# Determining Regression Models of Almond and its Kernel Mass Based on Geometric Properties (Shahrud 12 and Mama'e Varieties)

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**Abstract:** Almond (Prunus amygdalus) belongs to Rosaceae family and sub-family of Pronoideae. Physical traits of agricultural products are main parameters in designing of grading, conveying, processing, and packing systems. In this study the physical traits such as dimensions, mass, volume, sphericity, geometric average of Mama'e and Shahrud 12 almonds and their kernels were measured and calculated. The average amounts of length, width, and thickness for both almond varieties were 37.41, 23.21, and 16.63 mm, respectively, and for almonds' kernel were 28.05, 13.4, and 7.82 mm, respectively. Results from modeling of almond and its kernel masses based on dimensions and volume showed that there exists a great correlation coefficient between the samples actual volumes and masses, but since determining actual volume of almond and its kernel is a time-taking task, it was suggested to use calculated volume and presuming that the cross-sectional area of the almond is oval. Also the mass model based on the thickness had the highest determination coefficient and lowest regression error which was the best option for industrial and economical applications. [Journal of American Science. 2010;6(11):59-64]. (ISSN: 1545-1003).

**Keywords:** Almonds, Physical Properties, Mass Modeling, Dimensional Models, Volumetric Models

## 1. Introduction

According to the statistics released by FAO (2004), Iran with 80000 tonnes of almonds is fourth throughout the world which implies that with proper climatic conditions and development of various main and wild types of almond, Iran is a favorite place to grow almond and by paying special attention to this product, quiet a considerable wealth would be earned [FAO,2007].

Recognizing the physical and mechanical properties of agricultural produce has always been on the center of attention and interest of agriculture researchers. This especially in relation with designing of machineries and equipments which are used during harvest, transport, storing, and process of agricultural products is of utmost importance. Among physical properties of agricultural products, dimensions, mass, volume, projected area, and surface area have the most importance in grading systems. Therefore, dimensional grading of products decreases the packaging and transportation costs and allows using of proper packaging models [Peleg,1958].

Post harvest operations for almond generally consist of 3 phases of breaking the almond, slicing the kernel, and packaging. In Iran these operations often is done in small workshops and manually. Lack of standard principles for packaging and not considering consumers tastes have led to problems in importing section. Therefore, in order to design machinery to process almond, determining some of its physical and mechanical properties is essential. Otherwise, incoherence between machinery and product causes losses of kernel and a decrease in final product quality [Khaza'e,2003].

Due to dissimilarity in almond dimensions, the almond breaking device should favor an adjusting ability for almonds with different dimensions. Therefore, in order to determine the working range of the device, knowledge about the averages of all the three dimensions of almond is necessary. Also for designing slicing devices and almond's kernel grading machineries, determining of all the three dimensions of almonds kernel and other center-inclination parameters are necessary.

Based on this, several studies on determining the physical and mechanical properties of different products have been carried out, which some of them are pointed out in the following.

Aydin studied the mechanical and physical properties of a kind of almond which grows in Turkey. Average amounts for length, width, and thickness for almond were 25.49, 12.03, and 12.17 mm, respectively, and for the kernel were 21/19, 11.34, and 6.38, respectively. Also averages for mass, volume, geometric average, and sphericity were 2.64 g, 2.61 $cm^3$, 18.13 mm, and 69.59% for almond, respectively, and for the kernel were 0.73 g, 0.82 $cm^3$, 11.42 mm, and 55.17%, respectively [Aydin,2003].

Turkan et al measured the average length, width, and thickness of a Golkan 23-101 almond cultivar to be 36.60, 19.24, and 11.47 mm, respectively, and 31.10, 18.31, and 11.04 mm for Nanparil cultivar, respectively. Also averages for mass, volume, geometric average, sphericity, and surface area for Golkan 23-101 cultivar were 3.02 g, 4.24 $cm^3$, 20.03 mm, 54%, and 12.61 $cm^2$, respectively, and for Nanparil cultivar were 1.72 g, 3.33 $cm^3$, 18.50 mm, 59%, and 12.80 $cm^2$, respectively [Turkan et al,2007].

