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Changes related to storage conditions in the quality of quail eggs of different sizes

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Abstract This study assesses the impact of storage temperature – ST (4–6 °C and 20–22 °C), storage duration – SD (7, 14, 21, and 28 days), and egg weight group – EWG (A ≤ 10, B = 10.01–11.00, C = 11.01–12.00, D = 12.01–13.00 gram) on the EWL as well as quality attributes of 400 quail eggs. Various parameters were assessed, including egg weight loss (EWL), external quality attributes: egg weight (EW), egg shape index (ESI), eggshell weight (ESW) and eggshell thickness (EST), and internal characteristics: albumen weight (AW), albumen index AI, albumen pH (ApH), Haugh unit (HU), yolk weight (YW), yolk index (YI), yolk pH (YpH), yolk color (YC) and yolk/albumen ratio (Y/A). This comprehensive analysis aimed to provide a thorough understanding of the eggs' physical and internal qualities. The data obtained was analyzed using JMP IN 7, revealing impacts of ST, SD, and EWG on quail eggs quality (P <0.05). The storage temperature parameters not only demonstrated statistically significant differences in AW (P < 0.05) but also in YI, and YpH (P <0.05). Parameters such as AI, YW, ESW, EST, ESI, Y/A, YC, HU, and YpH did not reflect statistically significant differences by ST (P > 0.05). SD had significant impact on AW, AI, ApH, HU, YW, YR, YI, Y/W, YC and YpH (P <0.05). Changes in AW, AI, YW and HU were observed based on EWG (P < 0.05). Furthermore, significant effects (P < 0.05) were found for interactions between ST×SD×EWG on EWL, AW, YW, and Y/A. This research is focused on providing a comprehensive overview of storage conditions, necessary to maintain quality eggs.

Key words: egg quality, egg weight group, quail egg, storage duration, storage temperature.

INTRODUCTION

Quail eggs are gaining recognition as a valuable source of nutrition due to their nutrient profile and potential health benefits. This rich composition aligns with the criteria for food with functional properties. Quail eggs are becoming increasingly available to consumers, offering a complementary dietary option to chicken eggs. Despite their small size, quail eggs boast a superior nutrient content, being rich in protein, essential amino acids, and a variety of macro and micronutrients such as calcium, zinc, and selenium. Additionally, they are low in triglycerides and saturated fat (Ondrušíková et al., 2018). For consumers, the importance of quail eggs lies not only in their nutritional value but also in the fact that they are not harmful to people allergic to chicken egg albumen (Ali & Abd El-Aziz, 2019).

According to Ondrušíková et al. (2018), breed, quail's age, feed composition and storage conditions (temperature and storage time) are the factors that mainly affect the quality of quail eggs. According to Anderle et al. (2017), quail eggs contain 33% yolk, 59% protein and 8% eggshell.

The chemical composition of quail eggs consists of 74.6 % water, 13.1 % protein, 11.2 % fat, and 1.1 % ash, providing an energy content of 632 J/egg.

Carvalho et al. (2023) discussed that the inadequate quail egg storage condition can break down the egg very quickly and lose their quality. However, to ensure that the nutritional benefits of quail eggs are fully acceptable for human consumption, proper storage is essential.

Prolonged storage can significantly affect the internal quality of the eggs, as they deteriorate progressively after hatching (Nepomuceno et al., 2014; Roriz et al., 2016). Nepomuceno et al. (2014) also points out that eggs stored in poor conditions become unsuitable for consumption because the yolk may touch the shell or break the yolk membrane, causing the white and yolk to mix. Long-term storage of quail eggs increases weight loss and negatively affects the quality of internal egg parameters (albumen and yolk height, albumen and yolk index, and pH. These effects are more pronounced at higher storage temperatures (Adamski et al., 2017). Other researchers also reported that the egg weight matter decreases during storage (Daniel et al., 2022). In addition to the storage period, the size of the eggs also influences the external and internal properties of the eggs (Nowaczewski et al., 2010). From the perspective of producers and retailers, the storage conditions of quail eggs appropriate temperature and minimized storage time are essential for maintaining quality. These factors affect consumer acceptability of the eggs and economic profits for both farmers and retailers.

The objective of this study was to determine the effect of different storage temperatures, storage durations, and egg weight on changes of quail eggs quality properties.

MATERIAL AND METHODS

Egg sampling

A total of 400 fresh quail eggs were collected from local producers in center of Kosovo. Eggs obtained from the quails of the same age have been sent to the laboratory.

Before analyzing, egg weights were divided into four groups, with one-gram difference: ≤10 g (A), 10.01–11.00 g (B), 11.01–12.00 g (C), and 12.01–13.00 g (D) and subsequently stored under two conditions: room (20–22 °C) and refrigerated temperature (4–6 °C).

Each day, the temperature was carefully checked using a specialized digital thermometer, specifically a Combi Steel LCD Multi model. The quail eggs were stored for a maximum of 28 days, until the end of the experiments. The eggs were weighed with a digital analytical scale (KERN ALS 120-4N) with an accuracy of 0.01 g. The weight of each egg was recorded and analyzed in weekly intervals, starting at day 0, 7, 14, 21 and 28. The research was conducted in the laboratory of the Faculty of

Agriculture and Veterinary, University of Prishtina. For each treatment (storage duration, storage temperature and egg weight group), 10 eggs were used, ensuring homogeneity among all experimental groups. Table 1 shows the design of the experiment.

