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**INSTITUTE OF SCIENCE**

# DETERMINING THE VOLUME OF AIR CELLS IN HEN EGG DURING THE STORAGE TIME

**MASTER DEGREE THESIS**

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This thesis, entitled as **"DETERMINING THE VOLUME OF AIR CELLS IN HEN EGG DURING THE STORAGE TIME"**, prepared by Sonia Sardar Talb under supervision of Asst. Prof. Dr. RAHMI UYAR and Dr. **EMRE BAKKALBAŞI**, has been accepted as thesis study on the date 28/05/2018, as a Master's degree in the Department of Food Engineering at Siirt University, with majority votes by the jury below.

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## LIST OF ABBREVIATIONS

| **Abbreviation** | **Explanation** |
|---|---|
| HU | : Haugh unit |
| SG | : Specific gravity |
| NIR | : Near Infrared spectroscopy |
| MIR | : Mid-infrared spectroscopy |
| Vis–IR | : Visible infrared spectroscopy |
| FT-NIR | : Fourier Transform spectroscopy |
| ANN | : Artificial Neural Network system |
| ANFIS | : Adaptive neuro-fuzzy inference system |
| VIS | : Visible |
| E-nose | : Electronic nose |
| H | : Height of albumen |
| W | : Weight |
| S | : Surface area |
| V | : Volume |
| L | : Length |
| B | : Breadth |
| $CO_2$ | : Carbon dioxide |
| IPM | : Image processing method |
| WMD | : Water displacement method |
| RGB | : Red,Green,Blue |
| $V_C$ | : Volume egg by caliper |
| $V_{IPM}$ | : Volume egg by image processing method |
| $V_{WDM}$ | : Volume egg by water displacement method |
| $L_C$ | : Length of the egg by caliper |
| $L_{IPM}$ | : Length of the egg by image processing |
| $B_C$ | : Breadth of the egg by caliper |
| $B_{IPM}$ | : Breadth of the egg by image processing |
| $h_C$ | : Air cell height by caliper |
| $h_{IPM}$ | : Air cell height by image processing |
| $V_{water}$ | : Volume air cell by water |
| $L_{egg}$ | : Length of the egg |
| $W_{egg}$ | : Weight of the egg |
| $W_{loss}$ | : Weight loss of water |
| $V_{aircell}$ | : Volume of the air cell |
| $V_{egg}$ | : Volume of the egg |
| $h_{aircell}$ | : Air cell height |
| mm | : Millimeter |
| g | : Gram |
| $cm^3$ | : Cubic centimeter |
| nm | : Nanometre |

# ÖZET

## YÜKSEK LİSANS TEZİ

## DETERMINING THE VOLUME OF AIR CELLS IN HEN EGG DURING THE STORAGE TIME

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Yumurtanın boyutunu (uzunluk, genişlik, hava hücresi yüksekliği) elde etmek ve Narushin denklemi ile yumurta hacmini hesaplamak için bir görüntü işleme yöntemi geliştirilmiştir. Çalışmada, hava hücresi yüksekliği görüntü işleme yöntemi ile belirlenmiş ve elektronik kumpas ile manuel olarak ölçülmüştür. Görüntü işleme yöntemi ve manuel ölçüm arasındaki hatalar %10'dan daha az olarak bulunmuştur. Bu çalışmanın amacı, farklı sıcaklık ve depolama sürelerinde yumurtaların kalite parametrelerini tahmin etmektir. Yumurta örnekleri çiftlikte yumurtladıktan hemen sonra ölçüldü ve 10, 25 ve 30$^{o}$ C' lik çeşitli sıcaklıklarda 5, 10, 15 ve 20 günlük depolama süreleri ölçüldü. Yumurta ağırlığı, özgül ağırlık, ağırlık kaybı, hava hücresi yüksekliği ve hacmi, depolama süresi ve sıcaklığından büyük ölçüde etkilendiği görülmüştür. Depolama sırasında su ve bazı organik bileşiklerin kaybına uğrayan yumurtalarda hava boşluğu büyüklüğü tazeliği tahmin etmek için ana ölçümlerden biri olarak kabul edilmektedir. Hava hücresi, kabuğun dış zarı ve iç zarı albümen arasındadır. 20 günlük depolama periyodunda, sırasıyla 10, 25 veya 30 ° C'de saklandığında hava hücresi yüksekliği 4.17, 6.34 ve 7.22 mm olduğu görülmüştür. Yumurtalar 15 gün boyunca 25 ° C'de saklandığında, hava hücresi hacmi 0.80 cm$^{3}$'ü aşmıştır. Benzer şekilde, 5 gün sonra depolama sırasındaki hava hücresi hacmi 30 ° C'de 20 gün sonra 0.42 cm$^{3}$'e 1.82 cm$^{3}$'e arttığı görülmüştür. 20 günlük depolama süresince yumurta ağırlığı ve özgül ağırlığı doğrusal olarak azalmıştır.

## ABSTRACT

## MSc THESIS

# DETERMINING THE VOLUME OF AIR CELLS IN HEN EGG DURING THE STORAGE TIME

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**The Degree of Master of Science**
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In the study, an image processing method was developed to obtain dimensions of the egg and calculate the egg volume by using a formula suggested by narushin, the air cell height was determined by image processing method and measured manually by electronic caliper. The errors were less than %10 between the image processing method and manual measurement**.** The aim of this study was to predict quality parameters of eggs during different temperature and storage time. Egg samples were measured immediately after being laid and storage periods of 5, 10, 15 and 20 days at various temperatures 10, 25 and 30°C. Egg weight, specific gravity, loss of the weight, air cell height and volume were greatly influenced by storage time and temperature. Since during storage the eggs losing water and some organic compounds air room size is considered one of main nondestructive measurement to estimate freshness. The air cell is between the outer membrane of the shell and the inner membrane to the albumen. In 20 days storage period air cell height was 4.17, 6.34, and 7.22 mm when stored at 10, 25, or 30°C, respectively. When eggs were stored for 15 days at 25°C the volume of air cell exceeded 0.80 $cm^3$. Likewise, the air cell volume during storage after 5 days was 0.42 $cm^3$ increased to 1.82 $cm^3$ after 20 days at 30°C. During 20 days of storage egg weight and specific gravity linearly decreased.

Key words: Egg air cell, egg air cell height, egg air cell volume, egg air room, image processing, specific gravity, egg freshness, egg candling.

# 1. INTRODUCTION

## 1.1. Chicken Egg

Egg is an important food in the daily dietary and nutrition that contains proteins, lipids, minerals, vitamins are rich in food items. In the last 35 years, egg production has increased 203.2% in the world because of increased protein requirement in the developing countries (Wu, 2014).

Eggs are a good source of protein that is an elevation biological value. The protein quality of the egg is usually the standard for estimating the quality of all other food proteins. Eggs are a rich source of fundamental unsaturated fatty acids, Linoleic acid, minerals, the fat-soluble vitamins A, D, E, K and the water-soluble vitamins B (Stadelman et al., 1995).

Many biological activities have related to egg compound, including antimicrobial activity, antiadhesive traits, immunomodulatory, anticancer, and antihypertensive activities, antioxidant characteristics, and nutrient bioavailability shows the significance of egg and egg elements for the health of human (Kovacs-Nolan et al., 2005).

Eggs provide a singular, great-balanced source of nutrients for a person of all lifetimes. Eggs provide most of the body's nutrient requirements through rapid growth and are an important food for babies and teens. Eggs are good for any meal; they supply good nutrition with a low-calorie that is essential for person who have problems with weight. (Stadelman et al., 1995).

Eggs have many different functional characteristics such as emulsifying, foaming, gelling, which are eligible for a vast variety of applications in the food industry (Waimaleongora-ek et al., 2009).

## 1.2. Chicken Egg Components

Eggs have three main segments which are yolk, albumen, and shell, also eggshell (9–12%), egg white (60%), and yolk (30–33%). The whole egg consists of water (75%), lipids (12%), proteins (12%), carbohydrates and minerals (1%) (Abeyrathne et al., 2013). These components of the egg are separated from each other by membranes. Albumen and shell separated by shell membrane, and the albumen is separated from the yolk by a vitelline membrane shown on (Figure 1.1.) (Jacob et al., 2000).

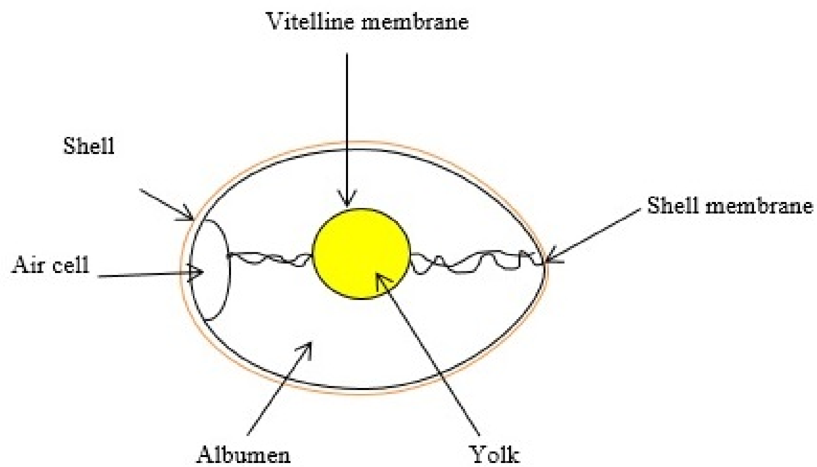



**Figure 1.1.** The parts of the egg

The yolk is in the middle of the egg enclosed by albumen and include about 80% of the calories and all lipids existing in the egg (Al-Obaidi, et al. 2011). Yolk and albumen are fundamentally composed of water, protein, lipids, carbohydrates and minerals, the yolk has 1% carotinoides, it gives the yellow colour to the yolk (Abeyrathne et al., 2013).

The proteins are present mainly in the egg white, yolk and a small ratio in the eggshell. Most of the lipids are in the egg yolk which is in the form of lipoproteins (Kovacs-Nolan, et al. 2005). Carbohydrates are a small amount present in eggs, their rates are around 0.5 g per an egg, they are exist in free forms and are attached with proteins and lipids. Eggs have several minerals such as calcium, magnesium, phosphorus, sulfur, and iron. Most of the minerals, about 95%, exist in the eggshell (Sugino et al., 1996).

The large part of the eggshell contains crystalline calcium carbonate. Approximately 2 to 3% of this calcified layer is an organic matrix composed essentially of protein. In the crystalline layer, penetrate pores allow diffusion gases (Brake et al., 1997). The surface of the eggshell comprises of about 7000 to 17000 pores that permit go outside moisture, carbon dioxide, and air to get inside (Waimaleongora-ek et al., 2009).

### 1.3. Chicken Egg Quality Parameters

Many factors effects of the chicken egg quality such as bird genotype, age, environmental situation and fodder additives (Batkowska et al., 2014).

The most important exterior and interior egg quality parameters are egg weight, shell thickness, breaking strength, specific gravity, air cell, albumen height, albumen weight, Haugh unit and yolk index (Samli et al., 2005).

Haugh units (HU) are the principal method to estimate the internal egg quality (Keener, et al., 2006), the larger values of HU determine the higher quality of the egg (Biladeau and Keener, 2009).

Eggs like meat and milk are perishable food which requires fast cooling and refrigerator treatments through the storage time for preserving good quality. Storage time has a significant effect on the quality of egg such as the loss of weight, change in pH of albumen and yolk (Al-Obaidi et al., 2011).

Egg has many problems during the storage time are the loss of weight, internal quality decline, and microbial contamination. The carbon dioxide and moisture migration from the shell alters albumen, yolk and loss of weight of the egg (Bhale, 2003).

The newborn egg does not have an air gap. When the temperature is cool down, the egg component will shrink and makes the air cell formation (Wang, et al., 2009). Air cell is generally at the large end of the egg, the air space is forming between the outer membrane of the shell and the inner membrane to the albumen the egg loses water through the shell pores by evaporation during storage time, thus causing the air room to increase (Jacob et al., 2000).

The objective of this study is to estimate the volume of air cell in the chicken eggs and showing a relation with the freshness of eggs since air gap is one of the parameters to evaluate egg freshness. Also, investigate the effect of storage time, storage temperature on egg weight and the air space size in the egg.

# 2. LITERATURE REVIEW

Freshness, the properties normally correlated with the quality of egg depends on storage time and temperature. This quality decline is related to the chemical, nutritional, functional, and hygienic changes (Hidalgo et al., 2006).

Freshness is the main quality property of egg and egg products. A significant aim in the food industry is accomplishing a uniform quality of raw materials and the final product. One of the main problems of the egg industry is the automatic assessment of egg freshness (Karoui et al., 2006)

## 2.1. Egg Quality Parameters

The most significant egg quality parameter changes during storage time and temperatures such as HU, albumen height, albumen pH, yolk index, specific gravity (Jin, 2011) and air cell size increases with the loss of water through the shell pores by evaporation and diffuse, $CO_2$ from the egg white (Williams, 1992).

### 2.1.1. The internal egg quality parameters

The internal egg quality parameter is related mostly to the albumen of eggs like albumen quality, albumen height, the pH of albumen and yolk, yolk weigh, yolk width, air cell and Haugh unit.

