Mass and Surface Area Modeling of Bergamot *(Citrus medica)* Fruit with Some Physical Attributes

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ABSTRACT

In this study mass and surface area of bergamot fruit were predicted with using different physical characteristics in linear models classified as follows: (1) Single or multiple variable regressions of bergamot dimensional characteristics, (2) Single or multiple variable regressions of bergamot projected areas, (3) Single regression of bergamot mass and surface area based on measured (actual) volume and volumes of shapes assumed (oblate spheroid and ellipsoid) and (4) Single regression of bergamot surface area based on mass. The results showed that all of the mass and surface area models are satisfactorily appropriate models. In the first classification of mass modeling, the lowest determining coefficients were as R^2=0.87 and R^2=0.88 based on length and width, respectively, while all the other determining coefficients were higher than R^2=0.90. The highest determining coefficient in all mass models was obtained based on actual volume as R^2=0.99. Based on the results, all determining coefficients for surface area modeling were higher than R^2=0.92. The highest determining coefficient in all models was obtained as R^2=1.00 for some combinations of projected areas.

Keywords: Bergamot, citrus, fruit, Jahrom, physical attributes, grading, peeling

Nomenclature

L	Length (mm)	P_L	First projected area (mm^2)
W	Width (mm)	P_W	Second projected area (mm^2)
T	Thickness (mm)	P_T	Third projected area (mm^2)
M	Mass (g)	GM	Geometric mean diameter (mm)
V_m	Measured (actual) volume (cm^3)	S	Surface area
V_{osp}	Volume of oblate spheroid (cm^3)	K_i	Regression Coefficient
V_{ell}	Volume of ellipsoid (cm^3)	R^2	Determining coefficient

1. INTRODUCTION

Bergamot *(Citrus medica)* is a species of citrus fruit and is one of the important horticultural products of Iran. Its tree is called citrus bergamia. Bergamia is an evergreen tree (like other trees of this family). Bergamot is characterized with its thick rind. From Fig. 1, bergamot fruit consists of an oval shape meat in the center and a thick skin around it. Bergamot skin consists of albedo (protuberances) and flevedo (pulp).

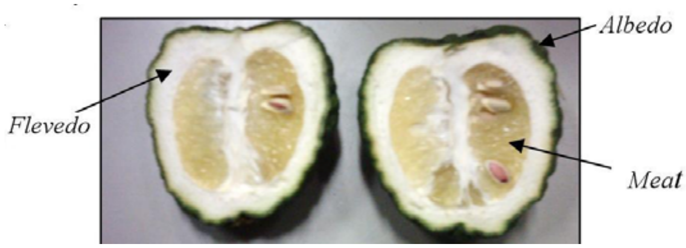

Fig.1. Longitudinal section of bergamot fruit

Bergamot outer skin (albedo) has a bitter taste and should be detached in food production. The albedo is initially green and as the fruit ripens, becomes yellow. Usually before the yellow stage, the crop is harvested in iran. The flevedo (pulp) is white in both green and yellow stages of the albedo and is used in jam production and also in medical applications. Bergamot oil has many therapeutic properties as an antiseptic, antibiotic, anti-spasmodic and antidepressant. Bergamot oil is an ideal way to remedy skin infections, nervous eczema, stress, depression, anorexia, emotional fear, and tension. Bergamot meat is edible and very sour and can be used instead of lemon juice or in making various pickles. In addition, bergamot skin (pulp) as dried fruit is exported to many countries. Dried skins are used in jam production in seasons that fresh fruit is not available.

Most of the methods employed in the processing of agricultural products in Iran like bergamot are still traditional. There is the need to develop appropriate technologies for their processing. The development of the technologies will require the properties of these products. There are instances in which it is desirable to determine relationships among fruit physical attributes. For example, fruits are often graded by size, but it may be more economical to develop a machine which grades the fruit by weight. Grading fruit based on weight is important in packing and handling and provides suitable packing patterns. The different grading systems require different fruit sizing based on particular parameters. Nearly all fruit and vegetables are graded for quality when delivered for processing or for the fresh markets. In nearly all cases raw product grades are based on weight (O'Brian and Floyd, 1978). Shape and physical dimensions are important in screening solids to separate foreign materials and in sorting and sizing of fruit and vegetables. Size and shape determine how many fruit can be placed in shipping containers or plastic bags of a given size. Peeling is an efficient process for citrus fruit, too. Immersing the products to be peeled in a treating solution is one method of peeling agricultural products having skins. The albedo of the fruit is weakened by releasing the vacuum or changing pressure and the citrus peel can be readily removed. Amount of required treating solution depends on fruit surface area. Also volumes and surface areas of solids must be known for accurate modeling of heat and mass transfer during cooling and drying (Stroshine, 1998).

