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PHENOTYPIC CORRELATIONS BETWEEN EXTERNAL EGG QUALITY TRAITS IN NATIVE DUCKS AND GEESE

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ABSTRACT

The aim of this research was to evaluate the phenotypic correlations between external egg quality traits in native duck and goose populations reared in Bosnia and Herzegovina. In the native ducks considered, the average egg weight, shape index, shell weight, shell ratio, and shell thickness were 75.21 g, 70.84%, 6.47 g, 8.61%, and 0.34 mm, respectively. In the native geese considered, these traits averaged 163.31 g, 64.34%, 18.21 g, 11.20%, and 0.58 mm, respectively. The correlation analysis revealed that the egg weight was significantly and positively associated with the geometric mean diameter and shell weight in both species (p < 0.05), whereas its correlations with the shape index and sphericity were non-significant (p > 0.05). Moreover, the shape index was significantly and positively correlated with the sphericity (p < 0.05), while both traits exhibited non-significant and negative correlations with the shell weight, shell ratio, and shell thickness (p > 0.05). The shell thickness was significantly and positively correlated with the shell weight and shell ratio in both species (p < 0.05), but largely independent of geometric traits, except in the ducks, where a positive association with the geometric mean diameter was observed. The shell density showed no significant correlation with the egg weight in either species (p < 0.05), whereas the egg weight was significantly positively correlated with the shell weight per unit surface area in the ducks (p < 0.05). These results indicate that geometric traits primarily determine egg weight, while shell quality traits are partially independent of egg size. The findings provide valuable data on the external egg quality traits and their interrelationships in the native ducks and geese considered, offering useful insights for the selection and improvement of their productive traits, particularly within small-scale and extensive poultry systems.

Key words:
native duck, native goose, eggshell quality, phenotypic correlation

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INTRODUCTION

Ducks and geese represent traditionally reared poultry species in Bosnia and Herzegovina, although their meat and eggs account for only a minor share of the country's commercial poultry production. In addition to their role in household production, both species are also kept for ornamental purposes. The population structure is dominated by local, non-standardized types that have arisen through long-term spontaneous selection, resulting in pronounced variability in external traits and production performance (Milošević and Perić, 2011). The native duck is a medium-sized, dual-purpose type, with males averaging approximately 2.5 kg and females around 2.0 kg, and an annual egg production of 60–80 eggs with an average egg weight of 65–80 g. The native goose is primarily reared for meat and feather production, with an adult body weight of around 5 kg and an annual egg production of up to 25 eggs, averaging 130–150 g. Both native ducks and geese are considered hardy birds, characterized by modest housing, feeding, and management requirements, which makes them well adapted to extensive and semi-intensive production systems.

The eggshell plays a fundamental role in protecting egg contents from external influences and in providing the conditions necessary for normal embryonic development and successful hatching. Consequently, it represents an important subject of research across all poultry species. Egg geometric parameters include shape index, geometric mean diameter, surface area, sphericity, and volume. Among these, the shape index is most frequently applied to describe egg shape, and its influence on incubation success has been documented (Mitrovic et al., 2017). Geometric parameters are also used in predicting eggshell quality (Wang et al., 2021) and in analyzing the mechanical properties of eggs (Zhang et al., 2017; El Helew et al., 2023).

Eggshell quality is most commonly evaluated using shell weight, shell ratio, and shell thickness. In ducks, eggshell and overall egg quality can be influenced by genotype (Kralik et al., 2015; Galić et al., 2017), age of the laying bird (Sulaiman et al., 2023), laying period (Okruszek et al., 2006), rearing system (Shoimah et al., 2019; Shi et al., 2022), and egg weight (Onbaşılar et al., 2011; Ipek and Sozcu, 2017; Dassidi et al., 2022). Similar effects have been reported in geese, where genotype (Karabulut, 2021; Yurtseven et al., 2024), rearing system (El-Hanoun et al., 2012; Djermanovic et al., 2024), egg weight (Boğa Kuru and Kırmızıbayrak, 2024), laying period (Mazanowski and Adamski, 2006), and age of the laying bird (Adamski et al., 2016) have been shown to affect egg weight and shell quality traits.

Phenotypic correlations between egg weight and quality traits have been reported in Shan Ma ducks (Lin et al., 2016), local and standard duck breeds (Bondoc et al., 2021), and Pengging ducks (Hartati et al., 2024). Relationships between egg dimensions and the weight of major egg components have been examined in Alabio ducks (Hartati et al., 2021). Comparable studies in geese include analyses of Zatorska geese (Rabsztyn et al., 2010), White Kołuda geese (Biesiada-Drzazga et al., 2015), and native geese from the Kars region (Saatçi et al., 2002; Boğa Kuru and Kırmızıbayrak, 2024). Differences in egg quality traits and their phenotypic correlations have also been reported by Amin et al. (2019) and Wang et al. (2021). Collectively, these studies demonstrate significant associations among egg quality traits, which are relevant for selecting hatching eggs and improving laying performance and egg quality across breeds and populations. However, research on these relationships in ducks and geese remains far less developed than in chickens.

