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Imaging of cracked-broken areas of quail eggshells with different ground colors

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Abstract:

Eggshell integrity is a critical factor influencing food safety, embryonic development, and the economic viability of quail production. Shell defects, such as cracks and breakages, lead to significant financial losses. This study aimed to visualize and characterize shell defects in relation to their shell background color (brown-grayish-white) and to compare the weight-based quality characteristics of these defective eggs. The study was conducted over 63 days, beginning from the sixth week of the laying period. Defective eggs were collected daily and visually classified as brown-ground (n=40) or grayish-white-ground (n=30). Egg weight was measured, and key quality traits—including shell weight, shell thickness, shell ratio, egg surface area, and shape index—were calculated using formulas based on egg weight. Defect locations were documented photographically using digital photographs. Statistical analysis (t-test) revealed no significant differences (P>0.05) in the calculated weight-based quality characteristics between the two-color groups. However, the incidence of defects was higher in the brown-ground eggs than in the grayish-white-ground eggs. Morphological analysis of the images indicated differences in defect location; large and deep fractures were commonly observed in the pointed end and equatorial regions of brown-ground eggs, whereas in grayish-white-ground eggs, severe defects were most prevalent in the equatorial region. This preliminary study contributes to the limited literature on quail shell defects, allowing the determination and sharing of visuals of shell fracture-crack areas. Further studies will be carried out to extend this study to cover a production period to detail quail eggshell defects.

Keywords: Quail egg, eggshell defect, shell color, shell integrity.

Farklı zemin renklerine sahip bıldırcın yumurtası kabuklarının çatlak-kırık alanlarının görüntülenmesi

Özet:

Yumurta kabuk bütünlüğü, gıda güvenilirliğini, embriyonik gelişimi ve bıldırcın üretiminin ekonomik sürdürülebilirliğini etkileyen kritik bir faktördür. Çatlak ve kırık gibi kabuk kusurları, önemli finansal kayıplara yol açmaktadır. Bu çalışmada, bıldırcın yumurtalarındaki kabuk kusurlarının kabuk zemin rengine (kahverengi-grimsi-beyaz) bağlı olarak görselleştirilmesi ve karakterize edilmesi amaçlanmıştır. Ayrıca, kusurlu yumurtaların ağırlığa dayalı kalite özelliklerinin karşılaştırılması hedeflenmiştir. Çalışma, yumurtlama döneminin altıncı haftasından itibaren toplam 63 gün süreyle yürütülmüştür. Kusurlu yumurtalar günlük olarak toplanmış ve görsel muayene ile kahverengi zeminli (n=40) ve grimsi-beyaz zeminli (n=30) olarak sınıflandırılmıştır. Yumurta ağırlıkları ölçülmüş; bu ağırlık verileri kullanılarak kabuk ağırlığı, kabuk kalınlığı, kabuk oranı, yumurta yüzey alanı ve şekil indeksi gibi temel kalite özellikleri ilgili denklemler aracılığıyla hesaplanmıştır. Kusurlu bölgeler, fotoğrafları çekilerek kaydedilmiştir. İstatistiksel analiz (t-testi), iki renk grubu arasında hesaplanan ağırlığa dayalı kalite özellikleri bakımından anlamlı bir farklılık (p>0.05) olmadığını ortaya koymuştur. Bununla birlikte, kusur görülme sıklığının kahverengi zeminli yumurtalarda, grimsi-beyaz zeminli yumurtalara göre daha yüksek olduğu tespit edilmiştir. Görüntülerin makroskopik analizi, kusur bölgelerinde farklılıklar olduğunu göstermiştir; kahverengi zeminli yumurtaların sivri uç ve ekvator bölgelerinde büyük ve derin kırıklar yaygın olarak gözlenirken, grimsi-beyaz zeminli yumurtalarda ciddi kusurların çoğunlukla ekvator bölgesinde yer aldığı belirlenmiştir. Bu çalışma, bıldırcın yumurtası kabuk kusurları üzerine sınırlı literatüre katkı sağlamayı amaçlayan bir ön çalışma niteliğindedir ve kabuk kırık-çatlak alanlarına ait görsellerin belirlenmesine ve paylaşılmasına olanak tanımaktadır. Bıldırcın yumurtası kabuk kusurlarını detaylandırmak amacıyla, bu çalışmanın bir üretim periyodunu kapsayacak şekilde genişletilmesi için yeni çalışmalar yürütülecektir.

