



Research article

Non-destructive method for whole-egg freshness inspection in food manufacturing

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Abstract

Importance of the work: Expired eggs can ruin an entire batch in the food industry; however, under current practice, only a subset of the eggs is randomly tested for freshness.

Objectives: To develop a non-destructive testing method for full egg-freshness inspection based on the analysis of the yolk movement speed.

Materials and Methods: Experiments were conducted on eggs from three farms, with storage periods ranging from 1 to 14 days. The inspection apparatus incorporated image processing with the traditional candle testing method and consisted of egg holder hardware and a vision system. A camera was used to capture yolk images that were subsequently used to calculate the yolk movement speed. From the literature review, it was found that the viscosity of egg whites decreases as the storage duration of eggs increases. Consequently, the egg yolk moves more rapidly over time. This study utilizes this principle to assess the freshness of eggs.

Results: The storage period increased the average yolk movement speed. With storage for up to 6 d, the yolk movement speed of the tested eggs was similar (16.3 mm/s on average), to 7–8 d of storage (25.4 mm/s), with a slight increase after 9–13 d. After 14 d of storage, the average yolk movement speed was 31.4 mm/s or approximately twice that of the fresh eggs. The results were verified based on other benchmarked methods.

Main finding: The proposed method was verified as a non-destructive method for egg-freshness inspection. A full-inspection system could be developed and integrated into the manufacturing process.

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Introduction

Eggs are often used in various food recipes and have become one of the most important raw materials in food production (Adeyemi et al., 2020). Unfortunately, if an addled or tainted egg is used in the manufacturing process by mistake, the entire production lot can be rejected. Because the expired egg has a bad smell that deteriorates the quality of the goods, the contamination of the expired egg can cause widespread losses in the manufacturing process. Furthermore, if undetected, the expired eggs mixed in the food could aggravate a consumer's health. Therefore, the current study investigated developing a system for the non-destructive freshness inspection of eggs to prevent the usage of non-fresh eggs in the manufacturing process.

Various methods and techniques are applied for egg inspection in the conventional manufacturing process. The candle egg test is commonly used by food factories and egg farms to determine egg fertility due to this test's non-destructive nature; however, only 5% of all eggs can be so tested in a food factory (Adeyemi et al., 2020) because of the slow inspection speed. Various methods for different purposes have been used for the internal inspection of eggs. For example, ultrasonographic images were used to identify fertility in brown eggs (Önler et al., 2017), with a reported 86% level of accuracy of fertility recognition. Ghaderi et al. (2018) used dielectric signals to classify hatching eggs during incubation with nearly 100% accuracy. A thermal imaging method was used by Lin et al. (2013) to inspect egg fertility, with a reported 96% level of accuracy for the inspection of live embryos.

In addition, image processing is an innovative method used to inspect eggs, involving a combination of image processing software and a lighting method. The type and position of lighting and the camera used can affect image processing performance. To mitigate this unreliability problem, Das and Evans (1992) developed an image processing system for inspecting egg fertility by integrating the threshold and the neural network methods, with the neural network improving the accuracy of the recognition result. Similarly, Qinghua et al. (2018) developed an image processing and neural network system for detecting dirt on the eggshell. Applying a different approach, Dehrouyeh et al. (2010) used a histogram technique to detect dirt on the eggshell, as well as blood spots. Their results suggested that the accuracy of their system incorporating image processing and a neural network was

better than from using just the image processing system. This combination has been used in various food processing applications (Zhang et al., 2014; Geng et al., 2018; Geng et al., 2020). However, to date, there has been no reported application of this compound system to determine egg freshness.

