Egg Quality Index: A more accurate alternative to the Haugh unit to describe the internal quality of goose eggs

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ABSTRACT

Enhancing goose production for human consumption requires evaluating the quality of goose eggs based on their physical characteristics. Grounded on the theoretical and experimental studies, we developed two calculation formulae that enabled the computation of Egg Quality Index (*EQI*) as an alternative to the widely used Haugh unit (*HU*) score in assessing goose egg quality. In addition to the egg weight (*W*) and the height of thick albumen (*H*), this computation takes into account the indicators for the yolk, i.e., its diameter (*d*) and height (*h*). Depending on the research preferences when measuring *d* or *h*, one of the two proposed calculation equations can be employed. Using simulation methods that considered all possible combinations of *W*, *H* and *d* values, we created and analyzed a database of virtual goose eggs. As a result, we found that the use of *EQI* as compared to *HU* seems preferable due to the possibility to evaluate a greater number of options and nuances of variation in quality characteristics in goose eggs. The proposed novel index for defining the goose egg quality can be a promising and useful tool for linking structure and functionality in goose eggs and for further application in food and poultry industries.

1. Introduction

Contemporary goose farming is one of the leading segments of the poultry industry in the world that produces meat, liver and eggs for food (Kozák, 2021). Evaluation of the quality of goose eggs based on their physical properties is instrumental in enhancing the production, breeding and commercial use of geese (Tereshchenko et al., 2008; Romanov, 2018). In this respect, it seems important to employ and develop egg quality indices (Narushin, 2001) resulting from measuring, calculating and analyzing a suite of goose egg parameters and their interrelationships. This will be instrumental in tying together structure and functionality in goose eggs using novel experimental and modelling techniques.

1.1. Haugh unit as a quality index of egg interior

More than 85 years ago, an article by Raymond Haugh (1937) was published, in which the author presented a formula that enabled the mathematical expression of the quality of hen egg contents. It is undoubtedly an indispensable tool for both researchers and practitioners working in the poultry egg industry. Indeed, instead of purely descriptive characteristics, i.e., categorizing eggs as high quality, not so high quality or sometimes even bad quality, it enables egg quality gradation in a wide range. In addition, to calculate this, it was enough to identify only two physical properties, i.e., the egg weight (*W*) and the height of the thick albumen (*H*) when pouring the latter onto a flat surface and measuring *H* approximately in its center. Haugh (1937) proposed to refer to this index as the Haugh unit (*HU*).

Despite the wide popularity of this index, and perhaps because of it, a

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number of publications appeared that criticized *HU* and/or were implied to improve it. Here, we did not aim to analyze the pros and cons of this index in detail, as we did this in our previous paper (Narushin et al., 2021a). Using goose eggs in the present study, we claim the deficiency of applying *HU* mainly because Haugh derived his formula from chicken eggs weighing from 42.5 to 62.5 g. However, the analysis of recent publications (e.g., Adamski et al., 2016; Dang et al., 2023; Gogoi et al., 2021; Kucharska-Gaca et al., 2022; Sari et al., 2019) shows that, despite such discrepancies, *HU* continues to be actively used as an indicator of goose egg quality. In this regard, there is great doubt about the adequacy of its use for goose eggs weighing at least three times more than that of chicken eggs (Narushin, 2001; Adamski et al., 2016; Dang et al., 2023; Kucharska-Gaca et al., 2022; Salamon & Kent, 2013, 2020).

1.2. EQI as an alternative to HU score

We decided to structure the theoretical foundations presented in this subsection in such a way as to make the derivation of *EQI* for goose eggs universal in terms of a similar derivation of this index for eggs of any other poultry species.

To make it easier to comprehend the logic of the authors when deriving mathematical dependencies and not constantly refer to our previous article (Narushin et al., 2021a); Narushin et al., 2021b number of formulae used for the derivation of *EQI* will be repeated here.

Following the principles laid down by us in this article, as well as the fundamental indicator on the basis of which Haugh derived his formula, we will start from such a qualitative indicator of an egg as albumen index (*AI*) proposed by Heiman and Carver (1936) as the ratio of *H* to mean thick albumen diameter (*D_a*):

$$AI = \frac{H}{D_a}. \tag{1}$$

To go from *AI* to *EQI*, we multiplied Eqn(1) by 100, as suggested by Wilhelm and Heiman (1936) for making *AI* integer. Also, fully agreeing with Haugh that taking the logarithm of the resulting function will make its use more convenient, due to the change of the data in a linear dependence, and multiplying the logarithm again by 100 to get rid of decimal places after the logarithm operation, we got the original formula for calculating *EQI*, on the basis of which further mathematical transformations were performed:

