

Nectarine Mass Modeling Based on Geometrical Characteristics

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Abstract: In this study, eighteen linear regression models for modeling nectarine mass from some geometrical properties of nectarine such as major diameter (a), intermediate diameter (b), minor diameter (c), geometrical mean diameter (GMD), first projected area (PA_1), second projected area (PA_2), third projected area (PA_3), criteria area (CAE), estimated volume based on an ellipsoid assumed shape (V_{Eil}) and measured volume (V_M) were suggested. Models were divided into three main classifications, i.e. first classification (outer dimensions), second classification (projected areas) and third classification (volumes). The statistical results of the study indicated that in order to predict nectarine mass based on outer dimensions, the mass model based on GMD as $M = -112.4 + 3.624 \text{ GMD}$ with $R^2 = 0.95$ can be recommended. Moreover, to predict nectarine mass based on projected areas, the mass model based on CAE as $M = -26.46 + 4.838 \text{ CAE}$ with $R^2 = 0.95$ can be suggested. Besides, to predict nectarine mass based on volumes, the mass model based on V_{Eil} as $M = 2.401 + 1.006 V_{Eil}$ with $R^2 = 0.98$ can be utilized. These models can also be used to design and develop sizing machines equipped with an image processing system.

Key words: Nectarine • Mass • Modeling • Geometrical characteristics

INTRODUCTION

Peaches and nectarines belong to the Rosaceae family and are thought to have originated in China [1]. Chinese literature dates cultivation of the peach in China to 1000 B.C. and it was probably carried from China to Persia (Iran). Peach, at one time called “Persian apple”, quickly spread from there to Europe. In the 16th century, it was established in Mexico and in the 18th century Spanish missionaries introduced the peach to California, which turned out to be the most important production area after China and Italy [2]. Like other stone fruits, peaches and nectarines, both closely related [3], have a characteristic, lignified endocarp (pit or stone) that encloses the seed, a fleshy mesocarp and a thin exocarp. However, nectarine cells have smaller intercellular spaces than peaches and are, therefore, denser. In addition, they lack pubescence on the skin, which is controlled by a single gene [4]. On the basis of the separation of the

stone from the flesh, peaches and nectarines can be divided into two groups: freestone and clingstone. In addition, based on the amount of softening of the flesh that occurs during ripening, peaches and nectarines can be either of a melting or non-melting type [5]. Most cultivars have yellow flesh, but white-fleshed cultivars have always been known and are being increasingly planted and currently are 30% of the plantings of the yellow flesh cultivars. The peel of both types may be highly colored due to the accumulation of anthocyanin. Peaches and nectarines with low, medium or high acid concentrations are also available [6]. Peaches and nectarines are also rich in ascorbic acid (vitamin C), carotenoids (provitamin A) and phenolic compounds that are good sources of antioxidants [7]. Currently, world production of peaches and nectarines stands at 11 million tones, with the three major producing countries being China, Italy and the United States in the Northern hemisphere and Chile, South Africa and Australia in the

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Southern hemisphere. All of these different combinations of fruit types, i.e. peach or nectarine, clingstone or freestone, yellow or white flesh, low, medium or high acidity, are available as freshly harvested fruit from April through September in the Northern Hemisphere and from November to March in the Southern Hemisphere [8].

Similar to other fruits, nectarine size is one of the most important quality parameters for evaluation by consumer preference. Consumers prefer fruits of equal size and shape [9]. Sorting can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [10-13]. Moreover, sorting is important in meeting quality standards, increasing market value and marketing operations [14-16]. Sorting manually is associated with high labor costs in addition to subjectivity, tediousness and inconsistency which lower the quality of sorting [17]. However, replacing human with a machine may still be questionable where the labor cost is comparable with the sorting equipment [18]. Studies on sorting in recent years have focused on automated sorting strategies and eliminating human efforts to provide more efficient and accurate sorting systems which improve the classification success or speed up the classification process [19, 20].

