EggScale: a new method for evaluation of eggshell characteristics

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ABSTRACT

Geometric and visual characteristics of eggshells have been studied for more than half a century to determine their health and suitability for the various stages of the production chain. This article proposes a non-destructive, fast-processing and low-cost method for evaluate some of the most determinant eggshell characteristics in this context. We obtained mean error rate of 9% with a standard deviation of 2.16 in the worst case. We also provide method for eggshell color analysis. This analysis is challenging since the data obtained indicated a low reliability in establishing a reference standard given the high level of subjectivity involved in color perception by human evaluators.

1. Introduction

Chicken eggs are one of the most widely consumed foods by populations from different countries in the world. This predilection for the consumption of eggs can be primarily related to factors such as their high nutritional value and low cost, and the processing of these eggs in the aviary industries is of great importance for the food industry. In this context, the main stage of egg processing is the classification of these eggs according to their estimated quality (Vasileva et al., 2018). Eggshell quality is a factor of considerable commercial importance for producers due to the fact that low eggshell quality often results in the loss of these eggs (Yang et al., 2009).

Eggshell characteristics can be measured objectively or subjectively. In the latter, the cultural factors involved in the individual's relationship with the choice of food perceived by him/her as more nutritionally adequate are weighted, for example: brown-shelled eggs are commonly preferred in Australia and Western Europe, while white and brown eggs are equally preferred in Germany, Holland and Spain. In general, uniform brown eggs are preferred over mottled or pale eggs. In addition, eggshell color and spotting can be measures of stress and disease conditions and an abnormally thin or pale shell is usually associated with these factors (Milovanovic et al., 2021).

Despite the trend towards mechanization of several stages in the production chain of these industries, the egg classification and selection process, in many cases, is still manual. Human visual inspection is typically performed at a rate of up to 12 eggs per second in a high-speed inspection at leveling/packing plants. Thus, any automation in the inspection process would lead to a reduction in the visual stress of those in charge of this classification and an improvement in the quality control process (García-Alegre et al., 1997).

Several factors are considered when adjusting the quality of an egg, notably: its dimensions, the color of the shell, the presence of stains of different kinds, the porosity and the difference in shell thickness and the presence of cracks. The consideration of these factors guides the decision process regarding both the potential of these eggs for consumption and for reproduction. While factors such as the presence of stains (which may indicate fungal or bacterial contamination) and the presence of cracks primarily influence the suitability of that egg for human consumption, other characteristics such as color, porosity and shell thickness, as well as the size of the egg, constitute determining factors for measuring the hatching potential of these eggs (Vasileva et al., 2018).

The hatchability of eggs is a very important factor in the production chains of poultry farmers, given the need to maintain a high level of supply of day-old chicks (King'Ori et al., 2011). Several studies have been carried out in an attempt to determine the factors that influence this potential. Narushin's et. al. V.G. (Narushin and Romanov, 2002) pointed out that among the most important characteristics for determining the hatching potential of an egg are its weight, the thickness and level of porosity of the shell, its dimensions (in the form of the proportion between the maximum width and maximum height), and the consistency of its internal contents. Other characteristics such as genotype, hen age, storage time and type of incubator were indicated in (Grochowska et al., 2019) as influencing factors for hatchability. Finally, A.M. King'ori points out in (King'Ori et al., 2011) more external factors that influence reproductive success, his study indicating that, in addition to the physical characteristics of the egg, an adequate diet for the hens, and temperature control to avoid heat stress (which can influence the interior characteristics of the egg) may be determinant factors.

Techniques for gauging the characteristics of an egg that may indicate a greater potential for hatching are divided into destructive and non-destructive techniques. Since the measurement of characteristics in a destructive way implies the loss of the studied egg, it is, of course, of greater interest

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to propose techniques that can raise characteristics in order to preserve the embryo. In this context, the use of Computer Vision tools has been shown to be highly efficient and highly suitable for this purpose. Several works have been published in recent years proposing Computer Vision algorithms for use in poultry industry processes. Such processes include security inspection; monitoring, evaluation and prediction of freshness; quality inspection; characterization and health inspection; detection of defects and dirt and the classification of eggs; estimation of egg weight, volume and freshness; and (Nyalala et al., 2021) egg sorting and classification.