$$EQI = 100 \log \left(\frac{100H}{D_a} \right). \tag{2}$$

The *D_a* parameter can be expressed in terms of the surface area of the thick albumen (*A*) that, in turn, can be determined by the formula for the area of a circle minus the area occupied by the yolk. If we denote the mean yolk diameter as *d*, then

$$A = \frac{\pi}{4} \left(D_a^2 - d^2 \right). \tag{3}$$

Given that the volume of the thick albumen (*V_ta*) is the product of *A* and *H*, i.e.:

$$V_{ta} = AH, \tag{4}$$

Eqn(4) can be further rewritten as follows:

$$V_{ta} = \frac{\pi H}{4} \left(D_a^2 - d^2 \right). \tag{5}$$

Then, *D_a* will be expressed by the following dependence:

$$D_a = \sqrt{\frac{4V_{ta}}{\pi H} + d^2}. \tag{6}$$

As a result, formula (2) will be rewritten as

$$EQI = 100 \log \left(\frac{100H}{\sqrt{\frac{4V_{ta}}{\pi H} + d^2}} \right), \tag{7}$$

where *H* and *d* are measured in cm and *V_ta* in cm³.

The undoubted convenience of the Haugh formula is that it does not require to measure *V_ta* and relies on *W*. When deriving *EQI* for chicken eggs, Narushin et al. (2021a) selected the appropriate functions for *V_ta* depending on *W* based on the results of measuring data values reported by other authors. There are lots of such measurements carried out on chicken eggs. As for goose eggs, there is no such database; hence we undertook the experiments to explore the morphological parameters of goose eggs.

Thus, we aimed the present study at a detailed theoretical analysis of the goose egg physical parameters with a hope to contribute to the derivation of an alternative quality indicator. The latter will be developed here specifically for goose eggs, akin to the Egg Quality Index (*EQI*) we previously deduced for chicken eggs (Narushin et al., 2021a). Some aspects in the derivation of mathematical dependencies will, however, be simplified and/or changed considering the differences in the morphological parameters of goose and chicken eggs, as well as the already accumulated experience in using *EQI*. Also, the goal of developing a quality index in this study was reduced to determining dependencies for calculating *V_ta* depending on *W* of goose eggs, as well as to analyze its possible use in comparison with *HU*.

2. Materials and methods

A total of 94 goose eggs originating from the Kuban, Gorky, Italian White, and Obroshino Gray breeds were used to measure their physical parameters. In particular, the eggs were weighed (*W*, in g) using an electronic balance. Their length (*L*) and maximum breadth (*B*) were measured with a vernier caliper in cm. Egg volume (*V*, cm³) and surface area (*S*, cm²) were determined using the calculation formulae described by Narushin et al. (2021b).

The eggs were broken, their contents were poured onto a flat surface, and *d* and *H* were measured with a vernier caliper in cm. After that, the yolk of each egg was carefully separated from the egg white and weighed (*W_y*). The yolk volume (*V_y*) values were determined with an accuracy of 0.5 ml by placing it in a volumetric flask. Similar measurements were carried out with the thick albumen by separating it from the thin fraction, weighing (*W_ta*) and placing it in a volumetric flask to identify its volume (*V_ta*).

For possible subsequent analysis and determination of correlations, we also produced shell measurements. In particular, shell volume, *V_s* was determined by the Archimedes' principle. Then, it was dried in air for a day and weighed (*W_s*). The respective values for the egg interior were evaluated as the difference between the corresponding values of the whole egg and the shell, i.e., interior volume, $V_i = V - V_s$, and interior weight, $W_i = W - W_s$. Interior density (*D_i*) was calculated as the ratio of *W_i* to *V_i*.

The values of *HU* were calculated according to Haugh's formula (Haugh, 1936), and *EQI* with Eqn(7).

The results were processed using the STATISTICA 5.5 program (StatSoft, Inc./TIBCO, Palo Alto, CA, USA), as well as computational applications in Microsoft Excel. At the same time, the validity of the obtained relationships was assessed by the value of the correlation coefficient (*R*), and that of regression models using the coefficient of determination (R^2) followed by confirmation of their significance at the level $p < 0.05$.

3. Results and discussion

3.1. EQI derivation and its comparison with HU

The appropriate measured and calculated goose egg variables are given in Table 1.

Based on the experimental data, the desired dependence $V_{ta} = f(W)$ was obtained and is presented graphically in Fig. 1.