Table 1. Design of the experiment

ST, °C	SD, day	Egg weight group, g			
		A	B	C	D
	0	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	7	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
4–6	14	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	21	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	28	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	0	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	7	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
20–22	14	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	21	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00
	28	≤ 10	10.01–11.00	11.01–12.00	12.01–13.00

Material for evaluating eggs quality properties

For the purpose of this experiment, the following equipment were used: a digital scales (KERN ALS 120–4N) for measuring the egg weight and its parts; a digital Verner calliper with an accuracy of 0.01 mm used to measure the length and width of the egg (length, width, and height of white; height and width of the yolk and thickness of the eggshell); a Yolk Color Fan of 1–15 degrees (Roche) for measuring the intensity of the yolk color; a glass table for breaking the eggs; a plastic strainer for separating the parts of the eggs; a pH meter for measuring the pH of albumen and yolk; and finally, a tripod micrometer for measuring the HU. Each egg was weighed and recorded with a digital analytical scale. This measurement was taken in weekly intervals, starting at day 0, for an overall period of 4 weeks, as described in Table 1. At each week interval, the egg weight loss (%) was calculated using the following formula:

$$EW\ loss\ (\%) = [(Initial\ weight - Current\ weight) / Initial\ weight] \cdot 100. \quad (1)$$

Egg loss in weight and external quality of quail eggs

Egg weight loss during storage has been calculated by comparing the initial weight of the egg at the beginning of the storage (day 0) with its weight at a given time point (7, 14, 21 and 28 days).

This value provides a reliable indicator of egg quality during storage and leads to the fact that the higher weight loss is usually associated with reduced freshness, increased air cell size and potential deterioration of internal quality parameters such as albumen height and Haugh unit.

Each egg included in the experiment was measured for width and length to calculate the egg shape index, according to formula (2) and was manually broken and placed on a flat glass surface to measure the length, width and height of albumen, as well as the length, width and height of the yolk.

$$Shape\ index = egg\ width/egg\ length) \cdot 100. \quad (2)$$

The following formula was used to estimate the surface area of the quail eggs.

$$Egg\ surface\ area = 3.9782 \cdot EW^{0.7056}\ \text{(Carter, 1975), EW – Egg weight.} \quad (3)$$

The specific gravity of quail eggs was calculated using the following formula:

$$Specific\ gravity = Egg\ weight/Egg\ volume. \qquad (4)$$

The eggshell ratio was calculated by dividing the weight of the eggshell by the total egg weight and multiplying the results by 100.

$$Eggshell,\ \% = (Eggshell\ weight\ /\ Egg\ weight) \cdot 100. \qquad (5)$$

The eggshell index was determined using the formula (6) described by Ahmed et al. (2005).

$$Eggshell\ index = (eggshell\ weight/eggshell\ surface) \cdot 100. \qquad (6)$$

The eggshell weight and ratio were calculated after breaking the eggs and segregating their contents (albumen and yolk) using an egg separator. Before weighing the eggshell, the inner membrane remained intact, and the eggshell was gently wiped with a paper towel.

The eggshell thickness was measured by digital Verner calliper with accuracy of 0.01 mm.

The internal quality of quail eggs

In addition to the height of the air cell, the consistency of the albumen is one of the other indicators of the freshness and internal quality of the egg. To evaluate how different storage conditions influenced the internal quality of quail eggs (including factors like albumen weight and ratio, yolk weight and ratio, albumen and yolk index, albumen and yolk pH, HU, yolk colour and yolk:albumen ratio), each egg was weighed and subsequently broken open. Once an egg was broken onto a flat glass surface, precise measurements were taken for the height, width, and length of the dense albumen, as well as the height, width, and length of the yolk, using a digital Vernier caliper. The intensity of the yolk`s pigmentation was measured using the Roche Yolk Colour scale, which ranges from 1 to 15. Furthermore, the albumen was separated from the yolk, and the individual weights of both were recorded as absolute values. Their relative weight was then calculated by dividing their absolute weight by the total egg weight and expressing the results as a percentage. The albumen and yolk index were calculated using the following formulas, where AH – albumen height, ALD – albumen long diameter, and ASD – albumen short diameter:

$$AI = [AH,\ \mathrm{mm}\ \ (ALD + ASD)\ \ 2] \cdot 100. \qquad (7)$$

$$YI = (yolk\ height\ /\ yolk\ width) \cdot 100. \qquad (8)$$

The pH levels of both the egg albumen and egg yolk were ascertained using pH meter (pH-Meter GLP 21, developed and manufactured in Spain by Crison Instruments, S.A). Finally, the Haugh Unit was calculated based on the determined egg weight and the height of the dense albumen, according to the following formula:

$$Haugh\ Unit\ (HU) = 100\ log\ [h - 1.7W0.37 + 7.6]\ \text{(Haugh, 1937).} \qquad (9)$$

Statistical analysis

All the data are presented as the mean of 10 eggs and ± standard error of the mean (Mean ± SEM). The data collected on various quail egg quality parameters were statistically analyzed using JMP IN 7, statistical software (business unit of SAS). Prior to parametric analysis, the normality of the egg weight for each egg weight group distribution was evaluated using the Shapiro–Wilk Test (A: W = 0.8989; B: W = 0.9228; C: W = 0.9526 and C: W = 0.9289). Tukey-Kramer HSD post hoc test was used to compare mean differences among groups. Differences in the mean were considered statistically significant at $P < 0.05$.

RESULTS AND DISCUSSION

The effect of storage duration, storage temperature and egg weight group on egg weight loss percentage (Table 2) of quail eggs was highly significant ($P < 0.001$). Also, the interaction between SD × ST and SD × ST × EWG, has shown statistically significant results ($P < 0.001$) in egg weight losses. In addition, the interaction between SD × EWG and ST × EWG were non-significantly ($P > 0.05$) on egg weight loss. The highest weight losses of eggs were recorded on the 28th day (4.88%). During the storage period, egg loss levels were observed to be highest (1.55%) between day 21 and day 28. In contrast, the lowest loss (0.86%) occurred between day 14 and day 21. These results are consistent with findings of Lacin et al. (2008), whose research demonstrated that storage duration significantly influenced both egg weight after storage and overall egg weight loss (with statistical significance at $P < 0.05$ and $P < 0.01$, respectively).