Vasileva et. al. (2018) (Vasileva et al., 2018) proposed a capture apparatus consisting of a camera attached to a wooden structure containing several LEDs arranged in two layers, one above the egg receptacle and one below, combined with light diffusers to ensure lighting uniformity and where the lighting modes were controlled by a microcontroller. From the images obtained in this camera, the morphological characteristics of the egg were raised, allowing the calculation of its format index, following the classification of two manuals (the *USDA Egg Grading Manual* and *The Russian Guide*), and also at the mottling grade of the eggshells. The comparison of the results obtained by the proposed method with those obtained by the traditional manual method showed a difference in mean radius values between 0.095 ± 0.058 mm for the sharp end and 0.080 ± 0.047 mm for the flat end of the egg with a standard deviation of 0.58 mm and 0.49 mm, respectively. The correlation coefficient between the shape indices determined by the two methods was 0.93 and the accuracy rate of the staining level estimation was 0.78 compared to the classification performed by an expert. Despite the good results obtained, the high complexity of the apparatus for acquiring the images and the costs involved in their production are high, making, in many cases, their use too expensive.

Jakhfer Alikhanov et al. (2019) (Alikhanov et al., 2019) presented a method for automated classification of eggs using the survey of some characteristics of these eggs, namely the dimensions of the major and minor axis, area, perimeter, index and form factor. A modified industrial classification machine was used where the eggs were arranged on a conveyor belt passing through a capture zone coupled to a controller that analyzed the eggs using the proposed algorithm and these eggs were then directed using pneumatic tubes. In this work, a mathematical model was proposed for the calculation of the volume of eggs based on a regressive analysis performed to determine which morphological characteristic presented the greatest relation to the volume. The results presented reached a classification accuracy rate between 91.53 and 98.33% for the speed of two eggs per second and between 88.33 and 93.45% for the speed of three eggs per second.

Narushin et. al. (2021) (Narushin et al., 2021b) highlighted that Volume and Surface Area are the external characteristics of eggs that hold the greatest importance for applications in researching areas involving food engineering and the development of technologies in the poultry industry. They used the model Hügelschäffer to propose a simplified formula for calculating these characteristics based only on measurements that can be obtained by non-destructive methods, notably Length and Maximum Breadth. The reported results show an error ranging from 0.0-3.4% between the proposed optimized formula and data obtained by a simulation model that represents the entire range of egg variations using data extracted from (Romanoff et al., 1949). The authors further argue that further increments in the accuracy of the formula did not seem feasible.

Despite the high accuracy rates, the indication of the method used in (Alikhanov et al., 2019) to determine the area of the eggs is not clear. An this feature is used to calculate the volume of the egg. On the other hand, the results obtained by (Narushin et al., 2021b) need to be applied to concrete data obtained from real measurements to assess the accuracy of the proposed formulas for predicting egg volume.

Therefore, this paper proposes an automated and non-destructive method for the evaluation of important characteristics for determination of the hatching potential in order to feed future studies in the area and potentially allow such analysis to be carried out in a faster and more accurate in incubators that are components of the poultry products production chain. We introduce EggScale, a set of techniques for automated analysis of egg characteristics. EggScale has three main features: (i) a simple and low-cost apparatus for image acquisition that allows the analysis of several eggs per batch in a fast way; (ii) an alternative model to calculate the volume of the egg, independently of its area, from the analysis of the characteristics extracted from its image; (iii) the proposal of a new index to classify the eggshell according to its color.

2. Materials and Methods

2.1. Image acquisition apparatus

An apparatus was built for the acquisition of eggs images. A conventional high resolution camera attached to a platform supported by four parallel MDF plates was used in order to constitute a chamber. The chamber has a support for egg positioning and interior lighting in order to eliminate any influence of different conditions of ambient lighting (Figure 1 [A] - [I]). The images are capture from black trays containing up to 24 eggs positioned in the bottom of the chamber (Figure 2).

2.2. Dataset

A total of 254 eggs of different colors and sizes were used in the experiments. From these, 60 were used in the assessment of physical characteristics and 194 were used in the assessment in color characteristics.

2.3. Dataset 1: Egg dimensions

The width and length of the 60 eggs were obtained manually by two different operators using a digital caliper. Each tray was photographed five times – before each photo, the eggs were slighted adjusted in their respective niche. Our

