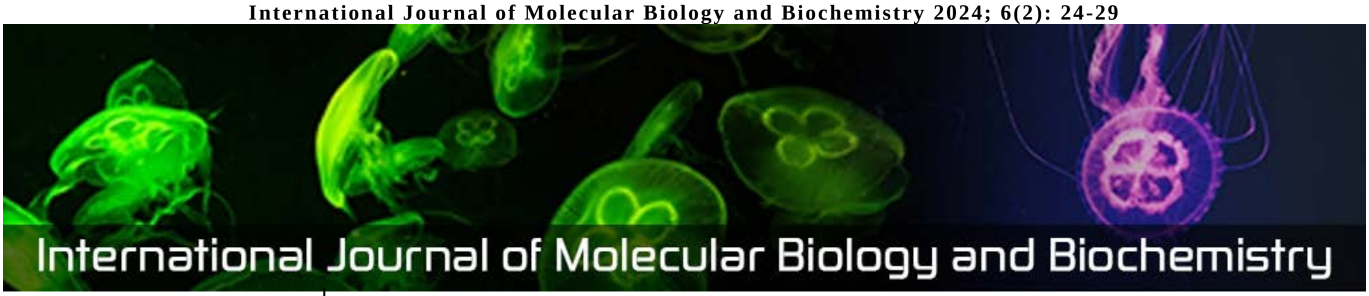
International Journal of Molecular Biology and Biochemistry 2024; 6(2): 24-29



ISSN Print: 2664-6501
ISSN Online: 2664-651X
Impact Factor: RJIF 5.4
IJMBB 2024; 6(2): 24-29
www.biologyjournals.net
Received: 26-05-2024
Accepted: 03-07-2024

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Calculation of some internal quality characteristics of goose eggs with mathematical formulas

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DOI: https://doi.org/10.33545/26646501.2024.v6.i2a.72

Abstract
Eggs play a significant role in the poultry sector, both in the procurement of breeding stock and in the food industry. Geese have the potential to support this sector, so studies conducted on chicken egg quality can be adapted and applied to goose eggs as well. Key variables in determining egg internal quality include Haugh Unit, albumen weight, albumen ratio, yolk weight, and yolk ratio, and which are estimated using formulas based on Length and Breadth measurements of eggs without breaking them. In this study, 360 eggs from Grey China, Linda, and Aksaray Native geese were evaluated, with Length and Breadth measurements made with a digital caliper with a precision of 0.01 mm. Egg weight for Native, China, and Linda geese were 138.3 g, 129.5 g, and 156.2 g, respectively. Haugh Unit values were 138.6, 126.8, and 151.6, respectively. Yolk weight was 52.83 g, 49.39 g, and 59.79 g, respectively, and yolk ratio was 38.18%, 38.13%, and 38.27%, respectively. Albumen weight was 72.71 g, 68.25 g, and 81.72 g, respectively, and albumen ratio was 52.59%, 52.71%, and 52.34%, respectively. The formulas used to calculate the variables, apart from the formula for determining Haugh Unit without breaking the eggs, yielded results that closely matched reality.

Keywords: Correlation, egg composition, geese, regression

Introduction
In the poultry sector, eggs are essential for providing breeding stocks and for serving the food industry. Owing to cage systems, high efficiency can be achieved in limited spaces, making chickens the predominant players in the market. Recently, in alignment with developed countries, Turkey has also supported the transition from cage systems to "free-range poultry farming" for animal welfare and the production of higher quality eggs [1-2].
In pasture-based systems, geese have emerged as a type that can rival chickens. Given that adequate roughage can be supplied through good pastures, certain breeds have demonstrated the ability to produce over 100 eggs per a season with minimal maintenance [3-6]. Considering that a goose egg is approximately three times larger than a chicken egg, it can be argued that geese could potentially yield more eggs than the most prolific laying hens. Given the potential for intensive future production of goose eggs, it would be beneficial to extend egg quality studies to include goose eggs as well [7]. The internal quality of an egg is determined by the condition of the albumen and egg yolk. Achieving this requires breaking the egg and conducting measurements and calculations on its properties, which entails labour, time, and egg loss [8].
Haugh Unit (HU), developed by Haugh [9], is a method that assesses egg quality based on albumen height and weight of the broken egg. The formula to calculate Haugh Unit is:

$$HU = 100 \log(H + 7.57 - 1.7xW^{0.37}),$$

Where
H = Albumen height (mm),
W = Egg weight (g).