One technique that can inspect egg freshness is hyperspectral imaging using a spectroscope. Hyperspectral imaging uses the acquisition of spatial images in numerous spectrally congruent bands (Burger and Geladi, 2005; Burger and Geladi, 2006; Burger and Geladi, 2007; Burger and Gowen, 2011). Thus, the hyperspectral image consists of three dimensions: two spatial dimensions, length (x) and width (y) and one spectral dimension (λ). This method is a powerful analytical tool for non-destructive food analysis since hyperspectral imaging can detect the spectrum and information better than conventional imaging. Furthermore, hyperspectral imaging is ideal for research purposes in food science and beyond. For example, various research studies have demonstrated the ability of hyperspectral imaging to evaluate the properties of food products that are vital to the food industry (Liu and Ngadi, 2013; Pu et al., 2015; Sendin et al., 2018; Ma et al., 2019; Geng et al., 2020). This method provides researchers with spatially resolved data, permitting localization and visualization of chemical and biochemical compounds within samples (Qin and Lu, 2005; Noh and Lu, 2007; Ariana and Lu, 2008; Izumi et al., 2012). In addition, hyperspectral imaging has been applied to determine egg freshness. Nicolas et al. (2011) applied visible light (VIS) and near infrared (NIR) to inspect the quality and freshness of eggs during 1–16 d of storage. Their results showed that VIS/NIR transmission spectroscopy was correlated with egg freshness. In summary, hyperspectral imaging can be used for inspecting the egg freshness. However, this method requires intensive computing power and long calculation times (Nicolas et al., 2011).

Currently, there are very few techniques for detecting egg freshness. One method is to directly measure the viscosity of the albumen. For example, Kemps et al. (2010) measured the albumen's viscosity using the shear rate method. Based on their results, the viscosity decreased from 0.0304 pa/s for fresh eggs to 0.0181 pa/s for eggs stored for 24 d. Similarly, Tatiana et al. (2019) reported the period of storage affected the egg viscosity, pH and color of eggs. Although the viscosity measurement of the egg albumen can determine egg freshness, this method is destructive, resulting in the tested eggs not being suitable for use in manufacturing processes.

Contamination from non-fresh eggs or eggs exceeding their expiry date in manufacturing process results in unacceptable,

defective goods and production losses, as well as representing a consumer health threat. However, very few studies have developed a non-destructive egg-freshness inspection system. Therefore, the current investigated the development of a non-destructive inspection system for possible implementation in a food factory.

Materials and Methods

As mentioned above, the viscosity of the albumen decreases as the storage period increases; however, the viscosity measurement method applied destroys the inspected eggs. Therefore, the current study investigated an indirect viscosity measurement method, assuming that as the albumen viscosity decreases, the yolk movement speed increases. Based on this assumption, a system was developed for the measurement of the yolk movement speed and the correlation was determined between yolk-movement speed and storage period.

Hardware

Specialized hardware and software were developed for measuring the movement of the egg yolk. The hardware consisted of a gripper with an egg clamp, a stepping motor, a spotlight source, an industrial-grade camera and a programmable logic control (PLC). The gripper was designed to hold an egg using a clamp for loading and unloading. The stepping motor at a controlled speed of 60 revolutions per minute rotated the entire gripper and egg along the major axis to create the yolk movement. The light source was fixed on one side of the egg, while the camera was installed on the opposite side. The PLC was used to control the motor and send the captured signal to the industrial camera. The experiment apparatus is illustrated in Fig. 1.

