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Modeling physical properties of lemon fruits for separation and classification

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Abstract

Getting the relationship between physical properties of fruits and their mass can create tremendous change in the packaging industry. A part of this study was aimed to present some physical traits of two lemon varieties (Seedless Lisbon and Frost Eureka) which are very similar in appearance but different in interior quality. In addition, lemon mass was predicted by different physical characteristics with linear and nonlinear models as three different classifications: (1) single and multiple variable regressions of lemon dimensions, (2) single and multiple variable regressions of projected areas and (3) single regression of lemon mass based on its actual volume and calculated volume assuming the lemon shapes of ellipsoid and prolate spheroid. According to the obtained results, many attributes considered in the current study were found to be statistically significant ($P < 0.01$). In economical and agronomical points of view, suitable sizing system of lemon mass was ascertained based on third projected area. At last, the obtained results and regression models showed that separation can be promised for these two varieties. Among different models, two mass based models in linear form showed the highest separation performance. The first model was based on mass-volume and the second one based on mass-major dimension.

Introduction

Citrus fruits as a group of fruits which are in high demand in the world have remarkable economical, social and cultural impacts in our society (Iglesias *et al.*, 2007). Among these fruits, lemon (*Citrus limon* Burm. f.) is the third most important citrus species after orange and mandarin (Perez-Perez *et al.*, 2005). Lemons are favorite fruits for many consumers around the world because of their exceptional flavor and acidity, and also potential application as industrial and value-added food products. They are known to possess nutritive as well as medicinal values, mainly as rich source of vitamin C. They also contain other vitamins such as vitamin B, riboflavin and minerals like calcium, phosphorous, magnesium besides proteins and carbohydrates. Lemons are known to reduce the risk of heart diseases, cancer and also work as antiseptic, astringent, digestive stimulant etc (Hrishikesh-Tavanandi *et al.*, 2013).

The knowledge of physical characteristics of agricultural produce is crucial to proper establishment of standards and design criteria for fabrication of sorting, grading, conveying, storing, processing and packaging systems (Tabatabaeefar and Rajabipour, 2005; Lorestani and Tabatabaeefar, 2006; Khoshnam *et al.*, 2007; Shahi-Gharahlar *et al.*, 2009; Seyedabadi *et al.*, 2011; Shahbazi and Rahmati, 2013). Amongst all various properties, dimensions, mass, volume, projected and surface areas are the momentous factors in the design of grading systems (Bahnasawy *et al.*, 2004; Khoshnam *et al.*, 2007). Grading of fruits is a common processing operation as consumers prefer fruits with similar mass and uniform shape. Mass grading of fruit can provide an optimum packaging appearance, while it reduces packaging and transportation costs and damage (Tabatabaeefar and Rajabipour, 2005; Khoshnam *et al.*, 2007; Shahi-Gharahlar *et al.*, 2009; Seyedabadi *et al.*, 2011; Shahbazi and Rahmati, 2013).

From external appearance point of view, sorting and grading of agricultural and food products are performed based on their appearance, texture, color, shape and size. However, the more complicated a processing operation is the more difficult it is to separate fruits which are similar in appearance but different in inner quality. In this case, these traits may not work properly. Manual sorting and grading which are performed based on traditional visual quality inspection, are tedious, time-consuming, slow and inconsistent. On the other hand a cost effective, consistent, superior speed and accurate sorting can be achieved with machine vision based sizing mechanisms which are expensive and sometimes complicated (Tabatabaeefar and Rajabipour, 2005). Other grading techniques such as mass based methods

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may be promising from economy and accuracy points of view. Grading by mass may be performed by direct weighing of fruits or applying their suitable mass models which are estimated based on other attributes of fruits models. Therefore, study on the potential relationships between mass and geometric properties of fruits e.g. dimensions, volume and projected areas may lead to an economic, fast and accurate sizing method (Seyedabadi *et al*., 2011).

In the case of mass modeling, Shahbazi and Rahmati (2013) provided some models for predicting mass of sweet cherry fruit by its dimensions, volumes, and projected areas. They reported that the first projected area was more appropriate to estimate the mass of sweet cherry fruit. Lorestani and Kazemi (2012) studied the physical properties of castor seed and found some models for predicting seed mass while employing dimensions, volume, projected and surface areas. They reported that mass modeling of castor seed based on the second projected area is economically recommended. Miraei Ashtiani et al. (2012) used this method for predicting the mass of two lime varieties. These researchers reported that prolate spheroid volume model was the best and could be considered as a good model for line grading machine. Likewise, there were many studies focusing on predicting the mass of plant materials such as apple (Tabatabaeefar and Rajabipour, 2005), kiwi (Lorestani and Tabatabaeefar, 2006), pomegranate (Khoshnam *et al*., 2007), apricot (Naderi-Boldaji *et al*., 2008), loquat (Shahi-Gharahlar *et al*., 2009) and cantaloupe (Seyedabadi *et al.*, 2011).

