Goose eggshell geometry

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Abstract

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The paper presents a new approach of the eggshell geometry determination using and analysing the egg digital image and edge detection techniques. The detected points on the eggshell contour were fitted by the Fourier series. The obtained equations describing an egg profile were used to calculate the egg volume, surface area, and radius of curvature with much higher degree of precision in comparison with previously published approaches. The paper shows and quantifies the limitations of the common and frequent procedures.

Keywords: image analysis; goose's egg; eggshell profile; radius of curvature; egg volume; egg surface area

Description of chicken egg shape is important for numerous applications and studies. Generally, when talking about avian eggs (both domestic and wild species), the knowledge of their geometric parameters is relevant to a number of studies, such as population and ecological morphology (Mänd 1998), predicting chick weight (Narushin et al. 2002), egg hatchability (Narushin, Romanov 2002a,b), eggshell quality (Altuntaş, Şekeroğlu 2008; Nedomová et al. 2009), egg interior parameters, avian biology, taxonomy, classification, reproduction, poultry selection, genetics, and processing. The knowledge of the egg's shape is also necessary for the numerical simulation of the egg behaviour under mechanical loading (Perianu et al. 2010), at numerical analysis of different thermal treatments (Sabliov et al. 2002; Denys et al. 2003; Kumar et al. 2012), for the numerical simulation of diffusion processes (Fabbri et al. 2011), and for the solution of many other problems.

There is a natural variability in egg shape. High variability of egg shapes creates difficulties in their description. Egg shape evaluation can be performed by two ways: (a) by mathematical equations, and (b) by different indices, which show the deviation of a true shape from some model object. Mathematical description of an egg profile allows calculating the egg volume, surface area, long circumference length, normal projected area of the egg, radius of curvature and angle between the long axis and the tangent to the shell at any point.

Characterization of egg's shape by use of two indices: (a) egg length to a max. width ratio (shape index) and (b) the ratio of long and short sections of the longitudinal axis of the egg after division by the axis of max. diameter, was proposed by Schonwetter (1960). The most popular is the shape index:

$$SI = \frac{B}{L} \times 100 \quad (\%)$$

where:
B – width of eggs
L – length of the eggs

Eggs are characterized by the SI as sharp, normal (standard) and round if they have an SI value of < 72, between 72 and 76, and > 76, respectively (Sarica, Erensayin 2004).

The knowledge of the egg dimension enables to evaluate the geometric mean diameter (D_g), sphericity (Φ), volume (V), surface area (S) of eggs using the following equations (Mohsenin 1970; Baryeh, Mangope 2003):

$$D_g = \left(LB^2\right)^{\frac{1}{3}} \quad (1)$$

$$\Phi = \frac{D_g}{L} \times 100 \quad (\%) \quad (2)$$

$$S = \pi D_g^2 \quad (3)$$

$$V = \frac{\pi}{6} LB^2 \quad (4)$$

Narushin (2005) gave also a more accurate and available formula for V and S:

$$V = (0.6057 - 0.0018B)LB^2 \quad (5)$$

$$S = (3.155 - 0.013L + 0.0115B)LB \quad (6)$$

The dimensions of the eggs have been also used for the derivation of the mathematical form of the egg shape. The main results were achieved by Narushin (2001b) and Narushin and Romanov (2002a,b) who proposed the mathematical equation for the profile of any avian egg:

$$y = \pm\sqrt{L^{\frac{2}{n+1}} \times x^{\frac{2n}{n+1}} - x^2} \qquad n = 1.057\left(\frac{L}{B}\right)^{2.372} \quad (7)$$

where:

x – coordinate along the longitudinal axis

y – the transverse distance to the profile

Even if there are many other functions describing the eggshell shape (Kitching 1997; Sabliov et al. 2002).

However, there are still at least two main problems: firstly, the supposed curve in the reported model (Eq. 7) will not always best resemble all eggs' shapes; secondly, if the measurements of L and B with a vernier calliper cannot be fast and automatic, it will not be acceptable in poultry industry. The second of these problems is solved by Zhou et al. (2009). In the given paper the main attention is focused on the evaluation of egg volume and surface using the exact description of the egg profile. In order to achieve this exact description of the egg shape a new application is used. This method uses a graphical user interface, which allowed the user to accurately determine the necessary dimensional properties of eggs from digital photographs of the eggs.

