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Mathematical Models for Estimating the Mass of Plum Fruit by Selected Physical Properties

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Abstract: Dimensional, optical properties and volume of agricultural products are the most important parameters in the design of postharvest equipment. In this study mass of plum fruit was estimated with using selected physical properties in linear and non-linear models. The result showed that the selected properties which were determined in this research such as length, width, thickness, geometric mean diameter, sphericity, mass, volume, projected areas and surface area values of Santa Rosa variety were significantly ($p < 0.01$) greater than for Can variety except for fruit density. For the practise applications, for estimating the mass of plum fruit, the thickness for Can and width for Santa Rosa can be used. The models based on projected are $M = 0.026PA_1 - 5.247$, R^2=0.934, RMSE=0.891 for Can variety, $M = 0.046PA_3 - 24.083$, R^2=0.961, RMSE=1.300 for Santa Rosa variety had highest R^2 among the others, can be used. In third classification, the best model was obtained on the basis of the oblate spheroid volume as $M = 1.027V_{os}^{1.008}$, R^2=0.981, RMSE=0.507 for Can variety and $M = 1.438V_{os}^{0.937}$, R^2=0.959, RMSE=1.326 for Santa Rose variety.

Keywords: Plum fruit, physical properties, mass modelling

Seçilmiş Fiziksel Özellikleriyle Erik Meyvesinin Kütlesinin Matematiksel Modeller ile Tahmin Edilmesi

Öz: Tarımsal ürünlerin boyutları, optik özellikleri ve hacimleri hasat sonrası ekipmanlarının tasarımlarında en önemli parametrelerdir. Bu çalışmada erik meyvesinin kütlesi, seçilmiş fiziksel özellikleri kullanılarak doğrusal ve doğrusal olmayan modellerle tahmin edilmiştir. Elde edilen sonuçlara göre; bu çalışmada belirlenmiş uzunluk, genişlik, kalınlık geometric ortalama çap, küresellik, kütle, hacim, projeksiyon alanı ve yüzey alanı gibi seçilmiş özelliklere ait değerler meyve yoğunluğu hariç Can çeşidine göre Santa Rosa çeşidinde daha yüksek bulunmuştur ($p<0.01$). Pratik uygulamalarda her iki çeşit içinde kalınlık değeri meyve kütlesinin tahmin edilmesi için kullanılabilir. Projeksiyon alanlarına göre diğerleri arasında en yüksek R^2 değerine sahip olan modeller; Can çeşidi için $M = 0.026PA_1 - 5.247$ R^2=0.934, RMSE=0.891, Santa Rosa çeşidi için $M = 0.046PA_3 - 24.083$ R^2=0.961, RMSE=1.300 olarak bulunmuştur. Oblate sferoid hacim değerlerine göre belirlenen en iyi model Can çeşidi için, $M = 1.027V_{os}^{1.008}$ R^2=0.981, RMSE=0.507, Santa Rosa çeşidi için ise, $M = 1.438V_{os}^{0.937}$ R^2=0.959, RMSE=1.326 dir.

Anahtar Kelimeler: Erik Meyvesi, fiziksel özellikler, kütle modellemesi

1. Introduction

Plum fruit is a source of essential nutrients, vitamins and minerals. The most common types of plums are grown in *S. domestica* L. (European plum) and *P. salicina* Lindl. (Japanese plum). (Ertekin et al. 2006).

In the world, plum production is about 11.3 million tonnes in 2014. Nowadays, China is the one of the most important plum-producing countries in the world. Approximately, half of world plum production is done in the China which produces about 6.2 million tonnes. Then, Serbia, USA, Romania and Turkey, respectively (FAO

2017). Plum fruit is grown in Turkey with a production rate of 274,136 tonnes (TUIK 2017).

The consumers are getting highly selective. They prefer to be properly shaped and of an equal weight of fruits. Because of this, their suppliers to distribute the goods according to high standards (Khoshnam et al. 2007; Khanali et al. 2007).

