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Effect of Cage Environmental Enrichment on Egg Quality in Two Laying Hen Strains

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ABSTRACT
This study investigated the effects of environmental enrichment in cage systems on egg quality, focusing on two laying hen strains, Hyline Brown (HB) and Isa Tinted (IT). Conventional cage systems (CC) were compared with environmentally enriched cages (EEC) that included nest boxes, perches, and pecking stones. Egg quality was evaluated every eight weeks from 24 to 72 weeks of age using one randomly selected egg per cage (4 groups × 14 eggs = 56 eggs). Measured parameters included egg weight, shape index, breaking strength, shell thickness, yolk color, Haugh unit, albumen index, yolk index, and the presence of blood and meat spots. Results revealed no statistically significant differences in egg quality parameters between CC and EEC systems, suggesting that environmental enrichments alone do not influence egg quality. However, strain-specific differences were identified: HB hens produced heavier eggs with thicker and stronger shells, whereas IT hens laid eggs with darker yolks. Age-related changes in egg quality were observed in both strains, with declines in shell thickness, breaking strength, and Haugh unit over time. These findings emphasize the limited impact of cage enrichments on egg quality and highlight the significant roles of genotype and age. Further research is warranted to explore the broader implications of environmental enrichments on poultry production.

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Kafeste Çevresel Zenginleştirmenin İki Farklı Yumurtacı Hibritte Yumurta Kalitesi Üzerine Etkisi

ÖZET
Bu çalışmada, kafes sistemlerindeki çevresel zenginleştirmenin yumurta kalitesi üzerindeki etkileri araştırılmış ve iki yumurtacı hibrit olan Hyline Brown (HB) ve Isa Tinted (IT) ait yumurtalar incelenmiştir. Geleneksel kafes sistemleri (CC), folluk, tünek ve gagalama taşları içeren çevresel olarak zenginleştirilmiş kafeslerle (EEC) karşılaştırılmıştır. Yumurta kalitesi, 24 ila 72 haftalık yaşlar arasında her sekiz haftada bir, her kafesten rastgele seçilen bir yumurta kullanılarak değerlendirilmiştir (4 grup × 14 yumurta = 56 yumurta). Yumurta kalitesi parametreleri olarak yumurta ağırlığı, şekil indeksi, kırılma mukavemeti, kabuk kalınlığı, sarısı rengi, Haugh birimi, albümin indeksi, sarısı indeksi ve kan ve et lekelerinin varlığı belirlenmiştir. Araştırma bulgularında, CC ve EEC sistemleri arasında yumurta kalitesi parametrelerinde istatistiksel olarak anlamlı bir fark olmadığı ve çevresel zenginleştirmelerin tek başına yumurta kalitesini etkilemediği tespit edilmiştir. Ancak, hibrite özgü farklılıklar belirlenmiştir: HB tavukları kırılma mukavemeti yüksek, daha kalın kabuklu daha ağır yumurtalar üretirken, IT tavukları daha koyu sarılı yumurtalar vermiştir. Her iki hibritte de yumurta kalitesinde yaşa bağlı değişiklikler gözlemlendi ve zamanla kabuk kalınlığında, kırılma mukavemetinde ve Haugh biriminde düşüşler belirlendi. Bu bulgular, kafes içi zenginleştirmelerin yumurta kalitesi üzerindeki sınırlı etkisini ve genotip ile yaşın önemli etkisini vurgulamaktadır. Kanatlı üretiminde çevresel zenginleştirmenin etkilerini daha iyi anlamak için ek araştırmalara ihtiyaç vardır.

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INTRODUCTION

Eggs are an affordable and widely consumed source of animal protein, prized for their exceptional nutritional content and contributions to human health (Hisasaga et al., 2020; Özentürk & Yıldız, 2020). As consumer preferences evolve, there is a growing demand for healthier, higher-quality egg products. In the food industry, egg quality encompasses both physical and nutritional attributes that significantly influence consumer acceptance (Özentürk & Yıldız, 2020; Rakonjac et al., 2021; Çınar & Arslan Duru, 2022). The primary objective of the egg industry is to produce high-quality eggs and deliver them to consumers efficiently. Several factors, including genotype, age, and housing systems, play critical roles in determining egg quality (Göger, 2019; Lordelo et al., 2020; Özentürk & Yıldız, 2020; Rakonjac et al., 2021).

