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Mass Modelling of Eggs Based on Shape Index Using Regression Analysis

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ABSTRACT
This study was conducted to determine the correlation between the mass of eggs based on its geometrical dimensions characteristics such as length (*L*), width (*W*), geometric mean diameter (*GMD*), the first and second projection areas (PA_1, PA_2), criteria area (*CAE*), oblate spheroid volume (V_{osp}), measured volume (V_m) and shape index (*SI*). Based upon the *SI*, eggs were characterized as sharp (<72), normal (72 -76) and round (>76), respectively. For mass prediction, different classifications *viz.* dimension as 1st classification, projection area as 2nd classification, and volume as 3rd classification were considered. 1st classification (dimension), 2nd classification (projection area), and 3rd classification (volume) were considered. The analysis was executed using 33 linear regression models and the models were recommended by considering maximum coefficient of determination (R^2) and minimum regression standard error (*RSE*). Based on the modelling analysis, 10 model equations based on the selected classifications were recommended for mass estimation. The findings of this investigation will be helpful for the researchers involved in the design and development of process equipments in the production and processing of eggs.

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Yumurtaların Şekil İndeksine Göre Regresyon Analiziyle Kütle Modellemesi

ÖZET
Bu çalışma, uzunluk (*L*), genişlik (*W*), geometrik ortalama çap (*GMD*) gibi geometrik özellikleri; birinci ve ikinci projeksiyon alanları (PA_1, PA_2), kriter alanı (*CAE*) ile basık küre hacmi (Vosp) ve ölçülen hacim (Vm) ve şekil indeksi (SI) ile yumurta kütlesi arasındaki ilişkiyi belirlemek amacıyla yapılmıştır. Şekil indeksine göre yumurtalar sırasıyla sivri (<72), normal (72-76) ve yuvarlak (>76) olarak karakterize edildi. Kütle tahmini için farklı sınıflandırmalar yani boyut 1. sınıflandırma, projeksiyon alanı 2. sınıflandırma ve hacim 3. sınıflandırma olarak gözönüne alındı. Analiz 33 lineer regresyon modeli kullanılarak uygulandı ve modeller maksimum belirtme katsayısı (R^2) ve minimum regresyon standart hatası (*RSE*) dikkate alınarak önerildi. Modelleme analizine göre, kütle tahmini için seçilen sınıflandırmalara dayalı 10 model denklem önerilmiştir. Bu araştırmanın bulguları, yumurta üretimi ve işlenmesinde proseslerdeki ekipmanların tasarımı ve geliştirilmesinde araştırmacılara yardımcı olabilecektir.

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INTRODUCTION

An egg is an encapsulated source of macro and micronutrients that meet all requirements to support embryonic development until hatching (Réhault-Godbert et al., 2019). It is presumed to be a basic foodstuff due to its very high nutritive value (high protein content, nutrients, and vitamins) as reported by Rashidi et al., (2008). The major nutrients present in a whole, raw and freshly laid egg are, water (76.1%), protein, (12.6%), fat (9.5%), carbohydrates (0.7%), and ash (1.1%), respectively. Egg proteins are distributed equally between egg white and yolk, whereas vitamins, minerals and lipids are concentrated in egg yolk (Rath et al., 2015).

The factors like age and breed of the hen, weight, nutrition, maturity, and type of rearing system determine the egg quality characteristics (USDA 2018). Some environmental factors *viz.* heat, stress, overcrowding, and poor nutrition may also result in eggs having lesser weight. Even a minor variation in egg weight influences size classification which in turn affects the egg price (Altuntas & Sekeroglu, 2008).

From the consumer perspective, egg size is the most imperative characteristic as eggs having identical shapes and sizes are preferred (Rashidi et al., 2008). Sorting can help in gaining uniform size and shape, thereby reducing the costs involved in packaging and transportation and simultaneously resulted in an optimum packaging configuration (Rashidi & Gholami, 2008). It also contributes to meeting quality standards, increasing market value, and marketing operations.