#### 2.1.1.1. Haugh Unit (HU)

Haugh unit (HU) is calculated from the height of the inner thick egg white and the egg weight by equation (1) (Silversides and Villeneuve, 1994) and it determines the albumen quality (Jin, 2011). Haugh units decline with extending storage time, increasing temperature and hen age (Jones and Musgrove, 2005).

$$HU = 100\log(H - 1.7W^{0.37} + 7.5) \quad (1)$$

Where HU is Haugh unit, H is the height of the albumen in millimeters and W is the weight of an egg in grams, shown on (Figure 2.1.).

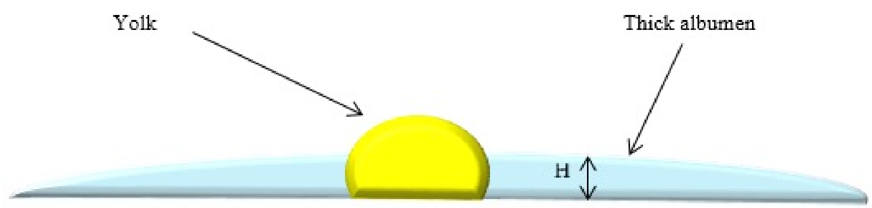



**Figure 2.1.** Haugh unit

Albumen quality is a normative measure of the egg quality. The strain, storage condition, and age of hens are the main factors on the albumen quality. The albumen height and egg weight deteriorates with increasing storage time and storage conditions (Silversides and Scott, 2001).

### 2.1.1.2. The pH of an egg

Albumen pH is in a fresh egg between 7.6 and 8.5. The pH of albumen increases with the loss of $CO_2$ from the egg during the storage time, the buffering ability is weakest at pH 7.5 and 8.5 (Keeneret al., 2000).

The yolk pH is 6.0 and with the addition of carbon dioxide during storage time, the water movement from the albumen to the yolk is delayed. When storage temperature decreased the movement of water reduces from the albumen to yolk (Akyurek and Okur, 2009).

Kemps, et al. (2007) investigated three important physical and chemical properties for measurement of the freshness of albumen; the air cell height, pH of albumen and viscosity. The air cell height and pH of the albumen are raised with storage time and temperature. The increase in air cell height is caused by the water evaporation and the pH of albumen must be increased by loss of CO2 from an egg through the eggshell pores. Also, the albumen viscosity decreased and the vitelline membrane got thinner during storage time.

#### 2.1.1.3. Air cell of the egg

The egg contains two shell membranes separate, air cell is generally at the large end of the egg, the air space is forming between the outer membrane of the shell and the inner membrane to the albumen. The egg loses water through the shell pores by evaporation during storage, thus causing the air gap to enlarge. When the inner shell membrane is damaged the air gap moves freely to any part of the egg. Candling tool used to decide the internal egg quality and measuring the air cell. The benefits of candling have been quick and nondestructive. Accurate candling can be accomplished via means of passing light through each egg in a dark place (Jacob et al., 2000).

The air cell height is most common indices used to estimate the egg freshness affected by egg weight, storage humidity, and temperature (Hidalgo et al., 2006). Air cell height is the only parameter to estimate the egg freshness regarded by the European Union, regulation relies on the egg weight (Rossi, et al. 2013). Up to expiring date grade A, egg air cell height has to be less than 6 mm. The air cell height depends on the storage conditions, relative humidity and temperature (Karoui et al., 2006).

### 2.1.2. The external egg quality parameters

The external quality parameter is related mostly to the eggshell and egg dimensions such as specific gravity, shell weight, shell thickness, length, width and weight of the egg.

#### 2.1.2.1. Specific gravity

Specific gravity (SG) is one of the most common methods for measuring shell strength. SG increases with increasing the shell thickness and strength since SG of an egg is related to the ratio of the egg shell (Hamilton, 1982).

The specific gravity of eggs gradually decreased with storage time and storage temperature. The specific gravity of eggs kept at room temperature decreases more than eggs, which are kept the refrigerating temperature (Akter et al. 2014).

Hamilton (1982) measured the specific gravity of the egg by Archimedes' principle, the egg is weighed in the air, after that immersed in the water and reweighed at room temperature. The difference between the weight of egg in the air and in water is the weight displaced of water by equation (2). It is equal to the volume of egg.

$$SG = \frac{(Egg\ weight\ in\ air)}{((Egg\ weight\ in\ air) - (Egg\ weight\ in\ water))} \quad (2)$$

In another study, the saline flotation technique was used to estimate specific gravity by the sequential immersion of eggs in a series of salt solutions of rising density (Hempe, et al. 1988).

#### 2.1.2.2. Egg geometric parameters

Bird eggs lose weight after they are laid, but their volume and dimensions do not change through storage period. The volume of an egg can be evaluated within 2% error from the relation: where L and B are length and breadth of the egg (Hoyt, 1979).

$$V = 0.51\ LB^2 \quad (3)$$

Egg geometric computations of volume and surface areas are essential for the poultry industry and in biological studies. Narushin (2005) tried to develop precise calculations of egg volume and surface area based on the estimation of the egg length and width by equation (4). The resulting formula for egg volume is V, L and B is the egg length and breadth in millimeters.

$$V = (0.6057 - 0.0018B)LB^2 \quad (4)$$

The egg surface area is S, in which both L and B are the length and breadth of eggs in millimeters by equation (5) (Narushin, 2005).

$$S = (3.155 - 0.0136L + 0.0115B)LB \quad (5)$$

## 2.2. Evaluation The Egg Freshness

### 2.2.1. Spectroscopic techniques

Karoui et al., (2006) studied to measuring egg freshness by destructive and non-destructive techniques. Destructive egg freshness was estimated by sensory evaluation and physical-chemical methods such as Haugh unit, air cell and the pH of albumen. Non-destructive egg freshness determination techniques are near-infrared, mid-infrared and fluorescence spectroscopies.

Near Infrared (NIR) spectroscopy is non-destructive measures, good and a fast technique with great use in the food industry and for quality evaluation of eggs. As well, NIR spectroscopy technique is an important tool to evaluate the chemical and physical characteristics of eggs, eggshell and interior quality of the egg. NIR spectroscopy is used transmittance mode (530-1130 nm) for estimation the egg freshness (Galiş et al., 2012).

Mid-infrared (MIR) spectroscopy is used to predict the eggshell quality parameters and the shell strength characteristics such as shell thickness, shell percentage, shell weight and shell fracture force. Mid-infrared showed precise prediction for all shell parameters, shell thickness is the best parameter measured by (MIR) technique and the correlation coefficient is 0.52 (Narushin et al., 2004).

Fluorescence spectroscopy is used to determine quality changes during storage times, also used for measurement of the animal products and vegetable quality such as dairy, meat, egg, cereal, sugar, and fruit. Karoui and Blecker, (2011) used fluorescence spectroscopy to monitor the egg freshness during long storage time. Also, recorded the thick and thin albumen of the egg, the difference between the fresh and egg age.

Mehdizadeh et al., (2014) studied to evaluate the internal quality of egg freshness during storage time, temperature and relative humidity by the visible infrared (Vis–IR) (400–1100 nm) transmittance. The Vis–IR spectroscopy is a non-destructive technique used to egg quality classification mixed with mathematical pre-processing to develop an intelligent system. This is accomplished egg quality taxonomy based on egg interior quality during storage. The grading process automation is significant for quality control, to decrease costs and lessen the workload on grades.

Visible (VIS) and near infrared (NIR) spectroscopy are a fast and non-destructive technique for evaluation of egg quality. Visible/near infrared transmission spectroscopy is a good instrument for prediction of egg freshness, pH of albumen, HU, during storage times. The VIS and NIR are used spectral range from 411 to 1.729 nm (Abdel-Nour et al., 2011).

Kemps et al., (2006) determined the freshness of egg by the visible transmission spectroscopy and compared the non-destructive spectral measurement with destructive measurement for two widely parameters used to define freshness, i.e. Haugh units and the pH of albumen.

Kemps et al., (2007) assessed the potential of visible near-infrared transmission spectroscopy and low-resolution proton nuclear magnetic resonance to estimate albumen freshness, which can be carried out a good evaluation of albumen freshness.

Fourier Transform (FT-NIR) spectroscopy is Non-destructive freshness estimation for egg shells and rating through storage and characterized by different rearing system. FT-NIR spectroscopy is used spectral range 833–2500 nm on egg samples (Giunchi et al., 2008).

### 2.2.2. Machine vision techniques

Egg grading equipment can grade, today, up to 180.000 eggs/hour, that amount of order cannot be controlled individually by a trained human eye. This can be achieved by specially developed sensor devices to estimate one or more quality aspects of the graded eggs. In general, three various techniques can be special for non-invasive assessment of product quality which are mechanical measurements, spectroscopic measurements, and vision techniques (Bamelis et al., 2006).

Machine vision is a non-destructive system that includes image analyses and image processing methods that are used to volume grading of farming products (Asadi et al., 2012).

Yolk index and air cell height are major parameters to define the egg freshness, are very hard to be precisely estimated in practices. Wang, et al., (2009) measured egg freshness and obtained an image of the egg by computer vision device. The yolk area and air cell area are detached from the egg photo by an image processing. The pixel regions and lengths of the feature areas are counted and analyzed respectively. Image processing system can readily define the distance among the yolk and albumen index that estimate the egg freshness. Also, this system can be calculated and compared to the parameter of a fresh egg with standard determined dimensions (Avinash et al., 2017).

Zhang et al., (2016) used machine vision and three-dimensional modeling to estimate geometric parameters of egg volume and surface area which have great importance in the poultry industry. Machine vision has a precise measurement compared with the traditional methods since measurement error is less than 1%.

To calculate volume and surface area of ellipsoidal agricultural products (eggs, lemons, limes, and peaches) an image processing method was developed and the results showed a good agreement with analytical and experimental data. The developed method proved to be accurate, precise, and easy to use. The difference of the results between volume data obtained by the image processing method and the water displacement method is around 10% (Sabliov et al., 2002).

Computer vision system has the ability for categorizing and can determine the properties of food products like color, shape, size, surface flaws. Computer vision system has some advantages such as rapid, ease of use and the minimum sample preparation. Hence, computer vision system is widely used for food-quality evaluation, including for meat products, fruit and vegetable, cheese, nuts, grains, and eggs. Computer vision systems are used to determine micro cracks in eggshells, this system is achieved with precision results 100% (Ma et al., 2016).

Jones et al., (2010) used modified pressure and image processing to determine micro cracks in eggs during cold storage with the precision of 99.6% in detecting cracked and intact eggs. The shell is the first line of protecting the egg from exterior bacterial contamination. Cracks in the eggshell surface expose food safety concerns for users more than intact eggs since large cracks in the shell can be seen easily by the human eyes or with lighting candling. Micro cracks are tiny cracks in the eggshell surface these are hard to see by human graders.

Egg size is one of the most significant characteristics of egg and decided by consumers. Soltani et al., (2015) used machine visions to evaluate the volume of the egg without measuring the egg weight. Two developed ways are used to predict egg size; a mathematical model is suggested based on Pappus theorem and Artificial Neural Network (ANN) system, these methods determine the egg volume and compared statistically. For the mathematical model the correlation coefficient, mean and maximum absolute error values are obtained as 0.993, 1.41 $cm^3$ and 1.69 $cm^3$. For Artificial Neural Network (ANN) system, the correlation coefficient, mean and maximum absolute error values are obtained as 0.990, 0.89 $cm^3$ and 2.06 $cm^3$ (Soltani et al., 2015).

Severa et al., (2013) estimated the eggshell geometry using new process by analyzing the egg digital image and edge discovery techniques. The points detected on the eggshell contour by the Fourier series, and the obtained equation which describes an egg are used to measure the volume of egg, surface area, and radius curve with a higher degree of accuracy.

In the poultry industry the main unit for controlling egg process lines is egg mass estimation. Asadi et al., (2012) used a machine vision technique to determine the size properties of eggs and calculating the mass of eggs by multi regression analysis. The correlation coefficient between eggs mass measured and predicted by machine vision is around 95%.

Alikhanov et al., (2015) suggests an algorithm for egg weight prediction and egg geometric parameters using machine vision system and compared with the traditional method based on displacement of water and the error value is less than 10%.

Omid, et al., (2013) studied machine vision technique, fuzzy logic inference and Simulink instruments to classify egg and egg parameters such as blemish and egg size. Also, it detects interior blood spots, cracks, and breakage of the eggshell. Image processing technique showed a good result for defects and size detection.

The most important parameter in calibration, transportation, producing and packaging systems is physical properties of agriculture products. In sizing systems most, important physical properties are volumes, mass, surface area, and center of gravity. Fellegari and Navid (2011) used image processing method (IPM) for measuring the volume of the orange and compared with measuring volume by water displacement method (WMD). Then using the T-test evaluation shows there is no significant difference between the two methods.

In food processing manufacturing, the egg weight in the real-time measurement is a big problem. Javadikia et al., (2011) estimated the width and length of an egg by real-time image processing and find the best relation between image processing and the weight of eggs by ANFIS (adaptive neuro-fuzzy inference system). The correlation coefficient between the experimental value for the egg weight and measured value by (ANFIS) model is 0.9942.