No documented studies concerning mass modeling of lemon have yet been performed. Modeling different properties of two lemon varieties, Seedless Lisbon and Frost Eureka, to provide a cost effective, quick and still accurate sizing method was the objective of this research. The importance of this issue was that both varieties have similar appearance, while their interior characteristics are different. The former is seedless and the latter is seedy. Moreover, Seedless Lisbon lemon has high acid content, therefore it is a good option for juice extraction, but Frost Eureka lemon has low acid content which is suitable for fresh consumption. Naringin as the prime bitter component of lemons is found in different parts of the fruit, including its seeds (Yusof *et al*., 1990). The bitterness of the extracted juices is one of the major problems in food processing industry, and trying to remove its sources would have significant economic impact. In other words, if seedy and seedless lemons are mixed up (accidentally or intentionally) or not consumed properly, this causes dissatisfaction to the fresh fruit consumers and reduction of juice quality. Therefore, the possibility of distinguishing between these two lemon varieties using their difference in physical attributes was investigated.

Materials and Methods

Sample preparation

Two common varieties of lemon called Seedless Lisbon and Frost Eureka were obtained from Jahrom region in the southern part of Iran in October 2013. Samples of matured and defect-free lemons had smooth skin and yellow-green color. The number of obtained fruits was 70 for each variety. They were directly transferred to the laboratory on the same day. To avoid any environmental side effect, samples were kept in temperature of 10-12^{o}C and relative humidity of 85-95% recommended by Jomori *et al*. (2003). The cut parts of 10 fruits from each variety were weighed and dried in an oven (Behdad, BSC-2006, Iran) at a temperature of 80^{o}C for 72 h, then mass loss on drying was recorded as initial moisture content (Miraei Ashtiani *et al*., 2012). Average of three replications was reported as moisture content of the samples. The average moisture contents were 85.07 and 82.18% (w.b.) for Seedless Lisbon and Frost Eureka varieties, respectively. The rest of samples (60 fruits of each variety) were used for the experiments. The required quantities of the samples were taken out of the refrigerator and allowed to warm up to room temperature before starting the experiments (Aghkhani *et al*., 2012).

Determination of physical properties

For each fruit, three mutually perpendicular axes were specified, major (*a*, the longest intercept), intermediate (*b*, the longest intercept normal to *a*), minor (*c*, the longest intercept normal to *a* and *b*) and projected areas (PA) were measured from images taken by a digital camera (SONY DSC-W35, 7.2 MP, Japan) in a light-controlled condition. The captured images were transmitted to a computer and then processed in ImageJ Ver. 1.46d software program. The average projected area (known as criteria projected area) was calculated using the following equation (Khoshnam *et al*., 2007):

$$\mathrm{CPA} = \frac{\mathrm{PA}_1 + \mathrm{PA}_2 + \mathrm{PA}_3}{3} \qquad (1)$$

where CPA is the criteria projected area; PA_1, PA_2 and PA_3 are the first, second and third projected areas perpendicular to the major, intermediate and minor diameters, respectively.

The mass (*M*) of each lemon was measured by an electronic balance with an accuracy of 0.01 g. The property of measured volume (V_m) was determined by water (25°C) displacement method. The true density was estimated as the ratio of sample mass to the volume of displaced water (Mohsenin, 1986). Due to the short duration of the experiment and the nature of the skin of the lemon which does not allow water to be absorbed easily, the lemons were not coated to prevent moisture absorption. The geometric mean diameter, sphericity and surface area were calculated from the three linear dimensions according to Naderi-Boldaji *et al.* (2008). Aspect ratio was calculated as the ratio of intermediate diameter to major diameter (Mohsenin, 1986). The bulk density was determined using the mass and volume relationship by filling an empty plastic container of predetermined volume and mass. The lemons were dropped into a container from a height of 15 cm. The container was tapped several times and the excess fruits were removed without compressing them. The ratio of weight of lemon fruits to the container volume gave the bulk density (Naderi-Boldaji *et al*., 2008). The percentage porosity was obtained using the method described by Mohsenin (1986) and also for determination of packing coefficient, the total volume of fruits was divided by the packed volume (Topuz *et al*., 2005).

To estimate the volume of a lemon from its diameters, the fruit was assumed as ellipsoid and prolate spheroid (Mohsenin, 1986):

$$V_{ellip} = \frac{\pi}{6}abc \qquad (2)$$

$$V_{PSP} = \frac{\pi}{6}ab^2 \qquad (3)$$

where V_{ellip} and V_{PSP} are the estimated volume of fruit assuming ellipsoid and prolate spheroid, respectively.