Anahtar kelimeler: Bıldırcın yumurtası, yumurta kabuk kusuru, kabuk rengi, kabuk bütünlüğü.

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Introduction

Quail is an important poultry used in biological, genetic, and embryological studies, as well as in nutrition, due to its meat and eggs. Quail eggs, like other poultry eggs, consist of a shell, white, and yolk. However, quail eggs, like partridge and turkey eggs, have a speckled shell, and the color of the speck changes from brown to black, blue, or green (Gutiérrez et al., 2021; Lan et al., 2021). Quail eggshells have been reported to have different colors in terms of shell background color, including brown, grayish white, and chalky white, as well as speckled characteristics (Sezer and Tekelioglu, 2009; Alaşahan et al., 2015). Quail eggshell characteristics play a significant role in embryo development during the incubation process, the quality of hatched chicks, and the preservation of internal quality in edible eggs. In other words, it has been reported that eggshell color affects both the quality and biological value of the egg (Zhao et al., 2006; Aygun, 2014; Alasahan et al., 2016). Although the thickness, shape, size, or porosity of the eggshell varies between species, the basic structure of the shell is similar in all birds (Board and Love, 1983). In addition, eggshell color has been reported to have a significant impact on the total number of hatched chicks and early and late mortality rates (Ismael et al., 2024). It is concluded that differences in shell quality are observed between eggs with different shell colors (Nowaczewski et al., 2025). Eggs with broken shells are of low quality and can be dangerous for food safety (Fathi et al., 2016). In egg production enterprises, shell integrity is a significant factor that determines the number of eggs produced and sold. Abnormally shaped eggs are not preferred by the consumer, and defects in the structure of the eggshell can cause the development of the embryo to stop or deteriorate during incubation (Roberts, 2004).

Eggshell quality is expressed as a significant factor that affects consumer preference and the economic profitability of producers, which varies with the prolongation of the egg production process of poultry (Cheng and Ning, 2023). Any defect in the shell structure causes a decrease in eggshell quality (Salem and Haj-Saeed, 2020). Defects such as hairline cracks, nail breaks, soft shells, and shell-less eggs, which compromise eggshell integrity, are common negative conditions that cause significant financial losses for production facilities and raise food safety concerns for consumers (Cheng and Ning, 2023). Eggshell defects occur due to genetics, ration content, cage floor slope, cage egg cradle, and production time (Sokołowicz et al., 2018). It is stated that a selection program is applied throughout the generation in poultry breeding to have high egg production and a low broken egg rate. Thus, it can be concluded that the improvement in eggshell quality is due to long-term selection for lower rates of cracked and broken eggs from generation to generation (Fathi et al., 2016). To reduce the number of broken eggs, the durability of the shell needs to be increased (Roberts, 2004). Shell thickness in quail eggs varies depending on the base color of the shell (Alaşahan et al., 2015). It is stated that the eggshells with brown shell ground color have invisible defects, and the shell thickness is less (Liu and Cheng, 2010).

This study aimed to visualize cracked and broken areas in quail eggs with different shell base colors during the egg production process. In addition, it was aimed to determine some weight-based quality characteristics of the broken-cracked eggs collected daily.

Matarial and Methods

The study data were collected from quail eggs at the Alternative Poultry Breeding Unit of the Experimental Research Application and Research Center of Hatay Mustafa Kemal University. The Japanese quails used in the study started laying eggs at the age of 35 days, and as of the sixth week of egg production (July 7, 2025), the study continued for a total of 63 days. Eggs were collected in the morning and afternoon of the day, and visually inspected, and the eggshell ground color was classified as brown and grayish white. The weights of eggs classified by shell color were determined by weighing them on a scale accurate to 0.01 grams.