### 2.2.3. Other techniques to egg freshness measurement

Eggshell cracks are determined by sound signals with dynamic frequency analysis, the frequency domain can be used for classifying the intact and crack of the eggs, it is the better way for detecting cracked eggs (Wang and Jiang 2005).

Yongwei et al., (2009) developed an electronic nose (E-nose) technique for observation of egg storage time and quality characteristics of eggs. The prediction models for Haugh unit and yolk factor showed a good prediction performance. The correlation coefficient for Haugh unit is 0.91 and yolk factor is 0.93.

Yimenu et al., (2017) investigated egg freshness prediction model in terms of weight loss, HU, albumen index and yolk index. The model can be used during variable storage temperature situations.

# 3. MATERIAL AND METHOD

## 3.1. Material

In the study, the eggs were obtained from a chicken farm near Siirt University,and evaluated to calculate dimensions of the eggs and eggs air cell by two different methods. Hot incubator (WTB binder, D-78532 Tuttlingen), miprolab laboratory machine (mçi series incubator / mçi-120), cool incubator (VELP SCIENTIFICA, F-10300310), electronic caliper (WORK ZONE -1.55V), sensitive balance (Shimadzu-ATX224), distil water machine (Mini Pure 1, MDM-0170), candle (Black Watton, WT-037), humidity meter (HTC-2), digital humidity and temperature meter (ZenJi S-002), cell phone (iPhone7, A-1779), cell phone stand (YUNTENG, YT-228), special box, injection, and beaker.

Eggs were obtained from Brown hens in a chicken farm. Fresh eggs were measured within 1.30 h of being laid. Directly after collection, eggs were labelled and weighted by using a sensitive balance and the egg samples were stored in the incubator for terms of 0, 5, 10, 15, and 20 days in cool incubator 10°C, at 25°C and in hot incubator 30°C temperature. Humidity in cool incubator 10°C was (62 - 80%), at 25°C was (37 - 53%) and in hot incubator 30°C temperature was (22 - 36%) during all period storage days. To determine the effect of storage time and temperature on the egg quality parameters specific gravity, loss of the weight, the volume of eggs and volume of air cell in the eggs were calculated.

## 3.2. Method

### 3.2.1. Measuring volume of eggs

Volume of the egg was calculated by different methods which are the water displacement method (WDM) based on Archimedes principle, image processing method and the electronic caliper was used to measure the dimensions (length and breadth) of eggs, after obtained the dimensions used to calculate the volume of eggs by Narushin equation (2005).

#### 3.2.1.1. Water displacement method (Archimedes Principles)

Volume of the egg was calculated by the traditional method based on the displacement of water. Displace of water was weighted by sensitive balance and divided to the density of water at specified temperature, to calculate the volume of an egg as shown in the (Figure 3.1.).

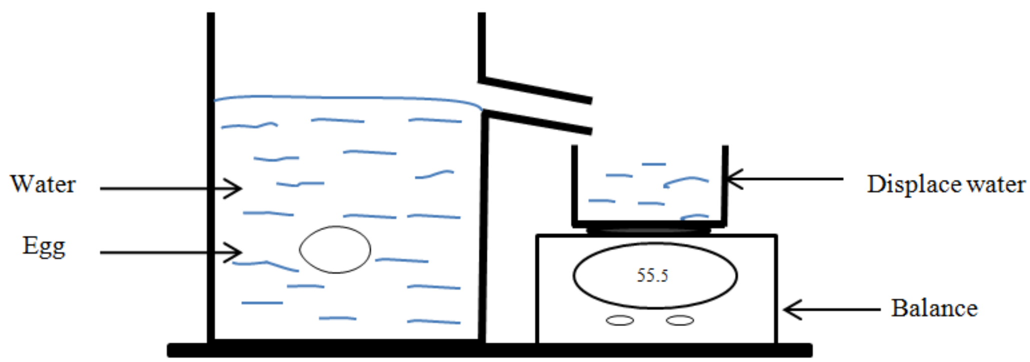



**Figure 3.1.** Archimedes principles of the egg volume measurement

#### 3.2.1.2. Measuring dimensions of the egg by electronic caliper

The dimensions of eggs were measured by electronic caliper. This measurement was used to calculate the volume of eggs, by equation (4) which is suggested by Narushin (2005), shown on (Figure 3.2.).

$$V = (0.6057 - 0.0018B)LB^2 \quad (4)$$

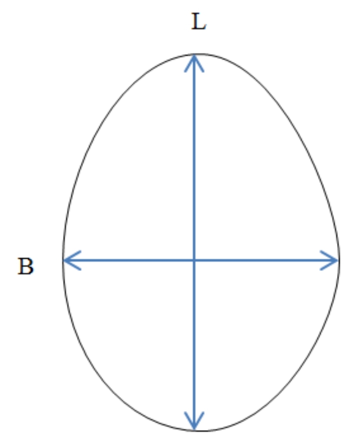



**Figure 3.2.** The egg dimensions measurement by electronic caliper

### 3.2.1.3. Measuring volume of egg with image processing

In the image processing method a was used a special box for candling to take a proper image. From the image to obtain dimensions of the egg MATLAB software used to measure the minor axis and major axis. The geometric egg parameters used to calculate the volume of the egg according the Narushin equation (2005).

#### 3.2.1.3.1. Image acquisition

To take images a special candling system must be used; a customised box was prepared (Figure 3.3.). In this special box, the light was put under location of the sample egg. The high resolution of images obtained with camera (iPhone 7). For calibration the same camera, light positions used for all sample sets. Images were processed by MATLAB software version 8.4.0.150421 (R2014b). Images were taken immediately after determining dimensions of the egg by electronically caliper and each image were also recorded.

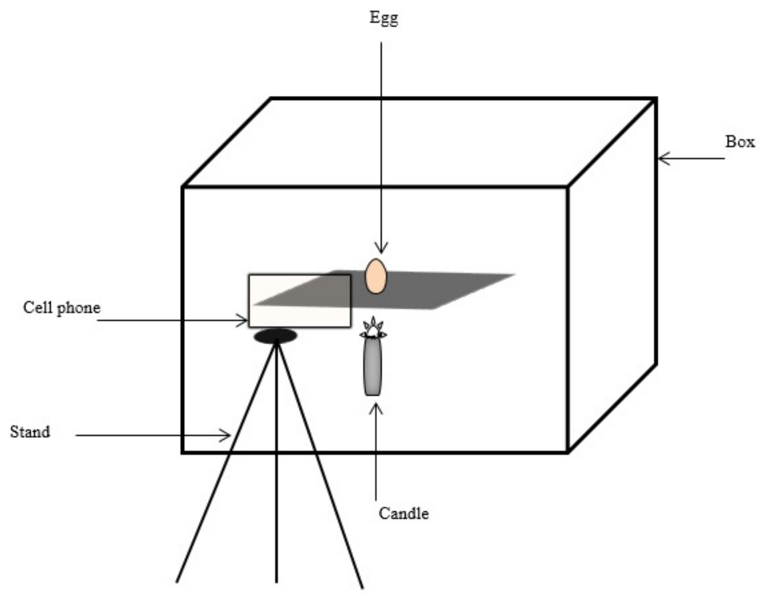



**Figure 3.3.** Image acquisition box to measure egg volume and air cell height

#### 3.2.1.3.2. Measuring dimensions of the egg in image processing

In this step, the aim was to obtain a convenient image of the object to get dimensions of the egg. All images have three main colours  Red, Green and Blue (RGB). The Matlab algorithm is shown at (Figure 3.4.) After acquiring the image, at first, the image (RGB) was converted to Gray image (step 3 in fig 3.4.) and Gray image was converted to a binary image by making the threshold for each egg samples (step 4 in fig 3.4). The binary image was two parts of pixels; the white was an object pixel and a black was the background pixel, then filtered and cleared of the noise in a binary image. After that, the geometric egg parameters were calculated by Matlab function *regionprops* shown on (step 5 in fig 3.4). Geometric egg parameters for egg images are the minor axis and major axis which are used to calculate the volume of the egg shown on (Figure 3.5.).

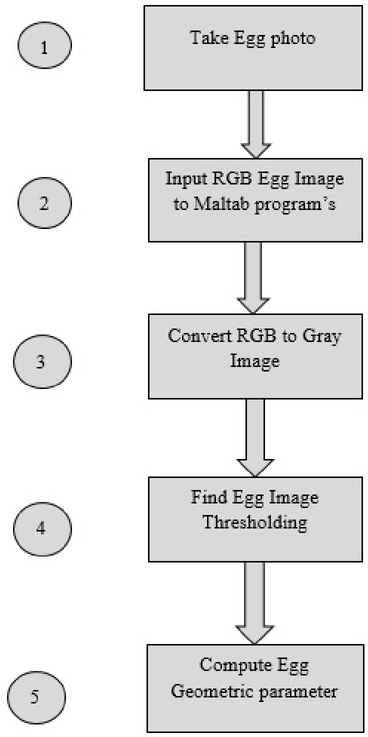



**Figure 3.4.** Block diagram to measure egg volume and air cell height by image processing

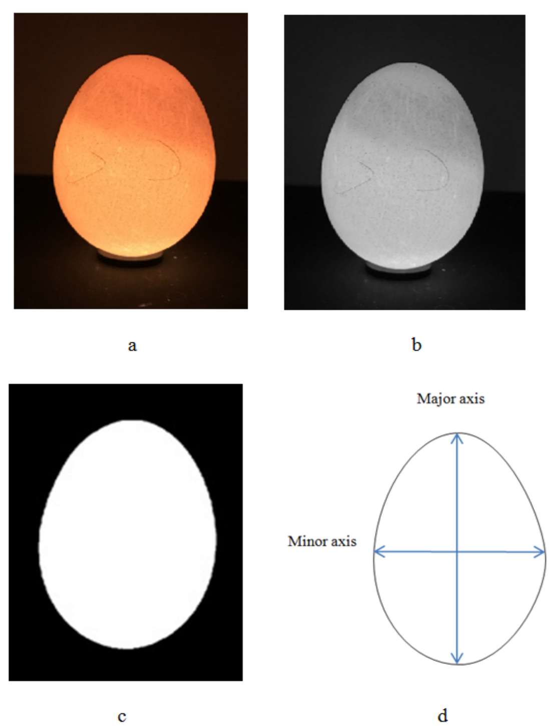



**Figure 3.5.** Main steps of egg volume measurement in the image processing. a)RGB egg image, b) gray egg image, c) binary egg image, d) geometric parameters calculation.

In the image processing function of Matlab software, the egg length and breadth were calibrated in pixel these were converted to millimeter by using actual dimensions. Determining two coefficients $K_x$ and $K_y$ provide millimetres corresponding to one pixel in x and y directions;

$$K_y = \frac{L}{P_y}$$

$$K_x = \frac{B}{P_x}$$

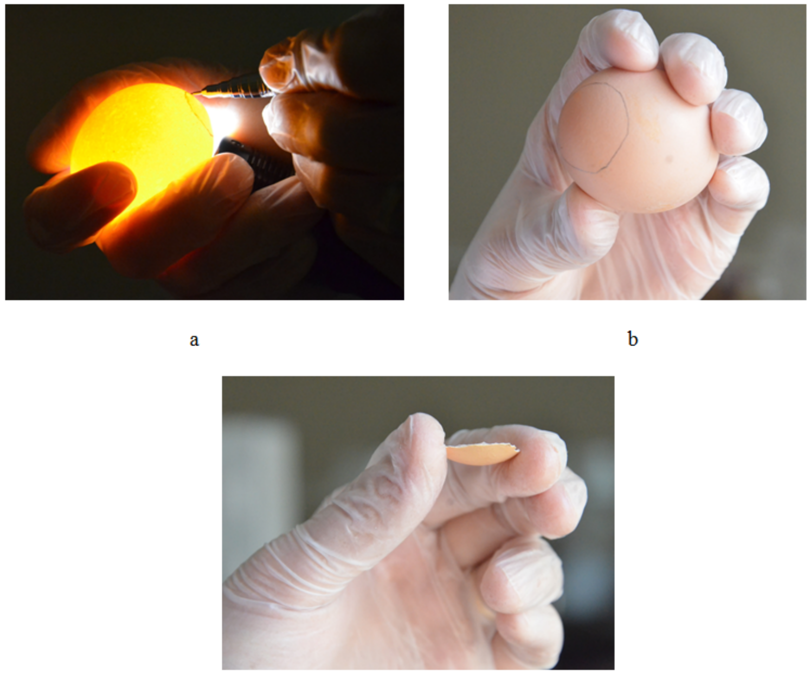
Where L and B, (mm) are actual lengths measured by electronic caliper. $P_x$, $P_y$: the numbers of pixels in direction X and Y corresponding to the egg dimensions.

### 3.2.2. Measuring air cell volume in the egg

The air cell region was determined in the dark place by candle and the line drawn around the air cell for all period storage day 0, 5, 10, 15 and 20 days at 10, 25, and 30°C. Image processing method was used to measure the air cell height by the candling system and a special box to take a clear image of air cell in the eggs. At the end of storage, eggs were broken and measured air cell height by electronic caliper. After that, the volume of the air cell was calculated by the weight of water.