Moradi studied some of qualitative and quantative properties of both Shahrud 12 and Mama'e cultivars of almond. He measured length, width, and thickness averages of Mama'e cultivar 22, 35, and 14.7 for almond, respectively, and for its kernel 26.7, 13, and 7.25 mm, respectively. Also length, width, and thickness averages for Sharud 12 almond were 37.6, 21.9, and 16.2 mm, respectively, and for its kernel were 25.9, 12, and 7.14 mm [Moradi,2002].

Aydin evaluated physical properties of hazelnut as a function of its moisture content. The objective of the study was to determine and evaluate dimensions, weight, unit volume, sphericity, density, porosity, projected area, limit velocity, breakage resistance, and static and dynamic friction coefficients of full hazelnut and its kernel. Moisture content of samples ranged between 2.87% to 19.98% (based on dry weight) [Aydin,2002].

Balasubramanian (2001) studied the physical properties of raw cashew nut due to lack of information on this field and the possibility of applying the results for designing process machineries. In this study average amounts of main dimensions (length, width, and thickness), weight ratio, equal diameter, and sphericity at 8.46% of moisture content and weight of a thousand seeds, porosity, bulk density, actual density, and friction coefficient at moisture range of 3.15 to 20.05% (5 levels of moisture content) were determined [Balasubramanian,2001].

Craig and Debra in addition to study physical properties of three almond kernels namely Nanparil, 23.5-16, and 23-122, also obtained regression models for kernel mass of three almond cultivars based on length, width, and thickness. According to their report it was determined that kernel mass favors the most correlation with length and lowest correlation with thickness [Craig,2006].

In this study some of the physical properties of two almond cultivars (Mama'e and Sharud 12) such as dimensions, mass, volume, diameter, geometric average, and sphericity degree were studied. Also regression models for almond and its mass based on geometric properties were determined.

## 2. Material and Methods

In this study tests were carried out on two almond cultivars of Saman region, Shahrud 12 and Mama'e. After cleaning and separating samples from their husks, the samples were packed. The package containing samples were held inside a refrigerator at 5˚C in order to keep the moisture conditions and maintaining them for tests.

In order to determine almond dimensions, 3 perpendicular axes were defined. The longest dimension was considered as length (L). The longest dimension perpendicular to the length axis was considered as sample width (W) and the dimension perpendicular to length and width axes, was defined as thickness (T).[Eshaghbeigi et al,2008] Therefore, 120 almonds were selected and by a digital caliper with 0.01 accuracy length, width, and thickness of each almond were measured and then by breaking it and taking out its kernel, length, width, and thickness of the kernels were also measured, and in order to measure almond and kernel masses a digital weight with 0.1 g accuracy was used.

For determining the volume of almond and its kernel (V), platform weight method was used. In this method a bulb containing some water was placed on a weight with platform (0.1 g accuracy) and its mass was measured ($M_{bw}$). Then the sample was floated in the water so that it would have no contact with bottom and edges of the bulb. This can be done by means of a nylon string (in case the sample is heavier than water) or a thin metal string (in case the sample is lighter than water).

In this case, the weight of bulb with water and the floated sample were determined ($M_{bws}$). The difference in weight is caused by Archimedes force and the volume can be calculated by dividing the Archimedes force to water density.

$$V = (M_{bws} - M_{bw})/\rho_w \quad (1)$$

Since the seed shape and other granule agricultural crops are usually irregular, seeds size is determined as geometric diameter. Geometric diameter can be calculated from equation 2.

$$D_g = (L * W * T)^{1/3} \quad (2)$$

If almond volume is presumed to be equal to an oval with three L, W, and T axes so that the peripheral sphere will have the longest axis of ellipsoid (L), then the sphericity coefficient can be calculated as follow.