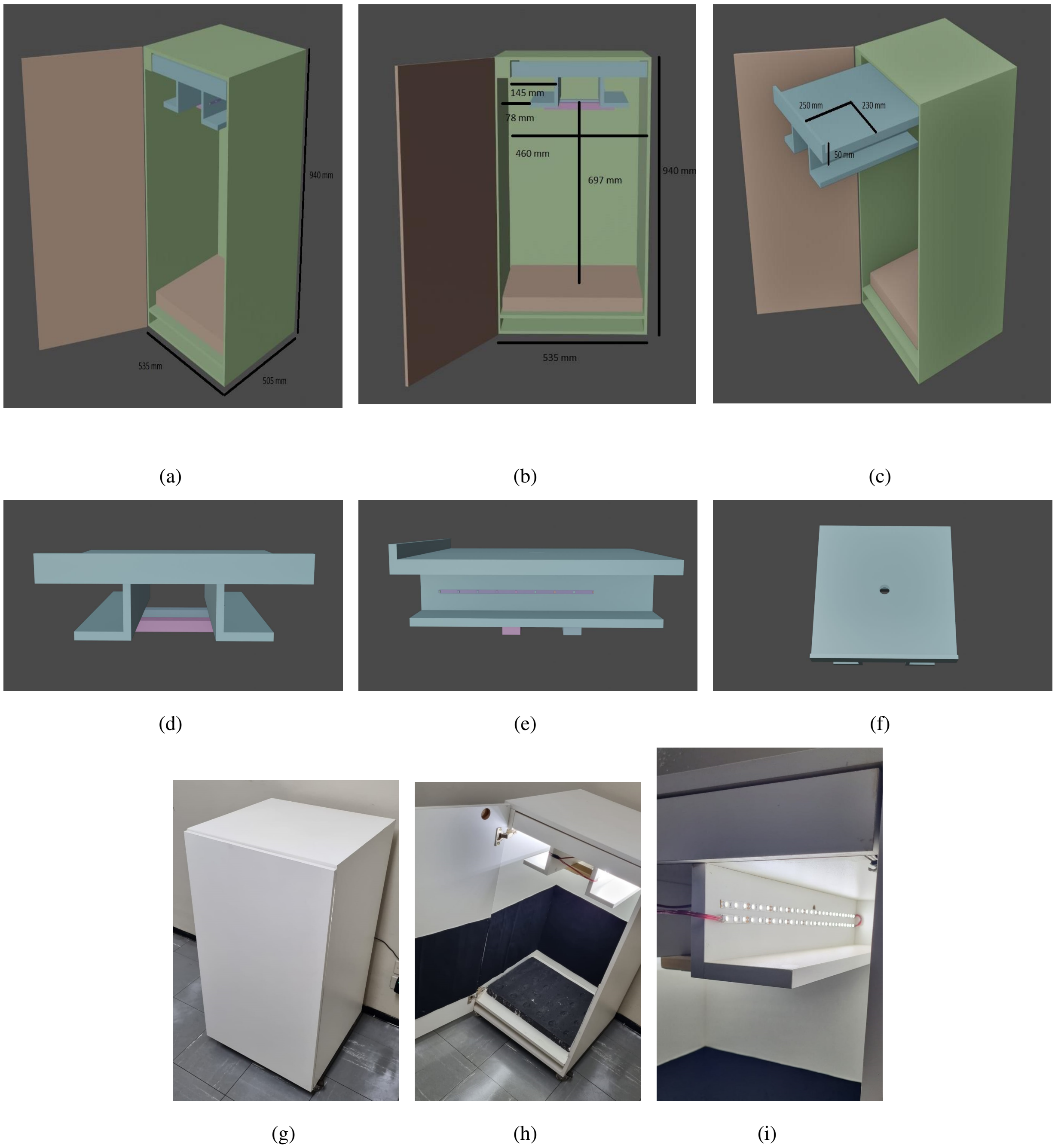


Figure 1: Image acquisition apparatus. (a) - (c) Chamber and drawer dimensions.

goal is to evaluate if these variations would impact in the precision of the proposed method.

To measure the volume of the egg, we used a common beaker with dyed blue water in order to enhance the contrast. Photographic records of the beaker filled with the liquid were taken before and after the immersion of the egg in it in order to determine the amount of liquid displaced, and hence its volume Fig. 4). After collecting the images, they were processed in the software *GIMP* version 2.10.32, where reference measurements were taken to determine the pixel per millimeter ratio in each photo using the real measurements obtained with a caliper, in millimeters, of the photographed beaker in relation to the distance measurements in pixels taken for each photo and using as a reference, for both measurements, the 100ml mark. With the volume/millimeter ratio established through the physical measurement of the dimension contained between each marking engraved on the beaker and checked by weighing the beaker filled with distilled water (whose weight/volume ratio is known) at room temperature for each marking and with the pixel/millimeter ratio determined, these ratios were, then, used in each of the photos to correlate the measurement obtained for the volume of liquid in each of the photos and, thus, determine the difference in volume between them, a value that would correspond to the volume of the egg.

2.4. Dataset 2: Egg color

For the classification of shell color, a batch of 194 eggs was analyzed by two different human evaluators who used a standard colorimeter palette provided by a farming company and used in visual classifications carried out in it to classify these eggs into color classes (the palette represents shades of eggshells ranging from the lightest to darkest). In this process, 19 classes were found among the 24 present in the palette (eggs belonging to color classes 1 to 5 were not indicated by any of the evaluators).

