DENSOVO : A Chicken Egg Spoilage Detection Device Based on Volume and Density Calculation Using Mathematical Modeling

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Abstract

Food products generally undergo spoilage over time, which affects their quality and safety for consumption. One of the most widely consumed foods worldwide is the chicken egg, due to its high nutritional value and importance as a protein source. However, when eggs are stored for extended periods, spoilage occurs, and such deterioration cannot be clearly identified by visual inspection. Consumption of spoiled eggs may pose health risks. Therefore, this study investigated the physical changes of chicken eggs over a period of 12 days. The results showed that both mass and density decreased continuously over time, while the volume remained relatively constant, based on this relationship, a linear equation was established between density and time, and further developed into an innovation capable of sorting and assessing egg freshness, as well as predicting spoilage in a non-destructive manner. The system utilizes a mathematical model developed by the authors to estimate egg volume $V = \frac{20\pi ab^2 + \left(4\pi a^3\right)\left(\tan\left(\theta\right)^2\right)}{15}$ where a represents the half-longitudinal length of the chicken egg in centimeters, b represents the half-transverse length of the chicken egg in centimeters, which is then used to calculate density. In addition, the linear model is applied to estimate the remaining time before spoilage. The volume estimation model of the device exhibited a low average error of only 2.93%, indicating acceptable accuracy for practical applications.

keywords : Egg freshness assessment, Egg spoilage prediction, Density analysis, Mathematical modeling, Non-destructive testing, Volume estimation

1Introduction

Chicken eggs are a source of high-quality, easily digestible protein containing all essential amino acids. A single chicken egg provides high-quality protein and approximately 75 calories of energy. Additionally, eggs contain essential amino acids, and the yolk contains saturated fats as well as omega-3 fatty acids, which help reduce the risk of ischemic heart disease. Chicken eggs also contain several vital minerals, such as calcium and phosphorus, which are essential for bone formation, and serve as an important source of vitamins, including Vitamin A, B1, B2, B6, and various other vitamins. According to the Food and Agriculture Organization of the United Nations (FAO), global chicken egg production exceeds 80 million tons annually. In Thailand, the average consumption of chicken eggs is approximately 200–300 eggs per person per year (Department of Health, 2023), reflecting the significance of chicken eggs in both nutritional and economic dimensions.

However, prolonged storage of chicken eggs often leads to physical alterations, such as weight loss, decreased density, and overall quality degradation, which can eventually result in spoilage. Most consumers cannot visually detect these changes with the naked eye. Currently, methods for detecting egg spoilage still rely on traditional techniques, such as candling and water flotation. These methods can potentially damage the eggs and carry a high margin of error. Consequently, the researchers investigated the relationships among weight, volume, and density by collecting the physical data of chicken eggs daily over a 12-day period. This physical data was integrated with mathematical principles, wherein an ellipse function was modified to construct a novel egg-profile function. This derived function was then rotated around its axis to calculate the volume of the eggs. Furthermore, a linear equation was utilized to assess freshness and predict spoilage. These findings were subsequently applied to develop an innovative, non-destructive device for sorting and assessing the freshness of chicken eggs.

Methodology

1. Physical Data Collection of Chicken Eggs

Every egg in the tray was uniquely labeled and assigned to a specific schedule for daily data collection. A sample of five eggs was measured each day over a total period of 12 days to track physical changes

Fig. 1 Labeled chicken eggs with designated data collection dates.

Table 1 Density values of chicken eggs over a 12-day period.

	Day 1	Day 2	Day 3	...	Day 12
ฟองที่ 1	1.078	1.076	1.072	⋯	1.037
ฟองที่ 2	1.086	1.084	1.080	⋯	1.042
ฟองที่ 3	1.055	1.055	1.053	⋯	1.033
⋮	⋮	⋮	⋮	⋮	⋮
ฟองที่ 60	1.048	1.046	1.045	⋯	1.026

Additionally, an egg holder was designed using the Tinkercad 3D modeling software to ensure precise and upright alignment of the eggs, which were then photographed to generate mathematical functions, as shown in Figures 2 and 3.

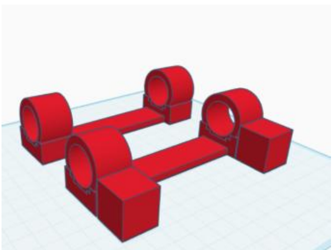


Fig. 2 The egg holder designed in the Tinkercad 3D modeling software.

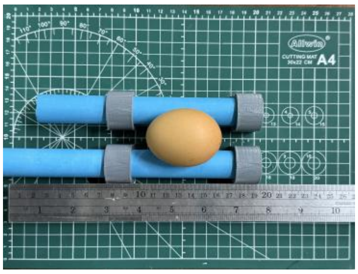


Fig. 3 The implemented egg holder used for photography.

