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# Modeling of Apple Mass Based on Some Geometrical Attributes

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**Abstract:** In this study, nine linear regression models for predicting apple mass from some geometrical attributes of apple such as length (L), diameter (D), geometrical mean diameter (GMD), first projected area ($PA_1$), second projected area ($PA_2$), criteria area (CAE) and estimated volume based on an oblate spheroid assumed shape ($V_{Sp}$) were suggested. The statistical results of the study indicated that in order to model apple mass based on outer dimensions, the mass model based on GMD as M = - 168.5 + 47.01 GMD with $R^2 = 0.77$ may be recommended. In addition, to predict apple mass based on projected areas, the mass model based on CAE as M = - 26.82 + 4.948 CAE with $R^2 = 0.77$ may be suggested. Moreover, to predict apple mass based on estimated volume, the mass model based on $V_{Sp}$ as M = 20.68 + 0.814 $V_{Sp}$ with $R^2 = 0.76$ may be advised.

**Key words:** Apple · Mass · Geometrical attributes · Modeling · Iran

## INTRODUCTION

The apple is the pomaceous fruit of the apple tree, species *Malus domestica* in the rose family (*Rosaceae*). It is one of the most widely cultivated tree fruits. There are more than 7500 known cultivars of apples [1]. At least 55 million tones of apples were grown worldwide in 2005, with a value of about $10 billion. China produced about 35% of this total. The United States is the second-leading producer, with more than 7.5% of world production. Iran is third, followed by Turkey, Russia, Italy and India [2]. Iranian apple are not exported because of variance in size and shape and lack of proper packaging [3].

Similar to other fruits, apple size is one of the most important quality parameters for evaluation by consumer preference. Consumers prefer fruits of equal size and shape [4, 5]. Sorting can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [6]. Moreover, sorting is important in meeting quality standards, increasing market value and marketing operations [7, 8]. Sorting manually is associated with high labor costs in addition to subjectivity, tediousness and inconsistency which lower the quality of sorting [9]. However, replacing human with a machine may still be questionable where the labor cost is comparable with the sorting equipment [10]. 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 [11, 12].

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 [13]. The size of produce is frequently represented by its mass because it is relatively simple to measure. However, sorting based on some geometrical attributes may provide a more efficient method than mass sorting. Moreover, the mass of produce can be easily estimated from geometrical attributes if the mass model of the produce is known [14-17]. Therefore, modeling of apple mass based on some geometrical attributes may be useful and applicable. The main objective of this research was to determine suitable mass models based on some geometrical attributes of apple.

## MATERIALS AND METHODS

**Experimental Procedure:** One of the commercial varieties of apple in Iran, i.e. Damavandi (Fig. 1) was considered for this study. One hundred randomly selected apples of various sizes were purchased from an orchard located in Damavand, Iran. Apples were selected for freedom from defects by careful visual inspection, transferred to the

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Table 1: The mean values, standard deviation (S.D.) and coefficient of variation (C.V.) of physical and geometrical attributes of the 100 randomly selected apples used to determine mass models

| Parameter | Minimum | Maximum | Mean | S.D. | C.V. (%) |
|---|---|---|---|---|---|
| Mass (M), g | 83.00 | 144.0 | 118.5 | 17.07 | 14.41 |
| Length (L), cm | 5.000 | 7.000 | 6.042 | 0.365 | 6.044 |
| Diameter (D), cm | 5.350 | 6.800 | 6.140 | 0.341 | 5.560 |
| Geometrical mean diameter (GMD), cm | 5.300 | 6.698 | 6.105 | 0.317 | 5.198 |
| First projected area ($PA_1$), $cm^2$ | 22.48 | 36.32 | 29.70 | 3.253 | 10.95 |
| Second projected area ($PA_2$), $cm^2$ | 21.85 | 36.02 | 29.20 | 3.014 | 10.32 |
| Criteria area (CAE), $cm^2$ | 22.06 | 35.25 | 29.36 | 3.013 | 10.26 |
| Estimated volume ($V_{Sp}$), $cm^3$ | 77.94 | 157.4 | 120.1 | 18.28 | 15.22 |

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

| Classification | Model No. | Model | Relation |
|---|---|---|---|
| Outer dimensions | 1 | $M = k_0 + k_1 L$ | $M = -72.50 + 31.61 L$ |
| | 2 | $M = k_0 + k_1 D$ | $M = -144.4 + 42.82 D$ |
| | 3 | $M = k_0 + k_1 GMD$ | $M = -168.5 + 47.01 GMD$ |
| | 4 | $M = k_0 + k_1 L + k_2 D$ | $M = -167.3 + 11.35 L + 35.38 D$ |
| Projected areas | 5 | $M = k_0 + k_1 PA_1$ | $M = -14.92 + 4.491 PA_1$ |
| | 6 | $M = k_0 + k_1 PA_2$ | $M = -21.72 + 4.801 PA_2$ |
| | 7 | $M = k_0 + k_1 CAE$ | $M = -26.82 + 4.948 CAE$ |
| | 8 | $M = k_0 + k_1 PA_1 + k_2 PA_2$ | $M = -26.17 + 2.559 PA_1 + 2.351 PA_2$ |
| Estimated volume | 9 | $M = k_0 + k_1 V_{Sp}$ | $M = 20.68 + 0.814 V_{Sp}$ |