Eggs can be classified into different sizes based on its weight, inclusive of peewee, small, medium, large, extra-large, and jumbo size. For the packaged egg material, mechanical strength of the eggshell is an important quality aspect to be considered. Egg shape index (SI) and shell thickness affect the proportion of damaged eggs while handling and transportation (Anderson et al., 2004; Yang et al. 2014).

Physical properties such as mass, volume, shell thickness, surface area and weight are the parameters affecting mechanical properties of chicken eggs. The correlation between the physical and mechanical properties of eggs was most significant (Altuntas & Sekeroglu, 2010). There is natural variability in egg shape and this variability can be characterized using SI. The significance of this indicator is mostly revealed in determining the direction of rotation during incubation and the movements of the embryo during the utilization of nutrients (Keranova et al., 2017).

Mass, being a relatively simple parameter, the size of any product is frequently correlated by its mass. However, sorting on the basis of selected geometrical characteristics might result in a more effective technique than mass sorting. Moreover, the mass of product can be easily estimated from geometrical attributes if the mass model of the product is known. Therefore, modelling of egg mass based on geometrical properties may be beneficial and applicable on a commercial scale (Rashidi & Gholami, 2011).

Mathematical relationships established using mass modeling will assist in grading eggs at a commercial scale making the process more accurate and less labor-intensive. This in turn will enhance the market value and commercialization potential of the eggs. Therefore, this research was inducted to determine the optimum mass models based on the shape index of the egg for mass prediction.

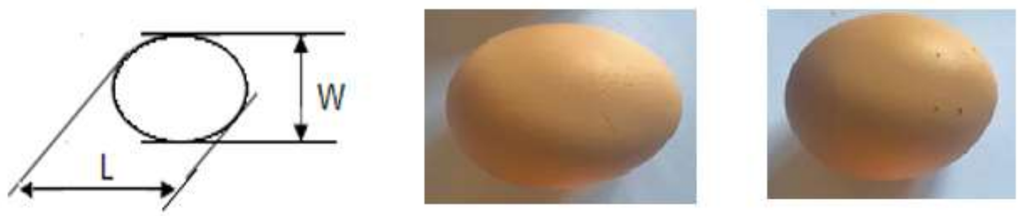
MATERIAL and METHODS

Raw Material

For this study, the egg materials used were obtained from a company located in Tokat, 39° 52' – 40° 55' north latitude and 35° 27' – 37° 39' east longitude, province. Eggs belong to brown layer "Atak-S" hybrid chickens developed by Ankara Poultry Research Institute in Turkey. The average air temperature and relative humidity was 20°C and 55% during the egg collection period. The chickens were 75 weeks old, and the facility housed 8 chickens per cage and brown eggs were used in this experiment.

Physical Properties

By assuming the shape of eggs as an oblate spheroid, the dimensions including length (*L*) and width (*W*) were measured using a digital vernier caliper (M/s Mitutoyo, Japan, ±0.01 mm) as shown in Figure 1.



(a) Axes of an egg (b) Normal egg (SI=72-76) (c) Round egg (SI>76)

Figure 1. Description of the axes (a), normal (b) and round (c) shape indexed egg samples.
Şekil 1. Yumurtaların eksen tanıtımı (a), normal (b) ve yuvarlak (c) şekil indeksli yumurta örnekleri.

The mass (*M*) of eggs was measured with a digital weighing balance (±0.001 g). The geometric mean diameter (*GMD*) of each egg was then calculated by Equation 1 (Altuntas and Sekeroglu, 2008; Meena et al. 2021).

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

The shape index (*SI*) was calculated using the Equation 2 given below (Anderson et al., 2004):

$$SI = \frac{W}{L} \times 100 \quad (2)$$

Based upon the SI, eggs are characterized as sharp (<72), normal (72 -76), and round (>76), respectively and 100 egg were used for each SI group (Sarica & Erensayin, 2004; Altuntas & Sekeroglu, 2008; Altuntas & Mahawar, 2021).