Many different methods are used for grading of agricultural products. Kheiralipour (2010) decelerated that electrical classification systems are expensive, and mechanical sorting systems are slow to react. Near-infrared technologies are expensive, and In addition, there is a need for skilled personnel for calibration and maintenance jobs. Determining a relation between mass, dimension and projected area is useful and applicable in weight classification (Khanali et al. 2007). Additionally, in the design of post-harvest equipment, optical properties and volume of agricultural products are the important parameters too.

As the currently used systems have been designed without considering these criteria, this causes insufficient applications. This causes a decrease in working efficiency and an increase in product loss. For this reason, the identification and evaluation of these criteria have played important role in design of this equipment (Ertekin et al. 2006).

Many researchers have studied mass modeling for various fruits and vegetables such as pomegranate fruit (Khoshnam et al. 2007), cantaloupe fruit (Seyedabadi et al. 2011), apricot fruit (Naderi-Boldaji et al. 2008), kiwi fruit (Lorestani and Tabatabaeefar 2006; Rashidi and Seyfi 2008), mango fruit (Spreer and Müller 2011), tangerine fruit (Khanali et al. 2007), apple fruit (Tabatabaeefar and Rajabiopour 2005; Chakespari et al. 2010), date fruit (Jahromi et al. 2008), onion (Ghabel et al. 2010), citrus fruit (Omid et al. 2010), saffron crocus corm (Hassan-Beygi et al. 2010), sweet lemon (Taheri-Garavand and Nassiri 2010), potato (Berberoglu et al. 2014) and loquat fruit (Shahi-Gharahlar et al. 2009).

The objective of this study was to develop generalized estimate model for the mass of two plum fruit variety based on its selected physical properties. The results are appreciated by the engineers for the use of appropriate classification equipment and the useful data that can be used in the design of their machines.

2. Materials and Methods

The plum fruits were randomly hand-picked at a commercial orchard at Sultanhisar-Aydın province. 50 samples were randomly selected from each variety (Can and Santa Rosa). During the experiment, samples were stored in the in cold storage at 4 ºC.

In order to determine three linear dimensions which are length (*L*), width (*W*), and thickness (*T*), and the projected areas (PA_1, PA_2 and PA_3) in three vertical axes of the fruits, digital images of the fruits were taken with using a digital camera (CASIO EX FH20) and then uploaded the image processing software Image Tool 3.0. Main dimensions defined for fruit was shown in the Figure 1.

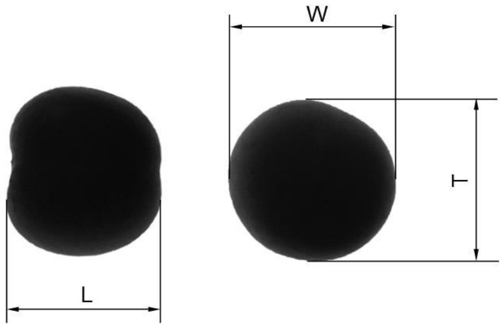

Figure 1. Main dimensions defined for fruit
Şekil 1. *Meyvenin ana boyutları*

The geometric mean diameter (D_g) in mm, sphericity (φ) in decimal and surface area (*S*) in mm^2 were calculated by Mohsenin, 1986.

$$D_g = (LWT)^{\frac{1}{3}} \quad (1)$$

$$\varphi = \frac{(LWT)^{\frac{1}{3}}}{L} \quad (2)$$

$$S = \pi (D_g)^2 \quad (3)$$

The average projected areas (knows as criteria projected areas, *CPA* in mm^2) were calculated from the following relationship (Mohsenin 1986).

$$CPA = \frac{PA_1 + PA_2 + PA_3}{3} \quad (4)$$

The actual fruit volume (V_{act}) was determined using the water overflow method. The fruit mass (M) was measured with an electronic balance of 0.01 g accuracy. The actual volume and fruit density were calculated by Mohsenin, 1986.

$$V_{act} = \frac{W_w}{\rho_w} \quad (5)$$

$$\rho_t = \frac{M}{V_{act}} \quad (6)$$

where W_w is the weight of displaced water in g, ρ_w is the weight density of water in g cm^{-3}, and ρ_t is fruit density in g cm^{-3}.