The aim of this study was to analyze the phenotypic correlations between external egg quality traits in native duck and goose populations in Bosnia and Herzegovina.

MATERIAL AND METHODS

Eggs were collected from a single flock of native ducks and a single flock of native geese, both reared on the same farm located in the northern region of Bosnia and Herzegovina. The flocks were managed separately under a semi-intensive system and housed indoors, with access during the laying season to pasture. Their diet consisted primarily of a grain mixture, supplemented occasionally with household food residues. The birds were exposed to natural light and were not treated with medications before and during the laying period.

Eggs were sampled during the first two months of the laying season, with 100 eggs analyzed from the native ducks and 100 from the native geese. Egg weight was measured using a technical scale (precision: 0.01 g), whereas egg length and egg width were recorded using a digital micrometer (precision: 0.01 mm). Eggshell weight was determined with a technical scale (precision: 0.01 g), following washing and air-drying of shells at room temperature for 24 hours. Shell thickness, including shell membranes, was measured using a digital micrometer (precision: 0.01 mm). Thickness was determined at the blunt, equatorial, and sharp regions, with five replicate measurements taken per region. The regional mean was used as the representative value.

Previously established formulas (Boğa Kuru et al., 2023; Boğa and Kırmızıbayrak, 2024) were used to calculate egg shape index (%), sphericity (%), geometric mean diameter (mm), shell ratio (%), shell thickness (mm), shell density (g/cm³), and shell weight per unit surface area (mg/cm²).

Descriptive statistics (mean, minimum, maximum, standard deviation, and coefficient of variation) were calculated for all the traits. Pearson's correlation coefficients (r) were determined to assess the phenotypic associations between external egg quality traits. All statistical analyses were performed using R software.

RESULTS AND DISCUSSION

Descriptive analysis of the egg quality traits in the native ducks
The descriptive statistics for the external egg quality traits in the native ducks are presented in Table 1.

Table 1. External egg quality traits in the native ducks

Quality traits	Mean	Min	Max	SD	CV (%)
Egg weight, g	75.21	56.87	89.18	7.04	9.36
Egg length, mm	65.29	58.4	75	3.03	4.64
Egg width, mm	46.19	40.5	49.85	1.64	3.54
Shape index, %	70.84	61.73	78.56	3.04	4.29
Sphericity, %	79.45	72.5	85.14	2.28	2.87
Geometric mean diameter, mm	51.83	45.76	54.95	1.74	3.35
Shell weight, g	6.47	4.55	8.26	0.77	11.87
Shell ratio, %	8.61	6.86	11.07	0.75	8.66
Shell thickness of sharp region, mm	0.33	0.26	0.42	0.03	10.22
Shell thickness of equatorial region, mm	0.37	0.29	0.44	0.03	9.05
Shell thickness of blunt region, mm	0.32	0.25	0.39	0.03	9.53
Overall shell thickness, mm	0.34	0.27	0.41	0.03	8.73
Shell density, g/cm^3	2.24	1.91	2.46	0.09	4.16
Shell weight per unit surface area, mg/cm^2	76.51	58.23	95.96	6.7	8.76

Legend: Min – Minimal value; Max – Maximum value; SD – Standard deviation; CV – Coefficient of variation

The mean egg weight recorded in the present study (75.21 g) aligns closely with previously reported values for native ducks (72.70 g) (Vekić et al., 2018), Pekin ducks (75.15 g) (Boğa Kuru et al., 2023), Indian Runner ducks (75.04 g) (Vrbančić and Nervo, 2017), and Rouen and Muscovy ducks (74.77 g and 74.6 g, respectively) (Kralik et al., 2015). Lower values were reported in a local duck population in Iraq (54.75 g) (Amin et al., 2019), Mallard ducks (59.31 g) (Dahloum et al., 2024), Pekin ducks, Cherry Valley ducks (63.88 g and 67.70 g, respectively) (Galić et al., 2019), and Pengging ducks (66.1 g) (Hartati et al., 2024). Such variation across studies may reflect differences in genotype, age of the laying birds, rearing conditions, and environmental factors. The mean egg length and width recorded in this study were 65.29 mm and 46.19 mm, respectively. Similar values for egg length and width in native ducks (63.64 mm and 45.21 mm) were reported by Vekić et al. (2018). Lower values for length and width were reported by Hartati et al. (2024) (56.3 mm, 45.6 mm), Amin et al. (2019) (57.86 mm, 41.90 mm), and Dahloum et al. (2024) (59.20 mm, 42.32 mm).