The objective of this paper consists in the comparison of the results following from Eq. (7) with exact description of the eggshell contours obtained from digital photographs of the eggs. The main attention is focused on the evaluation of the radii of the curvatures of the curve describing eggshell profile. Even if the knowledge of these parameters is necessary to interpret forces at the contact between egg and another body at both static and dynamic loading (Chung Wei-Li et al. 2011), nearly no attention has been focused on this problem. The attention was also paid to the prediction of the exact values of the eggshell volume and surface using the Eqs (3)–(6).

MATERIAL AND METHODS

226 eggs from Landes geese were chosen for the experiment. Geese were kept in free range technology at a commercial breeding farm in Hodonín in the Czech Republic. Eggs were collected from 3-year-old geese. In order to describe the shape of egg samples the linear dimensions, i.e. length (L) and width (B), were measured with a digital calliper to the nearest 0.01 mm. These quantities were used for the evaluation of the shape index SI. The corresponding geometrical characteristics are given in Table 1.

In the second step the digital photos of the eggs were performed. The image analysis performed using the Matlab software (ver. 7.12.0.635-R; MathWorks, Inc., Natick, USA) was used for the evaluation of the coordinates x_i and y_i of the egg contour. Instead of Cartesian coordinates the shape of the eggshell contour can be described using the polar coordinates r and j:

$$x = r\cos j \qquad y = r\sin j$$

The experimental points r_i, j_i were fitted by the Fourier series:

$$r = a_0 + \sum_{i=1}^{i=\infty}\left[a_i \cos(iw\varphi) + b_i \sin(iw\varphi)\right] \quad (8)$$

where

a_0, a_i, b_i, w – coefficients which were determined using of the Matlab software

The agreement with experimental curve determined by digital photo is described using an error function which is defined as:

Table 1. Main geometric characteristics and mass of the tested eggs

Parameter	Minimum	Average	Maximum	STD
L (mm)	70.77	89.57	100.29	3.94
B (mm)	50.97	58.16	95.32	3.12
D_g (mm)	60.56	67.14	92.73	2.65
SI (%)	55.75	65.03	108.63	4.13
F	0.6774	0.7503	1.0567	0.0305
S (mm^2) Eq. (3)	11,521.44	14,117.21	16,749.26	854.50
V (mm^3) Eq. (4)	116,287.77	159,206.95	417,458.99	22,307.90
S (mm^2) Eq. (5)	11,414.77	13,798.07	16,129.59	755.36
V (mm^3) Eq. (6)	112,126.90	151,182.35	191,232.00	12,691.46
m (g)	126.15	163.69	215.35	14.44

L – egg length; B – egg width; SI – shape index; D_g – equivalent diameter; Φ – sphericity, S – eggshell surface; V – egg volume; STD – standard deviation

$$\text{Error} = \left(\frac{Y_{\text{measured}} - Y_{\text{fitted}}}{Y_{\text{measured}}}\right) \times 100 \quad (\%) \tag{9}$$

where:

Y_{measured} – y coordinate determined from the digital photo

Y_{fitted} – y coordinate obtained from the Fourier series

The values of the radius of the curvature (R), egg surface (S) and the egg volume (V) are given by the equations of the differential geometry:

$$R = \frac{\left[\left(\frac{dx}{d\varphi}\right)^2 + \left(\frac{dy}{d\varphi}\right)^2\right]^{\frac{3}{2}}}{\left|\frac{dx}{d\varphi}\frac{d^2y}{d\varphi^2} - \frac{dy}{d\varphi}\frac{d^2x}{d\varphi^2}\right|} \tag{10}$$

$$V = \pi \int_{\phi_1}^{\phi_2} r^2(\varphi)\sin^2\varphi \frac{dx(\varphi)}{d\varphi} d\varphi$$
$$S = 2\pi \int_0^{\pi} r \sin\varphi \sqrt{\left(\frac{dx}{d\varphi}\right)^2 + \left(\frac{dy}{d\varphi}\right)^2} d\varphi \tag{11}$$

The next parameters which can be obtained are namely the area A of the egg normal projection and the long circumference length (l). These parameters are given by:

$$A = \frac{1}{2}\int r^2 d\varphi \qquad l = \int ds = \int r\, d\varphi \tag{12}$$

These parameters are given in Table 2.