To estimate the plum fruit mass from the dimensions, projected areas and volume, the following three major categories of models were considered to determine regression models between the parameters of either linear or nonlinear form.

1. Single and multiple variable regressions of plum fruit dimensions that are length (L), width (W), and thickness (T).

2. Single and multiple variable regressions of plum fruit projected areas that are PA_1, PA_2 and PA_3.

3. Single and multiple variable regressions of plum fruit volumes that are actual volume (V_{act}), oblate spheroid (V_{os}) and prolate spheroid (V_{ps}). V_{os} and V_{ps} values were calculated as:

$$V_{os} = \frac{4}{3}\pi\left(\frac{L}{2}\right)\left(\frac{W}{2}\right)^2 \quad (7)$$

$$V_{ps} = \frac{4}{3}\pi\left(\frac{L}{2}\right)^2\left(\frac{W}{2}\right) \quad (8)$$

The models accuracy were determined by a coefficient of the determination R^2 and the root mean square error $RMSE$, calculated according to following equation.

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(M_{est} - M\right)^2} \quad (9)$$

where n is the number of samples, and M and M_{est} are the measured and estimated fruit mass, respectively.

In order to develop regression models between the parameters and analyze the data Microsoft Excel 2003 and SPSS13 software were used.

3. Results and Discussion

3.1. Physical Properties of plum fruit

The selected physical properties of two variety plum fruit (Can and Santa Rosa) such as length, width, thickness, geometric mean diameter, mass, fruit volume, sphericity, projected areas (three perpendicular directions), criteria projected area, surface area and fruit density are represented in Table 1.

The average values of sphericity were 0.95 for Can and 0.97 for Santa Rosa varieties. Ertekin et al (2006) reported the sphericity values of 0.76 for Stanley variety and 0.72 for Frezen 90 variety of plum fruit.

The average mass of Santa Rosa (57.16 g) was about 3.39 times more than the average mass of Can (16.88 g). The mean values of fruit volume for Can and Santa Rosa plum varieties were 16.34 to 56.06 cm^3, respectively.

Altuntas and Yaldiz (2016) obtained the mean values of the fruit volume for Santa Rosa plum variety as 44.48, 44.57 and 46.47 cm^3, respectively, with three application of AVG (Aminoethoxyvinylglycine) at the three different harvest date.

The selected properties which were determined in this research (length, width, thickness, geometric mean diameter, sphericity, mass, volume, projected areas and surface area) for Santa Rosa variety were significantly greater than for Can variety. But, the analysis of variance revealed that fruit density was not significantly ($p < 0.01$) between two varieties.

The fruit density was 1032.49 kg m^{-3} for Can variety and 1020.47 kg m^{-3} for Santa Rosa variety. Fruit density for wild plums was reported 1057.99 kg m^{-3} by Çalışır et al. (2005). Ertekin et al. (2006) reported the fruit density values of Stanley and Frenze90 plum varieties were 1050 and 1029 kg m^{-3}, respectively.

Table 1. Selected physical properties of two plum varieties
***Çizelge 1.** İki erik meyvesinin seçilmiş fiziksel özellikleri*

Characteristics	*Variety*		*Significant*
	Can	*Santa Rosa*	
L (mm)	29.72±2.02	44.71±1.62	p<0.01
W (mm)	31.91±2.45	46.51±2.05	p<0.01
T (mm)	29.21±2.23	44.41±2.33	p<0.01
D_g (mm)	30.27±2.07	45.20±1.98	p<0.01
φ	0.95±0.02	0.97±0.01	p<0.01
M (g)	16.88±3.51	57.16±6.65	p<0.01
V_{act} (cm^3)	16.34±3.29	56.06±6.82	p<0.01
PA_1 (mm^2)	840.92±128.94	1796.63±172.89	p<0.01
PA_2 (mm^2)	840.52±128.95	1744.67±163.60	p<0.01
PA_3 (mm^2)	842.81±130.31	1750.28±140.40	p<0.01
CPA (mm^2)	841.46±129.08	1763.86±158.17	p<0.01
S (mm^2)	2889.66±395.23	6426.07±559.11	p<0.01
ρ_t (kg m^{-3})	1032.49±50.21	1020.47±16.21	*