Two projected areas of each egg i.e. first projected area (*PA_1*) and second projected area (*PA_2*) were calculated using Equations 3 and 4, respectively. The average projected area known as the criteria area (*CAE*) of each egg was determined from Equation 5 as suggested by Rashidi and Gholami (2011).

$$PA_1 = \frac{\pi LW}{4} \quad (3)$$

$$PA_2 = \frac{\pi W^2}{4} \quad (4)$$

$$CAE = \frac{2PA_1 + 2PA_2}{3} \quad (5)$$

The volume of egg having assumed shape as oblate spheroid (V_{osp}) was calculated using Equation (6).

$$V_{osp} = \frac{\pi LW^2}{6} \quad (6)$$

For the measurement of volume (V_m), each egg was submerged into water and the volume of displaced water was measured (Rashidi and Gholami, 2011).

The relationship between *M*, *L*, *W*, *GMD*, PA_1, PA_2, *CAE*, V_{osp} and V_m was determined. A typical linear multiple regression model (Equatiion 7) for predicted mass for egg in this research is shown below:

$$Y = k_0 + k_1X_1 + k_2X_2 + k_3X_3 + \cdots + k_nX_n \quad (7)$$

Where:
Y = Dependent variable (for example mass of shape indexed egg)
$X_1; X_2, \dots X_n$ = Independent variables (for example physical attributes of egg)
$k_0, k_1, k_2, \dots, k_n$ = Regression coefficients

Mass Modelling

The predicted modelling was achieved using 3 different classifications i.e. dimensions as first, projection area as second, and volume as the third classification. For dimensional model classification, mass modeling was accomplished according to the independent variables (*L, W, GMD*) of different eggs was taken into account. For the second projected area models classification, projected areas i.e. PA_1, PA_2 as well as *CAE* of eggs from each SI was considered for mass prediction. Volume parameters (V_m and V_{osp}) from each SI were used as third classification for modelling.

A total of 33 linear regression models in three classifications (12 for dimensions, 12 for the projected area, and 9 for volume) were adopted and the data was subjected to linear regression analysis using SPSS (Version 13.0). The coefficient of determination (R^2) and Regression Standard Error (*RSE*) and were Root mean squared error (RMSE) considered. The models having maximum R^2 and minimum *RSE* and *RMSE* (Root mean squared error) values values represented the best fit (Mahawar et al., 2019).

Root mean squared error (RMSE) and Coefficient of variation [C.V(%)] was calculated as following below Equations 8,9 (Rashidi and Gholami, 2011).

$$RMSE = \sqrt{\Sigma(ni=1Mi-M*i)2n} \quad (8)$$

$$CV = (Standard\ deviation/Mean)100 \quad (9)$$

Where:
Mi = egg measured by digital balance, g
*M*i* = egg estimated by mass model, g
n = number of samples

RESULTS and DISCUSSION

Some physical attributes of different eggs having variable shape index i.e. (72-76) (standard), (>76) (round) and mixed (72≤SI>76) which were used to determine the mass models are presented in Table 1.

For normal group, the range of parameters i.e. 59.84-79.73 g (M), 5.75-6.43 cm (L), 4.34-4.76 cm (W), 4.78-5.21 cm (*GMD*), 27.19-32.42 cm² (CAE), 67-72 cm³ (V_m), respectively. The *SI* values were ranged between 71.41%-75.97%. For round *SI* group, the range of parameters i.e. 60.75-80.12 g (mass), 5.66-6.21 cm (length), 4.37-4.95 cm (width), 4.79-5.27 cm (*GMD*), 27.36-32.95 cm² (*CAE*), 73-83 cm3 (V_m), respectively. The *SI* values were ranged between 72.54-82.38. For mixed group, the range of parameters i.e. 59.84-80.12 g (mass), 5.66-6.43 cm (length), 4.37-4.95 cm (width), 4.78-5.27 cm (*GMD*), 27.19-32.95 cm² (*CAE*), 67-83 cm³ (V_m), respectively. The *SI* values were ranged between 71.41%-82.38%.

