T.R.
NİĞDE ÖMER HALİSDEMİR UNIVERSITY
GRADUATE SCHOOL OF NATURAL AND APPLIED SCIENCES
DEPARTMENT OF ANIMAL PRODUCTION AND TECHNOLOGIES

THE EFFECT OF CAGE DIRECTION (WALL SIDE – INNER SIDE), CAGE TIER AND LAYING AGE ON EGG QUALITY CHARACTERISTIC OF LAYER HYBRIDS IN ENRICHED CAGES

YUNUS EMRE ŞENTÜRK

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MASTER THESIS

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Master Thesis

Supervisor

Prof. Dr. Ahmet ŞEKEROĞLU

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The study entitled "**The Effect of Cage Direction (Wall Side – Inner Side), Cage Tier And Laying Age on Egg Quality Characteristic of Layer Hybrids in Enriched Cages**" and presented by Yunus Emre ŞENTÜRK with the help of supervisor Prof. Dr. Ahmet ŞEKEROĞLU**,** has been found as Master thesis by the jury at the Department of Animal Production and Technologies of Nigde Ömer Halisdemir University Graduate School of Natural and Applied Sciences.

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CONFIRMATION:

This thesis has been found appropriate at the date of …./…./20.... by the jury mentioned above who have been designated by Board of Directors of Graduate School of Natural and Applied Sciences and has been confirmed with the resolution of Board of Directors dated …./…./20.... and numbered ……………

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Prof. Dr. Murat BARUT
DIRECTOR

THESIS CERTIFICATION

I declare that all the information presented in this thesis report is derived and compiled following the scientific and academic rules. Moreover, any help and resources that I have sought in compiling this thesis are duly mentioned wherever required.

Yunus Emre ŞENTÜRK

ÖZET

ZENGINLEŞTRILMIŞ KAFES SISTEMINDE, KAFES YÖNÜ (DUVAR – İÇ), KAFES KATI VE YUMURTLAMA YAŞININ YUMURTACI HIBRIT'IN YUMURTA KALITESINE ETKISI

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Bu çalışma zenginleştrilmiş kafes sisteminde, kafes yönü (duvar – iç), kafes katı ve yumurtlama yaşının, yumurtacı hibritte yumurta kalitesi üzerine etkilerini araştırmak amacıyla yapılmıştır. Niğde Ömer Halisdemir Üniversitesi Ayhan Şahenk Tarımsal Uygulama ve Araştırma Merkezinde yetiştirilen Lohman LSL yumurtacı hibridlerden elde edilen 720 adet yumurta kullanılmıştır. Araştırma sonucunda; kafes yönün ak indeksine, Haugh unit'e ve sarı indeksine; yumurtlama yaşının yumurta ağırlığı, şekil indeksi, kırılma mukavemeti, kabuk kalınlığı, ak indeksi, Haugh unit ile sarı rengi skoru ve sarı indeksi skoru üzerine etkisi istatistiksel olarak önemli bulunmuştur. Kafes katının ise yumurta kalitesine anlamlı derecede etkisi gözlemlenmemiştir. Ayrıca birçok kalite kriteri açısından kafes yönü, kafes katı ve yumurtlama yaşı arasındaki interaksiyonlar önemli bulunmuştur.

Anahtar Kelimeler: Zenginleştirilmiş kafes, yumurtacı hibrit, yumurta kalitesi, kafes katı, kafes yönü, hibrit yaşı

SUMMARY

THE EFFECT OF CAGE DIRECTION (WALL SIDE – INNER SIDE), CAGE TIER AND LAYING AGE ON EGG QUALITY CHARACTERISTIC OF LAYER HYBRIDS IN ENRICHED CAGES

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This study investigated the effect of cage direction (wall side- inner side), cage tier, and laying hen age on egg quality in layer hybrid in enriched cage system. A total of 720 egg obtained from Lohman LSL layer hybrids reared in Ayhan Şahenk Agricultural Research and Application Centre were used. Cage direction significantly affected albumen index, Haugh unit, and yolk index. The effect of laying hen age on egg weight, shape index, breaking strength, shell thickness, albumen index, Haugh unit, yolk color score, and yolk index score was found statistically significant. No significant effect of cage tier on egg quality characteristics was observed. In addition, the interactions between cage direction, cage tier, and layer age were found significant for many egg quality parameters.

Keywords: Enriched cage, layer hybrid, egg quality, cage tier, cage direction, hybrid age

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I dedicate this thesis to my mother Hülya ÖZDİN for her support in my entire education life.

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SYMBOLS AND ABBREVIATIONS

Symbols	**Descriptions**
%	Percent
µl	Microliter
µm	Micrometer
cm	Centimeter
e	Random error
g	Gram
kg	Kilogram
kgf/cm^2	Klogram force / cantimeter square
mg	Milligram
mg/cm^2	Milligram / square centimeter
mL	Milliliter
mm	Milimeter
N	Newton
^oC	Degrees centigrade
W	Watt
W/m^2	Watt / meter square
α	Alfa
β	Beta
γ	Gamma
µ	Mu / Population mean

Abbreviations	**Descriptions**
L:D	Light – Dark
LSL	Lohmann Selected Leghorn
Min - Max	Minimum - Maximum
O/C	Open / Close
Wk	Week

CHAPTER I

INTRODUCTION

The history of chicken products goes back a long way, and humans have used chicken products to meet their animal protein needs since ancient times. Factors including industrialization, increasing urbanization, population growth, socialization of people, and increased demand for protein needs have increased the demand for chicken products. The demand for this cheap source of protein also forced the chicken sector to increase its production capacity. With the transition to intensifying production of chicken, the establishment of large production facilities in the chicken sector, low cost and high efficiency operations, and increased stocking density emerged. For example, in the 1960s, a forementioned changes accelerated with the transition from free-range and floor (barn) production systems to cage systems. Meanwhile, several non-governmental organizations, especially in Europen Union countries criticized the production of hens in conventional cages citing its role in causing metabolic and skeletal disorders. Taking these criticisms into account, manufacturers developed enriched cage and cage-free systems (aviary) that enhances hen behavior and welfare (Perry, 2004; Sekeroglu et al., 2010).

As a food source for people, eggs are cheap, easy-to-find, and adequately balanced in terms of nutrient composition. An egg has a high biological value since it contains almost all the nutrients needed by humans. Consumer preferences for egg consumption focus on the eggshell color, thickness, cleanliness, and freshness of the egg. Producers may be more successful in marketing eggs if they consider consumer preferences in terms of egg quality (Efil and Sarıca, 1997). However, egg quality is also defined as "the sum of the properties of a particular foodstuff that affect the consumer's acceptability or preference for that food". (Kramer, 1951 Hisasaga et al., 2020).

In the light of this description, it is possible that egg quality can raise dissimilar meanings for each person and the above definition may be subjected to different interpretations depending on the consumer's perception of quality associated with the purpose of an egg and egg preferences in line with their quality standards (Türkoğlu and Sarıca, 2009). In addition, animal welfare is increasingly seen as an important tool in marketing strategy since it influences the quality of animal products (Poltowiez and Doktor, 2011).

The productivity of laying hens has increased with advances in genetics, feeding, breeding, and health information (Leenstra et al., 2016; Weeks et al., 2016). Such as in commercial egg-laying hybrids, the feed conversion ratio decreased below 2.0 on average, and an average of 360 eggs are laid during 80 weeks of the egg production period (Lohmann, 2021; ISA, 2021). It has been claimed that the products obtained due to the failure to meet the comfort needs of animals in intensive systems are inferior in quality. (Öztürk, 2016).

With consumer preference in mind, the enriched cage system has been developed with increased floor space for hens, nesting box, perches, etc. Moreover, it is thought that the developed alternative production systems (enriched cage and cage-free) can meet the behavioral and welfare needs of hens as much as possible (Farm Animal Welfare Council, 2007).

Egg quality is influenced by many factors such as genotype, nutrition, age, production systems, disease (Silversides and Scotts, 2001; Petek et al., 2009; Şekeroğlu et al., 2014; Englmaierová et al., 2018; Vlčková et al., 2019; Charvátová and Tůmová, 2010; Tůmová and Gous, 2012).

Several studies have reported the effect of flock age, cage tier and cage direction on the quality of eggs in cage systems (Orhan et al., 2001; Ipek et al., 2002; Onbaşılar and Aksoy, 2005; Yıldız et al., 2006; Sahin, 2012; Şekeroğlu et al., 2014; Yılmaz Dikmen et al. 2017; Akkuş and Yıldırım, 2018; Vlčková et al., 2018; Eleroğlu, 2019; Tünaydın and Dikmen, 2019; van den Brand et al., 2004; Tůmová et al., 2011). Regarding the egg quality of hens housed in conventional cages, the above studies stated that egg weight and production have a significant effect on some internal and external quality parameters such as albumen index, Haugh unit, and eggshell thickness. In addition, it is indicated that the enriched cage system for laying hens affects internal and external egg quality parameters (e.g., yolk index, eggshell thickness, eggshell breaking strength) however, more eggs are produced even with reduced stocking density.

In the light of this description, it is possible that egg quality can raise dissimilar meanings for each person and the above definition may be subjected to different interpretations depending on the consumer’s perception of quality associated with the purpose of an egg and egg preferences in line with their quality standards (Türkoğlu and Sarıca, 2009).

1.1 Aims and Objectives

The major aim of this thesis study was to determine the effects of cage direction, cage tier, and flock age on egg quality characteristic such as egg weight, shell thickness, shape index, eggshell breaking strength, albumen index, yolk index, yolk color score and Haugh unit of layer hybrids in enriched cages.

CHAPTER II

LITERATURE REVIEW

2.1 Production System (Effect of Enriched Cage and Other Production Systems on Egg Quality)

The ban on conventional cage production system has led to research for alternative housing systems. In terms of hen welfare, alternative housing systems have been preferable to cages. Some detailed studies have shown that cage type, laying hen age, cage tiers, and cage direction influences egg internal and external characteristics (Appleby et al., 2002; Onbaşılar and Aksoy, 2005; Lewko and Gornowicz, 2011; Fidan and Nazlıgül, 2012; Denli et al., 2016; Baykalir and Simsek, 2018; Vlčková et al., 2019)

Housing system is a major factor that influences egg quality and performance characteristics of layers. Englmaierová et al. (2018) observed higher eggshell and albumen qualities in eggs obtained from conventional cages. In addition, it was identified that eggs in enriched cages and aviary system had a higher yolk index.

Vlčková et al. (2018), observed significant interaction between the housing system (enriched cage and free range) and hen age (26 and 51 weeks) in egg weight and most of eggshell quality measurements. Regarding individual factors, heavier eggs were obtained from enriched cage (61.7 g) compared with free range (59.6 g) environment at 51 wk. It was concluded that housing system and age of laying hens (26 and 51 weeks) significantly affected eggshell breaking strength (43.1 and 41.9 g/cm2) and eggshell thickness (331 and 333 mikrometer) respectively.)

Baykalir and Simsek (2018), studied on 4 different Bovans White hybrid flocks and to determine possible age-related changes on external and internal quality traits of their eggs in the conventional cage and organic rearing systems. For this purpose, 4 different Bovans White hybrid flocks at the same age were monitored in each of these two systems for 52 weeks. A total of 360 eggs were examined to determine the effects of rearing system and age on egg quality traits. While egg weight, albumen weight, yolk weight, shell weight, shape index, and yolk colour were higher in the organic system, shell ratio were higher in the conventional system. In terms of age, it was also found that the egg weight, albumen weight, yolk weight, shell weight, and the percentage of yolk were higher at 60 weeks of age. The percentage of shell and albumen, shape index, and yolk colour were higher at 30 weeks of age. The interactions between rearing system and age were statistically significant in terms of shell thickness, shape index, crude ash ratio, and yolk colour.

Denli et al. (2016), compared that the productivity performance and egg quality of laying hens housed in enriched cages and free-range systems Lohmann Brown hens (19-wk old) were housed in enriched cages and in freerange system (25 hens per cage). They observed that hen-egg production was significantly higher in enriched cages than free range system throughout the experiment and hens raised in free-range system had greater egg weight, eggshell thickness and dirty eggs than in enriched cages. However, the height and width of egg albumen and yolk were not affected by the raising systems.

Fidan and Nazlıgül, 2012 investigated the effect of cage position on some production traits in Denizli chickens. In the experiment, they used California type battery cages (three tier level: top, middle and bottom). It was found that egg weight differences among hens in the various cage positions were statistically significant.

Lewko and Gornowicz (2011), evaluated the quality of eggs from hens of selected Polish breeding; KA62, KA-42, KA-68 and KA-48 in housed in three systems: cage, litter and free range. One hundred eggs were randomly chosen from each experimental group between 34 and 36 weeks of age. They observed that caged hens produced the heaviest eggs (61.06 g) with the lowest shape index (77.86%) and highest percentage of albumen (57.04%) and yolk (29.89%) in the egg. The most favourable quality traits of albumen from the analysed eggs, i.e., greatest height (5.00 mm) and Haugh units (69.70) were characteristic of eggs from hens raised on litter. Shell quality analysis showed that the eggs of free-range birds were characterized by the highest shell weight (5.76 g) with the greatest shell thickness (360.14 µm) and density (81.01 mg/cm^2). Detailed analysis of the physical characteristics of eggs from the layer hybrids revealed significant differences between the housing systems.

