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Models for predicting the mass of persimmon *(Diospyros kaki)* fruits by some physical properties

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Abstract

The main aim of this study was to predict the mass of two Indian persimmon cultivars (Hachiya and Fuyu) based on their physical properties by applying linear regression models with three different classification i.e. mass models based on dimensions, projected area and volume. Results showed that the mean values of all properties are higher for hachiya cultivar than fuyu cultivar. Mass modelling of persimmon based on its length, projected area perpendicular to length and assumed volume (oblate spheroid) were the most appropriate models in the first, second and third classification respectively. And it was finally concluded that the suitable grading system of persimmon mass is based on projected area perpendicular to length(PA_L) and showed a linear relationship (M=5.53=PAL-18.88, R^2= 0.95 (for Hachiya) and M=9.93PAL-164.02, R^2= 0.97 (for Fuyu)) with mass of persimmon fruits.

Introduction

Persimmon *(Diospyros kaki)*, belongs to the family of Ebenaceae and has been cultivated for thousands of years. It is believed to have originated in China (Luo and Wang, 2008) and introduced later to Korea and Japan, where it is a considered as a traditional crop (Karaman *et al*., 2014). Apart from these palces it is also grown in India to a minor extent (Nazir *et al*., 2013). The world-wide production of persimmon stands at 4.63 million tonnes 2013 (FAO, 2013). Persimmon is a rich source of dietary fibers, phenolic compounds, minerals and trace elements that makes persimmon a preferable fruit for staying healthy life (Luo, 2006). All of these nutrients are usually considered as powerful antioxidants that protect against free radicals, prevent risk of cardiovascular diabetes, disease and cancer (George and Redpath, 2008). It is mainly eaten fresh due to its pleasant flavour and can also be frozen, canned and dried to improve its shelf life (Telis *et al*., 2000).

Physical properties of agricultural crops are considered to be most important for appropriate design equipment for harvesting, storage, handling, transporting, conveying, separation, and other processes. Researchers generally show interest in knowing various physical properties of fruits for designing of handling and processing equipments (Kilickan and Guner, 2008). It is crucial to have precise estimate of various physical properties. Physical properties like size, shape, sphericity, porosity, bulk and true density are needed in air flow studies, heat studies, design of silos, grading, separation, drying and storage from undesirable materials (Athmaselvi *et al*., 2014).The engineering properties of agriculture crops have special importance in sizing systems and depend on dimensions, mass, volume and surface area (Ashtiani *et al*., 2014). Grading fruits by their weight is more economical than grading them with size in packing and handling (Ghabel *et al*., 2010), hence grading of fruits is mostly based on their weight. Consumers prefer fruits with equal weight and uniform shape (Khanali *et al*., 2007). Packing and transportation costs can be reduced by mass grading of fruits and also may provide an optimum packaging configuration (Mansouri *et al*., 2010;). Therefore, for the persimmon fruit grading by weight will be more economical than grading by size. Hence, study on relationships among mass, dimensions and projected areas are essential (Shahbazi and Rahmati, 2014).Many studies have been recorded on the physical properties of fruits such as anola (Goyal *et al*., 2007), mango (Jha *et al*., 2006) orange (Topuz *et al*., 2005), kumquat (Jaliliantabar *et al*., 2013), cider apple (Guillermin *et al*., 2006). In the case of mass modeling, Ashtiani *et al*. (2014) determined models for predicting mass of Iranian lime fruits from its dimensions, projected areas and volumes. They

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found a linear equation between mass and its minor diameter.

Physical properties of fruits vary with the cultivar, soil and geographical location (Goyal *et al*., 2007). In India, persimmon fruits are cultivated only in Himalayan ranges, hence long transportation and storage is necessary,for this reason knowledge on some physical properties of persimmon fruits is essential in every stage of handling and processing. Hence, it is necessary to make a comprehensive study on the physical properties and their relationships, to develop appropriate technologies for its processing. The main objectives of this study was to determine the most suitable model for predicting persimmon mass by its physical properties and to investigate the detailed physical properties of two Indian persimmon cultivars (Hachiya and Fuyu). This information can be used to design and develop of sorting equipment for persimmon fruits.

Materials and Methods

Material

Two persimmon cultivars, viz. 'Hachiya' and 'Fuyu' were harvested from the Dirang valley (Arunachal Pradesh, India) in the month of late November, 2015. Harvested fruits were transferred to the laboratory and then stored at refrigerated condition (4±1°C) before conducting the experiments. All the measurements were conducted at room temperature (25 ± 2°C).