This formula has been widely used. Devices that measure albumen height and egg weight while calculating the Haugh units are commercially available.

There even exists a quality classification for chicken eggs is based on albumen height, known as the USDA Quality Rating [8]. It is important to maintain a consistent Haugh Unit value during egg storage.

However, there are some challenges in the application of this method. While some researchers acknowledge its success with chicken eggs (49.5-63 g), they note that it deviates when applied to larger eggs and emphasize that the egg needs to be broken for the method to be applicable [8, 10-12]. This method has also been tested in goose eggs. Sari *et al.* [13] reported values of 81.86 for Linda geese with 125.54 g eggs, Tilki and Inal [14] found 71.5 for freshly collected 154.7 g France White goose (INRA) eggs, and Adamski *et al.* [15] recorded 89.19 for Polish White Goose eggs weighing 158 g.

Tilki and Inal [16] found HU values of 67.7, 65.2, and 65.6 respectively for Native geese eggs weighing 145.1, 148.5, and 147.2 g in Isparta-Armutlu, Konya-Tatlıcak, and Konya-Başkuyu regions. Saatci *et al.* [17] found a HU of 89.19 for 144.51 g eggs in their study on native geese in Kars province.

Sari *et al.* [13] measured albumen height as 9.48 mm in Linda geese, whereas Adamski *et al.* [15] reported 9.40 mm in Polish White Goose eggs.

Albumen is a clear gel-like substance between the eggshell and the yolk. Thus, the remaining portion after separating the eggshell and yolk is known as albumen weight. Albumen weights include 64.92 g in Linda geese [13], 88.3 g in freshly collected INRA eggs in the study of Tilki and Inal [14], 84.5 g in Polish White Goose eggs in the research by Adamski *et al.* [15], and 69.28 g in Obroshyn geese [18]. Tilki and Inal [16] found albumen weights of 72.9 g, 73.7 g, and 74.1 g respectively for Native geese eggs in Isparta-Armutlu, Konya-Tatlıcak, and Konya-Başkuyu regions, and Saatci *et al.* [17] measured it as 66.50 g in their study on native geese in Kars province.

The albumen ratio is the ratio of albumen weight to egg weight. Reported values include 64.92% for Linda geese [13], 57.0% for freshly collected INRA eggs in the study of Tilki and Inal [14], 53.4% for Polish White Goose eggs in the research by Adamski *et al.* [15], and 48.9% for Obroshyn geese [18]. Tilki and Inal [16] found albumen ratios of 51.2%, 50.6%, and 51.2% respectively for Native geese eggs in Isparta-Armutlu, Konya-Tatlıcak, and Konya-Başkuyu regions, and Saatci *et al.* [17] reported it as 47.64% in their study on native geese in Kars province.

Egg yolk weight is obtained by weighing the yolk after separating it from the albumen. Reported values include 45.80 g for Linda geese [13], 48.1 g for freshly collected INRA eggs in the study of Tilki and Inal [14], 53.8 g for Polish White Goose eggs in the research by Adamski *et al.* [15], and 52.82 g for Obroshyn geese (18). Tilki and Inal [16] found egg yolk weights of 50.1 g, 50.3 g, and 50.4 g respectively for Native geese eggs in Isparta-Armutlu, Konya-Tatlıcak, and Konya-Başkuyu regions, and Saatci *et al.* [17] measured it as 51.71 g in their study on native geese in Kars province.