Fig. 1: Apple (Damavandi variety)

laboratory and held at 5±1°C and 90±5% relative humidity until experimental procedure. In order to obtain required parameters for determining mass models, the mass of each apple was measured to 1.0 g accuracy on a digital balance. By assuming the shape of apple as an oblate spheroid, the outer dimensions of each apple, i.e. length (L) and diameter (D) was measured to 0.1 cm accuracy by a digital caliper. The geometric mean diameter (GMD) of each apple was then calculated by equation 1.

$$GMD = (LD^2)^{1/3} \quad (1)$$

Two projected areas of each apple, i.e. first projected area ($PA_1$) and second projected area ($PA_2$) were also calculated by using equations 2 and 3, respectively. The average projected area known as criteria area (CAE) of each apple was then determined from equation 4.

$$PA_1 = \pi D^2/4 \quad (2)$$
$$PA_2 = \pi LD/4 \quad (3)$$
$$CAE = (PA_1+2PA_2)/3 \quad (4)$$

In addition, the estimated volume of each apple by assuming the shape of apple as an oblate spheroid ($V_{Sp}$) was calculated by using equation 5.

$$V_{sp} = \pi LD^2/6 \quad (5)$$

Table 1 shows physical and geometrical attributes of the 100 apples used to determine mass models.

**Regression Model:** A typical multiple variables linear regression model is shown in equation 6:

$$Y = k_0 + k_1X_1 + k_2X_2 + \ldots + k_nX_n \quad (6)$$

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

| | p-value | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Model No. | L | D | GMD | $PA_1$ | $PA_2$ | CAE | $V_{Sp}$ | $R^2$ |
| 1 | 1.16E-14 | --- | --- | --- | --- | --- | --- | 0.46 |
| 2 | --- | 7.04E-30 | --- | --- | --- | --- | --- | 0.73 |
| 3 | --- | --- | 1.79E-32 | --- | --- | --- | --- | 0.77 |
| 4 | 0.000152 | 8.48E-20 | --- | --- | --- | --- | --- | 0.76 |
| 5 | --- | --- | --- | 7.71E-30 | --- | --- | --- | 0.73 |
| 6 | --- | --- | --- | --- | 9.47E-29 | --- | --- | 0.72 |
| 7 | --- | --- | --- | --- | --- | 2.16E-32 | --- | 0.77 |
| 8 | --- | --- | --- | 1.19E-05 | 0.000159 | --- | --- | 0.76 |
| 9 | --- | --- | --- | --- | --- | --- | 3.93E-32 | 0.76 |

Where:
Y = Dependent variable, for example mass of apple
$X_1$, $X_2$, …, $X_n$ = Independent variables, for example geometrical attributes of apple
$k_0$, $k_1$, $k_2$, …, $k_n$ = Regression coefficients

In order to model apple mass based on geometrical attributes, nine linear regression 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 (estimated volume).

## 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 apple mass can be predicted using single variable linear regressions of length (L), diameter (D) and geometrical mean diameter (GMD) of apple, or multiple variables linear regression of apple outer dimensions (length and diameter). As indicated in Table 3, among the first classification models (models No. 1-4), model No. 3 had the highest $R^2$ values (0.77). Also, the p-value of independent variable (GMD) was the lowest (1.79E-32). Based on the statistical results model No. 3 was selected as the best model of first classification. Model No. 3 is given in equation 7.

$$M = - 168.5 + 47.01\ GMD \quad (7)$$

**Second Classification Models (Projected Areas):** In this classification apple mass can be predicted using single variable linear regressions of first projected area ($PA_1$), second projected area ($PA_2$) and criteria area (CAE) of apple, or multiple variables linear regression of apple projected areas. As showed in Table 3, among the second classification models (models No. 5-8), model No. 7 had the highest $R^2$ values (0.77). Moreover, the p-value of independent variable (CAE) was the lowest (2.16E-32). Again, based on the statistical results model No. 7 was chosen as the best model of second classification. Model No. 7 is given in equation 8.

$$M = - 26.82 + 4.948\ CAE \quad (8)$$

**Third Classification Model (Estimated Volume):** In this classification apple mass can be predicted using single variable linear regression of estimated volume of apple ($V_{sp}$). As indicated in Table 3, model No. 9 had an acceptable $R^2$ value (0.76). In addition, the p-value of independent variable ($V_{Sp}$) was (3.93E-32). Once more, based on the statistical results model No. 9 was chosen as a suitable model. Model No. 9 is given in equation 9.

$$M = 20.68 + 0.814\ V_{Sp} \quad (9)$$

## CONCLUSIONS

In order to model apple mass based on outer dimensions, the mass model based on GMD as M = - 168.5 + 47.01 GMD with $R^2$ = 0.77 may be recommended. In addition, to predict apple mass based on projected areas, the mass model based on CAE as M = - 26.82 + 4.948 CAE with $R^2$ = 0.77 may be suggested. Moreover, to predict

apple mass based on estimated volume, the mass model based on $V_{Sp}$ as $M = 20.68 + 0.814\ V_{Sp}$ with $R^2 = 0.76$ may be advised.

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