Based on the egg shape index, eggs can be classified as sharp (<72), normal (72-76), or round (>76) (Duman et al., 2016). The mean shape index obtained in this study was 70.84%, indicating a sharp egg shape in the native ducks. This value is close to those reported for native ducks (71.07%), Mallard ducks (71.56%), Indian Runner ducks (71.64%), and Orpington ducks (72.22%) (Vekić et al., 2018; Dahloum et al., 2024; Vrbančić and Nervo, 2017; Okruszek et al., 2006). Higher values were reported for Khaki Campbell ducks (75.8%) and Pengging ducks (81%) (Nageswara et al., 2005; Hartati et al., 2024). The differences observed across studies may be attributed to the breed, age of laying birds, rearing system, and egg weight, which varied among the examined populations.

The mean eggshell weight in this study was 6.47 g, which is comparable to values reported for native ducks (6.21 g) (6.21 g) (Vekić et al., 2018). Lower values were observed in local duck populations in Iraq (5.61 g) (Amin et al., 2019) and in Mallard ducks (6.15 g) (Dahloum et al., 2024), whereas higher values were recorded in Rouen, Pekin, and Muscovy ducks (8.23 g, 9.29 g, and 8.52 g, respectively) (Kralik et al., 2015). The mean eggshell ratio was 8.61%, which is consistent with the values reported for native ducks (8.57%) (Vekić et al., 2018) and Pekin ducks (8.53%) (Boğa Kuru et al., 2023). Higher ratios were recorded for Rouen, Pekin, and Muscovy ducks (11.01%, 11.98%, and 11.41%, respectively) (Kralik et al., 2015), while a lower ratio was reported for Orpington ducks (7.85%) (Okruszek et al., 2006). The variations in eggshell weight and ratio across studies may be attributed to differences in the breed, age of laying birds, egg weight, and rearing system.

The mean shell thickness at the blunt, equatorial, and sharp ends was 0.32, 0.37, and 0.33 mm, respectively. Comparable values were reported in Muscovy ducks (0.35, 0.36, and 0.36 mm, respectively) (Fu et al., 2023), whereas higher thickness values were recorded in Pekin ducks (0.435, 0.451, and 0.476 mm, respectively) (Balkan and Biricik, 2006). The overall mean shell thickness of 0.34 mm was in agreement with previously reported values for several genotypes, including native duck (0.35 mm), Cherry Valley (0.336 mm), Khaki Campbell (0.349 mm), and Pekin duck (0.379 mm) (Vekić et al., 2018; Galić et al., 2019; Nageswara et al., 2005; Boğa Kuru et al., 2023). Higher values were reported in Indian Runner ducks (0.44 mm) (Vrbančić and Nervo, 2017) and Orpington ducks (0.65 mm) (Okruszek et al., 2006). As the shell thickness is influenced by the breed, age, nutrition, rearing conditions, and egg weight, these factors likely explain the observed differences among studies.

In this study, the mean shell density and shell weight per unit surface area were 2.24 g/cm³ and 76.51 mg/cm², respectively. Higher values for shell density were reported in Pekin ducks (3.17 g/cm³) and Cherry Valley ducks (2.85 g/cm³) (Galić et al., 2019), while higher values for shell weight per unit surface area were observed in Muscovy ducks across the first three laying seasons (92.33, 90.91, and 91.05 mg/cm², respectively) (Paci et al., 1991).

Correlation analysis of the egg quality traits in the native ducks

Table 2 shows the phenotypic correlations between the external egg quality traits in the native ducks.

Table 2. Coefficients of the phenotypic correlations (r) between the external egg quality traits in the native ducks

Quality traits	EL	EW	ESI	S	Dg	SW	SR	ST	SD	SWUSA
EM	0.74*	0.88*	-0.06	-0.06	0.96*	0.70*	-0.12	0.24*	-0.06	0.22*
EL		0.45*	-0.68*	-0.68*	0.78*	0.55*	-0.05	0.19	-0.10	0.15
EW			0.34*	0.34*	0.91*	0.62*	-0.11	0.19	-0.09	0.15
ESI				0.99*	-0.07	-0.08	-0.03	-0.06	0.05	-0.04
S					-0.08	-0.08	-0.03	-0.06	0.05	-0.04
Dg						0.69*	-0.10	0.22*	-0.11	0.18
SW							0.62*	0.78*	0.12	0.84*
SR								0.81*	0.24*	0.92*
ST									-0.23*	0.89*
SD										0.24*

