Determination of Quality Parameters And Shelf Life of Hen Egg

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ABSTACT

DETERMINATION OF QUALITY PARAMETERS AND SHELF LIFE OF HEN EGG

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The quality parameters (changes in the weight, pH, area and height of albumen and yolk) of shell egg were determined. Weight and color change of shell egg was determined at 10, 16, 20 and 30^{o}C. Area and height change of albumen and yolk and pH change of whole egg were determined at 10, 20 and 30^{o}C. Haugh unit which is accepted as the most important parameter for shelf-life determination of egg was calculated using weight and height change. The order of the quality loses of egg was evaluated as zero order because a linear relation was observed for all quality changes with respect to storage time at studied temperature ranges.

It was determined that quality of egg is strictly temperature dependent and especially Haugh unit and pH were affected more than weight changes. The highest quality loss observed at 30^{o}C. Arrhenius-type equation was used for calculation of activation energies for each quality parameter. The effect of temperature and storage time were found as significant for weight and pH change and Haugh unit ($P<0.05$). The most temperature dependent quality parameter was determined as Haugh unit and the second one is pH and the least temperature dependent parameter weight due to activation energies. Shelf life of the shell egg was calculated as 50 ± 2, 33 ± 2 and 20 ± 2 days at 10, 20 and 30^{o}C according to pH changes, respectively.

Key words: Shell egg, Chicken egg, Haugh unit, Shelf life

ÖZET

TAVUK YUMURTASINDA KALİTE PARAMETRELERİNİN VE RAF ÖMRÜ BELİRLENMESİ

ÖZDEMİR Hüseyin Haldun

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Kabuklu yumurtanın kalite parametreleri (ağırlık, pH, albumen ve yolkun alan ve yüksekliklerinin değişimi) tespit edildi. Yumurtanın ağırlık ve renk değişimi 10, 16, 20 ve 30^{o}C için tespit edildi. Yumurta albumeninde ki ve sarısında ki alan, yükseklik değişimi ve tüm yumurtanın pH değişimi 10, 20 ve 30^{o}C tespit edildi. Her bir sıcaklıkta elde edilen ağırlık ve yükseklik değişimi kullanılarak, yumurta raf-ömrü tayininde en önemli parametre olarak kabul edilen Haugh birimi hesaplandı. Çalışılan sıcaklık değerlerinde ve çalışılan tüm kalite parametrelerinin zamana karşı değişimlerinin doğrusal değişim göstermesi nedeni ile yumurta kalite kaybı kademesi sıfır derece olarak belirlenmiştir. Yumurtanın kalitesinin üzerine sıcaklığın etkisinin belirgin olduğu gözlenerek, özellikle Haugh birim ve pH değişimlerinin ağırlığa göre sıcaklık değişiminden daha fazla etkilendiği belirlendi. En yüksek kalite değişkeni kaybı 30^{o}C' de gözlemlendi. Aktivasyon enerjilerine göre sıcaklıktan en çok etkilenen kalite parametresinin Haugh birimi, ikincil sırada pH ve en az etkilenen olarak ise ağırlık olduğu tespit edildi. Kabuklu yumurtanın 10, 20 ve 30^{o}C depolama sıcaklıklarında raf ömürleri pH değişimi dikkate alınarak hesaplandı ve sırasıyla 50 ± 2, 33± 2 and 20 ± 2 olarak bulundu.

Anahtar Kelimeler: Kabuklu Yumurta, Tavuk Yumurtası, Haugh Birimi, Raf Ömrü

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CHAPTER I

INTRODUCTION

1.1 General Objectives

Egg is an important food obtained from fowls. Egg refers hen egg in codex (Food codex) and throughout the study, besides of duck, turkey, bird egg which they are so not important in human diet. Egg is biologically high quality food according to highly nutritious and almost contains all nutrition which human metabolism need. Chicken eggs are widely used in many types of dishes, both sweet and savory. Eggs can be pickled, hard-boiled, soft-boiled, scrambled, fried and refrigerated. Egg can used as an additive in the form of emulsifier, humectants, baking agent, coloring agent, for enhance taste, odor and consistency in cake, pasta etc. products (Tayar, 1996).

1.2 Egg Production and Marketing Worldwide and Turkey

In 2008 totally 60295000 tons egg produced. First 20 egg producer countries were China, USA, Japan, Mexico, India, Russia, Brazil, Indonesia, France, Ukraine, Turkey, Germany, Iran, Spain, Italy, Holland, England, Korea, Thailand, Philippines. China was the first country all over the world by producing 22749000 tons of eggs.

Turkey was in the top 20 as 11^{th} by producing 824000 tons or 1.37 % of egg all over the world (Figure 1) (Yum-Bir, 2010). In Turkey, the production rate of egg is increased within time, furthermore in last three years there is an important increment as shown Figure 2. The 8401 million eggs were produced in 2006. There is an increasing trend observed as 25.2, 34.0 and 41.8% in 2007, 2008 and 2009, respectively (Yum-Bir, 2010).

Last three years, an increasing trend was seen also in consumption (Figure 3) of egg per human like production. At 2007 consumption was 131 eggs per human, at 2008, 157 eggs per human and at 2009, and 164 eggs per human as average in a year.

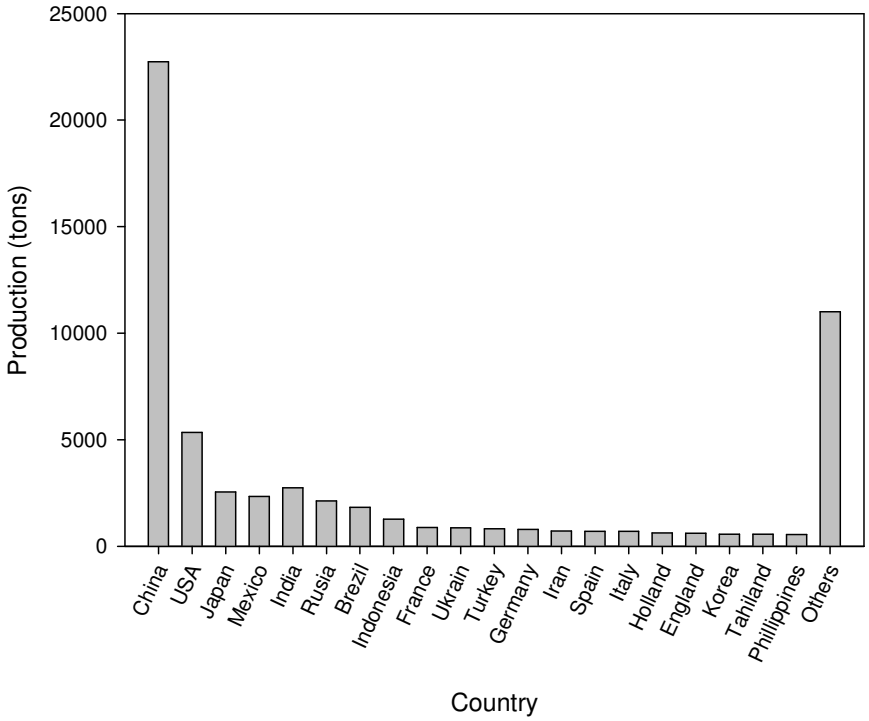


Figure 1.1. Egg production of first 20 countries in 2008

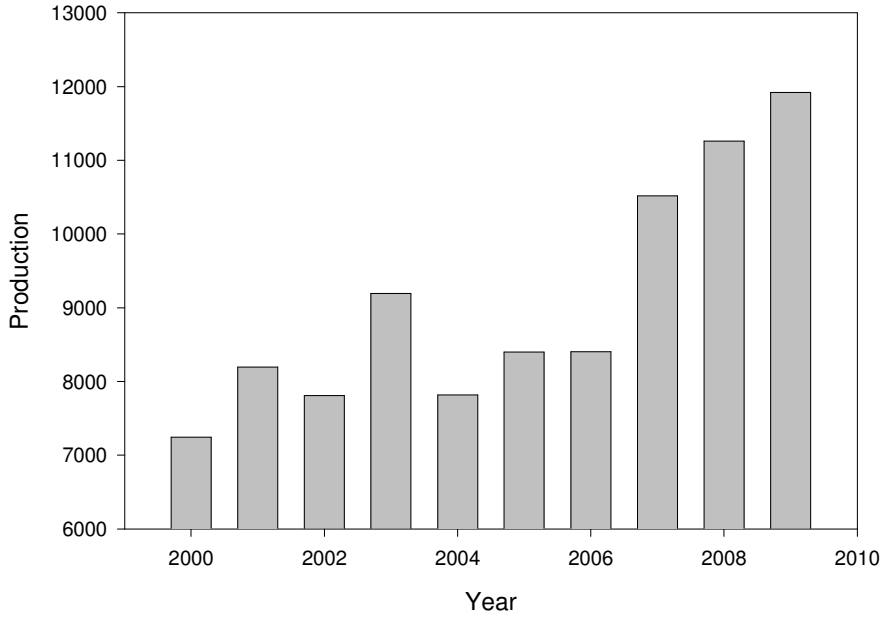


Figure 1.2. Egg productions (million) in Turkey

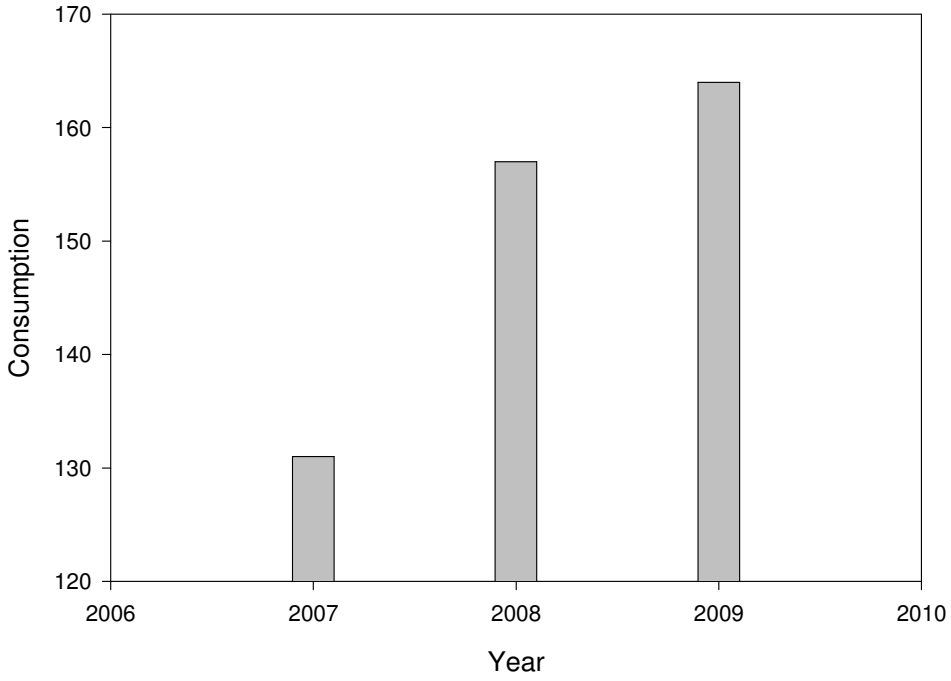


Figure 1.3. Egg consumption in Turkey

1.3 Egg Structure

The structure of egg is divided into four parts as the yolk (ovum), the white (albumen), shell membrane and shell as in Figure 4 (Scanes, 2004).

1.3.1 The Egg Yolk (Ovum)

The yolk consists of the *latebral germinal disc,* concentric ring of *yolk material,* and *vitelline membrane,* a colorless membrane that surrounds and contains the yolk. The yolk constitutes approximately 31 % of the total weight of the egg (USDA, 2000). Egg yolk consists of 48.7 % water, 32.6 % fat, 16.6 % protein, 1 % carbohydrate and 1.1 % mineral. The yolk has yellow or yellow-red color. The yolk covered with a vitelline membrane, colorless and thin, which provides annular shape. The egg yolk is suspended in the egg white by one or two spiral bands of tissue called the chalazae (Roberts et al, 1997).