Correlation coefficients (R) for these relations are given Table 2. The relationship between mass, length, width, geometric mean diameter, first projected area, second projected area, criteria area, spheroid volume and measured volume was determined as follows:

For normal egg (SI=72-76);
M = 11.48 L = 15.43 W = 14.01 GMD = 3.22 PA1 = 4.32 PA2 = 2.34 CAE= 1.06 V_{osp} (10)

For round egg (SI=>76);
M = 11.69 L = 15.13 W = 13.91 GMD = 3.24 PA1 = 4.20 PA2 = 2.33 CAE= 1.06 V_{osp} (11)

For mixed egg (72≤SI>76);
M = 11.59 L = 15.26 W = 13.95 GMD = 3.23 PA1 = 4.25 PA2 = 2.34 CAE= 1.06 V_{osp} (12)

The relations between *M/L, M/W, M/GMD, M/PA1, M/PA2, M/CAE,* M/V_{osp} have been found to be statistically significant.

Altuntas and Sekeroglu (2008) have reported the *L* (64.02 to 59.28 mm) and *W* (44.61 to 46.16 mm), *GMD*

(50.28 to 49.97 mm), and mass (72.34 to 70.31 g) of chicken eggs for the three *SI* categories tested. Rashidi and Gholami (2011) have reported the physical and geometrical properties of egg as, 42.05-58.33 g (mass), 5.02-5.88 cm (length), 3.85-5.23 cm (width), 4.27-5.43 cm (*GMD*), 14.50-23.19 cm² (CAE), 37.02-49.74 cm³ (V_m), respectively. Rath et al. (2015) reported different traits of White Leghorn to flock eggs as, 57.78±0.20 g (M) 54.39±0.11 mm (L), 39.92±0.07 (W), and 73.53±0.18% (*SI*), respectively. Duman et al. (2016) reported the weight of hen eggs with reference to the shape index as, 59.80 g (sharp), 60.00 g (standard), and 61.10 g (round), respectively.

Table 1. Physical attributes of different eggs having variable shape index.
Çizelge 1. *Farklı şekil indeksine sahip farklı yumurtaların fiziksel özellikleri.*

Shape Index	Parameter	Minimum	Maximum	Mean (*)	S.D.	C.V. (%)
SI 72-76 Normal (standard)	Mass (*M*), g	59.84	79.73	70.13	3.93	5.60
	Length (*L*), cm	5.75	6.43	6.11	0.126	2.06
	Width (*W*), cm	4.34	4.76	4.54	0.088	1.95
	Geometrical mean diameter (*GMD*), cm	4.78	5.21	5.01	0.092	1.85
	First projected area (PA_1), cm²	19.71	23.75	21.81	0.808	3.71
	Second projected area (PA_2), cm²	14.81	17.78	16.22	0.630	3.88
	Criteria area (*CAE*), cm²	27.19	32.42	29.92	1.11	3.69
	Oblate spheroid volume (V_{osp}), cm³	57.33	74.46	66.10	3.64	5.51
	Measured volume (V_m), cm³	67.00	72.00	68.49	1.26	1.84
	Shape Index	71.41	75.97	74.39	1.11	1.49
SI >76 Round	Mass (*M*), g	60.75	80.12	69.44	0.080	1.62
	Length (*L*), cm	5.66	6.21	5.94	0.125	2.11
	Width (W), cm	4.37	4.95	4.59	0.087	1.90
	Geometrical mean diameter (*GMD*), cm	4.79	5.27	4.99	0.081	1.62
	First projected area (PA_1), cm²	19.72	23.43	21.42	0.691	3.23
	Second projected area (PA_2), cm²	15.00	19.23	16.55	0.632	3.82
	Criteria area (*CAE*), cm²	27.36	32.95	29.70	0.959	3.23
	Oblate spheroid volume (V_{osp}), cm³	57.98	76.99	65.57	3.20	4.88
	Measured volume (V_m), cm³	73.00	83.00	76.83	2.60	3.38
	Shape Index	72.54	82.38	77.25	1.85	2.39
SI (72≤SI>76) Mixed	Mass (*M*), g	59.84	80.12	69.74	3.67	5.27
	Length (*L*), cm	5.66	6.43	6.01	0.150	2.50
	Width (W), cm	4.37	4.95	4.57	0.091	1.98
	Geometrical mean diameter (*GMD*), cm	4.78	5.27	5.00	0.086	1.73
	First projected area (PA_1), cm²	19.72	23.75	21.59	0.767	3.55
	Second projected area (PA_2), cm²	14.81	19.23	16.41	0.650	3.96
	Criteria area (*CAE*), cm²	27.19	32.95	29.70	1.029	3.45
	Oblate spheroid volume (V_{osp}), cm³	57.33	76.99	65.80	3.41	5.18
	Measured volume (V_m), cm³	67.00	83.00	73.22	4.65	6.35
	Shape Index	71.41	82.38	76.00	2.13	2.80