$$Sp = \frac{D_g}{L} \quad (3)$$

In this study to estimate almond and its kernel masses two kind of models were used:

a) A model that predicts the mass with one or a combination of two or three dimension parameters (length, width, and thickness) as equation (4).

$$M = F(L,W,T) \quad (4)$$

b) A model that predicts mass based on real volume or calculated mass based on the extended sphere and ellipsoid as equation (5).

$$M = F(V_x) \qquad (5)$$

In order to estimate crops volume through similarity of geometric shapes, equations (6) and (7) are respectively used for bodies like extended sphere and ellipsoid.

$$V = \frac{4\pi}{3} ab^2 \qquad (6)$$

$$V = \frac{4\pi}{3} abc \qquad (7)$$

In above equations a, b and c are half of diameters at direction of three main axes (X, Y, Z), respectively.

The measured data were transferred to Excel software and were categorized and saved in separate files. Average amounts and conditioning operations were done through Excel and regression equations on data were performed by MiniTab(12 version) software.

## 3. Results And Discussion

### 3-1. Physical Properties of Almond its Kernel

Average amounts for dimensions, mass, volume, geometric diameter, and sphericity for both almond cultivars and kernels at moisture rage of 9-10% (on dry basis) are shown in tables 1 and 2.

Ranges of changes for dimensions i.e. length, width, and thickness for Mama'e almond were 34.65-45.35, 18.51-29.26, and 14.08-24.56 mm, respectively, and for Shahrud 12 were 28.93-40.11, 20.47-27.55, and 14.57-18.23 mm, respectively. Also ranges of changes of length, width, and thickness for Mama'e almond kernel were 23.67-34.5, 9.46-15.91, and 5.44-16.95 mm, respectively, and for Shahrud 12 almond kernel were 28.93-40.11, 20.47-27.55, and 14.57-18.23 mm, respectively.

### 2-3 Determining Regression Models of Almond Mass Based on Geometric Properties

**a) Dimensional Models**

In table (3) seven models to show mass based on almond dimensions are shown. As it appears for both cultivars, model number 7, which models mass based on three perpendicular dimensions, has the highest determination coefficient ($R^2$) and lowest regression standard error (RSE) among all the other models. Since in this model all the three dimensions should be measured is used for grading and sorting machineries which require high accuracy and the high costs have economic justifications. Among models 1, 2, and 3 which are single-variable models, model number 3 which predicts mass based on thickness is the best model. Due to above mention points equation (8) is suggested for predicting almond mass based on thickness for both cultivars. $M=-4.27+0.525T \quad R^2= 0.76 \qquad (8)$

**b) Volumetric Models**

Models that predict almond mass based on volume are indicated in table (4). Model 1 has the highest determination coefficient ($R^2$) and lowest RSE rather than all the other models. Since determination of actual volume of almond is performed by expensive and complex machineries, therefore, it has fewer usages in practical applications; instead, one can use volumes calculated from dimensions, ($V_{psp}$) and ($V_{ellip}$). Results from table (4) show that mass predicting model based on presumed volume as an ellipsoid volume ($V_{ellip}$) for all the observations has the highest $R^2$ and lowest RSE. Therefore, this volume is suggested for determining almond mass in machineries, also mass model based on ellipsoid volume for all observations is determined from the following equation:

$$M=0.563+0.000518V_{ellip} \quad R^2=0.75 \quad (9)$$

### Determining Regression Models of Almond Kernel Mass Based on Geometric Properties

**a) Dimensional Models**

In table (5) seven models that estimate kernel mass based on geometric dimensions are shown. As it seems, model number 7 which predicts mass based on three perpendicular dimensions, has the highest $R^2$ and lowest RSE rather than the other models.

Almond kernel mass model based on model number 7 (for total observations) is shown by equation (10).

