

## Modeling of Egg Mass Based on Geometrical Attributes

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**Abstract:** Eggs are often graded on the basis of size, but it may be more suitable and economical to develop a system which grades by mass. Thus, a relationship between egg mass and some geometrical attributes of egg is needed. In this study, nine linear regression models for predicting egg mass from some geometrical attributes of egg such as length (L), diameter (D), geometrical mean diameter (GMD), first projected area (PA<sub>1</sub>), second projected area (PA<sub>2</sub>), criteria area (CAE) and estimated volume or volume calculated from an oblate spheroid assumed shape (V<sub>OSP</sub>) were suggested. Models were divided into three main classifications and the egg mass was estimated as a function of some independent variables. The statistical results of the study indicated that in order to predict egg mass based on outer dimensions, the mass model based on geometrical mean diameter as  $M = -24.42 + 1.67 \text{ GMD}$  with  $R^2 = 0.595$  and the mass model based on length and diameter as  $M = -27.81 + 0.69 L + 1.01 D$  with  $R^2 = 0.619$  can be recommended. Also, to predict egg mass based on projected areas, the mass model based on the first projected area as  $M = 13.12 + 2.16 \text{ PA}_1$  with  $R^2 = 0.599$  can be suggested. These models can be used to design and develop sizing machines equipped with an image processing system.

**Key words:** Egg mass • Modeling • Sorting • Grading • Geometrical attributes

### INTRODUCTION

Egg is considered as one of the basic foodstuffs due to its very high nutritive value. Besides a rich source of protein, it contains a fair amount of nutrients (Sodium, Potassium, Calcium, Phosphorus, Magnesium, Iron, Zinc, Copper, Iodine, Sulfur and Selenium) and vitamins (A, B<sub>1</sub>, B<sub>2</sub>, B<sub>3</sub>, B<sub>6</sub>, B<sub>12</sub>, D and E). Egg contains 87-90% edible portion, 65-70% moisture, 11.0-12.5% protein and 9.5-10.8% oil [1-3].

Egg size is one of the most important quality parameters for evaluation by consumer preference. Consumers prefer eggs of equal size and shape [3]. Sorting can increase uniformity in size and shape, reduce packaging and transportation costs and also may provide an optimum packaging configuration [4-7]. Moreover, sorting is important in meeting quality standards, increasing market value and marketing operations [8-10]. Sorting manually is associated with high labour costs in addition to subjectivity, tediousness and inconsistency which lower the quality of sorting [11].

However, replacing human with a machine may still be questionable where the labour cost is comparable with the sorting equipment [12]. Studies on sorting in recent years have focused on automated sorting strategies (eliminating human efforts) to provide more efficient and accurate sorting systems which improve the classification success or speed up the classification process [13, 14].

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 [15]. Therefore, modeling of egg mass based on some geometrical attributes may be useful and applicable. Physical characteristics of products are the most important parameters in design of sorting systems. Among these physical characteristics, mass, projected area and center of the gravity are the most important ones in sizing systems [16]. Other important parameters are outer dimensions [17-19].

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Therefore, the main objectives of this study were: (a) to determine optimum mass model (s) based on some geometrical attributes of egg and (b) to verify determined mass model (s) by comparing their results with those of the measuring method.

## MATERIALS AND METHODS

**Experimental Procedure:** Ninety randomly selected eggs of various sizes were purchased from a local market. Eggs 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 egg was measured to 0.1 g accuracy on a digital balance (Fig. 1). Moreover, the volume of each egg was measured using the water displacement method (Fig. 2). Each egg was submerged into water and the volume of water displaced was measured. Water temperature during measurements was kept at  $25^\circ\text{C}$ . The density of each egg was then calculated from the mass divided by the measured volume. By assuming the shape of eggs as an oblate spheroid (Fig. 3), the outer dimensions of each egg, i.e. length (L) and diameter (D) was measured to 0.1 mm accuracy by a caliper (Fig. 4). The geometric mean diameter (GMD) of each egg was then calculated by equation 1.

