_{n1}), %	78.32	91.16	85.83	3.44	4.01
2nd Roundness (R_{n2}), %	84.09	94.83	88.63	2.89	3.26
3rd Roundness (R_{n3}), %	84.89	95.80	90.12	3.02	3.35
Crit. Roundness (CR_n), %	85.01	91.59	88.19	2.22	2.52
Mass *(M)*, g	171.60	413.30	313.83	67.16	21.40
Sphericity *(Sph)*, %	89.06	96.61	92.98	1.50	1.61
Actual Volume *(V)*, cm³	118.00	420.00	319.83	66.46	20.78
Oblate Sph. Volume (V_{osp}), cm³	142.62	360.49	270.61	58.57	21.64
Ellip. Volume (V_{ellip}), cm³	162.96	437.50	313.16	69.90	22.32
True Density (ρ_t), kg/m³	953.33	999.07	979.86	12.94	1.32
Bulk Density (ρ_b), kg/m³	546.78	632.72	588.65	22.32	3.79
Void (ε), %	35.69	43.96	39.98	2.15	5.37
Surface Area (S_A), cm²	144.26	278.65	221.69	34.10	15.38
1st Proj. Area (A_{p1}), cm²	39.91	77.22	62.74	9.90	15.78
2nd Proj. Area (A_{p2}), cm²	39.53	76.79	60.49	9.53	15.76
3rd Proj. Area (A_{p3}), cm²	44.97	79.62	64.61	10.34	16.00
Crit. Proj. Area (CA_p), cm²	41.47	77.57	62.61	9.61	15.35

* These data were collected from 30 samples and mean of 3 replicates.

Table 2

Pomegranate mass models based on selected independent variables.

No.	Models	R^2	*R.S.E.*	*Sig.*
1	$M = \beta_1 a + \beta_2$	0.932	17.788	0.000
2	$M = \beta_1 b + \beta_2$	0.857	25.838	0.000
3	$M = \beta_1 c + \beta_2$	0.892	22.485	0.000
4	$M = \beta_1 a + \beta_2 b + \beta_3 c + \beta_4$	0.964	13.394	0.000
5	$M = \beta_1 (S_A) + \beta_2$	0.966	12.592	0.000
6	$M = \beta_1 (A_{p1}) + \beta_2$	0.974	11.122	0.000
7	$M = \beta_1 (A_{p2}) + \beta_2$	0.966	12.643	0.000
8	$M = \beta_1 (A_{p3}) + \beta_2$	0.775	33.800	0.000
9	$M = \beta_1 (A_{p1}) + \beta_2 (A_{p2}) + \beta_3 (A_{p3}) + \beta_4$	0.978	10.447	0.000
10	$M = \beta_1 V + \beta_2$	0.998	3.385	0.000
11	$M = \beta_1 (V_{osp}) + \beta_2$	0.942	16.398	0.000
12	$M = \beta_1 (V_{ellip}) + \beta_2$	0.918	19.560	0.000

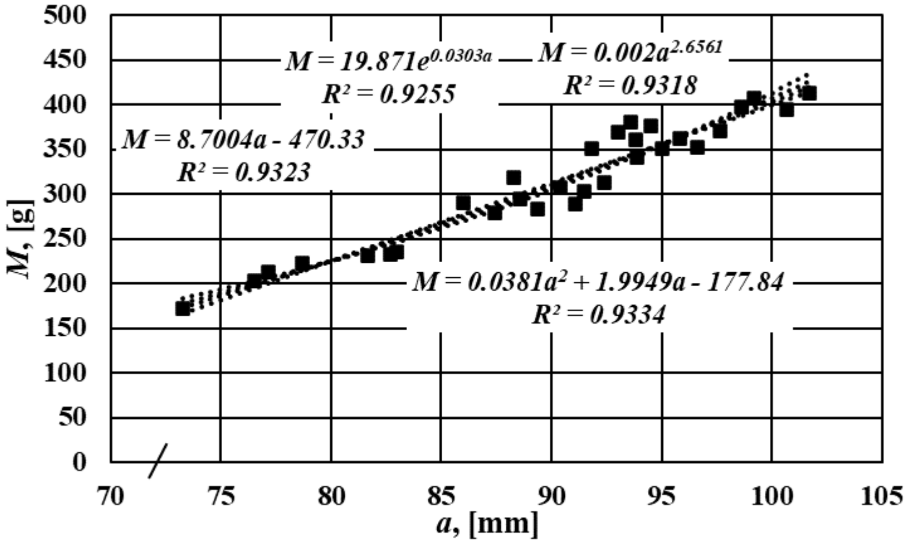


Fig. 4. Pomegranate mass model based on major diameter.