Indeed, since this model increase the costs and complexity of machineries is cost worthy.

$$M = -2.2+0.114\,T+ 0.121\,W + 0.04\,L \quad R^2= 0.91 \quad (10)$$

Regarding the results obtained from table (5), among single-variable models, model 3 that predicts mass based on thickness (equation 11) for Mama'e kernel, model 1 that predicts mass based on length (equation 12) for Shahrud 12, and model 3 that predicts mass based on thickness (equation 13) for total observations, have the highest $R^2$ and lowest RSE. Also among bivariate models for both observed cultivars, model 6 that predicts mass based on width and thickness has the highest $R^2$.

$$M = 0.36+0.128\,T \quad R^2=0.53 \quad (11)$$

$$M = -1.67+0.114\,L \quad R^2= 0.86 \quad (12)$$

$$M = 0.252+0.151\,T \quad R^2= 0.60 \quad (13)$$

**b) Kernel Mass Model Based on Volume**

Models that estimate kernel mass based on volume are shown. Model 1 has the highest $R^2$ and lowest RSE rather than the other models. Results indicate that calculated volume based on ellipsoid ($V_{ellip}$) has a higher determination coefficient with mass; therefore, it is suggested to use ellipsoid volume to predict kernel mass in machineries. Mass model based on ellipsoid volume for total observations is determined by equation (14).

$M=0.365+.000691V_{ellip}$ $R^2=0.82$ (14)

**Table 1 – Average amounts for some of physical properties of Shahrud 12 and Mama'e cultivars**

| Volume ($mm^3$) | Mass g | Sphericity % | Geometric Average mm | thickness mm | width mm | length Mm | Cultivar |
|---|---|---|---|---|---|---|---|
| 4167/5 | 4/21 | 68 | 23/73 | 16/12 | /79 23 | 34/87 | Shahrud 12 |
| /55 4877 | 4/74 | 62/3 | 24/9 | 17/15 | /62 22 | 39/97 | Mama'e |

**Table 2 – Average amounts for some of physical properties of Shahrud 12 and Mama'e cultivars kernels**

| Volume ($mm^3$) | Mass g | Sphericity % | Geometric Average mm | thickness mm | width mm | length Mm | Cultivar |
|---|---|---|---|---|---|---|---|
| 1363/23 | 1/38 | 51 | 13/78 | 7/02 | 13/98 | 26/73 | Shahrud 12 |
| 1451/53 | 1/47 | 50 | 14/72 | 8/59 | 12/84 | 29/29 | Mama'e |

**Table 3 – Mass modeling of almond using dimensions**

| Total Observations | Shahrud 12 | Mama'e | Statistical Parameters | Model | # |
|---|---|---|---|---|---|
| 0/53 | 0/68 | 0/62 | $R^2$ | M= al +b | 1 |
| 0/49 | 0/33 | 0/49 | R.S.E | | |
| 0/6 | 0/59 | 0/26 | $R^2$ | M= aw +b | 2 |
| 0/44 | 0/38 | 0/7 | R.S.E | | |
| 0/76 | 0/71 | 0/63 | $R^2$ | M= aT +b | 3 |
| 0/42 | 0/31 | 0/51 | R.S.E | | |
| 0/7 | 0/83 | 0/68 | $R^2$ | M= al +bw+c | 4 |
| 0/39 | 0/23 | 0/46 | R.S.E | | |
| 0/72 | 0/75 | 0/82 | $R^2$ | M= al +bT+c | 5 |
| 0/38 | 0/3 | 0/37 | R.S.E | | |
| 0/71 | 0/79 | 0/73 | $R^2$ | M= aw +bT+c | 6 |
| 0/39 | 0/29 | 0/46 | R.S.E | | |
| 0/84 | 0/83 | 0/85 | $R^2$ | M= al +bw+cT+d | 7 |
| 0/29 | 0/26 | 0/33 | R.S.E | | |