RESULTS AND DISCUSSION

The analysis of our data led to the conclusion that the first eight coefficients of the Fourier series are quite sufficient for the egg's contour shape description (the correlation coefficient between measured and computed egg's profiles lies between 0.98 and 1). Owing to some reasonable extent of this paper the values of these coefficients are not presented in this paper. They can be obtained upon request. In Fig. 1 an example of the egg's contour curve is shown.

This function is limited to very low values as can be seen in Fig. 2.

Table 2. Parameters given by the Eqs (11) and (12)

	S (mm^2)	V (mm^3)	A (mm^2)	l (mm)
Minimum	11,316.39	114,177.8	3,086.799	196.1663
Average	13,717.89	155,487.5	4,044.794	222.5091
Maximum	16,146.08	197,773.8	4,735.822	241.1127
STD	826.6536	13,969.77	254.173	6.9252

S – eggshell surface; V – egg volume; A – area of the egg normal projection; l – long cimcumference lenght; STD – standard deviation

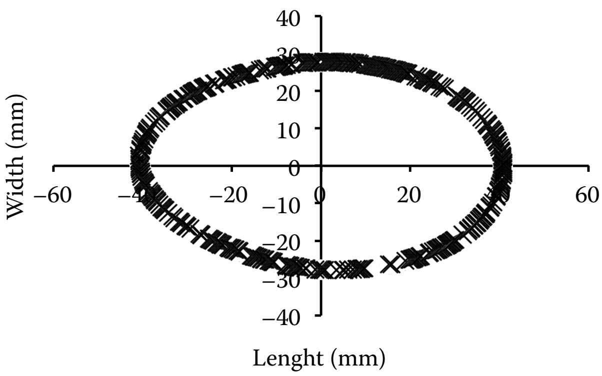


Fig. 1. Egg's contour

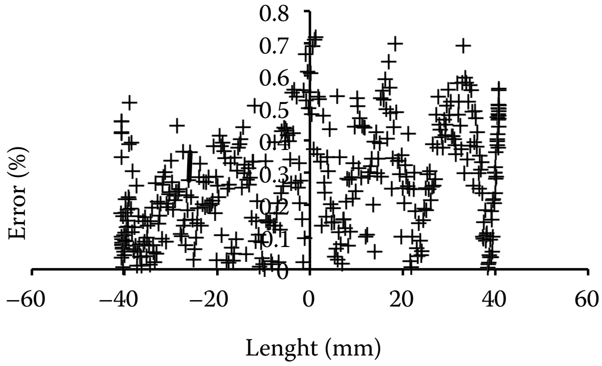


Fig. 2. Difference in the y coordinates of the egg's contours

In Fig. 3 the egg's profile given by the Eq. (2) in Table 1 (Narushin approximation) is compared with that obtained from the digital photo. One can see that the difference is more pronounced than that shown in Fig. 1. The largest difference is observed near the sharp end. The knowledge of the mathematical description of the curve describing the egg's contour enables to evaluate the radius of the curvature (Eq. 10). An example of this radius is given in the Fig. 4. The values of this radius were evaluated at the sharp and blunt ends of the egg. At the same time this radius was also evaluated at the point, x_m, where the egg width reaches the value $B = 2y(x_m)$. These radii of the curvature are displayed in Fig. 5. A more detailed statistical analysis of the obtained results showed the independency of these curvature radii of the egg shape index SI. Values of the egg curvature radii are given in Table 3.

In the next step the prediction of the egg surface and volume from some available data is possible. The easily achievable data are the egg length L and egg width B. These quantities are used for the egg shape index SI. In Fig. 6 there are plotted values of the egg volume and surface vs. shape index. The statistical analysis of the data shows that there is no significant dependence of both the quantities on the egg shape.

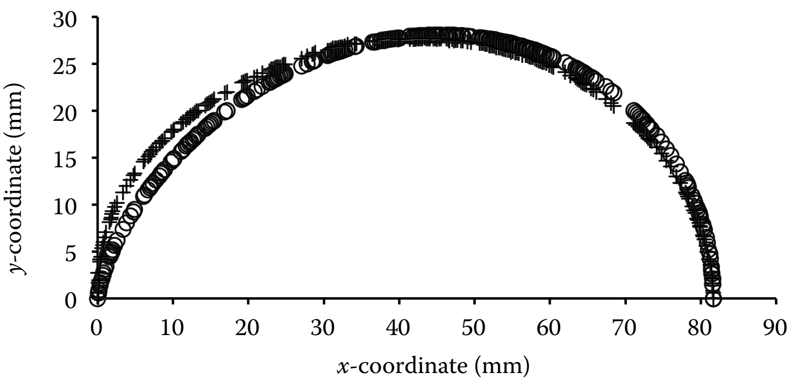


Fig. 3. The egg's contours computed from Eq. (2) and determined by the experimental data fitting