Legend: EM – Egg weight; EL – Egg length; EW – Egg width; ESI – Shape index; S – Sphericity; Dg – Geometric mean diameter; SW – Shell weight; SR – Shell ratio; ST – Shell thickness; SD – Shell density; SWUSA – Shell weight per unit surface area; * $p < 0.05$

The egg weight showed a significant ($p < 0.05$) and positive phenotypic correlation with both the egg length ($r = 0.74$) and egg width ($r = 0.88$). This is consistent with previous results reported for native ducks (Vekić et al., 2018), Pengging ducks (Hartati et al., 2024), Mallard ducks (Dahloum et al., 2024), and native ducks in Iraq (Amin et al., 2019). In contrast, the egg weight was non-significantly ($p > 0.05$) and negatively correlated with the egg shape index (-0.06). Similar patterns have been reported in native ducks (Vekić et al., 2018), Pengging ducks (Hartati et al., 2024), and Mallard ducks (Dahloum et al., 2024), whereas Lu et al. (2020) observed a significant and positive correlation between the egg weight and egg shape index in Leizhou Black Duck.

The correlation between the egg weight and sphericity observed (-0.06) was non-significant ($p > 0.05$), while a significant ($p < 0.05$) and positive correlation (0.96) was found with the geometric mean diameter. Comparable results have been reported for Jinding and Shaoxing ducks, where the egg weight showed a non-significant correlation with the sphericity in Jinding ducks and a significant negative correlation in Shaoxing ducks, while in both breeds the correlation between the egg weight and geometric mean diameter was significant and positive (Wang et al., 2021).

The egg weight was significantly ($p < 0.05$) and positively correlated with the shell weight (0.70), while its correlation with the shell ratio was non-significant ($p > 0.05$) and negative (-0.12). Previous studies also confirm that egg weight has a significant positive relationship with shell weight (Amin et al., 2019; Bondoc et al., 2021; Boğa Kuru et al., 2023; Dahloum et al., 2024). Conversely, the relationship between egg weight and shell ratio showed some inconsistencies, with some studies reporting a significant negative correlation (Bondoc et al., 2021), while others found a significant positive correlation (Boğa Kuru et al., 2023).

In this study, the egg weight was significantly ($p < 0.05$) and positively correlated with the shell thickness (0.24). A similar relationship was previously confirmed in native ducks (Vekić et al., 2018), while the opposite findings were reported by Amin et al. (2019), Bondoc et al. (2021), and Boğa Kuru et al. (2023). Furthermore, the egg weight showed a non-significant ($p > 0.05$) and negative correlation with the shell density (-0.06), whereas a significant ($p < 0.05$) and positive correlation (0.22) was found with the shell weight per unit surface area. Contrary to this, Boğa Kuru et al. (2023) reported a significant and positive correlation between the egg weight and shell density in Pekin ducks.

A significant ($p < 0.05$) and positive correlation (0.45) was found between the egg length and egg width, which is consistent with previous findings in native ducks (Vekić et al., 2018), native ducks in Iraq (Amin et al., 2019), and Mallard ducks (Dahloum et al., 2024). The egg width showed a significant ($p < 0.05$) and positive phenotypic correlation with the shape index (0.34), whereas the egg length was significantly ($p < 0.05$) and negatively correlated with this trait (-0.68). Similar patterns of phenotypic correlations were reported in native ducks (Vekić et al., 2018) and Mallard ducks (Dahloum et al., 2024).

The shell weight was significantly ($p < 0.05$) and positively correlated with both the egg length (0.55) and egg width (0.62). These results are consistent with previous findings in native ducks (Vekić et al., 2018), Mallard ducks (Dahloum et al., 2024), and Pengging ducks (Hartati et al., 2021). Conversely, in native ducks from Iraq (Amin et al., 2019) and Pekin ducks (Boğa Kuru et al., 2023), a significant positive association with shell weight was observed only for egg width.

The shell ratio showed a non-significant ($p > 0.05$) and negative correlation with both the egg length (-0.05) and egg width (-0.11). Similar findings were previously reported in native ducks (Vekić et al., 2018). In contrast, in Pekin ducks, both the egg length and width were significantly and positively correlated with the shell ratio (Boğa Kuru et al., 2023).

The egg length and width showed a non-significant ($p > 0.05$) and positive correlation with the shell thickness (0.19). In previous studies on native ducks, only egg width was significantly and positively correlated with shell thickness (Vekić et al., 2018). Conversely, in Pekin ducks, a significant and negative correlation between shell thickness and both egg length and width was reported (Boğa Kuru et al., 2023), while in native ducks in Iraq, these correlations were non-significant (Amin et al., 2019).