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

Two projected areas of each egg, i.e. first projected area ( $\text{PA}_1$ ) and second projected area ( $\text{PA}_2$ ) was also calculated by using equations 2 and 3, respectively. The average projected area known as criteria area (CAE) of each egg was then determined from equation 4.

$$\text{PA}_1 = \pi \text{LD}/4 \quad (2)$$

$$\text{PA}_2 = \pi \text{D}^2/4 \quad (3)$$

$$\text{CAE} = (2\text{PA}_1 + \text{PA}_2)/3 \quad (4)$$

In addition, the volume of assumed shape or estimated volume of each egg ( $V_{\text{OSP}}$ ) was calculated by using equation 5. Table 1 shows some physical and geometrical properties of the eggs used to determine mass models.

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



Fig. 1: Measuring of egg mass using a digital balance



Fig. 2: Measuring of egg volume using the water displacement method

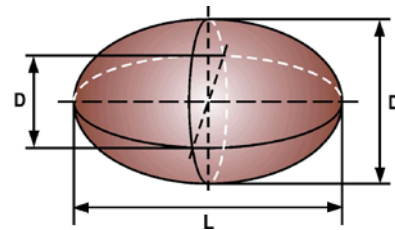


Fig. 3: The outer dimensions of an egg, i.e. length (L) and diameter (D) by assuming the shape of egg as an oblate spheroid

Also, in order to verify mass models, physical and geometrical properties of ten randomly selected eggs of various sizes were determined as above-mentioned methods. Table 2 shows some physical and geometrical properties of the eggs used to verify mass models.

Table 1: The mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of some physical and geometrical properties of the 90 randomly selected eggs used to determine mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	42.05	58.33	50.73	2.78	5.49
Length (L), mm	50.15	58.85	53.98	1.94	3.59
Diameter (D), mm	38.45	52.30	40.99	1.47	3.59
Geometrical mean diameter (GMD), mm	42.74	54.31	44.92	1.28	2.86
First projected area (PA <sub>1</sub> ), cm <sup>2</sup>	15.91	24.05	17.38	0.99	5.73
Second projected area (PA <sub>2</sub> ), cm <sup>2</sup>	11.61	21.48	13.21	1.03	7.82
Criteria area (CAE), cm <sup>2</sup>	14.50	23.19	15.99	0.96	6.00
Estimated volume (V <sub>OSP</sub> ), cm <sup>3</sup>	40.87	83.85	47.57	4.62	9.71
Measured volume (V <sub>M</sub> ), cm <sup>3</sup>	37.02	49.74	44.22	2.64	5.97
Density (ρ), g cm <sup>-3</sup>	1.060	1.246	1.148	0.036	3.15

Table 2: The mean values, Standard Deviation (S.D.) and Coefficient of Variation (C.V.) of some physical and geometrical properties of the ten randomly selected eggs used to verify mass models

Parameter	Minimum	Maximum	Mean	S.D.	C.V. (%)
Mass (M), g	48.26	56.57	52.66	2.63	4.99
Length (L), mm	42.80	55.50	52.94	3.69	6.96
Diameter (D), mm	39.85	42.60	41.70	0.93	2.23
Geometrical mean diameter (GMD), mm	41.90	46.53	45.13	1.40	3.10
First projected area (PA <sub>1</sub> ), cm <sup>2</sup>	13.93	18.57	17.34	1.33	7.69
Second projected area (PA <sub>2</sub> ), cm <sup>2</sup>	12.47	14.25	13.66	0.60	4.42
Criteria area (CAE), cm <sup>2</sup>	13.79	17.13	16.11	1.00	6.20
Estimated volume (V <sub>OSP</sub> ), cm <sup>3</sup>	38.50	52.73	48.24	4.30	8.92
Measured volume (V <sub>M</sub> ), cm <sup>3</sup>	40.27	52.14	46.03	3.25	7.07
Density (ρ), g cm <sup>-3</sup>	1.085	1.210	1.146	0.05	0.04



Fig. 4: Measuring the outer dimensions of each egg by a caliper

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

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

where:

Y = Dependent variable, for example mass of egg

X<sub>1</sub>, X<sub>2</sub>, ..., X<sub>n</sub> = Independent variables, for example geometrical attributes of egg

k<sub>0</sub>, k<sub>1</sub>, k<sub>2</sub>, ..., k<sub>n</sub> = Regression coefficients