Physical properties

Fifty samples from each cultivar were taken and their mass was measured using digital electronic balance (CPA 225D, Sartorious AG, Germany) with an accuracy of 0.001 g. Other properties like length (L), width (W), and thickness (T) were measured using a Vernier caliper with an accuracy of 0.02 mm. Geometric mean diameter (D_g) sphericity (Φ) and aspect ratio (R_a) values were also calculated using the relationships given by Razavi and Parvar,(2007). The surface area (S) was estimated using the relationship given by McCabe *et al*. (1993). The bulk density was determined with a hectolitre tester, which was calibrated in kg per hectolitre (Athmaselvi *et al*., 2014). The true density (ρ_t) and true volume (V_t) were determined by using toluene displacement method (Kilickan and Guner, 2008). The porosity was calculated using the relationship given by Singh and Goswami, (1996). Projected area of persimmon fruit perpendicular to dimensions was calculated using equation (1), (2) and (3), respectively. Then the average projected area known as criteria projected area (CPA) was determined from equation (4) (Salihah *et al*., 2015).

$$PA_L = \frac{\pi LW}{4} \quad (1)$$

$$PA_w = \frac{\pi WW}{4} \quad (2)$$

$$PA_T = \frac{\pi TW}{4} \quad (3)$$

$$CPA = \frac{PA_L + PA_W + PA_T}{3} \quad (4)$$

Where, PA_L is the Projected area perpendicular to the length of fruit, PAW is the projected area perpendicular to width of fruit and PAT is the projected area perpendicular to thickness of fruit.

The assumed oblate spheroid (V_{osp}) and ellipsoid (V_{ellip}) shapes were determined according to Shahbazi and Rahmati, (2014)

$$V_{osp} = \frac{\pi L W^2}{6} \quad (5)$$

$$V_{ellip} = \frac{LWT}{6} \quad (6)$$

Regression models for mass prediction

In order to estimate the persimmon mass, the following model equations (7-11) were considered from its dimensions, volume and projected area. These models were obtained with single and combination of three variables (Ghabel *et al*., 2010).

$$M=k_1X_i+k_2 \quad (7)$$
$$M=k_1X_1+k_2X_2+k_3X_3+k_4 \quad (8)$$
$$M=k_1Y_i+k_2 \quad (9)$$
$$M=k_1PA_L+k_2PA_W+k_3PA_T+k_4 \quad (10)$$
$$M=k_1Z_i+k_2 \quad (11)$$

Where: i=1,2 and 3

X_1=L, X_2=W and X_3=T

Y_1= PA_L, Y_2= PA_W and Y_3= PA_T

Z_1= V_t, Z_2= V_{ellip} and Z3=V_{osp}

k_1, k_2, k_3 and k_4 are regression coefficients

Statistical analysis

Spreadsheet software, Microsoft Excel 2013 was used to analyze and interpret the data to determine regression models between the parameters of linear or nonlinear forms. Coefficient of determination (R2) and standard error of estimate (SEE) were used to evaluate the regression models. The model which has higher value of R^2 and the lower value of SEE represented a better model for mass prediction.

Table 1. Some physical properties of two Indian persimmon cultivars

Property	Hachiya			Fuyu		
	max	min	mean±SD	max	min	mean±SD
Length(L),cm	9.34	7.20	8.22±0.52	6.32	5.24	5.80±0.30
Width(W),cm	9.20	7.235	8.10±0.47	9.23	7.85	8.79±0.40
Thickness(T),cm	9.40	6.90	7.63±0.61	9.23	7.62	8.48±0.44
Geometric mean diameter(D_g),cm	9.25	7.11	7.98±0.49	8.16	6.86	7.56±0.36
Sphericity(Φ),%	101.49	93.12	97.04±0.02	130.36	127.42	130.03±0.01
Mass(M),g	359	210	271.92±36.06	300	155	234.88±39.29
True Volume(V_t),cm^3	359.93	194.26	265.70±39.84	316.355	162.07	236.67±44.81
Ellipsoid volume(V_{ellip}),cm^3	414.89	188.48	269.14-52.58	284.89	169.18	228.22±32.71
Prolate spheroid volume(V_{psp}),cm^3	410.60	197.43	285.46±52.14	289.49	169.34	236.75±32.17
True density(ρ_t),g/cm^3	1.25	0.936	1.028±0.08	1.02	0.90	0.98±0.08
Bulk density(ρ_b), g/cm^3	0.724	0.512	0.593±0.05	0.71	0.50	0.58±0.05
Porosity (ε),%	58.35	25.66	41.91±7.99	57.99	24.13	40.95+8.19
Surface area(S),cm^2	268.96	158.94	200.78+25.47	209.34	147.90	180.15±4.90
Projected area(PA_L),cm^2	67.08	40.93	52.49±6.36	46.42	32.34	40.18±3.89
Projected area(PA_T),cm^2	67.39	39.22	48.72±6.16	67.60	48.35	58.70±5.44
Projected area(PA_W),cm^2	66.57	41.09	51.69±6.16	68.66	48.40	60.89±5.32
Criteria projected area(CPA),cm^2	66.29	40.41	50.97±6.14	60.71	43.03	53.26±4.90