The static coefficient of friction and rolling resistance coefficient of lemon fruits against surfaces covered with different materials, namely Medium Density Fiberboard (MDF), glass, rubber, plexiglas, aluminum and galvanized iron sheets were investigated using inclined plane method. A tilting platform was fabricated and used for experiments. For examination of static coefficient of friction, a plastic box open on two opposite sides was filled with the fruits and placed on the adjustable tilting plate without allowing the box to touch the inclined surface. The tilting surface was raised gradually by means of a screw device. The angle of inclination to the horizontal surface was recorded as soon as the fruit began to slide down. The tangent of the angle of inclination of the surface was considered as the coefficient of the static friction (Bahnasawy *et al.*, 2004; Solomon and Zewdu, 2009). This experiment was replicated ten times for each material and the average values were reported. For each replication, the samples in box was emptied and refilled with new samples.

Rolling resistance coefficient of samples was measured as recommended by Bahnasawy *et al.* (2004). A fruit was placed on tilting table covered with the studied material in the stable position and then the table was slowly inclined by a handle until the fruit began to roll. Subsequently, the angle of inclination of the surface was recorded and the tangent of this angle was used as the rolling resistance coefficient for that material. The platform was returned to its horizontal position for the next assessment. The same test also was conducted but in non-stable position of the lemon (on their sides). The experiment was repeated ten times.

Mass modeling

For grading purpose and in order to estimate the lemon mass from the studied properties including dimensions, projected areas and volume, three classifications of models were considered as follows:

1. Single and multiple variable regressions of lemon dimensional characteristics: major diameter (*a*), intermediate diameter (*b*) and minor diameter (*c*). The general form of these models is shown in the following equation:

$$M = k_1a + k_2b + k_3c + k_4 \qquad (4)$$

2. Single and multiple variable regressions of lemon for three projected areas. The general form of these models is presented as follow:

$$M = k_1PA_1 + k_2PA_2 + k_3PA_3 + k_4 \qquad (5)$$

3. Single regression of lemon mass with actual volume (V_m), volume of the lemon assumed as ellipsoid (V_{ellip}) and prolate spheroid shapes (V_{psp}). The general forms of these models are shown in Equations (6) to (8):

$$M = k_1V_m + k_2 \qquad (6)$$

$$M = k_1V_{ellip} + k_2 \qquad (7)$$

$$M = k_1V_{psp} + k_2 \qquad (8)$$

where k_1 to k_4 are constants.

Separation models

Mass modeling of fruits may provide easier and faster method of fruits sorting, it can be applied to separate the fruits that are similar in size and the other appearance attributes. To separate Seedless Lisbon and Frost Eureka lemons from the bulk of their mixture, the relation between mass and each of their studied properties for both varieties were investigated by plotting them in the same figure, then the regression models namely separation models were obtained. This procedure was performed for all investigated properties and in each case the best separation line was drawn by trial and error. The best separation models were introduced.

Data analysis

Duncan's test was used for the mean comparison of the results. Microsoft Excel 2007 and SPSS (version 17) software were used to analyze the data and to determine regression models in either linear or nonlinear forms. Coefficient of determination (R^2) and standard error of estimate (SEE) were used to evaluate the regression models. The models with the higher value of R^2 and lower SEE gave a better estimation.

Results and Discussion

Physical properties of lemon

The results of some physical properties of two lemon varieties evaluated in this study are presented in Table 1. The mean values for the properties of the two varieties showed significant ($P < 0.01$) difference for all the studied properties except the bulk density and the porosity. The Frost Eureka variety had higher values than Seedless Lisbon for many properties, except intermediate diameter, sphericity, aspect ratio, true density, porosity and packing coefficient. The mean values of major, intermediate and minor diameters for Seedless Lisbon and Frost Eureka varieties were 55.30, 51.07 and 49.74 mm and 64.82, 50.95 and 50.08 mm, respectively. The axial dimensions are important parameters in determining aperture size of sorters, particularly in separation of undesirable materials, and may be useful in estimating the size of machine components (Naderi-Boldaji *et al*., 2008). The average mass of Frost Eureka (82.71 g) was about 1.08 times of that for Seedless Lisbon (76.31 g). This difference between two varieties may be attributed to the size of the Frost Eureka which is bigger than the Seedless Lisbon. The average true density of Seedless Lisbon lemon was about 1.04 times of that for Frost Eureka. The values obtained for the true density of the Seedless Lisbon variety revealed that it will sink in water while Frost Eureka variety with a true density of 0.97 g cm^{-3} will float in water. So, these properties are applicable in the separation and transportation of the two varieties of lemon fruits by hydrodynamic apparatus (Naderi-Boldaji *et al*., 2008).

The lemon shape was determined in terms of its sphericity and aspect ratio. The sphericity and aspect ratio of the Seedless Lisbon variety were found to be 94.11 and 92.56%, respectively while these values were 84.74 and 78.75% for Frost Eureka variety (Table 1). The high sphericity value of both lemon varieties is indicative of the tendency of the shape towards a sphere. Also considering high value of aspect ratio, it may be deduced that lemon fruits will roll easily on flat surfaces. The significant difference ($P < 0.01$) of these two parameters revealed the feasibility of their separation using spiral inclined surfaces. As observed in Table 1, the average value of packing coefficient for Frost Eureka was less than that for Seedless Lisbon. This discrepancy could be due to the different volume and shape of the lemon varieties. The packing coefficient increased with decreasing fruit volume as reported by previous researchers (Topuz *et al*., 2005). As the packing coefficient indicates the void spaces inside the pack, having any data about packing coefficient could result in efficient control of fruit quality during storage (Lorestani and Kazemi, 2012) because it provides necessary information about the void spaces inside the pack, the size of pack and the number of probable bruising points. The significant difference in values of projected areas including criteria projected area ($P < 0.01$) of both varieties (Table 1) revealed their separation possibility using machine vision techniques.