Table 2. The effect of SD, ST and EWG on egg weight loss (%) (Mean ± SEM)

Treatments	Parameters		
	EWBS, g	EWAS, g	EWL, %
SD, day			
0	10.76 ± 0.18	10.76^{a} ± 0.18	0.00^{e} ± 0.00
7	10.69 ± 0.19	10.56^{ab} ± 0.18	1.24^{d} ± 0.07
14	10.67 ± 0.22	10.40^{bc} ± 0.22	2.47^{c} ± 0.15
21	10.75 ± 0.18	10.39^{bc} ± 0.18	3.33^{b} ± 0.20
28	10.68 ± 0.24	10.17^{c} ± 0.24	4.88^{a} ± 0.44
P value	*ns*	<.0001	<.0001
ST, °C			
4–6	10.73 ± 0.12	10.56^{a} ± 0.12	1.61^{b} ± 0.11
20–22	10.69 ± 0.13	10.37^{b} ± 0.13	3.10^{a} ± 0.27
P value	*ns*	0.0016	<.0001
EWG, g			
A	9.29^{d} ± 0.08	9.04^{d} ± 0.10	2.73^{a} ± 0.38
B	10.51^{c} ± 0.04	10.28^{c} ± 0.04	2.10^{b} ± 0.24
C	11.37^{b} ± 0.04	11.13^{b} ± 0.04	2.15^{b} ± 0.28
D	12.41^{a} ± 0.06	12.13^{a} ± 0.08	2.26^{b} ± 0.34
P value	<.0001	<.0001	<.0001

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; *ns* – nonsignificant; EWBS – Egg weight before storage; EWAS – Egg weight after storage; EWL, %-Egg weight loss; A – ≤10 g; B – 10.01–11.00 g; C – 11.01–12.00 g; D – 12.01–13.00 g.

[abcd] Means with different superscripts within the same column are significantly different at P <0.05.

This conclusion is further supported by studies from Roriz et al. (2016); Taha et al. (2019); Gonzalez-Redondo et al. (2023) and Carvalho et al. (2023), all of whom reported a statistically significant influence ($P < 0.05$) of storage duration on egg weight loss.

The effect of storage temperature (Table 2) followed a similar trend, with quail egg stored at 20–22 °C exhibiting significantly ($P < .0001$) greater weight loss (3.10%) compared to those stored under refrigeration conditions (1.61%). These results correspond to the studies of Marek et al. (2017), who noted that the intensive decrease in egg weight was observed in eggs stored at a temperature of 23 °C. This weight loss is mainly attributed to water loss that happened from the eggshell pores.

Even though lighter eggs (categorized as a group A, Table 1) possessed a smaller surface area, they exhibited a higher percentage of egg weight loss at 2.73%. This was a greater loss compared to heavier eggs, which had EWL percentage of 2.10%, 2.15% and 2.26% for their respective larger weights (group B, C and D respectively). Our research results align with previous studies, such as that by Nowacyewski et al. (2010), which indicated that eggs with lighter weights experienced a greater loss, specifically 11%. Similarly, Hegab & Hanafy, (2019) observed that smaller eggs (averaging 12.62 g) incurred a higher weight loss (16.08%) when compared to larger eggs (which weighed 14.84 g and lost 12.36%, respectively). Furthermore, our findings, detailed in Table 2.1, reveal highly significant differences due to the interaction between SD × ST on the percentage of EWL. This observation is consistent with Mustafa & Dere (2011), who also reported that the interplay of storage period and temperature significantly impacted EWL ($P = 0.000$). In our study, the three-way interaction (SD × ST × EWG) indicates that egg weight loss is caused not only by the individual effects of these factors but also by their combined effects. This means that quail eggs of different weights respond differently to storage conditions because they have different surface-area-to-volume ratios, and thus shell conductivity also varies. Moreover, smaller eggs may have a proportionally larger surface area relative to their internal volume. In this case, they may be more sensitive when exposed to higher temperatures and for longer periods of time. While our study also found that the interaction of all three factors (SD × ST × EWG) influence EWL percentage, we were unable to locate existing comparative data for this specific three-way interaction. Consequently, our results are particularly valuable for highlighting the combined effect of SD × ST × EWG on EWL (%).

Table 2.1. The effectof the interaction of all factors on egg weight loss (%)

Treatments	Parameters		
	EWBS, g	EWAS,	EWL, %
SD × ST	*ns*	*ns*	<.0001
SD × EWG	*ns*	*ns*	*ns*
ST × EWG	0.0048	*ns*	*ns*
SD × ST × EWG	*ns*	*ns*	<.0001

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; *ns* – nonsignificant; EWBS – Egg weight before storage; EWAS – Egg weight after storage; EWL, % – Egg weight loss.

The data presented in Table 3 illustrates how different temperatures, length of storage and egg weight affect the quality characteristics of egg albumen. Our research findings demonstrate that as storage time increases, a significant decline is observed in weight (both in gram and percentage), index and pH level of albumen. The fresh eggs in this study had an albumen weight of 6.34 g and an albumen ratio (or percentage) of 58.79%. The weight and ratio of albumen were observed to change as the storage period progressed. In other words, as the storage time increases, the liquefaction of the albumen also increases. The results of our research presented in Table 3 show a decrease in weight and albumen ratio after the first week. At the end of the storage period, the albumen weight (g) decreased by 6.34%, while the albumen ratio decreased from 58.79% to 56.74%. These differences were more noticeable after the second week of storage. Our results are in harmony with the Ondrušíková et al. (2018), who presented the fact that after the second week of storage, the amount of albumen started to decrease. In our study findings, the values of the albumen index in fresh eggs (day 0) were 5.87%, suffering a decrease to 3.86% after storage (day 28). This trend of decreasing albumen index during storage in this study coincides with the results of the study of Ondrušíková et al. (2018), who also report a decrease in albumen index at the end of storage period. But, in contrast to our results, in their research the albumen index in the first, second and fourth weeks was higher (11.35, 10.19 and 10.47%), than at the beginning of the experiment (9.37%), while after the fourth week until the end of the storage period, it decreased to 6.77%.