2 Mathematical Function Construction

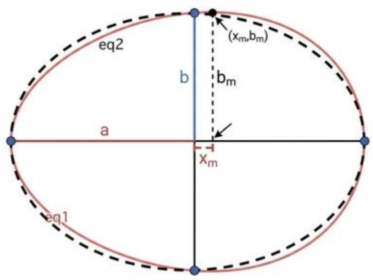


Fig. 4 Comparison of the egg profile and an ellipse.

According to Figure 4, the transverse lengths of both the ellipse and the egg profile are identical, and their longitudinal lengths share the same boundary points. However, the curve of the egg shifts further to the right compared to the standard ellipse. The maximum width of the chicken egg is denoted by b_m, while x_m represents the longitudinal distance between the points where two straight lines, b and b_m , intersect perpendicularly with the major axis, which yields the following relationship:

$$\frac{(x+h)^2}{a^2}+\frac{(y+k)^2}{b^2}=1$$

Because the curvature of a chicken egg deviates from a standard ellipse, it is necessary to add $x\tan(\theta)$ to b to expand one side of the curve. Consequently, the equation is expressed as:

$$\tan(\theta)=\frac{b_m-b}{x_m}$$

The modified egg-shaped ellipse equation derived from the arc can be written as:

$$\frac{(x+h)^2}{a^2}+\frac{(y+k)^2}{(b+x\tan(\theta))^2}=1$$

Rearranging the modified egg-shaped ellipse equation in terms of $f(x)$ relative to the origin yields:

$$f(x)=\sqrt{(1-\frac{x^2}{a^2})(b+x\tan(\theta))^2}$$

Integrating $f(x)$ to determine the volume yields:

$$\int_{-a}^{a}\pi(f(x))^2\,dx=\pi\int_{-a}^{a}(1-\frac{x^2}{a^2})(b+x\tan(\theta))^2\,dx$$

Since the lengths obtained from the photographs do not represent the actual dimensions, a scaling factor must be applied to calibrate the image measurements to the actual size before performing the volume calculations, expressed as:

$$k=\frac{L_1}{L_2}$$

Therefore, the approximation equation for calculating the volume of a chicken egg is formulated as:

$$V=\pi\int_{-ak}^{ak}(1-\frac{x^2}{(ak)^2})(bk+x\tan(\theta))^2\,dx$$

Where:

a represents half of the longitudinal length of the chicken egg (cm)

b represents half of the transverse length of the chicken egg (cm)

b_m represents the maximum transverse length (width) of the chicken egg (cm)

x_m represents the longitudinal distance between point b and point b_m (cm)

$x\tan(\theta)$ represents the curvature function of the chicken egg along the x axis.

L_1 represents the actual measured length.

L_2 represents the length measured from the image.

V represents the volume of the chicken egg $(cm)^3$

k represents the scaling constant for image-to-actual size conversion.

3. Innovation Development

3.1 Internal and External Structural Design of the Egg Freshness Inspection Device

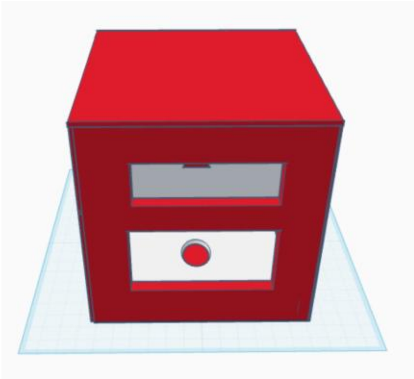


Fig. 5 The main structure of the device

3.2 Installation and assembly of the ESP32-CAM and Load Cell to acquire egg length and weight data for subsequent image processing.

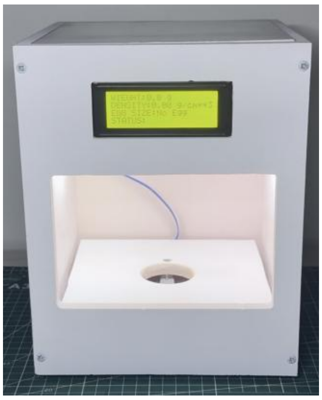


Fig. 6 Innovation development process.

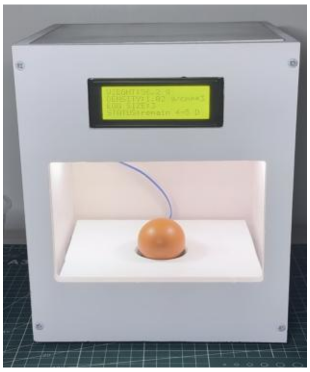


Fig. 7 Device testing and evaluation.