The egg length and width showed a non-significant ($p > 0.05$) and negative correlation with the shell density (-0.10; -0.09), but non-significant ($p > 0.05$) and positive correlations with shell weight per unit surface area (both $r = 0.15$). In contrast, in Pekin ducks only egg width was significantly and negatively correlated with shell density (Boğa Kuru et al., 2023).

The egg shape index showed non-significant ($p > 0.05$) and negative correlations with the geometric mean diameter (-0.07), shell weight (-0.08), shell ratio (-0.03), shell thickness (-0.06), and shell weight per unit surface area (-0.04). A non-significant and positive correlation with shell density ($r = 0.05$) was observed. The shape index was significantly and positively correlated with the sphericity ($p < 0.05$; $r = 0.99$). Wang et al. (2021) similarly reported a significant positive correlation between shape index and both sphericity and geometric mean diameter in Shaoxing ducks. The correlations of the shape index with the shell weight and ratio were also non-significant in native ducks (Vekić et al., 2018), whereas in Pekin ducks these correlations were significant and positive (Boğa Kuru et al., 2023). Furthermore, the shape index was significantly and positively correlated with the shell thickness in native ducks (Vekić et al., 2018), while Pekin ducks showed a significant negative correlation between these traits (Boğa Kuru et al., 2023). Additionally, the shape index was significantly and negatively correlated with the shell density in Pekin ducks (Boğa Kuru et al., 2023).

The sphericity measured showed a non-significant ($p > 0.05$) and negative correlation with the geometric mean diameter (-0.08), shell weight (-0.08), shell ratio (-0.03), shell thickness (-0.06), and shell weight per unit of surface (-0.04). Its correlation with the shell density ($r = 0.05$) was non-significant and positive. The geometric mean diameter was significantly ($p < 0.05$) and positively correlated with the egg length (0.78), egg width (0.91), shell weight (0.69), and shell thickness (0.22), while it showed a non-significant and negative correlation with the shell ratio (-0.10) and shell density (-0.11). Wang et al. (2021) reported that correlations of sphericity with geometric mean diameter, shell weight, and shell thickness were non-significant, whereas according to Boğa Kuru et al. (2023), sphericity and geometric mean diameter showed significant and positive correlations with shell weight and ratio. Furthermore, Wang et al. (2021) reported a significant and positive correlation of geometric mean diameter with shell weight, while Boğa Kuru et al. (2023) found that sphericity was significantly and negatively correlated with shell thickness and shell density, and that geometric mean diameter was significantly and negatively correlated with shell density.

The shell weight and shell ratio showed a significant ($p < 0.05$) and positive phenotypic correlation (0.62). Additionally, the shell thickness was significantly ($p < 0.05$) and positively correlated with the shell weight (0.78) and shell ratio (0.81). Similar correlations were previously confirmed in native ducks (Vekić et al., 2018). In contrast, Amin et al. (2019) did not find a significant relationship between shell weight and thickness in native ducks from Iraq. In this study, the shell weight showed a non-significant ($p > 0.05$), but positive correlation with the shell density (0.12), and a significant ($p < 0.05$) and positive correlation with the shell weight per unit of surface area (0.84). The shell ratio was significantly ($p < 0.05$) and positively correlated with the shell density (0.24) and shell weight per unit of surface area (0.92). The shell thickness showed a significant ($p < 0.05$) and negative correlation with shell density (-0.23), while it was significantly ($p < 0.05$) and positively correlated with the shell weight per unit of surface area

(0.89). A significant ($p < 0.05$) and positive phenotypic correlation (0.24) was found between the shell density and shell weight per unit of surface area.

Descriptive analysis of egg quality traits in native geese

The results of the descriptive analysis of external egg quality traits in native geese are presented in Table 3.