SD: Standard deviation; CV: Coefficient of variation; (*): 100 eggs

Mass Modelling

Models based on selected attributes (dimensions, projected area, and volume) for normal, round, and mixed-shaped eggs were screened and the one model with a higher R^2 value and lower *RSE* in each model category was selected. The linear regression equations along with R^2, *RSE and RMSE* are presented in Table 3-5.

First classification: Dimensions Based Models

Among the first classified models, for normal *SI* eggs, the model based on *GMD* i.e. *M= k0 + k1 GMD* was found best with R^2 (0.916), and lower *RSE* (1.137). The model equation was M= - *133.047 + 40.576GMD*. For round eggs, the model based on *L* and *W* i.e. $M= k_0 + k_1L + k_2W$ was best with R^2 (0.889), and lower *RSE* (1.187) and lowest *RMSE* (1.125). The model equation was *M= - 134.369 +11.794L +29.107W.* For mixed-shaped eggs, the model based on *GMD* as well as *L* and *W* was found best. The model equations are: *M= -132.878 + 40.529 GMD* having R²=0.904, *RSE*=1.140 and *M= 132.076 +11.876L +28.529W* with R^2=0.904, *RSE*=1.140, respectively (Table 3). A graph of the estimated and measured values of a normal (standard) shape index egg shown in Figure 2.

Second classification: Projected Areas Based Models

Among the models based on the projected area, the linear model comprising *CAE* was the best fitted for normal *SI* eggs. The model equation was *M= -*

31.724+3.404 CAE having 0.917 (R^2) and 1.126 (*RSE*), and 1.123 *(RMSE)* respectively. For round *SI* and mixed *SI* eggs the best fitted model equations are: $M= - 32.293 + 3.245\ PA_1 + 1.940\ PA_2$ (R^2=0.890 and *RSE*=1.185) and $M= - 31.458 + 3.300\ PA_1 + 1.826\ PA_2$ (R^2=0.906 and *RSE*=1.131), respectively as also depicted in Table 4.

Table 2. Correlation coefficients of different eggs having variable shape index.
Çizelge 2. *Farklı şekil indeksine sahip farklı yumurtaların korelasyon katsayıları.*

Shape index	Particulars	Ratio	Degress of freedom	Correlation coefficient (R)
SI 72-76 (Normal)	*M/L*	11.480	128	0.850 **
	M/W	15.434	128	0.918 **
	M/GMD	14.007	128	0.957 **
	M/PA_1	3.216	128	0.953 **
	M/PA_2	4.323	128	0.918 **
	M/CAE	2.344	128	0.958 **
	M/V_{osp}	1.061	128	0.958 **
	M/V_m	1.024	128	-0.005 ns
SI >76 (Round)	*M/L*	11.685	168	0.635 **
	M/W	15.130	168	0.854 **
	M/GMD	13.905	168	0.945 **
	M/PA_1	3.241	168	0.919 **
	M/PA_2	4.196	168	0.854 **
	M/CAE	2.338	168	0.944 **
	M/V_{osp}	1.059	168	0.944 **
	M/V_m	0.904	168	0.015 ns
SI (72≤SI>76) Mixed	*M/L*	11.594	298	0.662 **
	M/W	15.261	298	0.827 **
	M/GMD	13.949	298	0.951 **
	M/PA_1	3.230	298	0.926 **
	M/PA_2	4.251	298	0.827 **
	M/CAE	2.341	298	0.952 **
	M/V_{osp}	1.060	298	0.951 **
	M/V_m	0.952	298	-0.080 ns