Table 3. Effect of SD, ST and EWG on egg albumen parameters (Mean ± SEM)

Treatments	Parameters			
	AW, gr	AR, %	AI, %	ApH
Storage duration, day (SD)				
0	$6.34^{a} \pm 0.11$	$58.79^{a} \pm 0.53$	$5.87^{a} \pm 0.30$	$9.08^{c} \pm 0.03$
7	$5.86^{ab} \pm 0.10$	$55.40^{b} \pm 0.49$	$4.48^{b} \pm 0.18$	$9.49^{b} \pm 0.07$
14	$5.89^{ab} \pm 0.15$	$56.62^{b} \pm 0.57$	$4.31^{b} \pm 0.13$	$9.86^{a} \pm 0.04$
21	$5.78^{b} \pm 0.12$	$55.65^{b} \pm 0.46$	$4.32^{b} \pm 0.10$	$9.87^{a} \pm 0.04$
28	$5.76^{b} \pm 0.13$	$56.74^{b} \pm 0.47$	$3.86^{b} \pm 0.10$	$8.91^{c} \pm 0.05$
P value	0.0075	<.0001	<.0001	<.0001
Storage Temperature, °C (ST)				
4–6	$6.04^{a} \pm 0.08$	57.06a ± 0.36	4.72 ± 0.14	9.47 ± 0.06
20–22	$5.83^{b} \pm 0.08$	56.23b ± 0.32	4.47 ± 0.13	9.43 ± 0.04
P value	<.0001	0.0291	*ns*	*ns*
Egg weight group, g (EWG)				
A	$5.18^{d} \pm 0.09$	57.02 ± 0.51	$5.08^{a} \pm 0.26$	9.44 ± 0.07
B	$5.76^{c} \pm 0.04$	56.12 ± 0.30	$4.46^{ab} \pm 0.12$	9.49 ± 0.07
C	$6.35^{b} \pm 0.07$	57.02 ± 0.51	$4.18^{b} \pm 0.13$	9.43 ± 0.06
D	$6.86^{a} \pm 0.08$	56.35 ± 0.54	$4.62^{ab} \pm 0.17$	9.42 ± 0.08
P value	<.0001	*ns*	0.0052	*ns*

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; AW – Albumen weight; AR – Albumen ratio; AI – Albumen index; ApH –Albumen pH; *ns*–non-significant; A – ≤ 10 g; B – 10.01–11.00 g; C – 11.01–12.00 g; D – 12.01–13.00 g; [abcd] Means with different superscripts within the same column are significantly different at $P < 0.05$.

In addition, the research carried out by Taha et al. (2019) noted the same trend of decreasing albumen index during 10 days of storage (from 52.79% at the day 0 to 49.73% on day 10), like our experiments. According to Hassan et al. (2017), fresh eggs have a higher albumen index than older eggs. The data regarding albumen pH presented in Table 3 revealed significant differences in pH with the storage duration. The pH of the egg albumen increased from 9.08 to 9.87 by day 21, but after storage for 28 days the pH value decreased to 8.91. Albumen naturally becomes more alkaline (higher pH) as they age due to the loss of carbon dioxide and changes in the way proteins interact (Kocetkovs et al., 2022). This makes the albumen runnier, but it does not necessarily mean the egg is bad. Our results are consistent with those presented by Carvalho et al. (2023), who reported that at the beginning of the experiment (day 0) the eggs had an average pH of 8.69, reaching the highest albumen pH value on the 20th day of storage, decreasing in sequence, and at the end of the experimental period (day 30) a pH of 9.10 was presented. Adamski et al., (2017) emphasized that the storage duration has influenced the increase in pH even in chicken eggs. On the other hand, Nepomuceno et al. (2014) did not find any effect of storage duration on the albumen pH. Our results regarding the influence of temperature on albumen parameters are presented in Table 3. Statistically significant differences were observed in the decrease in albumen weight from 9.04 g in eggs stored in the refrigerator to 5.83 g in eggs stored at room temperature. The ratio of albumen marked a decrease from 57.06% to 56.23%, in eggs stored in the refrigerator and in room temperature, respectively. The results of our study show that the storage temperature resulted in a decrease in the albumen index (from 4.72% to 4.47%). According to these findings, it can be concluded that the higher storage temperatures lead to increased water evaporation from the egg white through the pores of the eggshell (Carvalho et al., 2023). This dehydration process weakens the protein structure within the albumen, especially ovomucin, which is responsible for the thick, viscous consistency of fresh egg whites. As the albumen loses moisture, it becomes thinner and runnier (Adamski et al., 2017).

Eggs stored at room temperature resulted in lower albumen pH (9.43) compared to eggs stored at refrigerator (9.47). This difference is not statistically significant. Therefore, based on our experimental conditions, storage temperature had a limited effect on albumen pH, whereas Carvalho et al. (2023) observed a more pronounced response in albumen pH change, depending on temperature and storage duration, which are different from those of our experiment. On the other hand, Luo et al. (2020) concluded that the higher the storage temperature, the faster changes the pH value of the albumen chicken eggs ($P < 0.05$). From the results of our study, it is evident that the interaction between storage temperature and storage duration showed a significant effect on albumen weight (g). In the present study, albumen weight (g) decreases from 6.43 to 6.08 g at 4–6 °C. The greatest loss of albumen weight during storage was noted in the 22–24 °C (from 6.43 to 5.71). Contrary to our research, other authors, such as Reski et al. (2024), did not demonstrate the influence of storage temperature and storage duration interaction on changes in egg albumen weight (g). During storage at different temperatures, no significant changes were observed in the albumen ratio and index (Table 3), and as a result, no changes were presented in the HU (Table 5.1). Matos Júnior et al., (2023), has previously observed that that the egg albumen weight (g and %) did not changed significantly ($P > 0.05$) after keeping the quail eggs in different temperatures. The albumen weight (g and %) and index (%) was significantly influenced by the interaction (Table 3.1) of EWG × SD ($P < 0.05$). The greater losses of albumen weight (g) were recorded in group A (14.75%). While the losses of group B, C, D were 2.39, 3.98 and 11.83%, respectively. The results of our research also show a decrease in the albumen index in all groups of eggs (at group A, the albumen index decreased from 7.87 to 4.13%; B from 5.48 to 3.70%; C from 4.55 to 3.66% and at group D from 5.40 to 3.81). Related to the effect of this interaction we did not find any data to compare with our results. The interaction effect of ST × EWG was non-significant on albumen weight (g and %) and index (Table 3.1). Regarding the albumen parameters, the interaction ($P < 0.05$) between SD × ST × EWG were observed for albumen weight (g and %). But this interaction did not show changes in AI and ApH.