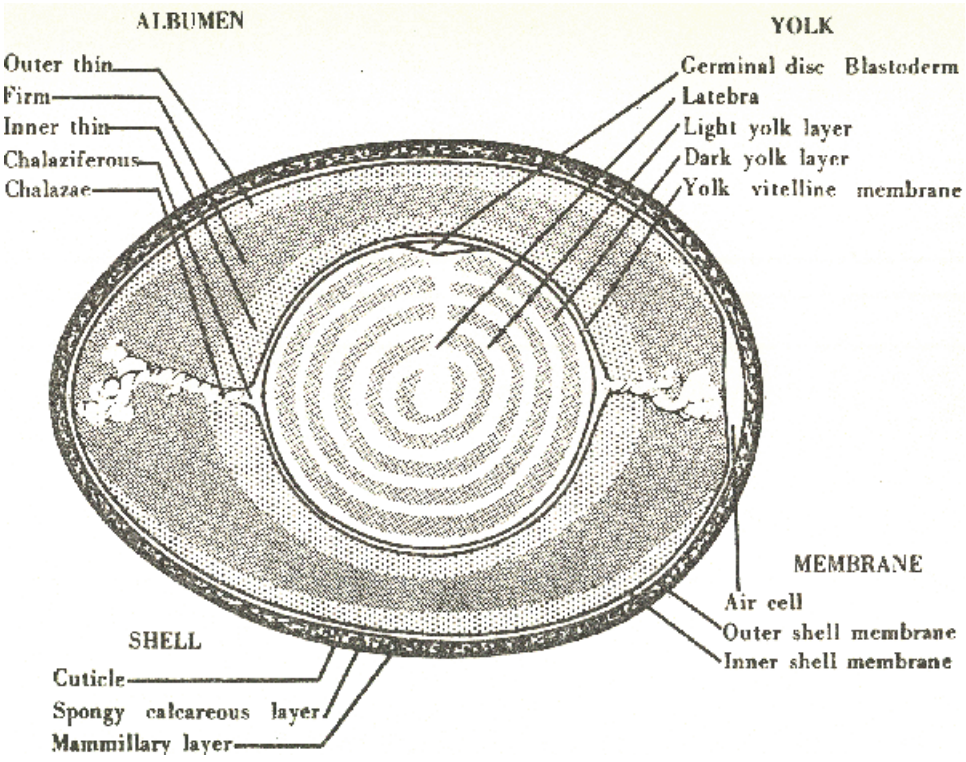


Figure 1.4. The structure of egg

1.3.2 The Egg White (Albumen)

The egg white consists of four distinct layers which together constitute about 58 % of the weight of the egg. The *chalaziferous* layer immediately surrounds the yolk and is continuous with the *chalazae*. This is a very thin, but firm layer of albumen and makes up 3 % of the total white. The inner thin layer surrounds the chalaziferous layer and comprises about 17 % of the white. The firm or thick layer of white provides an envelope, or jacket, that holds the inner thin white and the yolk. It adheres to the shell membrane at each end of the egg. Approximately 57 % of the white is firm white. The outer thin layer lies just inside the shell membranes, except where the thick white is attached to the shell, and accounts for about 23 % of the total white (USDA, 2000).

1.3.3 The Egg Shell Membrane

The shell membranes are tough and fibrous and are composed chiefly of a protein similar to that in hair and feathers. The inner membrane is thinner than the outer, and together they are only about 0.00609 mm thick (USDA, 2000).

1.3.4 The Egg Shell

The shell is composed of three layers (Figure 5) and constitutes approximately 11 % of the egg. The mamillary or inner layer covers the outer cell membrane. Next is the spongy layer, then the cuticle pores connecting the surface and the mammilla. The egg, as laid, normally has no air cell. The air cell forms as the egg cools, usually in the large end of the egg and develops between the shell membranes. The air cell is formed as a result of the different rates of contraction between the shell and its contents. The albumen also contains water-soluble B vitamins such as riboflavin. Riboflavin gives the greenish tint to the albumen (USDA, 2000).

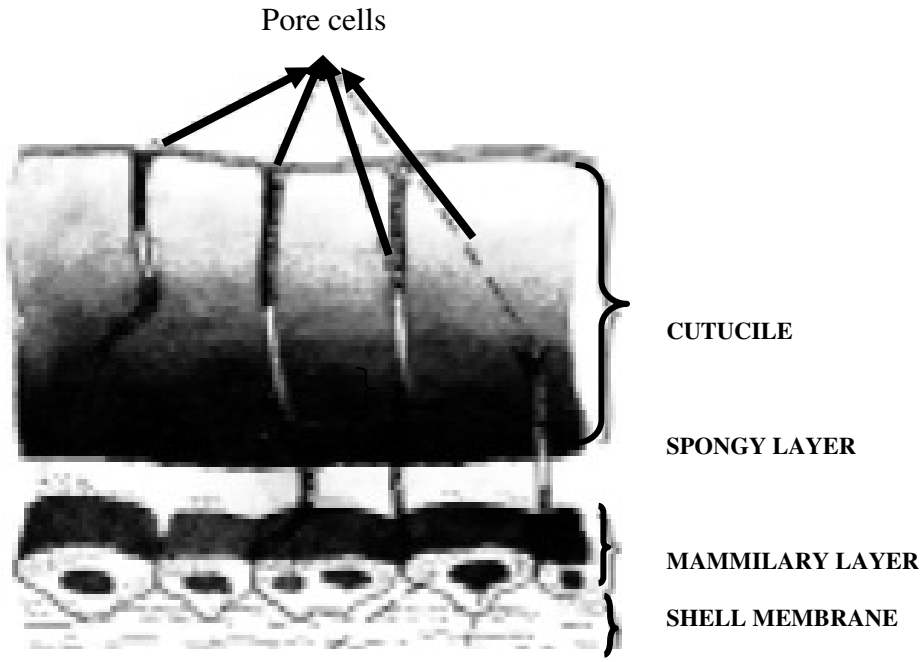


Figure 1.5. Structure of egg shell

1.4 Chemical Composition of Egg

The egg is an excellent source of high-quality protein and of certain vitamins and minerals. The hen egg contains 65.6 % water, 12.1 % proteins, 10.5 % lipid, 0.9 % carbohydrates and 10.9 % minerals. Egg composition not constant and shifts according

to feed style, genetic heritage of chicken and housing condition. % chemical composition of hen egg was given in Table 1 and Table 2 (Tayar, 1996).

Table 1.1. % composition of hen egg

	Whole egg	Shell	Albumen	Yolk
Weight (gram)	58.0	6.0	33.0	19.0
Water (%)	65.6	1.6	87.9	48.7
Solid (%)	34.4	98.4	12.1	51.3
Protein (%)	12.1	3.3	10.6	16.6
Lipid (%)	10.5	Trace	Trace	32.6
Carbohydrate	0.9	-	0.9	1.0
Minerals	10.9	95.1	0.6	1.1

Table 1.2. Chemical composition of hen eggs for 100 g of dietary part

	Whole	Albumen	Yolk
Energy (kcal)	75.0	17.0	59.0
Protein (g)	6.25	3.52	2.78
Total lipid (g)	5.01	0	5.12
Total carbohydrate (g)	0.60	0.30	0.30
Fatty acids (g)	4.33	0	4.33
Saturated fatty acids (g)	1.55	0	1.55
Monounsaturated fatty acids (g)	1.91	0	1.91
Polyunsaturated fatty acids (g)	0.68	0	0.68
Cholesterol(mg)	213	0	213
Thiamin (mg)	0.03	0.002	0.03
Riboflavin (mg)	0.25	0.15	0.10
Niacin (mg)	0.03	0.03	0.005
Vitamin B_6(mg)	0.07	0.001	0.007
Folat (mcg)	23.5	1.00	22.5
Vitamin B12 (mcg)	0.50	0.07	0.43
Vitamin A (IU)	317	0	317
Vitamin E (mg)	0.70	0	0.70
Vitamin D (IU)	24.5	0	24.5
Choline (mg)	215	0.42	214
Biotin (mcg)	9.98	2.34	7.58

	Whole	Albumen	Yolk
Calcium, Ca (mg)	25.0	2.00	23.0
Iron, Fe (mg)	0.72	0.01	0.59
Magnesium, Mg (mg)	5	4	1
Copper, Cu (mg)	0,007	0,002	0,004
Iodine, I (mg)	0,024	0,001	0,0022
Zinc , Zn (mg)	0,55	0	0,52

Sodium, Na (mg)	63	55	7
Manganese, Mn (mg)	0,012	0,001	0,0012

The high mineral content (10%) of egg is caused with the high amount of calcium in the shell. Chicken egg weight changes between 45 and 65 grams and average 58 grams. It refers 33 grams (58%) albumen, 19 grams (32%) yolk and 5-6 grams (11%) egg shell.

1.4.1 White (Albumen) Composition

The egg's protein content is complete; it contains all of the essential amino acids in well-balanced proportions. Water is the major component of albumen. The pH of albumen from a newly laid egg is between 7.0 and 8.5 (USDA, 2000). The pH value of egg increased during storage due to the loss of carbon dioxide (Karouri, 2006). The thick albumen is made up mainly of the proteins ovomucin, ovalbumin, conalbumin, ovoglobulin, and ovomucoid. Ovomucin gives structure to the thick albumen. The thin albumen is composed mostly of the same proteins contained in the thick albumen, with the exception of ovomucin. The albumen also contains water-soluble B vitamins such as riboflavin. Riboflavin gives the greenish tint to the albumen.

1.4.2 Yolk Composition

The major components of yolk are proteins and lipids (fats). The important yolk proteins are ovovitellin (about three-fourths of the yolk protein) and ovolivetin. The fatty substances of the yolk are the mostly triglycerides (true fat) 65.5%, phospholipids 28.3%, and cholesterol 5.2%. The pH of the yolk in a freshly laid egg is generally about 6.0 but gradually increases to about 7.0 during storage. Yolk pigments (mostly *xanthophylls*) come from green plants and yellow corn that the birds eat. The yolk contains most of the known vitamins with the exception of vitamin C. The vitelline membrane is composed mostly of protein similar to that found in the shell membranes and is fairly permeable to water. The higher concentration of solids in the yolk causes the yolk to increase in size and become less viscous because of the inflow of water from the white as the egg ages. The yolk contains iron, phosphorus, sulphur, copper, potassium, sodium, magnesium, calcium, chlorine, and manganese, all of which are essential elements.

1.5 Abnormalities and Quality Parameters of Egg

Some abnormalities may form during the formation of egg and ovulation. This type of abnormalities may seen both shell and inside of the egg.

1.5.1 External Abnormalities

1.5.1.1 Abnormalities in Shell Shape and Texture

The normal egg has an oval shape with one end larger than the other, and it tapers toward the smaller end. The ends of an egg are commonly called the large end (air cell end) and the small end. Investigators measured both strength and appearance of many eggs to develop the “ideal” egg shape. This ideal egg shape is illustrated in Figure 6. The shape of an egg can be considerably different from the ideal, but may still be considered practically normal. Eggs that are unusual in shape may have ridges, rough areas, or thin spots.

Abnormal shells may result from improper nutrition, disease, or the physical condition of the hen. Sometimes a shell is cracked while the egg is still in the body of the hen. These eggs, which are commonly referred to as “body checks,” are repaired by an additional deposit of shell over the cracked area, generally resulting in a ridged area. Shells with thin areas and some other types of defects are usually weaker than normal shells, and the danger of breakage en route to the consumer lowers the utility value of the egg. Eggs of abnormal shape also lack consumer appeal

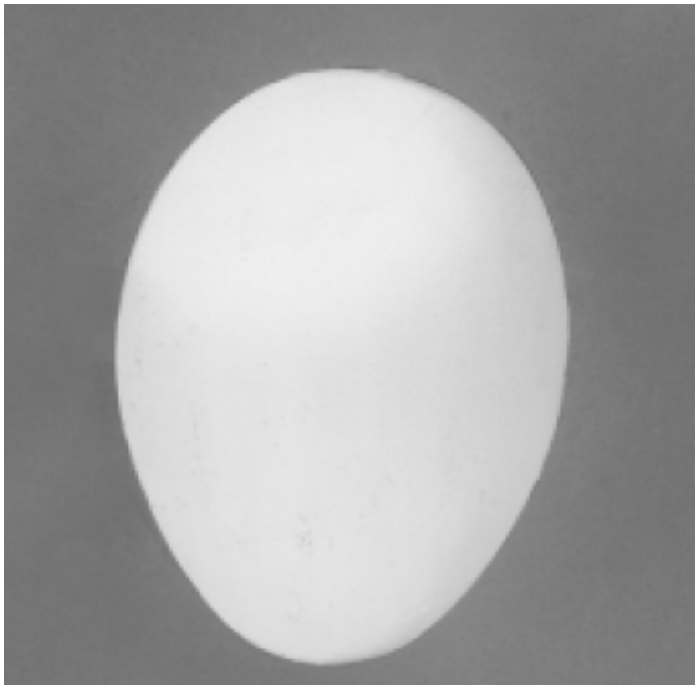


Figure 1.6. Ideal egg shape

1.5.1.2 Breakage of Egg

An individual egg that has a broken shell or a crack in the shell but its shell membranes is intact and its contents do not leak. Checks are an unavoidable problem in the marketing of eggs because eggs cannot be assembled, graded, packed, transported, and merchandized without some breakage. Such eggs will not keep well or stand even moderately rough handling, and they should be diverted to immediate use or further processing. Checks may range from eggs with plainly visible dented cracks that are removed during the grading process to very fine, hair like cracks (blind checks) that often escape detection because they cannot be seen. While many of these checks become detectable as time passes (due primarily to contraction caused by cooling); most of the eggs will have already moved into marketing channels, reaching the retail level within 1 to 3 days after being laid. “Blind checks” are the most common, and frequently the most difficult to detect in rapid candling, being discernible only before the candling light or by “belling.”