In order to carry out a comparative analysis for the results obtained by EggScale, a batch of 68 eggs, extracted from those groups with 194 eggs, was separated into representative groups of 17 color classes, with 4 eggs in each class, found in the sample among the 24 colors indicated by the reference palette. The reduction from 194 eggs to 68 was necessary in order to assure the uniformity of distribution among color groups identified by the evaluators. The images of these 68 eggs were then presented to two human evaluators together with a representative image of the colors present in the standard palette. The evaluators were asked to indicate the predominant shell color for the egg under analysis among the colors represented in the palette image (Fig. 3). Each component image of the sample was presented 10 different times and randomly to the same evaluator in order to guarantee the repeatability of the experiment and the obtained results were computed in order to compare them with the results obtained by the computational system.

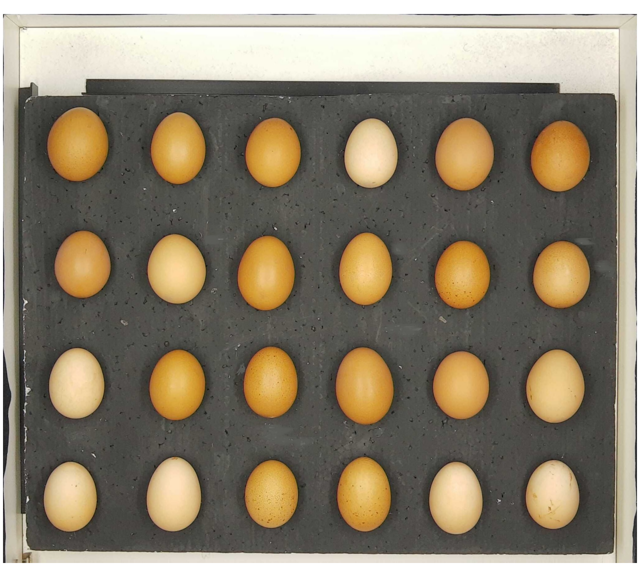


Figure 2: Egg tray example.

2.5. Methods

The first step to process the image tray is to generate individual images for each egg. This process performed interactively by positioning 5 horizontal and 7 vertical line cuts. Each individual egg image is indexed with its respective position in the tray (row and column).

The individual egg image (Figure 5 [A]) is then resized according to a configurable factor to optimize processing time. The resized image is then converted from RGB to HSV colorspace. We empirically verified that the HSV color space results in a more effective segmentation of the image's region of interest (ROI – i.e., the egg) in contrast to other tested color spaces, such as YCbCr and RGB itself. The image is then segmented through a binarization performed with the application of bitwise thresholds in the image brightness channel followed by a median filter with a 3x3 mask in order to eliminate noise and sparse points from the image. As an additional step to increase segmentation precision, the bounding box containing the ROI is computed by identifying connected components of the image and eliminating any

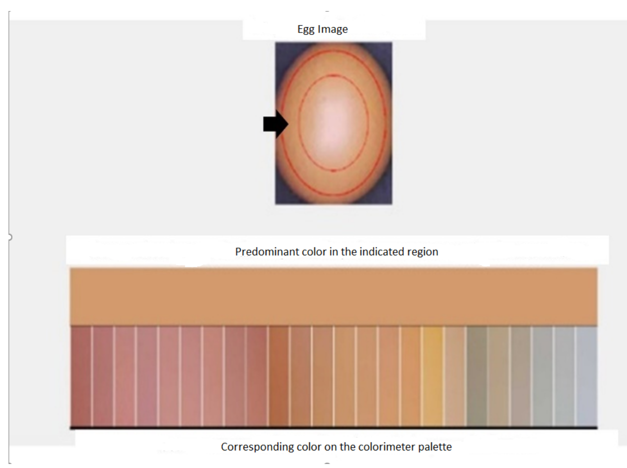
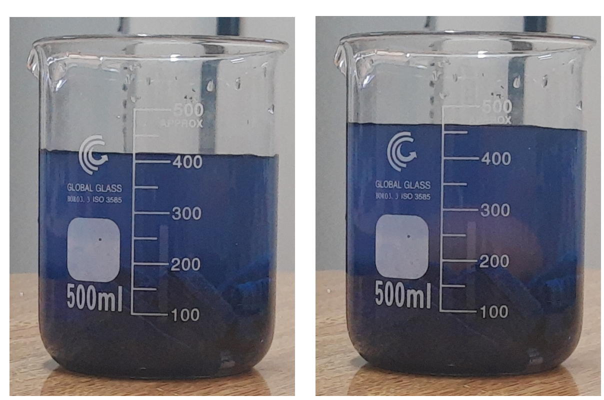


Figure 3: Screenshot of the system used for the classification of egg shell color by human evaluators.