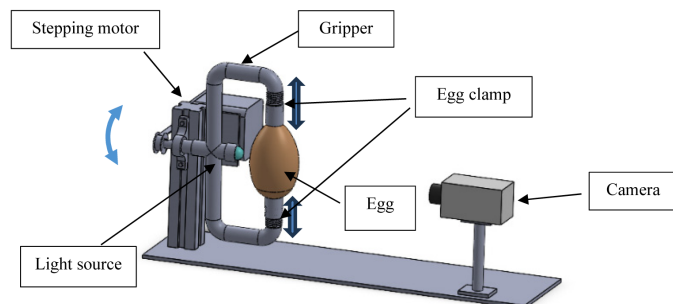


Fig. 1 Overview of mechanism for measurement of egg yolk movement

To perform the measurement, first, the egg was clamped into the gripper, and then the PLC controlled the motor to rotate the egg 180° for a 500 ms. Generally, the yolk floats on the albumen. However, this sudden motion was enough to cause the yolk to initially move beneath the albumen before gradually moving back to float on the albumen again. That is, when the egg was rotated 180° for 500 ms, the yolk was forced to move from the bottom to the top (the longest movement distance). The rotation time should be short to create close-to-impulse motion, as a longer rotation time would allow the yolk to finish floating up before image capturing commenced. The rotation time was fixed to 500 ms based on a preliminary study showed that by using this interval time, the yolk did not float up before the image was captured. As the yolk was floating up, the PLC sent capture signals to the camera twice, with captured images being used to calculate the yolk movement speed using the image processing software. The PLC sent the capture signals at 200 ms and 1,000 ms after the egg rotation, since the yolk started floating up at 200 ms and had nearly stopped moving at 1,000 ms. The Balser's camera model acA1600-60gc was used with an 8-mm-focal-length lens, an exposure time of 1 ms and an aperture setting of f/4.0. The light source was built from a hi-powered LED and was used as spotlight with brightness of 800 lumens. The data capture flowchart is shown in Fig. 2.

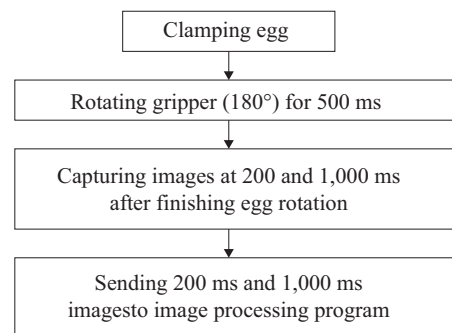


Fig. 2 Flow chart of image capture process

Software

After the motor rotated the egg 180° , the PLC sent capturing commands to the camera at 200 and 1,000 ms, with these captured images being sent to the image processing program, as shown in Fig. 3. Each captured image was processed with the threshold function twice, using two threshold values (125 and 80). The threshold value of 125 was used to identify the yolk (from the 200 ms image, Image 1 in Fig. 3), while the threshold value of 80 identified the whole egg (from the 200 ms image, Image 2 in Fig. 3).

Then, subtraction was performed using both images, with the resultant image displaying only the yolk section (from the 200 ms image, Image 2- Image 1 in Fig. 3). After that, the center of mass of the yolk section was determined using the x and y values. The same process was used at 1,000 ms to capture and process the image to provide the second set of reference data to calculate the yolk movement speed based on the centers of mass from the two captured images were used to calculate the egg yolk movement speed. The reason for using a duration of 1,000 ms is that, based on the preliminary experiment, 1,000 ms is the time at which the entire egg yolk moves close to its highest point.

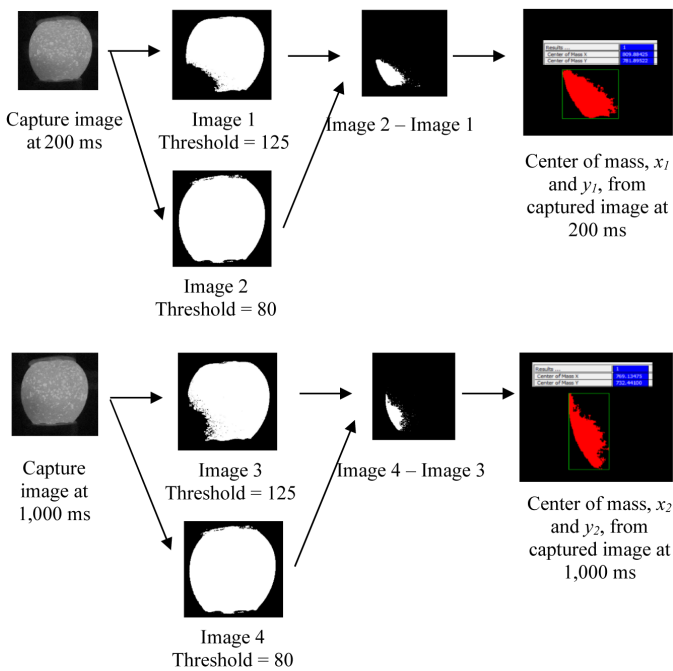


Fig. 3 The image processing program flowchart

The yolk movement speed was estimated from the distance the yolk moved between the two captured images at different times, calculated from the center of mass, (x, y) . First, the each distance was calculated between the center of mass at 200 ms, (x_1, y_1) and at 1,000 ms, (x_2, y_2) , using the Cartesian distance equation: $\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}$. Next, the distance values and the time interval, Δt , were used to calculate the yolk speed, using the formula $\text{speed} = \text{distance} / \Delta t$. The measurement was performed on 10 brown chicken eggs from three farms and repeated daily during the storage period of 14 d. All eggs were kept at room temperature. Lastly, the yolk speed values of the stored eggs were compared to those of fresh eggs to determine the correlation between egg yolk movement speed and egg freshness.