“Belling” is the practice of gently tapping two eggs together to assist in the detection of “blind checks” by sound. Hand candlers follow this practice by candling the eggs in order to verify and complete the findings arrived at by sound. With the use of

automatic processing equipment, the "belling" procedure is not used in examining the eggs for checks, although electronic check detectors are now available on new equipment. The candler must be especially attentive when these detectors are not being utilized so that all checks are removed prior to packaging. Quite often a bubbly air cell in fresh eggs indicates a "blind check". It is necessary to remove leakers and dented checks carefully to avoid causing further damage to them and to prevent dripping liquid from the leakers onto clean eggs, onto the packaging material, or into the mechanism of the candling equipment, therefore cross-contaminating the eggs. This is necessary not only for bacteriological reasons, but for good housekeeping and appearance of the packaged product, and to keep the mechanisms of automatic weighing equipment in proper adjustment (Tayar, 1996).

1.5.1.3 Shell Cleanliness

In machine processing, the examination for cleanliness is most often done immediately following the washing operation, during the mass scanning for interior quality, or after mass scanning prior to packaging. This operation should be in an area with sufficient lighting and adequate space for removing these types of eggs. Freedom from stains and foreign material on the shell must be considered in assigning a quality designation to an individual egg. The following terms are descriptive of shell cleanliness:

Clean; A shell that is free from foreign material and from stains or discolorations that are readily visible. An egg may be considered clean if it has only very small specks, stains, or cage marks, if such specks, stains, or cage marks are not of sufficient number or intensity to detract from the generally clean appearance of the egg. Eggs that show traces of processing oil on the shell are considered clean unless otherwise soiled.

Dirty; A shell that is unbroken and has dirt or foreign material adhering to its surface, has prominent stains, or has moderate stains covering more than one-thirty-second of the shell surface if localized, or one-sixteenth of the shell surface if scattered (Jaqualine et al, 2009).

1.5.2 Internal Abnormalities

Air Cell: As already stated, when the egg is first laid, it has no air cell et all or only a small one. Its temperature is about 40.6 °C and, as the egg cools, the liquids

contract more than the shell. As a result of this contraction, the inner shell membrane separates from the outer to form an air space. Further increase in the size of the air cell beyond that resulting from contraction is due to evaporation of water from the egg (USDA, 2000). Rapidity of air cell formation affects many factors, such as age, shell texture, temperature, and humidity. The air cell is normally at the large end of the egg (USDA, 2000). There are some terms used to define air cells in egg:

i) Depth of air cell; the depth of the air cell is the distance from its top to its bottom when the egg is held air cell upward.

ii) Free air cell; an air cell that moves freely towards the uppermost part in the egg as the egg is rotated slowly.

iii) Bubbly air cell; a ruptured air cell resulting in one or more small, separate air bubbles, usually floating beneath the main air cell.

Yolk Quality: The appearance of the yolk is dependent on the condition of the white. The rate of carbon dioxide and moisture loss in the white increases with ageing of the egg and this affects the condition of the white. The ticker the white, the less distinct the outline appears, because the yolk is prevented from moving close to the shell.

The yolk in a freshly-laid egg is round and firm (Figure 7). As the yolk ages, the strength of the yolk membrane weakens allowing water to be absorbed from the white. This increases its size and weight and causes it to stretch and weaken the vitelline membrane and to assume a somewhat flattened shape on top and an “out of- round” shape generally, resembling a balloon partially filled with water. If the yolk membranes and tissues have weakened and/or moisture has been absorbed from the white to the yolk, the yolk appears definitely enlarged and flat (Figure 8).

Double-Yolked Eggs: Result when two yolks are released about the same time, or when one yolk is lost into the body cavity for a day and is picked up by the funnel when the next day’s yolk is released.

Yolkless Eggs: Are usually formed around a bit of tissue that is sloughed off the ovary or oviduct. This tissue stimulates the secreting glands of the oviduct and a yolkless egg results.

White (Albumen) Quality: The albumen has a major influence on overall interior egg quality. Thinning of the albumen is a sign of quality loss. When a fresh egg is carefully broken out onto a smooth flat surface, the round yolk is in a central position surrounded by thick albumen Figure 7. When a stale egg is broken out, the yolk is flattened and often displaced to one side and the surrounding thick albumen has become thinner, resulting in a large area of albumen collapsed and flattened to produce a wide arc of liquid Figure 8.

The albumen occasionally contains blood and/or meat spots. Both chemically and nutritionally, these eggs are fit to dietary.

An Egg within an Egg: This abnormality is due to the reversal of direction of the egg by the wall of the oviduct. One day's egg is added to the next day's egg and the shell is formed around both.

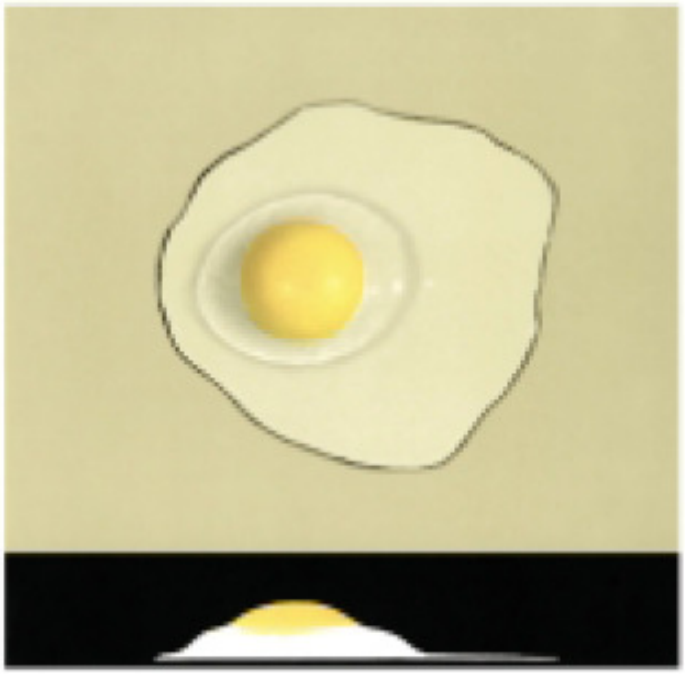


Figure 1.7. Photograph of a fresh egg from front side (USDA, 2000)

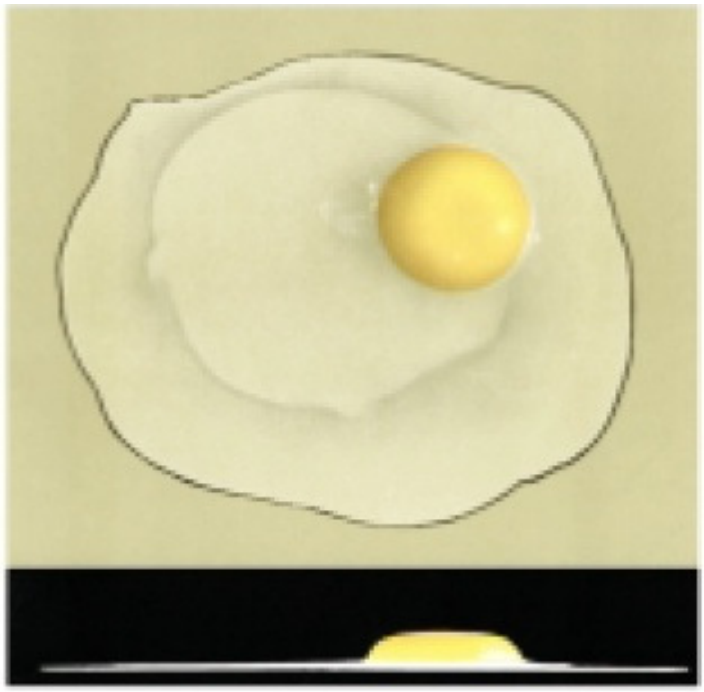


Figure 1.8. Photograph of fresh egg from top side (USDA, 2000)

Blood Spots: blood spots are caused by a rupture of one or more small blood vessels in the yolk follicle at the time of ovulation.

Off Flavor Egg: Microorganisms leaked inside of the egg from cracks on the shell and denature the egg proteins and causes off odor. Main chemical causes off flavor are hydrogen sulphur (H_2S). Hydrogen sulphur causes pressure inside of the egg and an exploding sound obtained simultaneously or when the egg was broken. It has an undesirable odor and causes the egg unacceptable (Tayar, 1996). Also off flavor formation due to diffusion of flavor from housing or storing environment; and some low quality feeds may cause this.

Frozen Egg: Stored eggs under -5^{o}C starts to freezing and crack observed along one pole to other, mottling occur as a result.

Mottling: It is essential that the vitelline membrane remain intact and strong in order to prevent the contents of the albumen and yolk from mixing. If mixing occurs, the quality of the egg and consumer acceptance of these eggs declines because of "mottling."

1.6 Standards and Grading

Grading generally involves the sorting of products according to quality, size, weight, and other factors that determine the relative value of the product. Egg grading is the grouping of eggs into lots having similar characteristics as to quality and weight. Grading aids orderly marketing by reducing waste, confusion, and uncertainty with respect to quality values.

The primary advantage in using official standards and grades for eggs is that they furnish an acceptable common language in trading and marketing the product, thus making possible:

- Impartial official grading that eliminates the need for personal inspection of the eggs by sellers, buyers, and other interested people.
- Pooling of lots of comparable quality.
- Development of improved quality at producer level through "buying on grade" programs.
- Market price reporting in terms understood by all interested parties.
- Negotiation of loans on generally accepted quality specifications.
- A basis for settling disputes involving quality.
- A basis for paying damage claims.
- A basis for developing advertising.
- A uniform basis for establishing brand names.
- Establishment of buying guides for consumers.

1.6.1 Turkish Food Codex (T.F.C.)

According to Turkish Food Codex which pressed official gazette at 23.01.2008; Egg was defined as; *shell egg which obtained from Gallus gallus var. domesticus type chicken and directly suitable for human consumption or suitable for egg containing foods* (Turkish Food Codex, 2009).

Some general properties of egg at Turkish food codex are defined as below;

a) Eggs have to obtained from healthy animal
b) Egg and egg products has to specific odor, taste and color.
c) Their shell must complete growing and not contains any crack.
d) Egg must be clean and dry.

1.6.1.1 Grading of Egg Due to T.F.C.

According to Turkish Food Codex egg was divided into two sections depend on properties as A grade and B grade and the weight class is given in Table3.

B grade eggs only uses in industry.

Properties of A grade egg was

1) Egg shell have to normal shape, clean and without any damage
2) Air cell not exceed 4 mm for “extra fresh” and 6 mm for others and must be stable.
3) Albumen has to clean, transparent and jelly and any contamination.
4) Egg yolk seen at center round shaped during candling and when the egg rotated not leave the center and not contain any foreign material.
5) Any embryo must not seen with naked eye.
6) Not contain any foreign flavor.

Table 1.3. Weight classes of A grade egg

Weight class	Weight (g)
XL –extra large	≥ 73
L –large	63 – 72
M- medium	53 – 62
S- small	≤ 52

1.6.2 United States Standard

The grading for quality of eggs is the classifying of the individual egg according to established standards. U.S. standards for quality of individual eggs have been developed on the basis of such interior quality factors as condition of the white and yolk, size of the air cell, and the exterior quality factors of cleanliness and soundness of the shell. These standards apply to eggs of the domesticated chicken.

Eggs are also classified according to weight (or size) expressed in ounces per dozen. Although eggs are not sold according to exact weight, they are grouped within relatively narrow weight ranges or weight classes, the minimum net weight per unit being specified. When grading, eggs must meet minimum individual egg, carton, and case weight requirements.

1.7 Testing Methods for Egg Freshness

Egg freshness is determined using some testing methods. These methods are divided into two headline “destructive” and “non- destructive” methods.

1.7.1 Non-Destructive Methods

The simplest and therefore the most widely used method is egg candling (Thompson et al, 1985). The internal quality characteristic in this case depend the yolk mobility, which can be considered as an indicator of albumen viscosity as if the albumen viscosity decreases, the yolk mobility was increases. Therefore eggs are revolved in front of a source of light. The faster the yolk moves in the albumen from one pole to the other, the lower is the internal quality of the egg. Hand candling was originally developed as a method of sorting fresh eggs from aged eggs and for the detection of incubator rejects. With the changes in production practices and processing technologies, hand candling is used very little in present commercial grading operations. Automated equipment and mass scanning devices have practically replaced these manual operations. However, hand candling is still an excellent method for teaching and demonstrating quality determination, and is used for spot checking.