#### 3.2.2.1. Measuring air cell height in the egg by electronic caliper

The area of air cell in the egg was determined in the dark place by candle and the line drawn around the air cell for all period storage day 0, 5, 10, 15 and 20 days (Fig 3.6-a). The air cell couldn’t be seen in the new egg born by a candle in the dark place. In the last day of storage, eggs were broken and measured the air cell height by electronic caliper shown on (Figure 3.6.).



a b

c

**Figure 3.6.** Main steps of air cell height measurement by electronic caliper

#### 3.2.2.2. Measuring air cell height in the egg by the image processing

The air cell height was determined by using the candling system with a special box to obtain the proper image. Egg pictures were obtained and imported to Matlab software. The image processed according the diagram as shown on (Figure 3.4.) and the height of air cell measured during storage period. To obtain  clear image of air cell of the eggs , the light source should be kept close to egg air cell region shown on (Figure 3.7.). In the image processing, the air cell height was calibrated in pixel, it was converted to milimeter by using actual measurement. Determining coefficient $K_y$ provide a milimeter corresponding to one pixel in y directions;

$$K_y = \frac{h}{P_y}$$

Where h, (mm) is the air cell height in the egg of the actual calibrate by electronic caliper.  $P_y$: the number of pixel in direction of Y corresponding to the air cell height in the egg.

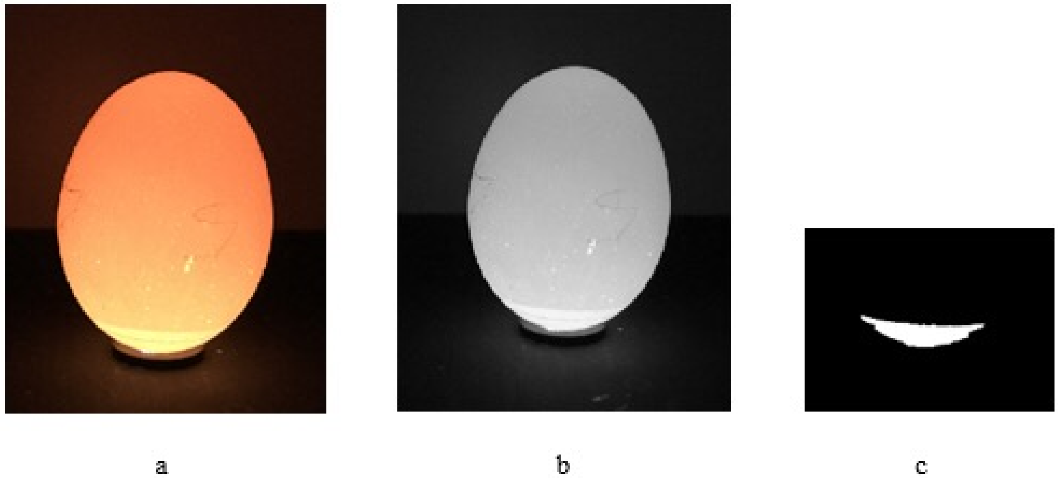
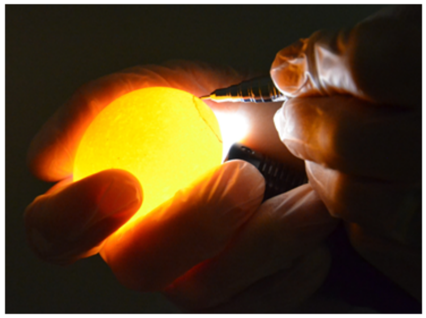



**Figure 3.7.** Main steps of air cell height measurement in the image processing
a) RGB egg image, b) gray egg image, C) binary air cell height image.

### 3.2.2.3. Measuring air cell volume by weight of water

A volume of the air cell was calculated by the weight of water for a period of storage days. The distill water was put in the air cell by injection (step c in figure 3.8.) and weighted. The weight of water was divided to the density of water at specified temperature, to calculate the air cell volume shown on (Figure 3.8.).



a

b

c

**Figure 3.8.** Main steps of air cell volume measurement by weight of water in the air cell

### 3.2.3. Measuring the loss of weight

Eggs were weighed for periods of 0, 5, 10, 15 and 20 storage days by sensitive balance, the egg weight loss calculated a difference between the egg weight during the storage days.

### 3.2.4. Measuring specific gravity

In this study, the specific gravity of eggs were determined by Archimedes principles for periods of 0, 5, 10, 15 and 20 storage days, eggs were weighed in air after that they were immersed in water reweight by sensitive balance at room temperature shown on (Figure 3.1.). Calculation of Archimedes principle shows difference between the egg weight in air and in water is the weight of water displaced. SG was defined by equation (2):

$$SG = \frac{(Egg\ weight\ in\ air\ )}{((Egg\ weight\ in\ air\ ) - (Egg\ weight\ in\ water))} \quad (2)$$

# 4. RESULT AND DISCUSSION

In this study, obtained results for egg quality parameters are egg volume, air cell height and volume, loss of weight and the specific gravity by different methods are the water displacement method, image processing method and manuel measuring by electronic caliper.

## 4.1. Egg Volume Measurement

Egg volume obtained results in this study by three methods. The first, volume obtained by water displacement method (WDM) based on Archimedes principle. The second measured the dimensions of the egg by electronic caliper and image processing method. Based on obtained dimensions (length and breadth) Narushin equation (2005) has been used to calculate egg volume. The errors were under 10% between the volumes calculated from WDM and dimensions (length and breadth) obtained from image processing method and electronic caliper by Narushin equation (Table 4.1.).

**Table 4.1.** Volume of egg obtained by caliper, image processing and the weight displacement method

| | Egg volume by Narushin equation | | | | | | Archimedes' principles | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $V_C$ | | | $V_{IPM}$ | | | $V_{WDM}$ | Error % | | |
| Egg number | L(mm) | B(mm) | V(cm$^3$) | L(mm) | B(mm) | V(cm$^3$) | V(cm$^3$) | $L_C$&$B_{IPM}$ | $B_C$&$B_{IPM}$ | $V_{IPM}$&$V_{WDM}$ |
| 1 | 57.92 | 43.79 | 58.52 | 58.00 | 44.22 | 59.67 | 55.99 | 0.13 | 0.99 | 1.97 |
| 2 | 59.27 | 45.11 | 63.26 | 58.57 | 45.30 | 62.99 | 62.56 | 1.18 | 0.42 | 0.42 |
| 3 | 58.28 | 42.13 | 54.81 | 57.97 | 42.33 | 55.00 | 55.86 | 0.52 | 0.47 | 0.35 |
| 4 | 57.56 | 42.33 | 54.61 | 58.05 | 42.85 | 56.33 | 56.00 | 0.85 | 1.23 | 3.15 |
| 5 | 54.30 | 42.77 | 52.52 | 54.09 | 42.86 | 52.52 | 51.68 | 0.39 | 0.21 | 0.00 |
| 6 | 59.88 | 45.29 | 64.38 | 59.61 | 45.01 | 63.37 | 63.99 | 0.45 | 0.61 | 1.58 |
| 7 | 53.56 | 42.19 | 50.51 | 53.43 | 41.93 | 49.80 | 51.68 | 0.25 | 0.62 | 1.40 |
| 8 | 59.07 | 42.71 | 56.98 | 58.71 | 42.60 | 56.35 | 55.85 | 0.61 | 0.27 | 1.10 |
| 9 | 58.40 | 41.92 | 54.42 | 57.66 | 41.53 | 52.79 | 53.72 | 1.27 | 0.94 | 2.98 |
| 10 | 54.47 | 42.42 | 51.88 | 53.66 | 41.93 | 50.02 | 50.18 | 1.49 | 1.15 | 3.59 |
| 11 | 58.55 | 42.54 | 56.06 | 58.26 | 42.66 | 56.07 | 56.80 | 0.50 | 0.28 | 0.02 |
| 12 | 55.70 | 41.60 | 51.17 | 54.94 | 41.12 | 49.39 | 50.60 | 1.36 | 1.16 | 3.48 |
| 13 | 57.15 | 39.92 | 48.62 | 56.31 | 39.78 | 47.60 | 48.32 | 1.47 | 0.34 | 2.10 |
| 14 | 56.53 | 42.67 | 54.44 | 56.34 | 42.44 | 53.72 | 54.34 | 0.33 | 0.54 | 1.32 |
| 15 | 56.70 | 43.24 | 55.96 | 56.46 | 43.52 | 56.38 | 56.24 | 0.43 | 0.64 | 0.76 |
| 16 | 53.57 | 42.02 | 50.14 | 52.83 | 41.81 | 48.98 | 49.65 | 1.38 | 0.51 | 2.30 |
| 17 | 55.49 | 42.82 | 53.78 | 54.95 | 42.63 | 52.84 | 54.00 | 0.97 | 0.43 | 1.76 |
| 18 | 55.00 | 42.24 | 51.98 | 54.45 | 42.11 | 51.16 | 51.40 | 0.99 | 0.32 | 1.57 |
| 19 | 61.00 | 43.09 | 59.82 | 60.60 | 42.78 | 58.64 | 59.97 | 0.66 | 0.71 | 1.97 |

$V_C$ = volume egg measurement the dimensions by caliper. $V_{IPM}$ = volume egg measurement the dimensions by image processing method. $V_{WDM}$ = volume measurement by water displacement method based on the Archimedes' principles. $L_C$= length of the egg by caliper. $L_{IPM}$= length of the egg by image processing. $B_C$= breadth of the egg by caliper. $B_{IPM}$= breadth of the egg image processing.

## 4.2. The Air Cell Volume Calculation

Air cell height is one of the parameters of the egg freshness and it is affected by storage time and temperature. In this study air cell height was obtained from image processing method and measured by electronic caliper, error was less than 10% (Table 4.2.). Image processing is a non-destructive assessment method, can be measured the dimensions of the egg automatically, easy to use, fast speed, and precise.

**Table 4.2.** Air cell height obtained from image processing method and electronic caliper

| Egg number | Air cell height (mm) | | Error % |
|---|---|---|---|
| | $h_C$ | $h_{IPM}$ | $h_C$ & $h_{IPM}$ |
| 1 | 3.24 | 3.29 | 1.64 |
| 2 | 3.49 | 3.49 | 0.14 |
| 3 | 3.68 | 3.62 | 1.62 |
| 4 | 3.25 | 3.25 | 0.03 |
| 5 | 3.23 | 3.27 | 1.33 |
| 6 | 3.67 | 3.65 | 0.41 |
| 7 | 3.40 | 3.55 | 4.46 |
| 8 | 3.50 | 3.62 | 3.42 |
| 9 | 3.79 | 3.72 | 1.97 |
| 10 | 3.87 | 3.87 | 0.08 |
| 11 | 3.33 | 3.47 | 4.23 |
| 12 | 3.39 | 3.37 | 0.58 |
| 13 | 3.48 | 3.70 | 6.21 |
| 14 | 3.11 | 3.09 | 0.73 |
| 15 | 3.15 | 3.14 | 0.33 |
| 16 | 3.30 | 3.33 | 0.85 |
| 17 | 3.44 | 3.54 | 2.86 |
| 18 | 3.88 | 3.86 | 0.54 |
| 19 | 3.97 | 4.09 | 3.02 |

$h_C$ = Air cell height measurement by caliper,
$h_{IPM}$ = Air cell height measurement by image processing method.

## 4.3. Effect of Storage Time and Temperature on The Egg Quality Parameters

In this study, 10 samples were used for each at 10, 25 and 30°C groups stored for 20 days and the mean values, standard deviations of the results presented in (Table 4.3). Storage time and temperature affected almost all parameters of internal (Egg weight, loss of weight and air cell size) and external quality parameters (specific gravity) in the study investigated. Egg weight, specific gravity reduced with increased of the storage time and temperature. The loss of weight, air cell size was increased by extended storage time and temperature.

**Table 4.3.** Effects of storage time and temperature on the egg quality parameters

| Storage Day | Storage temperature | Air cell height (mm) | | Air cell volume ($cm^3$) | Loss weight (g) | Specific gravity | Egg weight (g) |
|---|---|---|---|---|---|---|---|
| | | $h_C$ | $h_{IPM}$ | $V_{water}$ | | SG | W(g) |
| Fresh egg | 10°C | - | - | - | - | 1.074±0.022 | 56.43±3.75 |
| 5 | | 2.26±0.29 | 2.23±0.30 | 0.15±0.03 | 0.21±0.03 | 1.070±0.022 | 56.22±3.74 |
| 10 | | 2.96±0.26 | 2.95±0.26 | 0.24±0.04 | 0.42±0.06 | 1.066±0.022 | 56.00±3.73 |
| 15 | | 3.57±0.32 | 3.69±0.49 | 0.38±0.06 | 0.64±0.09 | 1.062±0.022 | 55.79±3.72 |
| 20 | | 4.17±0.35 | 4.64±0.82 | 0.54±0.07 | 0.85±0.12 | 1.057±0.022 | 55.58±3.71 |
| Fresh egg | 25°C | - | - | - | - | 1.080±0.014 | 55.73±2.81 |
| 5 | | 2.26±0.29 | 2.25±0.28 | 0.32±0.08 | 0.68±0.07 | 1.067±0.015 | 55.06±2.81 |
| 10 | | 3.72±0.37 | 3.71±0.40 | 0.56±0.13 | 1.39±0.16 | 1.053±0.017 | 54.34±2.83 |
| 15 | | 5.16±0.53 | 5.18±0.61 | 0.82±0.26 | 2.09±0.25 | 1.040±0.018 | 53.64±2.85 |
| 20 | | 6.34±0.88 | 6.46±1.01 | 1.26±0.11 | 2.90±0.36 | 1.024±0.020 | 52.83±2.88 |
| Fresh egg | 30°C | - | - | - | - | 1.093±0.029 | 55.63±3.06 |
| 5 | | 3.69±0.37 | 3.72±0.37 | 0.42±0.11 | 1.13±0.15 | 1.070±0.026 | 54.49±3.06 |
| 10 | | 4.66±0.70 | 4.62±0.76 | 0.76±0.12 | 2.31±0.31 | 1.047±0.024 | 53.31±3.07 |
| 15 | | 5.99±0.74 | 5.96±0.73 | 1.22±0.28 | 3.51±0.48 | 1.023±0.022 | 52.11±3.09 |
| 20 | | 7.22±0.77 | 6.91±1.36 | 1.82±0.23 | 4.80±0.65 | 0.998±0.021 | 50.83±3.12 |

$h_C$ = Air cell height measurement by caliper, $h_{IPM}$ = Air cell height measurement by image processing method. $V_{water}$ = Air cell volume measured by water. SG = Specific gravity.