Notably, the tested eggs had variations in size, shell color and the amount of shell dirt; thus, the system had to be designed to handle the different egg characteristics. The clamp could be adapted for different egg sizes and the various egg sizes did not affect the image processing procedure. However, the various shell colors affected the process, with dark and light shell colors resulting in differences in the threshold function. However, it was found that in this experiment, the threshold values of 80 and 125 could be used for all eggs. A dirty shell had a significant impact on the inspection result. If the egg was very dirty, the software program could not determine the image of the yolk inside the shell. However, in this experiment, all the tested eggs had been purchased from a supermarket and had been cleaned before sale; consequently, some eggs with a little dirt on the shell did not affect the program.

Image processing function

The image processing application used the image processing library from National Instruments' IMAQ (National Instruments Corporation, 2025). IMAQ provides image processing functions for use by developers. The functions used in the current study were thresholding, subtraction and practical analysis.

Threshold function

The threshold function helps to differentiate an object from its background. Converting the in-range grayscale values to "1" and the out-of-range grayscale values to "0", improves the threshold function and the clarity of the image section of interest. The threshold function was applied to separate the whole egg from the background and then to separate the yolk from the whole egg. After threshold processing, the yolks were clearly detected.

Subtract function

The subtract function is a pixel-by-pixel logic operation between two images (a and b), as shown in Equation 1.

$$p_n = \max(p_a - p_b, 0) \quad (1)$$

where p_a and p_b are the same pixel location in images a and b , respectively.

This function was used to detect changes between the two images. The pixel from the second image was subtracted

from the pixel from the first image at the same position. A negative returned a “0” value, indicating the black color.

Particle analysis function

The particle analysis function was used to analyze particles of interest in the image. This function returns the details of a particle such as angle, area and the center of mass. The center of mass values was used to calculate the yolk movement distance. The center of mass was calculated from the summation of the x and y coordinates divided by the area, A, of the particle, as shown in Equations 2 and 3:

$$\text{Center of mass } x = \frac{\sum x}{A} \quad (2)$$

$$\text{Center of mass } y = \frac{\sum y}{A} \quad (3)$$

Results

In total, 30 eggs from three farms (10 eggs from each farm) were used in the experiment. The eggs were purchased from a supermarket and all eggs were graded as sized 3–4 (50–59 g) and had similar shell colors. Although the egg shell on each egg was clean enough for sale in the supermarket, some eggs shell were slightly dirty; however, this did not affect measurements. All eggs were stored for 14 d; each day each egg yolk movement speed was determined. Fig. 4 shows

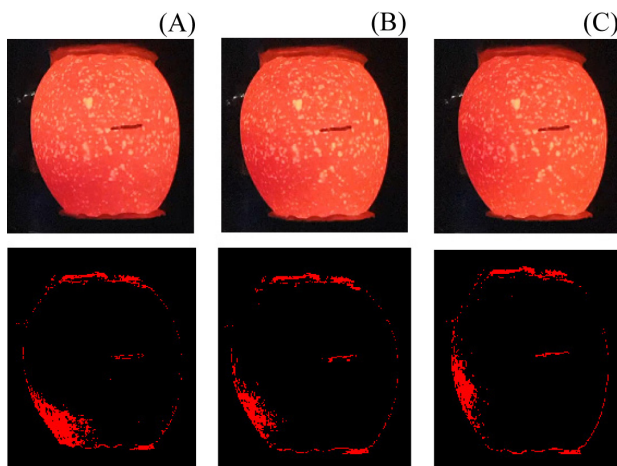


Fig. 4 Sample images of fresh egg (1 d of storage) from Farm 1: (A) original (top) and threshold-processed (bottom) images captured immediately after egg rotation; (B) original (top) and threshold-processed (bottom) images captured at 200 ms; (C) original (top) and threshold-processed (bottom) images captured at 1,000 ms.