Table 3.1. The effect of the interaction of all factors on egg albumen parameters

Treatments	Parameters			
	AW, gr	AR, %	AI, %	ApH
SD × ST	0.0288	*ns*	*ns*	<.0001
SD × EWG	0.0016	<.0001	<.000	*ns*
ST × EWG	*ns*	*ns*	*ns*	*ns*
SD × ST × EWG	0.0283	0.0081	*ns*	*ns*

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; AW – Albumen weight; AR – Albumen ratio; AI – Albumen index; ApH – Albumen pH; *ns* – non-significant.

The quality of egg yolk parameters is shown on Table 4. All egg yolk parameters were negatively affected ($P < 0.05$) by increase in storage time.

Table 4. Effect of SD, ST and EWG on egg yolk parameters (Mean ± SEM)

Treatments	Parameters				
	YW, g	YR, %	YH, mm	YI, %	YpH
Storage duration, day (SD)					
0	$3.15^{ab} \pm 0.07$	$29.13^{b} \pm 0.5$	$10.84^{a} \pm 0.11$	$46.80^{a} \pm 0.40$	$6.29^{c} \pm 0.03$
7	$3.44^{a} \pm 0.09$	$32.40^{a} \pm 0.4$	$10.40^{a} \pm 0.11$	$44.15^{ab} \pm 0.77$	$6.65^{b} \pm 0.08$
14	$3.22^{ab} \pm 0.09$	$31.01^{a} \pm 0.5$	$10.13^{b} \pm 0.08$	$42.04^{bc} \pm 0.64$	$7.16^{a} \pm 0.05$
21	$3.35^{ab} \pm 0.06$	$32.39^{a} \pm 0.4$	$10.06^{b} \pm 0.11$	$41.24^{bc} \pm 0.64$	$7.17^{a} \pm 0.04$
28	$3.12^{b} \pm 0.09$	$30.60^{ab} \pm 0.$	$9.25^{c} \pm 0.28$	$39.12^{c} \pm 1.30$	$6.35^{c} \pm 0.08$
P value	0.0254	<.0001	<.0001	<.0001	<.0001
Storage Temperature, °C (ST)					
4–6	3.25 ± 0.05	30.72 ± 0.33	$10.46^{a} \pm 0.08$	$44.40^{a} \pm 0.40$	$6.80^{a} \pm 0.06$
20–22	3.27 ± 0.05	31.50 ± 0.31	$9.93^{b} \pm 0.12$	$41.20^{b} \pm 0.64$	$6.68^{b} \pm 0.05$
P value	*ns*	*ns*	0.0002	<.0001	0.0330
Egg weight group, g (EWG)					
A	$2.79^{d} \pm 0.06$	30.81 ± 0.55	$9.73^{b} \pm 0.20$	43.84 ± 1.05	6.74 ± 0.07
B	$3.22^{c} \pm 0.03$	31.40 ± 0.26	$10.12^{ab} \pm 0.1$	42.75 ± 0.60	6.75 ± 0.07
C	$3.43^{b} \pm 0.05$	30.81 ± 0.50	$10.31^{a} \pm 0.08$	42.22 ± 0.58	6.70 ± 0.08
D	$3.84^{a} \pm 0.05$	31.60 ± 0.43	$10.65^{a} \pm 0.17$	41.86 ± 0.72	6.73 ± 0.08
P value	<.0001	*ns*	0.0004	*ns*	*ns*

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; YW – Yolk weight; YR – Yolk ratio; YH – Yolk height; YI – Yolk index; YpH – Yolk pH; *ns* – non-significant; A – ≤10 g; B – 10.01–11.00 g; C – 11.01–12.00 g; D – 12.01–13.00 g; [abcd]Means with different superscripts within the same column are significantly different at *P* <0.05.

The yolk weight (Table 4) has increased, and significant differences are high, where the average yolk weight (g) increases by 9.20%, 2.22%, 6.35% at the end of days 7, 14 and 21, but decreased by 0.95% at the end of storage (day 28). This effect has previously been discussed by Carvalho et al. (2023) and Adamski et al. (2017). They reported that the yolk weight increased during storage because of water diffusion from albumen through the vitelline membrane into the yolk. But the storage period in their study did not affect yolk weight.

Our study showed that the height of the yolk during the storage period decreased by 1.59 mm or 14.67%, while the yolk index decreased from 46.80 to 39.12. The results of the current study are in line with the findings made by Carvalho et al. (2023) who reported that the storage duration did affect the height and index of the yolk. In terms of YpH value, an increase from 6.29 to 6.65, 7.16, 7.17 and 6.35 was evident (from day 0 to 7, 14, 21 and 28 days, respectively). On the 21st day, the greatest increase in pH was recorded, reaching 13.99%. The results are like those observed by Wlaźlak et al. (2024) who indicate that the increase of yolk pH during storage time (one week), and those changes were significant. Changes in pH increase during the storage period were also evidenced by Altunatmaz et al. (2020), but these changes were not statistically significant, compared to ours.