(a) (b)

Figure 4: Egg volume estimation using a beaker. (a) Image before egg immersion. (b) Image after egg insertion. The volume is estimated based on the water displacement.

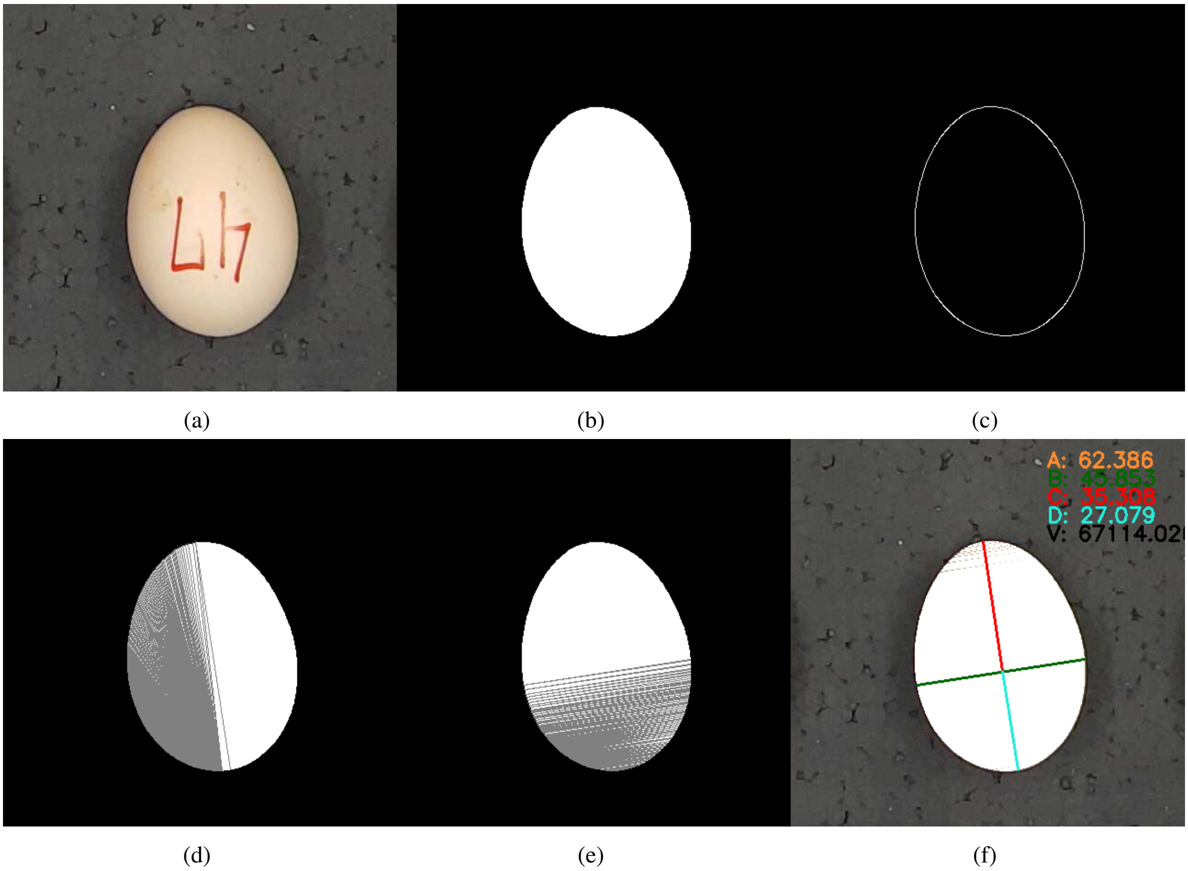


Figure 5: Steps of the identification process for the dimensions of the egg. (a)Original egg identified (b) Segmented object (c) Egg contour identification (d) Identification process of the longest line between two points (e) Identification process of the longest perpendicular line to the one identified on step d (e) Maximum breadth and length lines identified.

identified component whose dimensions are smaller than 30% of the horizontal dimension and 15% of the original vertical dimension of the image (Figure 5 [B]).

2.5.1. Egg dimensions computation

After ROI identification, it is possible to compute the egg dimensions. First, the identification of the set P_1 composed of the all the points (x, y) in the egg contour is performed using the Canny method (Canny, 1986). Next, we compute the pairwise distance between all points in P_1 (Figure 6 [B]). The largest distance identified and a straight line corresponding to the distance between the two respective points will correspond to the primary axis L of the egg. The secondary axis, B, is defined by the largest line segment between the line segments formed by the pairs of points in $P1$ and perpendicular to L (Figure 6 [C]).