Onbaşılar and Aksoy (2005), examined the body weight, mortality rate, egg production, egg quality characteristics and egg yolk cholesterol content in battery cages with three different battery floors (top, middle and bottom). The egg weight on the bottom were greater than the other floor levels. However, egg breaking strength, yolk index, egg cholesterol content, and foot health score were not affected by cage density and floor. While the body weight, egg production, egg weight and plasma corticosterone cocentration were significantly lower in the group with five hens, egg albumen index and Haugh unit were significantly higher in the group with one hen per cage.

2.2 Effect Of Laying Age on The Egg Quality

Several studies have showed changes in internal and external egg characteristics (egg weight, albumen weight, egg yolk weight, eggshell break strength, shell thickness, shape index, albumen index, egg yolk index, egg yolk color, Haugh unit, albumen ratio, egg yolk ratio and shell ratio, etc.) over the laying period (Zita et al., 2009; Silversides and Scott, 2001; Roberts et al., 2013; Chung and Lee, 2014; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017; Eleroğlu, 2019).

Eleroğlu (2019) reported that age had a significant effect on shape index in a study on white egg-laying pure line chickens at the ages of 24, 28, 32, 36, and 40 weeks. In the first two months of laying, age had no effect on shape index. After week 32, shape index started to differ compared to the first two months and continued until the end of the study (week 40). The effect of breeder age on external egg quality traits was found significant during the 5-month study period. Egg weight averaged 49.94 g at week 24, but at week 40, increased to 61.94 g andthere was a significant difference between age groups for egg weight. The effect of age on albumen height was observed only at 24 weeks. The difference between Haugh unit in eggs obtained at week 40 was significant.

In a study on white and brown layers (Nick) hybrids, Akkuş and Yıldırım (2018), showed that the effect of age was statistically significant on egg weight, shape index, breaking strength, and shell surface area. Egg weight (g); 63.6, 69.9 and 70.4, shape index (%); 77.3, 75.8 and 76,6, shell thickness (μ); 0.390, 0.392 and 0.386, shell breaking strength (kgf/cm^2); 4.774, 4.238 and 4.551, were identified for the different layer age groups; 28, 52 and 70 weeks, respectively.

Yılmaz Dikmen et al. (2017), identified an effect of age (30, 40 50 and 60 weeks), 50% hen-day production age, and peak production age on internal and external egg quality parameters in Lohman Brown layers housed in different systems. Layer age together with laying period affected egg weight, shell weight, albumen weight, egg yolk weight, eggshell breaking strength, shell thickness, shape index, albumen index, egg yolk index, egg yolk color, Haugh unit, albumen ratio, egg yolk ratio, and eggshell ratio. During the laying period, eggweight, egg yolk weight and albumen weight increased steadily. Shell weight increased at week 40, then remained constant until the end of the production period. The lowest eggshell breaking strength was found at 50% daily egg production age and 60 weeks of age. The highest shell thickness was found at 40 weeks. The lowest shape index was found at 50% hen-day egg production age and 60 weeks of age. The albumen index decreased with age. The highest egg yolk index was found at 26 weeks of age, and then decreased with increasing until 40 weeks of age. Also, they reported darker egg yolk color was found in the Enriched cage systems as compared to the Conventional cage system at 50 weeks of age.

Şekeroğlu et al. (2014), indicated that ATAK-S hens produced medium weight eggs (56.5 g) 18 weeks old, and egg weight increased (63.2 g) at the end of the experiment (42 weeks old). Likewise, there were significant differences between ages in terms of shell-breaking strength, eggshell thickness, albumen and yolk index, Haugh unit score, shell weight, egg surface area and eggshell colour. However, shell index and albumen pH were not significant. Furthermore, specific gravity, albumen index, yolk index and Haugh unit decreased with age.

Chung and Lee (2014) reported that the average egg weight (64.3g and 64.0 g), Haugh unit score (86.3 and 86.9) and eggshell thickness (35.1 and 36.2 mm/100) were not different between age groups (40 and 60 week old hens) on Hy-Line Brown hens.

In a study by Roberts et al. (2013), it was observed that egg weight, eggshell parameters such eggshell thickness, shell breaking strength, and shell weight from four indigenous flocks in Australia were affected by flock age (24 and 64 weeks). Also, it was determined that albumen height and Haugh unit decreased with the increasing flock age.

Silversides and Scott (2001) found that egg weight increased with hen age in a study of ISA-White and ISA-Brown layers at different ages. Also, in both layers, albumen height decreased with advancing age.

Zita et al. (2009), stated that age and chicken genotype affects egg quality. They found that egg weight, yolk weight, Haugh Units increased with the hens' age in all genotypes, but albumen and eggshell percentage decreased, eggshell thickness and strength improved with age. At the end of the experiment, Moravia BSL chickens laid eggs with the highest egg weight (65.3 g) and yolk quality (yolk index 45.1%). In contrast, the best albumen quality (albumen percentage 60.0) was in Hisex Brown and the eggshell quality measurements (eggshell thickness 0.38 mm) were higher in ISA Brown.

2.3 Effect of Cage Tiers on The Egg Quality

Several research have shown changes in internal and external egg characteristics difference of cage tiers in terms of shell index, shell-breaking strength, eggshell thickness and albumen and yolk indices, Haugh unit score, shell weight, egg surface area, albumen pH and eggshell colour (Onbaşılar and Aksoy, 2005; Yıldız et al., 2006; Sahin, 2012; Şekeroğlu et al., 2014).

Eleroğlu (2019) found no difference between cage tiers in terms of shape index during the 5-month (24-40 weeks) egg production period. The effect of cage tier on egg weight was determined at only week 24. The weight of eggs obtained from the top tier was 51.21 g, followed by the middle (50.31 g), and lower (48.43 g) tiers. The effect of cage tier on albumen height at week 24 was significant. In measurements taken from week 24 to 36, the effect of cage tier on Haugh unit was not significant. The effect of cage tier on shell breaking strength was significant, and highest (42.10 Newton) identified in the middle tier followed by the top and lower tiers 41.02 N and 39.34 N, respectively.

Tünaydın and Yılmaz Dikmen (2019) indicated that the cage tier did not affect eggshell breaking strength and shell weight. In their study, the effect of cage tier on albumen and yolk weight and Haugh unit was not significant. In addition, they reported that there was no effect of cage tier on egg yolk color.

Akkuş and Yıldırım (2018), observed an effect of cage tier (1st, 3rd and 5th) on white and brown commercial egg-laying hybrids. Also, they found that egg weight, shape index, shell thickness, shell surface area was higher on the first cage tier than other tiers (3rd-5th). The highest shell breaking strength was found in eggs collected from the 3rd cage tier. It was observed that the eggs collected from the 5th cage tier were thinner in eggshell than the 1st and 3rd cage tiers, and therefore, the eggshell breaking strength was lower.

Yılmaz Dikmen et al. (2017), reported that egg quality, eggshell, yolk and albumen weight, shell thickness, shell breaking strength, shape index, albumen index, yolk index, yolk color and Haugh unit were found similar between upper and lower tier in enriched cage system.

Şekeroğlu et al. (2014), founded that there was no significant difference between cage tiers in terms of shape index, shell-breaking strength, eggshell thickness and albumen and yolk indices, Haugh unit score, shell weight, and eggshell colour in ATAK-S hybrid.

Yıldız et al. 2006 observed that eggshell strength increased linearly from tier top to bottom suggesting that as light intensity decreased eggshell got thicker and stronger. In addition, tier level was not affected shape index, yolk index and yolk color. Despite a lack of effect of tier level, there were significant cage location by tier level interaction effects on albumen index and Haugh unit.

Onbaşılar and Aksoy, 2005 reported that eggs on the first floor were heavier than the second or third floor and they observed eggshell thickness on the third floor was larger than that on the first floor. Egg shape index, eggshell breaking strength, albumen index, yolk index, and Haugh unit of laying hens were similar for cage floor positions.

2.4 Effect of Cage Direction on The Egg Quality

There are few studies regarding the effect of cage direction on internal and external egg quality. These studies indicated that cage direction alone has no significant effect on internal and external egg quality parameters (Ipek et al., 2002; Yıldız et al., 2006; Sahin, 2012).

Sahin (2012) reported that cage location did not affect egg internal and external quality traits.

Yıldız et al. (2006), determined that egg weight, albumen index and Haugh unit was affected by cage location. However, hens in window location produced eggs with thinner and weaker eggshell than hens on corridor location. Shape index, yolk color and yolk index were not affected by cage location.

Ipek et al. (2002), stated that the effect of cage position (window – corridor) on egg weight, shape index, shell thickness, shell weight, albumen index and yolk index was not significant in a study on Hisex Brown layers.

CHAPTER III

MATERIALS AND METHODS

This research focused on effects of layer age, cage tier (bottom, middle, top), and cage direction (wall side and inner side) on egg quality in enriched cage housing system. The experiment was conducted from 26 to 54 weeks of age.

3.1 Materials

The egg materials used in this study were obtained from white egg-laying hybrids (LOHMAN LSL-CLASSIC) housed at Niğde Ömer Halisdemir University Ayhan Sahenk Agricultural Application and Research Center – Laying hens unit (Figure 3.1.). Egg quality analyses were carried out at Niğde Ömer Halisdemir University, Faculty of Agricultural Sciences and Technologies, Department of Animal Production and Technologies laboratory.

Figure 3.1. Nigde Omer Halisdemir University Ayhan Sahenk Agricultural Application and Research Center – laying hens unit

3.1.1 Housing and management

There was 3 separate lines in one row with 3 tiers (top, middle, and bottom). There was 120 cage units on each line (each tier with 40 cage units) and these cages were positioned in two opposite directions (20 facing outside and 20 facing inside). Each line housed 2640 egg-laying chickens. (Total ±8,000 egg-laying chickens). Polypropylene manure conveyor belt carried manure to the end of the line and manure was thrown out with a horizontal manure conveyor of 50 cm. Every cage included stainless steel drinking nipples, two parallel perch with nail shortener (180 cm each), nest area with privacy curtains (dark blue color – was 40 cm x 33.5 cm x 30 cm; length width, and height), stratch pad and wire floor. Cage construction properties: cage wires were heat offsetting galvanized coating. The cage size was 240 cm x 63.5 cm x 60 cm: length, width, and height, respectively). There was egg conveyor belt, and feeder. (Figure 3.2.)

Figure 3.2. Enriched cage system

3.1.2 Lighting system

A photoperiod of 12 hours of light and 12 hours of darkness (12L:12D) was ensured up to 20 weeks to hens that were brought in the poultry houses at the age of 16 weeks. After 20 weeks, the weekly lighting schedule was increased by half an hour until 16 hours of light-8 hours of darkness (16L:8D), and thereafter, kept constant throughout the experiment. 24-W led bulbs (20 lux - $3.2 w/m^2$) were used as light source.

3.1.3 Animal material

In this study, the animal materials composed of “Lohman Lsl-Classic" egg-laying hybrids that were obtained from a private commercial enterprise at 16 weeks of age.

3.1.4 Feeding and feed material

Feeding was done three times a day, as follows: 1. feeding as soon as the lights came on in the morning, 2. six hours before the lights went off, and 3. three hours before the lights went off. Hens were provided pre layer feed between 12-20 weeks, and layer feed from 20 weeks to the end of the study (Table 3.1.). In addition, water was provided ad-libitum.

Table 3.1. Nutrient composition of layer feed

Nutrient	Max / Min	Layer grower feed, week 7 to 12	Layer developer feed, week 13 to 18	Pre-Layer feed, week 18 to %2 egg yield	Layer feed first period, from %2 egg yield to week 40	Layer feed second period, week 40 to 54
Water	Max, %	12	12	12	12	12
Crude Protein	Min, %	18	18	16	18	18
Crude Cellulose	Max, %	6	6	7	6	6
Crude Ash	Max, %	8	8	11	8	8
HCL Insoluble Ash	Max, %	1	1	1	1	1
Naci	Max, %	0,35	0,35	0,46	0,35	0,35
Metabolic Energy	Min, kcal/kg	2,800	2,800	2,800	2,800	2,800
Lysine	Min, %	0,85	0,85	0,85	0,85	0,85
Methionine	Min, %	0,3	0,3	0,3	0,3	0,3
Cystine	Min, %	0,3	0,3	0,3	0,3	0,3
Sodium	Min, %-Max, %	0,10 - 0,30	0,10 - 0,30	0,10 - 0,30	0,10 - 0,30	0,10 - 0,30
Phosphorus	Min, %	0,6	0,6	0,6	0,6	0,6
Vitamin A	Min, %, I.U./KG	5,000	5,000	5,000	5,000	5,000
Vitamin D3	Min, %, I.U./KG	500	500	500	500	500
Vitamin E	Min, %, mg/kg	10	10	10	10	10
Manganese	Min, %, mg/kg	60	60	60	60	60
Vitamin B2	Min, %, mg/kg	4	4	4	4	4
Vitamin B12	Min, %, mg/kg	10	10	10	10	10
Vitamin K3	Min, %, mg/kg	2	2	2	2	2
Calcium	Min, % - Max, %		0,6 – 1,2			

3.1.5 Health protection

The vaccines specified in the technical manual of the egg-laying hybrids were used during the study. In addition, vitamin supplements were given at regular intervals. All biosafety measures were ensured in the poultry house.