Result and Discussion

1.The continuous 12-day monitoring of the chicken eggs demonstrated a clear inverse relationship between storage time and egg weight. As time progressed, the average weight decreased from 56.64 g to 54.99 g, which is primarily attributed to the physiological loss of moisture and carbon dioxide gas escaping through the microscopic pores of the eggshell. Concurrently, since the physical volume of the egg remained constant, the average density calculated using the formula

$$V = \pi \int_{-ak}^{ak} (1 - \frac{x^2}{(ak)^2})(bk + x\tan(\theta))^2\, dx$$

decreased proportionally from 1.0736 to 1.0449. This concurrent decline confirms a strong, direct correlation between egg weight and density over time, proving that both parameters decrease progressively during post-laying storage.

2. The formulation of the egg volume estimation equation using the disk method incorporating the semi-major and semi-minor axes of the egg along with the ellipse equation successfully yielded the estimation equation:

$$V = \pi \int_{-ak}^{ak} (1 - \frac{x^2}{(ak)^2})(bk + x\tan(\theta))^2\, dx$$

This model demonstrates high accuracy in describing and calculating the physical volume of chicken eggs. The results highlight that utilizing the disk method is a highly significant and effective approach for precise egg volume measurement.

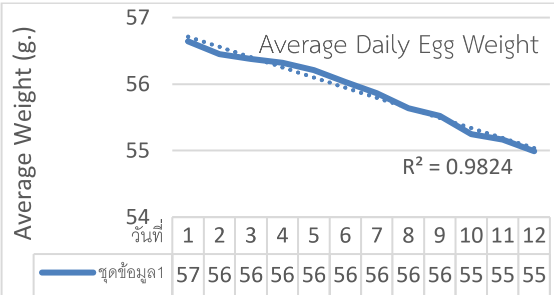
3. The performance validation of the innovative device demonstrated high practical accuracy, achieving a low error rate of only 2.93% compared to the reference Eureka water displacement method. This minor discrepancy can be attributed to a combination of mathematical model approximations—such as natural morphological variations at the egg apex that slightly deviate from the curvature function $x\tan(\theta)$ and hardware limitations, including camera resolution, edge-detection sensitivity, and perspective distortions during image acquisition. Nonetheless, an error rate of under 3% strongly validates the reliability of this device as an accurate, cost-effective, and non-destructive tool for egg volume measurement.

Conclusions

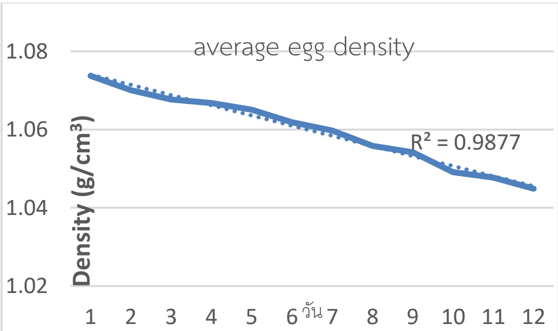
1.Continuous weighing of the chicken eggs over a 12-day period revealed a steady decrease in average weight, declining from 56.64 g on the first day to 54.99 g. Concurrently, the average density calculated using the formula

$$V = \pi \int_{-ak}^{ak} (1 - \frac{x^2}{(ak)^2})(bk + x\tan(\theta))^2\, dx$$

decreased from 1.0736 to 1.0449 over the same timeframe. Furthermore, experimental morphological analysis of the chicken eggs indicated that their two-dimensional shape closely approximated an ellipse but was not a perfect ellipse. Specifically, the egg apex demonstrated a distinct deviation from standard elliptical properties, yielding a percentage error of 4.8%.



Pig. 8 Relationship between average egg weight and time (days).



Pig. 9 Relationship between average egg density and time (days)

2. The equation is expressed as

$$V = \pi\int_{-ak}^{ak}(1-\frac{x^2}{(ak)^2})(bk + x\tan(\theta))^2\,dx$$

where a represents the semi-longitudinal length of the egg in centimeters (cm), b represents the semi-transverse length of the egg in centimeters (cm), b_m represents the maximum transverse length of the egg in centimeters (cm) x_m represents the longitudinal distance between point b and b_m in centimeters (cm); $x\tan(\theta)$ represents the curvature function of the egg along the x-axis; V represents the volume of the egg in cubic centimeters $(cm)^3$; and k represents the image-to-actual size conversion constant.

3.The performance of the innovative device in calculating egg volume was validated against the standard Eureka water displacement method. Based on the results, the volume calculated by the innovative device showed an error rate of only 2.93% compared to the physical measurements obtained from the Eureka method. This minimal deviation demonstrates that the integrated mathematical equation provides a highly accurate, reliable, and non-destructive approach for egg volume estimation

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