The primary axis found in the first step corresponds to the length and the secondary axis found in the second step corresponds to the maximum width of the egg (Narushin et al., 2021a), measured in pixels. Measurements in pixels are converted to millimeters by multiplying a constant factor, empirically identified through system calibration, considering the constant distance between the capture device and the base of the tray and the resolution of the generated images (Figure 5[F]).

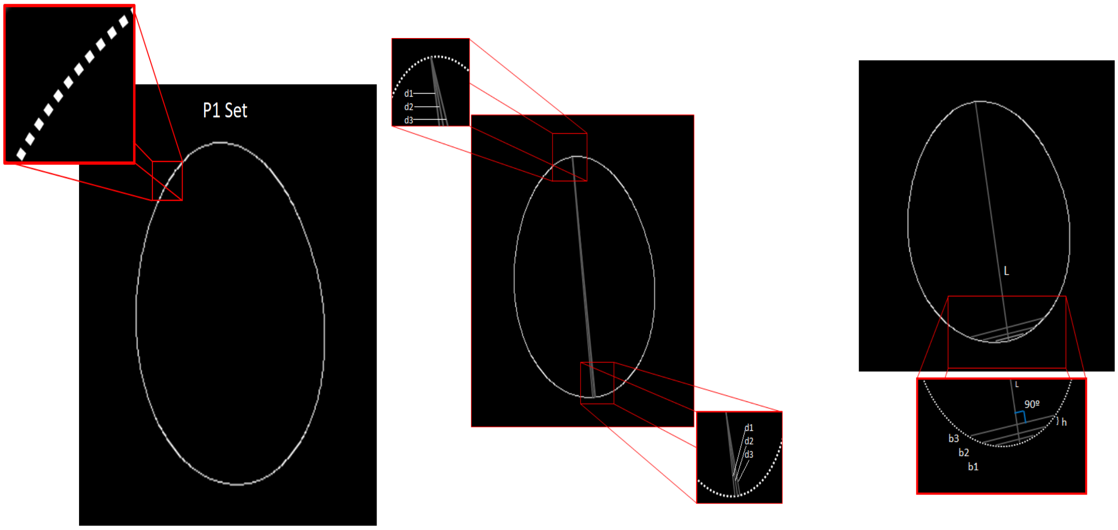
Finally, the egg volume is calculated based on sum of the various conical frustum's volume sliced from the eggshell projection (Fig. 7)(Equation 1). The distance h corresponds to the distance between each of the lines perpendicular to the principal axis of the egg found in the previous step. R and r correspond, respectively, to the major and minor size of two consecutive lines. Each volume calculated in this way will correspond to the volume of the truncated cone with dimensions of the larger base R, smaller base r and height h. The sum of the calculated volumes for all sequential lines will correspond to the approximate volume of the egg.

$$\sum((\pi * h)/3) * (R^2 + r^2 + R + r) \quad (1)$$

The final state of the frame processing is seen in Figure 8.

2.5.2. Color assessment

To define the color characteristics of the shell, it was necessary to define a region of the shell to be analyzed, given that there is an excessive saturation in the central region of the eggshell caused by specular reflection, which harmed color analysis. For the definition of this region, we defined two ellipses centered in the ROI, the largest one – Ellipse A – with a larger and a smaller radius equivalent to half of 95%



(a) (b) (c)

Figure 6: Egg dimensions computation. (a) Egg border points. (b) Primary axis (L) determined by the largest distance between the edge points. (c) Secondary axis determined by the largest segment perpendicular to L

of the height and width dimensions of the ROI respectively, that is, 95% of the dimensions of Axis A (Length) and Axis B (Maximum Breadth); and the smaller one –- Ellipse B –- with measures equivalent to half of 35% of the values of Axis A and Axis B respectively (Figure 9).

Then, the region corresponding to all pixels belonging to Ellipse A but not to Ellipse B is used to evaluate the color of the egg. The average values of each channel of the RGB color space and of the channels a* and b* of the CIELab color space in this region are calculated.

The averages of the colors obtained by the previous process are also converted to their corresponding frequency of the electromagnetic spectrum in order to perform a comparative analysis between the color identified by the computer vision system and the region of the spectrum in which this color would fit.

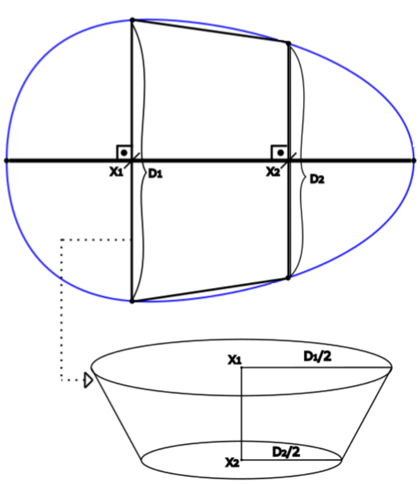


Figure 7: Cone frustum extracted from the horizontal section of the egg.