** Significant at 1% level. ns Non significant.

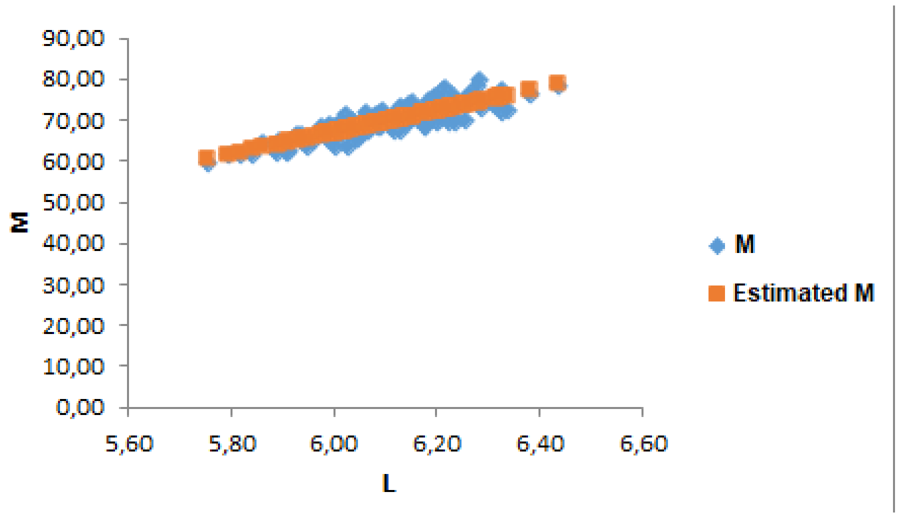


Figure 2. A graph of the estimated and measured values of a normal (standard) shape index egg.
Şekil 2. *Normal standart bir yumurtanın kütle tahmini ve ölçülen değerlerinin grafiği.*

Third classification: Volume-Based Models

Among the models based on the volume, the linear model compresing V_m was the best fitted for normal *SI* eggs. The model equation was, $M= 11.501+1.030V_{osp} - 0.139V_m$ having 0.919 (R^2) and the lowest 1.126 (*RSE*) and the lowest 1.119 *(RMSE)*. For round *SI* and mixed *SI* eggs the best-fitted model equations were based on V_{osp} and V_m i.e. $M= 1.292 + 1.017V_{osp} + 0.019V_m$ (R^2=0.889; *RSE*=1.142;

RMSE=1.128) and $M= 3.516+1.023\ V_{osp}-0.015\ V_m$ (R^2=0.904 and *RSE*=1.136; *RMSE*= 1.129), respectively as also depicted in Table 5.

The recommended model equations for mass prediction of eggs based on some geometrical attributes are summarized in Table 6.

Table 3. Coefficient of determination (R^2) and regression standard error (*RSE*) and root mean squared error (RMSE) for linear regression models based on dimensions classification for normal, round and mixed-shaped eggs.

Çizelge 3. *Normal, yuvarlak ve karışık şekilli yumurtalar için boyut sınıflandırmasına göre lineer regresyon modelleri için belirtme katsayısı (R^2) ve regresyon standart hatası (RSE), .*