The trend line of the graphic dependence (Fig. 1) was approximated by the following linear equation:

$$V_{ta} = 0.264W - 3.84, \qquad (8)$$

with $R^2 = 0.366$ ($p < 0.05$).

Taking into account the obtained equation (8), Eqn(7) can be rewritten as follows:

$$EQI = 100 \log \left(\frac{100H}{\sqrt{\frac{0.336W - 4.889}{H} + d^2}} \right). \qquad (9)$$

We noted a close correlation between the *HU* and *EQI* values at the level of 0.879 ($p < 0.05$), which is illustrated in the form of a graphic dependence in Fig. 2.

The scatter of points on the graph (Fig. 2) around the trend line indicated that, in the framework of the current experiment, *EQI* had a much larger data spread than *HU*. For example, the value $HU \approx 86$ corresponds to seven *EQI* values ranging between 92 and 105. That is, as expected, we achieved the effect of a more flexible approach to the gradation of goose egg quality categories. Therefore, within the framework of our example ($HU \approx 86$), several goose eggs can be assigned to a lower quality group, and a number of others, on the contrary, to a higher one. A better breakdown was made possible by the use of a third parameter in the *EQI* computation, i.e., *d*.

In our previous study (Narushin et al., 2021a) aimed at developing the *EQI* formula for chicken eggs, we suggested the possibility of its alternative calculation using *h*. This parameter is exploited in the indicator of the yolk index (h/d) that is often used as an additional index to *HU* or just *inter se* and indirectly characterizes the quality of the egg interior. In this respect, some researchers may incline (perhaps, "psychologically") more to the use of the *h* value than *d* in the computation of *EQI*. Such conversions are fairly simple to implement using V_y and the spherical cap volume calculation formula (e.g., Weisstein, 2020):

$$V_y = \frac{\pi h}{24} \left(3d^2 + 4h^2 \right). \qquad (10)$$

From Eqn(10) it is easy to get the desired transformation of *d* to *h*:

$$d = \sqrt{\frac{8V_y}{\pi h} - \frac{4h^2}{3}}. \qquad (11)$$

Taking into account (11), Eqn(9) will take the following form:

$$EQI = 100 \log \left(\frac{100H}{\sqrt{\frac{0.336W - 4.889}{H} + \frac{8V_y}{\pi h} - \frac{4h^2}{3}}} \right), \qquad (12)$$

where *H* and *h* are given in cm, *W* in g, and V_y in cm^3.

In order to recalculate *EQI* successfully and according to Eqn(12), we will need to determine V_y via *W*, i.e., similar to what we did with V_{ta} (Eqn(8)). Using the results of our measurements, a graphical interrelationship for these two parameters was built (Fig. 3).

The trend line of the graphic dependence (Fig. 3) was approximated by the following linear equation:

$$V_y = 0.325W + 6.591, \qquad (13)$$

with $R^2 = 0.170$ ($p < 0.05$).

A rather low coefficient of determination (0.17) immediately called into question the possibility of using the above recalculation reliably. Nevertheless, with the value of the coefficient of determination being significant, we decided to evaluate the resulting error in the practical application of Eqn(13). After substituting it into Eqn(12):

$$EQI = 100 \log \left(\frac{100H}{\sqrt{\frac{0.336W - 4.889}{H} + \frac{0.828W + 16.784}{h} - \frac{4h^2}{3}}} \right). \qquad (14)$$

Visualization of the interrelationship between equations (9) and (14) is shown in Fig. 4.

The correlation coefficient between the results of *EQI* calculation according to the two derived formulae (Eqns (9) and (14)) was 0.941 ($p < 0.05$), which, in principle, was quite sufficient for practical application. Therefore, we can safely recommend both formulae for their effective practical use.

3.2. Simulation-based testing of EQI

At the same time, we decided to test on a larger and more variable database than the parameters of the 94 eggs involved in the present experiment. In our previous study (Narushin et al., 2021a), we successfully applied the simulation method to create a database of virtual eggs with all possible combinations of parameters that can, even if extremely rarely, occur in actual eggs. In this investigation, we decided to apply the same approach with regard to the parameters of goose eggs. Based on measurements of the parameters of goose eggs obtained both in our research and other studies (e.g., Adamski et al., 2016; Dang et al., 2023; Gogoi et al., 2021; Kucharska-Gaca et al., 2022; Mazanowski & Adamski, 2006; Sari et al., 2019; Tilki & Inal, 2004), we defined the following variation intervals for the parameters included in Eqn(9) that was chosen as a reference for the simulation database:

$W = [100 \ldots 200]$ g,

$H = [5 \ldots 14]$ mm,

Table 1
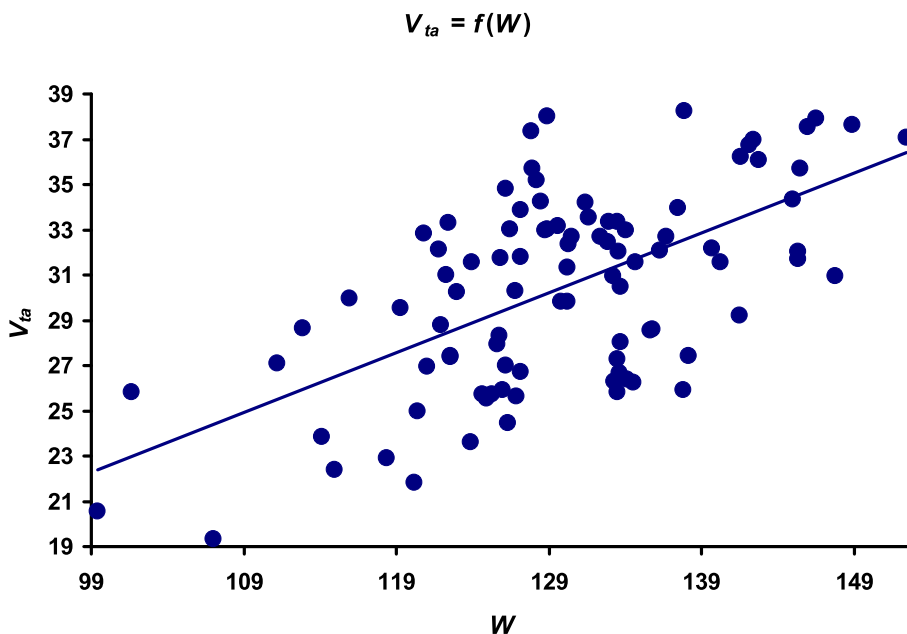Data of measured and calculated goose egg variables.

Parameters	Minimum value	Maximum value	Mean	Standard deviation
Egg weight, W (g)	99.40	152.44	129.87	9.90
Length, L (cm)	7.19	8.63	7.94	0.30
Maximum breadth, B (cm)	4.86	5.74	5.37	0.15
Egg volume, V (cm^3)	91.77	139.96	118.86	9.23
Surface area, S (cm^2)	101.38	133.51	120.15	6.32
Egg density, D (g/cm^3)	1.052	1.127	1.093	0.015
Shell weight, W_s (g)	11.00	19.20	15.29	1.59
Shell volume, V_s (cm^3)	4.60	10.8	7.94	1.33
Weight of interior, W_i (g)	88.13	135.96	114.59	8.91
Volume of interior, V_i (cm^3)	83.77	133.86	113.02	10.19
Density of interior, D_i (g/cm^3)	0.977	1.075	1.034	0.019
Yolk weight, W_y (g)	32.50	66.15	50.45	8.07
Yolk volume, V_y (cm^3)	31.44	63.99	48.80	7.80
Yolk height, h (cm)	1.71	2.55	2.02	0.14
Yolk diameter, d (cm)	4.77	8.70	7.46	0.83
Thick albumen weight, W_{ta} (g)	20.44	40.46	32.20	4.57
Thick albumen volume, V_{ta} (cm^3)	19.33	38.26	30.45	4.32
Thick albumen height, H (mm)	5.20	12.00	8.92	1.55
Haugh units, HU	40.32	96.15	77.72	12.13

$$V_{ta} = f(W)$$

Fig. 1. A graphic dependence of the interrelationship of goose egg parameters V_{ta} and W.
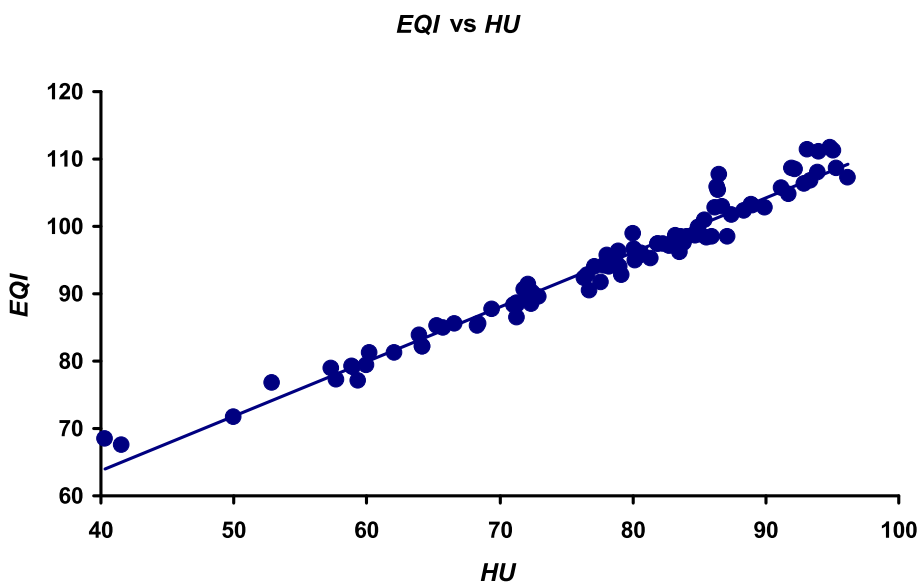
EQI vs HU