3. Results

Considering Dataset 1, the difference of the manual evaluation between the measurements taken by the two operators varied between 0.0 mm and 1.12 mm for length and between 0.00 mm and 0.13 mm for maximum breadth. The same 60 eggs were, then, evaluated by the system for the five runs of trays photographs. The measurements obtained by repeating the application of the system showed a variation of 0.00 mm – 2.29 mm in the length dimension, 0.00 mm – 1.45 mm in the maximum breadth dimension and 0.0 ml – 4.48 ml in volume, with average variations corresponding to 0.43 mm,

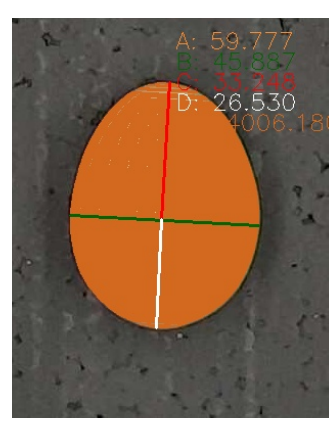


Figure 8: Segmented egg with both main axis and volume defined.

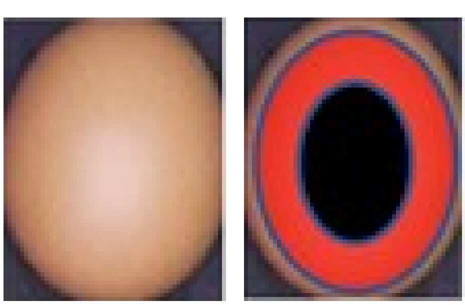
Table 1
Repeatability test - Values obtained after five runs.

Characteristic	Absolute Error	Average Error	Standard Deviation
Length(mm)	0,0 - 2,29	0,43	0,13 - 1,08
Max.Breadth (mm)	0,0 - 1,45	0,29	0,06 - 0,76
Volume (ml)	0,0 - 4,48	0,90	0,20 - 2,32

0.29 mm and 0.90 ml respectively. The divergence of values between the measurements taken by the computational system and the average of the measurements taken physically ranged between 0.01 mm – 3.70 mm in egg length, between 0.13 mm – 3.77 mm in egg maximum breadth and 0.04 ml – 10.70 ml in egg volume with mean variations of 1.64 mm, 1.83 mm and 4.27 ml respectively. The standard deviation obtained between the five measurements given by EggScale for the 60 eggs varied between 0.13 mm – 1.08 mm for length and 0.06 mm – 0.76 mm for maximum breadth, resulting in averages of 0.46 and 0.29, respectively. Such results are summarized in Tables 1 and 2.

It should also be noted that in the comparison between the results obtained by the proposed method and those presented by Narushin et. al. (Narushin et al., 2021b) we could observe greater precision and accuracy in the method proposed here in all five measurements as can be seen in Figure 10 and in the Table 3 .

In the visual analysis of colors of the eggshells, it was registered that Evaluator 1 identified eggs ranging from color classes 8 to 24 and Evaluator 2 identified eggs ranging from color classes 6 to 24 (Fig. 11). While in the visual analysis through the images of the eggs in comparison with the representative image of the color shells, it was possible to observe a coefficient of variance from 0 to 22.4 for Evaluator 1 and from 0 to 82.5 for Evaluator 2 (Fig. 12). The analysis carried out by the computational system presented results that placed the images of the analyzed eggs occupying a range of the visible light spectrum comprised between the wavelengths of 484.8 nm to 598.9 nm while the colors represented by the palette were comprised in the range of 487.48 nm to 600 nm (Fig. 13).



(a) (b)

Figure 9: Definition of eggshell region of interest. (a) Individual eggshell photo. (b) In red, the region considered for color evaluation.

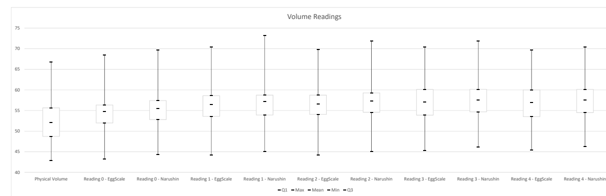


Figure 10: Volume readings dispersion.

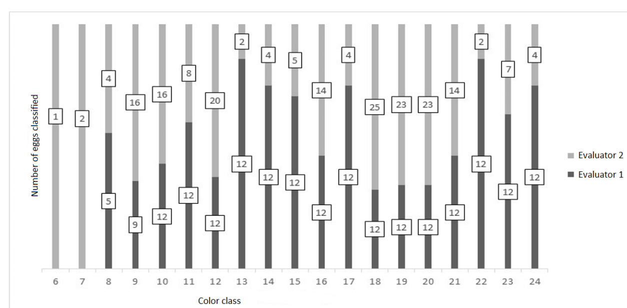


Figure 11: Egg color class distribution by appraiser.