In the study the ratio between air cell height and length of the egg ($h_{aircell}$ / $L_{egg}$), volume air cell and egg volume ($V_{aircell}$ / $V_{egg}$) and the ratio between loss weight of the egg and the weight of egg ($W_{loss}$ / $W_{egg}$) obtained. Storage time and temperature effect on the ratio of egg quality parameters are displayed in (Table 4.4.). The ratio of loss weight, air cell height and volume got larger when storage duration and temperature increased.

**Table 4.4.** Effects of storage time and temperature on the ratio egg quality parameters

| Storage Day | Storage Temperature | $W_{loss}$ / $W_{egg}$ | $h_{aircell}$ / $L_{egg}$ | $V_{aircell}$ / $V_{egg}$ |
|---|---|---|---|---|
| Fresh egg | | – | – | – |
| 5 | | 0.004 | 0.041 | 0.003 |
| 10 | 10°C | 0.008 | 0.054 | 0.005 |
| 15 | | 0.011 | 0.065 | 0.007 |
| 20 | | 0.015 | 0.076 | 0.010 |
| Fresh egg | | – | – | – |
| 5 | | 0.012 | 0.041 | 0.006 |
| 10 | 25°C | 0.025 | 0.068 | 0.011 |
| 15 | | 0.038 | 0.094 | 0.016 |
| 20 | | 0.052 | 0.116 | 0.024 |
| Fresh egg | | – | – | – |
| 5 | | 0.020 | 0.067 | 0.008 |
| 10 | 30°C | 0.042 | 0.084 | 0.015 |
| 15 | | 0.063 | 0.108 | 0.024 |
| 20 | | 0.086 | 0.131 | 0.035 |

$W_{loss}$ = loss weight of the egg. $W_{egg}$ = weight of the egg. $h_{aircell}$ = air cell height.
$L_{egg}$ = length of the egg. $V_{aircell}$ = volume of the air cell. $V_{egg}$ = volume of the egg.

### 4.3.1. Egg air cell size

The fresh eggs didn't have air cell or very small when they being laid. The air cell size become greater with prolongation of storage time at 20 days of storage in all temperatures 10, 25 and 30°C but the air cell size of egg kept at 30°C increased more rapidly than that of eggs kept in 10°C. The air cell size gradually increased by storage of 0 to 5 days at 10°C and 25°C, but it dramatically increased during storage at 30°C shown on (Figure 4.1.). In this study according to Turkish regulations A class, medium size (53 – 63 g) eggs were used and the initial air cell height of eggs was so small and neglected for measuring. But in Samli et. al. study the initial air cell measured 3.18 mm, after 10 days storage at 29°C temperature increased to 7.82 mm. The reason for the difference could be the size of the eggs, the weight was around 63 g, however, in this study, the initial weights were around 56 g. The size of an egg was bigger, the initial air cell size was 3.18 mm in Samli et. al., (2005) study. Obviously, its affected by the initial size of the eggs, for that reason also the ratio (air cell egg / whole egg) was used .

#### 4.3.1.1. Air cell height

The air cell height slowly increased from 2.26 mm to 4.17 mm during 20 days of storage at 10°C, whereas the height of air cell increased more during 20 days of storage at 25°C and 30°C. After 10 days of storage at 25°C and 30°C the air cell height were 3.72 mm and 4.66 mm, at the end of 20 days of the storage the air cell height increased to 6.34 mm and 7.22 mm shown on (Figure 4.1.). The ratio between air cell height and length of the egg got bigger with storage time at 20 days and storage temperatures 10, 25 and 30°C. The ratio of air cell height increased more at 30°C than at 10°C and 25°C for 0 to 5 days of storage shown on (Figure 4.2.). The ratio of air cell height in 5 days of storage was 0.041 at 10°C and 25°C at the end of 20 days of the storage exceeded to 0.076 and 0.116.

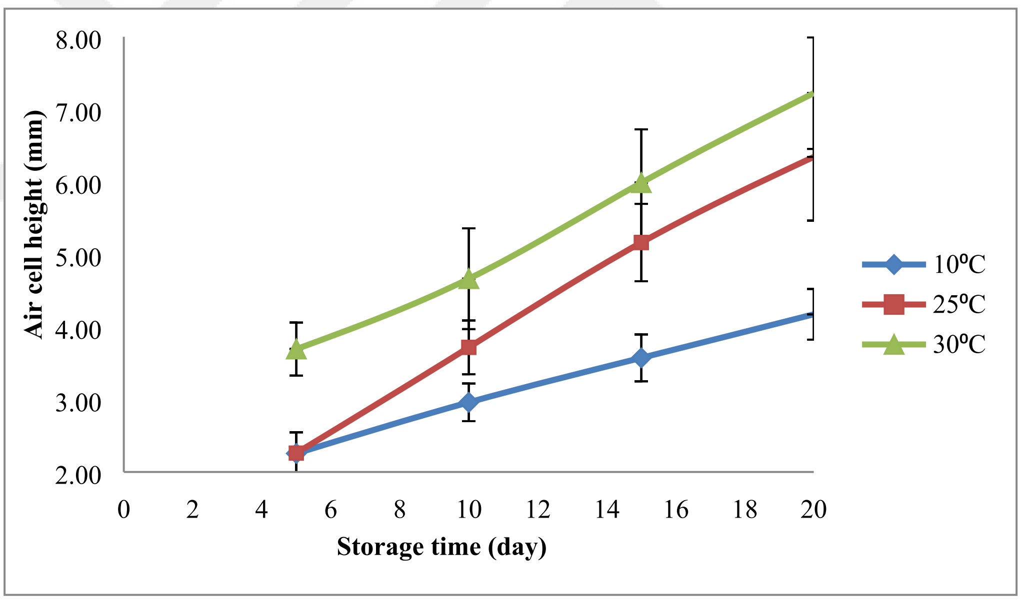



**Figure 4.1.** Effects of storage time and temperature on the air cell height of the chicken eggs

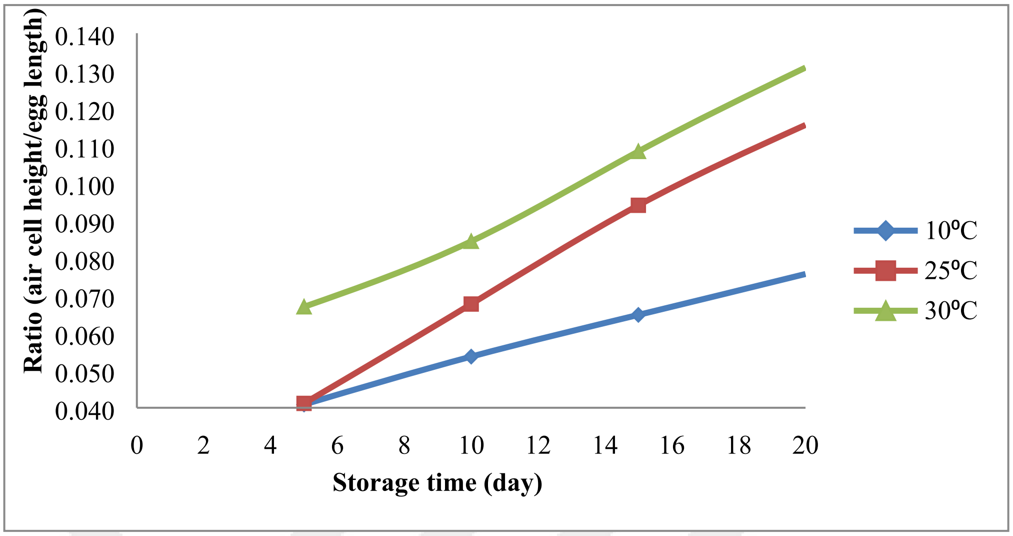



**Figure 4.2.** The ratio air cell height during storage time and temperature

#### 4.3.1.2. Air cell volume

The air cell volume increased in 20 days of storage at 10, 25 and 30°C. The fresh eggs didn't have air cell. Air cell volume in 5 and 10 days of storage at all storage temperature 10, 25, and 30°C below 1 $cm^3$ during 20 days of storage increased to 0.54, 1.26, and 1.82 $cm^3$ respectively. Air cell volume of the egg slowly increased at 10°C during 20 days of storage from 0.15 $cm^3$ to 0.54 $cm^3$ compared with the eggs storage at 30°C the air cell volume rapidly increased from 0.42 $cm^3$ to 1.82 $cm^3$ shown on (Figure 4.3.). The ratio between air cell volume and egg volume got larger during 20 days of storage at 10, 25 and 30°C. The ratio of air cell volume slowly increased in 20 days of storage at 10°C to 0.003 and 0.010, but at 30°C these ratio sharply increased from 0.008 to 0.035 shown on (Figure 4.4.).

The air cell of eggs occurs due to the loss of water through the shell pores by evaporation. The air cell depends on the storage time and temperature, thus causing the air cell size to enlarge. So the air cell of the egg is one of the important quality parameters to predict the egg freshness. The calculated air cell volume gives more precise relation with the freshness of the eggs than air cell height.

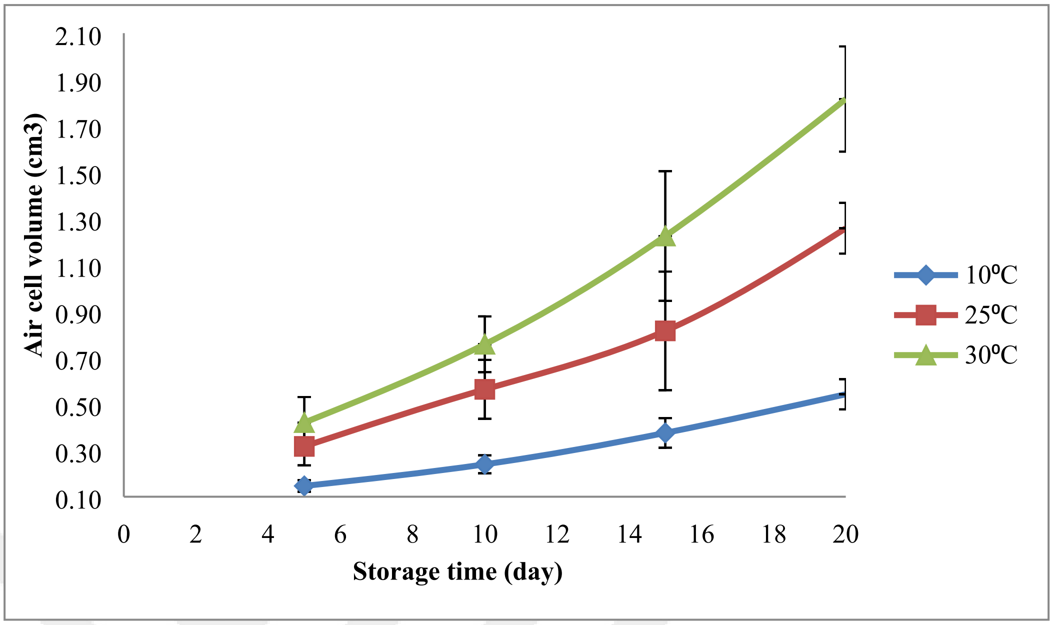



**Figure 4.3.** Effects of storage time and temperature on the air cell volume of the chicken eggs

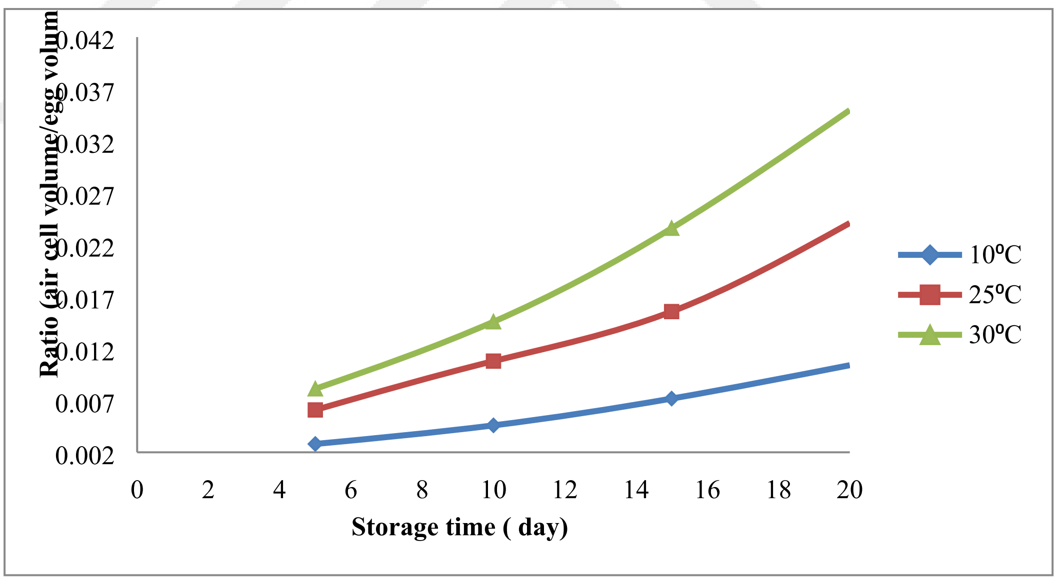



**Figure 4.4.** The ratio of air cell volume during storage time and temperature

### 4.3.2. Loss of weight

Egg weight sharply decreased during storage for 0 to 20 days at 25°C and 30°C. The egg weight gradually decreased from 56.43 g to 55.58 g with 20 days of storage at 10°C shown on (Figure 4.5.). However, during storage at 30°C, egg weight loss increased to 1.13 g and 4.80 g at 5 and 20 days of storage time, respectively shown on (Figure 4.6.).