±SD= standard deviations.

Results and Discussion

Physical properties of persimmon fruits

The mean values of some selected physical properties of persimmon cultivars (Hachiya and Fuyu) were presented in Table 1. All these properties for two persimmon cultivars (Figure 1) were determined at moisture content of 82.45±0.71 and 80.14 ±1.29 % (wet basis), respectively. According to the results shown in Table 1, the mean values of length, width, thickness, geometric mean diameter and mass of Hachiya cultivar was found to be significantly greater than Fuyu cultivar. From this study it was also concluded that the Indian persimmon cultivars were larger than Turkish persimmon cultivars (Celik and Ercisli, 2008; Altuntas *et al.*, 2010). The values of average volumes including true, ellipsoid and oblate spheroid shapes were resulted higher for Hachiya than Fuyu (Table 1). From these results it was found that Fuyu fruits could be packed in the predetermined volume compared with the Hachiya cultivar. The average values of true density, bulk density, surface area and porosity were found to be greater for Hachiya as shown in Table 1.

The average value of sphercity for Hachiya was resuted smaller when compared with Fuyu cultivar as shown in Table1. All the mentioned physical properties were found to be different from previous studies done by various researchers on persimmon from different regions (Celik and Ercisli, 2008; Altuntas *et al*., 2010; Shahbazi and Rahmati, 2014) but the average values of each property was within the limits of those reports. The variation of fruit mass, fruit length and fruit width of persimmon can be mainly due to different cultivars, the rootstocks used, nutritional status of orchards and environmental conditions (Celik and Ercisli, 2008).The average values of PAL, PAW and PAT for Hachiya cultivar were higher than Fuyu cultivar. The observed difference for the projected area was mainly due to the different values of dimensional characteristics and may be used for design and development of grading equipment (Ashtiani *et al*., 2014).

Figure 1. Indian persimmon cultivars (a) Hachiya and (b) Fuyu

Table 2. Coefficient of estimation (R^2) and standard error estimate for linear regression models of mass (M) for two Indian cultivars of persimmon fruits (Hachiya and Fuyu)

S.No	Model	Parameter	Hachiya	Fuyu	Total of observations
	Models based on dimensions				
1	$M=k_1L+k_2$	R^2	0.92	0.94	0.47
		SEE	9.97	9.28	30.455
2	$M=k_1W+k_2$	R^2	0.89	0.93	0.15
		SEE	11.55	10.17	72.109
3	$M=k_1T+k_2$	R^2	0.57	0.73	0.07
		SEE	23.76	20.78	40.59
4	$M=k_1L+k_2W+k_3T+k_4$	R^2	0.94	0.97	0.55
		SEE	8.35	6.72	28.55
	Models based on Projected areas				
5	$M=k_1PA_L+k_2$	R^2	0.95	0.97	0.78
		SEE	7.42	6.86	19.62
6	$M=k_1PA_W+k_2$	R^2	0.83	0.89	0.12
		SEE	14.69	12.81	39.56
7	$M=k_1PA_T+k_2$	R^2	0.90	0.97	0.15
		SEE	9.26	9.80	38.73
8	$M=k_1PA_L+k_2PA_W+k_3PA_T+k_4$	R^2	0.96	0.97	0.93
		SEE	6.80	6.62	10.0787
	Models based on volume				
9	$M=k_1V_t+k_2$	R^2	0.79	0.86	0 .84
		SEE	16.55	14.70	6.73
10	$M=k_1V_{ellip}+k_2$	R^2	0.91	0.94	0.88
		SEE	10.79	9.00	21.85
11	$M=k_1V_{psp}+k_2$	R^2	0.95	0.96	0.91
		SEE	7.99	6.67	22.12

Number of observations for each fruit was 50 and total of observation 100
k_1, k_2, k_3 and k_4 are coefficients, L, W and T are persimmon dimensions
PA_L, PA_W and PA_T are projected areas.
V_t, V_{ellip} and V_{psp} are true volume, ellipsoid and oblate spheroid volumes respectively.