The egg yolk ratio is the ratio of egg yolk weight to egg weight. Reported values include 36.62% for Linda geese [13], 30.4% for freshly collected INRA eggs in the study of Tilki and Inal [14], 34.0% for Polish White Goose eggs in the research by Adamski *et al.* (2016), and 37.3% for Obroshyn geese [18]. Tilki and Inal [16] found egg yolk ratios of 35.1%, 34.6%, and 35.0% respectively for Native geese eggs in Isparta-Armutlu, Konya-Tatlıcak, and Konya-Başkuyu regions, and Saatci *et al.* [17] reported it as 36.62% in their study on native geese in Kars province.

Scientists have been exploring methods to gather information about the mentioned traits without breaking the egg. In their studies, egg scientists, food scientists, biostatisticians, mathematicians, and biologists have developed formulas that provide insight into egg internal quality traits. These formulas have produced results that closely align with reality [19].

This study aims to assess the effectiveness of the formulas used to predict internal quality traits by applying them to eggs from three different goose genotypes. If successful, this approach could lead to saving efforts, time, and eggs typically required to assess egg internal quality

Materials and Methods

In this study, a total of 360 eggs from three different goose genotypes were evaluated, including Grey China, Linda, and Aksaray Native geese, collected from the local population. China and Linda breeds are considered pure, while the majority of Aksaray Native geese have grey or light-colored plumage, with only a small portion showing mixed blood from China geese and other breeds.

Egg measurements were taken using a digital caliper with a precision of 0.01 mm, capable of measuring distances up to 200 mm. The following estimated internal quality traits were assessed:

Haugh Unit (HU): A useful formula recommended by Narushın and Morgun [12] was used for HU calculation: $HU=128742W^{1.498}Wc^{-2.933}Vc^{2.393}$ Where: W: Egg Weight, Wc: Egg Content Weight, Vc: Egg Content Volume

a) Egg Weight and Egg Volume (V) were calculated based on the elliptical shape of the eggs [20]. The coefficients Kw and Kv were determined, corresponding to the egg weight of 142.6 g reported by Hoyt [21] for *Anser fabalis* eggs.

$W = KwLB^2$, $V = KvLB^2$ Where: Kw = 0.567, Kv = 0.507, L - Length, B - Breadth Wc = W - SW and Vc = V - SV (12) Where: SW - Shell Weight, SV - Shell Volume

b) $SW (g) = 0.0524 W^{1.113}$ (22), ($r^2 = 0.98$). $SV (cm^3) = ST \times S$ Where: S: Surface Area, ST: Shell Thickness, $ST (mm) = 0.0546 W^{0.441}$, $r^2 = 0.89$ [22, 23].

c) $S = (3.155 – 0.0136L + 0.0115B)LB\ cm^2$, $r^2 = 0.961$ (24). Nedomova and Buchar (25) reported that the equation for calculating S was useful in the egg classification when using imaging techniques in the poultry industry.

1. Egg content (Wc): It represents the part of the egg remaining after removing the eggshell. Wc = W - SW
2. Yolk Weight (YW): A highly correlated ($r^2 = 0.97$) formula for estimating yolk weight as suggested by Sotherland and Rahn (26): $YW = 0.345W^{1.02}$
3. Yolk ratio (%YW) = 100YW/W
4. Albumen Weight (AW) = W - (YW + SW)
5. Albumen ratio (%AW) = 100AW/W
6. Shell Ratio (SR) = 100WS/W as proposed by Rahn and Paganelli [22]

For each trait, genotype comparisons were performed using One-Way ANOVA, and differences between genotypes were further analyzed using the Duncan Test. The analyses were conducted using the SPSS software package [27].

Results

Significant differences ($p< 0.001$) were observed among genotypes for all traits. Mean values for all traits followed the order from highest to lowest as Linda, Native, and China genotypes. This ranking was largely attributed to the influence of egg weight on all traits. Differences could vary due to genetic factors (Breed, age) as well as environmental factors (Management, feeding, climate). However, even in traits with similar means, significant differences were observed. Since the formulas used for all traits were based on length and breadth measurements, the data were highly standardized, resulting in low and similar standard errors. This contributed to the significance of the differences among the means (Table 1).