the sample images of a fresh egg captured immediately after rotation of 180° at 200 ms and at 1,000 ms, along with the images after the threshold function had been applied. When the rotation occurred, the yolk immediately moved to the bottom of the egg. After that, the yolk gradually floated up to the top of the egg. In the original images, the yolks were unnoticeable; therefore, the threshold function was used to separate yolks from the background region. The results clearly showed that the yolk area became visible and the floating yolk could be observed.

Fig. 5 shows samples of threshold-processed images from the same egg at different storage periods of 3, 5, 7, 9 and 11 d, captured at 1,000 ms after the 180° rotation. The yolk position of the oldest image of the egg (day 11) was higher than that on a fresher egg (day 3), indicating that the yolk moved a greater distance as the storage period increased, demonstrating that the egg yolk movement speed increased with the storage period.

The average yolk movement speed versus storage period is shown in Fig. 6, indicating that the movement speeds of the yolks from the three farms had a similar trend. During 1–6 d of storage, the movement speeds were similar; however, for storage longer than 6 d, the movement speed increased noticeably. The average yolk movement speeds of the eggs for storage of 1–6 d from Farms 1–3 were 14.5 mm/s, 18.2 mm/s and 16.1 mm/s, respectively.

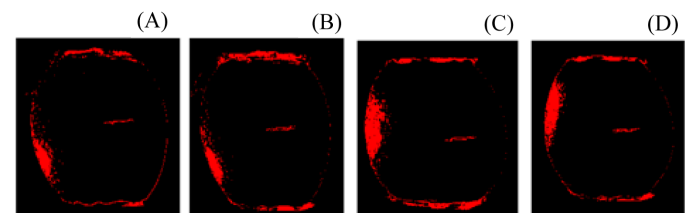


Fig. 5 Sample threshold-processed images of same egg captured at 1,000 ms after egg rotation at storage periods of: (A) 3 d; (B) 5 d; (C) 7 d; (D) 9 d

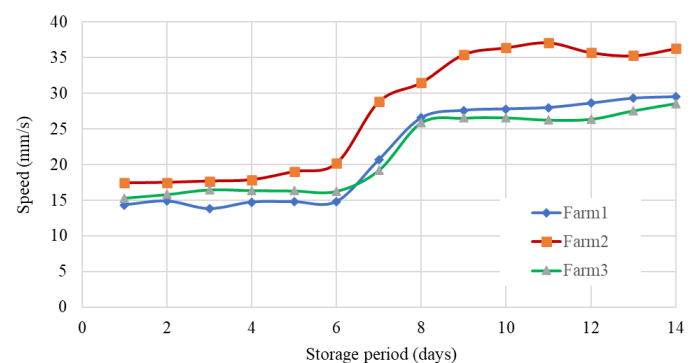


Fig. 6 Yolk movement speed versus storage period of eggs from three farms.

Compared to fresh eggs, on the 8th day, the yolk movement speed increased 82.5% for Farm 1, 72.3% for Farm 2 and 60.5% for Farm 3, while on the 14th day, the yolk movement speed increased 105.9% for Farm 1, 108.2% for Farm 2 and 86.2% for Farm 3. This increase in the yolk movement speed with increasing storage agreed with the results of Kemps et al. (2010), who reported that as the storage period increased, the viscosity of the albumen decreased, which inversely contributed to the yolk movement speed.