**Table 4 – Almond mass modeling using volume**

| Total Observations | Shahrud 12 | Mama'e | Statistical Parameters | Model | # |
|---|---|---|---|---|---|
| 0/87 | 0/92 | 0/98 | $R^2$ | $M= av_m +b$ | 1 |
| 0/27 | 0/18 | 0/11 | R.S.E | | |

| | | | | | |
|---|---|---|---|---|---|
| 0/75<br>0/4 | 0/54<br>0/44 | 0/75<br>0/41 | $R^2$<br>R.S.E | M= $av_{ellip}$ +b | 2 |
| 0/54<br>0/45 | 0/79<br>0/26 | 0/33<br>0/66 | $R^2$<br>R.S.E | M= $av_{psp}$ +b | 3 |

**Table 5 – Almond kernel mass modeling using dimensions**

| Total Observations | Shahrud 12 | Mama'e | Statistical Parameters | Model | # |
|---|---|---|---|---|---|
| 0/46<br>0/23 | 0/86<br>0/08 | 0/45<br>0/28 | $R^2$<br>R.S.E | M= al +b | 1 |
| 0/40<br>0/18 | 0/70<br>0/11 | 0/27<br>0/32 | $R^2$<br>R.S.E | M= aw +b | 2 |
| 0/60<br>0/18 | 0/40<br>0/15 | 0/53<br>0/22 | $R^2$<br>R.S.E | M= aT +b | 3 |
| 0/77<br>0/12 | 0/91<br>0/06 | 0/57<br>0/20 | $R^2$<br>R.S.E | M= al +bw+c | 4 |
| 0/65<br>0/17 | 0/86<br>0/07 | 0/90<br>0/10 | $R^2$<br>R.S.E | M= al +bT+c | 5 |
| 0/84<br>0/11 | 0/77<br>0/10 | 0/90<br>0/11 | $R^2$<br>R.S.E | M= aw +bT+c | 6 |
| 0/91<br>0/09 | 0/92<br>0/06 | 0/93<br>0/09 | $R^2$<br>R.S.E | M= al +bw+cT+d | 7 |

**Table 6 – Almond kernel mass modeling using volume**

| Total Observations | Shahrud 12 | Mama'e | Statistical Parameters | Model | # |
|---|---|---|---|---|---|
| 0/96<br>0/6 | 0/93<br>0/05 | 0/98<br>0/06 | $R^2$<br>R.S.E | M= $av_m$ +b | 1 |
| 0/82<br>0/11 | 0/81<br>0/07 | 0/92<br>0/10 | $R^2$<br>R.S.E | M= $av_{ellip}$ +b | 2 |
| 0/47<br>0/18 | 0/85<br>0/07 | 0/42<br>0/26 | $R^2$<br>R.S.E | M= $av_{psp}$ +b | 3 |

**4. Conclusions**

In this study, physical properties such as dimensions, mass, volume, sphericity, and geometric average were measured and calculated for Mama'e and Shahrud 12 almonds and kernels. The average amounts of length, width, and thickness for both almond cultivars were 34.41, 23.21, and 16.63 mm, respectively, and for both cultivars' kernels were 28.05, 13.40, and 7.82 mm, respectively. Mama'e dimensions were larger than Shahrud 12 and consequently had larger geometric diameter and volume.

Shahrud 12 cultivar had higher sphericity coefficient than Mama'e. At moisture range of 10-11 percent, 90% of Shahrud 12 masses were between 4.11 to 4.31 mm and also 90% of Mama'e cultivar's kernel masses were between 1.41 to 1.42 mm.

At moisture range of 7-8 percent, 90% of Shahrud 12 kernel masses were between 1.35 to 1.42 mm and also 90% of Mama'e cultivar masses were between 4.59 to 4.89 mm.

Results from modeling of almond and kernel masses based on dimensions and volume showed that there is great correlation between actual volume and mass of samples, which indicates the uniformity of almond's density. But since determination of actual volume of almond and kernel is a time-taking task, it is suggested to use calculated volume while presuming that the cross-section area of the almond is an ellipsoid ($V_{ellip}$). Also mass model based on thickness is suggested as the best option for industrial and economic applications in designing and manufacturing of machineries specified for breaking and grading.

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