Loss of egg weight slowly increased during storage 20 days at 10°C compared with the loss weight of egg at 25°C, and 30°C. Also during 20 days of storage time and all storage temperature, the ratio between loss of egg weight and egg weight increased. The loss weight ratio at 30°C for 5 to 20 days of storage rapidly increased from 0.020 to 0.086 shown on (Figure 4.7.). The loss of weight increased during storage time and temperature because of the loss of carbon dioxide and water from pores of the shell. The weight change of an egg is one of the quality parameters to determine the egg freshness. Samli et .al (2005) after 10 days of storage at 29°C egg weight loss was given 1.94 g, which is less than 2.31 g found in this study. The reason could be the relative humidity in the incubator was (22 - 36%) which was relatively low compared with that study (55 - 60%).

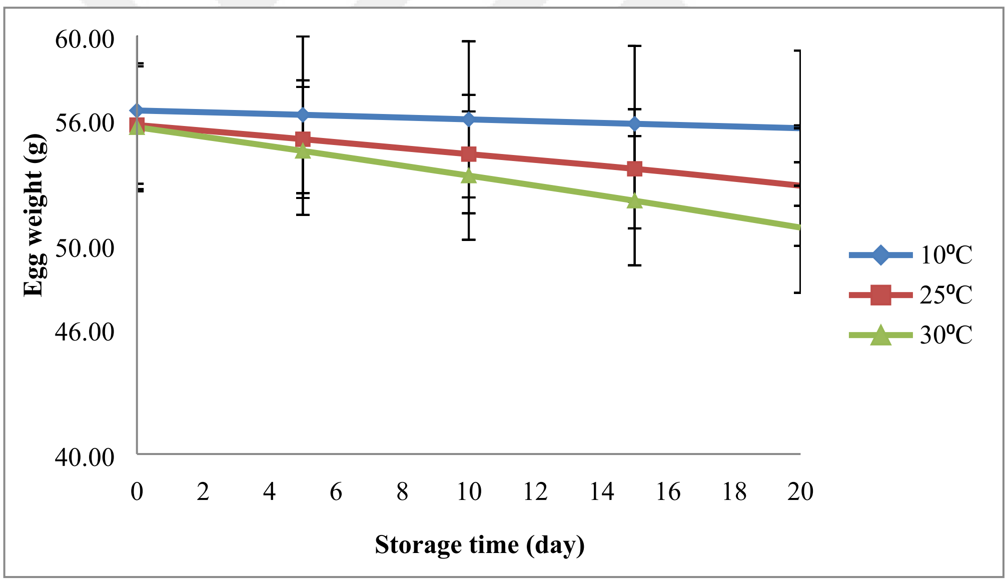



**Figure 4.5.** Effects of storage time and temperature on egg weight of the chicken eggs

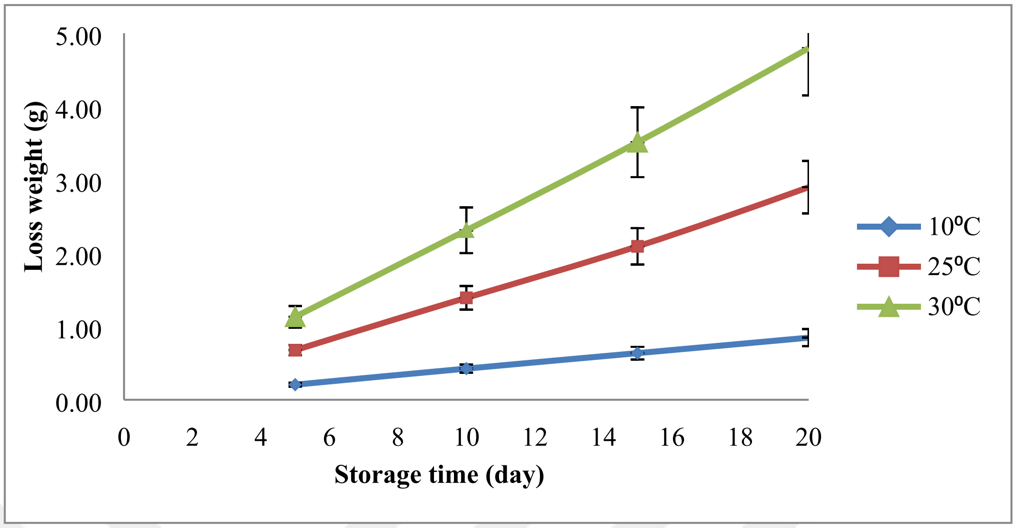



**Figure 4.6.** Effects of storage time and temperature on egg weight loss of the chicken eggs

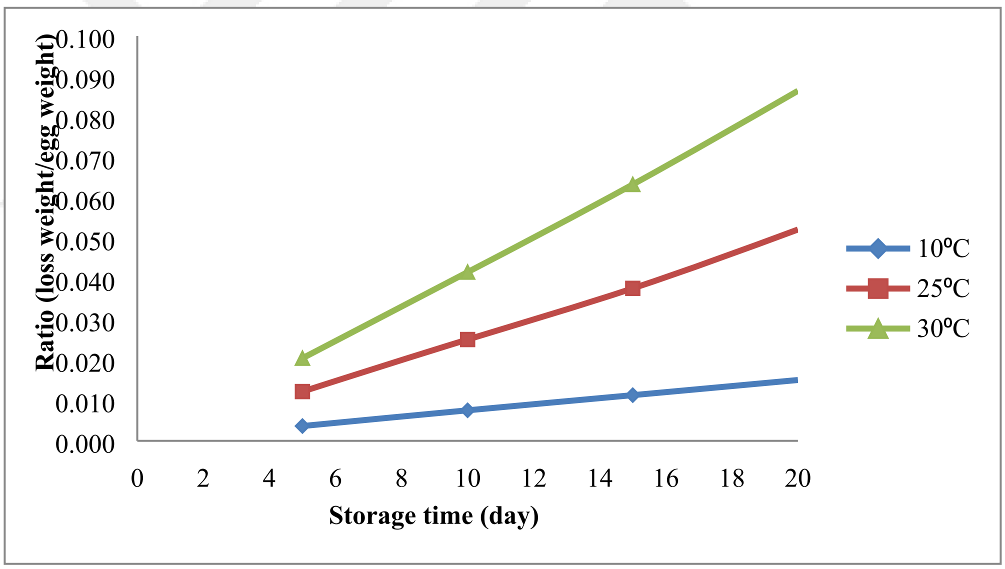



**Figure 4.7.** The ratio of loss weight during storage time and temperature

### 4.3.3. Specific gravity

Specific gravity depending on increased storage time and storage temperature, specific gravity dramatically decline with 20 days of storage at 10, 25 and 30°C. Specific gravity of the fresh egg before storage at 10, 25 and 30°C was 1.074, 1.080 and 1.093 respectively. While the specific gravity of egg decreased to 1.057, 1.024 and 0.998 during 20 days of storage with all storage temperature. However specific gravity of egg decreased less by storage in 5 days at 10, 25 and 30°C was 1.070, 1.067 and 1.070. Specific gravity rapidly declined at 30°C during 20 days of storage compared with the specific gravity at 10°C shown on (Figure 4.8.). In a previous study (Samli et. al., 2005) at the end of 10 days at 29°C temperature the eggs specific gravity changes 1.086 to 1.063, in this study after 10 days at 30°C temperature, the SG changes 1.093 to 1.047 which was consistent considering the size of the eggs. The bigger size of eggs could have bigger SG values because of the shell weight.

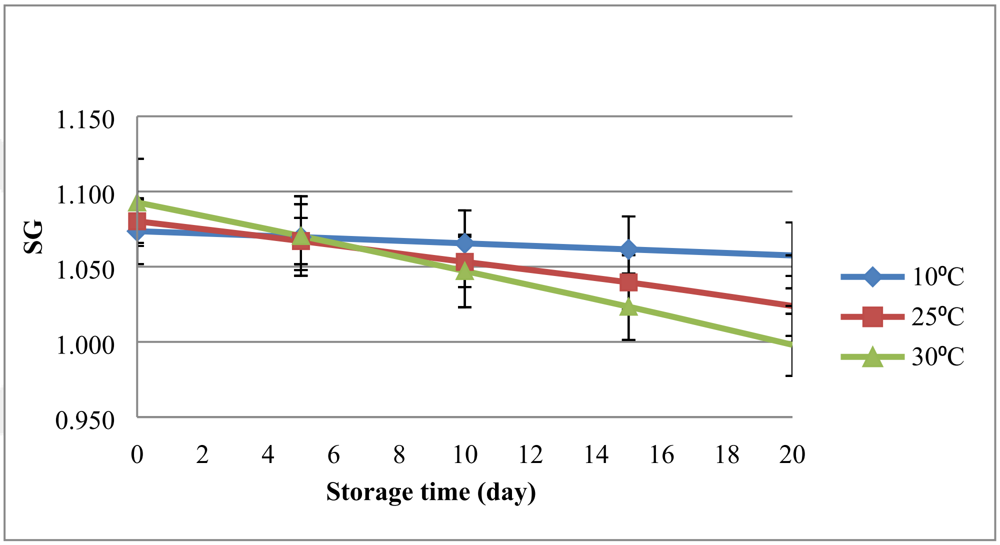



**Figure 4.8.** Effects of storage time and temperature on specific gravity of the chicken eggs

# 5. CONCLUSION AND RECOMMENDATIONS

## 5.1. Conclusions

In this research the air cell height and air cell volume of egg have been studied during storage with different temperature levels. Air cell height is one of the parameters to estimate egg freshness. Image processing is a non-destructive method and can be used to estimate air cell height of the egg. Also the effects of storage time and temperature on the egg quality parameters were investigated.

1) In the image processing toolbox, we get dimesions (L and B) from these dimesions the volume calculated by using Narushin equation with accuracy less than 10%.
2) To find an indirect measurement of egg freshness, air cell height is calculated by image processing toolbox in Matlab software. The image processing method have high detection accuracy, errors are less than 10%. These results show this method can be used as a non-destructive method detection of egg freshness.
3) The effect of storage time and temperature on the egg quality parameters estimated. The quality parameters of eggs were not clearly affected when eggs were stored in 10°C. Egg quality parameters affected negatively when the eggs stored in 25°C and 30°C by increasing the loss of weight, air cell height and air cell volume during 20 days of storage.

   — Air cell height of the stored eggs reached 4.17 mm in 20 days when stored at 10°C. Air cell height drastically increased from 3.69 mm to 7.22 mm in 5 to 20 days storage at 30°C.

   — Air cell volume in 5 and 10 days of storage at all storage temperature (10, 25, and 30)°C below 1 $cm^3$ during storage in 20 days increased to (0.54, 1.26, and 1.82 $cm^{3)}$ respectively.

   — The loss of weight was more increased at 25°C and 30°C than 10°C during 20 days of storage.

   —Specific gravity gradually decreased by storage period (5, 10, 15 and 20) days at all storage temperature of (10, 25 and 30)°C.

## 5.2. Recommendations

There is need to developing  a image processing method to calculate the air room volume of acquired images of eggs. Since the position of air room has not fixed position on the simetrical axis mathematical calculations of the air room is not an easy task.

The 3D scanners can be planned for this task for the further studies. Once acquired digital 3D model it can be calculated with the software.