Shape Index	Models No	Model	Model	R^2	*RSE*	*RMSE*	Sig. M	Sig. RC
(72-76) Normal (standard)	1	$M= k_0 + k_1 L$	$M= - 91.705 + 26.491 L$	0.720	2.071	2.060	*	* *
	2	$M= k_0 + k_1 W$	$M= - 113.799 + 40.472 W$	0.841	1.568	1.551	*	* *
	3	**$M= k_0 + k_1 GMD$**	**$M= - 133.047 + 40.576GMD$**	**0.916**	**1.137**	1.131	*	* *
	4	$M= k_0 + k_1 L + k_2 W$	$M= -131.905 +12.273 L +27.958 W$	0.914	1.148	1.127	*	* * *
(>76) Round	1	$M= k_0 + k_1 L$	$M= - 33.912 + 17.346 L$	0.416	2.726	2.655	*	* *
	2	$M= k_0 + k_1 W$	$M= - 87.880 + 34.263 W$	0.711	1.916	1.787	*	* *
	3	$M= k_0 + k_1 GMD$	$M= - 134.335 + 40.784 GMD$	0.889	1.190	1.125	*	* *
	4	**$M= k_0 + k_1 L + k_2 W$**	**$M= - 134.369 +11.794 L +29.107 W$**	**0.889**	**1.187**	1.125	*	* * *
Mixed (72≤SI>76)	1	$M= k_0 + k_1 L$	$M= - 27.572 + 16.178 L$	0.435	2.760	2.749	*	* *
	2	$M= k_0 + k_1 W$	$M= - 82.968 + 33.414 W$	0.682	2.070	2.059	*	* *
	3	**$M= k_0 + k_1 GMD$**	**$M= - 132.878 + 40.529GMD$**	**0.904**	**1.140**	1.131	*	* *
	4	**$M= k_0 + k_1 L + k_2 W$**	**$M= - 132.076 +11.876 L +28.529 W$**	**0.904**	**1.140**	1.126	*	* * *

M: the mass of egg; *L*: length, *W*: width; k_i is regression coefficient. *RSE*: Regression Standard Error *Sig. M*: Significant of model; *Sig. RC*: Significant of regression coefficient.

Table 4. Coefficient of determination (R^2) and regression standard error (*RSE*) and root mean squared error (RMSE) for linear regression models based on projected areas classification for normal, round and mixed-shaped eggs.

Çizelge 4. *Normal, yuvarlak ve karışık şekilli yumurtalar için projeksiyon alan sınıflandırmasına göre lineer regresyon modelleri için belirtme katsayısı (R^2) ve regresyon standart hatası (RSE).*

Shape Index	Models No	Model	Model	R^2	*RSE*	*RMSE*	*Sig. M*	*Sig. RC*
(72-76) Normal (standard)	1	$M= k_0 +k_1 PA_1$	$M= - 30.759+4.627PA_1$	0.906	1.198	1.191	*	* *
	2	$M= k_0 +k_1 PA_2$	$M= - 22.706+5.723PA_2$	0.840	1.563	1.552	*	* *
	3	**$M= k_0 +k_1 CAE$**	**$M= - 31.724+3.404CAE$**	**0.917**	**1.126**	1.123	*	* *
	4	$M= k_0 + k_1 PA_1 + k_2 PA_2$	$M= - 31.707+ 3.444 PA_1 +1.648PA_2$	0.916	1.132	1.123	*	***
(>76) Round	1	$M= k_0 +k_1 PA_1$	$M= - 28.418+4.560PA_1$	0.841	1.422	1.353	*	* *
	2	$M= k_0 +k_1 PA_2$	$M= - 9.408+4.762PA_2$	0.714	1.907	1.787	*	* *
	3	$M= k_0 +k_1 CAE$	$M= - 32.388+3.425CAE$	0.889	1.188	1.131	*	* *
	4	**$M= k_0 + k_1 PA_1 + k_2 PA_2$**	**$M= - 32.293+ 3.245 PA_1 +1.940 PA_2$**	**0.890**	**1.185**	1.128	*	* * *
Mixed (72≤SI>76)	1	$M= k_0 +k_1 PA_1$	$M= - 25.899+4.430 PA_1$	0.856	1.391	1.126	*	**
	2	$M= k_0 +k_1 PA_2$	$M= - 6.872+4.670 PA_2$	0.683	2.069	2.061	*	* *
	3	$M= k_0 +k_1 CAE$	$M= - 31.427+3.396CAE$	0.905	1.131	1.128	*	* *
	4	**$M= k_0 + k_1 PA_1 + k_2 PA_2$**	**$M= - 31.458+ 3.300 PA_1 +1.826 PA_2$**	**0.906**	**1.131**	1.125	*	* * *

M: the mass of egg; PA_1: first projected area, PA_2: second projected area; *CAE*: criteria area; $k_i$is regression coefficient. *Sig. M*: Significant of model; *Sig. RC*: Significant of regression coefficient.