The regression equation predicting the Haugh Unit based on egg weight has shown differences among the three genotypes (Figure 1). This disparity is a result of variations in egg weights among the genotypes (Table 1). However, it is worth noting that the determination coefficients (R^2) in the regression models for all three genotypes are approximately 1 (Figure 1). This implies that when the egg weight of these genotypes is known, it is possible to directly estimate the Haugh Unit using the respective genotype's regression equation.

The statistics for egg composition traits and the differences between genotypes are presented in Table 2. Significant differences were observed among genotypes for all traits ($p< 0.001$). Mean values for all traits followed the order from highest to lowest as Linda, Native, and China genotypes. The low and similar Standard Errors contributed to the significance of the differences among the means.

The regression equations predicting egg composition traits based on egg weight have shown differences among the three genotypes (Figure 2). This variation can be attributed to differences in egg weights among the genotypes (Table 1). However, it is important to note that the determination coefficients (R^2) in the regression models for all three genotypes are approximately 1 (Figure 2). This implies that when the egg weight of these genotypes is known, it is possible to directly estimate the egg composition traits using the respective genotype's regression equation.

While the weights of the traits comprising egg composition (Yolk Weight, Albumen Weight, and Shell Weight) differ among genotypes, there is no significant difference observed in their proportional distributions (Figure 3).

Table 1: Statistics of Haugh Unit and related traits, and differences among genotypes.

Traits	Genotypes	n	x̄	Sx̄	Min	Max	CV	p
Haugh Unit	Native	253	134.6b	0.976	100.8	186.8	11.53	
	China	75	126.3c	0.928	102.4	144.0	6.37	***
	Linda	32	151.6a	2.835	115.8	179.9	10.57	
	Total	360	134.4	0.825	100.8	186.8	11.65	
Egg Weight (gr)	Native	253	138.3b	1.027	102.7	193.0	11.81	
	China	75	129.5c	0.981	104.3	148.3	6.56	***
	Linda	32	156.2a	2.966	118.5	185.7	10.74	
	Total	360	138.1	0.868	102.7	193.0	11.93	
Egg Volume (cm^3)	Native	253	125.9b	0.935	93.4	175.7	11.81	
	China	75	117.9c	0.893	94.9	134.9	6.56	***
	Linda	32	142.1a	2.700	107.8	169.0	10.75	
	Total	360	125.7	0.790	93.4	175.7	11.93	
Shell Weight	Native	253	12.80b	0.108	9.12	18.64	13.43	
	China	75	11.87c	0.101	9.28	13.83	7.41	***
	Linda	32	14.68a	0.314	10.72	17.84	12.12	
	Total	360	12.77	0.091	9.12	18.64	13.57	
Shell Volume (cm^3)	Native	253	6.75b	0.058	4.71	9.76	13.72	
	China	75	6.23c	0.057	4.78	7.31	7.90	***
	Linda	32	7.73a	0.164	5.59	9.31	11.99	
	Total	360	6.73	0.049	4.71	9.76	13.84	
Shell Thickness (mm)	Native	253	0.485b	0.002	0.42	0.57	5.28	
	China	75	0.471c	0.002	0.43	0.50	3.03	***
	Linda	32	0.512a	0.005	0.45	0.56	4.99	
	Total	360	0.484	0.001	0.42	0.57	5.33	
Surface Area (cm^2)	Native	253	138.8b	0.718	111.2	173.6	8.22	
	China	75	132.2c	0.766	111.9	146.0	5.02	***
	Linda	32	150.3a	1.944	123.6	167.8	7.32	
	Total	360	138.4	0.605	111.2	173.6	8.29	

n: Yolk, x̄: Mean, Sx̄: Error, CV: Coefficient of Variance, ***: $p<0.001$.

Table 2: Statistics of egg composition traits and differences among genotypes.