Another non destructive method was measurement of the electrical conductivity of the albumen (Kemps et al, 2006). That gives an indication of the internal egg quality. To measure the electrical conductivity of an egg, an electrode chamber filled with electrolyte was used. The egg was located firmly between two electrodes. By measuring the resistance of the egg at a frequency of 300 kHz, a relationship with the interior parameters was found. Furthermore, they reported that there is a significant correlation between egg interior quality characteristics and the density of the albumen.

Near infrared (NIR) spectroscopy is widely used for the determination of organic constituents in feeds, foods, pharmaceutical products and related materials. In the sector of egg, the application of NIR for the determination of egg freshness is rather limited (Karouri et al, 2006).

Front-face fluorescence spectroscopy has been used extensively in the field of dairy products. However, in the literature, only preliminary studies explored the application of front-face fluorescence for the determination of egg freshness. This may be explained by the fact that eggs are complex products containing numerous fluorescent compounds, which makes it difficult to derive molecular information from their spectra.

1.7.2 Destructive Methods

The physical characteristic of the eggs is changed during aging, being influenced by storage temperature. The albumen has a major influence on overall interior egg quality. Thinning of the albumen is a sign of quality loss. When a fresh egg is carefully broken out onto a smooth flat surface, the round yolk is in a central position surrounded by thick albumen. When a stale egg is broken out, the yolk is flattened and often displaced to one side and the surrounding thick albumen has become thinner, resulting in a large area of albumen collapsed and flattened to produce a wide arc of liquid.

The most widely used and accepted measure of albumen quality is the Haugh unit. The Haugh unit is based on both the weight of the intact egg and the albumen height of a broken egg.

When a fresh egg is carefully broken on to a smooth flat surface, the yolk is in a central position surrounded by thick albumen. When a stale egg is broken, the yolk is often displaced to one side and the surrounding thick albumen has become thinner, resulting in a large area of albumen. This results in a decreased albumen height, which consequently leads to a decreased Haugh unit.

Another indices used to evaluate egg freshness is air cell height which is affected by egg weight and storage relative humidity. “Air cell height, the only quantitative egg freshness parameter considered by the European Union regulation depends on the egg weight. Theoretically, A grade an egg at packaging has to keep the characteristics of its grade (air cell height <6 mm) up to expiring date (Karouri et al, 2006). However, the strong dependence of the air cell height from environmental relative humidity and temperature makes it difficult to guaranty the quality without a strict control of these two variables throughout the whole egg marketing cycle.

The pH has been used to determine the egg freshness. The rise in the albumen pH is caused by a loss of carbon dioxide from the egg through the pores in the shell. Indeed,

the pH of albumen is dependent on the equilibrium between dissolved carbon dioxide, bicarbonates ions, carbonate ions and proteins. Hence, the pH of albumen from a newly laid egg is between 7.6 and 8.5. During the storage of shell eggs, the pH of albumen increases at a temperature-dependent rate to a maximum value of about 9.7 (Karouri et al, 2006).

Another indication of the egg freshness can be obtained from the albumen refractive index. In contrast to the measurements of Haugh unit and pH, this technique is too laborious to use in practice.

Albumen refraction index, which consist to measure the liquid concentration of albumen (index of refraction) by utilizing the refraction phenomenon of light at the boundary plane between the lanes of a small prism exposed at a part of the detection section of the refractometer and the liquid to be measured, has also been used as an indicator of egg freshness.

1.8 The Aim of Present Study

Eggs are among the most nutritious foods and can be part of a healthy diet. It is cheap, and the production in Turkey and whole world was not ignorable. However, they are perishable. Immediately after they are laid, ageing processes begin in shell eggs, altering their chemical, physical and functional properties. If the transport and marketing conditions are considered, the shelf-life of the egg becomes shorter as shorter.

The aim of this study was to determine the effect of storage temperature on shelf life of hen eggs according to changes in some physical properties. The study was planned as:

1- To determine the changes in weight of whole egg, albumen and yolk, pH, color changes, area of both yolk and albumen, height of yolk at different temperature (10-30^{o}C).
2- To calculate Haugh unit, yolk index, albumen index, from the data obtained from first step.
3- To estimate the kinetic analysis of the data.
4- To determine the average shelf-life of shell egg.

CHAPTER II

MATERIALS and METHODS

2.1 Material

The important point of the experiment was the freshness of the eggs. For this reason a local farm in Gaziantep was informed to provide 150 freshly laid eggs at the

same time. The species of the chicken kept constant that *Gallus gallus var. domesticus.* All chemicals used were reagent grade.

2.2 Preparation of Eggs

Eggs were checked for any crack, dirt or any foreign material on it and fault ones separated. The rest of the eggs were grouped according to their weight and size. Finally 130 eggs were determined as representative samples for experiments. The schematic representation of the preparation and design of the experiment was shown in Figure 2.1.

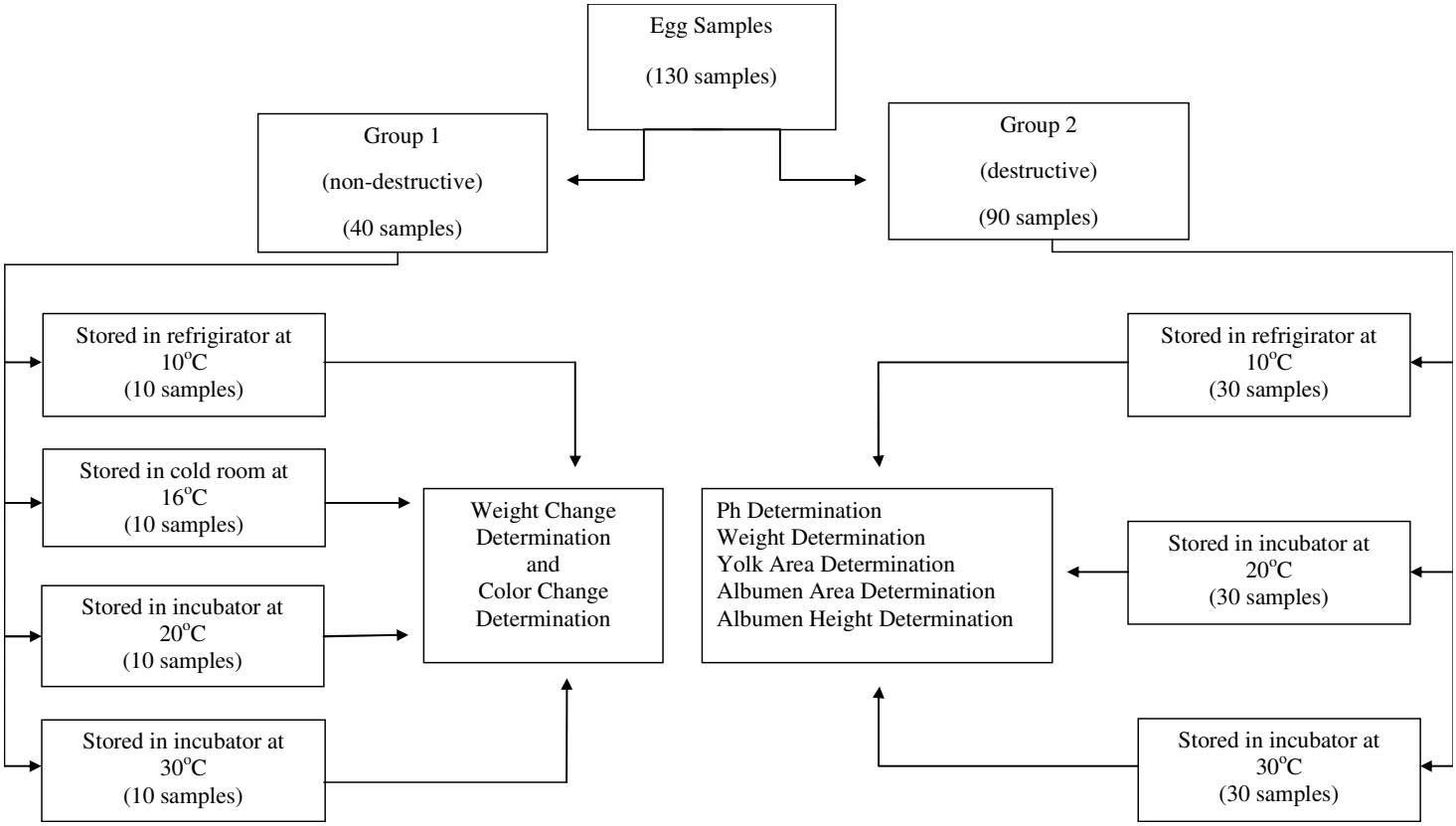
2.3 Weight Change Determination

After the eggs equilibrated to room temperature, their initial weights were obtained. 10 egg samples were numbered and placed into refrigerator (+10^{o}C), cold storage room (+16^{o}C), and incubators (Selectra digitheat and Nüve) at +20 and +30^{o}C to determine the weight change of the eggs at different storage temperatures. Storage temperatures were selected caring possible storage temperature in markets. Eggs were weighted periodically with a sensitive scale (Precisa XB220A with 0.0001g sensitive). After data collected the weight changes were calculated.

2.4 Color Change Determination

At this step, eggs were selected initially depending on the clearness of the shell on using determination of color in order to eliminate misreading of color changes due to possible differences in fresh eggs' shell color. The colors of the egg shells were measured from the same side of eggs (the back side).

Figure 2.1. Schematic Representation of Egg Sample Preparation



The color measurement was done using HunterLab ColorFlex (A60-1010-615 Model Colorimeter, Hunter Lab, and Reston VA). The color values are expressed as Hunter L- (whiteness or darkness), a-(redness/ greenness), and b- (blueness/yellowness).

The Hunter L-, a-, and b-values are the three dimensions of the measured color which gives specific color value of the material (HunterLab, 2008). After the data collected the color change was calculated.

2.5 Changes in pH, Weight, Area and Height Determination

Group 2 eggs were placed into refrigerator at 10^{o}C, incubator at 20 and 30^{o}C. Five runs were done for each temperature group. A contrivance (Figure 2.2) was set up by using a sensitive scale (Avery Barkel with 0.001 sensitive) to measure weight of shell egg, whole egg, albumen and yolk. A glass, 190 to 190 mm, was placed on the scale and then contrivance was balanced by using water gauge. A wood placed front of the scale to fix to height and distance of the photograph taken. Finally contrivance consist of a little box which the height during image analyzing process.

First the glass placed on the sensitive scale and calibrated to zero. The shell egg was weighted. Then it was broken on the glass carefully because the membranes are between yolk and albumen has to be undisturbed. After 5 minute waiting (waited to stop the enlargement of the albumen), picture of the eggs was picked up using camera Kodak (EasyShare C713 brand digital camera).

Then again whole egg weight was measured. Pictures of the whole egg were taken from both front and top side to determine height of yolk and area of yolk and albumen, respectively. The pH of the whole egg mixture measured using hand pH meter (Eutech, EcoScan pH 5) after mixing of the whole egg using a magnetic stirrer until the complete mixture was observed. To determine the height of yolk and areas of both yolk and albumen an image analyzer software (UTHSCSA Image Tool for Windows, V: 3.00) was used. A hard pin box placed near the whole egg and both photographs were taken to determine the height of the yolk. The height of the box was measured initially and this value was used to calibrate the system measurement (pixel to millimeter). The height of the yolk was measured using the defined program.

Figure 2.2. The picture of the contrivance

Similar technique was used to determine the area of yolk and albumen, At this point the material was the glass surface which the egg was broken on it. The length of the glass surface was measured. The pixel to millimeter calibration was done using predetermined value. Then the surface of the albumen which spread on the glass was pointed. When the pointing was done to create o closure the area of the albumen calculated automatically by program. Same steps were repeated also for calculation of yolk area.

2.6 Calculations of Haugh Unit and Other Parameters

The mean value of the runs was used for the calculations. The Haugh Unit is a measure of the internal quality of an egg. It was the correlation of the weight of the egg between heights of the thick albumen of the egg. It is formulated as;

$$HU = 100 \log(H - 1.7w^{0.37} + 7.6) \quad (1)$$

Where HU represents Haugh Unit, H shows observed height of albumen in mm and W is weight of egg in grams.

Albumen index and yolk index values were calculated using the Equations (Kul et al, 2004, Kirikçi et al, 2003):

Albumen index (%) = (albumen height/ albumen diameter) x100

Yolk index (%) = (yolk height/yolk diameter) x100

For the albumen and yolk diameter calculation, the area of the both assumed as circle. So the area formula of circle was used to determination of the diameters

$$A = \pi r^2 \quad (2)$$

$$r^2 = A/\pi \quad (3)$$

$$r = D/2 \quad (4)$$

$$D = 2\left(\sqrt{A/\pi}\right) \quad (5)$$

2.7 Shelf-Life and Activation Energy (E_A) Calculations

The shelf-life of a product is the length of time it can remain on a store shelf without adverse consumer reaction (Labuza, 1982).