There were no differences found ($P > 0.05$) in egg yolk weight and yolk ratio because of storage temperature effect. However, the storage temperature showed statistical differences ($P < 0.05$) in egg YH, YI and YpH. Our results showed that the yolk weight and ratio of eggs stored at 20–22 °C were higher (3.27 g and 31.50%) compared to those stored at 4–6 °C (3.25 g and 30.70%), but these changes were not statistically significant. This may have happened due to water diffusion from albumen through the vitelline membrane into the yolk (Carvalho et al., 2023). In our case, a reduction in yolk height (from 10.46 mm to 9.93 mm) contributed to a lower yolk index (from 44.40% to 41.20%), and these changes were statistically significant ($P < 0.05$). Storing eggs at higher temperatures (20–22 °C) resulted in a 1.76% decrease in yolk pH compared to those stored refrigerated (4–6 °C). The egg yolk weight and height were also influenced by EWG ($P < 0.05$), but the YR, YI and YpH were not ($P > 0.05$). The results from this study confirmed that the eggs of grade D had 27.34, 16.15, and 10.68% larger yolk compared to grade A, B, and C eggs, respectively. This supports the concept that larger eggs result in larger yolks. Larger eggs also had greater yolk height. The height of the egg yolk of group D was higher for 8.64, 4.97 and 3.20% than those of group A, B, and C. The results of our study agreed with the findings of Hegab & Hanafy (2019), who recorded the significant differences ($P < 0.0001$) on yolk weight and height. Storage temperature × storage duration interaction (Table 4.1) was not significant on yolk weight but was significant for all other yolk parameters (YR, YH, YI and YpH ($P < 0.05$). The interaction of SD × EWG influenced YW, YR and YH ($P <0.05$), but not YI and YpH ($P > 0.05$). The values of these parameters: YR, YH, YI (%) and YpH did not show statistically significant differences ($P > 0.05$) because of the ST × EWG interaction (Table 4.1), but YW did ($P < 0.05$).

Table 4.1. The effect of the interaction of all factors on egg yolk parameters

Treatments	Parameters				
	YW, g	YR, %	YH, mm	YI, %	YpH
SD × ST	*ns*	0.0195	0.0011	0.0028	<.0001
SD × EWG	0.0001	<.0001	0.0111	*ns*	*ns*
ST × EWG	0.0089	*ns*	*ns*	*ns*	*ns*
SD × ST × EWG	0.0056	0.0033	*ns*	*ns*	*ns*

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; YW – Yolk weight; YR – Yolk ratio; YH – Yolk height; YI – Yolk index; YpH – Yolk pH; *ns* – non-significant.

As a results of the interaction between SD × ST × EWG the values of YW and YR were changed ($P < 0.05$). Apart from this, yolk height, yolk index and yolk pH were not affected ($P > 0.05$) by that. Our study showed that during storage, eggs stored at 4–6 °C had a yolk ratio increase from 29.13 to 30.07, but those stored at 20–22 °C the yolk ratio increased from 29.28 to 31.21. The eggs stored at a lower temperature resulted in a decrease in yolk height from 10.95 to 9.97 mm, while in those stored at a higher temperature, the height decreased from 10.95 to 8.75 mm. Furthermore, the yolk index decreased from 46.85 to 42.41 for the eggs stored at 4–6 °C, and from 46.87 to 36.00 for eggs stored at 20–22 °C. This can happen because the decrease in the height of the yolk affects the increase in the diameter of the yolk and as a result it leads to a decrease in the yolk index. These results are consistent with other researchers (Carvalho et al, 2023), who reported a decrease in yolk height (from 11.04 to 4.24 mm) during storage (30 days) in room temperature from 9.70 to 9.00 mm in eggs stored in refrigerator. Additionally, they also reported that the yolk index decreased from 39.50 to 21.8 for the eggs stored at room temperature, and from 39.90 to 30.50 for the eggs stored in refrigerator. The interaction between EWG × SD influenced the changes (Table 4.1) in yolk weight, yolk ratio and yolk height (P = 0.0001, $P <0.0001$ and P = 0.0111) while no statistically significant changes were observed in the yolk index. The eggs of group A (Table 4) during storage had a much smaller decrease in the weight of the yolk (0.39%) compared to those of groups B (0.61%) and D (2.91%), while the eggs in group C recorded an increase (2.76%) of yolk weight. The interaction of ST × EWG affected only the yolk weight. Eggs of all groups during storage recorded an increase in yolk weight and that of 2.87, 3.18, 3.29 and 3.84 gram at temperature 4–6 °C, and 2.71, 3.26, 3.51 and 3.84 gram at temperature 20–22 °C. While the interaction between of three factors (SD × ST × EWG) showed significantly differences on yolk weight and ratio (P = 0.0056 and P = 0.033).

Table 5. Effect of SD, ST and EWG on YC, Y/A and HU (Mean ± SEM)

Treatments	Parameters		
	YC, Roche	Y/A	HU
SD, day			
0	11.61[a] ± 0.10	49.88[b] ± 1.06	87.43[a] ± 0.67
7	10.66[b] ± 0.16	58.91[a] ± 1.47	83.59[b] ± 0.56
14	10.21[b] ± 0.25	55.18[a] ± 1.32	82.60[b] ± 0.54
21	10.44[b] ± 0.22	58.59[a] ± 1.36	82.28[bc] ± 0.36
28	10.77[b] ± 0.19	54.21[ab] ± 1.47	80.39[c] ± 0.46
P value	<.0001	<.0001	<.0001
ST, °C			
4–6	10.82 ± 0.13	54.30 ± 0.89	83.63 ± 0.43
20–22	10.67 ± 0.12	56.40 ± 0.89	83.06 ± 0.41
P value	*ns*	*ns*	*ns*
EWG, g			
A	10.65 ± 0.20	54.76 ± 1.58	85.07[a] ± 0.63
B	10.49 ± 0.15	56.12 ± 0.73	83.08[b] ± 0.47
C	10.89 ± 0.18	54.49 ± 1.25	81.64[b] ± 0.45
D	11.00 ± 0.19	56.41 ± 1.27	83.44[ab] ± 0.71
P value	*ns*	*ns*	0.0003

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; *ns* – non-significant; YC – Yolk color; Y/A – Yolk/ Albumen ratio; HU – Haugh unit; ApH – Albumen pH; YpH – Yolk pH; A – ≤10 g; B – 10.01–11.00 g; C – 11.01–12.00 g; D – 12.01–13.00 g; [abcd]Means with different superscripts within the same column are significantly different at *P* <0.05.