Among these, housing systems are of particular importance for poultry, which are highly sensitive to environmental conditions. Globally, conventional cage systems are the predominant housing method for laying hens (Orihuela et al., 2019; Tainika & Şekeroğlu, 2020). However, increasing public concern regarding animal welfare has spurred efforts to improve these systems. In Europe, conventional cages have largely been replaced by enriched cages equipped with perches and nest boxes, reflecting advancements aimed at better accommodating the natural behavioral needs of poultry (Da Silva Pires et al., 2021; Rakonjac et al., 2021; Tainika & Şekeroğlu, 2021; Arulnathan et al., 2024; Majewski et al., 2024; Rodríguez-Hernández et al., 2024). Research on new cage enrichment designs is ongoing. Environmental enrichment refers to changes in the chicken's environment that provide practical and economic benefits, aimed at positively affecting the chicken's physiological development, natural behavior expression, reduction of abnormal and harmful behaviors, stress reduction, improved health, and increased use of available environmental resources (Riber et al., 2018; Campbell et al., 2019). While studies on cage enrichment typically focus on productivity and animal welfare, a key question in various production systems is whether egg quality can be influenced by environmental enrichment. Therefore, it is crucial to assess how these environmental changes impact egg quality (Ghanima et al., 2020; Philippe et al., 2020; Popova et al., 2020). Bari et al. (2020) reported significant effects of environmental enrichment on both internal and external egg quality traits. While studies suggest that providing hens with more freedom in their environment does not significantly increase egg defects, physical quality traits are still affected (Nannoni et al., 2022). In contrast, some studies show that hens in traditional cages tend to lay eggs with stronger eggshells (Englmaierová et al., 2014; Philippe et al., 2020). However, several studies indicate that the housing environment has no effect on egg quality (Dikmen et al., 2017; Ghanima et al., 2020; Ketta et al., 2020; Alig et al., 2023a). The effect of egg quality in newly designed systems with enriched environments remains a topic of interest, as previous studies have yielded conflicting results. Recent research has explored the use of materials such as hanging CDs, ropes, and toy balls for enrichment purposes, with ongoing investigations into various enrichment materials (Moroki & Tanaka, 2016; Campbell et al., 2019; Tainika & Şekeroğlu, 2021). The current study introduces the innovative use of pecking stones as an enrichment feature in the cage system. Previous studies have observed that egg albumen consistency decreased during the laying period when hens were reared in environments enriched with pecking stones and alfalfa bales (Schreiter et al., 2020a), Other studies have found that environmental enrichment with pecking stones and alfalfa bales during rearing resulted in a higher percentage of cracked eggs in different laying hen genotypes, and that environmental enrichment during the laying period increased egg weights (Schreiter et al., 2020b). These studies were conducted in litter housing systems (Schreiter et al 2020a; 2020b), whereas the present study introduces pecking stones into the cage system. Understanding how egg quality is affected in such new systems is crucial, as innovative designs and enrichments could influence consumer preferences.

Genotype is another key factor influencing egg quality (Özentürk & Yıldız, 2020; Krawczyk et al., 2023). Differences in egg quality traits between genotypes have been well-documented (Hisasaga et al., 2020; Özentürk & Yıldız, 2020; Sharma et al., 2022; Akintunde & Toye, 2023; Alig et al., 2023a; Alig et al., 2023b). However, the majority of research examining the effects of rearing systems on egg quality has focused on brown-egg-laying hens, as highlighted in the review by Pires et al. (2021). Therefore, further research is required to understand how housing environments influence egg quality in both brown and white layer hens. Some studies suggest that housing systems have no impact on white layers (Philippe et al., 2020; Dalle Zotte et al., 2021; Sharma et al., 2022), while others indicate that different strains may respond differently to various environmental conditions (Rakonjac et al., 2021; Sharma et al., 2022). Additionally, certain strains may benefit more from additional space and enrichment features (Campbell et al., 2019; Ross et al., 2020). Therefore, it is crucial to investigate the egg quality of different strains under enriched environmental conditions.

This study aims to evaluate the effects of environmental enrichment in cage systems on egg quality, focusing on two laying hen strains: Hyline Brown (HB) and Isa Tinted (IT). We compared conventional cage systems (CC) with environmentally enriched cage systems (EEC), which include nest boxes, perches, and pecking stones. By examining both internal and external egg quality traits, this study provides insights into how enrichment influences egg quality and explores the role of genotype in mediating these effects. The innovative use of pecking stones in cage systems underscores the potential of novel enrichment strategies to enhance egg quality.