The following egg characteristics were determined based on egg weight (Paganelli et al., 1974; Rahn and Paganelli, 1989; Ahmed et al., 2005; Alaşahan et al., 2019):

Shell Weight (g) = 0.0524 x (Whole egg weight)$^{1.113}$

Shell Ratio (%) = (Shell weight / Whole egg weight) x 100

Shell Thickness (mm) = 0.0546 x (Whole egg weight)$^{0.441}$

Shell Index (g/cm2) = (Shell weight / Egg surface area) x 100

White + Yolk Weight (g) = Whole egg weight – Shell weight

White + Yolk Ratio (%) = (White + Yolk weight / Whole egg weight) x 100

Egg Surface Area (cm2) = 4.835 x (Whole egg weight)$^{0.662}$

Egg Length (mm) = 13.04938 x (Whole egg weight)$^{0.373272}$

Egg Width (mm) = 8.01571 x (Whole egg weight)$^{0.448338}$

Shape Index (%) = (Egg width / Egg length) x 100

Elongation = (Egg length / Egg width)

After the egg weights were determined, the broken-cracked areas of the eggs were photographed with a camera and stored in flash memory. By examining these visuals, the formation locations of the broken-cracked areas are examined, and regional information is presented in the findings section.

Statistical Analysis

Normality of the data was evaluated before conducting statistical comparisons. The t-test was used in the comparison of the two groups formed based on the shell ground color of the broken-cracked eggs in terms of quality characteristics. Descriptive statistics were used for other characteristics.

Results

Some quality characteristics of broken-cracked eggs

The shell weight, shell thickness, egg length, egg width, egg surface area, and white+yolk weight were determined using the egg weight measured by weighing quail eggs, and are calculated and presented in Table 1. For eggs with a grayish-white background, the mean egg weight, shell weight, white+yolk weight, egg surface area, egg length, and egg width were determined to be 12.11 g, 0.84 g, 11.27 g, 25.15 cm², 33.04 mm, and 24.47 mm, respectively. In terms of the determined characteristics, it was determined that there was a numerical difference ($p>0.05$) between the grayish-white ground eggs and the brown ground eggs.

Table 1. Broken-cracked egg characteristics according to the shell ground color

Characteristics	Shell ground color			
	Brown	Grayish-white	F	P
Egg weight (g)	11.61	12.11	0.656	0.169
Shell weight (g)	0.80	0.84	0.729	0.166
Shell ratio (%)	6.91	6.94	0.273	0.190
Shell index (g/cm^2)	3.27	3.33	0.389	0.192
White + Yolk weight (g)	10.81	11.27	0.650	0.169
White + Yolk ratio (%)	93.09	93.06	0.273	0.190
Egg surface area (cm^2)	24.47	25.15	0.476	0.177
Egg length (mm)	32.54	33.04	0.361	0.184
Egg width (mm)	24.02	24.47	0.388	0.182
Shape index (%)	73.80	74.03	0.261	0.191
Elongation	1.355	1.351	0.215	0.195
	40	30		

The number of broken-cracked eggs of different weights in brown and grayish-white eggs is presented in Table 2. As shown in Table 2, the number of broken-cracked eggs (40) was higher in brown-ground eggs than in grayish-white-ground eggs (30). The highest number of broken-cracked eggs in brown-ground eggs was found in eggs with a mean egg weight of 11.50 g and 12.47 g, and mean shell thicknesses of 0.160 mm and 0.166 mm. The highest number of broken-cracked eggs in grayish-white ground eggs was determined in eggs with mean egg weights of 11.39 g (0.160 mm) and 12.34 g (0.165 mm).

Table 2. Number of eggs determined as broken-cracked according to shell ground color

Mean Egg weight (g)	Shell thickness (mm)	Number of broken-cracked eggs
		Brown background
8.80	0.142	2
9.61	0.148	4
10.69	0.155	5
11.50	0.160	14
12.47	0.166	9
13.31	0.171	4
14.28	0.176	2
General	0.161	40
Mean Egg weight (g)	Shell thickness (mm)	Grayish-white background
8.42	0.140	1
10.60	0.156	6
11.39	0.160	8
12.34	0.165	8
13.45	0.172	2
14.38	0.177	2
15.23	0.182	3
General	0.164	30

Evaluation of the images of broken-cracked eggs

In brown and grayish-white ground eggs, the broken-cracked shells were found in different sizes at the pointed, equatorial, and blunt ends of the eggs. The most common fracture and crack patterns are presented below under two headings based on the shell's ground color.