The regression analysis was used by Chuma et al. (1982) to develop equations for predicting volume and surface area. They used the logarithmic transformation to develop equations for wheat kernels at moisture content of 15.7% (dry basis). Frequently, the surface area of fruit is determined based on its diameter or weight. Knowing the diameter or weight of a fruit, its surface area may be calculated using empirical equations, or find from an appropriate plot (Sitkei, 1986; Frechette and Zahradnik, 1968). Mass grading of fruit can reduce packaging and transportation costs, and also may provide an optimum packaging configuration (Peleg, 1985). Sizing by weighing mechanism is recommended for the irregular shaped product (Stroshine, 1998). Determining relationships between mass and dimensions and projected areas may be useful and applicable (Stroshine, 1998; Marvin, et al., 1987). In weight-sizing machines, individual fruits are carried with cups or trays that may be linked together in a conveyor and are individually supported with spring-loaded mechanism. As the cups travel along the conveyor, the supports are engaged with triggering mechanisms which allow the trays to dump their contents, if there is sufficient weight. Successive triggering mechanisms are set to dump the tray contents at lower weights. If the density of the fruit is constant, the weight-sizing machine sorts the fruits by volume. The sizing error will depend upon the correlation between weight and volume (Stroshine, 1998).

Many researches have been conducted to find physical properties of various types of agricultural products. Topuz et al. (2005) investigated and compared several properties of four orange varieties. Keramat Jahromi et al. (2007) investigated some physical properties of date (cv. Lasht). They determined dimensions and projected areas by using image processing technique. Owolarafe and Shotonde (2004) investigated some physical properties of fresh okro fruit useful in designing of an okro slicer, chopper and/or grater. In the case of mass modeling, Tabatabaeefar et al. (2000) determined models for predicting mass of Iranian grown oranges. In another study, Tabatabaeefar (2002) determined physical properties of common varieties of Iranian grown potatoes and the relationships among their physical attributes. Lorestani and Tabatabaeefar (2006) determined models for predicting mass of kiwi fruit based on, dimensions, projected areas perpendicular to the major diameters and volumes (measured volume and volumes of supposed shapes). Also many studies have been reported on the physical properties of agricultural products such as gumbo fruit (Akar and Aydin, 2005), pear (Wang, 2004), onion (Abhayawick et al, 2002) and apple (Woensel, 1987).

The objective of this research was to determine the optimum bergamot mass and surface area models based on bergamot physical properties. This information could be used to design and develop sizing and peeling systems.

2. MATERIALS AND METHODS

Bergamot samples were directly selected randomly from a garden in Jahrom which is one of the most important horticultural centers in south of Iran. The fruits were transported to physical laboratory of Biosystems Faculty of University of Tehran. The experiments were carried out in three days at laboratory temperature ranged 25 to 29 °C. Bergamot moisture contents were 84.90% w.b. for peel and 87.34% w.b. for its meat.

Linear dimensions, i.e. length, width and thickness and also projected areas, were determined by image processing method. In order to obtain dimensions and projected areas, WinArea_-UT_06 system (Mirasheh, 2006) was used (Fig. 2).
WinArea_UT_06 system comprises following components:

1. Sony photograph camera Model CCD-TRV225E
2. device for preparing media to taking a picture
3. Card capture named Winfast model DV2000
4. Computer software programmed with visual basic 6.0

Captured images from the camera are transmitted to the computer card which works as an analog to digital converter. Digital images are then processed in the software and the desired user needs are determined. Total errors for those objects were less than 2%.