Fig. 2. A graphic dependence of the interrelationship of goose egg indices *EQI* and *HU*.

$d = [4 \dots 9]$ cm.

Dividing each interval into subgroups, with an interval of 10 g for W, 1 cm for d and 1 mm for H, respectively, we generated 600 various combinations of virtual goose eggs with all different values of parameters that are possible in nature. For each combination, the computation of *EQI* and *HU* was performed.

Having a virtual sample with parameters corresponding to all possible combinations of goose eggs, we tested the representativeness of our experimental sample, according to which two fundamental dependencies (Eqns (8) and (13)) were obtained that formed the basis of the EQI calculation formula. As such, the computation formula for minimum sample from Cochran (1977) and an assumption on the margin of error (*E*) were used. Its maximum value, according to our assumption, should not exceed 5% of our sample (94 eggs), that is, it should not exceed 5 eggs. Thus, our task was reduced to calculating the

value of *E* and comparing it with the admissible one. In this case, the calculation formula for minimum sample from Cochran (1977) can be converted to the following equation:

$$E = \frac{(N - n)\sigma^2}{(N - 1)n}, \tag{15}$$

where *N* is the number of different combinations in the simulation model corresponding to virtual goose eggs that can be found in nature (in our case $N = 600$); *n* is the number of eggs in our experimental sample (i.e., $n = 94$); and σ is the standard deviation of the parameters of our interest calculated for virtual eggs from the simulation model.

Of the parameters we were interested in, i.e., V_{ta} (Eqn(8)) and V_y (Eqn(13)), the latter had a higher σ value of 10.29, while it was equal to 8.36 for V_{ta}. Therefore, the σ value for V_y was used in Eqn(15). After substituting the values of the parameters, we obtained $E = 0.95$ (or 1%) that, with a margin, satisfied our condition on the 5% threshold. Thus,
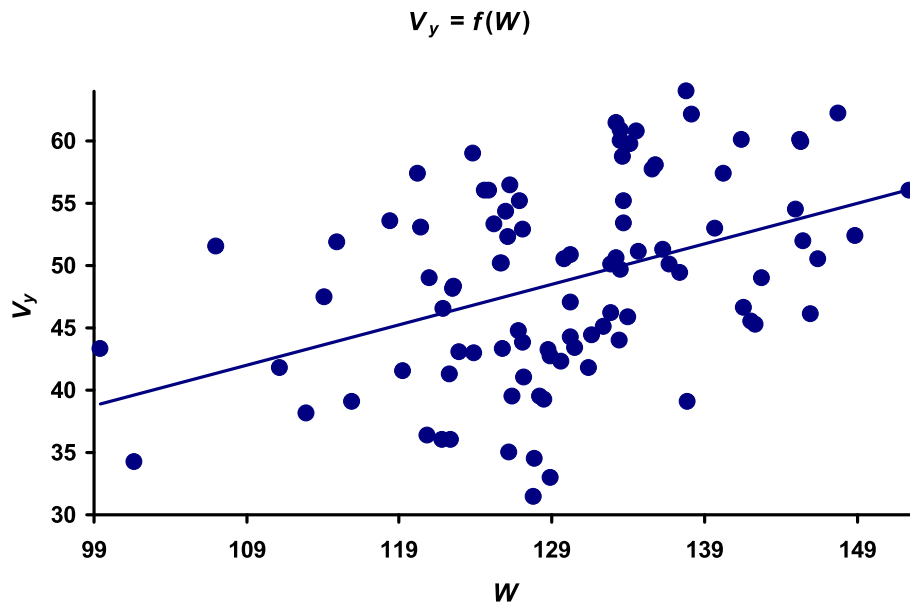
$$V_y = f(W)$$