Regional images of shell defects in brown-ground eggs

Pointed end region fracture-crack images: Small and deep cracks were observed in the shell near the apex of the pointed end of the brown-ground eggs (Figure 1). In addition, it was determined that medium and large deep fractures and cracks occurred in the defective area at the pointed end of the egg (Figures 2 and 3).


Figure 1. Small deep fracture-crack at the pointed end


Figure 2. Medium-sized deep fracture-crack at the pointed end

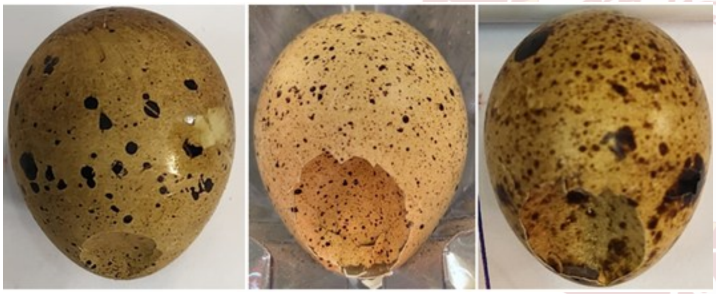
Figure 3. Large deep fracture-crack at the pointed end

Equatorial region fracture-crack images: Deep broken-cracked areas of different sizes were detected in the equatorial region of the brown-ground eggs. Figure 4 shows a small deep fracture-crack, Figure 5 shows a large deep fracture-crack, Figure 6 shows a large fracture extending from the blunt end to the equatorial region, and Figure 7 shows an open large fracture extending from the equatorial region to the blunt end.


Figure 4. Small and deep fracture-crack in the equatorial region


Figure 5. Large deep fracture-crack at the equatorial region

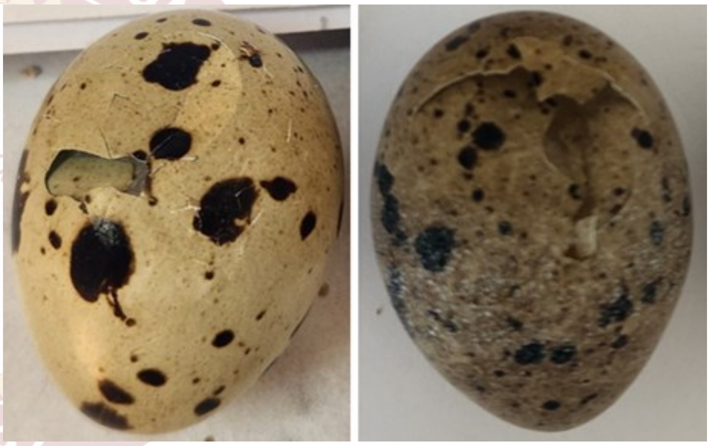
Figure 6. Large fracture starting from the blunt end and spreading to the equatorial region


Figure 7. Open large fracture starting from the equatorial region and spreading to the blunt end

Blunt end region fracture-crack images: The defects identified in the blunt ends of the brown-ground eggs ranged from deep fractures to large cracks. The defects in this region are defined as a small deep fracture near the apex of the blunt end area in Figure 8 and Figure 9, and a superficial crack and deep fracture near the blunt end equatorial region in Figure 10.


Figure 8. Small deep fracture at the blunt end


Figure 9. Small deep fracture at the blunt end


Figure 10. Superficial crack and deep fracture near the equatorial region of the blunt end

Regional images of shell defects in grayish-white ground eggs

Pointed end region fracture-crack images: Small deep fractures-cracks (Figure 11) were detected in different parts of the pointed end region of the grayish-white ground eggs.