The loss of food quality for most foods can be represented by a mathematical equation as;

$$dA/dt = kA^n \quad (6)$$

Where the A is the quality factor measured, t is time, k is a constant which depends on temperature and water activity (in this study, it was assumed that k value is only temperature dependent), n is power factor called the order of the reaction which

defines where the rate is dependent on the amount of A present, $^{dA}/_{dt}$ the rate of change of A with time, A negative sign is used if the deterioration is a loss of A.

If the shelf-life loss is constant the value n equals to zero. This assumption called zero order reaction scheme. So it implies that rate of loss at constant temperature constant. Then the Equation (7) obtained.

$$-^{dA}/_{dt} = kA^0 \tag{7}$$

If Equation (7) were integrated as follows:

$$\int_{A_o}^{A} -dA = \int_0^t k dt \tag{8}$$

$$A = A_0 - kt \tag{9}$$

Where A is the amount left after time t, A_o is initial quality value and t is time.

Deterioration constant (k) was determined as, quality parameter (A) graphed against to time (t). The slope of the graph gives the deterioration constant value.

The shelf-life in many cases does not obey zero order reaction in another words in most cases the loss of shelf-life is not constant. Many foods that do not deteriorate by zero order, follow a pattern where n=1 (first order) which results in an exponential decrease in rate of loss as quality decrease. In this situation the amount of A is an important factor.

For the first order reaction Equation (13) derived from Equation (6) as;

$$-^{dA}/_{dt} = kA^1 \tag{10}$$

$$\int_{A_o}^{A} {}^{dA}/_{A} = \int_0^t -k dt \tag{11}$$

$$ln\,{}^{A}/_{A_0} = -kt \tag{12}$$

$$lnA = lnA_0 - kt \quad (13)$$

Temperature dependency of the deterioration reactions can be determined using the Arrhenius-type equation (14):

$$k = k_0 e^{-E_A/RT} \quad (14)$$

$$\ln k = \ln k_0 - \frac{E_A}{R}\frac{1}{T} \quad (15)$$

Where, k_o is pre-exponent constant, E_A is the activation energy in cal/ mole, R is the gas constant in cal/(mole)(K) and equals to 1.986, T is the temperature in K.

If the Equation (14) derived to Equation (15), and a plot of the ln(k) as a function of absolute temperature (1/T) gives a straight line, and the slope of the line gives the value of $-E_A/R$.

2.8 Statistical Calculation

Analysis of variance (ANOVA) was conducted to determine the effect of temperature and time factors on Haugh unit, weight change and pH change parameters using SPSS software (v.15.0.0). Univariate linear model was used and Turkey test was applied as post-Hoc test.

CHAPTER III

RESULT AND DISCUSSION

3.1 General

Analysis of egg quality parameters requires a fundamental knowledge of egg structure, quality characteristics and deterioration steps. Also basic knowledge is required about shelf-life, temperature effect on food matrix. When deciding which process conditions perform, the environment conditions take cared at farm, store and house. Good quality can be defined as egg still corresponds as consumer expectation. The result of experimental studies and the treatment of the resultant data are given in graphical and tabular forms and discussed separately for egg samples.

3.2 Weight Change Determinations

The weight changes of egg samples during storage at different temperatures were analyzed and represented in Figure 3.1.

Storage time and temperature effect was significant ($P<0.05$) on weight change separately. However the interaction of the storage time and temperature was not significant ($P>0.05$) on weight change together (Appendix C.1).

The order of the reaction was estimated as zero order since the changes of weight was linear with respect to time, and k values determined from the slopes using the

Equation (9) were tabulated in Table 5 (The values of egg samples stored at 16°C was 0.0027 kg/hr).

Weight parameter shows an inverse relation with the egg quality. According to the results, the rate of the weight loss was increased with increasing temperature, and the highest weight loss rate was observed for the samples stored at 30°C. The weight loss is caused by the loss of carbon dioxide and water from pores of the shell. At the same time, losing of CO_2 and water cause quality loss. According to USDA (2000), egg having less weight than 15 ounce per dozen (425 gram for dozen) cannot be handled at market as shelled egg. Weight change continues on shelf, and after a while the egg becomes stale and reaches to the end of the shelf-life. So the weight change of the egg is one of the important quality parameter to determine the shelf-life of the egg.

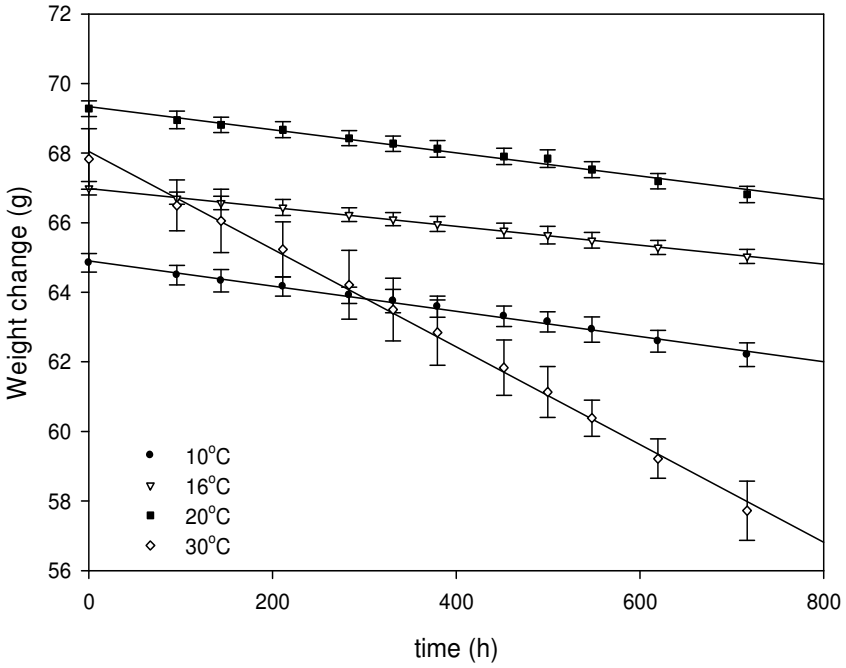


Figure 3.1. Weight changes of egg samples stored at 10, 16, 20 and 30°C

3.3 pH Determination

The pH values of whole egg samples stored at 10, 20 and 30°C were determined and given in Figure 3.2. Fresh egg's pH was observed as 7.6±0.1. During the storage of shell eggs, the pH increased at a maximum value of about 8.2. Parallel results were obtained by Karauri et al (2006), but they had measured only pH of the albumen.

Eggshells are breathable material; therefore they allow permeation of moisture and carbon dioxide through the shell (Caner, 2005). The dissolved carbon dioxide was released so the acidity of the egg was decreased. The evaporation of the water through the pores on the shell decreased the acidity, also.

The effect of time and temperature of storage were significant ($P<0.05$) on pH both separately and interaction (Appendix C.2).

The deterioration rate constants are shown in Table 5. Solubility of the gases decreased, and rate of water evaporation increased when the storage temperature was increased. The increasing constant values with increasing of storage temperature represent increasing of the quality loss. The rate of deterioration was the highest at 30°C and the highest the rate of quality loss was observed at same temperature. However the increment of the pH was not linear. The buffering capacity for pH changes of the albumen is the weakest which causes a rapid increase during the first few days of storage as discussed by Kemps (2006).

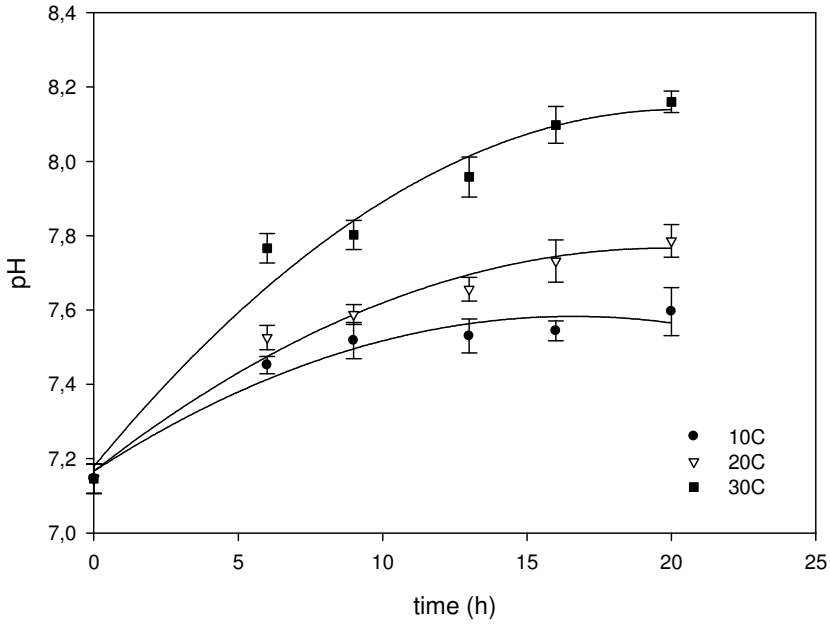


Figure 3.2. Changes in pH of egg samples stored at 10, 20 and 30°C

Table 3.1. The deterioration rate constants (k) for quality parameter change at studied temperature range

Quality parameters	Storage temperature °C					
	10	R^2	20	R^2	30	R^2
Weight Change	0.0023	0.9947	0.0033	0.9873	0.0140	0.9974
Haugh Unit	0.0076	0.9722	0.5332	0.9468	2.2012	0.9487
pH	0.0199	0.7788	0.0300	0.8895	0.0480	0.8927
Albumen Area	159.43	0.8991	297.06	0.8306	465.45	0.9151
Yolk Area	5.3338	0.4460	12.697	0.8407	99.340	0.9580
Albumen Index	0.1046	0.8842	0.4156	0.9659	0.4876	0.9538
Yolk Index	0.0742	0.4365	0.5124	0.9720	1.5081	0.9115

3.4 Area Change Determination of Albumen and Yolk

When a stale egg is broken out, the yolk is flattened and often displaced to one side and the surrounding thick albumen has become thinner, resulting in a large area of albumen collapsed and flattened to produce a wider arc of liquid (USDA, 2000). The area change of both albumen and yolk of the egg samples stored at 10, 20 and 30°C were tested and were plotted in Figure 3.3 and 3.4, respectively. The deterioration rate constants for albumen area and yolk area calculated using zero order rate equation is given in Table 5. Same increasing results have been obtained for albumen by Karauri et al (2006) and Kemps et al (2006).

The rate of increment depended on the temperature change with a direct proportion. The highest rate was obtained for egg samples stored at the highest temperature, 30°C for both albumen area and yolk area.

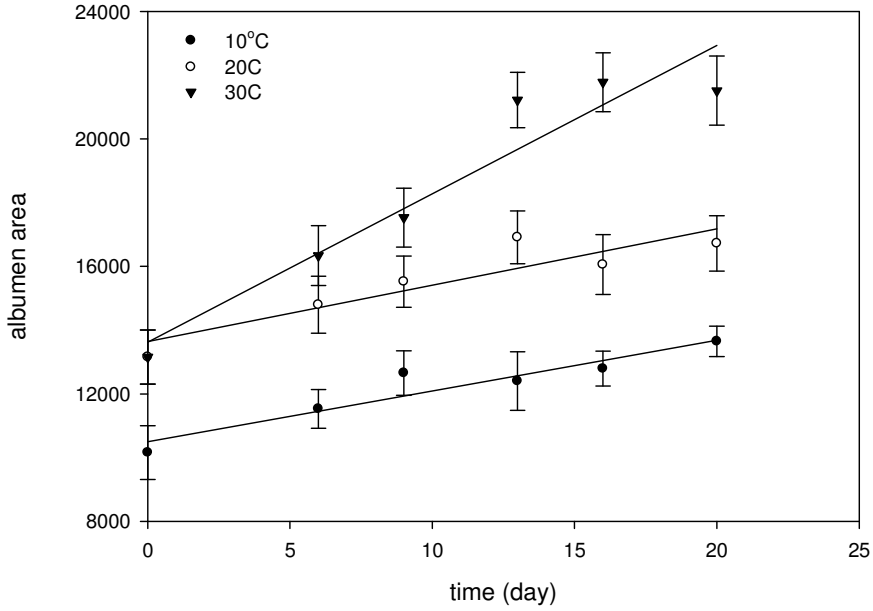


Figure 3.3. Changes in albumen area of egg samples stored at 10, 20 and 30°C

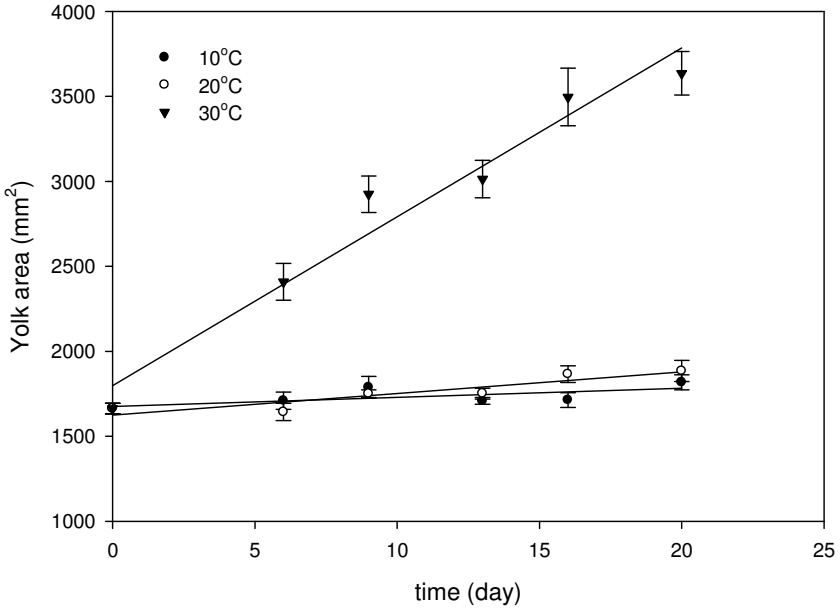


Figure 3.4. Changes in yolk area of egg samples stored at 10, 20 and 30°C

3.5 Albumen Index, Yolk Index Determination

Albumen and yolk index were calculated depending on the height and diameter of albumen and yolk after broken the egg on a flat surface and plotted (Figures 3.5-3.6). Both albumen index and yolk index showed a decreasing pathway. It could be explained with the inverse relation between index values and the area of yolk and albumen during storage. However there was a direct proportion within the height of yolk and albumen and the index values. The parallel results have been reported by Doğan and Bayındırlı (1996).