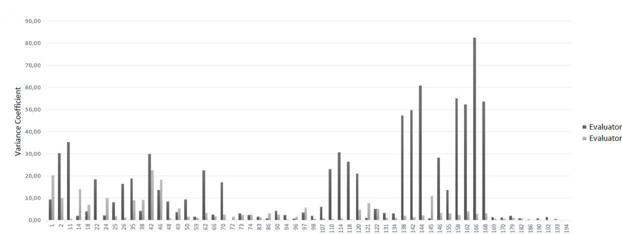


Figure 12: Color class egg distribution by each appraiser.

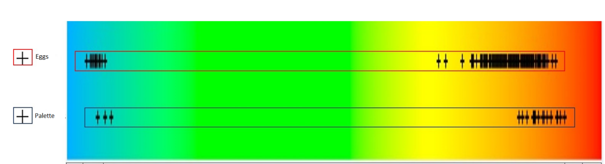


Figure 13: Color class egg distribution: Electromagnetic spectrum vs Reference Color Pallete.

4. Conclusion and discussion

It is noted that the measurement of physical characteristics by the system confers a high degree of precision (on average above 90% in all cases) which would allow the analysis and rapid classification of large batches of eggs in size categories with a acceptable reliability degree. It is

Table 2
Accuracy test -difference between manual evaluation and EggScale.

Characteristic	Absolute difference	Average Difference	Standard Deviation
Length	0,01 mm - 3,70 mm	1,64 mm	0,60 mm - 0,70 mm
Maximum Breadth	0,13 mm - 3,77 mm	1,83 mm	0,71 mm - 0,77 mm
Volume	0,04 ml - 10,70 ml	4,27 ml	1,90 ml - 2,16 ml

Table 3
Comparative analysis between Narushin's formula and the proposed method.

Method	Mean error	Mean percentual error	Standard Deviation
Narushin (run 0)	3,41 ml	7%	2,27
EggScale (run 0)	2,84 ml	5%	1,90
Narushin (run 1)	5,02 ml	10%	2,52
EggScale (run 1)	4,40 ml	8%	2,16
Narushin (run 2)	5,21 ml	10%	2,24
EggScale (run 2)	4,50 ml	9%	2,07
Narushin (run 3)	5,45 ml	10%	2,17
EggScale (run 3)	4,87 ml	9%	1,99
Narushin (run 4)	5,37 ml	10%	2,12
EggScale (run 4)	4,75 ml	9%	2,01

necessary, however, to point out that for analyzes that require an even higher precision, the use of other methods would be recommended. The method proposed here proved to be more efficient than the model proposed by Narushin in (Narushin et al., 2021b) with the advantage of dispensing manual measurements of any kind, using only image processing.

Future work may address the evolution of the proposed method, adding the computation of the surface area of eggs, in addition to the volume, a characteristic that was not addressed here given the difficulty and lack of resources to elaborate an adequate test that would serve as validation data. Another possible improvement would be to adapt the trays using a low-friction surface, causing any eggs placed in the niches to slide until stabilization in a perfectly horizontal position, thus eliminating small variances in the angle of egg deposition.

The analysis of eggshell color proved to be a more complicated task, since the validation of the data obtained indicated low reliability for the reference classifications carried out with the human eye and subject to a high degree of subjectivity, with variance rates reaching marks of up to 82.5% including the indication of regions of the spectrum of colors visible by the human being in which the visual analysis suffers more oscillations and a possible susceptibility of each individual to a greater or lesser sensitivity within that range. There was also a discrepancy between the reference values given by the palette and the values obtained by the effective analysis of the shells, even in the classification carried out by the computational system, which indicates that a new reference model is necessary for the development of a method that can provide a reasonable degree of reliability in the analysis of samples.

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CRediT authorship contribution statement

Marcos Paulo Souza Tomé: Methodology, Software, Validation, Writing - Original Draft. **Jocival Dantas Dias:** Software. **Otávio Olivieri:** Software, Testing, Specialist evaluation. **Thomas Abdo Costa Calil:** Specialist evaluation, Material supplier. **Bruno Augusto Nassif Travençolo:** Conceptualization, Methodology, Writing - Original Draft,Writing - Review & Editing, Supervision. **Maurício Cunha Escarpinati:** Conceptualization, Methodology, Software, Writing - Original Draft,Writing - Review & Editing, Supervision.

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