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Egg Volume Determination by Spheroid Approximation and Image Processing

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Abstract: Egg volume was determined using water displacement, spheroid approximation and image processing methods. The length and diameter of each egg was used in the Spheroid Approximation Method (SAM). Surface image of each egg, captured with a digital camera, was utilized in the Image Processing Method (IPM). The volumes determined from spheroid approximation and image processing methods was compared to the volumes measured by Water Displacement Method (WDM) using the paired samples t-test and the Bland-Altman approach. The volumes determined by SAM was not significantly ($P>0.05$) different from the volumes measured by WDM. There was a mean difference of -0.60 cm^3 (95% confidence interval: -1.47 and 0.27 cm^3; $P = 0.159$) between SAM and WDM. The standard deviation of the volume differences between SAM and WDM was 1.57 cm^3. Also, the volumes determined by IPM was not significantly ($P > 0.05$) different from the volumes measured by WDM. The mean difference between IPM and WDM was -0.37 cm^3 (95% confidence interval: -1.52 and 0.77 cm^3; $P = 0.498$). The standard deviation of the volume differences between IPM and WDM was 2.07 cm^3. The Bland-Altman approach also indicated that for all sized eggs, spheroid approximation and image processing methods satisfactorily determined egg volume. The average percentage differences for volume estimation with ellipsoid approximation and image processing were 2.30% and 2.60%, respectively. Therefore, both of the methods provide an accurate, simple and rapid methodology to estimate egg volume and can be easily used in estimating the weight of individual eggs and sorting of them.

Key words: Volume · spheroid approximation · image processing · egg

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, Chlorine, Sulfur and Selenium) and vitamins (A, B_1, B_2, B_3, B_6, B_{12}, D and E). Egg contains 87-90% edible portion, 65-70% moisture, 11.0-12.5% protein and 9.5-10.8% oil [1, 2].

Egg size is one of the most important quality parameters for evaluation by consumer preference. Consumers prefer eggs of equal weight and size. The estimation of mean egg size is important in meeting quality standards, increasing market value and sorting of eggs. Size estimation is also helpful in planning packaging, transportation and marketing operations [3].

The size of produce is frequently represented by its mass because it is relatively simple to measure. However, volume-based sorting may provide a more efficient method than mass sorting. In addition, the mass of produce can be estimated from volume if the density of the produce is known [4].

Two common methods of volume measurement include gas displacement and water displacement methods. Gas displacement method does not harm the object but it is time-consuming. While water displacement method takes less time, it may have harmful effects on the object. Both methods are best performed indoors and may not be practical [4].

Another method to determine object volume is the use of outer dimensions. Although most objects have irregular shapes, they are described in terms of standard shapes such as conic, elliptical, spherical and etc. The accuracy of determining volume depends on the uniformity of the object having the presumed shape [5, 6]. However, measuring dimensions using a caliper, subject to human error, may not be an efficient and practical approach to estimate volume, particularly in sorting large quantities of produce in distribution terminals [7].

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Nowadays, the use of image processing is gaining interest for the surface area and volume determination of objects. Sabliov *et al.* [8] used an image processing algorithm to determine the surface area and the volume of axisymmetric agricultural products. Wang and Nguang [9] used the methodology developed by Sabliov *et al.* [8] to measure the surface area and the volume of agricultural products. They created a representation of the produce with a set of elementary cylindrical objects and estimated the volume by summing the elementary volumes of individual cylinders. Both Sabliov *et al.* [8] and Wang and Nguang [9] reported that the method successfully estimated the surface area and the volume of lemons, limes and peaches. Koc [4] used image processing to determine the volume of watermelons. Rashidi *et al.* [10] reported that the method successfully estimated the volume of kiwifruits. Rashidi and Seyfi [11] also used image processing to estimate the volume of cantaloupe. Bailey *et al.* [12] demonstrated an image processing approach which estimated the mass of agricultural products rapidly and accurately. They used two perpendicular views to estimate fruit volume and then used the volume information to calculate the mass through a closed-loop calibration.

The image processing estimation methods reported in the literature were successfully applied to fruits such as lemons, limes, peaches, watermelons, kiwifruits and cantaloupes. Image processing can also provide an alternative method to estimate the volume of egg. The aim of this study was to estimate egg volume by image processing and utilizing of standard softwares for data handling and analysis.