Mass models based on dimensions

Among the linear regression models (1-4), model 4 had the highest R^2 and lowest SEE for both cultivars (Table 2). Same models were not fitted for total of observations, because of variation among the dimensions for both cultivars. However the three dimensions must be measured for the model 4, which makes sizing mechanism tedious and expensive (Asthiani et al., 2014). Among the models1 to 3 (Table 2), model 1 showed the highest R^2 value for both the cultivars, therefore model 1 which is obtained based on the length (L) dimension was recommended. Thus model 1 among the one dimensional model was selected as the best persimmon mass model based on length as illustrated in Figure 2.The mass model of persimmon for Hachiya and Fuyu based on the model 4 (all dimensions) is described by following equations, respectively.

$$M = 33.74L + 31.21W + 7.69T - 317.35 \quad (12)$$

R^2=0.94, SEE=8.35 (for: Hachiya)

$$M = 66.25L + 38.33W + 8.7T - 317.35 \quad (13)$$

R^2=0.97, SEE=6.72 (for: Fuyu)

By comparing linear, power, quadratic and logarithmic model, the best model based on single dimension could be suggested as follow

$$M = 16.07LL^2 - 201.33L + 836.25 \quad (14)$$

R^2=0.95, SEE=8.54 (for: Hachiya)

$$M = 0.093W^{3.59} \quad (15)$$

R^2=0.95, SEE= 8.54 (for: Fuyu)

Shahbazi and Rahmati, (2014) also recommended the quadratic model based on length for predicting the mass of Iranian Fuyu cultivar. They recommended quadratic equation as shown below

$$M = 356.17 - 12.66L + 0.13L^2, R^2= 0.96 \quad (16)$$

Ghabel *et al.* (2010) recommended nonlinear form model for predicting mass of onion based on length. Ashtiani *et al.* (2014) recommended linear form of model for approximate mass of lime fruit

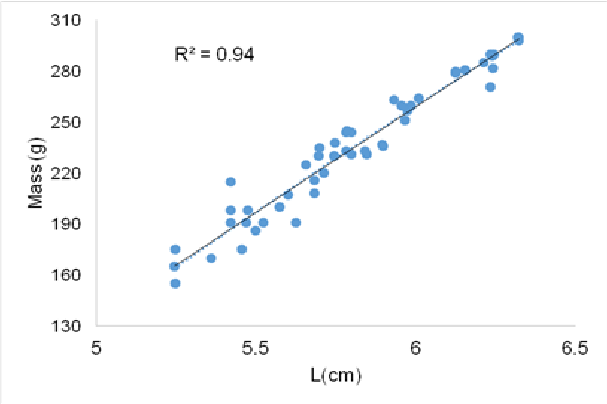

Figure 2. Linear model based on Length for Fuyu

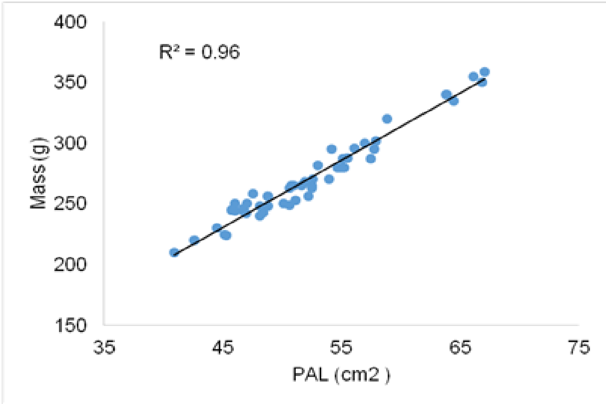

Figure 3. Linear model based Projected area (PAL) for Hachiya

based on minor diameter. In another study Boldaji *et al*. (2008) reported power equation based on minor diameter for predicting mass of apricots. Therefore in this study mass modelling of persimmon (Hachiya and Fuyu) fruits based on length is recommended among first class of models (1-4).