The overall mass model of the pomegranate based on the one projected area, as shown in Fig. 5, was given in nonlinear form in the following equation:

$$M = 1.1219\ (A_{p1})^{1.3595}\ , R^2 = 0.976$$

The mass model recommended for sizing pomegranate fruits based on the first projected area was reported by Khoshnam et al (2007) as $M = 1.29\ (A_{p1})^{1.28}$, $R^2 = 0.96$, and for sizing kiwi fruits based on the third projected area was reported by Lorestani and Tabatabaeefar (2006) as $M = 1.098\ (A_{p3})^{1.273}$, $R^2 = 0.97$. There is a need to have three cameras, in order to take all the projected areas and have an R^2 value close to the unit or even lower than R^2 for just one projected area; therefore, a model using only one projected area, possibly model 6, can be used.

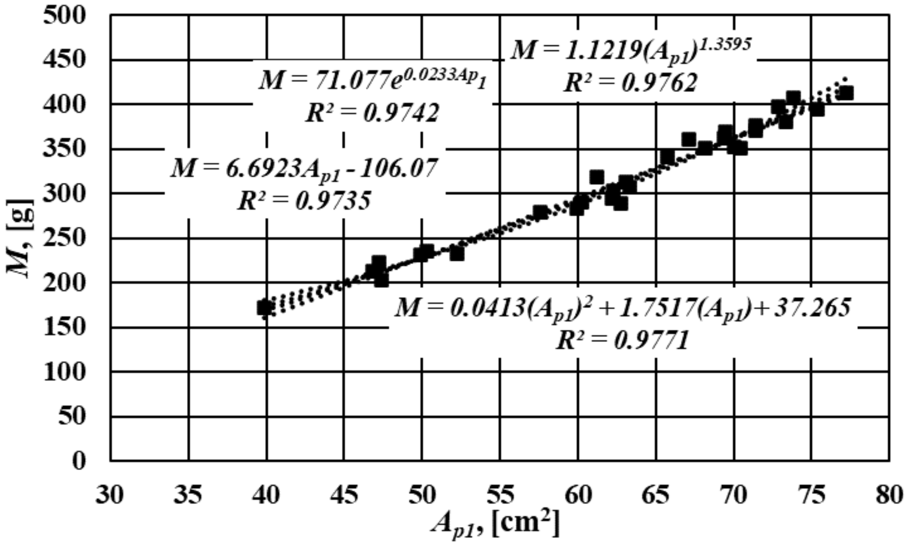


Fig. 5. Pomegranate mass model based on first projected area.

Among the models in the third classification (models 10, 11, and 12), the R^2 for model 10 had maximum value and minimum R.S.E. Among models 11 and 12, model 11 for the entire region had the highest R^2 value and the lowest R.S.E. Therefore, model 11 was recommended for predicting pomegranate mass. The mass model of overall pomegranates based on measured volume was given as linear form the following equation:

$$M = 1.0093V - 8.9848\ , R^2 = 0.998$$

Measuring actual volume is a time-consuming task; therefore, mass modeling based on it is not reasonable; consequently, it seems suitable for mass modeling of pomegranate to be accomplished based on the volume of the assumed oblate spheroid shape as Khoshnam et al. (2007) recommended.

The overall mass model of pomegranate based on the oblate spheroid volume, as shown in Fig. 6, was given in nonlinear form in the following equation:

$$M = 1.4909\ (V_{osp})^{0.9551}\ , R^2 = 0.9769426$$

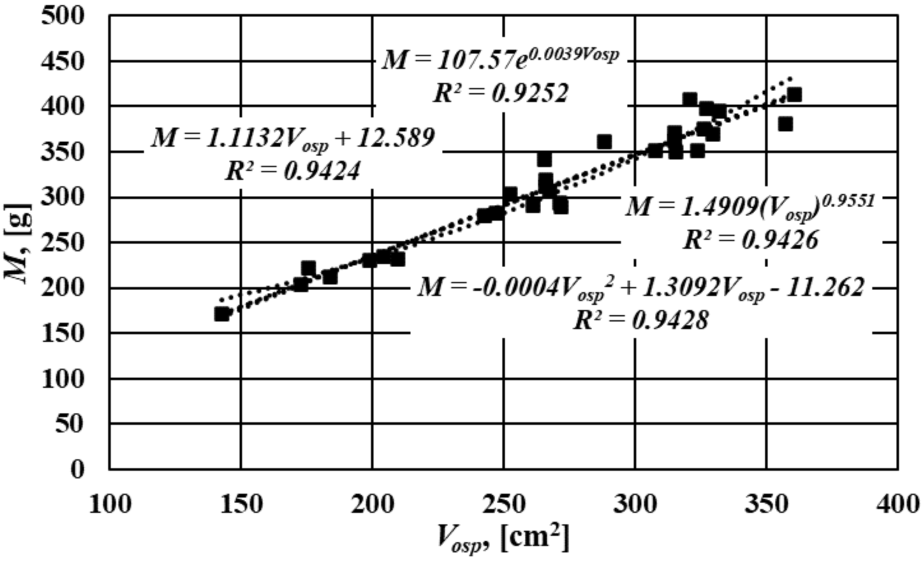


Fig. 6. Pomegranate mass model based on the volume of assumed oblate spheroid shape.

4. Conclusions

- The recommended equation to calculate pomegranate mass based on major diameter (model 3 was the best) was in linear form:

$$M = 8.7004a - 470.33 \ , R^2 = 0.932$$

- The mass model recommended for sizing pomegranates based on projected area (model 6 is suitable) was as nonlinear form:

$$M = 1.1219\ (A_{p1})^{1.3595} \ , R^2 = 0.976$$

- There was a very good relationship between mass and measured volume of pomegranates for the entire regions with R^2 as 0.998 (the highest R^2 value among all the models).
- The model which predicts the mass of pomegranates based on estimated volume, and the shape of pomegranates considered as an oblate spheroid was found to be the most appropriate (model 11 is recommended).
- Lastly, mass model No. 1 is recommended from an economic standpoint.

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نمذجة كتلة فاكهة الرمان مع بعض الخصائص الطبيعية

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الملخص العربي

يهدف البحث الي دراسة بعض الخصائص الطبيعية لثمار الرمان (صنف سويت) والتي يستفاد منها في تصميم متطلبات معظم العمليات التصنيعية لثمار الرمان ، كما تهدف الدراسة الي نمذجة كتلة ثمار الرمان مع بعض هذه الخصائص الطبيعية والتي تفيد في أنظمة المعالجة وبالأخص نظم التدريج.

تتلخص النتائج فيما يلي:

١- الخصائص الطبيعية :

كان متوسط القطر الرئيسي والقطر المتوسط والقطر الأصغر ومتوسط القطر الهندسي ٩٠,١٣ ± ٧,٤٥ و ٨٦,٨٦ ± ٧,٥٨ و ٧٥,١٣ ± ٥,٨٤ و ٨٣,٧٧ ± ٦,٦٧ ملليمتر على التوالي. متوسط الكتلة ٣١٣,٨٣ ± ٦٧,١٦ جم ،متوسط نسبة الاستدارة ٨٨,١٩ ± ٢,٢٢٪ ، متوسط نسبة الكروية ٩٢,٩٨ ± ١,٥٠٪ ، متوسط الحجم الفعلي ٣١٩,٨٣ ± ٦٦,٤٦ سم٣ ، متوسط الكثافة الحقيقية ٩٧٩,٨٦ ± ١٢,٩٤ كجم / م٣ ، متوسط الكثافة الظاهرية ٥٨٨,٦٥ ± ٢٢,٣٢ كجم / م٣، متوسط نسبة الفراغات ٣٩,٩٨ ± ٢,١٥ %، متوسط مساحة السطح ٢٢١,٦٩ ± ٣٤,١٠ سم٢ ، متوسط مساحة الاسقاط الضوئي ٦٢,٦١ ± ٩,٦١ سم٢

٢- نمذجة كتلة الثمار مع بعض الخصائص الطبيعية:

تمت عملية النمذجة طبقا لتصنيفها مع الخصائص الطبيعية إلي ثلاث تصنيفات رئيسية وهي: نمذجة الكتلة مع الأبعاد الرئيسية للثمار ، ومع مساحة السطح ومساحة الإسقاط الضوئي وأخيرا مع الحجم ، وتم اختيار أفضل نموذج طبقا لأكبر قيمة R^2 وأقل خطأ تجريبي.

كان أفضل نموذج في التصنيف الأول هو نمذجة الكتلة مع القطر الأكبر للثمار ، وكان أفضل نموذج في التصنيف الثاني هو نمذجة الكتلة مع مساحة الإسقاط الضوئي الأولي للثمار ، وكان أفضل نموذج في التصنيف الثالث هو نمذجة الكتلة مع الحجم الحقيقي للثمار، طبقاً للمعادلات الاتية:

$$M = 8.7004a - 470.33 , R^2 = 0.932$$

$$M = 1.1219 (A_{p1})^{1.3595} , R^2 = 0.976$$

$$M = 1.0093V - 8.9848 , R^2 = 0.998$$