The experimental results of the static coefficient of friction and rolling resistance coefficient of the studied lemon varieties on surfaces of six different materials are given in Table 2. The maximum and minimum values of static coefficient of friction, which affect the design of their processing machine, are for rubber and MDF, respectively in both varieties. This behavior may be as a result of the fact that the MDF has a surface that is smoother and less porous than the surfaces of other investigated materials (Sologubik *et al*., 2013). Static coefficient of friction for the Seedless Lisbon was less than that for Frost Eureka variety on all studied materials. This might be due to the rougher surface of the Frost Eureka variety compared with the Seedless Lisbon variety which has a smooth surface and allows easy moving on the studied surfaces. The coefficient values were significantly different on rubber ($P < 0.01$), plexiglas and galvanized iron ($P < 0.05$). It was noticed that friction between fruit and a surface is of paramount importance in movement of lemon fruit on oscillating conveyors, separation on oscillating sieves, estimating the power requirement of machines for loading and

Table 1. Some physical properties of two studied lemon fruits

Property	Seedless Lisbon			Frost Eureka			Sig.
	Max	Min	Mean ± St.dev	Max	Min	Mean ± St.dev	
Major diameter (mm)	62.85	49.31	55.30 ± 3.87	70.18	58.44	64.82 ± 3.71	**
Intermediate diameter (mm)	57.42	43.33	51.07 ± 3.23	59.26	46.35	50.95 ± 3.30	*
Minor diameter (mm)	55.32	42.60	49.74 ± 3.12	58.32	45.54	50.08 ± 2.88	*
Geometric mean diameter (mm)	58.45	45.30	51.96 ± 3.06	62.13	49.84	54.87 ± 2.85	**
Sphericity (%)	98.95	86.72	94.11 ± 3.76	91.39	79.44	84.74 ± 3.29	**
Aspect ratio (%)	98.08	90.23	92.56 ± 4.94	92.62	71.27	78.75 ± 5.30	**
Mass (g)	106.62	48.97	76.31 ± 13.20	122.28	62.24	82.71 ± 13.22	**
Actual volume (cm^3)	106.43	48.63	75.49 ± 13.22	126.32	63.37	85.5 ± 13.89	*
Ellipsoid volume (cm^3)	104.53	48.66	74.2 ± 13.13	125.58	64.81	87.17 ± 13.98	*
Prolate spheroid volume (cm^3)	108.50	49.50	76.21 ± 13.69	127.61	65.96	88.72 ± 14.65	*
True density ($g\,cm^{-3}$)	1.03	1.00	1.01 ± 0.01	0.99	0.95	0.97 ± 0.01	**
Bulk density ($g\,cm^{-3}$)	0.45	0.42	0.43 ± 0.05	0.49	0.46	0.48 ± 0.04	**
Porosity (%)	58.11	56.99	57.62 ± 0.30	51.83	50.03	51.09 ± 0.21	**
Packing coefficient	0.62	0.59	0.61 ± 0.02	0.56	0.53	0.55 ± 0.05	**
Surface area (mm^2)	10731.25	6445.87	8510.83 ± 1002.27	12127.62	7802.63	9482.85 ± 998.86	**
First projected area (mm^2)	2678.29	1502.80	2124.56 ± 269.08	3052.15	1732.47	2147.68 ± 281.93	**
Second projected area (mm^2)	2867.66	1682.34	2273.39 ± 280.97	3385.61	1979.73	2566.55 ± 298.73	*
Third projected area (mm^2)	2954.17	1756.81	2327.13 ± 290.32	3450.22	2058.71	2596.38 ± 300.09	*
Criteria projected area (mm^2)	2833.37	1647.31	2241.69 ± 277.40	3295.99	1923.64	2436.87 ± 290.09	**

± St.dev are standard deviations

Values are means of twenty replications for bulk density, porosity and packing coefficient, and sixty for others