The deterioration rate constants for albumen index and yolk index are given in Table 3.1.

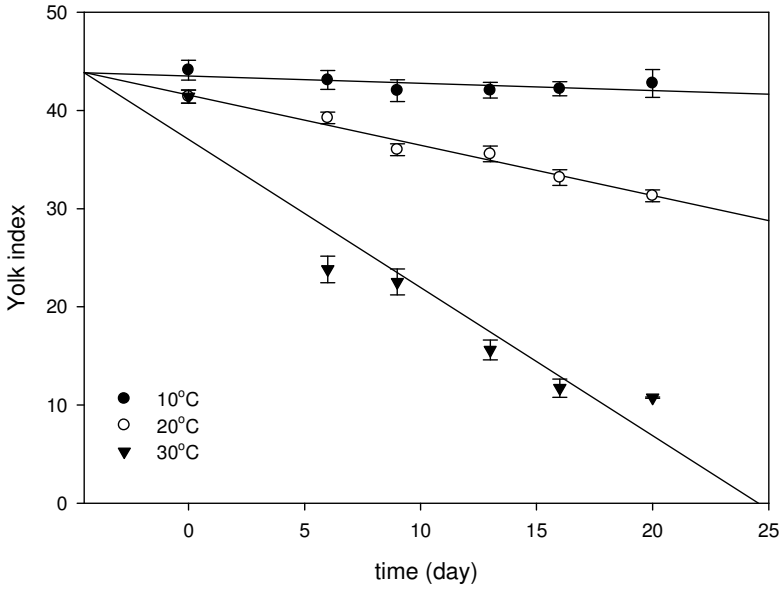


Figure 3.5. Yolk index of egg samples at 10, 20 and 30°C

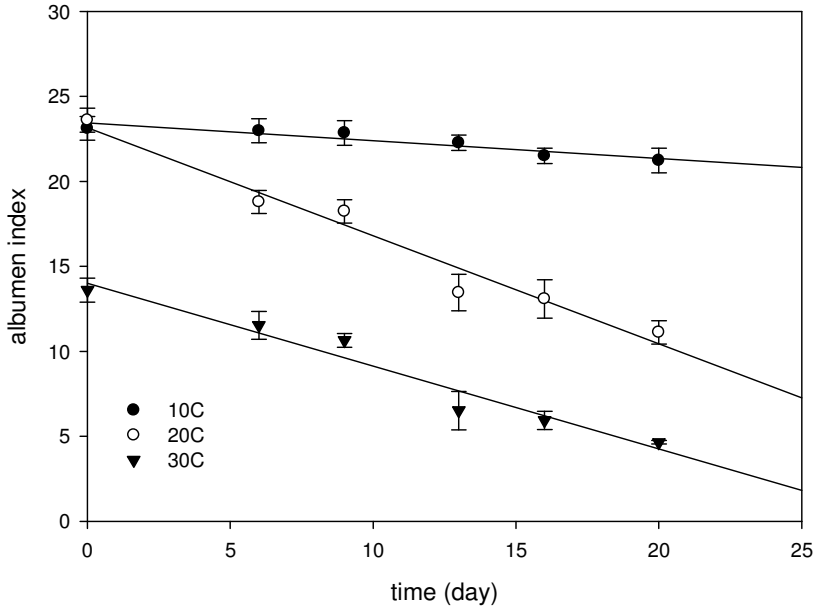


Figure 3.6. Albumen index of egg samples at 10, 20 and 30°C

3.6 Haugh Unit Determinations

Change of Haugh unit at 10, 20 and 30°C were plotted and represented in Figure 3.7. There was a steady decrease in Haugh unit during storage because the Haugh unit is the correlation of both weight and height of albumen. Similar observations have been reported in literature (Doğan and Bayındırlı, 1996).

Storage temperature and time effect on Haugh unit were significant ($P<0.05$) both separately and interaction (Appendix C.3).

The deterioration rate constants (k) at each studied temperature values were determined from the slopes of the lines and shown in Table 3.1. According to the deterioration rate constants, the highest rate of deterioration was found at 30°C, as it was expected. After twenty day storage of the egg samples at 30°C, they lost their acceptability due to the highest decreasing rates of the albumen height and weight. The decrease of the albumen height could be explained as the reduction of the strength of both yolk vitelline membrane and inner shell membrane and increased in the viscosity of the yolk (Karouri, 2006). They explained these changes with increasing of water content of the yolk.

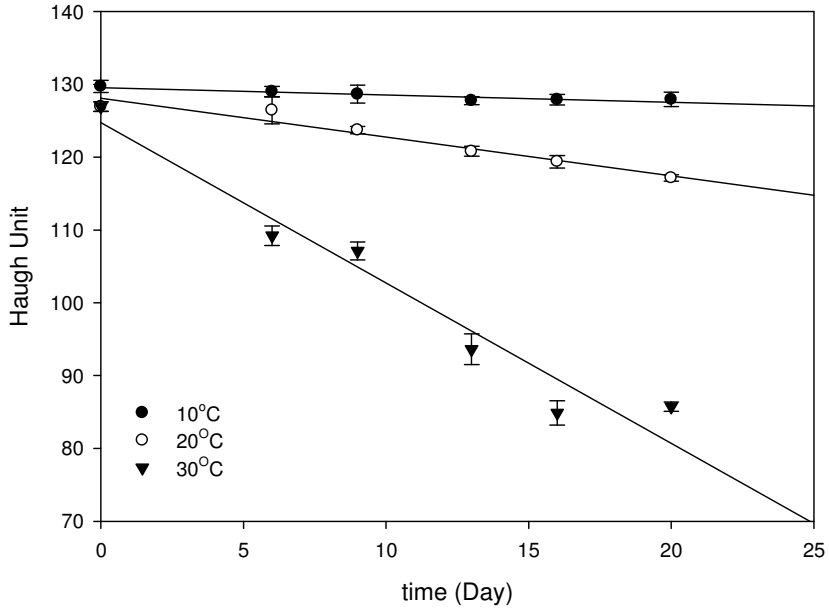


Figure 3.7. Change in Haugh unit of egg samples stored at 10, 20 and 30°C

3.7 Changes in Color of Shell Egg during Storage

In this study, changes of color parameters during storage were determined to measure whether there is any relation between the egg shell color and shelf-life of egg. The variation in color parameters as L-, a-, and b- of egg samples stored at 10, 20 and 30C were shown in Figure 3.8 and 3.9, respectively. Since the color of egg shell is variable from a wide range as seen in Appendix (Tables A8, A9, A10), it is not possible to state that any color parameters will be used to determine ageing of eggs alone, however their changes during storage only could be an indication of end of shelf-life.

The L- value showed a decrease during storage time. This means that final color of egg samples color is darker than the initial color. Also the a- value shows a decreasing during storage time; means that the final color of the egg samples are shift red to greenish color. But as seen the Appendix (Table A10), b- value shows an unsteady change during storage time. The L- value and a- values may be used as a quality parameter for the quality determination of egg. However, the b- value could not be a quality parameter of egg.

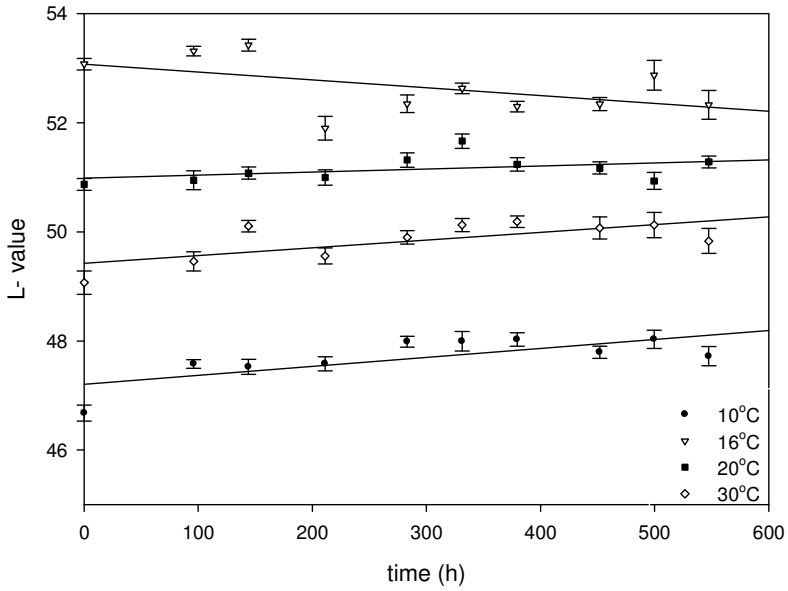


Figure 3.8. Relation between L- (whiteness or darkness) and time

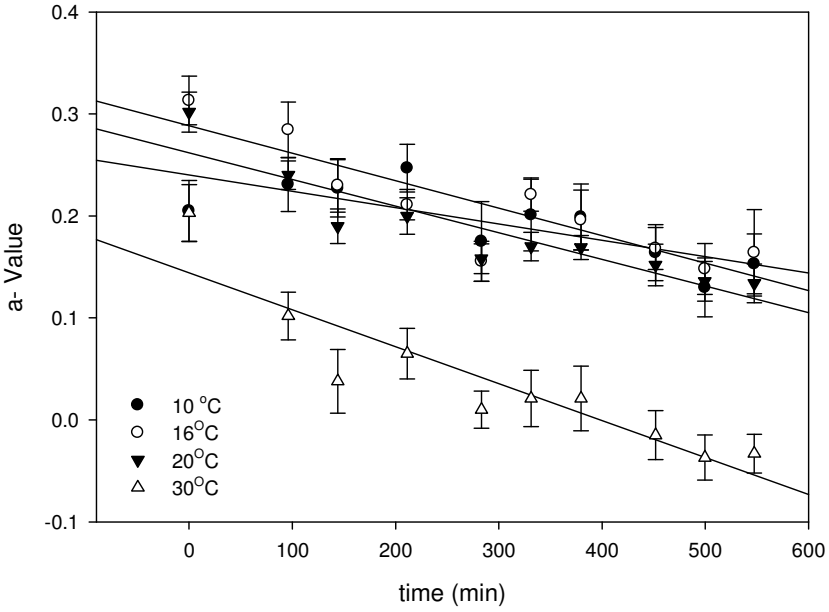


Figure 3.9. Relation between a-(redness/ greenness) and time

3.8 Effect of Temperature on Quality Parameters of Egg

When the natural logarithms of the rate constants were plotted against the reciprocal of the absolute temperature for each quality parameter (Appendix B) and

straight line relationship showed an Arrhenius types behavior. The activation energies of the egg samples at different quality test parameters are given in Table 3.2. Activation energy values can be used to evaluate temperature sensitivity of the food materials (Labuza, 1985).

It was determined that temperature sensitivity of the quality parameters of egg were decreased as in the order Haugh unit, yolk index, yolk area, albumen index, albumen area, pH and weight. According to this study, Haugh unit is the most sensitive because it is a relation between the weight of shell egg and the height of the albumen, and both parameters are affected with the storage temperature. Yolk of the egg is more sensitive to temperature change than the albumen of the egg. It could be explained with the higher concentration of solids in the yolk (USDA, 2000). This causes the yolk to increase in size and become less viscous because of the inflow of water from the white as the egg ages.