Mass models based on projected area

Among the second classification of models, from 5 to 8 shown in table (2), the model 8 for two cultivars had maximum R^2 value and minimum SEE. The overall mass model based on the projected areas (model 8) for total of observations had R^2 less than the individual cultivars. And these models are given as bellow

$$M = 5.48PA_L + 0.98PA_W - 0.95PA_T - 18.12 \quad (17)$$

R^2=0.97,SEE=6.80 (for: Hachiya)

$$M = 9.08PA_L + 1.06PA_W - 0.42PA_T - 167.25 \quad (18)$$

R^2= 0.97, SEE= 6.625 (for: Fuyu)

$$M = 9.62PA_L + 1.25PA_W + 0.96PA_T - 78.89 \quad (19)$$

R^2= 0.93, SEE= 10.0787 (for: Total of observations)

Models with multiple variables showed the sizing mechanism expensive and complicated (Asthiani *et al*., 2014), hence mass model based on single projected area was recommended for prediction among each one of the three projected areas of the model equations 5, 6, and 7, based on one projected area for mass modelling. The model equation 5 for both cultivars had highest R^2 value and lowest SEE. The comparison between area and predicted mass of persimmon applied for projected area was derived from the model 5 (Table 2) is shown in Figure 3. So the first projected area (PAL) which is perpendicular to length can possibly be recommended as the best choice for the sizing mechanism.The best equation to calculate mass of persimmon for two cultivars based on one projected area can be suggested by comparing linear and nonlinear models (equation 22-23). Lorestani and Tabatabaeefar (2006) recommended a power function to estimate kiwi fruit mass by third projected area. Ashtiani *et al* (2014) recommended mass model based on projected area for lime fruits based on major diameter. Shahbazi and Rahmati, (2014) recommended quadratic model for persimmon (Fuyu) based on projected area (PAL) given in equation (25), but in our study linear form model based on projected area (PAL) shown in equation (20) and (21) were fitted well. Therefore mass modelling of persimmon (Hachiya and Fuyu) fruits based on projected area is recommended.

$$M = 5.53PA_L - 18.88 \quad (20)$$

R^2=0.95, SEE= 7.42 (for: Hachiya)

$$M = 9.93PA_L - 164.02 \quad (21)$$

R^2=0.97, SEE= 6.82 (for: Hachiya)

$$M = 0.05PA_L^2 + 0.49PA_L + 116.97 \quad (22)$$

R^2=0.96, SEE= 7.07 (for: Hachiya)

$$M = 0.05PA_L^2 + 5.78PA_L - 82.09 \quad (23)$$

R^2=0.97, SEE= 6.81 (for: Fuyu)

$$M = 8.73PA_L^{0.88} \quad (24)$$

R^2=0.78, SEE= 28.97 (for: Total of observations)

$$M = 286.11 - 0.26PA_L + 7.5 \times 10^{-5}PA_L, \quad R^2 = 0.73 \quad (25)$$

Mass models based on volume

In this classification (models 9 to11) group the highest R^2 and lowest SEE values obtained for model 11 (Table 2) for each cultivar and total of observations. Actual volume is not mandatory according to this observation, because it is time consuming and noneconomic. The model 11 measures two dimensions rather than measuring three dimensions, hence it is recommended for predicting the mass of fruits.By comparing all the resulted estimations, the linear model for both cultivars and total of observations can be introduced for grading mechanism. The mass model based on volume for Hachiya and Fuyu cultivars are given as bellow

$$M = 0.67V_{osp} + 79.66 \quad (26)$$

R^2=0.95, SEE=7.996 (for: Hachiya)

$$M = 1.16V_{osp} - 39.91 \quad (27)$$

R^2=0.96, SEE=6.977 (for: Fuyu)

According to the results obtained from this study, linear and nonlinear models could predict the relationship between the mass and some physical properties of persimmon (Hachiya and Fuyu) fruits with proper values of coefficient of determination. While Shabazi and Rahmati, (2014) had reported the linear and quadratic models based on assumed ellipsoid shape with a high coefficient of determination for mass modelling of Iranian persimmon (Fuyu).

Conclusion

Some physical properties and their relationship with mass for persimmon cultivars (Hachiya and Fuyu) were proposed in this study. The mean values of physical properties for Hachiya cultivar resulted higher than the Fuyu cultivar. The recommended model to calculate persimmon mass based on its length (model 1) was as linear form: M=124.04L-485.22, R^2 =0.94 and the mass model recommended for persimmon based on projected area perpendicular to length (PAL) was as linear form ($M=k_1PA_L+k_2$) with regression coefficient of greater than 0.95 for both cultivars. There was not a good relationship between mass and measured volume of persimmon for both the cultivars. But the model to predict the mass of persimmon based on its estimated volume (oblate spheroid shape) was found to be the best fit, $M=1.1606V_{osp}-39.911$, R^2=0.96. And it was finally concluded that the suitable grading system of persimmon mass is based on projected area perpendicular to length(PAL) for both the cultivars.

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