3.2 Methods

Egg sampling and qualty analyses started from 26 week of age and during this period, approximately 720 eggs were used in total. Cage tiers were identified as top, middle, and bottom. Cage direction included wall side and inner side and divided into three-tier blocks (Figure 3.3). There were 120 cages on each line and 40 cages on each tier (20 inner side - 20 wall side). In the trial, a total of 18 cage units; 9 Inner side and 9 wall side from the 5th, 10th, and 15th Blocks were selected to represent the block length and the eggs from the same compartments were used during the trial. Each cage housed 22 chickens. A total of 90 eggs were randomly collected from each cage for egg quality analysis at an interval of four weeks. The collected eggs were transferred from trial center to the laboratory and kept for a day at room temperature before internal and external egg quality analyses.

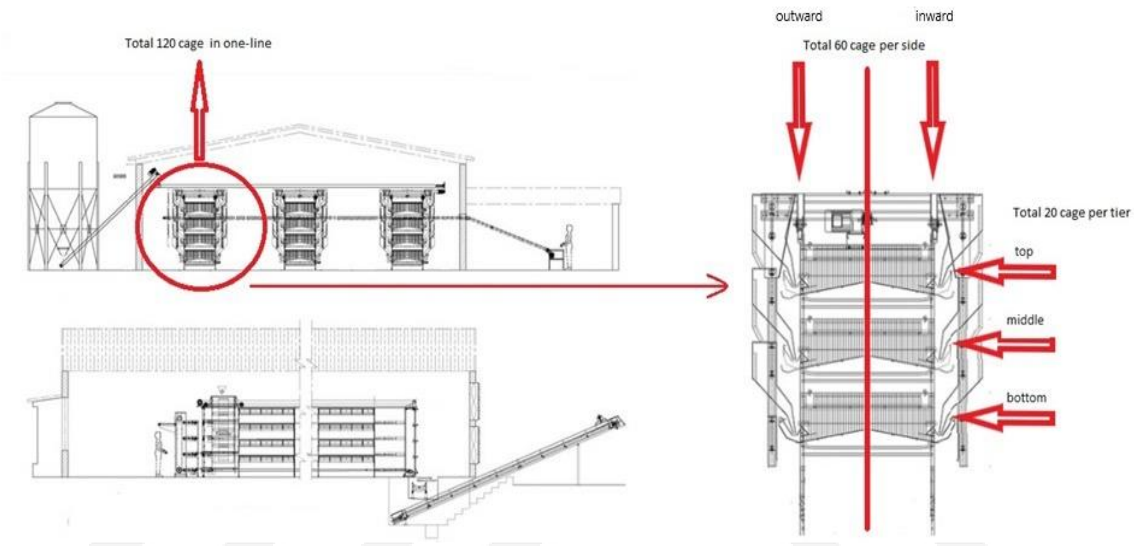


Figure 3.3. Enriched cage system plan for the study

3.3 Egg Quality Analyses

Every 4 weeks (26, 30, 34, 38, 42, 46, 50 and 54 wk), 5 eggs from each replicate were randomly collected for analysis. After 24 hours of storage, internal and external quality measurements were started. All samples were analyzed within the day.

3.3.1 External egg qualty

The analyzed external egg quality traits included egg weight, shape index, shell breaking strength and shell thickness.

<u>Egg Weight (g):</u> Egg weight was measured using a weighting scale with precision of 0.1-gram (Figure 3.4.)

Figure 3.4. Weighting scale (0,1 g precision)

<u>Shape Index (%):</u> Egg width (EW) and egg length (EL) were measured using a digital caliper (Figure 3.5). The shape index was calculated with the formula; SI= (EW/EL) *100 (Sarıca and Erensayın, 2014).

Figure 3.5. Digital caliper

Egg Shell Breaking Strength (kgf/cm^2): Egg force reader (orka food tech. FGV-10XY (5.000 kg) EFO493/2013) (Figure 3.6.) was used to determine eggshell breaking strength.

Figure 3.6. Egg force reader

Egg Shell Thickness (mm): A Metrica manual micrometer (0.01mm – 0-10mm) was used to measure eggshell thickness, which was determined as the average after measuring the thickness of samples taken from the blunt, medium, and pointed sections of an egg without shell membranes. (Figure 3.7.)

Figure 3.7. Egg shell thickness

3.3.1.1 Egg internal qualty

Internal egg quality traits included albumen index, yolk index, albumen height, Haugh unit and yellow color score were performed as below:

Egg Albumen and Yolk Index (%): Samples were broken on a special glass table to measure internal egg quality. (Figure 3.8.) Here, after waiting for 10 minutes, the yolk height was measured with a tripod 0.01 mm sensitivity manual micrometer (USSR, 193557), and albumen length, albumen width, and yolk diameter were measured with a digital caliper (0 – 150 mm). The albumen index and yolk index were calculated with the following formulas.

Albumen index: [(egg albumen height (mm)) / ((egg albumen length (mm) + egg albumen width (mm))/2)] x 100

Yolk index: (egg yolk height (mm) / egg yolk diameter (mm)) x 100 (Sarıca and Erensayın, 2014).

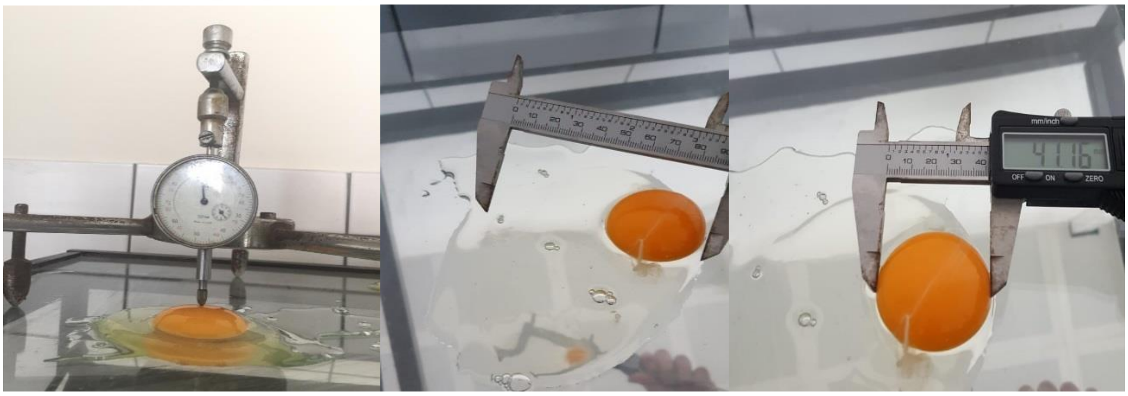


Figure 3.8. Egg albumen and Yolk index measuring

Albumen Height (mm): This was determined by Orka egg analyzer (Orca food tech. EA1459/2013) (Figure 3.9.)

Samples were broken on a black plate to measure albumen heigh. After, pressed to O/C button and the albumen height was measured with a automatically by egg analyzer gauge.

Figure 3.9. Orka egg analyzer

Haugh Unit (Score): After determination of albumen height with Orca egg analyzer (Orca food tech. EA1459/2013), Haugh unit was calculated automatically with the formula below.

Haugh unit score: $100 \times \log (H+7.57 - 1.7\ W^{0.37})$

H: observed albumen height (mm)   W: egg weight (g) (Sarıca and Erensayın, 2014).

Egg Yolk Color (Score): Egg yolk color was scored by DSM yolk color Figure 3.10

Figure 3.10. Dsm Yolk color fan

Statistical Analyses: The obtained data were analyzed according to factorial experimental design in SPSS package. The Duncan Multiple Range Test was used in the comparison of the mean. (SPSS Inc. Chicago, IL. USA).

Mathematical model;

$$Y_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\ \beta)_{ij} + (\alpha\ \gamma)_{ik} + (\beta\ \gamma)_{jk} + (\alpha\ \beta\ \gamma)_{ijk} + (e)_{ijkl}$$

Y_{ijkl} : Observation values,

μ *:* Population mean

α_i : Effect of i^{th} age

β_j : Effect of j^{th} cage tier

γ_k : Effect of k^{th} cage direction

$(\alpha\ \beta)_{ij}$: Interaction effect of the i^{th} and j^{th} treatment

$(\alpha\ \gamma)_{ik}$: Interaction effect of the i^{th} and k^{th} treatment

$(\beta\ \gamma)_{jk}$: Interaction effect of the j^{th} and k^{th} treatment

$(\alpha\ \beta\ \gamma)_{ijk}$: Interaction effect of the i^{th}, j^{th} and k^{th} treatment

$(e)_{ijkl}$: Random error

i: age , j: cage tier, k: cage direction l: observation

CHAPTER IV

RESULTS AND DISCUSSION

4.1 Egg Weight (gram)

Effects of laying age, cage tier and cage direction on egg weight in this study is shown in Table 4.1 and Figure 4.1

Table 4.1 Effects of laying age, cage tier and cage direction on egg weight (g)

Cage tier	Cage direction	Laying Age (week)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	62.62	66.03	67.12	66.39	65.95	66.77	67.91	66.95	65.89	0.268
	Inner Side	63.47	64.77	67.87	64.58	64.67	66.73	66.61	65.91		
2 (middle)	Wall Side	62.17	67.24	67.25	65.70	65.43	66.92	67.96	65.69	65.63	0.308
	Inner Side	60.67	64.60	64.13	64.90	66.98	66.07	67.57	66.88		
3 (top)	Wall Side	61.29	65.38	67.17	64.35	64.97	66.59	68.07	68.03	65.62	0.315
	Inner Side	61.63	65.35	65.97	64.47	64.55	66.84	66.55	68.66		
	Mean	61.97[a]	65.56[bc]	66.58[cd]	65.07[b]	65.43[bc]	66.65[cd]	67.44[d]	67.02[d]		
	SEM	0.282	0.402	0.517	0.446	0.405	0.520	0.453	0.571		
Cage direction	Wall Side Mean	62.03	66.22	67.18	65.48	65.45	66.76	67.98	66.89	66.00	0.237
	Inner Side Mean	61.92	64.91	65.99	64.65	65.40	66.55	66.91	67.15	65.44	0.248

Factors	Significant level (P)
Cage tier	0.733
Cage direction	0.085
Laying Age	0.00**
Cage tier x Cage direction	0.749
Cage tier x Laying Age	0.599
Cage direction x Laying Age	0.885
Cage tier x Cage direction x LayingAge	0.838

** The difference between the averages given with different letters in the same row is statistically significant (P<0,01). Abbreviation(s); SEM, standard error of the mean

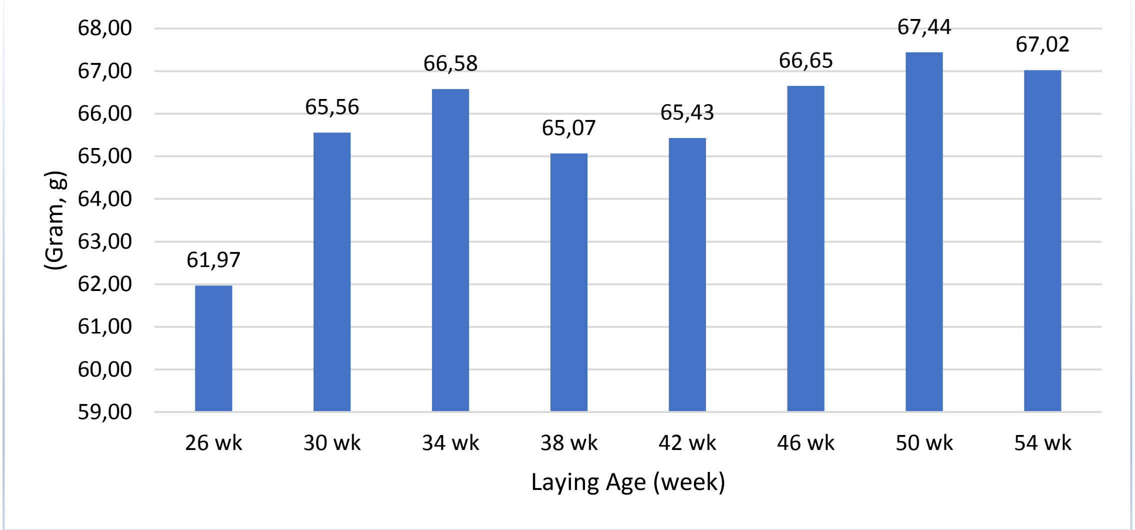


Figure 4.1. Effect of laying age on egg weight, g

<u>The Effect of Laying age on egg weight</u>

In the study, the mean egg weight was 61.97, 65.56, 66.58, 65.07, 65.43, 66.65, 67.44 and 67.02 g at week 26, 30, 34, 38, 42, 46, 50, and 54, respectively. Egg weight increased with advancing hen age and the effect of hen age on egg weight was significant ($P<0.01$). Statistically mean, egg weights were divided into 5 groups based on hen age. These groups included 26, 30, 34, 38, 42, 46, 50, 54 weeks of age. The lowest average egg weight was 61.97 g at week 26 and the highest average egg weights were 67.44 and 67.02 g at week 50 and 54, respectively. The results in this study are in line with several studies that reported statistically significant effect of hen age on gg weight (Silversides and Scott, 2001; Zita et al., 2009; Roberts et al., 2013; Şekeroğlu et al., 2014; Akkus, 2016; Yılmaz Dikmen et al., 2017; Eleroğlu, 2019).

<u>The Effect of cage tier on egg weight</u>

The mean egg weight was 65.89, 65.63, and 65.62 g on bottom, middle, and top cage tier, respectively. The egg weight was not affected by cage tiers. Several studies, in contrary to the findings of this study, found that the cage tier difference had a significant effect on egg weight. (Onbaşılar and Aksoy, 2005; Akkuş and Yıldırım, 2018). On the other hand, Eleroğlu (2019) determined the effect of cage tier on egg weight in only 24 weeks old hens.