*: not significant

3.2. The linear models based on dimensions

Linear models based on the selected independent variables are shown in Table 2. Model 4 had the highest R^2 and the lowest *RMSE* for two varieties. But this model needs a measurement of three diameters to make the sizing. Naderi-Boldaji et al. (2008) and Khoshnam et al. (2007) reported that these sizing systems are more tiresome and costly. Among the models 1, 2 and 3, model 3 based on thickness (T) for Can variety, model 2 based on width (W) for Santa Rosa variety had highest R^2 among the others. Tabatabaeefar and Rajabipour (2005), Khoshnam et al. (2007) and Naderi-Boldaji et al. (2008) suggested linear models for apple, pomegranate and apricot fruit mass on the basis of their thickness (T). But, Lorestani and Tabatabaeefar (2006) recommended an equation to determine kiwi fruit mass based on width (W).

Table 2. Linear models based on selected physical properties of two plum varieties
***Çizelge 2.** İki çeşit erik meyvesinin seçilmiş fiziksel özelliklerine göre doğrusal modeller*

No	*Models*	*Can Variety*		*Santa Rosa Variety*	
		R^2	*RMSE*	R^2	*RMSE*
1	$M=k_1L+k_2$	0.739	1.773	0.923	1.830
2	$M=k_1W+k_2$	0.926	0.941	0.951	1.461
3	$M=k_1T+k_2$	0.935	0.888	0.941	1.600
4	$M=k_1L+k_2W+k_3T+k_4$	0.986	0.408	0.963	1.261
5	$M=k_1PA_1+k_2$	0.934	0.891	0.958	1.355
6	$M=k_1PA_2+k_2$	0.934	0.890	0.943	1.574
7	$M=k_1PA_3+k_2$	0.865	1.274	0.961	1.300
8	$M=k_1PA_1+k_2PA_2+k_3PA_3+k_4$	0.957	0.721	0.971	1.125
9	$M=k_1V_{act}+k_2$	0.953	0.751	0.987	0.749
10	$M=k_1V_{os}+k_2$	0.979	0.508	0.959	1.330
11	$M=k_1V_{ps}+k_2$	0.925	0.949	0.957	1.361

The mass model of Can and Santa Rosa variety based on model 4 is shown in equation (10) and (11), respectively.

$$M = 0.473L + 0.362W + 0.829T - 32.954$$

R^2=0.986, $RMSE$=0.408 (10)

$$M = 1.173L + 1.558W + 0.649T - 96.529$$

R^2=0.963, $RMSE$=1.261 (11)

3.3. The nonlinear models based on dimensions

Nonlinear models based on the selected independent variables are shown in Table 3. A similar situation was shown in nonlinear models. Model 4 had the highest R^2 and the lowest $RMSE$ for two varieties. But, among the models 1, 2 and 3, model 2 based on width (W) for each variety had highest R^2 among the others. Spreer and Müller (2011) developed nonlinear models based on single dimensions to estimate the mass of mango fruit.