Table 3. External egg quality traits in native geese

Quality traits	Mean	Min	Max	SD	CV (%)
Egg weight, g	163.31	111.86	219.63	23.39	14.32
Egg length, mm	89.52	79.40	103.20	5.49	6.14
Egg width, mm	57.49	50.60	64.10	2.96	5.15
Shape Index, %	64.34	51.24	71.31	3.36	5.22
Sphericity, %	74.51	64.03	79.82	2.61	3.50
Geometric mean diameter, mm	66.61	58.80	73.79	3.25	4.88
Shell weight, g	18.21	12.00	27.00	2.75	15.10
Shell ratio, %	11.20	7.36	14.35	1.23	11.00
Shell thickness of sharp region, mm	0.58	0.34	0.75	0.07	11.96
Shell thickness of equatorial region, mm	0.62	0.43	0.81	0.06	10.42
Shell thickness of blunt region, mm	0.56	0.40	0.74	0.06	11.10
Overall shell thickness, mm	0.58	0.41	0.75	0.06	10.41
Shell density, g/cm^3	2.23	2.05	2.60	0.09	3.83
Shell weight per unit surface area, mg/cm^2	130.23	87.37	164.78	14.18	10.89

Legend: Min – Minimal value; Max – Maximal value; SD – Standard deviation; CV – Coefficient of variation

The average egg weight of the native geese in the present study was 163.31 g. A lower value for the native geese (156.93 g) was reported by Vekić and Jovičić (2025). Comparable egg weights were found in F1 hybrids (159.9 g) (Mazanowski and Adamski, 2006), whereas lower values were reported for Obroshyn geese (141.64 g) (Fiialovych and Kyryliv, 2016) and Lindovskaya geese (122.09 g) (Sari et al., 2019), and higher values for Grimaud geese (185.44 g) (Brassó et al., 2024) and the White Kołuda breed (194 g) (Biesiada-Drzazga et al., 2015). These variations in egg weight are likely influenced by the breed, age of the laying bird, laying period, and rearing system, which differed among the studies.

The average egg length and width of the native geese in the present study were 89.52 mm and 57.49 mm, respectively. The mean egg shape index was 64.34%, indicating a sharp egg shape according to the reference ranges (Duman et al., 2016). A similar egg shape index was reported for the native geese (65.48%) (Vekić and Jovičić, 2025), while higher values were observed in native geese from Turkey (68.18-70.98%) (Akın and Çelen, 2022), and a lower value was found in Obroshyn geese (60.00%) (Fiialovych and Kyryliv, 2016).

The average values of sphericity and geometric mean diameter were 74.51% and 66.61 mm, respectively, comparable to values reported for the native geese (75.39% and 65.71 mm) (Vekić and Jovičić, 2025). Higher values of sphericity were reported for Turkish Native Geese (77.08%) (Boğa Kuru and Kırmızıbayrak, 2024), and Taihu and Zhedong White Geese (77.13 and 77.32%, respectively) (Wang et al., 2021), while lower values of geometric mean diameter were found for Taihu and Zhedong White Geese (58.39 and 62.77 mm, respectively) (Wang et al., 2021). These differences are likely associated with variations in egg weight across the studies.

The average eggshell weight in the present study was 18.21 g, comparable to values reported for the native geese (17.89 g) (Vekić and Jovičić, 2025) and Grimaud geese (18.88 g) (Brassó et al., 2024), whereas higher values were observed in native geese in Turkey (22.06-22.74 g) (Akın and Çelen, 2022).

The average eggshell ratio in the present study was 11.20%, which is comparable to values reported for several genotypes: native geese (11.43%), F1 hybrids (11.5%), Graylag goose crossbreds (11.3%), and four regional varieties in Poland (11.8-12.3%) (Vekić and Jovičić, 2025; Mazanowski and Adamski, 2006; Mazanowski and Bernacki, 2006; Mazanowski et al., 2005). Lower values were observed in Grimaud geese (10.18%) (Brassó et al., 2024), whereas higher values were reported for native geese in Turkey (15.00-15.83%) (Akın and Çelen, 2022).

The average shell thickness measured at the sharp, equatorial, and blunt regions of the egg was 0.58, 0.62 and 0.56 mm, respectively. These variations in the shell thickness depending on the region of the shell are consistent with the findings by Zhang et al. (2017) on the geometric and mechanical properties of goose eggshells. Comparatively, Grimaud geese showed higher thickness values at the sharp, equatorial, and blunt ends (0.69, 0.65, and 0.61 mm, respectively) (Brassó et al., 2024), while the White Kołuda breed showed lower values (0.53, 0.47, and 0.50 mm, respectively) (Biesiada-Drzazga et al., 2015). The average overall shell thickness in this study was 0.58 mm, aligning with previously reported values for native geese (0.59 mm), F1 hybrids (0.567 mm), and four regional varieties in Poland (0.552-0.595 mm) (Vekić and Jovičić, 2025; Mazanowski and Adamski, 2006; Mazanowski et al., 2005). Lower and higher values were observed in the White Kołuda breed (0.50 mm) and native geese in Turkey (0.72 mm), respectively (Biesiada-Drzazga et al., 2015; Saatçi et al., 2002).