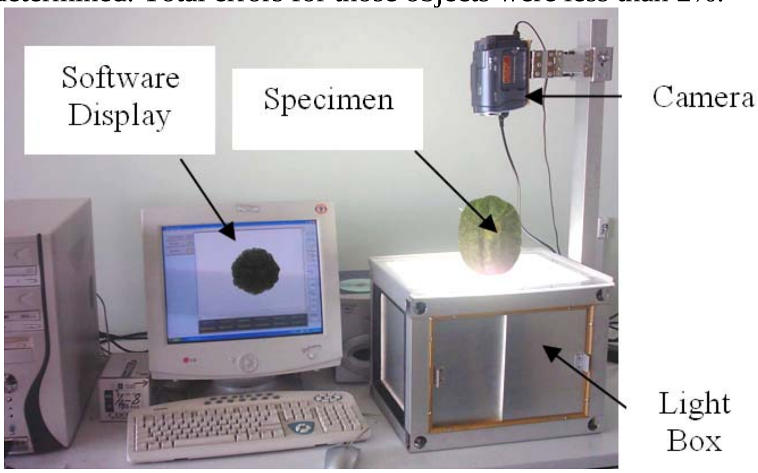

Fig.2. WinArea_UT_06 system

This method have been used and reported by several researchers (Keramat Jahromi et al., 2007; Khoshnam et al., 2007). From Fig. 3, L, W and T are perpendicular dimensions of the fruit namely length, width and thickness and P_L, P_W and P_T are the projected areas taken along these three mutual perpendicular axes.

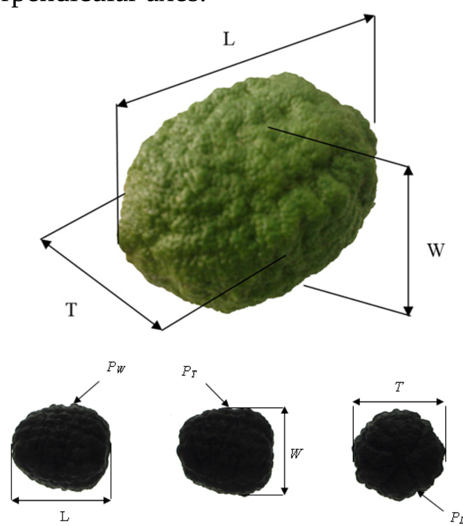

Fig.3. Three major dimensions and projected areas of fruit

Mass (g) of each fruit was determined with using an electronic balance with an accuracy of 0.0l g. Actual volume was measured by the water displacement method (Mohsenin, 1986; Kabas et al., 2005; Karababa, 2006).

Geometric mean diameter (GM) and surface area (S) were calculated with using the equations 1 and 2 respectively as reported by Mohsenin (1986) and Kabas *et al.* (2006).

$$GM = (LWT)^{1/3} \qquad (1)$$

$$S = \pi.(GM)^2 \qquad (2)$$

In order to estimate mass and surface area models of bergamot, the following models were considered:

1. Single or multiple variable regressions of bergamot dimensional characteristics: length (L), width (W) and thickness (T).
2. Single or multiple variable regressions of bergamot projected areas.
3. Single regression of bergamot mass and surface area based on measured (actual) volume and volumes of shapes assumed (oblate spheroid and ellipsoid)
4. Single regression of bergamot surface area based on mass.

In case of the first classification, mass and surface area modelings were accomplished with respect to length, width and thickness as following:

$$\mathrm{M} = \mathrm{k}_1\mathrm{L} + \mathrm{k}_2\mathrm{W} + \mathrm{k}_3\mathrm{T} + \mathrm{k}_4 \qquad (3)$$

$$\mathrm{S} = \mathrm{k}_1\mathrm{L} + \mathrm{k}_2\mathrm{W} + \mathrm{k}_3\mathrm{T} + \mathrm{k}_4 \qquad (4)$$

(Where k_1, k_2, k_3 and k_4 are constant values which are different in each equation)

In some instances only one or two diameters may adequately predict the mass or surface area. The appropriateness of using one, two or three diameters can be compared by examining their R^2.

In the Second classification models, mass and surface area modeling of bergamot were estimated based on mutually perpendicular projected areas as following:

$$\mathrm{M} = \mathrm{k}_1\mathrm{P}_\mathrm{L} + \mathrm{k}_2\mathrm{P}_\mathrm{W} + \mathrm{k}_3\mathrm{P}_\mathrm{T} + \mathrm{k}_4 \qquad (5)$$

$$\mathrm{S} = \mathrm{k}_1\mathrm{P}_\mathrm{L} + \mathrm{k}_2\mathrm{P}_\mathrm{W} + \mathrm{k}_3\mathrm{P}_\mathrm{T} + \mathrm{k}_4 \qquad (6)$$

(Where k_1, k_2, k_3 and k_4 are constant values which are different in each equation)

In this classification, the mass and surface area may be estimated as a function of one, two or three projected areas.