The effect of cage direction on egg weight

The egg weight in the wall side and Inner side cage directions were 66.00 and 65.44 g, respectively and the difference in egg weight between cage directions (wall side and inner side) was not statistically significant. An agreement, some studies stated that the effect of cage position on egg weight was not significant (Ipek et al., 2002; Sahin, 2012). Contrary to these studies, Yıldız et al. (2006), reported that egg weight was affected by cage position.

4.2 Egg Shape Index (%)

Effects of laying age, cage tier and cage direction on egg shape index during the study is shown in Table 4.2 and Figure 4.2.

Table 4.2 Effects of laying age, cage tier and cage direction on egg shape index, %

Cage tier	Cage direction	Laying Age (week)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	76.77	75.15	76.39	74.69	75.73	72.89	74.16	74.58	74.73	0.223
	Inner Side	76.06	71.68	74.81	75.42	75.01	74.23	73.78	74.37		
2 (middle)	Wall Side	76.35	74.53	75.58	73.66	74.87	72.28	73.80	73.78	74.55	0.223
	Inner Side	75.09	76.46	75.53	74.69	74.60	74.18	73.52	73.93		
3 (top)	Wall Side	76.09	76.37	75.10	74.34	74.65	74.72	74.56	73.51	74.85	0.224
	Inner Side	76.09	76.02	75.55	74.01	75.40	72.25	75.22	73.65		
	Mean	76.08 [d]	75.04 [bcd]	75.49 [cd]	74.48 [abc]	75.04 [bcd]	73.42 [a]	74.17 [ab]	73.97 [ab]		
	SEM	0.364	0.364	0.364	0.366	0.364	0.364	0.364	0.366		
Cage direction	Wall Side Mean	76.40	75.35	75.69	74.23	75.09	73.30	74.17	73.95	74.77	0.182
	Inner Side Mean	75.75	74.72	75.30	74.73	75.00	73.55	74.17	73.98	74.65	0.182

Fators	Significant level (P)
Cage tier	0.644
Cage direction	0.632
Laying Age	0.00**
Cage tier x cage direction	0.271
Cage tier x Laying Age	0.354
Cage direction x Laying Age	0.949
Cage tier x Cage direction x Laying Age	0.238

** The difference between the averages given with different letters in the same row is statistically significant (P<0,01). Abbreviation(s); SEM, standard error of the mean

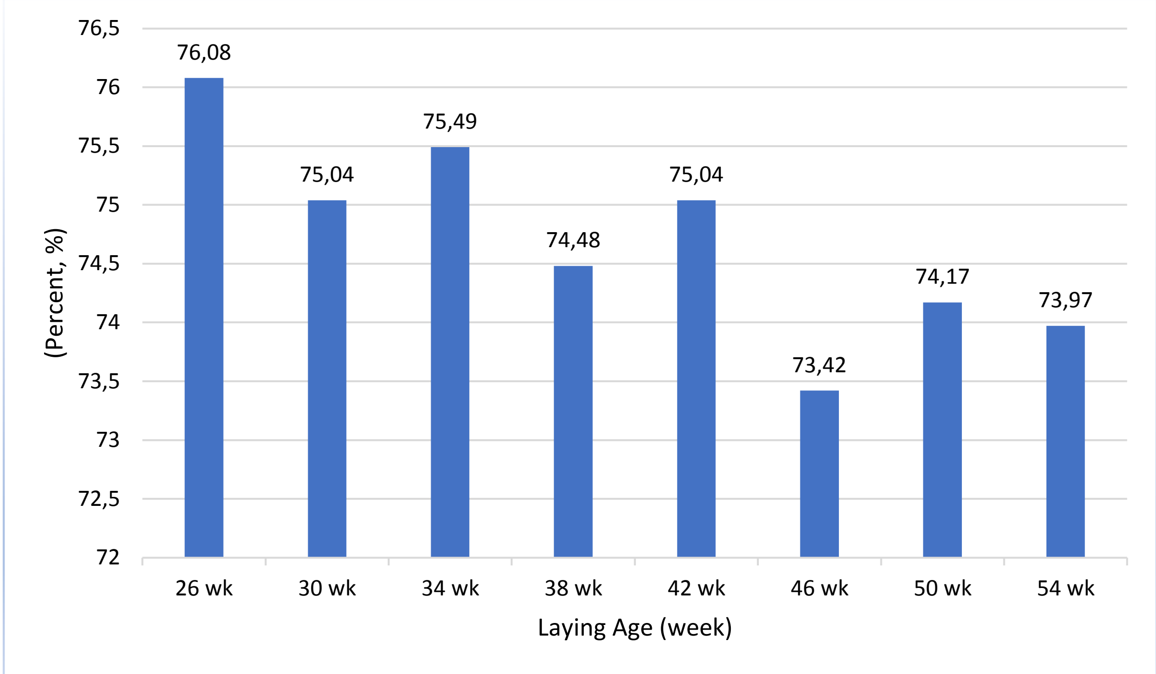


Figure 4.2. Effect of laying age on shape index, %

The effect of laying age on egg shape index

Egg shape index at week 26, 30, 34, 38, 42, 46, 50, and 54 was 76.08, 75.04, 75.49, 74.48, 75.04, 73.42, 74.17 and 73.97 %, respectively. In this study, egg shape index decreased with advancing hen age and the effect of hen age on egg shape index was statistically significant ($P<0.01$). In agreement with this study, various studies stated that egg shape index is affected by age and age has a significant effect on egg shape index (Yılmaz Dikmen et al., 2017; Akkuş and Yıldırım, 2018; Eleroğlu, 2019).

The effect of cage tier on egg shape index.

Egg shape index was observed as 74.73, 74.55, and 74.85 % on 1st, 2nd, and 3rd cage tiers, respectively. There was no statistically significant difference between cage tiers regarding egg shape index. Several authors reported that cage tier had no statistically significant effect on egg shape index (Onbaşılar and Aksoy, 2005; Yıldız et al., 2006; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017; Eleroğlu, 2019). These results are in line with this study.

The effect of cage direction on egg shape index.

The egg shape index on wall side and inner side cage direction were 74.77 and 74.65%, respectively, and no significant difference was observed in shape index between cage tiers. In the same way, in studies by Sahin (2012), Yıldız et al. (2006), and Ipek et al. (2002), it was observed that cage direction did not affect egg shape index. The results of these studies are consistent with the findings of this research. Also, the present results showed that interactions between the factors did not significantly affect egg shape index.

4.3 Eggshell Breaking Strength (kgf/cm^2)

Effects of laying age, cage tier and cage direction eggshell breaking strength in this study is shown in Table 4.3., Figure 4.3 and 4.4.

Table 4.3 Effects of laying age, cage tier and cage direction on eggshell breaking strength, kgf/cm^2

Cage tier	Cage direction	Laying Age (week)									
		26	30	34	38	42	46	50	54	Mean	SEM
1 (bottom)	Wall Side	5.39	4.94	5.01	4.85	4.75	4.61	4.53	4.51	4.80	0.050
	Inner Side	4.98	5.57	4.53	4.64	4.57	4.90	4.52	4.53		
2 (middle)	Wall Side	4.64	4.96	4.74	4.58	4.75	4.76	4.67	4.24	4.68	0.056
	Inner Side	4.85	4.53	4.41	4.85	4.71	5.65	3.99	4.53		
3 (top)	Wall Side	4.66	5.07	4.81	4.62	4.77	4.33	4.65	4.20	4.65	0.056
	Inner Side	5.17	5.18	4.60	4.76	4.55	4.39	4.06	4.59		
	Mean	4.95^{d}	5.21^{e}	4.68^{bc}	4.72^{cd}	4.68^{bc}	4.61^{abc}	4.40^{a}	4.43^{ab}		
	SEM	0.078	0.109	0.076	0.069	0.072	0.091	0.087	0.087		
Cage direction	Wall Side Mean	4.90	4.99	4.86	4.68	4.76	4.57	4.62	4.32	4.71	0.039
	Inner side mean	4.99	5.42	4.51	4.75	4.61	4.65	4.20	4.55	4.71	0.048

Factors	Significant level (P)
Cage tier	0.096
Cage direction	0.99
Laying Age	0.00**
Cage tier x cage direction	0.88
Cage tier x Laying Age	0.93
Cage direction x Laying Age	0.007**
Cage tier x Cage direction x Laying Age	0.52

** The difference between the averages given with different letters in the same row is statistically significant (P<0,01). Abbreviation(s); SEM, standard error of the mean

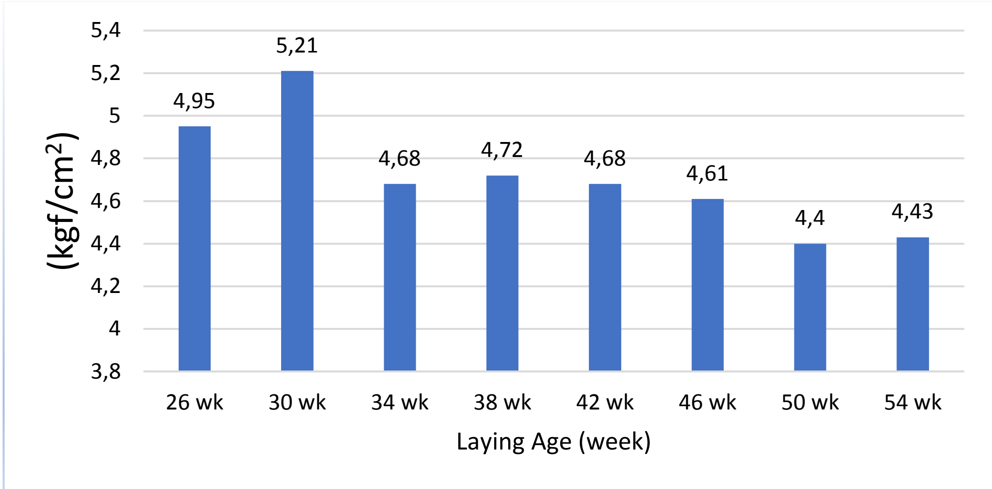


Figure 4.3. Effect of laying age on eggshell breaking strength, kgf/cm^2

The effect of laying age on eggshell breaking strength

In this study, it was found that eggshell breaking strength at week 26, 30, 34, 38, 42, 46, 50, and 54 was 4.95, 5.21, 4.68, 4.72, 4.68, 4.61, 4.40, and 4.43, respectively. The effect of hen age on eggshell breaking strength was statistically significant ($P<0.01$). In addition, eggshell breaking strength decreased with advancing hen age. Similar to this study, several researchers observed that layer age significantly affected eggshell breaking strength (Zita et al., 2009; Roberts et al., 2013; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017; Akkuş and Yıldırım, 2018). Also, in a study of white and brown layer (Nick White and Brown) hybrids, it was showed that the effect of age on eggshell breaking strength was statistically significant (Akkuş and Yıldırım, 2018). Furthermore, the preceding author found that eggshell breaking strength (kgf/cm2) at different age groups; 28, 52. and 70th weeks was 4.774, 4.238, and 4.551 kgf/cm^2, respectively).

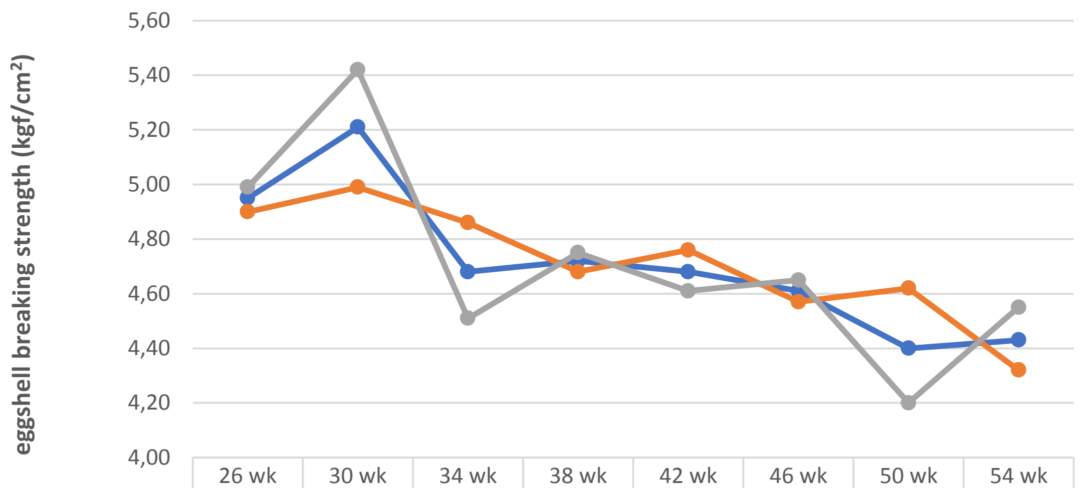
The effect of cage tier on eggshell breaking strength

It was determined that the eggshell breaking strength on the 1st, 2nd, and 3rd cage tiers was 4.80, 4.68, and 4.65 Newton, respectively. As the cage tiers increased upwards (1st to 3rd), the decrease in eggshell breaking strength did not result in a statistical difference. In a study conducted by Eleroğlu (2019) found that there was a significant effect of cage tier on eggshell breaking strength. In addition, the highest value was identified in the eggs obtained from the middle tier (42.10 N) followed by the upper

(41.02 N) and lower (39.34 N) tiers. Akkuş and Yıldırım (2018) observed that eggshell breaking strength was different between cage tiers (P<0.01). Although the results reported by Eleroğlu (2019) and Akkuş and Yıldırım (2018), were different from this study, several authors identifed similar results to the present study (Onbaşılar and Aksoy, 2005; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017; Tünaydın and Dikmen, 2019).