MATERIAL and METHOD

The research was ethically approved by the Atatürk University Faculty of Veterinary Medicine Unit Ethics Committee (Protocol no: 2024/22, dated 27.09.2024).

Animals and Housing

The study was conducted at the Poultry Unit of Atatürk University's Food and Livestock Research and Application Centre, using Hyline Brown (HB) and Isa Tinted (IT) hybrids, which were brown and white layer hens, respectively. At 20 weeks of age, 280 hens (140 of each strain) were randomly allocated to cages, with uniformity in body weight considered. The experiment spanned from 24 to 72 weeks of age.

Two hen strains (HB and IT) and two cage designs—conventional cages (CC) and environmentally enriched cages (EEC)—were used. For EECs, a nest area enclosed on three sides with a curtain was set up inside the existing cage. Wooden perches were installed at a height of 10 cm across the middle of the cage, providing each bird with a 15 cm-long perch. Additionally, plastic boxes (10 × 6 × 6 cm) containing pecking stones were mounted 25 cm above the cage floor. The pecking stones were commercially produced mineral stones composed of calcium, magnesium, sodium, trace elements, oyster shell flour, carob flour, and calcium carbonate.

The study utilized 56 cage compartments, with 28 compartments assigned to each system (CC and EEC). Within each system, 14 cages housed HB hens, and 14 housed IT hens, with five hens per cage, providing each bird 750 cm^2 of space.

The poultry house was ventilated using side wall windows, ceiling chimneys, and a 140 × 140 cm fan operating under negative pressure, keeping indoor temperatures between 16°C and 24°C. Lighting was maintained for 16 hours daily using fluorescent lamps emitting white light. During the productive period, hens were provided water and granulated feed ad libitum, formulated specifically for each production stage: first-stage layer feed from 21-45 weeks (2750 ME, 16.26% CP), second stage from 46-60 weeks (2720 ME, 15.83% CP), and third stage from 61-72 weeks (2720 ME, 15.65% CP).

Determination of Egg Quality Parameters

For egg quality analysis, a total of 56 eggs (one egg from each cage in 4 groups × 14 cages) were randomly selected every 8 weeks, beginning at the start of egg production (24 weeks) and continuing through 72 weeks. The eggs were kept at room temperature for 24 hours prior to evaluation. The shape index, representing the ratio of egg width to length, was measured using a Rauch index device. Egg weight (g) and breaking strength (kg/cm^2) were assessed with a Digital Egg Tester (DET-6000®). The eggs were then broken, and the yolk diameter, yolk height, albumen height, Haugh unit, yolk index, and yolk color were measured using the same device. The albumen index was manually calculated by measuring the albumen's length and width with a caliper. Blood and meat spot occurrence (%) and shell thickness were also assessed. Shell thickness (mm) was determined by taking samples from the blunt, middle, and pointed ends of each egg, removing the membranes, and measuring with a micrometer. The average of the three measurements was recorded as the final shell thickness value (Özentürk & Yıldız 2020).

Statistical Analysis

The data collected in this study were analyzed using IBM® SPSS version 20 for both descriptive and analytical purposes. A General Linear Model (GLM) was applied to evaluate egg quality parameters across different age periods. The Chi-square test (X^2) was used as a non-parametric method for assessing the presence of blood and meat spots in the eggs. Additionally, logistic regression analysis was conducted to further analyze the blood and meat spot data.

RESULTS

Data on egg external quality parameters are presented in Table 1, while data on egg internal quality parameters are presented in Table 2. Furthermore, egg blood and meat spot data are shown in Table 3. The egg weight, shell thickness, and shell fracture strength of eggs belonging to the HB strain were higher ($p < .05$). More blood and meat stains were observed in the eggs of the HB hybrid ($p < .01$). Egg yolk color differed between strains ($p < .01$). There was no significant difference between strains in terms of shape index, haugh unit, albumen, and yolk index values ($p > .05$). No statistical difference was observed in terms of egg quality parameters in eggs taken from both cage systems ($p > .05$). All egg internal and external quality characteristics, except for blood and meat stain data, varied over time. The effect of age on egg quality was found to be significant ($p < .01$).