The results on Table 5 indicate that the yolk color of quail eggs is directly influenced only by storage duration ($P < 0.05$).

The yolk color decreased to 7.23% (from 11.64 to 10.77 Roche scale) with an increase of storage duration. Different solute concentrations in the albumen and the yolk cause different osmotic pressures. During storage, degradation of albumen proteins alters the osmotic balance, and as a result, water moves from the albumen, which has a lower solute concentration, into the yolk, which has a higher solute concentration. From a physiological perspective, this water movement causes stress on the vitelline membrane, weakening it, while simultaneously increasing its permeability. Consequently, yolk pigments become diluted, leading to a reduction in yolk color intensity. This may be due to the rupture or damage of the vitelline membrane, enabling the penetration of water into the egg yolk and thus reducing the intensity of the yolk color (Krisnaningsih et al., 2022¸ Wlaźlak et al., 2024). Our results are in line with Santos et al. (2019) and Lee et al. (2016), who noticed significant differences on yolk color during storage ($P < 0.05$).

In contrast, Grashorn (2016) and Ondrušíková et al. (2018) reported that the yolk color was not affected by storage duration. At the end of our research, we found how different storage temperatures affected the YC. A slightly higher yolk color (1.38%) was observed at eggs stored at low temperature compared to eggs stored at higher temperatures, but this difference was not statistically significant. Lee et al. (2016) reported that the yolk color (7.00, 6.76 and 6.41) significantly decreased ($P < 0.05$)

when temperature increased (2, 12 and 25 °C, respectively). Similarly, no statistically significant differences in yolk color intensity were recorded between EWG.

The interaction of these factors (SD × ST, SD × EWG, ST × EWG and SD × ST × EWG) changed the intensity of the yolk color (Table 5.1) but these changes were very small and statistically non-significant ($P < 0.05$). These results agree with Oshibanjo et al. (2021); Reski et al. (2024), who observed that the yolk color was not significantly different ($P > 0.05$) with storage days both at room and refrigerator temperatures. The results on Table 5 showed that the yolk/albumen ratio was affected by storage duration, and interaction between SD × EWG and SD × PT × EWG interactions too ($P < 0.05$) presented in Table 5.1, but was not influenced by ST, EWG (Table 5) and interactions of SD × ST and SD × PT × EWG ($P > 0.05$) (Table 5.1). This ratio increased by 7.99% during storage. Moreover, this ratio (yolk/albumen) was higher by 3.72% on eggs stored in higher temperatures compared to those stored in lower temperatures, but this difference was not statistically significant. Although yolk/albumen ratio was not affected by EWG (Table 5), but the interaction between SD × EWG ($P < 0.0001$) and SD × ST × EWG (P = 0.0014) effect was observed (Table 5.1). These findings are consistent with results obtained by Hegab & Hanafy (2019), who recorded non-significant Y/A ratio. At the beginning of this study, the yolk/albumen ratio in eggs of group A was 43.34, and at the end of the storage period this ratio increased to 51.54. In the eggs of group B, the increase of this ratio was smaller (from 55.91 to 56.83). The yolk/albumen ratio in eggs of group C had a difference of 3.66 (from 50.11 to 53.77) from the beginning to the end of the experimental period (0–28 days). Group D of eggs had a greater increase (from 50.36 to 55.38) of the yolk/albumen ratio compared to the eggs of group B and C.

Table 5.1. The effect of the interaction of all factors on YC, Y/A and HU

Treatments	Parameters		
	YC,	Y/A	HU
SD × EWG	*ns*	<.0001	<.0001
ST × EWG	*ns*	*ns*	*ns*
SD × PT × EWG	*ns*	0.0014	ns

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; *ns*–nons-ignificant; YC – Yolk color; Y/A – Yolk/Albumen ratio; HU – Haugh unit; ApH – Albumen pH; YpH – Yolk pH.

The mean value of HU (Table 5) was significantly influenced ($P < 0.05$) by SD, EWG and the interaction between SD × EWG (Table 5.1). Our data clearly demonstrates that the Haugh unit of quail eggs is influenced by storage duration. A higher HU was found at the start of the experiment. Even though a decrease of HU was recorded (8.05%) during storage, still the HU of quail eggs was excellent at the end (80.39) of the experimental period. So, a decrease in the albumen index may indicate a decrease in Haugh units. The value of Haugh units in our study are much higher than those reported by Ondrušíková et al. (2018). According to them, the Haugh unit values during the storage period were 66.25, 73.72, 67.57, 66.34, 61.52 and 56.93, respectively (0, 1, 2, 4, 6 and 9 weeks) and were statistically significant. Also, same findings ($P < 0.05$) reported by Martínez et al. (2021), who stored chicken eggs in a room and controlled temperature for ten days. Our study found minimal difference in Haugh unit values between the two egg storage temperatures (83.63 and 83.06), and no statistically significant differences were observed. Results recorded from our study are in contrast with the findings of Wlaźlak et al. (2024), who reported significant influence ($P < 0.05$) of storage temperature on Haugh units. The Haugh unit from smaller eggs (group A) have been shown higher value (2.34, 4.03 and 1.91%) than those of group B, C and D. So, Haugh unit score was significantly different between groups. These results are not consistent with those reported by Hegab & Hanafy (2019), who found that Haugh unit was not significantly influenced ($P > 0.05$) by egg size. Eggs stored at 4 °C for 28 days recorded a lower decrease of Haugh units by 6.98 score, compared to those stored at 20–24 °C (7.69 score of HU). While a decrease in Haugh units was observed during egg storage at both temperatures, the results did not reach statistical significance. Our results are in line with data observed by Reski et al. (2024), finding non-significant effect of storage temperature and duration on Haugh unit. On the other hand, group A and D eggs, stored for 28 days at 4 °C, were characterized by a higher value of Haugh units (84.31) compared to group B and C eggs (83.31 and 82.21, respectively). Eggs from group A stored at 20–24 °C also recorded higher value of Haugh units (85.47 score), compared to those of groups B, C and D (82.67, 80.92 and 82.58, respectively). In both cases the differences were not statistically significant. On the other hand, eggs from group A recorded a statistically higher decrease ($P < 0.05$) of HU (by 9.75 score) at the end of storage period (28 days), compared to those of groups B, C and D (7.97, 4.16 and 7.67, respectively). A comprehensive review of the literature identified no previous studies that directly compared the effect of interaction between SD × EWG on Haugh units of quail eggs. This finding highlights a potential knowledge gap and invites further investigation to find interaction effect between SD × EWG in the Haugh unit of quail eggs.