In case of the third classification, to achieve the models which can predict bergamot mass and surface area on the basis of volumes, three volume values were measured or calculated. At first, actual volume (V_m) as stated earlier was measured then the bergamot shape was assumed as a regularly geometrical shape, i.e. oblate spheroid (V_{osp}) and ellipsoid (V_{ell}) shapes and thus their volumes (cm^3) were calculated as:

$$\mathrm{V}_{osp} = \frac{\pi}{6} LW^2 / 1000 \qquad (7)$$

$$\mathrm{V}_{ell} = \frac{\pi}{6} LWT / 1000 \qquad (8)$$

In this classification, the mass and surface area can be estimated as either a function of volume of supposed shape or the measured volumes as represented in following expressions:

$$\mathrm{M} = \mathrm{k}_1\mathrm{V}_\mathrm{m} + \mathrm{k}_2 \qquad (9)$$

$$\mathrm{M} = \mathrm{k}_1\mathrm{V}_\mathrm{osp} + \mathrm{k}_2 \qquad (10)$$

$$\mathrm{M} = \mathrm{k}_1\mathrm{V}_\mathrm{ell} + \mathrm{k}_2 \qquad (11)$$

$$\mathrm{S} = \mathrm{k}_1\mathrm{V}_\mathrm{m} + \mathrm{k}_2 \qquad (12)$$

$$S = k_1 V_{osp} + k_2 \qquad (13)$$

$$S = k_1 V_{ell} + k_2 \qquad (14)$$

(Where k_1 and k_2 are constant values which are different in each equation)

In fourth classification model for surface area modeling of bergamot, surface area was estimated based on mass as following:

$$S = k_1 M + k_2 \qquad (15)$$

(Where k_1 and k_2 are constants)

Packages of statistical programs, available on both main frame and personal computers, can perform such regression analyses. Many spreadsheet programs also can perform multiple regressions. When evaluating the usefulness of such regression analyses, it is necessary to know how well the data fit the model. One evaluation of the goodness of fit is the value of the determining coefficient which is usually designated as R^2. For regression equations in general, the nearer R^2 is to 1.00, the better the fit (Stroshine, 1998). If values of k_i exactly predict the mass or surface area, then R^2 would be equal to 1.00. WinArea_UT_06 software was used to analyze data and determine regression models between the physical attributes.

3. RESULTS AND DISCUSSION

A summary of some selected physical characteristics of Bergamot are shown in Table1.

Table1. Some physical characteristics of Bergamot

Property	observations	Mean	Min	Max	SD
Fruit mass (g)	250	291.90	98.69	572.05	103.07
Measured (actual) volume (cm3)	250	456.83	116.10	994.29	191.12
Volume of oblate spheroid (cm3)	250	539.08	181.40	1382.63	275.18
Volume of ellipsoid (cm3)	250	519.29	180.84	1344.97	263.65
Length (mm)	100	109.56	78.80	160.00	19.40
Width (mm)	100	93.05	64.20	128.50	16.11
thickness (mm)	100	89.76	64.00	125.00	15.16
First projected area (mm2)	100	7063.61	3476.00	12733.00	2408.79
Second projected area (mm2)	100	7933.39	4131.00	15176.00	2716.80
Third projected area (mm2)	100	8137.77	4233.00	15176.00	2763.41
Geometric mean diameter (mm)	100	70.17	136.98	97.02	16.40
Surface area (cm2)	100	30412.31	15471.03	58947.76	10305.84

Linear regression models based on the selected attributes are presented in Table 2 and 3 for mass and surface area modeling, respectively.

Table2. Bergamot mass models based on selected independent variables

Nos.	Models	Relation	R^2
1	$M=k_1L+k_2$	M = +4.82 L - 250.50	0.87
2	$M= k_1W+k_2$	M = +5.83 W - 264.37	0.88
3	$M= k_1T+k_2$	M = +6.25 T - 283.53	0.90
4	$M=k_1L+k_2T+ k_3$	M = +2.16 L +3.73 T - 293.85	0.93
5	$M=k_1L+k_2W+ k_3$	M = +2.45 L +3.16 W - 284.89	0.92
6	$M=k_1W+k_2T+ k_3$	M = +0.68 W +5.54 T - 282.78	0.90
7	$M=k_1L+k_2W+k_3T+k_4$	M = +2.16 L +0.44 W +3.28 T - 293.34	0.93