Table 1. Effects of genotype, cage system and age on external egg quality parameters ($\bar{X} \pm S_x$)
Çizelge 1. Genotip, kafes sistemi ve yaşın yumurta dış kalite parametreleri üzerine etkisi ($\bar{X} \pm S_x$)

	Group *(Grup)*	Egg weight (*Yumurta ağırlığı*)	Shape index (*Şekil indeksi*)	Shell fracture strength (*Kabuk kırılma mukavemeti*)	Shell thickness (*Kabuk kalınlığı*)
Mean values (*Ortalama değerler*)	Hyline Brown	63.70±0.32^{x}	77.37±0.16	4.43±0.06^{x}	0.428±0.003^{x}
	Isa Tinted	62.58±0.32^{y}	77.67±0.16	4.08±0.06^{y}	0.415±0.003^{y}
	Conventional cage	63.22±0.32	77.70±0.16	4.24±0.06	0.419±0.003
	Environmental enrichment	63.07±0.32	77.34±0.16	4.28±0.06	0.424±0.003
	w24	54.01±0.60^{d}	72.05±0.30^{e}	4.55±0.12^{a}	0.364±0.006^{e}
	w32	62.01±0.60^{c}	79.91±0.30^{a}	4.87±0.12^{a}	0.423±0.006^{bcd}
	w40	63.51±0.60^{bc}	79.13±0.30^{ab}	4.58±0.12^{a}	0.439±0.006^{abc}
	w48	65.67±0.60^{a}	78.70±0.30^{b}	4.55±0.12^{a}	0.441±0.006^{ab}
	w56	65.14±0.60^{ab}	78.84±0.30^{b}	4.04±0.12^{b}	0.447±0.006^{a}
	w64	65.55±0.60^{a}	77.54±0.30^{c}	3.76±0.12^{bc}	0.422±0.006^{cd}
	w72	66.11±0.60^{a}	76.48±0.30^{d}	3.46±0.12^{c}	0.413±0.006^{d}
p values (*p değerleri*)	Genotype	.014	.179	<.001	.009
	Cage system	.740	.113	.693	.308
	Genotype x Cage system	.937	.005	.331	.674
	Age*	<.001	<.001	<.001	<.001

HB: Hyline Brown; IT: Isa Tinted; CC: Conventional Cage System; EEC: Environmentally Enriched Cage; w: Week of age; $^{a\text{-}e}$: Differences between means with different letters on the same column are significant; (P<.001): $^{x\text{-}y}$: Different letters within one column are significantly different.(P<.05); *Repeated-measures analysis of variance results based on time in the interval of 24-72 weeks.

Table 2. Effects of genotype, cage system and age on internal egg quality parameters ($\bar{X} \pm S_x$)
Çizelge 2. Genotip, kafes sistemi ve yaşın yumurta iç kalite parametreleri üzerine etkisi ($\bar{X} \pm S_x$)

	Group (*Grup*)	Yolk color (*Sarı renk*)	Haugh unit (*Haugh birimi*)	Albumen index (*Ak indeksi*)	Yolk index (*Sarı indeksi*)
Mean values (*Ortalama değerler*)	Hyline Brown	9.71±0.06^{y}	85.65±0.76	10.11±0.18	44.93±0.24
	Isa Tinted	10.33±0.06^{x}	84.82±0.76	10.14±0.18	45.19±0.24
	Conventional cage	10.04±0.06	85.50±0.76	10.24±0.18	45.12±0.24
	Environmental enrichment	10.00±0.06	84.98±0.76	10.00±0.18	44.99±0.24
	w24	8.80±0.11^{d}	88.16±1.41^{ab}	11.96±0.33^{a}	49.95±0.44^{a}
	w32	10.66±0.11^{a}	89.97±1.41^{a}	11.64±0.33^{a}	48.70±0.44^{b}
	w40	10.59±0.11^{a}	84.68±1.41^{bc}	9.84±0.33^{bc}	48.31±0.44^{b}
	w48	10.38±0.11^{a}	85.45±1.41^{bc}	10.27±0.33^{b}	44.45±0.44^{c}
	w56	9.95±0.11^{bc}	82.46±1.41^{c}	9.26±0.33^{c}	41.58±0.44^{d}
	w64	10.04±0.11^{b}	83.01±1.41^{c}	8.92±0.33^{c}	41.35±0.44^{d}
	w72	9.74±0.11^{c}	82.93±1.41^{c}	8.98±0.33^{c}	41.06±0.44^{d}
p values (*p değerleri*)	Genotype	<.001	.439	.919	.440
	Cage system	.643	.622	.337	.704
	Genotype x Cage system	.037	.034	.095	<.001
	Age*	<.001	.001	<.001	<.001

HB: Hyline Brown; IT: Isa Tinted, CC: Conventional Cage System; EEC: Environmentally Enriched Cage; $^{a\text{-}d}$: Differences between means with different letters on the same column are significant (P<.001); $^{x\text{-}y}$: Different letters within one column are significantly different (P<.05); *Repeated-measures analysis of variance results based on time in the interval of 24-72 weeks.