Comparison with other methods

Comparison with albumen flow rate measurement method

Measurement of albumen viscosity is the traditional method for inspecting egg freshness, with Kemps et al. (2010) studies reporting the relationship between egg freshness and albumen viscosity. Because the fluid viscosity was correlated with the flow rate, the measurement of the albumen flow rate could be applied to determine egg freshness, using 20 mL of albumen placed inside a 22 mL test tube enclosed by the end cap that had been punctured to provide a 4 mm diameter hole. The apparatus is shown in Fig. 7. To perform the measurement, first, the hole on the end cap was blocked with a rubber plug and the test tube was filled with albumen. Then, the plug was removed and the time was recorded for the albumen to completely flow out of the tube. The albumen volume and the recorded time were used to determine the flow rate. This experiment used eggs with a storage period of 2–14 d. The experiment was repeated three times, each time using eggs from one of the three different farms.

Fig. 8 shows the relationship between the albumen flow rate and the storage period, with eggs stored for 2–6 d having a lower flow rate compared to eggs stored for 8–14 d, indicating that the albumen viscosity decreased during storage for 6–8 d.

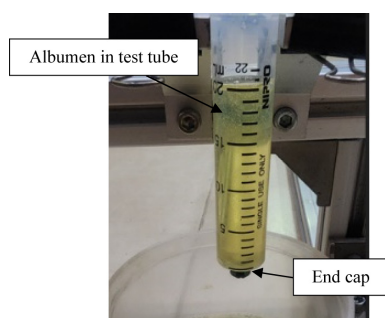


Fig. 7 Measurement setup for determining albumen flow rate using a syringe.

This result agreed with the result from the image processing method above, where the yolk movement speed increased at 6–8 d of storage (Fig. 6). The decrease in the albumen viscosity caused the increase in the yolk movement speed.

Comparison with yolk curve-radius measurement method

The yolk curve-radius measurement method was modified from the yolk index method, (an egg-freshness inspection method). The yolk index was determined based on the yolk curve radius or the ratio between the height and the width of the yolk. Generally, this technique is used to inspect egg freshness, based on the assumption that a fresh egg yolk having greater curvature (a narrow curve radius) than an expired egg yolk. When an egg is stored for an extended period, the yolk becomes flatter (Tatiana et al., 2019). The current study measured the yolk curvature using an image processing technique. The yolk was placed on a clear, flat plate. Then, the camera was used to capture the side-view image of the yolk, which was used in the calculation of the curve radius.

Fig. 9 shows the sideview image of the yolk and the measurement of the yolk curve radius using image processing in the NI Vision Software Suite from National Instruments (National Instruments Corporation, 2025). The yolk image was transformed to grayscale and the circle detection tool was used to determine the yolk radius. Fig. 10 shows the yolk images for different storage periods. The yolk at 12 d of storage was clearly flatter than in the fresh egg, indicating that the curve radius was larger when the storage period was longer.

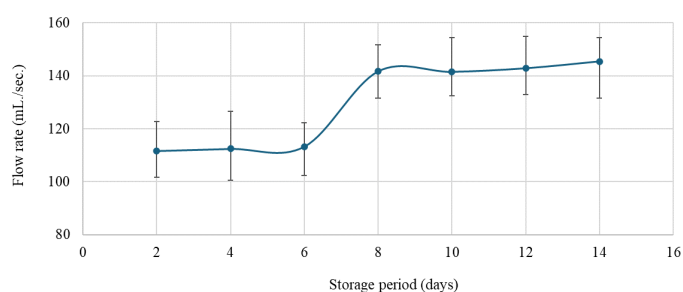


Fig. 8 Albumen flow rate versus storage period, where error bars = ± 11.55 mL/sec.

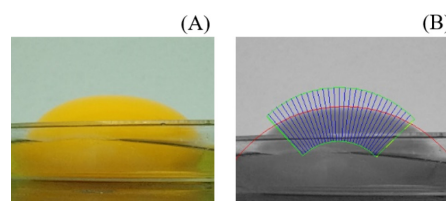


Fig. 9 (A) Sideview image of yolk on flat plate; (B) yolk curve radius determined using image processing method.