8	M= $k_1P_L+k_2$	M = +0.04 P_L- 1.60	0.91
9	M= $k_1P_W+k_2$	M = +0.04 P_W - 5.12	0.94
10	M= $k_1P_T+k_2$	M = +0.03 P_T - 7.68	0.94
11	M= $k_1P_L+k_2P_W+k_3P_T+k_4$	M = -0.00 P_L+0.01 P_W+0.02 P_T- 7.11	0.94
12	M= $k_1V_m+k_2$	M = +0.52 V_m + 44.72	0.99
13	M= $k_1V_{osp}+k_2$	M = +0.35 V_{osp} + 89.31	0.93
14	M= $k_1V_{ell}+k_2$	M = +0.37 V_{ell} + 87.63	0.93

3.1. First Classification Models, Dimensions

The results showed that all of the mass and surface area models of bergamot based on dimensions were appropriate in the first classification as shown in Table 2. The results of mass modeling in the single variable classification revealed the lowest and the highest determining coefficients as R^2=0.87 and R^2=0.90 relevant to length and thickness, respectively. In the case of mass modeling based on multiple dimensions, Nos. 4 and 7 respectively with two and three variables had the highest R^2 as 0.93. Then the best equations for single and multiple variables of mass modeling were determined as $M = +6.25\,T - 283.53$, R^2=0.90 and $M = +2.16\,L + 3.73\,T - 293.85$, R^2=0.93. Models Nos. 4, 5, and 7 (in Table 2) had the highest R^2 values in determining mass based on multiple dimensions. Then model 3 was selected as the best choice with respect to thickness as single independent variable of dimension ($M = +6.25\,T - 283.53$, R^2=0.90). In the case of surface area modeling equations Nos. 4 and 5 with two variables and equation No. 7 with three variables had the highest R^2 as 0.99. Also the lowest determining coefficient as R^2=0.92 relevant to length were determined as $S = +510.27\,L - 25512.16$.

Table3. Bergamot Surface area models based on selected independent variables

Nos.	Models	Relation	R^2
1	S=k_1L+k_2	S = +510.27 L - 25512.16	0.92
2	S= k_1W+k_2	S = +626.13 W - 27867.95	0.96
3	S= k_1T+k_2	S = +668.35 T - 29593.02	0.97
4	S=$k_1L+k_2T+ k_3$	S = +201.00 L +433.68 T - 30552.09	0.99
5	S=$k_1L+k_2W+ k_3$	S = +220.22 L +386.67 W - 29714.10	0.99
6	S=$k_1W+k_2T+ k_3$	S = +208.15 W +449.98 T - 29361.91	0.97
7	S=$k_1L+k_2W+ k_3T+k_4$	S = +198.82 L +185.98 W +241.10 T - 30335.19	0.99
8	S= $k_1P_L+k_2$	S = +4.23 P_L+ 480.80	0.98
9	S= $k_1P_W+k_2$	S = +3.77 P_W+ 481.96	0.99
10	S= $k_1P_T+k_2$	S = +3.71 P_T+ 183.59	0.99
11	S= $k_1P_L+k_2P_T+k_3$	S = +1.45 P_L+2.47 P_T+ 49.23	1.00
12	S= $k_1P_L+k_2P_W+k_3$	S = +1.71 P_L+2.28 P_W+ 184.95	1.00
13	S= $k_1P_W+k_2P_T+k_3$	S = +1.15 P_W+2.59 P_T+ 225.57	0.93
14	S= $k_1P_L+k_2P_W+k_3P_T+k_4$	S = +1.43 P_L+1.05 P_W+1.46 P_T+ 89.50	1.00
15	S= $k_1V_m+k_2$	S = +51.79 V_m + 7019.24	0.94
16	S= $k_1V_{osp}+k_2$	S = +37.27 V_{osp} + 10304.25	0.99
17	S= $k_1V_{ell}+k_2$	S = +38.95 V_{ell} + 10170.14	0.99
18	S= k_1M+k_2	S = +99.54 M + 2736.70	0.93

3.2. Second Classification Models, Projected Areas

The results showed that all mass and surface area models of bergamot based on projected areas also are appropriate in second classification. Mass modeling based on single variable projected area shows that mass modeling based on the first projected area has the lowest determining coefficient as 0.91 and the other models have determining coefficients as 0.94.

In order to predict bergamot mass based on one projected area, the best determining coefficient of one variable and multiple variable equations were equal to 0.94. Models with multiple variables make the sizing mechanism more complex and expensive because there is a need to have three cameras simultaneously, in order to take all the dimensions. Therefore, mass models using only one projected area was suggested as $M = +0.04\,P_W - 5.12$, R^2=0.94 and $M = +0.03\,P_T - 7.68$, R^2=0.94.