Table 3. Analysis of factors influencing blood and meat spots
Çizelge 3. Kan ve et lekelerini etkileyen faktörlerin analizi

Factors	Count in positive (*Pozitif değerler*)		Count in negative (*Negatif değerler*)		Total count (*Toplam değer*)	X^2 (df)	p
	N	(%)	N	(%)			
Genotype (*Genotip*)						28.638(1)	<.001
Hyline Brown	69	35.20	127	64.80	196		
Isa Tinted	23	12.04	168	87.96	191		
Cage System (*Kafes sistemi*)						0.643(1)	.423
CC	49	25.52	143	74.48	192		
EEC	43	22.05	152	77.95	195		
Age (Weeks) (*Yaş-haftalar*)						11.558(6)	.073
24	8	14.29	48	85.71	56		
32	14	25.00	42	75.00	56		
40	11	19.64	45	80.36	56		
48	8	14.29	48	85.71	56		
56	17	30.36	39	69.64	56		
64	19	33.93	37	66.07	56		
72	15	29.41	36	70.59	51		

HB: Hyline Brown; IT: Isa Tinted; CC: Conventional Cage System; EEC: Environmentally Enriched Cage.

DISCUSSION

Enrichments like perches, nest boxes, and pecking stones aim to fulfill these behavioral needs, which can potentially improve both welfare and production outcomes (Nicol, 2015; Nicol et al., 2017). Understanding the interplay between the ability of laying hens to perform natural behavior and egg quality is therefore a significant focus in poultry research (Tainika & Şekeroğlu, 2021). Behavioral enrichment contributes to the welfare of hens by reducing stress and encouraging physical activity. Lower stress levels could theoretically improve egg production and quality by mitigating the adverse effects of chronic stress on physiological processes (Henriksen et al., 2011; De Haas et al., 2013; Bari et al., 2020b; Hemsworth & Edwards, 2020). Some studies report that egg quality is positively affected by rearing systems designed to enhance welfare (Bhanja and Bhadauria, 2018; Dedousi et al., 2020). However, the results of this study challenge the assumption that enrichments inherently improve egg quality in cage systems. Results indicate no statistically significant differences in egg quality between hens housed in environmentally enriched cages (EEC) and conventional cages (CC). This suggests that enrichments alone do not substantially influence egg quality, as eggs produced in both systems showed minimal, non-significant differences. This outcome underscores the complexity of the physiological mechanisms regulating egg formation, which are predominantly driven by hormonal and metabolic factors (Gil, 2008; Zinca et al., 2024).

Previous research on egg quality and environmental enrichment has often focused on cage-free systems (Bari et al., 2020b; Dedousi et al., 2020). The observed differences in these studies may stem not only from environmental enrichments, such as perches and nest boxes, but also from the larger space and increased mobility provided by cage-free systems. In contrast, our study examines enrichment within cage systems, where stocking density remains unchanged. This restricted space may limit the potential welfare benefits of enrichment and, consequently, its impact on egg quality. These findings align with earlier studies reporting minimal or no effects of enrichment on internal and external egg quality traits in cage systems (Dikmen et al., 2017; Onbaşılar et al., 2020; Philippe et al., 2020). For instance, Alig et al. (2023a) found no significant differences in egg weight, albumen quality, Haugh unit, yolk color, shell breaking strength, or shell quality in brown layers housed in enriched and conventional cages. Similarly, Alig et al. (2023b) reported no significant differences in egg quality parameters in white eggs from enriched and conventional cage systems.

One consideration is the potential energy allocation trade-offs associated with enriched environments. While these environments encourage natural behaviors like perching and foraging, the additional energy expenditure required for these activities might offset any welfare-related benefits in terms of egg quality (Jacobs et al., 2023; Herrera-Alcaino et al., 2024). Another explanation for the lack of significant differences could be that egg quality is primarily influenced by intrinsic factors such as genetics, nutrition, and the age of the hens rather than by cage enrichments alone (Sarıca et al. 2018; Franco et al. 2020; Zinca et al. 2024). In this study, both cage design groups were fed diets with identical nutritional content. While enriched cages provide more opportunities for hens to express natural behaviors, these behaviors may not directly translate into measurable improvements in egg quality traits.