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# 7. APPENDICES

## APPENDIX A

**Table A.1.** Egg volume obtained by caliper, image processing and the weight displacement method

| | Egg volume by Narushin equation | | | | | | Archimedes' principles | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $V_C$ | | | $V_{IPM}$ | | | $V_{WDM}$ | Error % | | |
| Egg number | L(mm) | B(mm) | V(cm³) | L(mm) | B(mm) | V(cm³) | V(cm³) | $L_C$&$L_{IPM}$ | $B_C$&$B_{IPM}$ | $V_{IPM}$&$V_{WDM}$ |
| 1 | 53.13 | 42.29 | 50.32 | 52.76 | 41.95 | 49.23 | 51.86 | 0.69 | 0.80 | 5.08 |
| 2 | 60.01 | 42.67 | 57.79 | 59.36 | 42.12 | 55.81 | 57.75 | 1.09 | 1.28 | 3.36 |
| 3 | 53.30 | 40.53 | 46.64 | 52.81 | 40.38 | 45.91 | 47.98 | 0.92 | 0.36 | 4.33 |
| 4 | 53.42 | 42.29 | 50.60 | 52.90 | 41.97 | 49.39 | 51.32 | 0.98 | 0.76 | 3.76 |
| 5 | 56.39 | 42.10 | 52.96 | 55.95 | 41.96 | 52.24 | 53.33 | 0.78 | 0.32 | 2.04 |
| 6 | 55.07 | 42.23 | 52.02 | 54.74 | 42.37 | 52.03 | 52.08 | 0.59 | 0.33 | 0.09 |
| 7 | 54.86 | 41.99 | 51.28 | 54.58 | 41.63 | 50.21 | 50.92 | 0.51 | 0.85 | 1.40 |
| 8 | 56.28 | 44.76 | 59.21 | 56.23 | 44.56 | 58.66 | 56.38 | 0.09 | 0.46 | 4.04 |
| 9 | 54.53 | 41.91 | 50.79 | 54.51 | 41.44 | 49.72 | 50.78 | 0.04 | 1.11 | 2.09 |
| 10 | 54.79 | 42.73 | 52.90 | 54.50 | 42.28 | 51.58 | 53.07 | 0.53 | 1.06 | 2.80 |
| 11 | 53.79 | 42.32 | 51.01 | 53.26 | 41.79 | 49.34 | 51.30 | 0.99 | 1.25 | 3.81 |
| 12 | 55.05 | 40.96 | 49.13 | 55.43 | 41.04 | 49.65 | 48.59 | 0.69 | 0.20 | 2.19 |
| 13 | 54.94 | 42.63 | 52.81 | 55.48 | 42.35 | 52.69 | 52.17 | 0.98 | 0.65 | 0.99 |
| 14 | 54.36 | 43.34 | 53.88 | 54.40 | 43.13 | 53.42 | 52.42 | 0.07 | 0.50 | 1.92 |
| 15 | 54.56 | 42.57 | 52.31 | 54.55 | 42.28 | 51.65 | 51.46 | 0.03 | 0.67 | 0.37 |
| 16 | 53.98 | 41.65 | 49.70 | 54.25 | 41.95 | 50.63 | 49.44 | 0.50 | 0.73 | 2.40 |
| 17 | 56.70 | 42.19 | 53.47 | 56.91 | 42.10 | 53.45 | 52.25 | 0.37 | 0.22 | 2.30 |
| 18 | 53.95 | 41.69 | 49.76 | 54.05 | 41.68 | 49.83 | 49.05 | 0.18 | 0.02 | 1.59 |
| 19 | 55.92 | 43.19 | 55.07 | 55.89 | 42.88 | 54.31 | 54.96 | 0.05 | 0.72 | 1.17 |
| 20 | 56.20 | 43.45 | 55.97 | 56.29 | 43.42 | 55.99 | 55.75 | 0.15 | 0.06 | 0.42 |
| 21 | 55.04 | 41.42 | 50.15 | 54.88 | 41.74 | 50.73 | 48.81 | 0.29 | 0.77 | 3.92 |
| 22 | 54.51 | 42.18 | 51.38 | 54.46 | 42.50 | 52.05 | 49.85 | 0.10 | 0.76 | 4.42 |
| 23 | 53.30 | 41.93 | 49.69 | 53.37 | 42.68 | 51.42 | 47.28 | 0.14 | 1.79 | 8.76 |
| 24 | 54.29 | 41.05 | 48.65 | 54.15 | 41.27 | 49.01 | 46.12 | 0.26 | 0.53 | 6.27 |
| 25 | 54.09 | 41.34 | 49.11 | 54.07 | 41.50 | 49.45 | 48.41 | 0.05 | 0.39 | 2.15 |
| 26 | 57.65 | 43.61 | 57.80 | 57.49 | 43.64 | 57.71 | 56.93 | 0.28 | 0.06 | 1.38 |
| 27 | 55.35 | 43.02 | 54.11 | 55.29 | 43.31 | 54.73 | 53.73 | 0.11 | 0.67 | 1.86 |
| 28 | 55.23 | 42.30 | 52.33 | 54.98 | 42.37 | 52.26 | 52.08 | 0.45 | 0.17 | 0.35 |
| 29 | 57.65 | 41.51 | 52.75 | 57.72 | 41.86 | 53.65 | 51.59 | 0.12 | 0.85 | 4.00 |
| 30 | 55.38 | 43.88 | 56.16 | 54.98 | 44.29 | 56.72 | 57.22 | 0.72 | 0.93 | 0.86 |

$V_C$ = volume air cell measurement the dimensions by caliper. $V_{IPM}$ = volume air cell measurement the dimensions by image processing method. $V_{WDM}$ = volume measurement by water displacement method based on the Archimedes' principles. $L_C$ = length of the egg measured by electronic caliper. $B_C$ = breadth of the egg measured by electronic caliper. $L_{IPM}$ = length of the measured by image processing method. $B_{IPM}$ = breadth of the egg measured by image processing method.

**Table.A.2.** Effects of storage time and temperature on the egg quality parameters at 10 $^{0}$C

| Storage Day | Egg Number | Air cell height (mm) | | Error% | Air cell volume (cm$^3$) | Loss weight (g) | Specific gravity | Egg weight (g) |
|---|---|---|---|---|---|---|---|---|
| | | $h_C$ | $h_{IPM}$ | $h_C$ & $h_{IPM}$ | $V_{water}$ | | SG | W(g) |
| Fresh egg | 1 | – | – | – | – | – | 1.047 | 54.30 |
| | 2 | – | – | – | – | – | 1.068 | 61.66 |
| | 3 | – | – | – | – | – | 1.049 | 50.33 |
| | 4 | – | – | – | – | – | 1.061 | 54.43 |
| | 5 | – | – | – | – | – | 1.073 | 57.21 |
| | 6 | – | – | – | – | – | 1.078 | 56.10 |
| | 7 | – | – | – | – | – | 1.079 | 54.93 |
| | 8 | – | – | – | – | – | 1.125 | 63.41 |
| | 9 | – | – | – | – | – | 1.085 | 55.08 |
| | 10 | – | – | – | – | – | 1.071 | 56.83 |
| 5d | 1 | 2.31 | 2.30 | 0.32 | 0.15 | 0.21 | 1.043 | 54.09 |
| | 2 | 2.72 | 2.74 | 0.89 | 0.18 | 0.22 | 1.064 | 61.43 |
| | 3 | 2.11 | 2.09 | 0.72 | 0.18 | 0.19 | 1.045 | 50.14 |
| | 4 | 2.39 | 2.36 | 1.35 | 0.13 | 0.24 | 1.056 | 54.20 |
| | 5 | 2.04 | 2.02 | 1.04 | 0.15 | 0.17 | 1.070 | 57.04 |
| | 6 | 1.96 | 1.92 | 2.29 | 0.14 | 0.17 | 1.074 | 55.93 |
| | 7 | 2.77 | 2.73 | 1.59 | 0.14 | 0.23 | 1.075 | 54.70 |
| | 8 | 2.01 | 1.99 | 0.85 | 0.16 | 0.23 | 1.121 | 63.18 |
| | 9 | 2.22 | 2.14 | 3.56 | 0.12 | 0.19 | 1.081 | 54.89 |
| | 10 | 2.02 | 2.03 | 0.28 | 0.10 | 0.21 | 1.067 | 56.62 |
| 10d | 1 | 2.87 | 2.87 | 0.15 | 0.24 | 0.43 | 1.039 | 53.87 |
| | 2 | 3.26 | 3.24 | 0.54 | 0.30 | 0.46 | 1.060 | 61.19 |
| | 3 | 2.75 | 2.72 | 1.14 | 0.27 | 0.39 | 1.041 | 49.94 |
| | 4 | 3.07 | 3.08 | 0.38 | 0.25 | 0.49 | 1.051 | 53.94 |
| | 5 | 2.69 | 2.65 | 1.49 | 0.21 | 0.33 | 1.067 | 56.87 |
| | 6 | 2.73 | 2.80 | 2.38 | 0.25 | 0.36 | 1.071 | 55.74 |
| | 7 | 2.84 | 2.79 | 1.81 | 0.29 | 0.46 | 1.070 | 54.47 |
| | 8 | 3.22 | 3.22 | 0.07 | 0.21 | 0.49 | 1.116 | 62.92 |
| | 9 | 3.41 | 3.37 | 1.06 | 0.17 | 0.39 | 1.077 | 54.69 |
| | 10 | 2.76 | 2.73 | 0.92 | 0.23 | 0.44 | 1.063 | 56.40 |
| 15d | 1 | 3.11 | 3.05 | 1.97 | 0.34 | 0.65 | 1.035 | 53.65 |
| | 2 | 3.90 | 3.88 | 0.47 | 0.47 | 0.69 | 1.056 | 60.97 |
| | 3 | 3.71 | 4.72 | 27.35 | 0.38 | 0.57 | 1.037 | 49.76 |
| | 4 | 4.07 | 4.08 | 0.27 | 0.39 | 0.75 | 1.046 | 53.68 |
| | 5 | 3.37 | 3.43 | 1.75 | 0.31 | 0.49 | 1.064 | 56.71 |
| | 6 | 3.93 | 3.96 | 0.84 | 0.36 | 0.54 | 1.067 | 55.57 |
| | 7 | 3.54 | 3.42 | 3.43 | 0.47 | 0.69 | 1.065 | 54.24 |
| | 8 | 3.44 | 3.34 | 2.92 | 0.35 | 0.74 | 1.112 | 62.68 |
| | 9 | 3.48 | 3.70 | 6.43 | 0.28 | 0.59 | 1.073 | 54.49 |
| | 10 | 3.18 | 3.27 | 2.92 | 0.41 | 0.66 | 1.059 | 56.18 |
| 20d | 1 | 3.86 | 3.91 | 1.34 | 0.54 | 0.86 | 1.031 | 53.44 |
| | 2 | 4.1 | 6.29 | 53.30 | 0.57 | 0.92 | 1.052 | 60.74 |
| | 3 | 4.19 | 5.72 | 36.61 | 0.58 | 0.76 | 1.033 | 49.57 |
| | 4 | 4.49 | 4.82 | 7.34 | 0.55 | 1.01 | 1.041 | 53.42 |
| | 5 | 4.04 | 4.06 | 0.59 | 0.46 | 0.65 | 1.061 | 56.55 |
| | 6 | 4.05 | 4.24 | 4.73 | 0.52 | 0.72 | 1.064 | 55.39 |
| | 7 | 4.53 | 4.69 | 3.59 | 0.62 | 0.92 | 1.061 | 54.01 |
| | 8 | 4.86 | 4.84 | 0.35 | 0.50 | 0.98 | 1.108 | 62.43 |
| | 9 | 3.76 | 3.87 | 2.96 | 0.44 | 0.78 | 1.069 | 54.29 |
| | 10 | 3.86 | 3.90 | 1.03 | 0.64 | 0.87 | 1.055 | 55.96 |

$h_C$ = Air cell height measurement by electronic caliper, $h_{IPM}$ = Air cell height measurement by image processing method. $V_{water}$ = Air cell volume measured by water. SG = Specific gravity. W= weight of the egg.