Fig. 3. A graphic dependence of the interrelationship of goose egg parameters V_y on W.
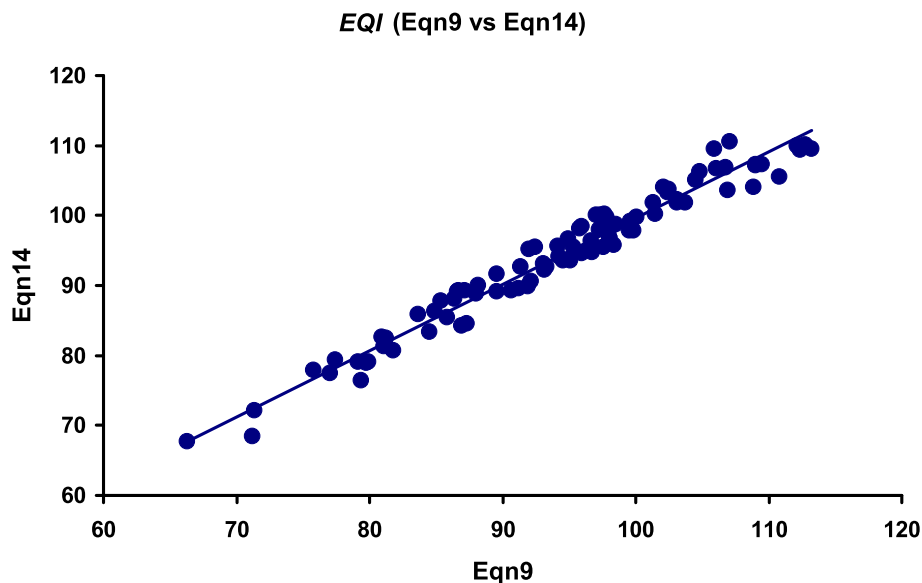
EQI (Eqn9 vs Eqn14)

Fig. 4. Visualization of the interrelationship for the results of calculating *EQI* using formulae (9) and (14).

the experimental sample of 94 goose eggs examined here can be considered representative for the achievement of our research goals.

We also decided to investigate in more detail the interrelationship between *EQI* and *HU* obtained from the computation of simulation data and presented this in the form of the respective graphical dependence in Fig. 5.

Analysis of the dependence and the data obtained shows that the range of the obtained parameters for *EQI* was between 54 and 136 units, while for *HU* between −30 and 109. Negative and/or very small *HU* values were noted for relatively large eggs with a lower albumen height. Such *HU* values were even theoretically impossible for chicken eggs (Narushin et al., 2021a). This fact suggests that the use of the *HU* score for eggs with a set of parameters typical for goose eggs was, in principle, unacceptable, since it can easily mislead when interpreting the results. It is likely that an egg of good quality may be rejected due to lower calculated *HU* values. In addition, the much wider variation in possible *EQI* values for the same *HU* result can be observed as the number of

points above and below the trend line (yellow line in the graph of Fig. 5). This provides much greater opportunities for analysis of goose egg quality indicators and selection for influencing parameters.

There may be a possible reluctance in the research community to abandon the established *HU* method of assessing qualitative characteristics in the case of goose egg interior. In view of this, the recalculation of the values of egg parameters will be relevant, and therefore we have approximated the trend line (yellow line in the graph in Fig. 5) with the following equation:

$$EQI = 57.39e^{0.007HU}, \tag{16}$$

with $R^2 = 0.881$ ($p < 0.05$).

However, the computation using Eqn (9) or 14 will be much more accurate, allowing a more adequate analysis of goose egg quality.