The average shell density and shell weight per unit of egg surface area were 2.23 g/cm³ and 130.23 mg/cm², respectively. These values closely match those reported for native geese (2.24 g/cm³ and 131.30 mg/cm²) (Vekić and Jovičić, 2025). Lower values were recorded for shell weight per unit surface area in Lindovskaya geese (122.54 mg/cm²) (Sari et al., 2019) and for shell density in Grimaud geese (2.03 g/cm³), Lindovskaya geese (2.08 g/cm³), and F1 hybrids (2.103 g/cm³) (Brassó et al., 2024; Sari et al., 2019; Mazanowski and Adamski, 2006).

Correlation analysis of egg quality traits in native goose

Table 4 shows the phenotypic correlations between external egg quality traits in native geese.

Table 4. Coefficients of the phenotypic correlations (r) between external egg quality traits in native goose

Quality traits	EL	EW	ESI	S	Dg	SW	SR	ST	SD	SWUSA
EM	0.82*	0.93*	-0.05	-0.05	0.99*	0.72*	-0.32*	0.08	0.09	0.10
EL		0.56*	-0.61*	-0.61*	0.81*	0.64*	-0.18	0.03	0.15	0.17
EW			0.31*	0.32*	0.94*	0.60*	-0.11	0.04	-0.14	-0.02
ESI				0.99*	-0.03	-0.16	-0.17	0.01	-0.13	-0.20
S					-0.03	-0.16	-0.17	0.01	-0.14	-0.21
Dg						0.69*	-0.35*	0.04	0.06	0.05
SW							0.42*	0.70*	0.27*	0.76*
SR								0.86*	0.25*	0.91*
ST									-0.03	0.94*
SD										0.32*

Legend: EM – Egg weight; EL – Egg length; EW – Egg width; ESI – Shape index; S – Sphericity; Dg – Geometric mean diameter; SW – Shell weight; SR – Shell ratio; ST – Shell thickness; SD – Shell density; SWUSA – Shell weight per unit surface area; * $p < 0.05$

The egg weight showed a significant ($p < 0.05$) and positive correlation with both the egg length (r = 0.82) and egg width (r = 0.93). Similar patterns have been reported in Zatorska geese (Rabsztyn et al., 2010), indigenous geese in Bangladesh (Islam et al., 2016), and native geese in Iraq (Amin et al., 2019). In contrast, the egg weight in the White Kołuda breed was found to be significantly and positively correlated only with the egg length (Biesiada-Drzazga et al., 2015).

The egg weight and egg shape index showed a non-significant ($p > 0.05$) and negative correlation (-0.05). Similar results have been reported for Zatorska geese (Rabsztyn et al., 2010) as well as for Taihu and Zhedong White geese (Wang et al., 2021). In contrast, a significant and positive correlation between the egg weight and shape index was observed in native geese in Turkey (Saatçi et al., 2002) and Italian White geese (Mitrovic et al., 2017). The correlation between egg weight and sphericity was also non-significant ($p > 0.05$) and negative (-0.05), whereas a significant ($p < 0.05$) and positive correlation (0.99) was found between the egg weight and geometric mean diameter. Comparable correlation patterns have been reported in Taihu and Zhedong White geese (Wang et al., 2021).

The egg weight and shell weight showed a significant ($p < 0.05$) and positive correlation (0.72), whereas the egg weight was significantly and negatively correlated with the shell ratio ($p < 0.05$; -0.32). A similar association between egg weight and shell weight has been previously reported in various goose populations (Saatçi et al., 2002; Amin et al., 2019; Boğa Kuru and Kırmızıbayrak, 2024). In contrast, Biesiada-Drzazga et al. (2015) did not observe a significant relationship between the egg weight and shell weight, while Boğa Kuru and Kırmızıbayrak (2024) reported a positive correlation between the egg weight and shell ratio.

The egg weight exhibited non-significant ($p > 0.05$) and positive correlations with the shell thickness (0.08), shell density (0.09), and shell weight per unit surface area (0.10). Previous studies have reported variable relationships between goose egg weight and shell thickness: some found a significant negative correlation (Boğa Kuru and Kırmızıbayrak, 2024), others a significant positive correlation (Amin et al., 2019), while several studies observed no statistically significant association (Saatçi et al., 2002; Biesiada-Drzazga et al., 2015).

The egg length and width were significantly ($p < 0.05$) and positively correlated (0.56), consistent with the findings in Zatorska geese, White Kołuda geese, and indigenous geese in Bangladesh (Rabsztyn et al., 2010; Biesiada-Drzazga et al., 2015; Islam et al., 2016). Furthermore, the egg length showed a significant ($p < 0.05$) and negative correlation with the shape index (-0.61), whereas the egg width was significantly ($p < 0.05$) and positively correlated with this trait (0.31), in agreement with the results reported for Zatorska geese (Rabsztyn et al., 2010).