Physical and geometrical characteristics of products are the most important parameters in design of sorting systems. Among these characteristics, mass, outer dimensions, projected areas and volume are the most important ones in sizing systems [21-24]. The size of produce is frequently represented by its mass because it is relatively simple to measure. However, sorting based on some geometrical properties may provide a more efficient method than mass sorting. Moreover, the mass of produce can be easily estimated from geometrical properties if the mass model of the produce is known [25]. For that reason, modeling of nectarine mass based on some geometrical properties may be useful and applicable. Therefore, the main objectives of this research were: (a) to determine optimum mass model(s) based on some geometrical properties of nectarine and (b) to verify determined mass model(s) by comparing their results with those of the measuring method.

MATERIALS AND METHODS

Experimental Procedure: Eighty five randomly selected nectarines (cv. Sunking) of various sizes were purchased from a local market. Nectarines were selected for freedom

from defects by careful visual inspection, transferred to the laboratory and held at $5\pm 1^\circ\text{C}$ and $90\pm 5\%$ relative humidity until experimental procedure.

In order to obtain required parameters for determining mass models, the mass of each nectarine was measured to 0.1 g accuracy on a digital balance. Moreover, the volume of each nectarine was measured using the water displacement method. Each nectarine was submerged into water and the volume of water displaced was measured. Water temperature during measurements was kept at 25°C .

By assuming the shape of nectarines as an ellipsoid (Fig. 1), the outer dimensions of each nectarine, i.e. major diameter (a), intermediate diameter (b) and minor diameter was measured to 0.1 mm accuracy by a digital caliper. The geometric mean diameter (GMD) of each nectarine was then calculated by equation 1.

$$\text{GMD} = (abc)^{1/3} \quad (1)$$

Three projected areas of each nectarine, i.e. first projected area (PA_1), second projected area (PA_2) and third projected area (PA_3) was also calculated by using equation 2, 3 and 4, respectively. The average projected area known as criteria area (CAE) of each nectarine was then determined from equation 5.

$$PA_1 = \eta ab/4 \quad (2)$$

$$PA_2 = \eta ac/4 \quad (3)$$

$$PA_3 = \eta bc/4 \quad (4)$$

$$\text{CAE} = (PA_1 + PA_2 + PA_3)/3 \quad (5)$$

In addition, the volume of ellipsoid assumed shape or estimated volume of each nectarine (V_{Eil}) was calculated by using equation 6.

$$V_{\text{Eil}} = \eta abc/6 \quad (6)$$

Table 1 shows some physical and geometrical properties of the nectarines used to determine mass models.

Regression Models: A typical linear multiple regression model is shown in equation 7:

$$Y = k_0 + k_1X_1 + k_2X_2 + \dots + k_nX_n \quad (7)$$

Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of some physical and geometrical attributes of the 85 randomly selected nectarines used to determine mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	39.3	104.1	55.8	11.6	20.7
Major diameter (a), mm	38.9	56.7	46.3	3.58	7.73
Intermediate diameter (b), mm	40.9	57.1	47.3	3.07	6.50
Minor diameter (c), mm	40.6	57.8	45.7	3.44	7.52
Geometrical mean diameter (GMD), mm	41.3	56.9	46.4	3.10	6.68
First projected area (PA ₁), cm ²	13.4	25.4	17.3	2.39	13.8
Second projected area (PA ₂), cm ²	13.0	25.3	16.7	2.42	14.5
Third projected area (PA ₃), cm ²	13.2	25.5	17.1	2.34	13.7
Criteria area (CAE), cm ²	13.4	25.4	17.0	2.33	13.7
Estimated volume (V _{Est}), cm ³	36.7	96.5	53.1	11.3	21.2
Measured volume (V _M), cm ³	36.6	109.7	56.0	12.3	22.0

Table 2: Eighteen linear regression mass models and their relations in three classifications