Table 6. Effect of SD, ST and EWG on eggshell parameters and shape index (Mean ± SEM)

Treatments	Parameters			
	ESW, g	ESR, %	EST, mm	ESI, %
SD, day				
0	1.30 ± 0.03	12.07 ± 0.24	0.38^{a} ± 0.01	80.80 ± 0.58
7	1.29 ± 0.03	12.20 ± 0.21	0.27^{b} ± 0.01	79.19 ± 0.54
14	1.27 ± 0.03	12.39 ± 0.25	0.25^{bc} ± 0.01	78.99 ± 0.63
21	1.24 ± 0.02	11.96 ± 0.18	0.23^{c} ± 0.01	79.40 ± 0.53
28	1.29 ± 0.04	12.65 ± 0.23	0.21^{c} ± 0.01	79.89 ± 0.46
P value	*ns*	*ns*	<.0001	*ns*
ST, °C				
4–6	1.29 ± 0.02	12.22 ± 0.15	0.28 ± 0.01	79.52 ± 0.34
20–22	1.27 ± 0.02	12.27 ± 0.13	0.26 ± 0.01	79.80 ± 0.37
P value	*ns*	*ns*	*ns*	*ns*
EWG, g				
A	1.10^{c} ± 0.02	12.18 ± 0.18	0.25 ± 0.01	80.49^{a} ± 0.40
B	1.28^{b} ± 0.01	12.48 ± 0.15	0.28 ± 0.01	80.14^{a} ± 0.37
C	1.35^{b} ± 0.02	12.16 ± 0.20	0.28 ± 0.01	79.24^{ab} ± 0.56
D	1.47^{a} ± 0.03	12.08 ± 0.28	0.27 ± 0.01	78.13^{b} ± 0.65
P value	<.0001	*ns*	*ns*	0.0085

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; *ns* – non-significant; ESW – Eggshell weight; ESR – Eggshell ratio; EST – Eggshell thickness; ESI – Egg shape index; A – ≤10 g; B – 10.01–11.00 g; C – 11.01–12.00 g; D – 12.01–13.00 g; [abcd]Means with different superscripts within the same column are significantly different at $P < 0.05$.

Table 6 shows the results of the eggshell parameters, egg shape index and the impact of storage duration, storage temperature, egg weight group and the effect interactions of all factors, on the eggshell parameters presented in Table 6.1.

The ESW was affected only by EWG and SD × ST interaction ($P < 0.05$). Whereas ESR was affected only by the interaction between SD × ST and SD × EWG ($P < 0.05$). The SD and interaction between SD × ST were the only ones that showed significant effect on EST (mm) ($P < 0.05$). Lastly, the ESI was affected by EWG, the interaction between SD × ST and the one between SD × PT × EWG ($P < 0.05$).

Table 6.1. The effect of the interaction of all factors on eggshell parameters and shape index

Treatments	Parameters			
	ESW, g	ESR, %	EST, mm	ESI, %
SD × ST	0.0002	0.0038	<.0001	0.0004
SD × EWG	*ns*	0.00371	*ns*	*ns*
ST × EWG	*ns*	*ns*	*ns*	*ns*
SD × PT × EW	*ns*	*ns*	*ns*	0.0024

SD – Storage duration; ST – Storage temperature; EWG – Egg weight group; *ns* – non-significant; ESW – Eggshell weight; ESR – Eggshell ratio; EST – Eggshell thickness; ESI – Egg shape index.

Regardless of how long and at what temperature the eggs are stored, the eggshell weight and the egg shape index did not change. The results presented in Table 5 show changes in the thickness of the eggshell and are negatively influenced by storage duration. The eggshell thickness decreased by 0.17 mm or 44.74%. These results partially agree with those found by Grashorn et al. (2016) who reported that the eggshell thickness is significantly affected by storage duration ($P < 0.037$) but not affected by storage temperature (P = 0.225). Our study showed that the larger eggs (group D) had greater eggshell weight (25.17, 12.92 and 8.16%) compared with eggs of group A, B and C, respectively. Eggs from smaller size (group A) had a statistically higher egg shape index for 0.43, 1.55 and 2.93% than those of group B, C and D, respectively.

CONCLUSIONS

Our study investigated how storage duration, storage temperature and egg weight group influence the quality of quail eggs. After carefully analyzing the results of our research, it is evident that the storage duration has a significant impact on the weight loss, internal quality parameters including AW, AI, ApH, HU, YW, YH, YI, YpH, YC, Y/A ratio of quail eggs. Furthermore, the findings of this experiment indicated that variations in storage temperature resulted in alterations in egg weight loss, albumen weight, yolk height, yolk index, and yolk pH. Our research suggests a significant influence of egg size on internal quality factors like albumen weight, albumen index, yolk weight, yolk height and Haugh unit, as well as external characteristics such as egg weight, eggshell weight and shape index. This research also found that the interaction of storage temperature and duration affected egg weight loss, albumen composition (weight and pH), yolk quality and eggshell properties. Storage duration (SD), storage temperature (ST), and egg weight group (EWG) interacted to reduce egg weight, albumen weight, yolk weight, the yolk-to-albumen ratio, and the shape index. Based on all these findings, it can be concluded that by storing quail eggs at the right temperature and for a minimum duration, we can ensure that quail eggs maintain their quality and nutritional benefits, while being safe for consumption. In addition, we suggest further research into how storage conditions and egg size affect the quality of quail eggs.

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