Table 3. Nonlinear models based on selected physical properties of two plum varieties
Çizelge 2. İki çeşit erik meyvesinin seçilmiş fiziksel özelliklerine göre doğrusal olmayan modeller

No	*Models*	*Can Variety*		*Santa Rosa Variety*	
		R^2	*RMSE*	R^2	*RMSE*
1	$M=k_1L^{k_2}$	0.762	1.730	0.919	1.869
2	$M=k_1W^{k_2}$	0.924	0.863	0.950	1.487
3	$M=k_1T^{k_2}$	0.919	0.977	0.950	1.510
4	$M=k_1L^{k_2}W^{k_3}T^{k_4}$	0.987	0.410	0.965	1.248
5	$M=k_1PA_1^{k_2}$	0.933	0,865	0.958	1.342
6	$M=k_1PA_2^{k_2}$	0.933	0.866	0.945	1.552
7	$M=k_1PA_3^{k_2}$	0.867	1.271	0.964	1,254
8	$M=k_1PA_1^{k_2}PA_2^{k_3}PA_3^{k_4}$	0.955	0.723	0.971	1.095
9	$M=k_1V_{act}^{k_2}$	0.946	0.752	0.985	0.749
10	$M=k_1V_{os}^{k_2}$	0.981	0.507	0.959	1.326
11	$M=k_1V_{ps}^{k_2}$	0.925	0.953	0.961	1.358

The best model of the nonlinear models based on dimensions for Can and Santa Rosa varieties are shown in equation (12) and (13), respectively.

$$M = 0.00064L^{0.935}W^{0.773}T^{1.280},$$

R^2=0.987, $RMSE$=0.410 (12)

$$M = 0.0027L^{0.699}W^{1.079}T^{0.832},$$

R^2=0.965, $RMSE$=1.248 (13)

When linear and nonlinear models were compared based on dimensions, model 4 in nonlinear form had the highest R^2 and the lowest $RMSE$ for two varieties. As seen from Figure 2, good agreement between the nonlinear model 4 and the measured data was achieved with a correlation coefficient of 99.3% for Can variety and 98.2% for Santa Rosa variety.

For the practical applications, model 3 (equation 14) for Can and model 2 (equation 15) for Santa Rosa can be used.

$$M = 1.523T - 27.613,$$

R^2=0.935, $RMSE$=0.888 (14)

$$M = 3.163W - 89.943,$$

R^2=0.951, $RMSE$=1.461 (15)

3.4. The linear models based on projected area

Linear models based on projected areas (models 5, 6, 7 and 8) shown in Table 2. The model 8 had maximum R^2 value and minimum $RMSE$ for two varieties. The best model of the linear models based on projected areas for Can and Santa Rosa varieties are shown in equation (16) and (17), respectively.

$$M = -0.024PA_1 + 0.076PA_2 - 0.025PA_3 - 5.114$$

R^2=0.957, $RMSE$=0.721 (16)

$$M = 0.024PA_1 - 0.012PA_2 + 0.032PA_3 - 19.892$$
R^2=0.971, *RMSE*=1.125 (17)

3.5. The nonlinear models based on projected area

Among the nonlinear models based on projected areas (models 5, 6, 7 and 8), shown in Table 3, the model 8 had highest R^2 and lowest *RMSE*. Model 8 based on three projected areas for Can and Santa Rosa varieties are given equation (18) and (19), respectively.

$$M = 0.0024PA_1^{6.375}PA_2^{-3.783}PA_3^{-1.278}$$
R^2=0.955, *RMSE*=0.723 (18)

$$M = 0.0025PA_1^{0,599}PA_2^{-0,195}PA_3^{0,939}$$
R^2=0.971, *RMSE*=1.095 (19)

Naderi-Boldaji et al. (2008) for sizing apricot, Lorestani and Tabatabaeefar (2006) for sizing kiwi, Khosnam et al. (2007), for sizing pomegranate and Shahi-Gharahlar et al. (2009) for sizing loquat suggested the mass model fruit based on one projected area.