*,** Significant levels at 5% and 1%, respectively

Table 2. Static friction and rolling resistance coefficients of lemon fruits

Surface	Variety		Sig.
	Seedless Lisbon (±St.dev)	Frost Eureka (±St.dev)	
Static coefficient of friction			
MDF	0.403 ± 0.014^{a}	0.449 ± 0.020^{a}	ns
Glass	0.433 ± 0.021^{b}	0.482 ± 0.029^{b}	ns
Rubber	0.611 ± 0.019^{c}	0.695 ± 0.022^{c}	**
Plexiglas	0.445 ± 0.017^{d}	0.508 ± 0.029^{b}	*
Aluminum	0.488 ± 0.021^{d}	0.547 ± 0.030^{d}	ns
Galvanized iron	0.522 ± 0.030^{e}	0.586 ± 0.040^{e}	*
Rolling resistance coefficient in non-stable position			
MDF	0.086 ± 0.017^{a}	0.111 ± 0.037^{a}	**
Glass	0.102 ± 0.026^{d}	0.128 ± 0.032^{b}	*
Rubber	0.145 ± 0.009^{cd}	0.156 ± 0.028^{b}	ns
Plexiglas	0.108 ± 0.022^{b}	0.134 ± 0.034^{ab}	*
Aluminum	0.129 ± 0.031^{b}	0.148 ± 0.024^{ab}	ns
Galvanized iron	0.139 ± 0.017^{c}	0.151 ± 0.025^{b}	ns
Rolling resistance coefficient in a stable position			
MDF	0.199 ± 0.015^{b}	0.242 ± 0.037^{a}	**
Glass	0.221 ± 0.019^{a}	0.252 ± 0.038^{a}	**
Rubber	0.252 ± 0.015^{d}	0.278 ± 0.043^{a}	ns
Plexiglas	0.231 ± 0.024^{cd}	0.257 ± 0.047^{a}	ns
Aluminum	0.240 ± 0.018^{bc}	0.261 ± 0.034^{a}	ns
Galvanized iron	0.243 ± 0.021^{bcd}	0.268 ± 0.024^{a}	ns

Means followed by different alphabets in the same column are significantly different at 95% confidence limit

*,** Significant difference in rows at 5% and 1% respectively, ns: not significant difference between two varieties

unloading operations (Solomon and Zewdu, 2009). As can be seen from Table 2, in a stable position, the highest rolling resistance coefficient values of the Seedless Lisbon (0.252) and Frost Eureka (0.278) varieties were on rubber followed by galvanized iron, aluminum, plexiglas, glass and MDF. In non-stable position, the highest rolling resistance coefficient value (0.156) was obtained for the Frost Eureka variety on the surface of rubber, meanwhile the lowest rolling resistance coefficient value (0.086) was recorded for the Seedless Lisbon variety on the MDF surface. Generally, the rolling resistance coefficient on stable position was always greater than that on the non-stable position for both varieties in the all studied surfaces. This behavior shows the tendency of non-stable fruits to become stable. This trend was in agreement with that obtained by Bahnasawy *et al.* (2004). Also, the average values of rolling resistance coefficient at stable and non-stable positions for Seedless Lisbon were lower compared to the other variety. This inequality could be attributed to the rough surface and sphericity of this variety. The

Table 3. Lemon mass models based on selected independent variables

No.	Model	Parameter	Seedless Lisbon	Frost Eureka	Total of Observations
Category 1					
1	$M = k_1 a + k_2$	R^2	0.61	0.48	0.40
		SEE	8.46	9.78	10.56
2	$M = k_1 b + k_2$	R^2	0.92	0.77	0.79
		SEE	3.86	6.56	6.25
3	$M = k_1 c + k_2$	R^2	0.88	0.94	0.88
		SEE	4.64	3.29	4.78
4	$M = k_1 a + k_2 b + k_3 c + k_4$	R^2	0.98	0.97	0.96
		SEE	1.90	2.59	2.69
Category 2					
5	$M = k_1 PA_1 + k_2$	R^2	0.93	0.95	0.90
		SEE	3.68	2.98	4.28
6	$M = k_1 PA_2 + k_2$	R^2	0.96	0.95	0.90
		SEE	2.83	2.89	4.22
7	$M = k_1 PA_3 + k_2$	R^2	0.94	0.96	0.92
		SEE	3.20	2.76	3.75
8	$M = k_1 PA_1 + k_2 PA_2 + k_3 PA_3 + k_4$	R^2	0.96	0.98	0.97
		SEE	2.65	1.89	2.39
Category 3					
9	$M = k_1 V_m + k_2$	R^2	0.99	0.99	0.98
		SEE	0.54	0.70	1.74
10	$M = k_1 V_{ellip} + k_2$	R^2	0.98	0.96	0.93
		SEE	2.06	2.56	3.60
11	$M = k_1 V_{psp} + k_2$	R^2	0.97	0.92	0.92
		SEE	2.18	3.91	3.85

The total number of observations was 120

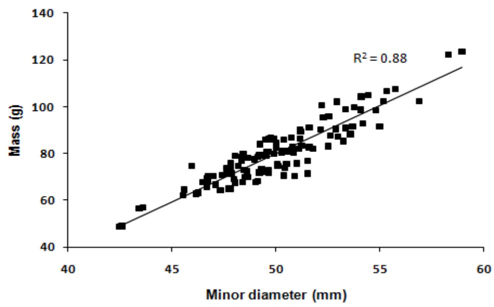

Figure 1. Linear model for total observations based on minor diameter

obtained values were significantly different only on MDF (P < 0.01) and glass for both stable and non-stable positions and just on plexiglas for non-stable position. Knowledge of rolling angle is useful for better design of specific equipment such as sorting, grading and conveying equipment (Tabatabaekoloor, 2013).