Table 3: Nine linear regression mass models in three classifications

Model classification	Model No.	Model
First	1	M = k <sub>0</sub> + k <sub>1</sub> L
	2	M = k <sub>0</sub> + k <sub>1</sub> D
	3	M = k <sub>0</sub> + k <sub>1</sub> GMD
	4	M = k <sub>0</sub> + k <sub>1</sub> L + k <sub>2</sub> D
Second	5	M = k <sub>0</sub> + k <sub>1</sub> PA <sub>1</sub>
	6	M = k <sub>0</sub> + k <sub>1</sub> PA <sub>2</sub>
	7	M = k <sub>0</sub> + k <sub>1</sub> CAE
	8	M = k <sub>0</sub> + k <sub>1</sub> PA <sub>1</sub> + k <sub>2</sub> PA <sub>2</sub>
Third	9	M = k <sub>0</sub> + k <sub>1</sub> V <sub>OSP</sub>

In order to estimate egg mass from geometrical attributes, nine linear regression mass models were suggested. Models were divided into three main classifications (Table 3).

**Statistical Analysis:** A paired samples t-test was used to compare the egg mass values predicted using models with the egg mass values measured by digital balance. Also, to check the discrepancies between the egg mass values measured by digital balance with the egg mass values predicted by mass models, root mean squared error (RMSE) and mean relative percentage deviation (MRPD) were calculated equations 7 and 8, respectively [20-25]:

$$RMSE = \sqrt{\frac{\sum_{i=1}^n (M_i - M_i^*)^2}{n}} \quad (7)$$

where:

- RMSE = Root mean squared error, g
- $M_i$  = Egg mass measured by digital balance, g
- $M_i^*$  = Egg mass predicted by mass model, g
- $n$  = Number of samples

$$MRPD = \frac{100 \times \sum_{i=1}^n \left| \frac{M_i - M_i^*}{M_i} \right|}{n} \quad (8)$$

where:

MRPD = Mean relative percentage deviation, %

### RESULTS

For mathematical describing mass models, all the data were subjected to linear regression analysis using the Microsoft Excel. The p-value of the independent variables and Coefficient of Determination ( $R^2$ ) of all the linear regression mass models are shown in Table 4.

**First Classification:** In this classification egg mass can be predicted using single variable linear regressions of length (L), diameter (D) and geometrical mean diameter (GMD) of egg or multiple variable linear regression of length and diameter of egg. As indicated in Table 4, among the first classification models (models No. 1-4), model No. 1 and model No. 2 had the lowest  $R^2$  value (0.344 and 0.400, respectively). However, model No. 3 and model No. 4 had the highest  $R^2$  value (0.595 and 0.619, respectively). Model No. 3 and model No. 4 are given in equations 9 and 10, respectively.

$$M = -24.42 + 1.67 \text{ GMD} \quad (9)$$

$$M = -27.81 + 0.69 \text{ L} + 1.01 \text{ D} \quad (10)$$

**Second Classification:** In this classification egg 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 egg or multiple variable linear regression of first and second projected areas of egg. As indicated in Table 4, among the second classification models (models No. 5-8), model No. 6 and model No. 7 had the lowest  $R^2$  value (0.367 and 0.657, respectively). Conversely, model No. 5 and model No. 8 had the highest  $R^2$  value (0.599 and 0.599, respectively). Model No. 5 and model No. 8 are given in equations 11 and 12, respectively.

$$M = 13.12 + 2.16 \text{ PA}_1 \quad (11)$$

$$M = 13.04 + 2.21 \text{ PA}_1 - 0.06 \text{ PA}_2 \quad (12)$$

**Third Classification:** In this classification egg mass can be predicted using single variable linear regression of estimated volume calculated from an oblate spheroid assumed shape ( $V_{OSP}$ ) of egg. As indicated in Table 4, the  $R^2$  value of model No. 9 was 0.517. Model No. 9 is given in equation 13.

$$M = 30.12 + 0.43 \text{ V}_{OSP} \quad (13)$$

### DISCUSSION

Among the linear regression models (models No. 1-9), models No. 3, 4 and 5 were chosen due to higher  $R^2$  value and simplicity and a paired samples t-test was used to compare the egg mass values predicted using models No. 3, 4 and 5 with the egg mass values measured by digital balance. Also, to check the discrepancies between the egg mass values predicted by models with the egg mass values measured by digital balance, RMSE and MRPD were calculated.