CONCLUSION

The present study comprised of an evaluation of some physical characteristics of eggs and then correlating the measured properties with mass. The dependency of the egg mass on measured physical properties was well established by regression equations. The effect of egg shape indices on the model parameters can be observed and substantiated with the presented results. The model equations for egg mass as a function of physical parameters *viz.* dimensions, projected area and volume were predicted and based on the regression analysis, the best fit models were selected. These fundamental findings of this study will be helpful for the researchers involved in the design and development of handling, transport and process equipments in the production and processing of eggs. Such application will make the overall process more precise, consistent and convenient, thus saving operation time, money and manpower.

Table 5. Coefficient of determination (R^2) and regression standard error (RSE) and root mean squared error (RMSE) for linear regression models based on volumes classification for normal, round and mixed-shaped eggs.

Çizelge 5. *Normal, yuvarlak ve karışık şekilli yumurtalar için hacim sınıflandırmasına göre lineer regresyon modelleri için belirtme katsayısı (R^2) ve regresyon standart hatası (RSE).*

Shape Index	Models No	Model	Model	R^2	*RSE*	*RMSE*	Sig. M	Sig. RC
(72-76) Normal (standard)	1	$M= k_0 +k_1 V_{osp}$	$M= 2.141+1.029V_{osp}$	0.917	1.131	1.126	*	* *
	2	$M= k_0 +k_1 V_m$	$M= 63.942+0.083V_m$	0.001	3.928	3.913	ns	ns
	3	$\mathbf{M= k_0 + k_1 V_{osp} + k_2 V_m}$	$\mathbf{M= 11.501+ 1.030 V_{osp}- 0.139V_m}$	**0.919**	**1.126**	1.113	*	* * *
(>76) Round	1	$M= k_0 +k_1 V_{osp}$	$M= 1.823+1.029V_{osp}$	0.889	1.190	1.133	*	* *
	2	$M= k_0 +k_1 V_m$	$M= 71.717-0.034V_m$	0.002	3.573	3.435	ns	ns
	3	$\mathbf{M= k_0 + k_1 V_{osp} + k_2 V_m}$	$\mathbf{M= 1.292+ 1.017V_{osp}+ 0.019V_m}$	**0.889**	**1.142**	1.132	*	* * *
Mixed (72≤SI>76)	1	$M= k_0 +k_1 V_{osp}$	$M= 2.372+1.024V_{osp}$	0.904	1.136	1.132	*	* *
	2	$M= k_0 +k_1 V_m$	$M= 74.335- 0.063V_m$	0.003	3.667	3.655	ns	ns
	3	$\mathbf{M= k_0 + k_1 V_{osp} + k_2 V_m}$	$\mathbf{M= 3.516+ 1.023V_{osp}- 0.015V_m}$	**0.904**	**1.136**	1.129	*	* * *

M: the mass of egg; V_{osp}: oblate spheroid volume; V_m: measured volume; k_i is regression coefficient. *Sig. M*: Significant of model; *Sig. RC*: Significant of regression coefficient; ns: not significant

Table 6. Recommended model equations for mass prediction of eggs based on SI.

Çizelge 6. *SI'ye göre yumurtaların kütle tahmini için önerilen model denklemleri*

Model/SI	Dimension	Projected area	Volume
Normal SI	$M=- 133.047 + 40.576GMD$	$M= -31.724+3.404\ CAE$	$M= 11.501+1.030V_{osp} - 0.139V_m$
Round SI	$M=-134.369+11.794L +29.107W$	$M= - 32.293+ 3.245\ PA_1 +1.940\ PA_2$	$M= 1.292+ 1.017V_{osp} + 0.019V_m$
Mixed SI	$M= - 132.878 + 40.529GMD$ and $M= 132.076 +11.876L +28.529W$	$M= - 31.458 + 3.300\ PA_1 +1.826\ PA_2$	$M= 3.516+1.023\ V_{osp}-0.015V_m$

Author Contributions

Authors declares the contribution of the authors is equal.

Conflict of Interest

The authors declare no conflict of interest.

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