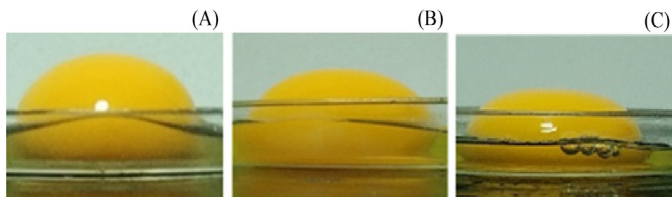


Fig. 10 Yolk images at storage periods of: (A) 4 d; (B) 8 d; (C) 12 d

Fig. 11 depicts the relationship between the yolk curve radius and the storage period. At 2 d and 4 d of storage, the values of the yolk curve radius were comparable. After that, the curve radius increased substantially during 6–8 d and remained relatively constant during 8–15 d. These results agreed with the result from the image processing method (Fig. 6). The yolk curve radius (from the yolk radius measurement method) and the yolk movement speed (from the image processing method) increased at 6–8 d of storage. With a longer storage period, both the yolk curve radius and the yolk movement speed were considerably greater than those of the fresh egg. In summary, the measurement of the yolk movement speed provided consistent results to the measurement of the yolk curve radius; thus, the former could be used to determine egg freshness as well.

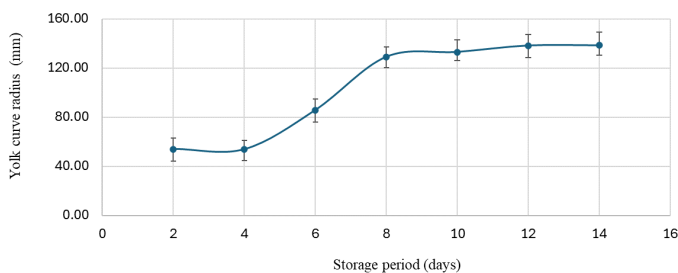


Fig. 11 Yolk curve radius versus storage period, where error bars = ± 9.41 mm.

Discussion

The current study successfully developed a non-destructive method for freshness inspection of unbroken eggs. The method utilized characteristics of the albumen, since its viscosity decreases as the storage period increases (Kemps et al., 2010). Therefore, the yolk movement speed of a fresh egg is slower than that of an old egg. The current study combined an image processing method with specially developed hardware to measure the yolk movement speed. Based on the current results, eggs stored for longer than 6 d had faster yolk movement

speeds than fresh eggs. In addition, the results for the egg samples from the three farms were similar, although there were some differences in the percentage increase in yolk movement speeds between the farms. For days 1–6 of storage, the egg yolk movement speed remained relatively constant (15–20 mm/s). However, after day 6, this speed from all farms tended to increase. Specifically, Farm 2 eggs had a greater increase than for the other two farms; compared to the 1st day, the yolk movement speed on the 14th day increased 105.9% for Farm 1, 108.2% for Farm 2 and 86.2% for Farm 3. These variations could have been due to differences in the care regime and the environmental conditions on the three farms such as poultry food, water and living conditions (Das and Evans, 1992; Adeyemi et al., 2020).

The egg-freshness inspection method developed in the current study was compared with two other traditional methods (measurements of the albumen flow rate and the yolk curve radius, respectively). The results from the currently developed method agreed with the results from both traditional methods (Kemps et al., 2010). Thus, the method developed from the current study could be used for inspecting the egg freshness.

Finally, this non-destructive method could identify expired eggs; therefore, it could be integrated with an automation system for fresh egg inspection that could prevent the usage of defective eggs in the manufacturing process.

Conclusions

The development of a non-destructive egg-freshness inspection system was investigated, based on the observation that the chemical composition of an egg naturally changes during a long storage period that in turn affects the mechanical properties of the egg. In particular, the viscosity of the albumen decreased as the storage period increased. Thus, this property of albumen was used to indirectly determine egg freshness, in combination with an the image processing technique and a lighting method. The egg inspection system measured the yolk movement speed that was inversely proportional to the albumen viscosity. Based on the current results, this method could clearly distinguish eggs stored for 1–6 d from those stored for 8–14 d. Compared to the other traditional methods tested, the current method produced the same results without having to break the egg. In summary, this method could be used to inspect egg freshness, and being non-destructive, it can be developed to the full egg-freshness inspection automation system in food manufacturing.

Conflict of Interest

The authors declare that there are no conflicts of interest.

Acknowledgements

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