MATERIALS AND METHODS

Fifteen 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±1°C and 90±5% relative humidity until experimental procedure.

Experimental procedure: The dimensions (length and diameter) were measured using a digital caliper. The mass of each egg was measured to 0.1 g accuracy on a digital balance. The volume of each egg was measured using the water displacement method. Each egg was submerged into water and the volume of water displaced was measured. Water temperature during measurements was kept at 25°C.

The image processing system consisted of a digital camera with USB connection, a fluorescent ring light source (40 W) and a Personal Computer (PC) equipped with ADOBE PHOTOSHOP 8.0 (Version 2003), COMPAQ VISUAL FORTRAN 6.5 (Version 2000) and MICROSOFT EXCEL (Version 2003) programs. A white cardboard was placed on a table to provide a white background. The digital camera was placed at the center of the fluorescent ring light source. The light source and camera mounted on an adjustable frame was attached to the measurement table. A schematic picture of the image acquisition system is presented in Fig. 1. The distance between the measurement table surface and the camera was set at 20 cm. Each egg was placed at the center of the camera's field of view and one RGB color image was captured.

The original RGB color image of each egg was converted to a grayscale image. Grayscale intensity represents 256 different shades of gray from black (0) to

Fig. 1: Image acquisition system

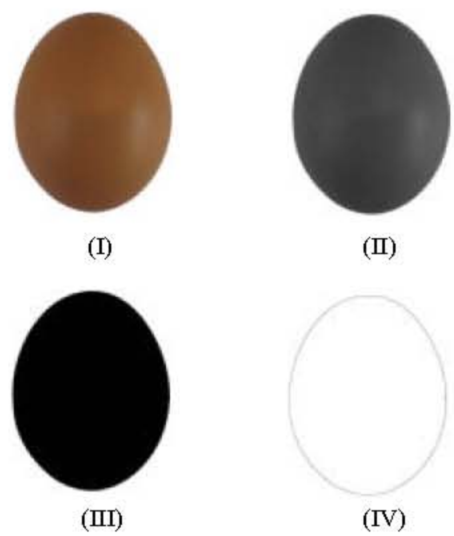

Fig. 2: (I) Original RGB color, (II) grayscale, (III) black-and-white and (IV) outline images of an egg

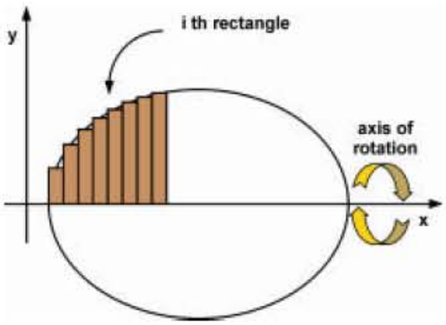

Fig. 3: The outline image of the egg was assumed to be composed of individual rectangular elements

white (255). Using threshold technique, the selected region of interest on the grayscale image was then converted to a black-and-white image with pixel values of 0 or 255. From the grayscale image, pixel values less than 115 were converted to 0 (black) and pixel values higher than 115 were converted to 255 (white), producing a black-and-white image for each egg. The threshold level of 115 was determined experimentally. The edge detection technique was then used to identify the egg edge in each image. The pixels showing the egg outline had the value of 0 and the remainder of the pixels in the image had the value of 255. Examples of the original RGB color, grayscale, black-and-white and outline images of an egg are shown in Fig. 2. The original RGB color, grayscale and black-and-white images were recorded as a jpeg file while the egg outline image was recorded as a DAT file with a two-dimensional array. The purpose of processing and converting the original RGB color images to black-and-white and outline images was to reduce the file size and processing time during volume calculation using the computer software.

Dimensional calibration: Each egg was placed at the center of the camera's field of view. Egg length and diameter were measured with a digital caliper. Without changing the position of the egg, one image was captured with the image acquisition system. The number of pixels representing the length and diameter of the egg was measured on the captured image. The dimensions in millimeters were divided by the dimensions in pixels and a mean conversion factor was calculated for each egg. The mean conversion factor of 15 eggs was averaged and a single conversion factor was determined. The same conversion factor was later used to estimate the volume of each egg.