Traits	Genotypes	n	x̄	Sx̄	Min	Max	CV	p
Egg Content (g)	Native	253	125.5b	0.919	93.6	174.4	11.64	
	China	75	117.6c	0.880	95.0	134.5	6.48	***
	Linda	32	141.5a	2.653	107.7	167.8	10.61	
	Total	360	125.3	0.777	93.6	174.4	11.76	
Yolk Weight (g)	Native	253	52.83b	0.400	38.97	74.21	12.05	
	China	75	49.39c	0.382	39.59	56.70	6.69	***
	Linda	32	59.79a	1.158	45.10	71.32	10.96	
	Total	360	52.73	0.338	38.97	74.21	12.17	
Yolk Weight (%)	Native	253	38.18b	0.005	37.96	38.44	0.23	
	China	75	38.13c	0.006	37.97	38.24	0.13	***
	Linda	32	38.27a	0.015	38.07	38.41	0.22	
	Total	360	38.18	0.005	37.96	38.44	0.23	

Albumen Weight (g)	Native	253	72.71b	0.519	54.58	100.20	11.35	
	China	75	68.25c	0.498	55.40	77.76	6.32	***
	Linda	32	81.72a	1.495	62.65	96.52	10.35	
	Total	360	72.58	0.438	54.58	100.20	11.46	
Albumen Weight (%)	Native	253	52.59b	0.014	51.90	53.16	0.43	
	China	75	52.71c	0.015	52.44	53.13	0.25	***
	Linda	32	52.34a	0.039	51.98	52.88	0.42	
	Total	360	52.59	0.012	51.90	53.16	0.44	
Shell Ratio	Native	253	9.23b	0.009	8.88	9.66	1.52	
	China	75	9.16c	0.009	8.90	9.32	0.89	***
	Linda	32	9.38a	0.024	9.05	9.61	1.47	
	Total	360	9.23	0.007	8.88	9.66	1.53	

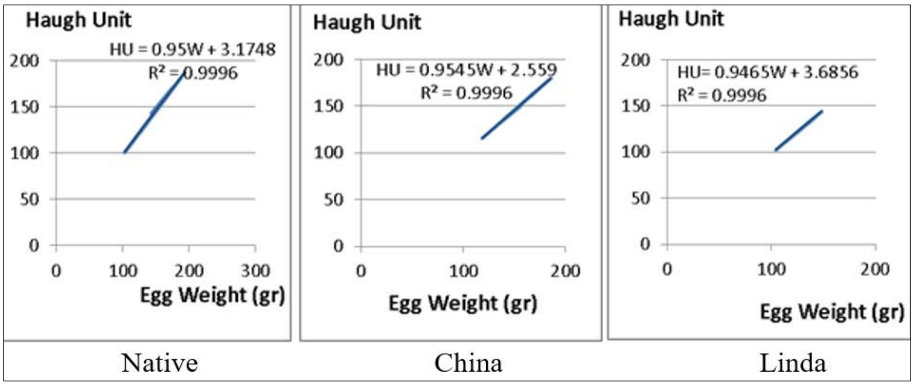

Fig 1: Regressions between Haugh Unit and Egg Weight by Genotype.