Mass modeling

Linear regression models based on the selected independent variables and their coefficients are shown in Tables 3 and 4, respectively. Three different categories of the models are discussed below.

First category, dimensions

Among the first classification models (Nos. 1, 2, 3 and 4 in Table 3), No. 4 (M = 0.73a + 1.26b + 2.35c - 145.46) which employs all three dimensions, had highest R^2 (0.96) and lowest SEE (2.69) for total observations of the both varieties. However, measuring the three diameters makes sizing mechanism more complicated and expensive. Among the single dimension mass models, model No. 2 for Seedless Lisbon (with intermediate diameter (b)), model No. 3 for Frost Eureka (with minor diameter (c)) and model No. 3 for total observations had the highest R^2 and lowest SEE. Therefore, model No. 3 based on the minor diameter (c) is recommended as illustrated in Figure 1. By comparing linear, quadratic, power and

Table 4. Coefficients for linear regression models of both studied lemon fruits and the total observations

Model No.	Seedless Lisbon				Frost Eureka				Total of observations			
	K_1	K_2	K_3	K_4	K_1	K_2	K_3	K_4	K_1	K_2	K_3	K_4
1	2.66	-70.55	-	-	2.46	-76.80	-	-	1.39	-3.96	-	-
2	3.91	-123.44	-	-	3.51	-96.01	-	-	3.70	-109.64	-	-
3	3.98	-121.42	-	-	4.46	-140.38	-	-	4.22	-131.53	-	-
4	1.05	2.31	0.90	-144.74	0.76	0.42	3.45	-160.52	0.73	1.26	2.35	-145.46
5	0.05	-23.97	-	-	0.05	-15.51	-	-	0.05	-20.92	-	-
6	0.04	-27.15	-	-	0.04	-29.02	-	-	0.04	-16.47	-	-
7	0.05	-27.46	-	-	0.04	-28.47	-	-	0.04	-19.35	-	-
8	0.02	0.04	-0.01	-27.80	0.02	-0.02	0.04	-24.78	0.02	0.03	-0.003	-26.27
9	1.00	0.96	-	-	0.95	1.43	-	-	0.93	4.48	-	-
10	0.99	2.57	-	-	0.93	1.79	-	-	0.87	9.38	-	-
11	0.95	3.80	-	-	0.86	6.06	-	-	0.84	10.28	-	-

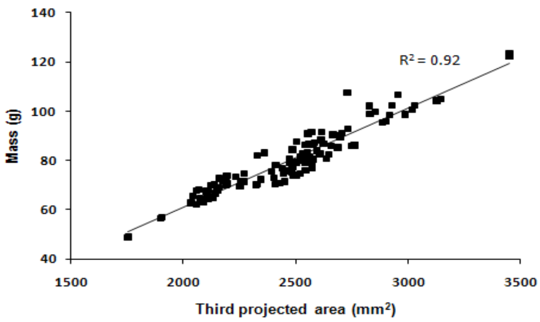

Figure 2. Linear model for total observations based on third projected area

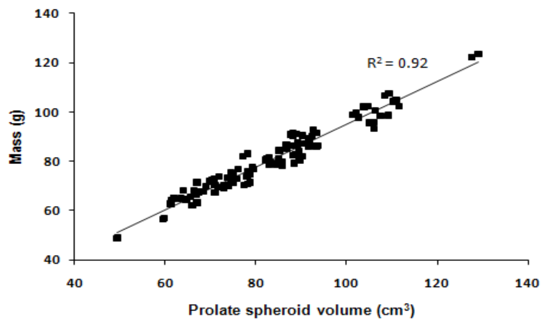

Figure 3. Linear model for total observations based on volume of assumed prolate spheroid shape

logarithmic models, the best model based on single dimension is as presented in Equation (9) for Seedless Lisbon and Equation (10) for Frost Eureka.

$$M = 0.09b^2 - 5.76b + 122.10, \quad R^2 = 0.93, \ SEE = 3.69 \qquad (9)$$

$$M = 4.46c - 140.38, \quad R^2 = 0.94, \ SEE = 3.29 \qquad (10)$$

For the two varieties, the best equation to calculate mass of lemon based on the minor diameter is a power-law model given in equation (11) for total observations

$$M = 0.003c^{2.63}, \quad R^2 = 0.88, \ SEE = 0.06 \qquad (11)$$

The R^2 and SEE based on minor diameter for Frost Eureka variety was equal in linear and quadratic models. Therefore, the linear model is here proposed because of its computational simplicity. Seyedabadi *et al.* (2011) suggested a power model with intermediate diameter for estimating mass of cantaloupe varieties ($M = 2.61b^{2.391}$, $R^2 = 0.96$). Lorestani and Tabatabaeefar (2006) reported suitable equation based on intermediate diameter for predicting the mass of kiwi ($M = 293b - 64.15$, $R^2 = 0.78$). Similar result concerning mass modeling of apricot was reported by Naderi-Boldagi *et al.* (2008). They suggested a power-law model ($M = 0.0019c^{2.693}$, $R^2 = 0.96$) with minor diameter to estimate mass of apricot. Furthermore, Miraei Ashtiani *et al.* (2012) reported a linear equation based on minor diameter for predicting the mass of lime. Their recommended model was $M = 2.017c - 43.868$, $R^2 = 0.97$.