<u>The effect of cage direction on eggshell breaking strength</u>

It was found that there was no significant difference between eggshell breaking strength in wall side and inner side cage direction (Figure 4.3.1.). Sahin (2012) and Ipek et al. (2002), reported that cage direction had no effect on eggshell breaking strength, which is in line with this study. On the contrary, Yıldız et al. (2006), reported that layers housed Inner side – wall side cages produced eggs with thinner and weaker eggshell than wall side layers. In addition, the interaction effect between cage direction and age on eggshell breaking strength was found significant (P<0.01). Although the effect of inner side and wall side cage direction on eggshell breaking strength was similar, the layer age and light intensity may be the possible reason for the significant effect of cage direction and age interaction on eggshell breaking strength.



	26 wk	30 wk	34 wk	38 wk	42 wk	46 wk	50 wk	54 wk
Laying age	4,95	5,21	4,68	4,72	4,68	4,61	4,40	4,43
Outward	4,90	4,99	4,86	4,68	4,76	4,57	4,62	4,32
Inward	4,99	5,42	4,51	4,75	4,61	4,65	4,20	4,55

Figure 4.4. Effect of laying age x wall side - inner side (cage direction) interactions on eggshell breaking strength, kgf/cm^2

4.4 Eggshell Thickness (milimeter)

Effects of laying age, cage tier and cage direction on eggshell thickness in this study is shown in Table 4.4., Figure 4.5 and Figure 4.6.

Table 4.4 Effects of laying age, cage tier and cage direction on eggshell thickness, mm

Cage tier	Cage direction	Laying Age (week)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	0.410	0.387	0.389	0.396	0.382	0.421	0.391	0.363	0.392	0.03
	Inner Side	0.394	0.359	0.379	0.428	0.362	0.419	0.393	0.393		
2 (middle)	Wall Side	0.405	0.364	0.401	0.361	0.398	0.422	0.394	0.355	0.388	0.03
	Inner Side	0.391	0.363	0.384	0.403	0.395	0.402	0.383	0.391		
3 (top)	Wall Side	0.399	0.373	0.406	0.380	0.390	0.417	0.390	0.384	0.389	0.03
	Inner Side	0.399	0.370	0.383	0.399	0.360	0.393	0.385	0.399		
	Mean	0.400^{cd}	0.369^{a}	0.390^{bc}	0.394^{bc}	0.381^{ab}	0.412^{d}	0.390^{bc}	0.381^{ab}		
	SEM	0.005	0.005	0.005	0.005	0.005	0.005	0.005	0.005		
Cage direction	Wall Side Mean	0.405	0.375	0.399	0.379	0.390	0.420	0.393	0.368	0.391	0.002
	Inner Side Mean	0.395	0.364	0.382	0.410	0.372	0.405	0.387	0.394	0.388	0.002

Factors	Significant level (P)
Cage tier	0.671
Cage direction	0.490
Laying Age	0.000**
Cage tier x cage direction	0.640
Cage tier x Laying Age	0.223
Cage direction x Laying Age	0.000**
Cage tier x Cage direction x Laying Age	0.969

** The difference between the averages given with different letters in the same row is statistically significant (P<0,01). Abbreviation(s); SEM, standard error of the mean

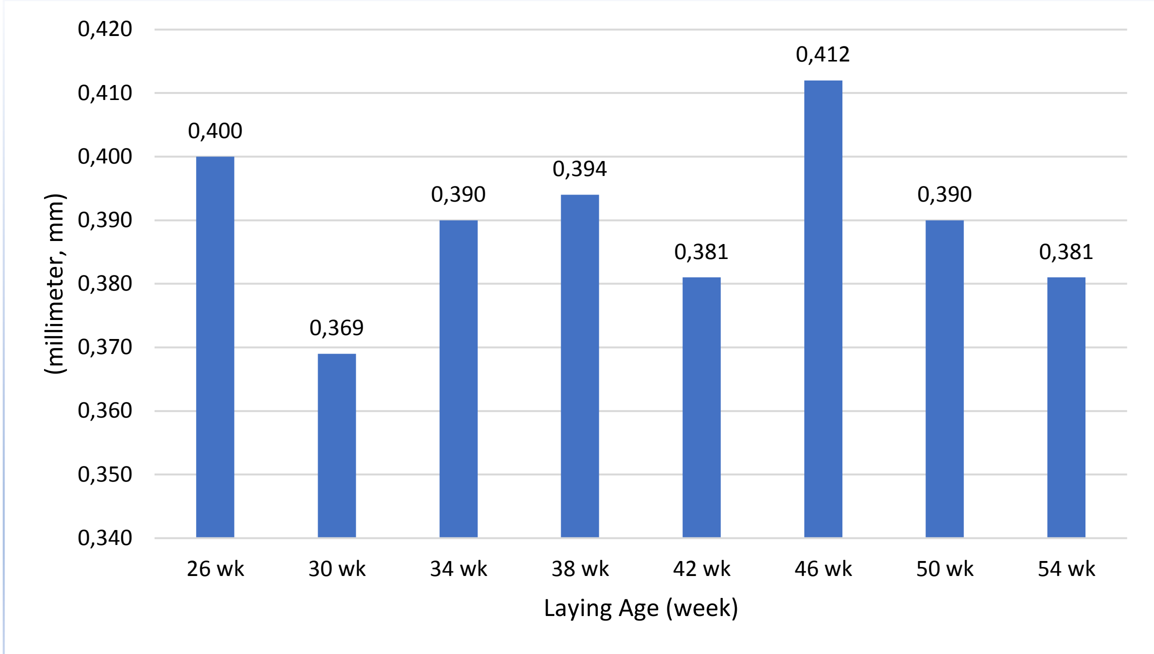


Figure 4.5. Effect of laying age on egshell thickness, mm

The effect of laying age on shell thickness

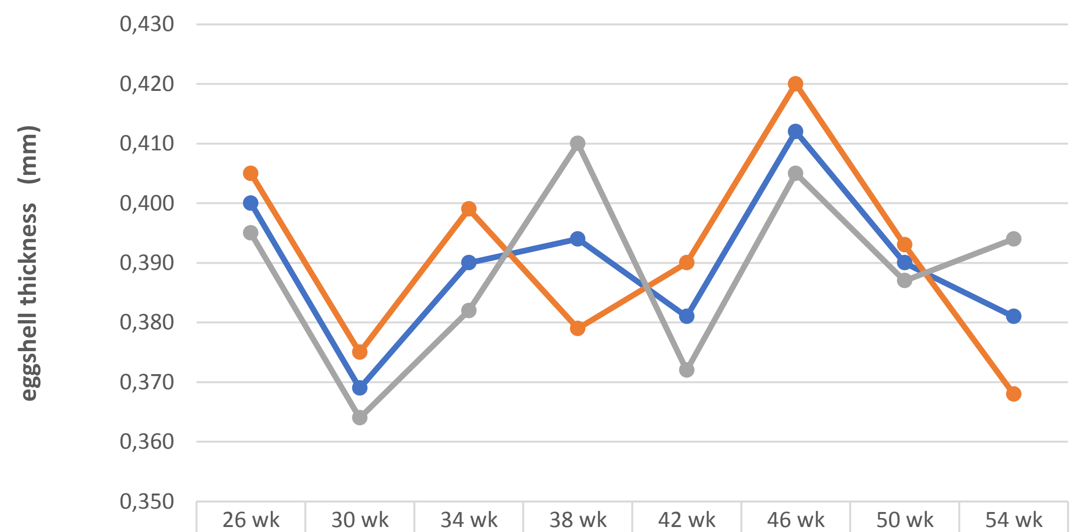
Eggshell thickness at week 26, 30, 34, 38, 42, 46, 50, and 54 was 0.400, 0.369, 0.390, 0.394, 0.381, 0.412, 0.390, and 0.381 mm, respectively. The effect of hen age on eggshell thickness was statistically significant ($P<0.001$). The highest and lowest shell thickness was found at week 46 (0.412mm) and 30 (0.369 mm), respectively. In agree with this study, several studies observed that eggshell thickness was statistically significant between different age groups (Zita et al., 2009; Roberts et al., 2013; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017). In disagreement, in a study of Hy-Line layers, Chung and Lee (2014), observed no statistical difference in shell thickness between age groups.

The effect of cage tier on eggshell thickness.

The shell thickness on 1st, 2nd, and 3rd cage tier was 0.392, 0.388, and 0.389 (mm), respectively. The effect of cage tier on eggshell thickness was not statistically significant. Similar to this study, studies by Yılmaz Dikmen et al. (2017) and Şekeroğlu et al. (2014), observed that cage tier had no effect on eggshell thickness. On the other hand, Akkuş and Yıldırım (2018) and Onbaşılar and Aksoy (2005), showed that the effect of cage tier on eggshell thickness was statistically significant.

The effect of cage direction on the eggshell thickness.

Eggshell thickness in wall side and inner side cage direction was 0.391 and 0.388 mm, respectively. The effect of cage direction on eggshell thickness was not statistically significant. Contrary to this study, Ipek et al. (2002), stated a statistically significant effect of cage direction on eggshell thickness. In this study, effect of cage direction and age interaction on eggshell thickness was statistically significant ($P<0.01$). It is thought that there might be differences in the quantity of consumed feed by the hens in different cage directions, which might result in calcium differences thus, differences in eggshell thickness. In addition, it is suggested the interaction effect might be associated with variation in nutrient composition of the hen’s ration, which was not controlled during the study.



	26 wk	30 wk	34 wk	38 wk	42 wk	46 wk	50 wk	54 wk
Laying age	0,400	0,369	0,390	0,394	0,381	0,412	0,390	0,381
Outward	0,405	0,375	0,399	0,379	0,390	0,420	0,393	0,368
Inward	0,395	0,364	0,382	0,410	0,372	0,405	0,387	0,394

Figure 4.6. Effect of laying age x wall side - inner side (cage direction) interactions on egshell thickness, mm

4.5 Egg Albumen Index (%)

Effects of laying age, cage tier and cage direction on egg albumen index in this study is shown in Table 4.5., Figure 4.7, 4.8. and Figure 4.9.

Table 4.5 Effects of laying age, cage tier and cage direction on egg albumen index

Cage tier	Cage direction	Laying Age (weeks)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	5.44	7.28	6.22	5.94	7.51	7.26	7.41	7.12	7.25	0.103
	Inner Side	7.19	6.29	7.68	7.17	6.17	6.27	8.14	7.37		
2 (middle)	Wall Side	5.96	7.72	6.20	5.95	7.39	6.46	7.33	8.52	7.09	0.104
	Inner Side	6.86	7.27	6.63	7.45	6.86	6.47	8.31	8.30		
3 (top)	Wall Side	6.90	7.68	6.08	5.96	7.21	6.20	7.00	8.15	6.97	0.103
	Inner Side	8.12	6.29	6.41	6.95	7.31	6.11	7.78	7.50		
	Mean	6.74^{ab}	7.09^{b}	6.52^{a}	6.58^{ab}	7.08^{b}	6.49^{a}	7.66^{c}	7.81^{c}		
	SEM	0.166	0.167	0.167	0.172	0.169	0.168	0.167	0.172		
Cage direction	Wall Side Mean	6.10	7.56	6.17	5.95	7.37	6.64	7.24	7.92	6.87	0.085
	Inner Side Mean	7.38	6.60	6.87	7.18	6.78	6.32	8.07	7.71	7.12	0.084

Factors	Significant level (P)
Cage tier	0.439
Cage direction	0.038*
Laying Age	0.000**
Cage tier x cage direction	0.868
Cage tier x Laying Age	0.013*
Cage direction x Laying Age	0.000**
Cage tier x Cage direction x Laying Age	0.704

*, ** The difference between the averages given with different letters in the same line is statistically significant (*P<0,05, **P<0,01). Abbreviation(s); SEM, standard error of the mean