The HB hybrid exhibited higher egg weight, shell thickness, and breaking strength compared to the IT hybrid. Differences in egg quality between strains are well-documented (Ketta et al. 2020; Lordelo et al. 2020). The higher egg weight observed in brown layer hybrids compared to white layer hybrids aligns with previous studies (Özentürk & Yıldız 2020; Özentürk & Yıldız 2021). Egg weight heritability is high (0.4-0.6), which helps explain the differences observed between hybrids (Sarıca et al. 2018; Göger 2019). The lower egg weight of white layer hybrids can be attributed to their lighter breed class compared to brown layer hybrids in terms of live weight (Özentürk & Yıldız 2020). The egg shape index values for HB and IT hybrids were within ideal ranges for commercial egg production (Sarıca et al. 2018; Mahawar et al., 2023). The higher shell thickness and breaking resistance of HB hybrid eggs indicate superior shell quality, possibly related to physiological differences between hybrids (Özentürk & Yıldız 2020).

We found that IT hybrid produced darker egg yolks. Darker yellow yolks are preferred by consumers in many countries and thus hold higher market value (Samiullah et al. 2017; Rondoni et al. 2020). Although egg yolk color is particularly influenced by the amount of synthetic xanthophyll in the diet (Nour et al. 2017), all hens in this study were fed the same diet. Philippe et al. (2020) suggest that yolk color intensity could also be affected by egg production levels, with paler yolks related to higher productivity. Reflecting this dilution effect, this study found that the HB hybrid, recognized for its higher laying rates in catalog results, produced lighter yolks. Additionally, it has also been reported that higher stress levels result in darker yolks, as higher levels of blood corticosterone lead to darker yolks (Alig et al. 2023a). The differences observed among strains could be attributed to studies indicating that different hybrids exhibit varying stress levels under cage conditions (Özentürk & Yıldız, 2021). Therefore, the darker egg yolk color in the IT hybrid in this study may be related to its high stress levels. Both HB and IT hybrid eggs had high Haugh unit values, indicating high quality. However, eggs from the HB hybrid exhibited a higher incidence of blood and meat stains, potentially due to physiological differences (Sarıca et al. 2018; Özentürk & Yıldız 2020;). Supporting this, studies have shown that brown layer hens generally produce eggs with more blood and meat stains compared to white layer hens (Yardım & Akşit, 2021; Uysal & Laçin, 2024).

Egg weight typically increased with time, while shell breaking strength and thickness peaked around the onset of peaked production and then declined with age. This decrease in shell thickness over time may result from reduced calcium deposition during shell formation in the uterus or from the same amount of calcium being distributed over a larger surface area as the size of the egg increases (Samiullah et al. 2017). A decrease in shell breaking resistance can also be attributed to these factors. As eggs age, the Haugh unit, a reliable indicator of freshness based on the relationship between egg weight and albumen height, decreases due to moisture loss and protein breakdown in the albumen (Da Silva Pires et al. 2021). This change in the Haugh unit over time is due to the fact that egg whites are heavier than yolks, causing the relative value to decrease as egg weight increases with age. The aging process may affect the egg white production function in the oviduct, leading to a reduction in albumen and yolk height by impacting the bonds holding the egg white and yolk (Özentürk & Yıldız 2020). Similarly, the white index and yolk index also decreased over time. While the shape index of eggs was higher at the beginning of the production period, it decreased towards the end. This change may be explained by alterations in the activity of oviduct muscles and changes in pelvic bone anatomy with age. Furthermore, feeding programs that evolve over time based on the egg production period and feed nutritional value, as well as variations in climatic conditions such as indoor temperature according to seasons, may also have affected the shape index. These results corroborate previous studies reporting similar findings for both cage systems (Dikmen et al. 2017; Samiullah et al. 2017; Özentürk & Yıldız 2020).

CONCLUSION

As a conclusion, this study provides comprehensive insights into the effects of cage design and strain on the egg quality. There were no significant differences in overall egg quality between the two rearing systems, indicating a need for further research to understand the specific impact of enrichment tools on egg quality. Breed selection played a crucial role in egg quality. In both CC and EEC, HB had higher egg weight, and better shell quality than IT, making them a preferred choice in both rearing systems. Results also indicated that while egg weight increased over time, eggshell quality and Haugh unit values decreased over time.

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Contribution Rate Statement Summary of Researchers

UÖ: Conception and design of study, Acquisition of data, Drafting the manuscript, Analysis and/or interpretation of data. AU: Acquisition of data, Drafting the manuscript, Critical review/revision.

Conflict of Interest

Authors have declared no conflict of interest.

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