Second category, projected areas

Among the second classification models based on projected areas of lemon fruits, model No. 8 (Table 3) that involves all three projected areas (PA_1, PA_2 and PA_3) had the highest R^2 and lowest SEE ($M = 0.02PA_1 + 0.03PA_2 - 0.003PA_3 - 26.27$, $R^2 = 0.97$, for total observations). But this model needs all three perpendicular projected areas that applying them in sizing machine is complicated and expensive. Among the other models (Nos. 5-7), based on one projected area, model 6 for Seedless Lisbon variety, model 7 for Frost Eureka variety and also model 7 for total observations had maximum R^2 and minimum SEE. Hence, the model which expresses the third projected area as independent variable was selected as the best choice. Figure 2 shows linear mass model for total observations based on lemon third projected area. For Seedless Lisbon and total observations linear models had higher R^2 in comparison with quadratic, power and logarithmic models. As a result equations 12, 13 and 14 are suggested for Seedless Lisbon, Frost Eureka and total observations, respectively.

$$M = 0.04PA_2 - 27.15, \quad R^2 = 0.96, \ SEE = 2.83 \qquad (12)$$

$$M = 0.001(PA_3)^2 + 8\times10^{-6}PA_3 + 27.23, \quad R^2 = 0.96, \ SEE = 2.74 \qquad (13)$$

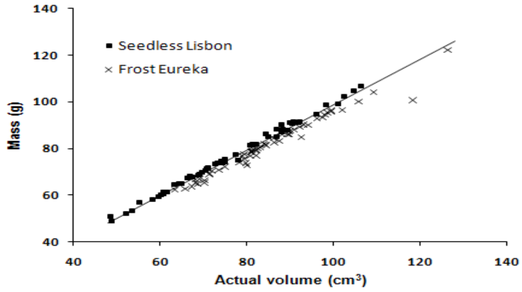

Figure 4. Revealed separation line based on mass and actual volume of two lemon varieties

$$M = 0.04PA_3 - 19.35,$$
$$R^2 = 0.92, SEE = 3.75 \quad (14)$$

Miraei Ashtiani *et al.* (2012) recommended a nonlinear model for lime mass determination based on first projected area as $M = 0.001(PA_1)^{1.552}$, $R^2 = 0.98$. Naderi-Boldaji *et al.* (2008) ($M = 0.0004PA_2^{1.586}$, $R^2 = 0.98$) and Khoshnam *et al.* (2007) ($M = 1.29PA_1^{1.28}$, $R^2 = 0.96$) recommended power mass models for apricot and pomegranate, respectively. Tabatabaeefar and Rajabipour (2005) also suggested a quadratic regression equation to predict the mass of apple fruits in function of PA_3 ($M = 0.009(PA_3)^2 + 3.4PA_3 - 16$, $R^2 = 0.94$).

Third category, volume

In the third classification group that was based on volume of samples (models 9 to 11 in Table 3), model No. 9 had the highest R^2 (0.98) and lowest SEE (1.74). However, this model needs the actual volume of lemon to estimate the mass. Because the measurement of actual volume is time consuming, the models based on ellipsoid volume (model No. 10 in Table 3) that needs sample dimensions, and prolate spheroid volume (model No. 11 in Table 3) are preferred for the design of sorting equipment. Model No. 10 had higher R^2 and lower SEE compared with model No. 11, but the latter is preferred, because it needs only two dimensions of fruit to be measured and still has good enough R^2 and SEE. Figure 3 shows linear mass model for total observations based on the volume of assumed prolate spheroid shape. It should be noted that for Frost Eureka variety, all the models investigated had equal R^2, but the power model had the lowest SEE, hence this model is recommended as follow.

$$M = 0.002(V_{psp})^2 + 1.29V_{psp} - 9.28,$$
$$R^2 = 0.98, SEE = 2.17 \text{ (Seedless Lisbon)} \quad (15)$$

$$M = 1.40(V_{psp})0.91,$$
$$R^2 = 0.92, SEE = 0.04 \text{ (Frost Eureka)} \quad (16)$$