Table 4: Linear regression mass models, p-value of model variable(s), Coefficient of Determination ( $R^2$ ) and Coefficient of Variation (C.V.)

Model No.	P-value							$R^2$
	L	D	GMD	$PA_1$	$PA_2$	CAE	$V_{OSP}$	
1	1.28E-09	-	-	-	-	-	-	0.344
2	-	2.27E-11	-	-	-	-	-	0.400
3	-	-	5.75E-19	-	-	-	-	0.595
4	3.68E-10	6.88E-12	-	-	-	-	-	0.619
5	-	-	-	3.48E-19	-	-	-	0.599
6	-	-	-	-	2.50E-10	-	-	0.367
7	-	-	-	-	-	1.18E-17	-	0.567
8	-	-	-	2.99E-10	0.838043	-	-	0.599
9	-	-	-	-	-	-	1.45E-15	0.517

Table 5: Geometrical attributes of the ten eggs used in evaluating selected mass models

Sample No.	Geometrical attributes of egg				Egg mass (g)			
	L (mm)	D (mm)	GMD (mm)	PA <sub>1</sub> (cm <sup>2</sup> )	Measured by digital balance	Predicted by model No. 3	Predicted by model No. 4	Predicted by model No. 5
1	52.7	39.9	43.7	16.5	48.3	48.7	48.7	48.8
2	54.0	40.5	44.6	17.2	50.3	50.2	50.2	50.3
3	52.8	41.5	44.9	17.2	50.3	50.8	50.4	50.3
4	54.3	41.3	45.2	17.6	51.6	51.2	51.2	51.2
5	53.2	42.5	45.8	17.7	52.5	52.1	51.7	51.5
6	53.1	42.2	45.6	17.6	52.8	51.8	51.4	51.2
7	54.7	42.1	45.9	18.1	53.6	52.4	52.3	52.3
8	53.7	42.6	46.0	18.0	54.8	52.6	52.2	52.0
9	55.4	42.0	46.1	18.3	55.8	52.6	52.7	52.7
10	55.5	42.6	46.5	18.6	56.6	53.4	53.4	53.3

Table 6: Paired samples t-test analyses on comparing egg mass determination methods

Determination methods	Average difference (g)	Standard deviation of difference (g)	p-value	95% confidence intervals for the difference in means (g)
Measuring vs. model No. 3	-1.08	1.37	0.983	-2.06, -0.10
Measuring vs. model No. 4	-1.24	1.33	0.992	-2.19, -0.29
Measuring vs. model No. 5	-1.30	1.38	0.992	-2.29, -0.31

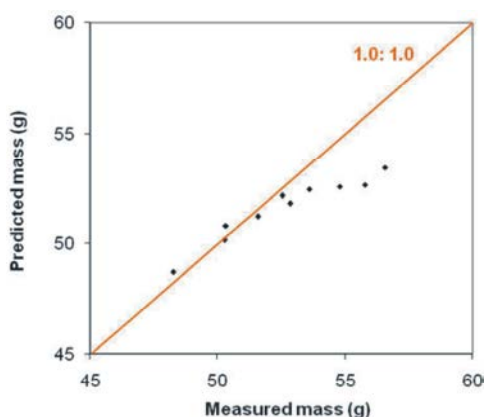


Fig. 5: Egg mass values measured using a digital balance (measured mass) and egg mass values predicted using model No. 3 (predicted mass) with the line of equality (1.0: 1.0)

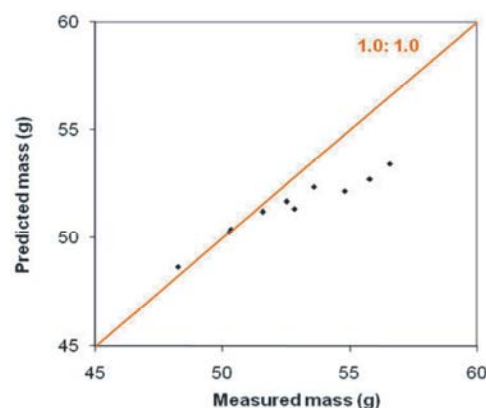


Fig. 6: Egg mass values measured using a digital balance (measured mass) and egg mass values predicted using model No. 4 (predicted mass) with the line of equality (1.0: 1.0)