The eggshell weight showed significant ($p < 0.05$) and positive correlations with the egg length (0.64) and egg width (0.60). Similar associations have been reported in native goose populations in Iraq (Amin et al., 2019) and Turkey (Boğa Kuru and Kırmızıbayrak, 2024). In contrast, no significant correlation between these traits was observed in the White Kołuda breed (Biesiada-Drzazga et al., 2015).

The eggshell ratio showed a non-significant ($p > 0.05$) and negative correlation with the egg length (-0.18), whereas its correlation with the egg width was significant ($p < 0.05$) and negative (-0.11), which in contrast with the significant and positive correlation reported by Boğa Kuru and Kırmızıbayrak (2024).

The shell thickness exhibited non-significant ($p > 0.05$) and positive correlations with the egg length (0.03) and egg width (0.04). These results are consistent with the findings of Biesiada-Drzazga et al. (2015), but differ from those of Boğa Kuru and Kırmızıbayrak (2024), who reported significant negative correlations. Amin et al. (2019) found that only the egg width was significantly and positively correlated with the shell thickness.

The egg length was non-significantly ($p > 0.05$) and positively correlated with the shell density (0.15) and shell weight per unit surface area ($p > 0.05$; 0.17). The egg width showed non-significant ($p > 0.05$) and negative correlations with the shell density (-0.14) and shell weight per unit surface area (-0.02).

The egg shape index showed a significant ($p < 0.05$) and positive correlation with the sphericity (0.99), which is consistent with the previous findings in Zhedong White geese and Taihu geese (Wang et al., 2021). The shape index showed non-significant ($p > 0.05$) and negative correlations with the geometric mean diameter (-0.03), eggshell weight (-0.16), shell ratio (-0.17), and shell weight per unit surface area (-0.20). The absence of significant associations between these traits has also been confirmed by Saatçi et al. (2002), Wang et al. (2021), and Boğa Kuru and Kırmızıbayrak (2024). Moreover, the shape index was non-significantly ($p < 0.05$) and negatively correlated with the shell density (-0.13).

The sphericity determined exhibited non-significant ($p > 0.05$) and negative correlations with the geometric mean diameter (-0.03), eggshell weight (-0.16), shell ratio (-0.17), shell density (-0.14), and shell weight per unit surface area (-0.21).

The geometric mean diameter was significantly ($p < 0.05$) and positively correlated with the shell weight (0.69), while it showed a negative correlation with the shell ratio (-0.35). These results partially align with the findings of Wang et al. (2021), who reported a significant and positive correlation between the geometric mean diameter and shell weight.

The shell weight showed a significant ($p < 0.05$) and positive correlation with the shell ratio (0.42), shell thickness (0.70), shell density (0.27), and shell weight per unit of surface area (0.76). Previous studies indicate varying patterns of association, ranging from significant positive correlations between shell weight and shell thickness (Amin et al., 2019) to a lack of statistical significance (Saatçi et al., 2002; Biesiada-Drzazga et al., 2015).

The shell ratio was significantly ($p < 0.05$) and positively correlated with the shell thickness (0.86), shell density (0.25), and shell weight per unit surface area (0.91).

The shell thickness showed a non-significant ($p > 0.05$) and negative correlation with the shell density (-0.03), but was significantly ($p < 0.05$) and positively correlated with the shell weight per unit surface area (0.94). Additionally, a significant ($p < 0.05$) and positive phenotypic correlation (0.32) was observed between the shell density and shell weight per unit surface area.

CONCLUSION

The evaluation of phenotypic correlations demonstrated that the egg weight in native ducks and geese was significantly and positively associated with the egg length and width, geometric mean diameter, and shell weight. The shape index exhibited a significant negative correlation with the egg length and a significant positive correlation with the egg width in both species. Additionally, the shape index was significantly and positively correlated with the sphericity, while these two traits showed a non-significant and negative correlation with the shell weight, shell ratio, and shell thickness in native ducks and geese. The shell thickness was in a non-significant correlation with the geometric traits, except in native ducks where a significant positive correlation with the geometric mean diameter was observed. The shell thickness was significantly and positively correlated with the shell weight and shell ratio in both native ducks and geese. The shell density showed a non-significant correlation with the egg weight in native ducks and geese, whereas the egg weight was significantly and positively correlated with the shell weight per unit of surface area in duck eggs. The results of this study show that the external characteristics of shell quality do not always depend on the egg size. This insight may be valuable for developing selection strategies aimed at improving production traits within indigenous duck and goose populations.

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