The mass model for total observations of both varieties of lemons based on prolate spheroid volume is the following linear equation:

$$M = 0.84V_{psp} + 10.28,$$
$$R^2 = 0.92, SEE = 3.85 \quad (17)$$

In relation to mass modeling based on volume similar result was reported by Miraei Ashtiani *et al.* (2012). They suggested the mass modeling of lime based on the prolate spheroid volume with linear form. Khoshnam *et al.* (2007) recommended $M = 0.96V_m + 4.25$, $R^2 = 0.99$ for predicting the mass of pomegranate by measured volume. Naderi-Boldaji *et al.* (2008) recommended $M = 0.997V_m + 0.301$, $R^2 = 0.98$ for predicting mass of apricot. In many cases the measurement of mass is much easier than the true volume of fruits. This type of modeling is not practical and therefore not justifiable. However, mass modeling with single parameters that are easily measurable (e.g. any single diameters, prolate volume (V_{psp}), etc.) is more feasible to employ for grading fruits such as lemon.

Lemon separation models

For the purpose of separation, the mass values of both lemon varieties against each of their investigated properties were plotted in the same figure. The possibility of drawing a separation line between the two varieties was investigated by trial and error. With regard to the data on different physical properties of lemons, many separation models were obtained. Among the various separation lines, those which led to the most separation of the two lemon varieties were selected as separation models (Figures 4 and 5). Figure 4 shows the relationship between mass and actual volume of both varieties in a single bulk. As shown in the figure, the best separation line for these data can be expressed as:

$$M = 0.973V_m + 1.052 \quad (18)$$

Figure 4 shows that about 93.3 percent of Seedless Lisbon lemons were above the separation line (expressed mathematically as Equation 18) while all Frost Eureka lemons were beneath the line. Therefore Equation 18 can be used to predict separation of the two lemon varieties successfully.

Figure 5 presents the relationship between mass and the major diameter (a) of lemon fruits as a single bulk mixture. The best separation equation of these data points can be expressed as:

$$M = 4.888a - 215.6 \quad (19)$$

As show in Figure 5, about 98.4 percent of

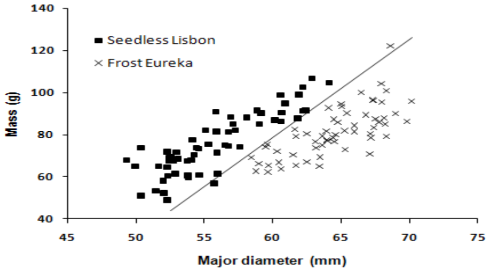

Figure 5. Revealed separation line based on mass and major diameter of two lemon varieties

Seedless Lisbon lemons were above the trend line of Equation (19), and 98.4 percent of Frost Eureka lemons placed under the line. Therefore the line of Equation (19) was introduced as another separation model for the two lemon varieties. However a closer look at Figures 4 and 5 shows that the separation model obtained from mass–major diameter was much better than that obtained from mass–actual volume. This is because in the mass–major diameter model, the data points spread over a wide area around the separation line but in the mass-actual volume model the data points clustered close to the separation line. The closer the data points are to the separation line, the more the possibility of an error in separation. Moreover, measuring the major diameter is much easier than the measuring of actual volume. Furthermore, measuring volume with water displacement increases surface's moisture of fruits which could probably increase the incidences of diseases such as powdery mildews, and reduce the quality of products (Reuveni and Rotem, 1974). For a better separation result the simultaneous use of both models is suggested. The separation process can be performed by measuring mass and major diameter, 'a' dimension or volume of each lemon fruit and comparing the measured mass with calculated mass from Equation (18) or (19). If the measured mass is below the calculated mass from Equation (18) or (19) then the fruit corresponding to that mass would be Frost Eureka variety. Conversely, it would be Seedless Lisbon variety.

Conclusions

The appearance of Seedless Lisbon and Frost Eureka lemon varieties are very similar and hence separating them from each other would be difficult. The separation of the two lemon varieties applying their density, static friction and rolling coefficients was found possible. The density of Seedless Lisbon lemon was above one g cm^{-3} so it sank in the water while the density of Frost Eureka lemon was less than one g cm^{-3} and so floats on water. Static coefficient of friction on rubber, plexiglas and galvanized iron and rolling resistance on MDF and glass surfaces were statistically different for both varieties.

In general the recommended model to calculate lemon mass based on minor diameter was a power-law model $M = 0.003c^{2.63}$, $R^2 = 0.88$ and the mass model recommended for sizing lemon based on second projected area was in a linear form as $M = 0.04PA_3 - 19.35$, $R^2 = 0.92$. There was a good relationship between mass and actual volume of lemon fruits with $R^2 = 0.98$ but for sorting machines a linear equation based on prolate volume is hereby recommended, $M = 0.84V_{psp} + 10.28$, $R^2 = 0.92$. Similarly, mass model based on third projected area from economical standpoint is here recommended. Seedless Lisbon and Frost Eureka varieties could be successfully separated from their mixture using a linear model based on actual volume and major diameter. However the second model based on major diameter ($M = 4.888a - 215.6$) was preferred because of its relative ease of measurement.

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