Volume evaluation using image processing: The outline image of each egg as shown in Fig. 2 (IV) was used to calculate volume using the disk technique [13]. Each outline image was assumed to be composed of individual rectangular elements as shown in Fig. 3. Revolving the height of each rectangular element around the x-axis produces a cylindrical disk with a diameter of Δy as shown in Fig. 4. The volume of each cylindrical disk (V_i) shown in Fig. 4 is equal to the cross sectional area of the disk (A_i) times the thickness of the disk (Δx). Eq. (1) shows the cross-sectional area of a cylindrical disk and Eq. (2) shows the volume of the same disk.

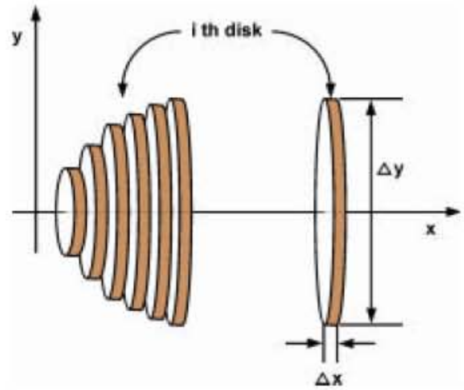

Fig. 4: Revolving each element around the x-axis generated cylindrical disks

$$A_i = \pi(\frac{\Delta y}{2})^2 \quad (1)$$

$$V_i = A_i \Delta x \quad (2)$$

The program developed in COMPAQ VISUAL FORTRAN considered each disk as having a thickness of 1 pixel and used a search algorithm to determine the diameter of each disk. Using the diameter, the volume of each disk was calculated. The volume of each disk was then summed to estimate the total volume as shown in Eq. (3). Finally, the same conversion factor was used to estimate the volume of each egg.

$$V = \sum_{i=1}^{n} V_i \quad (3)$$

Volume evaluation using spheroid approximation: Each egg was considered as an ideal spheroid. The volume of an ideal spheroid can be calculated from length (L) and diameter (D), which are shown in Fig. 5. Length and diameter of each egg were measured before capturing the image. The volume of eggs was then calculated by using Eq. (4):

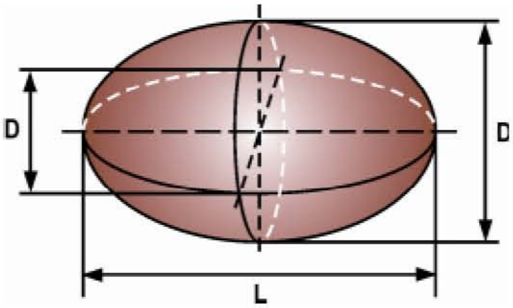

Fig. 5: The dimensions of an ideal spheroid

$$V_{spheroid} = \frac{4}{3}\pi\frac{L}{2}\frac{D}{2}\frac{D}{2} = \pi\frac{LD^2}{6} \qquad (4)$$

Statistical analysis: A paired samples t-test and the mean difference confidence interval approach were used to compare the volume determined from spheroid approximation and image processing methods with the volume measured by water displacement method. The Bland-Altman approach [14] was also used to plot the agreement between the egg volume measured by water displacement method with the volume determined from spheroid approximation and image processing methods. The statistical analyses were performed using MICROSOFT EXCEL.

RESULTS AND DISCUSSION

Dimensional calibration results: The dimensional calibration was determined by measuring egg length and diameter in millimeters using a digital caliper and determining these parameters in pixels using image processing from the outline images. The dimensions measured with the digital caliper and with image processing are shown in Table 1. From the digital caliper and image processing measurements, a conversion factor of 1 pixel to 0.52 mm was determined. This conversion factor was used to determine the volume of each egg using image processing.

Comparison of spheroid approximation method with water displacement method: The volume determined by spheroid approximation was compared with the volume measured by water displacement using the paired samples t-test. The paired samples t-test results (Table 2) showed that the volume determined with spheroid approximation was not significantly ($P>0.05$) different from the volume measured with water displacement. The mean volume difference between the two methods was -0.60 cm^3 (95% confidence interval: -1.47 and 0.27 cm^3; $P = 0.159$). The standard deviation of the volume differences was 1.57 cm^3. A plot of the volumes determined by Spheroid Approximation Method (SAM) and Water Displacement