**Table.A.3.** Effects of storage time and temperature on the egg quality parameters at 25 $^{0}$C

| Storage | Egg | Air cell height (mm) | | Error% | Air cell volume (cm$^3$) | Loss weight (g) | Specific gravity | Egg weight (g) |
|---|---|---|---|---|---|---|---|---|
| Day | number | $h_C$ | $h_{IPM}$ | $h_C$ & $h_{IPM}$ | $V_{water}$ | | SG | W(g) |
| Fresh egg | 1 | – | – | – | – | – | 1.042 | 53.29 |
| | 2 | – | – | – | – | – | 1.086 | 52.62 |
| | 3 | – | – | – | – | – | 1.079 | 56.14 |
| | 4 | – | – | – | – | – | 1.085 | 56.70 |
| | 5 | – | – | – | – | – | 1.089 | 55.87 |
| | 6 | – | – | – | – | – | 1.080 | 53.25 |
| | 7 | – | – | – | – | – | 1.087 | 56.63 |
| | 8 | – | – | – | – | – | 1.079 | 52.75 |
| | 9 | – | – | – | – | – | 1.080 | 59.21 |
| | 10 | – | – | – | – | – | 1.095 | 60.85 |
| 5d | 1 | 2.03 | 2.00 | 1.66 | 0.32 | 0.76 | 1.027 | 52.53 |
| | 2 | 2.27 | 2.26 | 0.63 | 0.21 | 0.61 | 1.074 | 52.02 |
| | 3 | 2.17 | 2.13 | 2.02 | 0.49 | 0.70 | 1.066 | 55.44 |
| | 4 | 2.02 | 2.11 | 4.21 | 0.33 | 0.63 | 1.073 | 56.07 |
| | 5 | 1.96 | 1.96 | 0.06 | 0.26 | 0.55 | 1.078 | 55.32 |
| | 6 | 2.84 | 2.82 | 0.85 | 0.38 | 0.67 | 1.067 | 52.57 |
| | 7 | 2.05 | 2.04 | 0.43 | 0.36 | 0.65 | 1.074 | 55.98 |
| | 8 | 2.6 | 2.57 | 1.09 | 0.34 | 0.77 | 1.063 | 51.98 |
| | 9 | 2.45 | 2.48 | 1.34 | 0.24 | 0.76 | 1.067 | 58.45 |
| | 10 | 2.21 | 2.16 | 2.26 | 0.25 | 0.67 | 1.083 | 60.19 |
| 10d | 1 | 3.2 | 3.19 | 0.31 | 0.54 | 1.58 | 1.011 | 51.71 |
| | 2 | 3.67 | 3.66 | 0.29 | 0.40 | 1.25 | 1.060 | 51.37 |
| | 3 | 3.53 | 3.54 | 0.42 | 0.75 | 1.45 | 1.051 | 54.69 |
| | 4 | 3.27 | 3.08 | 5.79 | 0.66 | 1.31 | 1.060 | 55.39 |
| | 5 | 3.77 | 3.93 | 4.31 | 0.39 | 1.10 | 1.068 | 54.78 |
| | 6 | 4.31 | 4.27 | 1.00 | 0.57 | 1.39 | 1.052 | 51.86 |
| | 7 | 3.95 | 3.93 | 0.63 | 0.68 | 1.33 | 1.061 | 55.29 |
| | 8 | 4.26 | 4.26 | 0.07 | 0.68 | 1.59 | 1.046 | 51.16 |
| | 9 | 3.66 | 3.65 | 0.17 | 0.47 | 1.57 | 1.052 | 57.63 |
| | 10 | 3.56 | 3.61 | 1.37 | 0.48 | 1.32 | 1.071 | 59.53 |
| 15d | 1 | 5.64 | 5.71 | 1.27 | 0.69 | 2.37 | 0.995 | 50.92 |
| | 2 | 5.44 | 5.77 | 6.06 | 0.59 | 1.91 | 1.047 | 50.71 |
| | 3 | 4.72 | 4.57 | 3.21 | 1.37 | 2.19 | 1.037 | 53.95 |
| | 4 | 5.15 | 5.28 | 2.50 | 0.75 | 1.97 | 1.047 | 54.73 |
| | 5 | 4.53 | 4.52 | 0.25 | 0.58 | 1.63 | 1.057 | 54.25 |
| | 6 | 4.77 | 4.56 | 4.51 | 0.70 | 2.10 | 1.038 | 51.15 |
| | 7 | 4.89 | 4.77 | 2.39 | 1.01 | 2.01 | 1.048 | 54.62 |
| | 8 | 6.34 | 6.31 | 0.48 | 0.78 | 2.39 | 1.030 | 50.36 |
| | 9 | 4.95 | 4.98 | 0.53 | 1.06 | 2.39 | 1.037 | 56.82 |
| | 10 | 5.2 | 5.30 | 1.86 | 0.63 | 1.97 | 1.059 | 58.89 |
| 20d | 1 | 6.92 | 7.10 | 2.60 | 1.13 | 3.30 | 0.977 | 49.99 |
| | 2 | 6.59 | 6.78 | 2.81 | 1.17 | 2.64 | 1.032 | 49.98 |
| | 3 | 5.19 | 5.20 | 0.19 | 1.45 | 3.04 | 1.021 | 53.10 |
| | 4 | 5.42 | 5.49 | 1.25 | 1.21 | 2.70 | 1.033 | 54.00 |
| | 5 | 5.19 | 5.12 | 1.41 | 1.14 | 2.24 | 1.045 | 53.63 |
| | 6 | 6.93 | 7.03 | 1.50 | 1.26 | 2.91 | 1.021 | 50.34 |
| | 7 | 7.31 | 7.26 | 0.67 | 1.25 | 2.79 | 1.033 | 53.84 |
| | 8 | 7.63 | 8.24 | 7.97 | 1.38 | 3.32 | 1.011 | 49.43 |
| | 9 | 6.01 | 6.05 | 0.61 | 1.20 | 3.34 | 1.020 | 55.87 |
| | 10 | 6.25 | 6.33 | 1.26 | 1.37 | 2.70 | 1.046 | 58.16 |

$h_C$ = Air cell height measurement by electronic caliper, $h_{IPM}$ = Air cell height measurement by image processing method. $V_{water}$ = Air cell volume measured by water. SG = Specific gravity. W= weight of the egg.

**Table. A.4.** Effects of storage time and temperature on the egg quality parameters at 30 $^0C$

| Storage | Egg | Air cell height (mm) | | Error% | Air cell volume ($cm^3$) | Loss weight (g) | Specific gravity | Egg weight (g) |
|---|---|---|---|---|---|---|---|---|
| Day | number | $h_C$ | $h_{IPM}$ | $h_C$ & $h_{IPM}$ | $V_{water}$ | | SG | W(g) |
| Fresh egg | – | – | – | – | – | – | 1.113 | 54.11 |
| | – | – | – | – | – | – | 1.099 | 54.57 |
| | – | – | – | – | – | – | 1.139 | 53.60 |
| | – | – | – | – | – | – | 1.123 | 51.55 |
| | – | – | – | – | – | – | 1.086 | 52.35 |
| | – | – | – | – | – | – | 1.084 | 61.42 |
| | – | – | – | – | – | – | 1.076 | 57.55 |
| | – | – | – | – | – | – | 1.074 | 55.67 |
| | – | – | – | – | – | – | 1.099 | 56.45 |
| | – | – | – | – | – | – | 1.036 | 58.99 |
| 5d | 1 | 3.12 | 3.18 | 2.05 | 0.40 | 0.95 | 1.094 | 53.16 |
| | 2 | 3.65 | 3.58 | 1.90 | 0.34 | 1.14 | 1.076 | 53.43 |
| | 3 | 4.17 | 4.26 | 2.18 | 0.72 | 1.39 | 1.109 | 52.21 |
| | 4 | 4.06 | 4.14 | 2.06 | 0.46 | 1.07 | 1.099 | 50.48 |
| | 5 | 4.1 | 4.04 | 1.57 | 0.41 | 1.22 | 1.061 | 51.13 |
| | 6 | 3.52 | 3.59 | 1.92 | 0.37 | 1.29 | 1.061 | 60.12 |
| | 7 | 3.73 | 3.78 | 1.41 | 0.39 | 1.13 | 1.055 | 56.42 |
| | 8 | 3.21 | 3.20 | 0.25 | 0.37 | 0.99 | 1.054 | 54.67 |
| | 9 | 3.89 | 3.88 | 0.38 | 0.37 | 1.19 | 1.076 | 55.26 |
| | 10 | 3.49 | 3.54 | 1.57 | 0.37 | 0.95 | 1.019 | 58.05 |
| 10d | 1 | 3.42 | 3.22 | 5.77 | 0.67 | 1.90 | 1.074 | 52.21 |
| | 2 | 4.54 | 4.50 | 0.78 | 0.64 | 2.34 | 1.052 | 52.23 |
| | 3 | 5.43 | 5.45 | 0.36 | 0.93 | 2.84 | 1.078 | 50.76 |
| | 4 | 4.88 | 4.89 | 0.23 | 0.78 | 2.19 | 1.075 | 49.36 |
| | 5 | 5.1 | 5.04 | 1.18 | 0.79 | 2.50 | 1.034 | 49.85 |
| | 6 | 5.48 | 5.60 | 2.22 | 0.84 | 2.65 | 1.037 | 58.77 |
| | 7 | 4.68 | 4.52 | 3.45 | 0.77 | 2.31 | 1.033 | 55.24 |
| | 8 | 3.73 | 3.73 | 0.11 | 0.64 | 2.01 | 1.035 | 53.66 |
| | 9 | 5.15 | 5.16 | 0.21 | 0.93 | 2.44 | 1.052 | 54.01 |
| | 10 | 4.23 | 4.11 | 2.72 | 0.59 | 1.93 | 1.002 | 57.07 |
| 15d | 1 | 5 | 4.76 | 4.88 | 1.10 | 2.88 | 1.054 | 51.23 |
| | 2 | 6.08 | 6.00 | 1.26 | 0.90 | 3.56 | 1.028 | 51.01 |
| | 3 | 6.87 | 6.89 | 0.29 | 1.69 | 4.31 | 1.047 | 49.29 |
| | 4 | 5.81 | 5.88 | 1.21 | 1.01 | 3.34 | 1.050 | 48.21 |
| | 5 | 6.38 | 6.24 | 2.24 | 1.62 | 3.82 | 1.007 | 48.53 |
| | 6 | 6.71 | 6.70 | 0.19 | 1.31 | 4.02 | 1.013 | 57.40 |
| | 7 | 6.84 | 6.74 | 1.41 | 0.96 | 3.52 | 1.010 | 54.04 |
| | 8 | 5.28 | 5.42 | 2.61 | 1.08 | 3.04 | 1.015 | 52.62 |
| | 9 | 6 | 5.98 | 0.30 | 1.46 | 3.72 | 1.027 | 52.73 |
| | 10 | 4.9 | 4.97 | 1.33 | 1.12 | 2.92 | 0.984 | 56.08 |
| 20d | 1 | 6.84 | 7.01 | 2.45 | 1.84 | 3.92 | 1.033 | 50.19 |
| | 2 | 6.73 | 6.72 | 0.17 | 2.01 | 4.87 | 1.001 | 49.70 |
| | 3 | 7.98 | 7.98 | 0.03 | 2.07 | 5.86 | 1.014 | 47.73 |
| | 4 | 7.22 | 7.87 | 8.98 | 1.75 | 4.57 | 1.023 | 46.98 |
| | 5 | 8.23 | 8.15 | 1.01 | 1.98 | 5.23 | 0.978 | 47.12 |
| | 6 | 7.55 | 7.58 | 0.41 | 1.86 | 5.47 | 0.987 | 55.95 |
| | 7 | 7.72 | 3.68 | 52.32 | 1.53 | 4.81 | 0.986 | 52.74 |
| | 8 | 5.76 | 5.82 | 0.99 | 1.48 | 4.15 | 0.994 | 51.52 |
| | 9 | 7.74 | 7.79 | 0.69 | 2.07 | 5.09 | 1.000 | 51.37 |
| | 10 | 6.46 | 6.50 | 0.64 | 1.56 | 3.99 | 0.965 | 55.00 |

$h_C$ = Air cell height measurement by electronic caliper, $h_{IPM}$ = Air cell height measurement by image processing method. $V_{water}$ = Air cell volume measured by water. SG = Specific gravity. W= weight of the egg.

**APPENDIX B**

Matlab code B.1: Volume of the egg

```
i=imread ('volume egg.jpg');
imshow (i);
%% convert rgb to gray:
i2=rgb2gray (i);
imshow (i2);
%% Thresholding:
level=graythresh (i2);
bw=im2bw(i2,level);
imshow (bw);
ba1=imfill (bw, ‘holes');
imshow (ba1);
ba2=imclearborder (ba1);
imshow (ba2);
se=strel('square',5);
open=imopen (ba2, se);
imshow (open);
c=imclose (open, se);
imshow (c);
stats=regionprops(c,'MajorAxislength','MinorAxisLength')
px2=stats.MinorAxisLength;    %breadth of the whole egg by image (px)
py2=stats.MajorAxisLength;    %length of the whole egg by image (px)
DB=Kx*px2;    %convert unit (px) to mm
DL=Ky*py2;    %convert unit (px) to mm
disp ('DB')       % breadth of the whole egg by Matlab (mm)
disp (DB)
disp ('DL')       % length of the whole egg by Matlab (mm)
disp (DL)
%% measure by caliper
B=42.10        %mm breadth of the whole egg by caliper
L=56.39        %mm length of the whole egg by caliper
EB= (DB-B)/B*100      % Erro by breadth
EL= (DL-L)/L*100      % Erro by length
```

Matlab code B.2: The air cell height of the egg

```
i=imread ('air cell height egg.jpg');
imshow (i);
%% convert rgb to gray:
b=rgb2gray (i);
imshow (b);
%% Thresholding:
ba=b>235;
imshow (ba);
%% remove noise and clear:
ba1=imfill (ba, 'holes');
imshow (ba1);
ba2=imclearborder (ba1);
imshow (ba2);
se=strel ('square', 8);
open=imopen (ba2, se);
imshow (open);
c=imclose (open, se);
imshow (c);
stats=regionprops (c,'MajorAxislength','MinorAxisLength')
px2=stats.MinorAxisLength;    % height of the air cell of the egg by image (px)
Dh=Kx*px2;                    % convert unit (px) to (mm)
disp ('Dh')                   % height of the air cell of the egg by Matlab (mm)
disp (Dh)
%% measure by caliper
h=3.54                  % mm height of the air cell of the egg by caliper
Eh= (Dh-h)/h*100        % Erro by height
```

**CURRICULUM VITAE**

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| | |
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