We also wondered how the produced *EQI* for goose eggs differs from its counterpart obtained earlier for chickens (Narushin et al., 2021a). In order not to confuse these indices, we assigned them the corresponding
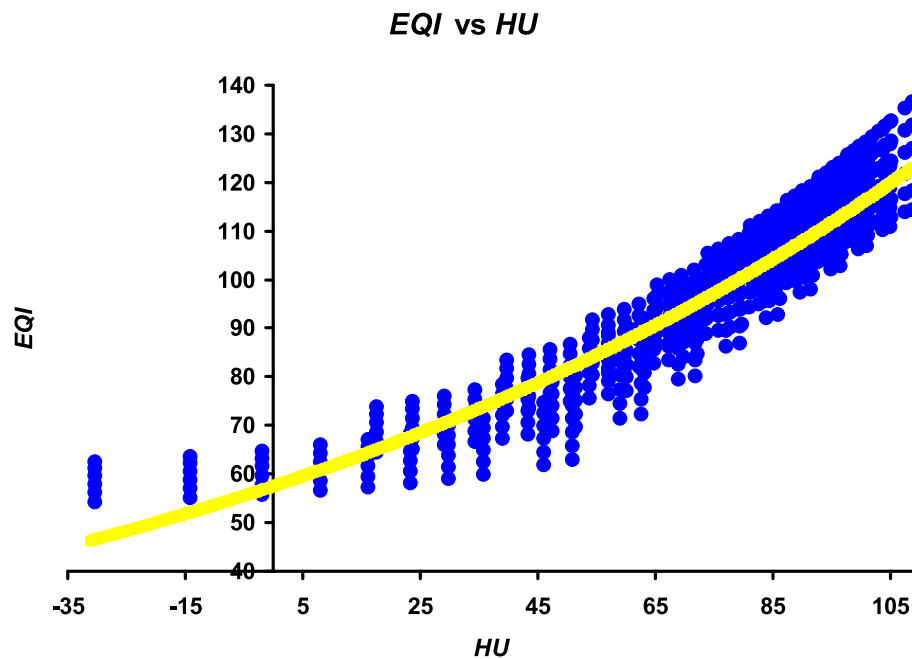
EQI vs HU

Fig. 5. Interrelationship between *EQI* (Eqn(9)) and *HU* calculated from a simulation model of a set of possible parameters *W*, *H* and *d* specific to goose eggs.

indices: 'g' (*EQI_g*) conforming to goose eggs, and 'h' (*EQI_h*) to chicken. For the convenience of this comparison, we decided to use a simpler, from our point of view, formula (Eqn(9)) that included data on such egg parameters as *W*, *H* and *d*. A similar calculation equation for chicken eggs (Narushin et al., 2021a) is as follows:

$$EQI_h = 100 \log\left(\frac{100H\sqrt{H}}{\sqrt{0.5W - 5 + d^2H}}\right) \quad (17)$$

To ensure the adequacy of the comparative analysis, we carried out the computation of *EQI_g* and *EQI_h* for the parameters of goose eggs obtained from the experiment and simulation. The comparison results are shown in the form of graphical dependences in Fig. 6.

The dependence analysis (Fig. 6) demonstrated that both parameters (*EQI_g* and *EQI_h*) have a fairly close correlation: $R = 0.947$ ($p < 0.05$) for the experimental data, and $R = 0.954$ ($p < 0.05$) for those obtained as a result of simulation. However, the *EQI_h* values for parameters typical of goose eggs are somewhat outside the normal range (approximately 30–120 units). In addition, one should also take into account the factor

of variability, i.e., the ratio of the standard deviation to the mean (in percent). The higher this indicator, the more capacity it has in displaying various values and nuances of qualitative egg characteristics. In our case, the variability of *EQI_g* values was ±19.7%, while for *EQI_h* it was ±8.6%, which testified again in favor of using the calculation formulae inferred for goose eggs. However, the tightness of the relationship between the two indices enables to apply them for mutual recalculation. The resulting trend lines were approximated by the following equations:
– for the experimental data (Fig. 6A)

$$EQI_g = 0.992 EQI_h - 108.77, \quad (18)$$

with $R^2 = 0.898$ ($p < 0.05$);
– for the simulation data (Fig. 6B)

$$EQI_g = 0.995 EQI_h - 113.45, \quad (19)$$

with $R^2 = 0.911$ ($p < 0.05$).

The resulting equations (18) and (19) seem quite similar. However, for possible practical use, we propose to choose Eqn (19) generated as a
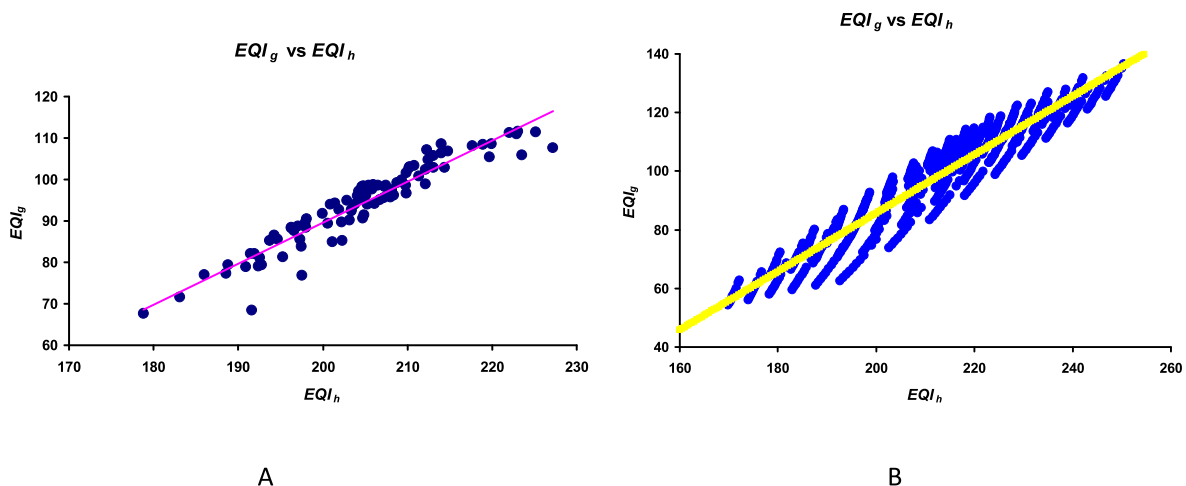
EQI_g vs EQI_h