Based on results presented in Table 3 all determining coefficients for surface area modeling were obtained higher than R^2=0.98. The results of single variable showed that the lowest determining coefficients in the single variable classification were belong to the first projected area as R^2=0.98 but other single variable models namely Nos. 9 and 10 had determining coefficients equal to 0.99. Therefore the latter models were ascertained as the best single variable models to predict the bergamot surface area as $S = +3.77\,P_W + 481.96$, R^2=0.99 and $S = +3.71\,P_T + 183.59$, R^2=0.99.

In the case of surface area modeling, among the multiple models, models Nos., 11, 12, and 14 (Table 3) had the highest R^2 as approximately 1.00.

3.3 Third Classification Models, Volumes

The results showed that both mass and surface area models based on actual volume and volume of assumed shapes (oblate spheroid and ellipsoid) are favorable. Considering Table 2 it can be concluded that among the models 12, 13, and 14, model 12 is the best model concerned with measured volume as $M = +0.52\,V_m + 44.72$, R^2=0.99.

Determining coefficients were obtained as R^2=0.93 both for oblate spheroid and ellipsoid assumed shapes. Considering equations Nos. 15, 16 and 17 presented in Table 3 this fact can be concluded that the best model for surface area modeling of bergamot is based on the assumed volumes, i.e. oblate spheroid and ellipsoid as $S = +37.27\,V_{osp} + 10304.25$, R^2=0.99 and $S = +38.95\,V_{ell} + 10170.14$, R^2=0.99. Determining coefficient of surface area modeling based on measured volume was obtained as R^2=0.94.

3.4. Fourth Classification for Modeling Surface Area Based on Mass

Surface area model of bergamot based on its mass was obtained as $S = +99.54\,M + 2736.70$, R^2=0.93.

Comparing mass models and their R^2 in Table 2, it is concluded that the mass model based on measured volume (R^2=0.99) is the most accurate model while measurement of one projected area (equations 9 and 10 with R^2=0.94) is far easier and reasonable than that of measured volume of bergamot. Comparing surface area models and their R^2 in Table 3, it is indicated that all the models based on projected areas are reasonable for predicting surface area of bergamot.

Tabatabaeefar et al. (2000) reported that among systems that sort oranges based on one dimension, the system that applies intermediate diameter is suited with nonlinear relationship. In other study, Tabatabaeefar (2002) plotted mass versus volume of mixed variety of potato and found that there is a linear relation between mass and volume with a very high determining coefficient as $M = +0.93\,V_m - 0.6$; R^2=0.99. Relation between the mean projected area and the volume of potatoes was determined from the plot and the determining coefficient, R^2=1.00 between them was very high and close to unity. A nonlinear regression equation between the 3rd projected area and volume for the mixed variety of potatoes was determined. The linear regression had a very high correlation, too ($P_T = 1.1\,V_m^{\ 0.71}$; R^2= 0.99). Lorestani and Tabatabaeefar (2006) concluded that the linear regression models of kiwi fruit have higher R^2 than nonlinear models for them, and are economical models for application. Among the linear regression dimensions models, the model that is based on width, and among the linear projected area models, the model that is based on third projected area, and among the other models, the model that is based on measured volume, had higher R^2, that are recommended for sizing of kiwi fruit. Also Tabatabaeefar and Rajabipour (2005) determined a total of 11 regression models in the three different categories for two different varieties of apple fruits.

4. CONCLUSIONS

1. In the first classification of single variable mass modeling of bergamot based on dimension, the highest determining coefficient was obtained as R^2=0.90 based on thickness ($M = +6.25\,T - 283.53$) while that was as R^2=0.93 for multiple variable models (equations Nos. 4 and 7 in Table 2).
2. In the first classification of single variable surface area modeling of bergamot, the highest determining coefficient were obtained as R^2=0.97 based on thickness ($S = +668.35\,T - 29593.02$) while the highest determining coefficient were obtained as R^2=0.99 for multiple variable models (equations Nos. 4, 5 and 7 in Table 3).
3. The best determining coefficients of mass and surface area models based on one projected area were obtained as 0.94 and 0.99, respectively.
4. The highest determining coefficient among mass models was obtained based on actual volume as R^2=0.99 ($M = +0.52\,Vm + 44.72$).
5. All determining coefficients for surface area models were obtained higher than R^2=0.92 and the highest determining coefficient in all the models was obtained as R^2=1.00 based on for some combinations of projected areas.

5. ACKNOWLEDGEMENT

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