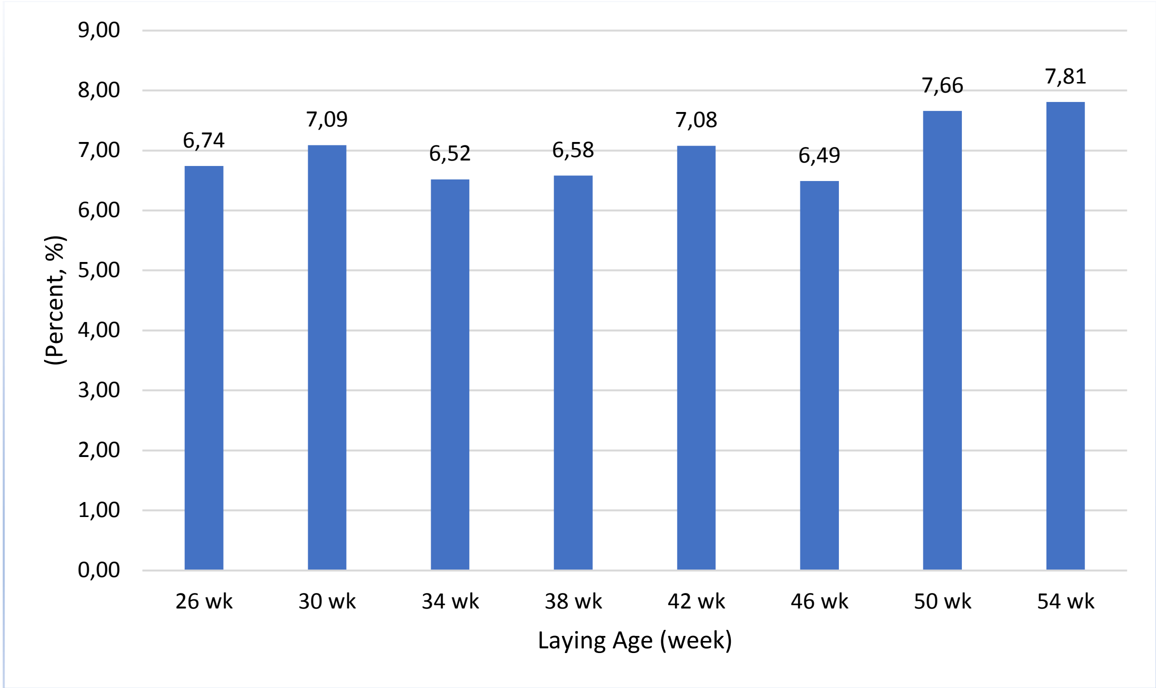


Figure 4.7. Effect of laying age on egg albumen index, %

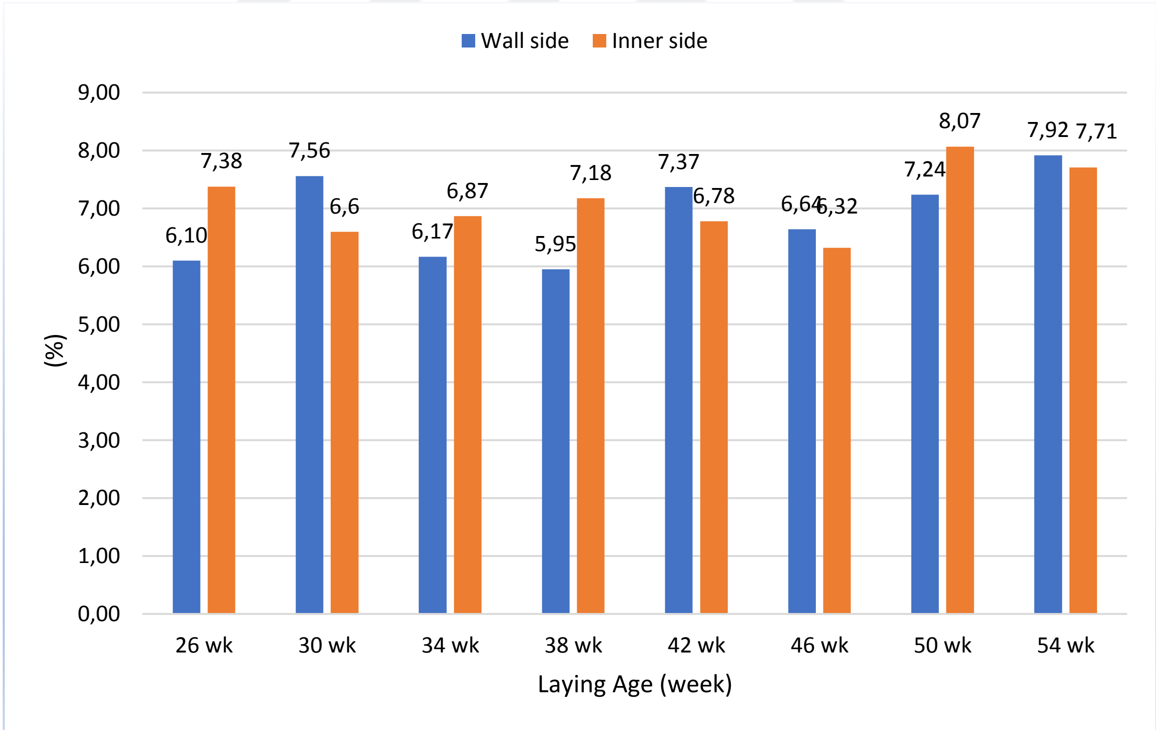


Figure 4.8. Effect of laying age on egg albumen index, %

The effect of laying age on egg albumen index

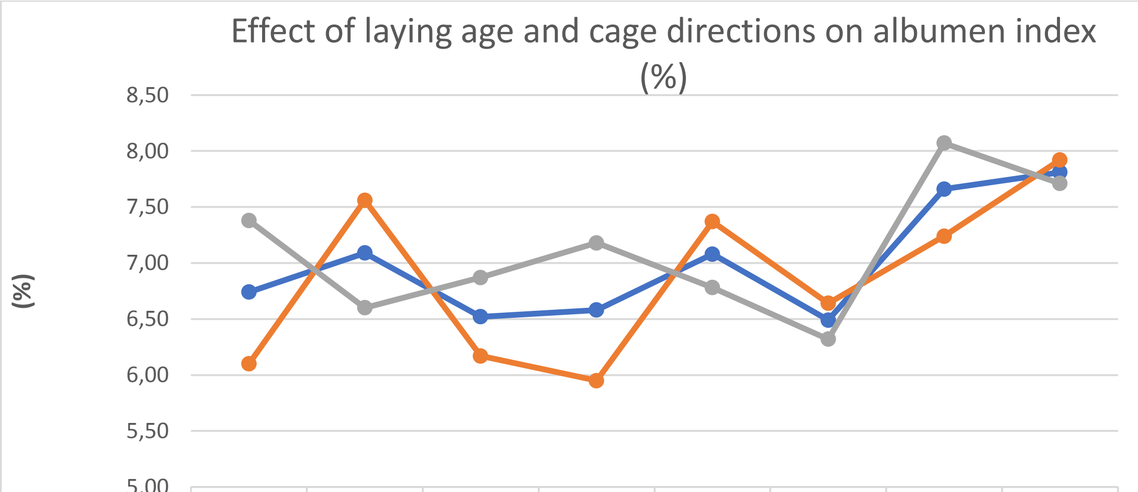
The egg albumen index at week 26, 30, 34, 38, 42, 46, 50, and 54 was 6.74, 7.09, 6.52, 6.58, 7.08, 6.49, 7.66, and 7.81 %, respectively. Lowest and highest egg albumen index was at week 34 (6.52) and 54 (7.81 %), respectively. It was observed that the effect of hen age on egg albumen index was statistically significant (P<0.01). Several studies agree with this study (Silversides and Scott, 2001; Zita et al., 2009; Roberts et al., 2013; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017). However, some studies observed that egg albumen index varies with hen age, and the effect of age on egg albumen index is associated with factors such as laying hen genotype, and seasonal factors. (Simeon et al., 2018; Rizzi, 2021)

The effect of cage tier on egg albumen index

It was observed that egg albumen index decreased with increasing cage tier; 1st (7.25%),2nd (7.09%), and 3rd (6.97 %), respectively, but this difference was not found statistically significant. This study is in line with several studies that reported no significant effect of cage tier on egg albumen index (Onbaşılar and Aksoy, 2005; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017). The effect of interaction between cage tier and age (P<0.05) on egg albumen index was statistically significant, which effect might be associated with changes in the egg albumen index due to flock age, layer feed composition, variation in temperature and light intensity.

The effect of cage direction on egg albumen index

It was found that the egg albumen index was higher in Inner side cage direction (7.12 %) than wall side (6.87 %), and this difference was statistically significant (P<0.05). Also, the effect of interactions (cage tier x age and cage direction x age) was statistically significant (P<0.05) and (P<0.01), respectively. No statistical difference was observed among other interactions. In parallel with this study, the effect of cage direction on egg albumen index was found statistically significant in a study by Yıldız et al. (2006). On the other hand, Ipek et al. (2002) and Sahin (2012), observed that cage direction had no effect on egg albumen index. The effect of interaction between cage direction and age (P<0.01) on egg albumen index was significant, which effect might have been caused by flock age and variation ın layer feed composition, temperature and light intensity.



	26	30	34	38	42	46	50	54
Hen age	6,74	7,09	6,52	6,58	7,08	6,49	7,66	7,81
Outward	6,10	7,56	6,17	5,95	7,37	6,64	7,24	7,92
Inward	7,38	6,60	6,87	7,18	6,78	6,32	8,07	7,71

Figure 4.9. Effect of laying age x wall side - inner side (cage direction) interactions on albumen index, %

4.6 Haugh Unit (Score)

Effects of laying age, cage tier and cage direction on Haugh unit is shown in Table 4.6, Figure 4.10., Figure 4.11. and Figure 4.12.

Table 4.6 Effects of laying age, cage tier and cage direction on Haugh unit

Cage tier	Cage direction	Laying Age (weeks)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	54.49	70.78	62.84	64.71	71.62	69.02	71.14	68.38	68.00	0.684
	Inner Side	72.38	65.63	71.20	68.23	60.01	65.56	76.24	75.81		
2 (middle)	Wall Side	59.58	73.03	64.94	64.15	71.67	63.13	71.22	76.99	69.34	0.692
	Inner Side	68.06	71.02	67.38	71.37	66.75	67.56	76.85	76.62		
3 (top)	Wall Side	69.35	72.63	61.01	64.77	69.97	61.01	71.01	74.19	68.90	0.687
	Inner Side	75.31	66.44	66.62	68.62	70.10	65.41	73.23	72.92		
	Mean	66.52^{ab}	69.91^{b}	65.70^{a}	67.03^{ab}	68.39^{ab}	65.28^{a}	73.24^{c}	73.98^{c}		
	SEM	1.107	1.113	1.113	1.149	1.126	1.120	1.113	1.140		
Cage direction	WALL SIDE Mean	61.14	72.14	62.93	64.57	71.07	64.39	71.12	73.16	67.54	0.562
	Inner side mean	71.91	67.62	68.40	69.38	65.65	66.21	75.40	74.74	69.94	0.562

Factors	Significant level (P)	
Cage tier	0.313	
Cage direction	0.003**	
Laying Age	0.000**	
Cage tier x cage direction	0.897	
Cage tier x Laying Age	0.047*	
Cage direction x Laying Age	0.000**	
Cage tier x Cage direction x Laying Age	0.233	

*, ** The difference between the averages given with different letters in the same line is statistically significant (*P<0,05, **P<0,01). Abbreviation(s); SEM, standard error of the mean