Table 1: Mass, dimensions and volumes of eggs used in this study

		Dimensions						
		With digital caliper (mm)		With image processing (pixel)		Volumes (cm^3)		
Sample number	Mass (g)	Length	Diameter	Length	Diameter	WDM	SAM	IPM
1	51.1	55.6	43.4	110	79	55.59	54.83	52.42
2	53.3	55.2	44.4	103	82	54.55	56.98	53.60
3	53.5	56.8	45.2	109	84	58.92	60.76	58.30
4	55.2	58.2	44.1	108	85	58.71	59.26	57.60
5	55.5	59.7	44.6	112	83	60.59	62.18	58.34
6	55.8	57.8	44.9	110	84	59.46	61.01	59.95
7	56.1	57.5	44.4	111	84	59.13	59.35	58.35
8	57.6	60.1	44.3	115	85	62.88	61.75	63.57
9	58.2	57.9	45.3	114	87	60.80	62.21	60.25
10	58.6	59.0	45.1	113	87	63.63	62.83	64.79
11	60.5	57.0	45.0	112	86	57.32	60.43	58.11
12	61.7	62.7	45.6	120	88	69.87	68.26	73.60
13	62.3	61.2	45.7	120	91	67.25	66.92	68.19
14	63.4	60.0	46.6	118	94	65.71	68.22	69.16
15	64.4	58.8	46.4	118	95	67.81	66.28	71.56

Table 2: Paired samples t-test analyses on comparing volume measurement methods

Measurement methods	Average difference (cm^3)	Standard deviation of difference (cm^3)	P value	95% confidence intervals for the difference in means (cm^3)
SAM & WDM	-0.60	1.57	0.159	-1.47, 0.27
IPM & WDM	-0.37	2.07	0.498	-1.52, 0.77

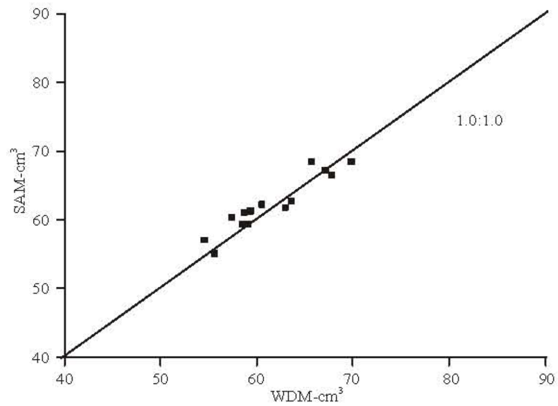

Fig. 6: Egg volume measured using Water Displacement Method (WDM) and Spheroid Approximation Method (SAM) with the line of equality (1.0: 1.0)

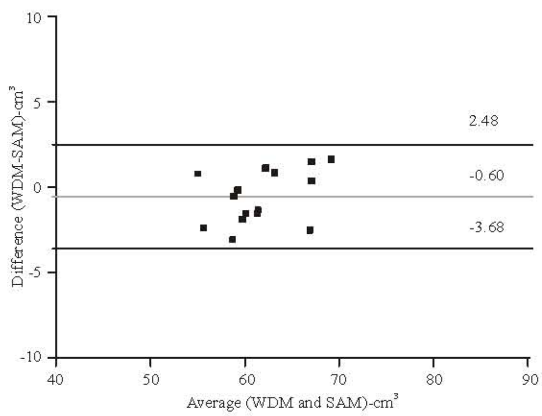

Fig. 7: Bland-Altman plot for the comparison of egg volumes measured with Water Displacement Method (WDM) and Spheroid Approximation Method (SAM); outer lines indicate the 95% limits of agreement (-3.68, 2.48) and center line shows the average difference (-0.60)

Method (WDM) with the line of equality (1.0: 1.0) is shown in Fig. 6. Also, as shown in Fig. 7, the volume differences between spheroid approximation and water displacement methods were normally distributed and the 95% of the volume differences were expected to lie between μ-1.96σ and μ+1.96σ, known as 95% limits of agreement [14]. The 95% limits of agreement in comparing these two methods were calculated to be -3.68 and 2.48 cm^3. Thus, volumes determined by SAM may be about 3.68 cm^3 lower or 2.48 cm^3 higher than volumes measured with WDM. The average percentage difference for volume estimation with SAM was 2.30%.