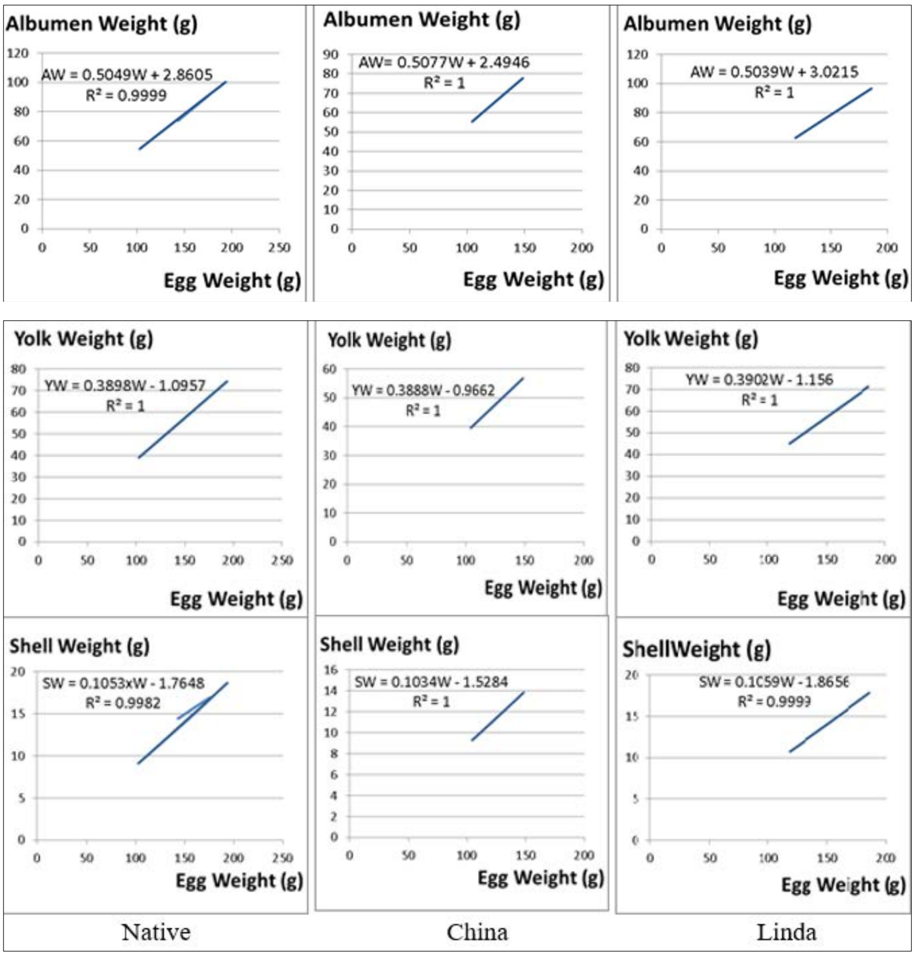

Fig 2: Regressions between Egg Composition Traits and Egg Weight by Genotype.

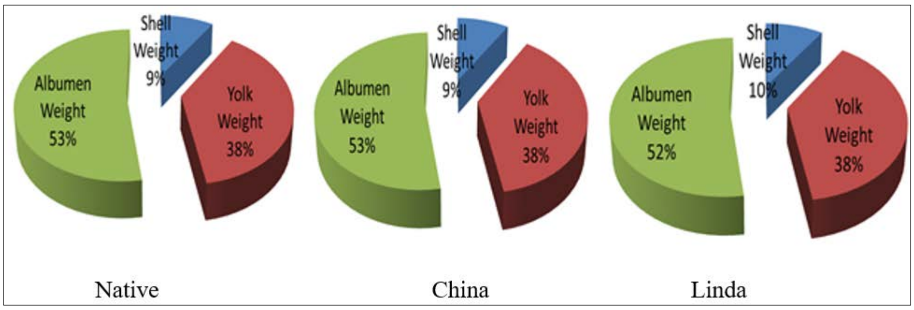

Fig 3: Egg composition according to genotypes

Discussion

Hoyt [21] reported egg weights of 138.3 g for Native geese, 129.5 g for China geese, and 156.2 g for Linda geese. However, the averages for all genotypes were calculated to be higher than those reported by Sari *et al*. [13]. While the averages for Native and China geese were lower than those reported by Tilki and Inal [14], Tilki and Inal [16], and Saatci *et al*. [17], the average for Linda geese was higher than the reported values. The differences in egg weight can be attributed to genetic factors such as breed and age, as well as environmental factors including feeding.

Haugh Unit, calculated using the formula recommended by Narushın and Morgun [12], resulted in values of 138.6 for Native geese, 126.8 for China geese, and 151.6 for Linda geese. These results were significantly higher than those reported in the literature. This discrepancy can be attributed to the fact that Haugh Unit is calculated based on both egg weight and egg volume. Since there is a positive correlation between egg weight and egg volume, egg weight became the determining trait for Haugh Unit. However, Haugh (9) used both egg weight and albumen height in his formula and applied a logarithmic transformation, reducing the impact of egg weight on Haugh Unit calculation.