Classification	Model No.	Model	Relation
Outer dimensions	1	$M = k_0 + k_1 a$	$M = -74.45 + 2.813 a$
	2	$M = k_0 + k_1 b$	$M = -110.0 + 3.504 b$
	3	$M = k_0 + k_1 c$	$M = -81.13 + 2.995 c$
	4	$M = k_0 + k_1 \text{GMD}$	$M = -112.4 + 3.624 \text{GMD}$
	5	$M = k_0 + k_1 a + k_2 b$	$M = -111.4 + 1.070 a + 2.486 b$
	6	$M = k_0 + k_1 a + k_2 c$	$M = -101.1 + 1.566 a + 1.846 c$
	7	$M = k_0 + k_1 b + k_2 c$	$M = -113.4 + 2.312 b + 1.308 c$
	8	$M = k_0 + k_1 a + k_2 b + k_3 c$	$M = -114.3 + 0.938 a + 1.523 b + 1.195 c$
Projected areas	9	$M = k_0 + k_1 \text{PA}_1$	$M = -23.62 + 4.598 \text{PA}_1$
	10	$M = k_0 + k_1 \text{PA}_2$	$M = -20.67 + 4.584 \text{PA}_2$
	11	$M = k_0 + k_1 \text{PA}_3$	$M = -25.01 + 4.739 \text{PA}_3$
	12	$M = k_0 + k_1 \text{CAE}$	$M = -26.46 + 4.838 \text{CAE}$
	13	$M = k_0 + k_1 \text{PA}_1 + k_2 \text{PA}_2$	$M = -23.73 + 1.956 \text{PA}_1 + 2.743 \text{PA}_2$
	14	$M = k_0 + k_1 \text{PA}_1 + k_2 \text{PA}_3$	$M = -24.70 - 0.907 \text{PA}_1 + 2.274 \text{PA}_3$
	15	$M = k_0 + k_1 \text{PA}_2 + k_2 \text{PA}_3$	$M = -24.81 + 2.303 \text{PA}_2 + 2.475 \text{PA}_3$
	16	$M = k_0 + k_1 \text{PA}_1 + k_2 \text{PA}_3 + k_3 \text{PA}_3$	$M = -27.65 + 1.878 \text{PA}_1 + 0.593 \text{PA}_2 + 2.412 \text{PA}_3$
Volumes	17	$M = k_0 + k_1 V_{\text{Est}}$	$M = 2.401 + 1.006 V_{\text{Est}}$
	18	$M = k_0 + k_1 V_M$	$M = 3.749 + 0.929 V_M$

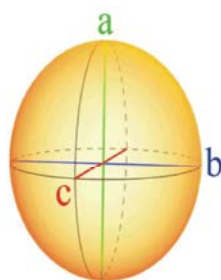


Fig. 1: The outer dimensions of a nectarine, i.e. major diameter (a), intermediate diameter (b) and minor diameter (c) by assuming the shape of nectarine as an ellipsoid

where:

Y = Dependent variable, for example mass of nectarine
 X_1, X_2, \dots, X_n = Independent variables, for example geometrical properties of nectarine
 $k_0, k_1, k_2, \dots, k_n$ = Regression coefficients

In order to model nectarine mass based on geometrical properties, eighteen linear regression mass models were suggested and all the data were subjected to linear regression analysis using the Microsoft Excel 2007. Models were divided into three main classifications (Table 2), i.e. first classification (outer dimensions), second classification (projected areas) and third classification (volumes).

RESULTS AND DISCUSSION

The p-value of the independent variable(s) and coefficient of determination (R^2) of all the linear regression mass models are shown in Table 3.