Figure 11. Small deep fracture-crack at the pointed end

Equatorial region crack-fracture images: Small to large fractures and cracks were found on the grayish-white ground eggs. These defects are determined as a small/medium deep fracture in Figure 12, a large deep crack-fracture in Figure 13, a large deep crack-fracture starting from the equatorial region and spreading to the pointed end in Figure 14, and a large open fracture in the equatorial region in Figure 15.

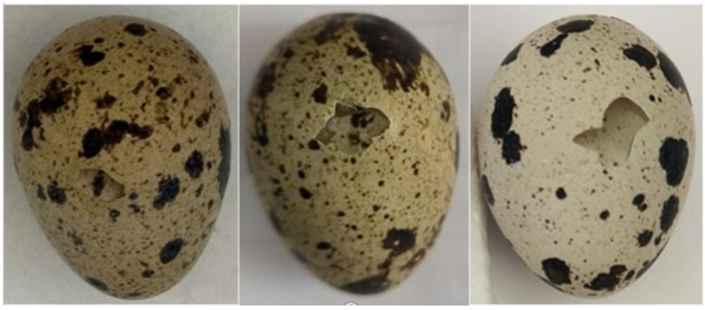
Figure 12. Small and deep fracture-cracks in the equatorial region


Figure 13. Large deep fracture-crack at the equatorial region


Figure 14. Large deep crack-fracture starting from the equatorial region and spreading to the pointed end

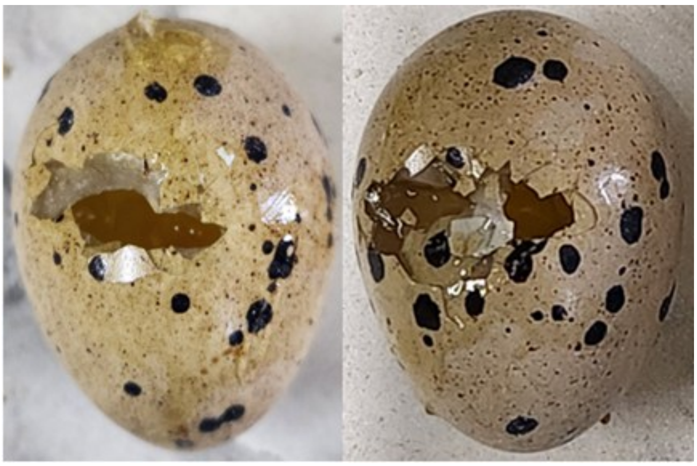
Figure 15. Large open fracture in the equatorial region

Blunt end region fracture-crack images: The cracks and fractures determined at the blunt ends of the grayish-white ground eggs differ in size. The defects in this region were found as small superficial and deep cracks and fractures in Figure 16 and large deep cracks and fractures in Figure 17.

Figure 16. Small superficial and deep crack-fracture at the blunt end

Figure 17. Large deep fracture at the blunt end

Very few nail scratches were detected in brown and grayish-white ground eggs. When examining Figure 18, nail scratches are clearly visible on brown-ground eggs, while careful examination is required to see nail scratches on grayish-white ground eggs.

Figure 18. Nail scratches

Discussion

The mean egg weight of quail eggs with brown background and grayish-white background was found to be 11.61 and 12.11 g (Table 1). In the current study, the egg weight determined for eggs with a broken-cracked brown background was 12.43 g and 12.76 g (Alaşahan et al., 2015), which was lower than the egg weights with a perfect brown background of 12.55 g (Ahmed, 2022) and 13.39 g (Ismael et al., 2024). A significant relationship was reported between eggshell color and egg weight, egg width, shell percentage, and yolk and white percentages (Ismael et al., 2024). A study of chicken eggs states that shell defects affect water loss and shell permeability (Wengerska et al., 2023). Studies based on shell color in quail eggs found egg weight to be 12.35 g in brown-shelled eggs, 12.15 g in grayish-white-shelled eggs (Alasahan et al., 2016), 10.73 g in cream to light brown-shelled eggs, and 10.44 g in white to cream-shelled eggs (Nowaczewski et al., 2025). Egg weight varies, especially depending on the age of the quails, gradually increasing from the age of sexual maturity to 5 months (35 + 150 days) (Yannakopoulos and Tserveni-Gousi, 1986; Salem and Haj-Saeed, 2020).