When spheroid approximation method was chosen for egg volume estimation, it was assumed that an ideal

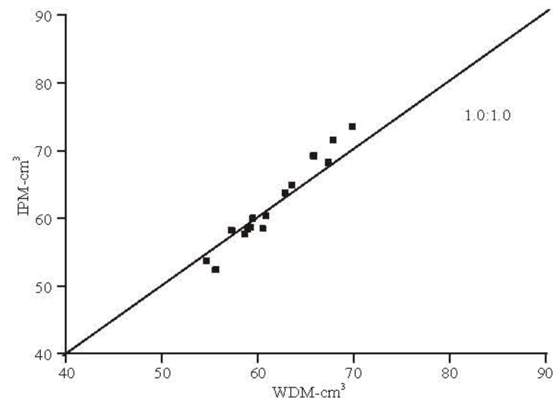

Fig. 8: Egg volume measured using Water Displacement Method (WDM) and Image Processing Method (IPM) with the line of equality (1.0: 1.0)

spheroid such as in Fig. 5 would be the standard shape to describe eggs. However, in reality, because the eggs were randomly selected from an unsorted source, their shapes were not ideal spheroids. As the accuracy of the spheroid approximation method depends highly on the uniformity of the egg having the presumed shape, the volume determined by spheroid approximation was a little higher or lower than the volume measured with water displacement.

Comparison of image processing method with water displacement method: The volume determined by image processing was also compared with the volume measured by water displacement using the paired samples t-test. The paired samples t-test results (Table 2) showed that the volume determined with image processing was not significantly ($P>0.05$) different from the volume measured with water displacement. The mean volume difference between the two methods was -0.37 cm^3 (95% confidence interval: -1.52 and 0.77 cm^3; $P = 0.498$). The standard deviation of the volume differences was 2.07 cm^3. A plot of the volumes determined by Image Processing Method (IPM) and Water Displacement Method (WDM) with the line of equality (1.0: 1.0) is shown in Fig. 8. Moreover, as indicated in Fig. 9, the volume differences between image processing and water displacement methods were normally distributed and the 95% limits of agreement in comparing these two methods were calculated to be -4.43 and 3.68 cm^3. Thus, volumes determined by IPM may be about 4.43 cm^3 lower or 3.68 cm^3 higher than volumes measured with WDM. The average percentage difference for volume estimation with IPM was 2.60%.

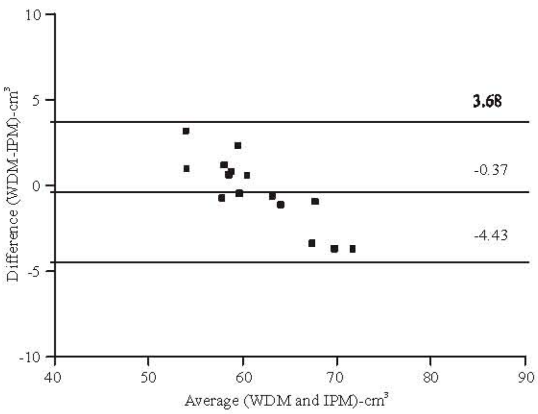

Fig. 9: Bland-Altman plot for the comparison of egg volumes measured with Water Displacement Method (WDM) and Image Processing Method (IPM); outer lines indicate the 95% limits of agreement (-4.43, 3.68) and center line shows the average difference (-0.37)

Figure 9 also shows that for small-sized eggs, the volume determined by image processing is less than the volume measured by water displacement (WDM-IPM>0). As the size of egg increases, the image processing method overestimates the volume (WDM-IPM<0). This is because of the change in distance between the digital camera and the egg surface. Although the distance between the digital camera and the measurement table is constant, the distance between egg and the digital camera reduces with increasing egg size.

As both spheroid approximation and image processing were based on the assumption that each egg was axisymmetric in shape, the accuracy of the methods depends highly on the uniformity of the egg having the presumed shape. If we do not take into account very slight amount of misshapen eggs, which are not axisymmetric in shape, spheroid approximation and image processing provide an accurate, simple and rapid methodology to estimate egg volume and can be easily used in estimating the weight of individual eggs and sorting of eggs.

CONCLUSIONS

Spheroid approximation and image processing methods were used to determine the volume of eggs of varying sizes. The volumes determined using these methods was statistically compared to the volumes measured with water displacement method. The paired samples t-test results indicated that the difference between the volumes determined by these methods and water displacement was not statistically significant. The Bland-Altman approach also indicated that for all sized eggs, spheroid approximation and image processing methods satisfactorily determined egg volume. Therefore, both spheroid approximation and image processing provide an accurate, simple, safe and rapid method to estimate egg volume and can be easily used in estimating the weight of individual eggs and sorting of eggs.

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