Table 3.2. Calculated activation energies of the egg samples at each test parameters.

Quality Parameter	Ea (Kcal/mole)
Weight Change	3190.630
Haugh Unit	48467.396
pH	7472.829
Albumen Area	9136.013
Yolk Area	24776.768
Albumen Index	13216.958
Yolk Index	25722.170

Ea: Activation Energy, R^2: coefficient of determination

3.9 Shelf-life Determination due to Different Quality Parameters

The important two parameters were determined according to the temperature dependency due to the activation energy. The Haugh unit is the most sensitive

parameter to temperature due to the higher activation energy. Yolk index, yolk area, albumen index, albumen area are seen as the sensitive parameters after the Haugh unit. But if checked the parameters of the indexes and Haugh unit same parameter were seen which is the height. So if the Haugh unit were selected as shelf-life determination parameter, the area, height and weight values were to be considered at the same time. The pH is an important indicator presenting the deterioration of egg (Karouri et al, 2006). For this reason the measurement of pH change was chosen as a second important parameter for shelf-life measurement of egg. Shelf life of egg (t) is calculated using Equation (17) derived from Equation (9);

$$-tk = A - A_0 \qquad (17)$$

If the end of the experiment was assumed as end of the acceptance of the egg, the final percent of quality parameters were seen different. According to Haugh unit, 33% of the quality lost and 67% of the quality left. According to pH value, 14% of the quality lost and 86% of the quality left. Calculating the shelf-life of the egg samples for Haugh unit, final quality parameter, A written as $0.670A_0$, and for pH parameter, final quality parameter, A written as $0.860A_0$. By substituting the new derived values to Equation (17), determined shelf-life of the egg samples at different temperatures are given in Table 3.3.

Another important description for the shelf-life determination is "Q_{10}" value. By Labuza (1982), the steeper the slope, the more sensitive to temperature change. A measure of this sensitivity is called the Q_{10} of the reaction, which is defined as Equation (18); the calculated Q_{10} values are given in Table 3.3.

$$Q_{10} = \frac{\text{rate at temperature } (T + 10\ ^\circ C)}{\text{rate at temperature } T\ ^\circ C} \qquad (18)$$

Table 3.3. Calculated shelf-life and Q_{10} values for Haugh unit (HU) and pH

	Temperature (^{o}C)			Q_{10}
	10	20	30	
CSL for HU	475.139	78.561	19.030	4
CSL for pH	50.273	32.694	20.843	2

CSL for HU; calculated shelf life Haugh Unit in days, CSL for pH; calculated shelf life pH in days

CONCLUSION

The study of determination of egg quality parameters, shelf life and temperature dependency of these quality parameters and shelf life revealed the following conclusions:

1- When the shell egg aged, important physical changes occur within yolk, albumen, egg weight and shell egg colour.
2- Area of albumen and pH of whole egg increased, weight of shell egg and height of albumen decreased during aging process.
3- Quality parameters of egg (weight, pH, Haugh unit, colour change, area and height of albumen change) have the zero order as deterioration kinetic.
4- Colour change (L-, a-) during aging of egg could be used as a quality parameter but the b- value was not a good parameter for quality of egg.
5- Haugh unit was the most temperature sensitive quality parameter for egg quality.
6- Weight change was the least temperature sensitive quality parameter.
7- pH change was more applicable parameter for the shelf life determination.
8- Shelf life of the egg was decreased when the storage temperature was increased.

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APPENDICES

APPENDIX A

Table A.1. Weight change of egg samples at 10, 16, 20 and 30°C

Time (day)	Temperature (°C)			
	10	16	20	30
0	64.84	66.98	69.27	67.82
4	64.49	66.70	68.95	66.49
6	64.33	66.56	68.81	66.04
9	64.16	66.43	68.66	65.23
12	63.91	66.22	68.42	64.21
14	63.74	66.10	68.27	63.49
16	63.58	65.96	68.12	62.84
19	63.30	65.77	67.90	61.83
21	63.14	65.64	67.84	61.13
23	62.93	65.49	67.52	60.38
26	62.59	65.28	67.19	59.21
30	62.20	65.03	66.81	57.72

Table A.2. pH change of egg samples at 10, 20 and 30^{o}C

Time (day)	Temperature (^{o}C)		
	10	20	30
0	7.14	7.14	7.14
6	7.45	7.52	7.76
9	7.51	7.58	7.80
13	7.53	7.65	7.95
16	7.54	7.73	8.09
20	7.59	7.78	8.16

Table A.3. Albumen area change of egg samples at 10, 20 and 30^{o}C, (mm^{2})

Time (day)	Temperature (^{o}C)		
	10	20	30
0	10154.42	13154.42	13154.42
6	11525.95	14794.92	16340.55
9	12653.68	15523.40	17532.52
13	12402.21	16912.22	21222.71
16	12790.38	16053.12	21780.91
20	13648.22	16721.59	21515.81

Table A.4. Yolk area change of egg samples at 10, 20 and 30°C, (mm^2)

Time (day)	Temperature (°C)		
	10	20	30
0	1663.56	1663.56	1663.56
6	1709.25	1643.14	2408.63
9	1788.09	1751.02	2924.71
13	1707.73	1751.65	3013.56
16	1713.48	1865.92	3496.85
20	1817.28	1884.12	3636.45

Table A.5. Yolk index change of egg samples at 10, 20 and 30°C

Time (day)	Temperature (°C)		
	10	20	30
0	44.10	41.41	41.41
6	43.10	39.24	23.81
9	42.01	36.01	22.52
13	42.05	35.56	15.61
16	42.21	33.16	11.73
20	42.76	31.30	10.75

Table A.6. Albumen index change of egg samples at 10, 20 and 30°C

Time (day)	Temperature (°C)		
	10	20	30
0	23.12	23.60	13.60
6	22.98	18.79	11.53
9	22.85	18.24	10.64
13	22.27	13.45	6.51
16	21.50	13.09	5.93
20	21.23	11.12	4.65

Table A.7. Haugh unit change of egg samples at 10, 20 and 30°C

Time (day)	Temperature (°C)		
	10	20	30
0	129.71	126.94	126.94
6	129.01	126.44	109.21
9	128.65	123.70	107.12
13	130.76	120.80	93.63
16	131.08	119.38	84.89
20	127.91	117.15	85.73

Table A.8. L- (whiteness or darkness) change of egg samples at 10, 16, 20 and 30^{o}C

Time (day)	Temperature (^{o}C)			
	10	16	20	30
0	46.67	53.07	50.87	49.06
4	47.57	53.31	50.94	49.45
6	47.52	53.42	51.07	50.10
9	47.57	51.90	50.99	49.55
12	47.98	52.34	51.31	49.89
14	47.99	52.63	51.66	50.12
16	48.02	52.29	51.23	50.18
19	47.79	52.34	51.16	50.07
21	48.02	52.87	50.93	50.12
23	47.71	52.32	51.28	49.83

Table A.9. a-(redness/ greenness) change of egg samples at 10, 16, 20 and 30^{o}C

Time (day)	Temperature (^{o}C)			
	10	16	20	30
0	0.20	0.31	0.30	0.20
4	0.23	0.28	0.24	0.10
6	0.22	0.23	0.19	0.03
9	0.24	0.21	0.20	0.06
12	0.17	0.15	0.15	0.01
14	0.20	0.22	0.17	0.02
16	0.19	0.19	0.16	0.02
19	0.16	0.16	0.15	-0.01
21	0.13	0.14	0.13	-0.03
23	0.15	0.16	0.13	-0.03

Table A.10. b- (blueness/yellowness) change of egg samples at 10, 16, 20 and 30°C

Time (day)	Temperature (°C)			
	10	16	20	30
0	1.25	1.62	2.13	1.76
4	1.26	1.71	2.65	1.78
6	1.81	1.34	1.90	1.87
9	2.86	1.73	2.31	3.14
12	1.28	1.54	2.18	1.59
14	1.14	1.51	2.44	2.48
16	1.32	1.86	2.77	2.27
19	1.32	1.53	1.81	1.98
21	2.32	1.57	2.06	2.05
23	1.63	1.43	1.93	2.00

APPENDIX B

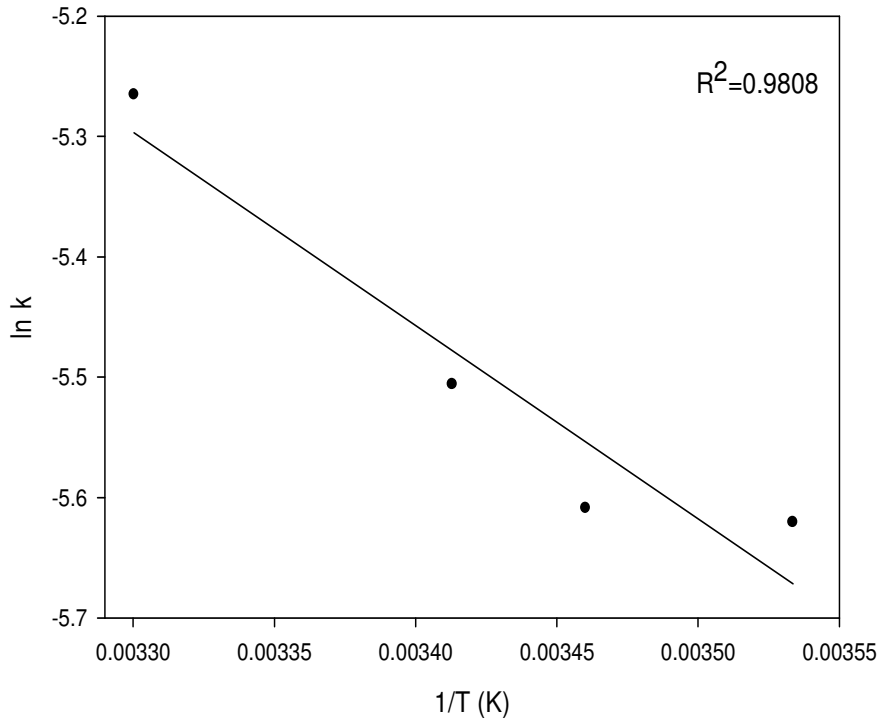

Figure B.1.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for weight change.

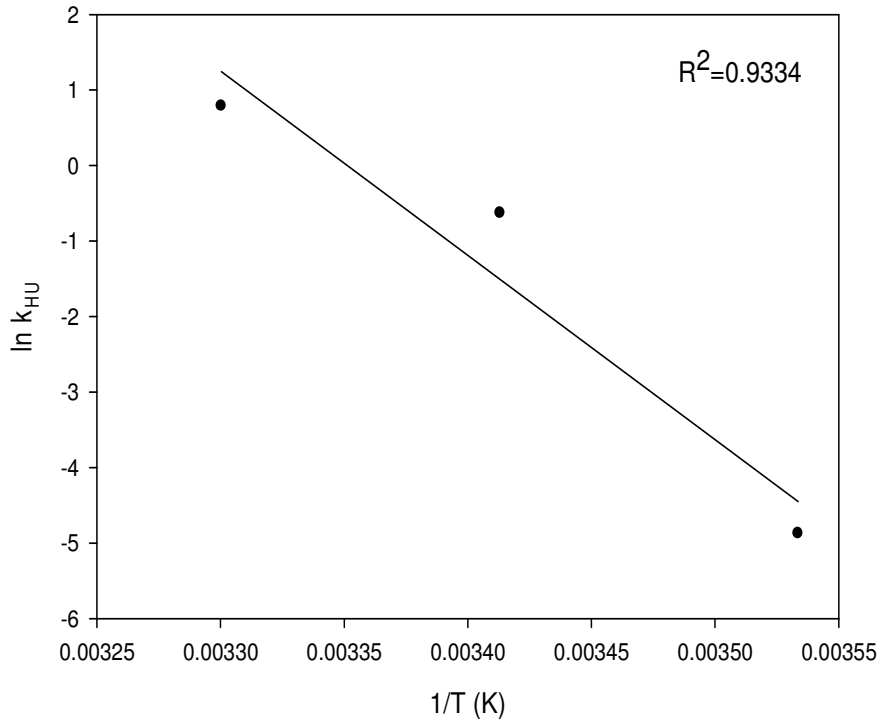

Figure B.2.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for Haugh unit change.