In the present study, it was determined that the numerical difference in shell weight (0.80 and 0.84 g) and shell thickness (0.161 mm and 0.164 mm) in eggs with cracked-broken brown and grayish-white ground shells was statistically insignificant (P>0.05) (Table 1 and Table 2). Egg weight was reported as 1.67 g for eggs with perfect brown ground shell (Ayman, 2011) and 1.29 g for eggs without shell color identification (Salem and Haj -Saeed, 2020). Although the thickness, shape, and porosity of the eggshell vary among eggs of different poultry species, the basic structure of the shell is similar in all poultry (Board and Love, 1983). Studies conducted on quail eggs indicate that the shell thickness of eggs with perfect shells is 0.225 mm (Ismael et al., 2024), 0.178 mm for shells ranging from cream to light brown, and 0.177 mm for shells ranging from white to cream (Nowaczewski et al., 2025). Studies have shown that the shell weight and thickness of eggs with shell defects differ from those of eggs without shell defects.

In our study, the shape index and elongation value describing the shape of the egg were determined as 73.80% - 1.355 and 74.03% - 1.351 for brown-shelled eggs and grayish-white-shelled eggs, respectively. Nowaczewski et al. (2025) reported quail egg shape index as 75.60% in eggs with cream to light brown grounds and 74.47% in eggs with white to cream grounds. Ayman (2011) reported that the shape index was 81.11% in brown-ground quail eggs and was higher than that of eggs with white, black spots, and slightly blue spots. The fact that the shape index is a feature affected by other quality characteristics of the egg creates the difference between the sources.

The number of broken-cracked eggs is higher in eggs with brown ground shell than in eggs with grayish-white ground shell (Table 2). In addition, the highest number of broken-cracked eggs occurred in brown ground eggs weighing 11.50 g (14 pieces) and 12.47 g (9 pieces), and grayish white ground eggs weighing 11.39 g (8 pieces) and 12.34 g (8 pieces). The most significant factors affecting shell quality can be listed as breed, type of production, rearing system, environmental conditions, and the presence of mineral additives in the feed (Tůmová et al., 2007). The cracking of the eggshell requires less resistance than the strength of the environmental force to which it is exposed (Kemps et al., 2006). Cracked and broken eggshells are a significant economic loss factor in egg production enterprises. Broken (or cracked) eggs cause a significant economic loss as bacteria penetrate the shell and cause a food safety problem. External environmental conditions and genetic defects of laying hens can be stated as the main factors causing broken eggs (Cheng and Ning, 2023). In an improper cage, eggs can roll into the egg cradle at high speed, which can lead to fractures in the shell. Eggs in the egg cradle may not be collected in time, which can pile up and lead to cracks and falls (Cheng and Ning, 2023). In addition, shell formation during a spawning year is a biologically stressful event, and age-related changes in shell thickness and ultra-structure of the shell have been reported to be reflected in the deterioration of physical parameters such as fracture strength (Solomon, 2010). It is stated that as chickens approach the end of the laying period, there is a decrease in eggshell quality (Mazzuco and Hester, 2005). Therefore, the condition of the eggshell during the laying period and the cage floor slope feature may affect the frequency of shell breakage.

Conclusion

In the process of the study, different sizes and depths of broken-cracked areas were imaged in quail eggs with shell ground color differences. In quail eggs with grayish-white ground shells, large and deep fracture-crack areas were found in the equatorial region, while in eggs with brown ground shells, they were found in the pointed end and equatorial regions. The study allowed us to determine and share the visuals of shell fracture-crack areas that may be encountered during the egg production year, depending on various factors of economic importance. This study constitutes a preliminary investigation, with the objective of contributing to the limited extant literature on quail shell defects. Further studies will be carried out to extend this study to cover a production period to detail quail eggshell defects.