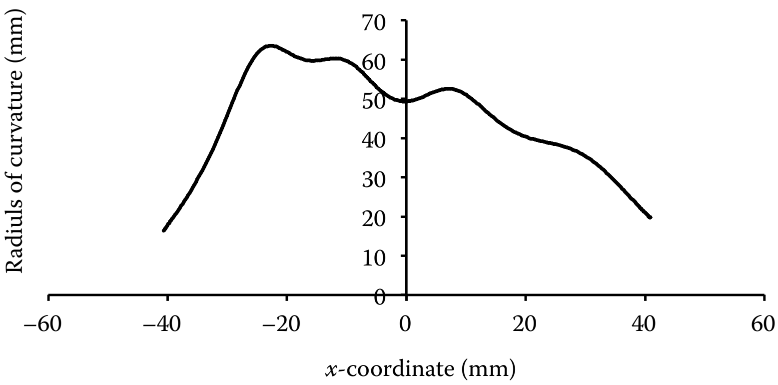


Fig. 4. Radius of the curvature along the egg's symmetry axis

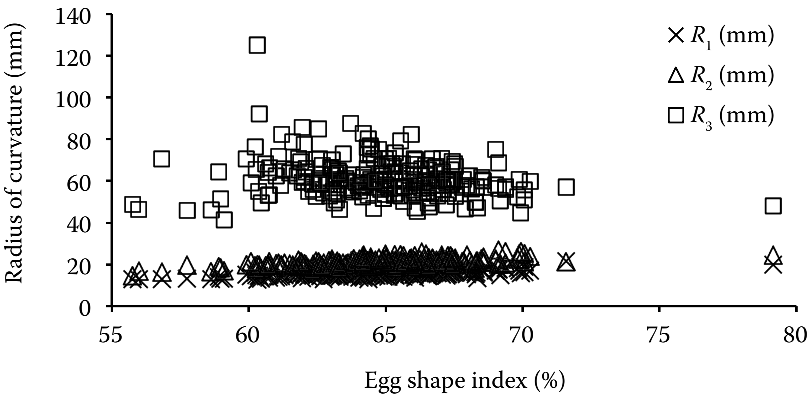


Fig. 5. Radii of the curvature for eggs of different shape
R_1–R_3 – for explanation see Table 3

Table 3. Radii of the curvature

	Minimum	Average	Maximum	STD
R_1 (mm)	12.57	15.71	21.68	1.387
R_2 (mm)	14.64	21.10	26.84	1.844
R_3 (mm)	41.15	61.25	125.20	9.624
x_m (mm)	37.89	48.06	58.71	2.746

R_1 – radius at the sharp end; R_2 – radius at the blunt end; R_3 – radius of curvature in the equator plane, x_m – x coordinate where the egg width reaches the value $B = 2y(x_m)$; STD – standard deviation

At the same time there is a good correlation between egg surfaces evaluated using Eq. (11) and egg surface S1 given by the Eq. (6) (Fig. 7a).

Owing to linear dependence of the egg volume on the egg surface (Fig. 7b) the knowledge of main egg dimensions L and B is sufficient also for the prediction of this quantity.

The volume of the egg can also be determined by water displacement method using a sinker. The next egg characteristics which can be easily determined is