First Classification Models (Outer Dimensions):
 In this classification nectarine mass can be predicted using single variable linear regressions of major diameter (a), intermediate diameter (b), minor diameter (c)

Table 3: Mass models, p-value of model variable(s) and coefficient of determination (R^2)

Model No.	p-value										R^2
	a	b	c	GMD	PA ₁	PA ₂	PA ₃	CAE	V _{Ell}	V _M	
1	2.16E-27	---	---	---	---	---	---	---	---	---	0.76
2	---	2.70E-38	---	---	---	---	---	---	---	---	0.87
3	---	---	4.60E-30	---	---	---	---	---	---	---	0.79
4	---	---	---	3.01E-54	---	---	---	---	---	---	0.95
5	2.52E-07	3.16E-18	---	---	---	---	---	---	---	---	0.90
6	1.05E-16	---	2.34E-19	---	---	---	---	---	---	---	0.91
7	---	2.08E-18	3.37E-10	---	---	---	---	---	---	---	0.92
8	6.39E-09	1.28E-10	9.55E-12	---	---	---	---	---	---	---	0.95
9	---	---	---	---	4.92E-44	---	---	---	---	---	0.90
10	---	---	---	---	---	3.42E-47	---	---	---	---	0.92
11	---	---	---	---	---	---	1.34E-47	---	---	---	0.92
12	---	---	---	---	---	---	---	2.28E-57	---	---	0.95
13	---	---	---	---	3.61E-05	2.17E-08	---	---	---	---	0.93
14	---	---	---	---	0.000495	---	3.97E-37	---	---	---	0.92
15	---	---	---	---	---	2.83E-07	1.09E-07	---	---	---	0.94
16	---	---	---	---	1.87E-06	0.230047	6.35E-09	---	---	---	0.95
17	---	---	---	---	---	---	---	---	1.18E-75	---	0.98
18	---	---	---	---	---	---	---	---	---	5.20E-60	0.96

and geometrical mean diameter (GMD) of nectarine or multiple variable linear regressions of nectarine diameters. As indicated in Table 3, among the first classification models (models No. 1-8), model No. 4 had one of the highest R^2 values (0.95). Also, the p-value of independent variable (GMD) was 3.01E-54. Based on the statistical results model No. 4 was selected as the best model of first classification. Model No. 4 is given in equation 8.

$$M = - 112.4 + 3.624 \text{ GMD} \tag{8}$$

Second Classification Models (Projected Areas): In this classification nectarine mass can be predicted using single variable linear regressions of first projected area (PA₁), second projected area (PA₂), third projected area (PA₃) and criteria area (CAE) of nectarine or multiple variable linear regressions of nectarine projected areas. As showed in Table 3, among the second classification models (models No. 9-16), model No. 12 had one of the highest R^2 values (0.95). Moreover, the p-value of independent variable (CAE) was 2.28E-57. Again, based on the statistical results model No. 12 was chosen as the best model of second classification. Model No. 12 is given in equation 9.

$$M = - 26.64 + 4.838 \text{ CAE} \tag{9}$$

Third Classification Models (Volumes): In this classification nectarine mass can be predicted using single variable linear regressions of estimated volume calculated from an ellipsoid assumed shape (V_{Ell}) or

measured volume (V_M) of nectarine. As indicated in Table 3, between the third classification models (models No. 17 and 18), model No. 17 had the highest R^2 value (0.98). In addition, the p-value of independent variable (V_{Ell}) was 1.18E-75. Once more, based on the statistical results model No. 17 was chosen as the best model of third classification. Model No. 17 is given in equation 10.

$$M = 2.401 + 1.006 \text{ V}_{\text{Ell}} \tag{10}$$

CONCLUSIONS

To predict nectarine mass (M) based on outer dimensions, the mass model based on geometrical mean diameter (GMD) as $M = - 112.4 + 3.624 \text{ GMD}$ with $R^2 = 0.95$ can be recommended. Moreover, to predict nectarine mass based on projected areas, the mass model based on criteria area (CAE) as $M = - 26.64 + 4.838 \text{ CAE}$ with $R^2 = 0.95$ can be suggested. Besides, to predict nectarine mass based on volumes, the mass model based on estimated volume calculated from an ellipsoid assumed shape (V_{Ell}) as $M = 2.401 + 1.006 \text{ V}_{\text{Ell}}$ with $R^2 = 0.98$ can be utilized. These models can also be used to design and develop sizing machines equipped with an image processing system.

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