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Author Contributions:

Mahmut Şamil ŞAMLI: Conducting practical applications, statistical analysis, data visualisation, and preparing the draft ofthe article.

Sema ALAŞAHAN: Development of methodology, execution andsupervision of the statistical analysis process, project management, critical review and editing of the article.

Cafer Tayyar ATEŞ: General supervision of the work, review and approval of the final version of the article.

References

1. Ahmed, A., Rodríguez-Navarro, A. B., Vidal, M.-L., Gautron, J., García-Ruiz, J. M., & Nys, Y. (2005). Changes in eggshell mechanical properties, crystallographic texture and in matrix proteins induced by moult in hens. British Poultry Science, 46(3), 268-279. https://doi.org/10.1080/00071660500065425
2. Ahmed, L. S. (2022). Impact of egg shell and spots colour on the quality of hatching eggs derived from three lines of local quail. Iraqi Journal of Agricultural Sciences, 53(6), 1256-1269. https://doi.org/10.36103/ijas.v53i6.1640
3. Alasahan, S., Akpinar, G. C., Canogullari, S., & Baylan, M. (2016). The impact of eggshell colour and spot area in Japanese quails: I. eggshell temperature during incubation and hatching results. Revista Brasileira de Zootecnia, 45(5), 219-229. https://doi.org/10.1590/S1806-92902016000500003
4. Alaşahan, S., Akpınar, G. Ç., Canoğulları, S., & Baylan, M. (2015). Determination of some external and internal quality traits of Japanese quail (Coturnix coturnix japonica) eggs on the basis of eggshell colour and spot colour. Eurasian Journal of Veterinary Sciences, 31(4), 235-241. https://doi.org/10.15312/EurasianJVetSci.2015413529
5. Alaşahan, S., Hark, B. D., & Eltas, Ö. (2019). Prediction of the length and width of quail eggs using linear regression analysis. Eurasian Journal of Veterinary Sciences, 35(3). https://doi.org/10.15312/EurasianJVetSci.2019.237
6. Aygun, A. (2014). The relationship between eggshell colour and egg quality traits in table eggs. Indian Journal of Animal Research, 48(3), 290-294. https://doi.org/10.5958/j.0976-

0555.48.3.061

7. Ayman, E. (2011). Analyzing of quail eggs hatchability, quality, embryonic mortality and malposition in relation to their shell colors.

8. Board, R., & Love, G. (1983). Magnesium distribution in avian eggshells with particular reference to those of wildfowl (Anatidae). Comparative Biochemistry and Physiology Part A: Physiology, 75(1), 111-116. https://doi.org/10.1016/0300-9629(83)90053-1

9. Cheng, X., & Ning, Z. (2023). Research progress on bird eggshell quality defects: a review. Poultry Science, 102(1), 102283. https://doi.org/10.1016/j.psj.2022.102283

10. Fathi, M., El-Dlebshany, A., El-Deen, M. B., Radwan, L., & Rayan, G. (2016). Effect of long-term selection for egg production on eggshell quality of Japanese quail (Coturnix japonica). Poultry Science, 95(11), 2570-2575. https://doi.org/10.3382/ps/pew233

11. Gutiérrez, E., Ordaz, G., Pérez, R. E., Ortiz, R., & Juárez, A. (2021). Effect of the pigmentation, shine, weight, and shape index of the quail egg (Coturnix coturnix japonica) on the hatchability rate. Journal of Advanced Veterinary and Animal Research, 8(4), 629. https://doi.org/10.5455/javar.2021.h554

12. Ismael, N. A., Abdelmonem, U. M., El-Kholy, M. S., El Nagar, A., Ahmed, A. F., Almalki, M., El-Tarabily, K. A., & Reda, F. M. (2024). The relationship between eggshell color, hatching traits, fertility, mortality, and some qualitative aspects of Japanese quail (Coturnix japonica) eggs. Poultry Science, 103 (2), 103298. https://doi.org/10.1016/j.psj.2023.103298