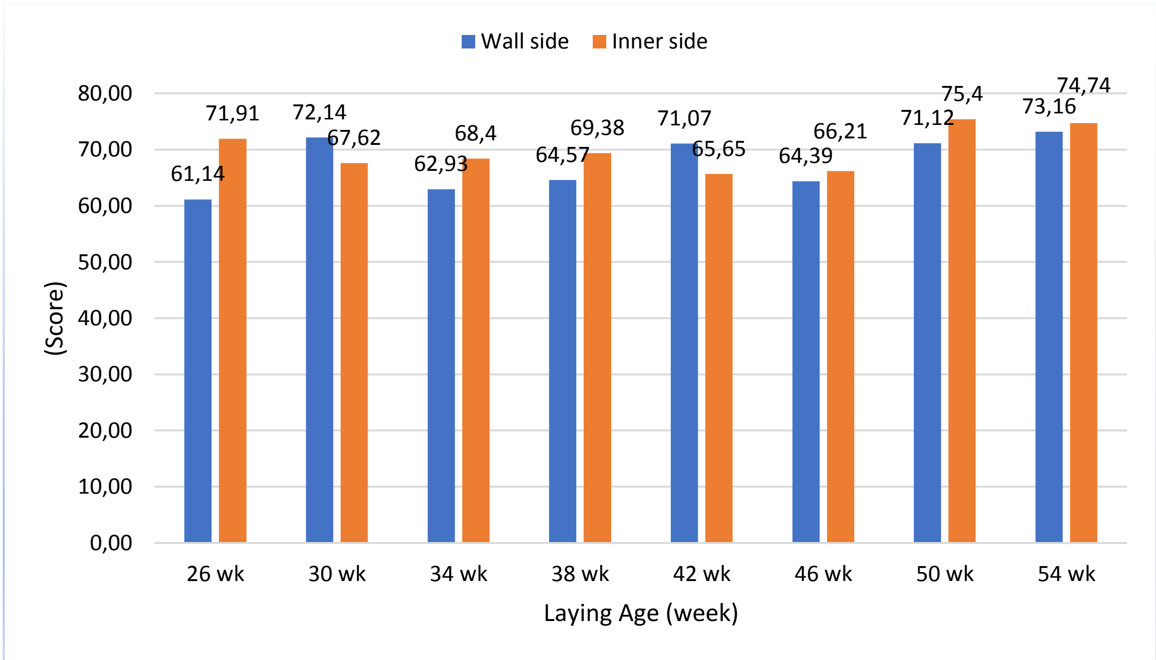


Figure 4.10. Effect of cage direction on haugh unit score

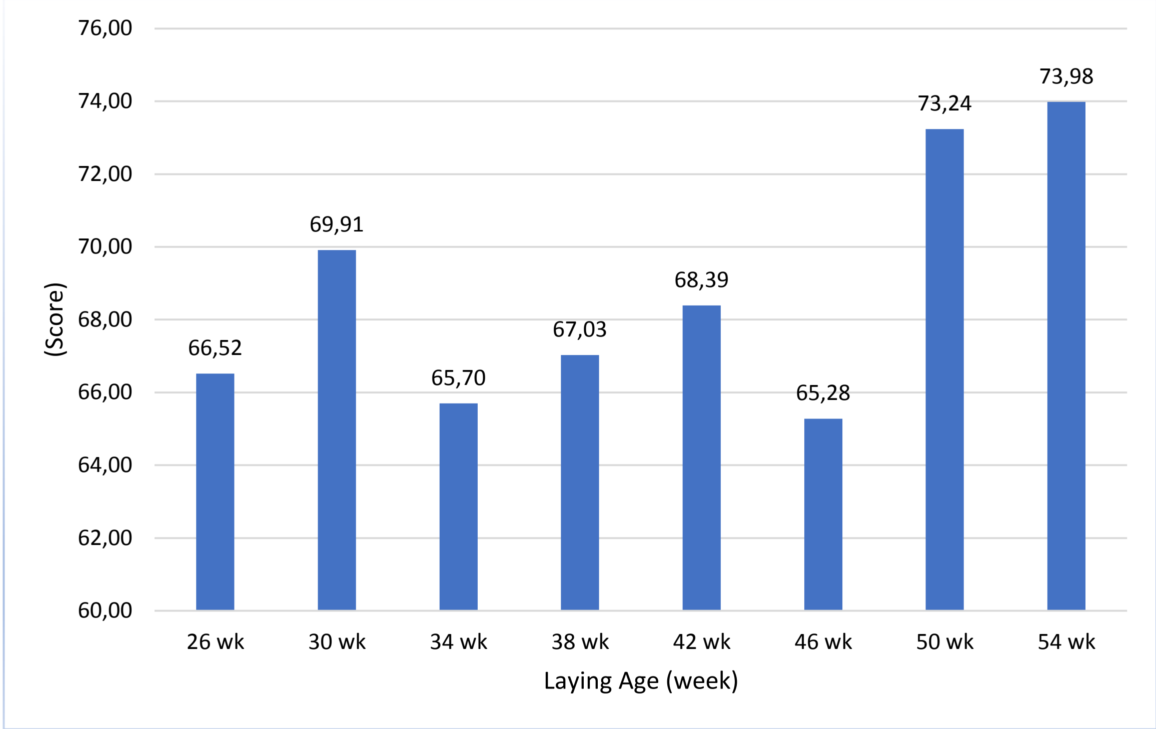


Figure 4.11. Effect of laying age on haugh unit score

The effect of laying age on Haugh unit;

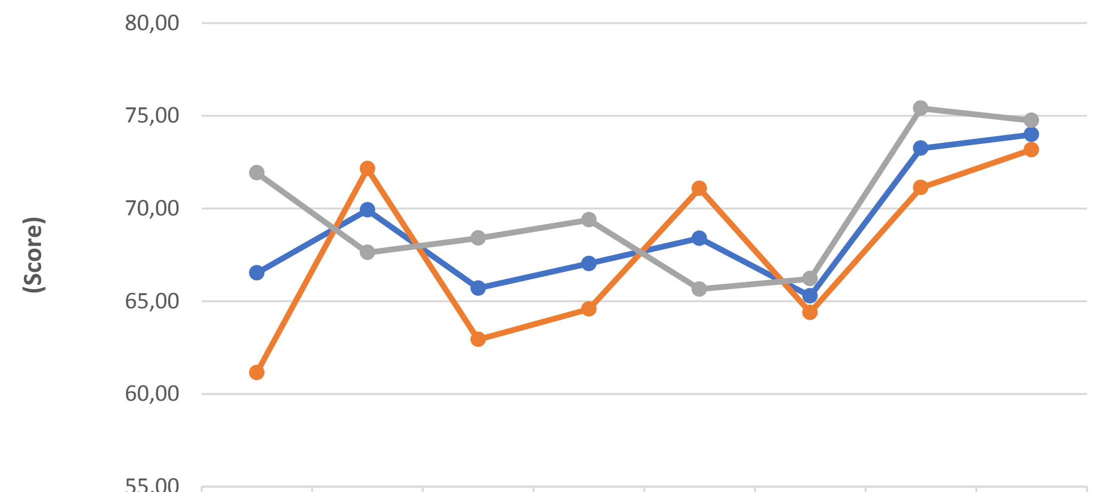
Haugh unit at week 26, 30, 34, 38, 42, 46, 50, and 54 was 66.52, 69.91, 65.70, 67.03, 68.39, 65.28, 73.24, and 73.98, respectively. Highest and lowest Haugh unit was found at week 54 (73.98) and 46 (65.25), respectively. The effect of hen age on Haugh unit was statistically significant ($P<0.01$). In addition, Haugh unit decerased with increase of hen age. Zita et al. (2009), observed increased Haugh unit in eggs of different genotypes depending on layer age. The results of this study is in agreement with the results of several studies (Roberts et al., 2013; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017; Eleroğlu, 2019). Additionally, whilethe increase in Haugh unit is linked to age, the decrease might be due to factors such as genotype differences, and seasonal changes.

The effect of cage tiers on Haugh unit;

The Haugh unit on 1st, 2nd, and 3rd cage tier was 68.00, 69.34, and 68.90, respectively. There was no difference in Haugh unit between cage tiers in this study. This result is similar to results of some studies (Onbaşılar and Aksoy, 2005; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017; Eleroğlu, 2019; Tünaydın and Dikmen, 2019).

<u>The effect of cage direciton on Haugh unit;</u>

The Haugh unit on wall side and inner side cage direction was 67.54, and 69.94, respectively and the effect of cage direction on Haugh unit was statistically significant ($P<0.05$). The result of this study is in agreement with Yıldız et al. (2006) but contrary to Sahin (2012), who showed that Haugh unit was not affected by cage direction. In this study, the effect of interaction between cage tier and age on Haugh unit was significant ($P<0.01$).



	26 wk	30 wk	34 wk	38 wk	42 wk	46 wk	50 wk	54 wk
Laying age	66,52	69,91	65,70	67,03	68,39	65,28	73,24	73,98
Outward	61,14	72,14	62,93	64,57	71,07	64,39	71,12	73,16
Inward	71,91	67,62	68,40	69,38	65,65	66,21	75,40	74,74

Figure 4.12. Effect of laying age x wall side - inner side (cage direction) interactions on Haugh unit score

4.7 Egg Yolk Color Score

Effects of laying age, cage tier and cage direction on egg yolk color score in this study is shown in Table 4.7., Figure 4.13. and Figure 4.14.

Table 4.7 Effects of laying age, cage tier and cage direction on egg yolk color score

Cage tier	Cage direction	Laying Age (weeks)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	10.87	11.13	10.86	11.00	11.13	10.93	11.00	10.60	10.92	0.085
	Inner Side	10.67	11.07	10.80	11.07	11.14	10.33	10.73	11.40		
2 (middle)	Wall Side	10.13	11.20	10.87	10.08	11.07	11.00	10.87	10.0	10.77	0.086
	Inner Side	10.73	11.00	10.60	11.13	11.13	10.93	10.20	10.73		
3 (top)	Wall Side	10.53	11.13	18.80	11.00	11.13	11.00	10.80	8.47	10.81	0.086
	Inner Side	10.47	11.00	10.93	10.93	11.21	10.27	11.13	11.13		
	Mean	10.57^{a}	11.09^{abc}	10.81^{abc}	10.88^{abc}	11.14^{ac}	10.74^{abc}	10.79^{abc}	10.66^{ab}		
	SEM	0.139	0.139	0.140	0.142	0.141	0.139	0.139	0.139		
Cage direction	Wall Side Mean	10.51	11.16	10.84	10.71	11.11	10.98	10.88	10.22	10.80	0.070
	Inner Side Mean	10.62	11.02	10.78	11.05	11.16	10.51	10.69	11.09	10.86	0.070

Factors	Significant level (P)
Cage tier	0.424
Cage direction	0.515
Laying Age	0.054*
Cage tier x cage direction	0.728
Cage tier x Laying Age	0.855
Cage direction x Laying Age	0.042*
Cage tier x Cage direction x Laying Age	0.547

*, ** The difference between the averages given with different letters in the same line is statistically significant (*P<0,05, **P<0,01). Abbreviation(s); SEM, standard error of the mean

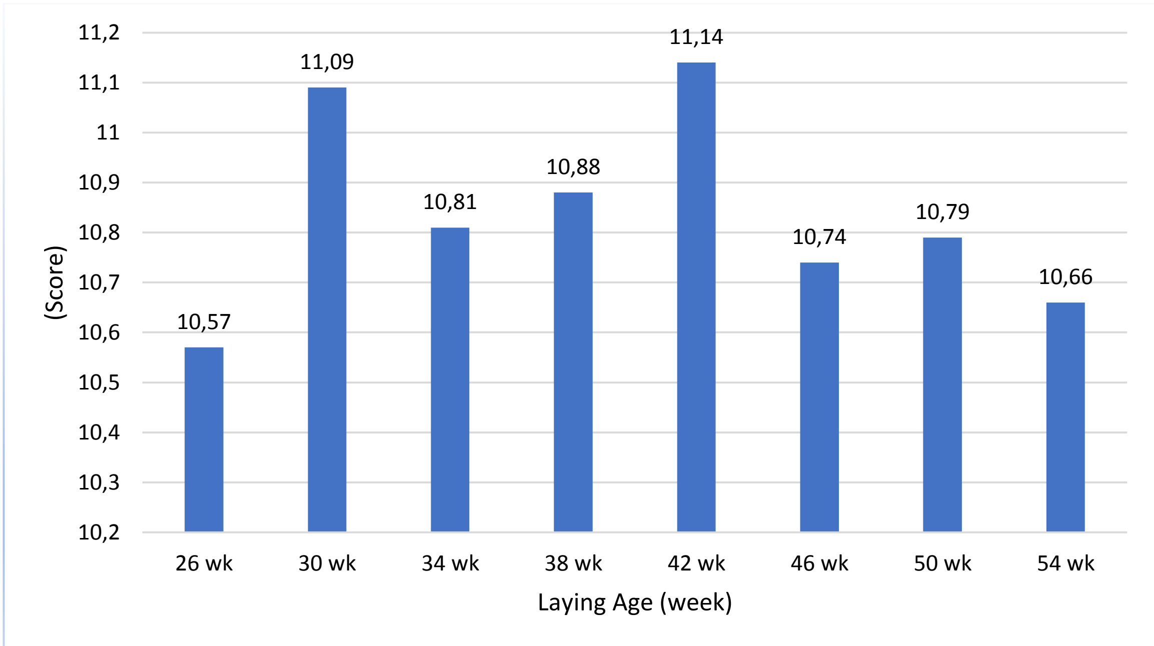


Figure 4.13. Effect of laying age on egg yolk color score

The effect of laying age on Egg yolk color Score

The study found that egg yolk color score was 10.57, 11.09, 10.81, 10.88, 11.14, 10.74, 10.79, and 10.66 at week 26, 30, 34, 38, 42, 46, 50, and 54 respectively. The effect of age on egg yolk color score was observed significant (P<0.05). The results of this study are in agreement with Yılmaz Dikmen et al. (2017) and Şekeroğlu et al. (2014), who stated a significant effect of hen age on egg yolk color score. Contrary, Roberts et al. (2013), observed no interaction between egg yolk color score and age.

The effect of cage tier on egg yolk score.

The egg yolk color score was 10.92, 10.77, and 10.81 on 1st, 2nd, and 3rd cage tier, respectively, and the effect of cage tier on egg yolk score was not statistically different. The result of this study is consistent with Tünaydın and Dikmen (2019), Yılmaz Dikmen et al. (2017), Şekeroğlu et al. (2014) and Yıldız et al. (2006), who stated that the differences between cage tiers had no significant effect on egg yolk colour score.

The effect of cage direction on egg yolk color score.

The egg yolk color score was 10.80 and 10.86 in inner side and wall side cage direction, respectively, and there was no statistical difference between cage direction. The result of this study is similar to Sahin (2012) and Yıldız et al. (2006), who reported that cage direction had no effect on egg yolk color score. While the effect of cage direction and laying age interaction on egg yolk color score was significant (P<0.05), interactions among other factors were not statistically significant.