While it may appear in the literature that there is no correlation between Haugh Unit and egg weight, this is not always the case. Markos *et al*. [28] found correlations between egg weight and Haugh Unit for three groups of chickens with egg weights of 43.7, 41.2, and 36.8 g, with correlation coefficients of 0.58 ($p < 0.01$), -0.17 ($p > 0.05$), and 0.61 ($p < 0.01$), respectively. However, there is indeed a high correlation between egg weight and Haugh Unit [28, 29].

Yolk weight, calculated using the highly correlated formula by Sotherland and Rahn [26], was 52.83 g for Native geese, 49.39 g for China geese, and 59.79 g for Linda geese. The averages for all genotypes were higher than those reported by Sari *et al*. [13] and Tilki and Inal [14]. The averages for Native and China geese were similar to those reported by Adamski *et al*. [15], Fiialovych and Kyryliv [18], Tilki and Inal [16], and Saatci *et al*. [17], while the average for Linda geese was higher than all reported values. Apart from the influence of egg weight, genetic factors such as breed and age, as well as environmental factors including feeding, could contribute to these differences.

The yolk ratio was very close among the three genotypes, with values of approximately 38%. These values were higher than those reported by Sari *et al*. [13], Tilki and Inal [14], and Saatci *et al*. [17], but similar to those reported by Fiialovych and Kyryliv [18].

Albumen weight was calculated as 72.71 g for Native geese, 68.25 g for China geese, and 81.72 g for Linda geese. These values were higher than those reported by Sari *et al*. [13], Fiialovych and Kyryliv [18], and Saatci *et al*. [17], but lower than those reported by Tilki and Inal [14] and Adamski *et al*. [15]. The averages for Native and China geese were similar to those reported by Tilki and Inal [16], while the average for Linda geese was higher. Since albumen weight constitutes the part of the egg after subtracting yolk and eggshell weights, the reasons for differences in yolk weight could also apply to albumen weight.

The albumen ratio was very close among the three genotypes, with values of approximately 52%. These values were smaller than those reported by Sari *et al*. [13] and Tilki and Inal [14], similar to those reported by Adamski *et al*. [15], Fiialovych and Kyryliv [18], and Tilki and Inal [16], and larger than those reported by Saatci *et al*. [17].

The Haugh Unit, developed by Haugh [9], is an important method for evaluating the internal quality of standard-sized chicken eggs. However, this method requires breaking the egg for analysis. Since it is not feasible to break all eggs in a commercial operation, there is a need to classify eggs based on their size, take samples, weigh the selected eggs, measure albumen height after breaking, and perform calculations. This meticulous and labour-intensive process also tends to yield inaccurate results for non-standard eggs. Since goose eggs are 2.5-3 times larger than chicken eggs, the adaptation of this method to goose eggs is necessary. Work is ongoing to adapt the formula to non-standard eggs and explore alternative methods.

Apart from the formula recommended by Narushın and Morgun [12] for calculating Haugh Unit without breaking the egg, other formulas for calculating additional traits have yielded results close to reality. However, Narushın and Morgun (12)'s formula, while intriguing, deviates significantly from the logic of Haugh Unit calculation.

Conclusion

The study reveals notable variations in egg weights, yolk weights, and Haugh Unit values among different goose genotypes, highlighting the influence of genetic and environmental factors. While the observed averages for Native, China, and Linda geese surpassed those reported in existing literature, the results suggest a consistent correlation between egg weight and Haugh Unit values, contrary to some previous findings. Additionally, the challenges associated with accurately assessing Haugh Units in goose eggs underline the necessity for adapted methodologies suitable for larger egg sizes. Continued research into refining these measurement techniques is essential for enhancing the evaluation of egg quality in geese.

Author contribution: All stages of the study were carried out by the author.

Conflict of Interest: The authors declare that they have no conflict of interest.

Data access: All data generated or analyzed during this study are included in this manuscript.

Ethics: The manuscript does not contain clinical studies or patient data.

Funding: No financial support was received for the study.

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