**Model No. 3:** The egg mass values predicted by model No. 3 were compared with the egg mass values measured by digital balance and are shown in Table 5. A plot of the egg mass values predicted by model No. 3 and measured by digital balance with the line of equality (1.0: 1.0) is shown in Fig. 5. The paired samples t-test results indicated that the egg mass values predicted with model No. 3 were significantly less than the egg mass values measured by digital balance (Table 6). The mean egg mass difference between two methods was -1.08 g (95% confidence interval: -2.06 and -0.10 g; P = 0.983). RMSE and MRPD were also used to check the

discrepancies between the two methods. The amounts of RMSE and MRPD were 1.7 g and 2.3%, respectively. Thus, egg mass predicted by model No. 3 may be 1.7 g or 2.3% less than egg mass measured by a digital balance.

**Model No. 4:** The egg mass values predicted by model No. 4 were compared with the egg mass values measured by digital balance and are shown in Table 5. A plot of the egg mass values predicted by model No. 4 and measured by digital balance with the line of equality (1.0: 1.0) is shown in Fig. 6. The paired samples t-test results indicated that the egg mass values predicted with model

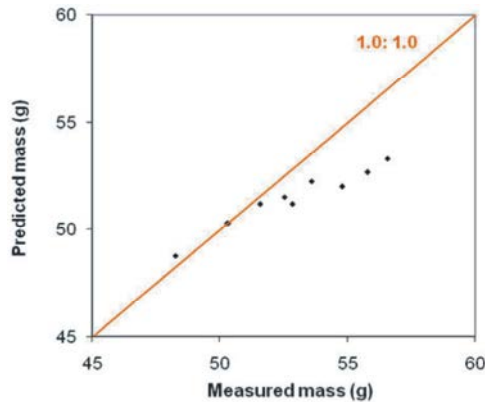


Fig. 7: Egg mass values measured using a digital balance (measured mass) and egg mass values predicted using model No. 5 (predicted mass) with the line of equality (1.0: 1.0)

No. 4 were significantly less than the egg mass values measured by digital balance (Table 6). The mean egg mass difference between two methods was -1.24 g (95% confidence interval: -2.19 and -0.29 g;  $P = 0.992$ ). Again, RMSE and MRPD were used to check the discrepancies between the two methods. The amounts of RMSE and MRPD were 1.8 g and 2.4%, respectively. Therefore, egg mass predicted by model No. 4 may be 1.8 g or 2.4% less than egg mass measured by a digital balance.

**Model No. 5:** The egg mass values predicted by model No. 5 were compared with the egg mass values measured by digital balance and are shown in Table 5. A plot of the egg mass values predicted by model No. 5 and measured by digital balance with the line of equality (1.0: 1.0) is shown in Fig. 7. The paired samples t-test results indicated that the egg mass values predicted with model No. 5 were significantly less than the egg mass values measured by digital balance (Table 6). The mean egg mass difference between two methods was -1.30 g (95% confidence interval: -2.29 and -0.31 g;  $P = 0.992$ ). Once more, RMSE and MRPD were used to check the discrepancies between the two methods. The amounts of RMSE and MRPD were 1.9 g and 2.6%, respectively. As a result, egg mass predicted by model No. 5 may be 1.9 g or 2.6% less than egg mass measured by a digital balance.

### CONCLUSION

It can be concluded that in order to predict egg mass based on some geometrical attributes, the mass model based on geometrical mean diameter as  $M = -24.42$

+ 1.67 GMD with  $R^2 = 0.595$  and the mass model based on length and diameter as  $M = -27.81 + 0.69 L + 1.01 D$  with  $R^2 = 0.619$  can be recommended. Also, to predict egg mass based on projected areas, the mass model based on the first projected area as  $M = 13.12 + 2.16 PA_1$  with  $R^2 = 0.599$  can be suggested. These models can be used to design and develop sizing machines equipped with an image processing system.

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