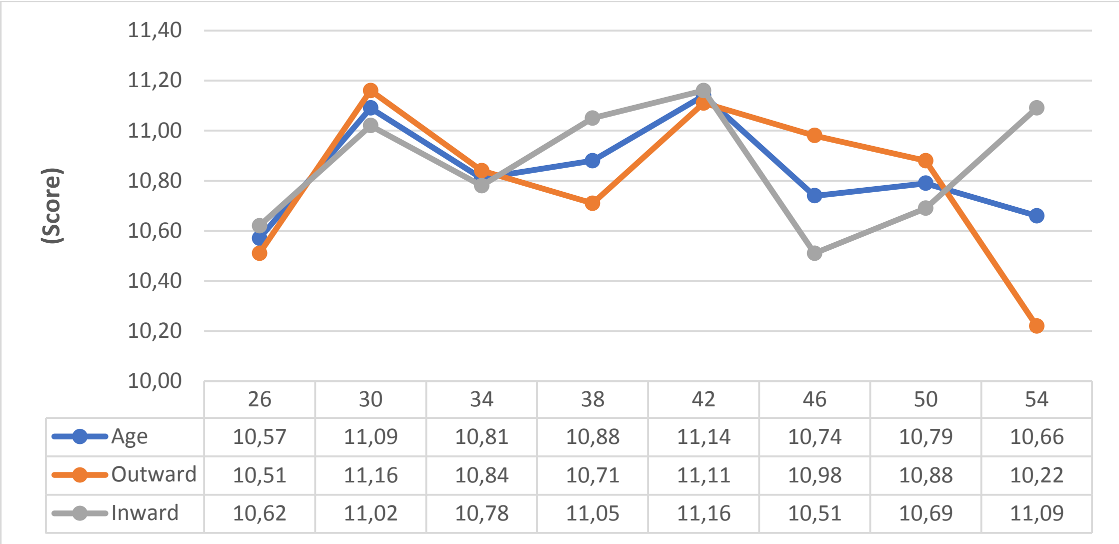


Figure 4.14. Effect of laying age x wall side - inner side (cage direction) interactions on Yolc color score

4.8 Egg Yolk index (%)

Effects of laying age, cage tier and cage direction on egg yolk index in this study is shown in Table 4.8, Figure 4.15., Figure 4.16. and Figure 4.17

Table 4.8 Effects of laying age, cage tier and cage direction on egg yolk index

Cage tier	Cage direction	Laying Age (weeks)								Mean	SEM
		26	30	34	38	42	46	50	54		
1 (bottom)	Wall Side	45.58	44.19	40.46	41.00	42.69	44.11	44.17	43.37	43.49	0.185
	Inner Side	45.87	44.17	44.71	44.08	43.15	42.96	42.50	42.61		
2 (middle)	Wall Side	44.31	43.65	43.09	40.01	42.29	43.22	42.93	43.77	43.14	0.187
	Inner Side	45.67	43.13	43.00	42.69	44.19	40.69	42.84	43.12		
3 (top)	Wall Side	45.20	44.38	43.91	40.58	42.91	43.27	41.85	44.87	43.71	0.186
	Inner Side	47.86	41.94	42.70	43.77	45.53	42.25	44.95	43.41		
	Mean	45.75^{c}	43.58^{b}	43.01^{bb}	42.09^{a}	43.45^{b}	42.75^{ab}	43.37^{b}	43.48^{b}		
	SEM	0.299	0.301	0.301	0.311	0.305	0.305	0.303	0.311		
Cage direction	Wall Side Mean	45.03	44.07	42.54	40.57	42.64	43.54	42.99	43.97	43.19	0.152
	Inner Side Mean	46.47	43.08	43.47	43.53	44.29	41.94	43.76	43.05	43.71	0.152

Factor	Significant level (P)
Cage tier	0.065
Cage direction	0.012**
Laying Age	0.000**
Cage tier x cage direction	0.850
Cage tier x Laying Age	0.393
Cage direction x Laying Age	0.000**
Cage tier x Cage direction x Laying Age	0.002**

** The difference between the averages given with different letters in the same row is statistically significant (P<0,01). Abbreviation(s); SEM, standard error of the mean

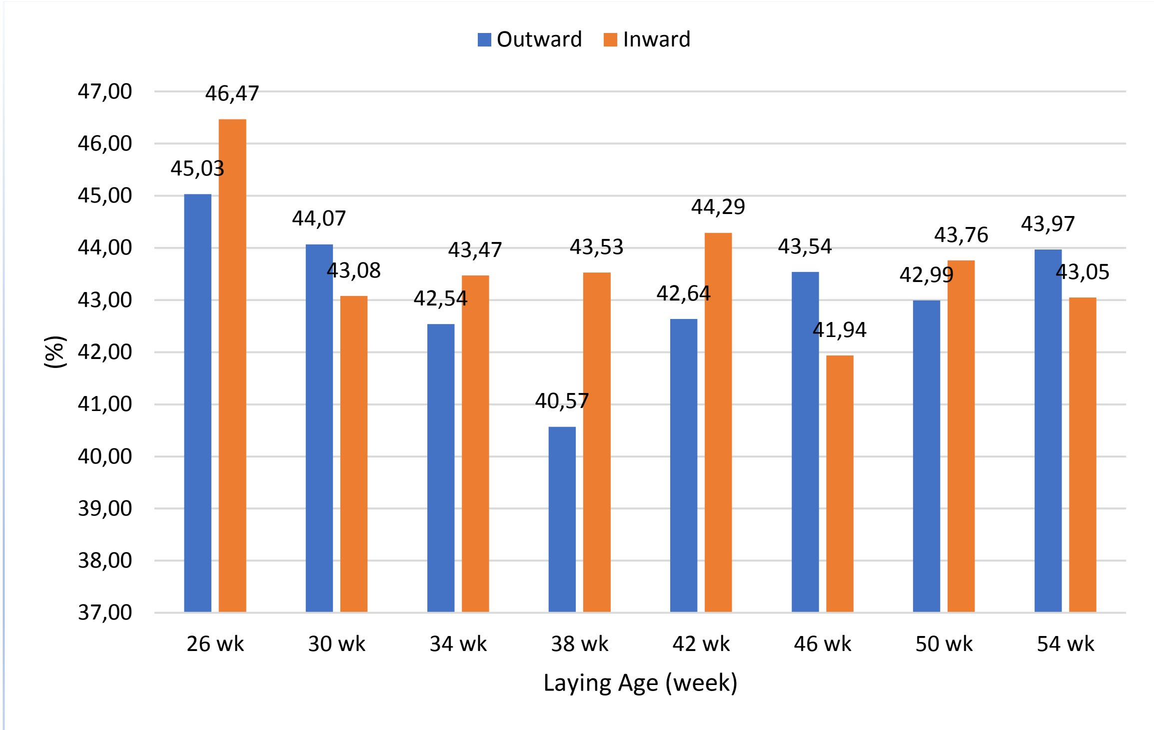


Figure 4.15. Effect of cage direction on Yolk index, %

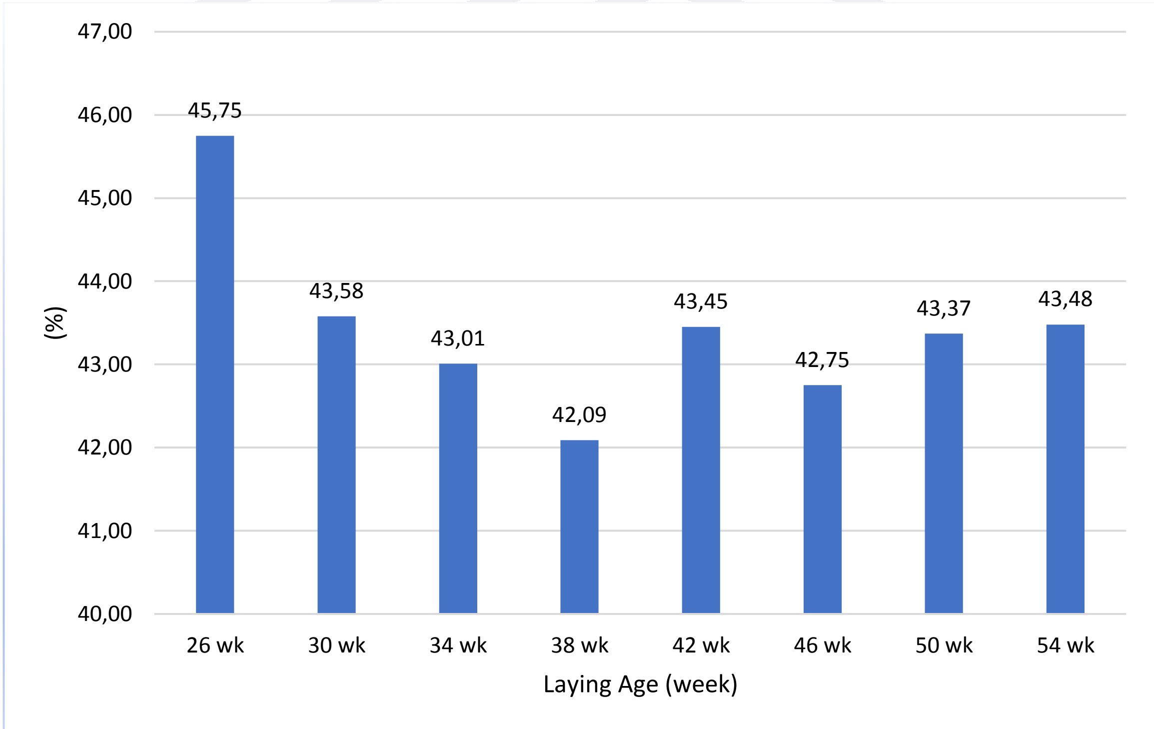


Figure 4.16. Effect of laying age on Yolk index, %

The effect of Laying age on egg yolk index

Egg Yolk index 45.75, 43.58, 43.01, 42.09, 43.45, 42.75, 43.37, and 43.48 at week 26, 30, 34, 38, 42, 46, 50, and 54 was, respectively. The highest and lowest egg yolk index was 45.75 (week 26) and 42.09 (week 38). It was observed that the difference in egg yolk index with increasing age was statistically significant (P<0.01). The results of this study are in agreement with Şekeroğlu et al. (2014) and Yılmaz Dikmen et al. (2017), who reported statistical differences between age effect on egg yolk index and the results are similar with several studies.

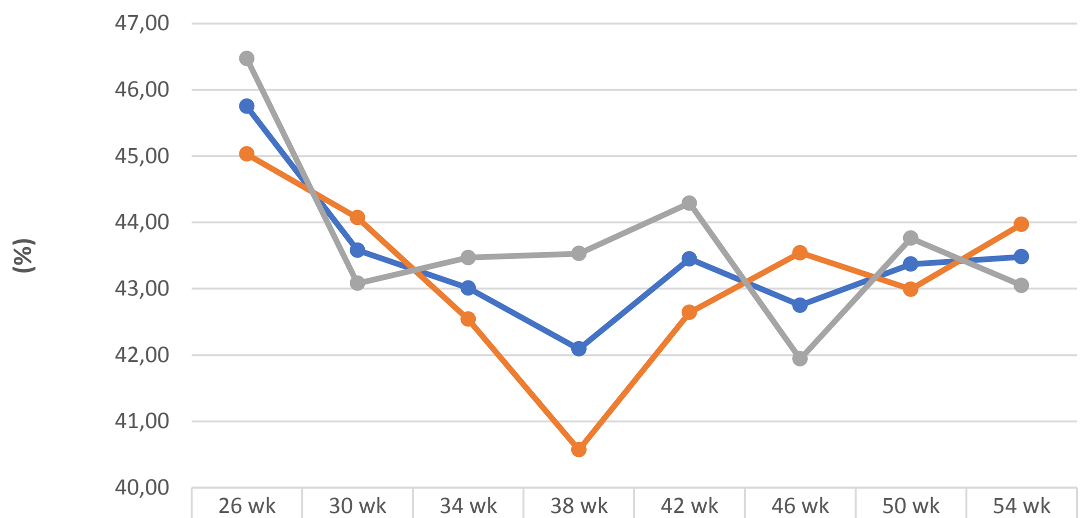
The effect of cage tier on egg yolk index

The egg yolk index on 1^{st}, 2^{nd}, and 3^{rd} cage tier was 43.49, 43.14, 43.71, respectively and no statistically significant effect was found. Many studies found that the egg yolk index does not differ statistically between cage tiers (Onbaşılar and Aksoy, 2005; Yıldız et al., 2006; Şekeroğlu et al., 2014; Yılmaz Dikmen et al., 2017).

The effect of cage direction on egg yolk index

The egg yolk index in the wall side and inner side cage direction was 43.19 and 43.71, respectively, and the difference in egg yolk index was statistically significant (P<0.05). In line with our study, Yıldız et al. (2006), identified a statistically significant effect of cage direction on egg yolk index. Contrary, Sahin (2012) and İpek et al. (2002), did not find any significant relationship between egg yolk index and cage direction. Also, the interaction between cage direction and age was significant (P<0.01). It is suggested that the difference in egg yolk index between age groups may be the main cause of this interaction.

Furthermore, (cage tier x cage direction x age) interaction effect was statistically significant (P<0.05). Although the effect of cage tier on egg yolk index was not statistically significant, the main reason why this interaction was significant may be associated with interaction between cage direction and laying age.



	26 wk	30 wk	34 wk	38 wk	42 wk	46 wk	50 wk	54 wk
Laying age	45,75	43,58	43,01	42,09	43,45	42,75	43,37	43,48
Outward	45,03	44,07	42,54	40,57	42,64	43,54	42,99	43,97
Inward	46,47	43,08	43,47	43,53	44,29	41,94	43,76	43,05

Figure 4.17. Effect of laying age x wall side - inner side (cage direction) interactions on Yolk index, %

CHAPTER V

CONCLUSION

The ban on conventional or battery cage production system for laying hens in EU member countries and some other countries accelerated the development and shift to enriched cage system, which is characterized by enhanced chicken welfare and behavior. In this regard, it has become important to investigate layers housed in enriched cages in terms of egg quality characteristics.

In this study, the results indicate that there is a decrease and increase in internal and external egg quality traits, respectively, with increasing layer age. Furthermore, there is an effect of interaction between age, cage tier and cage direction on some egg quality parameters.

Cage tier was found no significant on egg internal and external egg qualty however, eggs obtained from layer hybrids that are produced in the inner side cage direction are superior in terms of egg internal quality. In addition, external egg qualty in the wall side direciton are superior than inner side.

Therefore, layer age, cage tier and direction lead to variation in egg quality characteristics in enriched cage system.

This researh will be the source for further studies about layer chicken that housed in enriched cages.

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CURRICULUM VITAE

I am Yunus Emre ŞENTÜRK, I was born on the , Turkey. I have done my bachelors from . After B.Sc, I started . I have a total of 8 numbers of publications and had various projects done.

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