13. Kemps, B., Govaerts, T., De Ketelaere, B., Mertens, K., Bamelis, F., Bain, M., Decuypere, E., & De Baerdemaeker, J. (2006). The influence of line and laying period on the relationship between different eggshell and membrane strength parameters. Poultry Science, 85(7), 1309-1317. https://doi.org/10.1093/ps/85.7.1309

14. Lan, L. T. T., Nhan, N. T. H., Hung, L. T., Diep, T. H., Xuan, N. H., Loc, H. T., & Ngu, N. T. (2021). Relationship between plumage color and eggshell patterns with egg production and egg quality traits of Japanese quails. Veterinary World, 14(4), 897. https://doi.org/10.14202/vetworld.2021.897-902

15. Liu, H.-C., & Cheng, W. (2010). Eggshell pigmentation: a review. Journal of the Chinese Society of Animal Science, 39 (2), 75-89.

16. Mazzuco, H., & Hester, P. (2005). The effect of an induced molt and a second cycle of lay on skeletal integrity of White Leghorns. Poultry Science, 84(5), 771-781. https://doi.org/10.1093/ps/84.5.771

17. Nowaczewski, S., Grzegrzółka, B., Gruszczyńska, J., Szablewski, T., Stuper-Szablewska, K., Cegielska-Radziejewska, R., Tomczyk, Ł., Biadała, A., Lewko, L., & Szulc, K. (2025). Physical and biochemical characteristics of Japanese quail (Coturnix japonica) eggs based on shell color. Animal Science Papers & Reports, 43(2). https://doi.org/10.2478/aspr-2025-0014

18. Paganelli, C. V., Olszowka, A., & Ar, A. (1974). The avian egg: surface area, volume, and density. The condor, 76(3), 319-325. https://doi.org/10.2307/1366345

19. Rahn, H., & Paganelli, C. V. (1989). Shell mass, thickness and density of avian eggs derived from the tables of Schönwetter. Journal für Ornithologie, 130(1), 59-68. https://doi.org/10.1007/BF01647162

20. Roberts, J. R. (2004). Factors affecting egg internal quality and egg shell quality in laying hens. The Journal of Poultry Science, 41(3), 161-177. https://doi.org/10.2141/jpsa.41.161

21. Salem, N., & Haj-Saeed, B. (2020). Evaluation of the External and Internal Quality Characteristics of Quail Eggs Produced in Benghazi. International Journal of Current Microbiology and Applied Sciences(9), 750-758. https://doi.org/10.20546/ijcmas.2020.906.096

22. Sezer, M., & Tekelioglu, O. (2009). Quantification of Japanese quail eggshell colour by image analysis. Biological research, 42 (1), 99-105. https://doi.org/10.4067/S0716-97602009000100010

23. Sokołowicz, Z., Krawczyk, J., & Dykiel, M. (2018). The effect of the type of alternative housing system, genotype and age of laying hens on egg quality. Annals of Animal Science, 18(2), 541. https://doi.org/10.2478/aoas-2018-0004

24. Solomon, S. (2010). The eggshell: strength, structure and function. British Poultry Science, 51(sup1), 52-59. https://doi.org/10.1080/00071668.2010.497296

25. Tůmová, E., Zita, L., Hubený, M., Skřivan, M., & Ledvinka, Z. (2007). The effect of oviposition time and genotype on egg quality characteristics in egg type hens. Czech Journal of Animal Science, 52(1), 26-30. https://doi.org/10.17221/2326-CJAS

26. Wengerska, K., Batkowska, J., & Drabik, K. (2023). The eggshell defect as a factor affecting the egg quality after storage. Poultry Science, 102(7), 102749. https://doi.org/10.1016/j.psj.2023.102749

27. Yannakopoulos, A., & Tserveni-Gousi, A. (1986). Quality characteristics of quail eggs. British Poultry Science, 27(2), 171-176. https://doi.org/10.1080/00071668608416870

28. Zhao, R., Xu, G.-Y., Liu, Z.-Z., Li, J.-Y., & Yang, N. (2006). A study on eggshell pigmentation: biliverdin in blue-shelled chickens. Poultry Science, 85(3), 546-549. https://doi.org/10.1093/ps/85.3.546