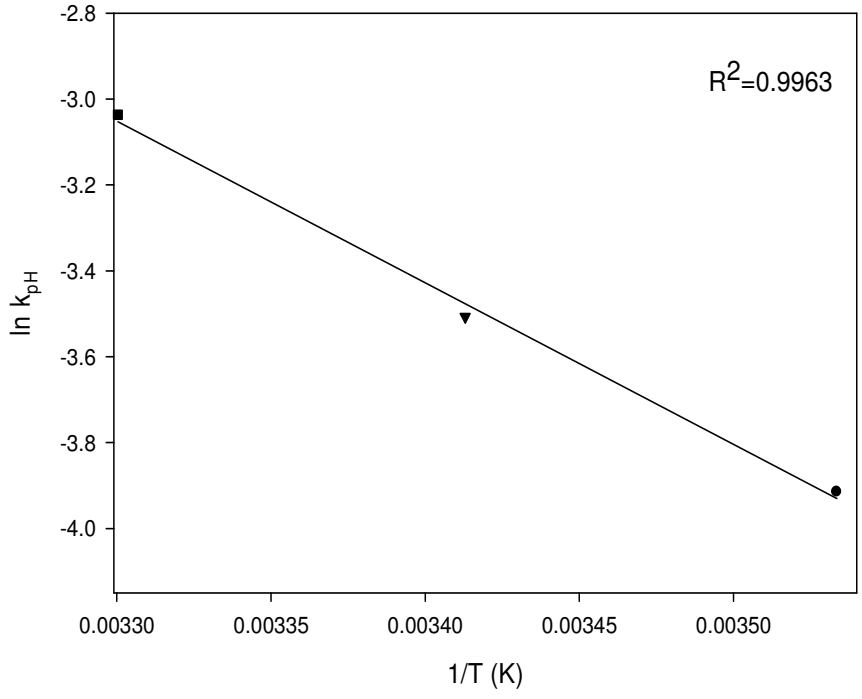

Figure B.3.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for pH change.

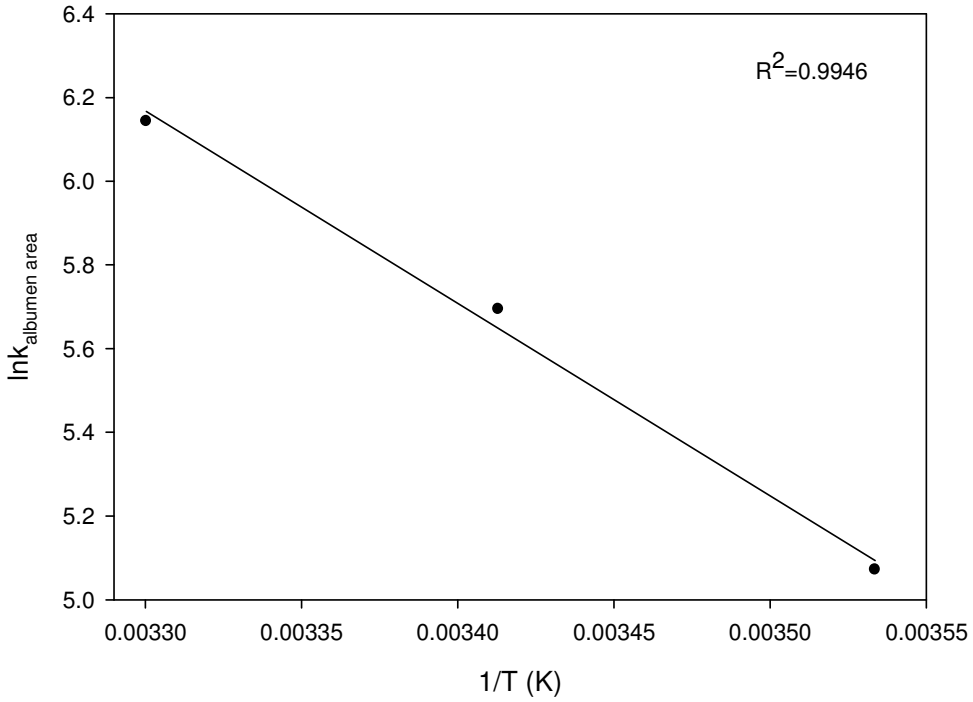

Figure B.4.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for Albumen Area change.

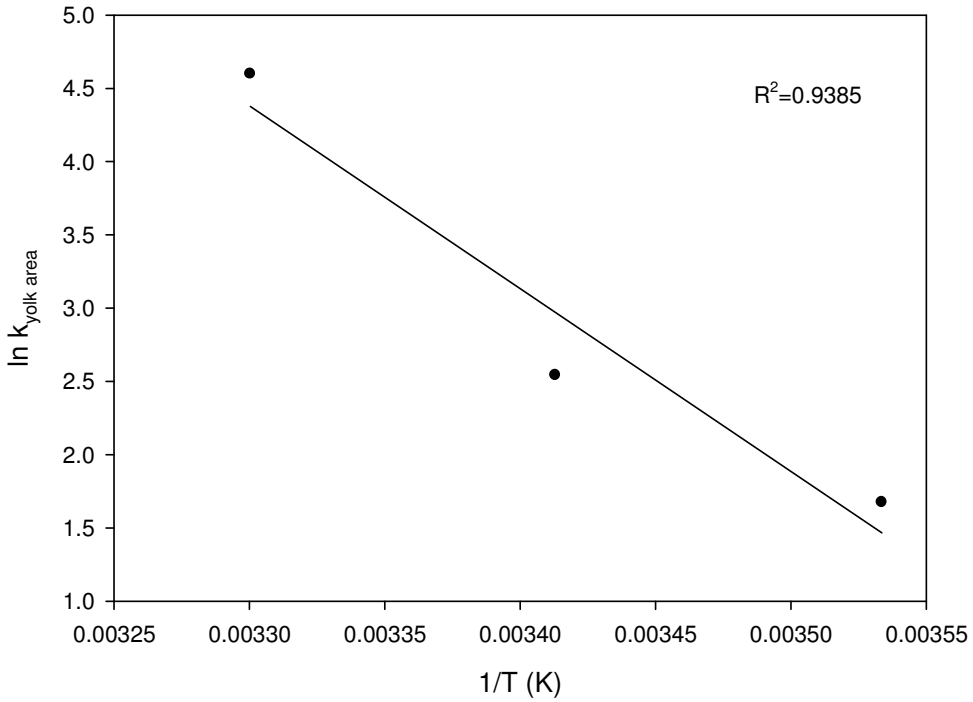

Figure B.5.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for Yolk Area change.

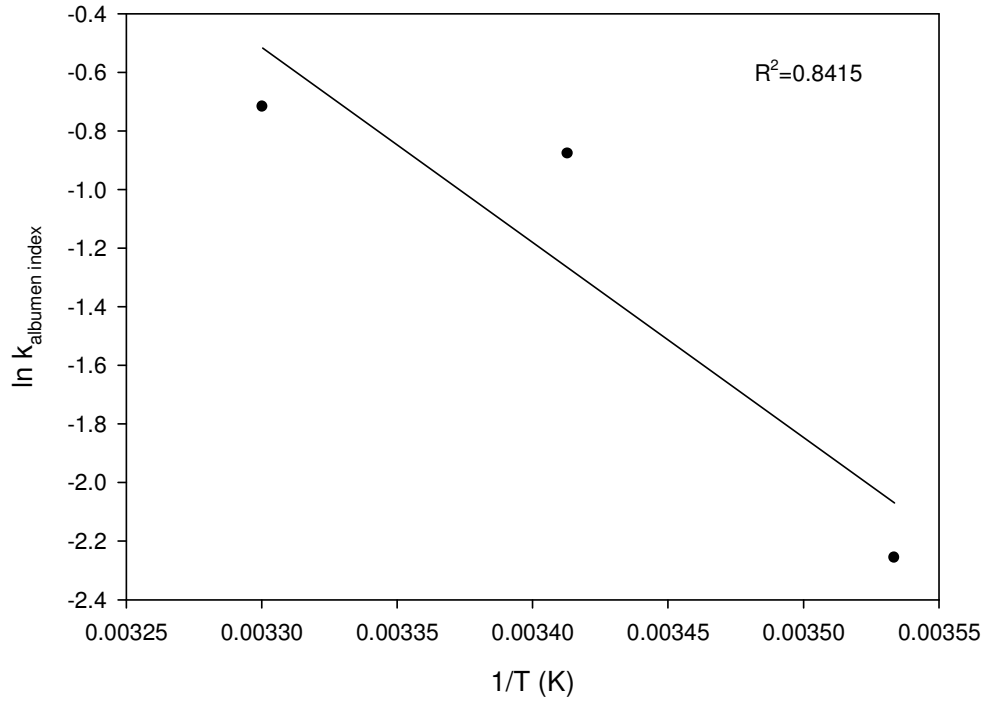

Figure B.6.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for Albumen Index change.

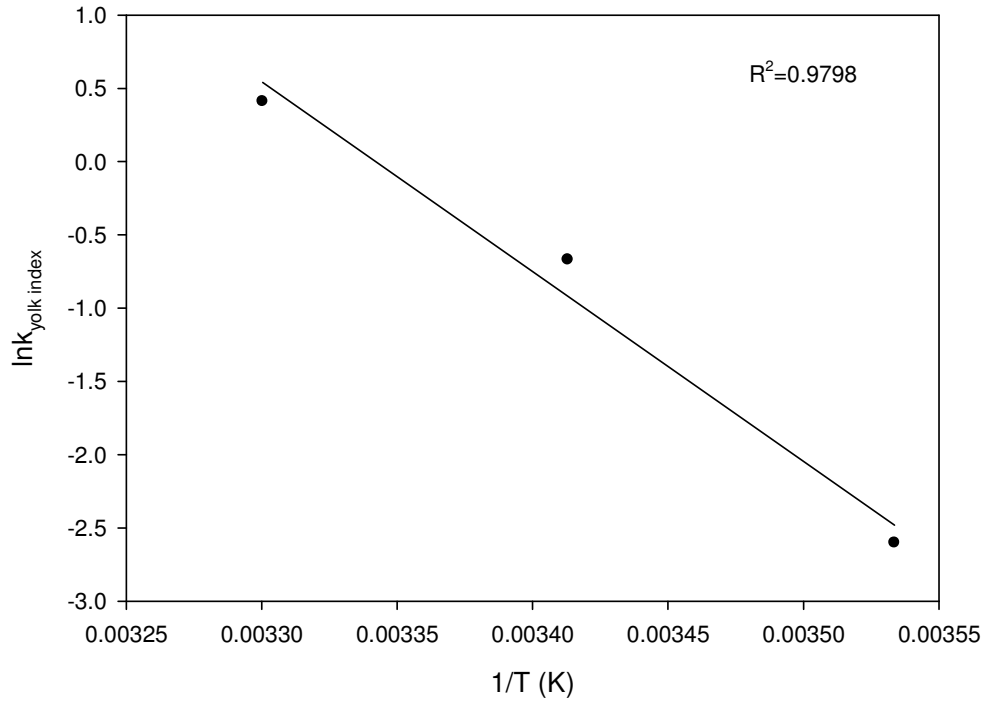

Figure B.7.Natural logarithms of the rate constants versus reciprocal of the absolute temperature for Yolk Index change.

APPENDIX C

Table C.1 Tests of effect of time and temperature on weight change

Dependent Variable: weight

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	3212.862(a)	47	68.359	2.510	.000
Intercept	2040560.945	1	2040560.945	74920.197	.000
temp	1995.105	3	665.035	24.417	.000
time	748.952	11	68.087	2.500	.005
temp * time	468.805	33	14.206	.522	.988
Error	11766.151	432	27.236		
Total	2055539.958	480			
Corrected Total	14979.013	479			

a R Squared = .214 (Adjusted R Squared = .129)

Table C.2 Tests of effect of time and temperature on pH change

Dependent Variable: ph

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	6.399(a)	17	.376	11.856	.000
Intercept	5238.453	1	5238.453	164996.415	.000
temp	2.195	2	1.097	34.565	.000
time	3.579	5	.716	22.546	.000
temp * time	.625	10	.063	1.969	.049
Error	2.286	72	.032		
Total	5247.138	90			
Corrected Total	8.685	89			

a R Squared = .737 (Adjusted R Squared = .675)

Table C.3 Tests of effect of time and temperature on Haugh unit change

Dependent Variable: haugh

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	21937.412[a]	17	1290.436	77.591	.000
Intercept	939409.721	1	939409.721	56484.833	.000
temp	5441.260	2	2720.630	163.586	.000
time	12599.058	5	2519.812	151.511	.000
temp * time	3897.094	10	389.709	23.432	.000
Error	898.084	54	16.631		
Total	962245.217	72			
Corrected Total	22835.496	71			

a. R Squared = .961 (Adjusted R Squared = .948)

PUBLICATIONS:

Symposiums

1. **H. H. ÖZDEMİR** and S. KAYA. Physical Changes of Hen Egg with Different Storage Temperatures, **The Second International Conference in Food Industries and Biotechnology and the associated Fair, Al-Baath University – Homs- Syria1-3 November 2010 (oral presentation).**