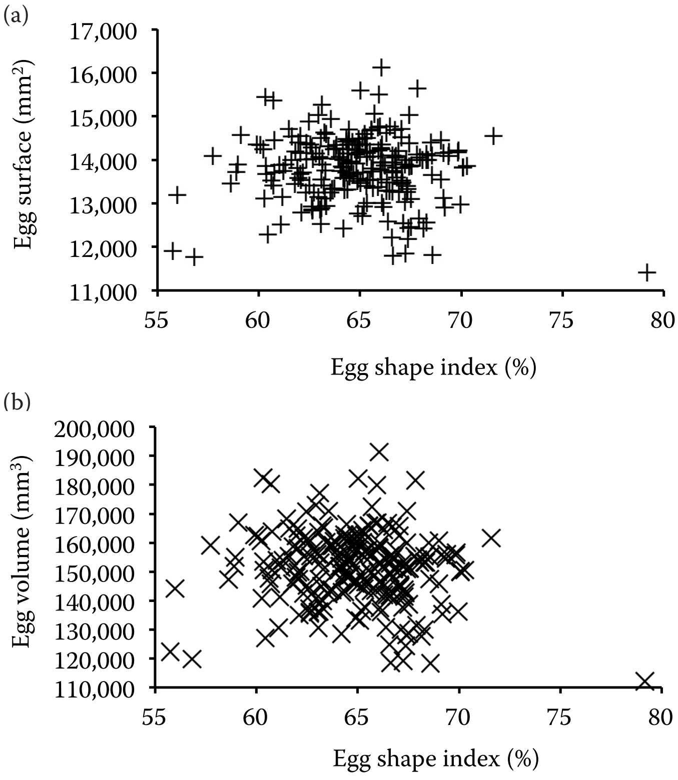
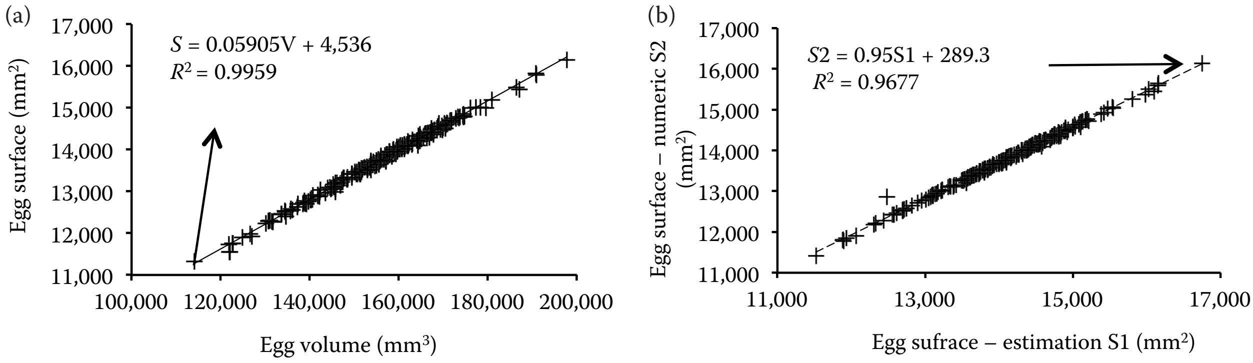


Fig. 6. Egg (a) surface and (b) volume as function of the egg shape



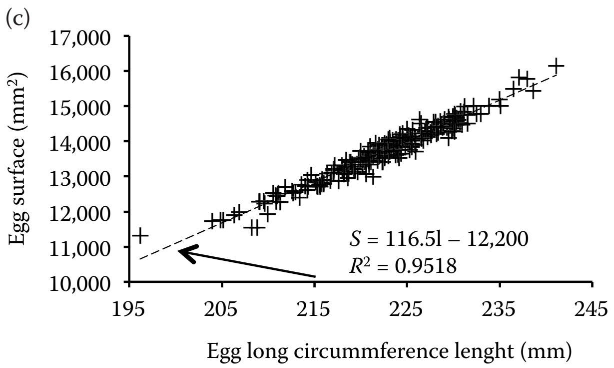


Fig. 7. The correlation between (a) values of egg surface area (Eqs 11 and 6), (b) the egg surface area vs. the egg volume (Eq. 11) and (c) egg surface vs. long circumference lenght

the egg mass *m* and the long circumference length, (Eq. 12). The dependence of the egg surface on the length (l) is shown in Fig. 7c. One can see that the correlation between egg mass and egg surface is relatively weak. The long circumference length can be used for very good estimation of the egg surface.

CONCLUSION

The analysis of the egg profile based on edge detection techniques was performed in this paper. The method described gives a representation of egg profile and such parameters as egg volume, surface, area, radius of curvature at any point on the egg surface.

The radii of the curvature at the important point of the egg profile (sharp end, blunt end and max. thickness) are independent of the egg shape index.

The exact values of the egg surface and the egg volume were obtained. These quantities are also independent of the egg shape index. These quantities can be successively estimated on the basis of Eqs (3)–(6) which are expressed in terms of the egg length and its width.

The surface area of the eggshells also exhibits good correlation with the egg long circumference length.

Generally, the eggshell surfaces can be estimated using the experimentally found values of the egg volume (e.g. by the liquid displacement method) and/or long circumference length.

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