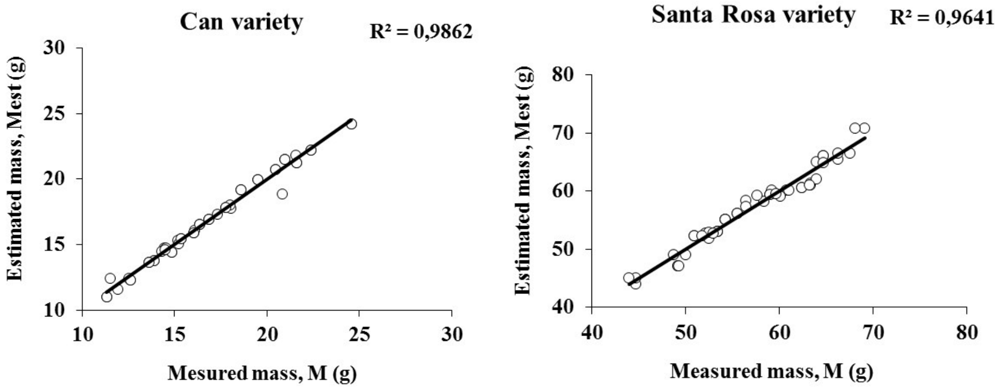

Figure 2. Comparison of the measured and estimated mass values based on dimensions
Şekil 2. *Boyutlara göre tahminlenen ve ölçülen kütle değerlerinin karşılaştırılması*

When linear and nonlinear models were compared based on projected areas, model 8 in linear form had the highest R^2 and the lowest *RMSE* for two varieties. As seen from Figure 3, good agreement between the linear model 8 and the measured data was achieved with a correlation coefficient of 97.8% for Can variety and 98.5% for Santa Rosa variety.

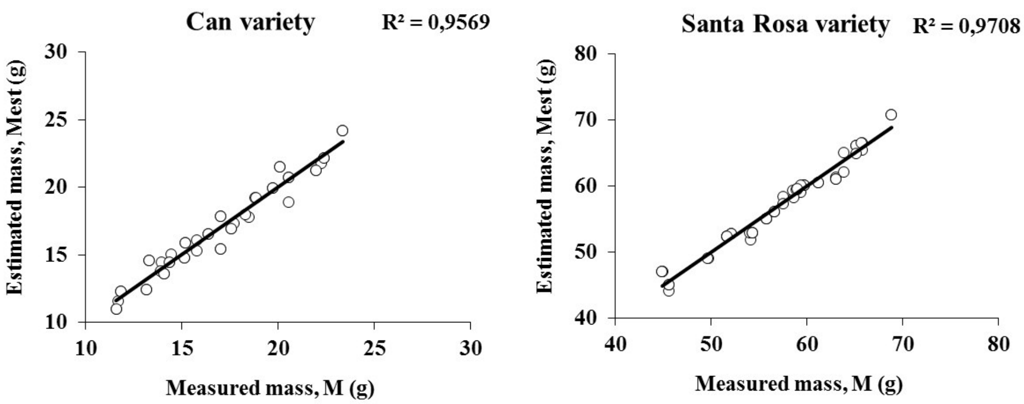

Figure 3. Comparison of the measured and estimated mass values based on projected area
Şekil 3. *Projeksiyon alanına göre tahminlenen ve ölçülen kütle değerlerinin karşılaştırılması*

In order to take all projected area, three cameras are needed. Therefore, it is not a practical application. Therefore, among the models (models 5, 6 and 7) based on projected area, the model 5 for Can variety, model 7 for Santa Rosa variety had highest R^2 among the others, can be used. The model based on one projected area for Can and Santa Rosa variety is given in equation (20) and (21), respectively.

$M = 0.026PA_1 - 5.247$,

R^2=0.934, *RMSE*=0.891 (20)

$M = 0.046PA_3 - 24.083$,

R^2=0.961, *RMSE*=1.300 (21)

3.6. The linear models based on volume

Linear models based on volume (models 9, 10 and 11) shown in Table 2. The model 10 for Can variety and the model 9 for Santa Rosa variety had maximum R^2 value and minimum *RMSE*. The best model of the linear models based on volume for Can variety is shown in equation (22) as:

$M = 1.062V_{os} - 0.186$,

R^2=0.979, *RMSE*=0.508 (22)

The mass model of Santa Rosa variety based on volume is given as linear form;

$M = 0.969V_{act} - 2.855$,

R^2=0.987, *RMSE*=0.749 (23)

3.7. The nonlinear models based on projected area

The nonlinear models based on volume (model 9, 10, and 11) are shown in Table 3. The model 10 for Can variety and the model 9 for Santa Rosa variety had maximum R^2 value and minimum RMSE. In the practice, measuring actual volume needs more time than the others. Therefore, model 10 based on volume for Santa Rosa variety can be used mass modelling. Seyedabadi et al (2001) recommended a model for the mass of cantaloupe-based on the volume of assumed oblate spheroid shape.

Nonlinear model 10 is better than linear model 10, due to model 10 in nonlinear form had the highest R^2 and the lowest *RMSE* for two varieties, when the compare linear and nonlinear models based on volume.

For Can and Santa Rosa varieties, the equations (equation 24 and 25) to calculate-mass of plum based on the volume is given as below;

$M = 1.027V_{os}^{1.008}$,

R^2=0.981, *RMSE*=0.507 (24)

$M = 1.438V_{os}^{0.937}$,

R^2=0.959, *RMSE*=1.326 (25)

It is clear that the model 10 in nonlinear form shows a good conformity between the estimated mass and measured mass (Figure 4).

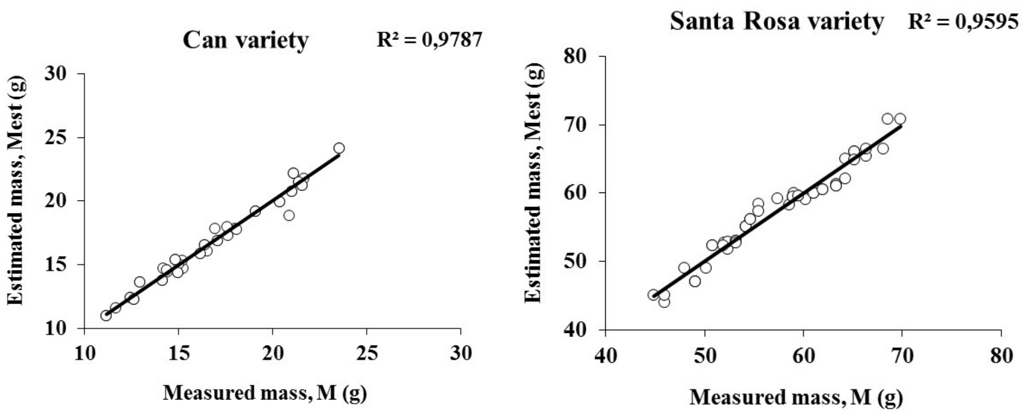

Figure 4. Comparison of the measured and estimated mass values based on volume

Şekil 4. *Hacimlerine göre tahminlenen ve ölçülen kütle değerlerinin karşılaştırılması*

4. Conclusion

In this study, the mathematical approximation was employed to estimate the mass of plum fruit according to dimensions, projected area and volume. The estimated models and data of physical properties of plum fruit can be used for the plum harvesting, sorting, planting and processing equipment. All properties considered in the current study were found to be statically significant at the 1% probability level except fruit density. The best model of the nonlinear models based on dimensions for Can and Santa Rosa varieties are recommended, respectively.

$M = 0.00064L^{0.935}W^{0.773}T^{1.280}$,
R^2=0.987, *RMSE*=0.410

$M = 0.0027L^{0.699}W^{1.079}T^{0.832}$,
R^2=0.965, *RMSE*=1.248

The recommended equations to calculate Can and Santa Rosa varieties projected area (model 8) are linear forms, respectively.

$M = -0.024PA_1 + 0.076PA_2 - 0.025PA_3 - 5.114$
R^2=0.957, *RMSE*=0.721

$M = 0.024PA_1 - 0.012PA_2 + 0.032PA_3 - 19.892$
R^2=0.971, *RMSE*=1.125

The model which predicts the mass of plum fruit based on estimated volume found to be most relevant (model 10 is recommended).

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