A

B

Fig. 6. Interrelationship between *EQI_g* (Eqn(9)) and *EQI_h* (Eqn(17)) calculated from the experimental data of goose eggs (A) and the simulation model of a set of possible parameters *W*, *H* and *d* specific to goose eggs (B).

result of mathematical processing of a much larger number of variations than the initial experimental data.

The derivation of both dependences for EQI_g and EQI_h was based on a similar approach and, first of all, depended on the association between V_{ta} and V_y in relation to W. Because of that, a high correlation between the two EQI indices suggests that this relationship has a similar trend for both types of eggs. If we assume that for the eggs of other poultry species, e.g., turkeys, quails, ducks, guinea fowls and ostriches, the same trend of functional change in V_{ta} and V_y depending on W is observed, we can safely use the formulae for calculating EQI_g and/or EQI_h to assess their qualitative characteristics. It should only be borne in mind that the numerical values in those cases will go beyond the usual limits, since they depend on W. The W values for eggs of various species can differ by tens and for some species even hundreds of times. In this regard, it would be more appropriate, in our opinion, to implement a similar approach for a more thorough and detailed derivation of the corresponding quality indices for eggs of other bird species.

4. Conclusions

The data of this study in relation to goose eggs are an extension of our previous work (Narushin et al., 2021a) on the derivation of EQI, which can be an adequate alternative to the widely used HU. Our present findings resulted from the conducted theoretical, analytical and experimental studies suggest that:

(i) The use of HU for research and analytical purposes related to assessing the quality of the goose egg interior is not advisable, since the results obtained may lead to false or not entirely reliable conclusions. As a result of the experiment using simulation methods, a number of eggs had extremely low or even negative HU values, although the use of EQI as an alternative calculation indicated their acceptable quality.

(ii) The developed quality index, EQI, can be a worthy alternative to HU because, in addition to W and H, it also evaluates the yolk parameters d or h. Subsequently, EQI can be recalculated according to the Eqn (9) or 14 we proposed here depending on which yolk parameter is preferable for a given study.

(iii) The detailed and theoretically substantiated EQI derivation algorithm we proposed can be taken as a basis for developing a similar calculation of the quality indicators for eggs of other poultry species that differ in size from goose or chicken, e.g., for quail, duck or even ostrich eggs.

In all, the study outcome will be instrumental for linking structure and functionality in goose eggs using novel experimental and modelling approaches, as well as for further research in the fields of egg-related research, goose reproduction and production, food science, engineering and quality control.

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CRediT authorship contribution statement

Valeriy G. Narushin: conceptualization, data curation, formal analysis, investigation, methodology, resources, software, visualization, writing – original draft, writing – review & editing. **Michael N. Romanov:** project administration, validation, writing – review & editing. **Attila Salamon:** validation, writing – review & editing. **John P. Kent:** validation, writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

References

Adamski, M., Kucharska-Gaca, J., Kuzniacka, J., Gornowicz, E., Lewko, L., & Kowalska, E. (2016). Effect of goose age on morphological composition of eggs and on level and activity of lysozyme in thick albumen and amniotic fluid. *European Poultry Science, 80*, 148. https://doi.org/10.1399/eps.2016.148

Cochran, W. G. (1977). *Sampling techniques* (3rd ed.). New York, NY, USA: John Wiley & Sons.

Dang, D. X., Li, C. J., Cui, Y., Zhou, H., Lou, Y., & Li, D. (2023). Egg quality, hatchability, gosling quality, and amino acid profile in albumen and newly-hatched goslings' serum as affected by egg storage. *Poultry Science, 102*, Article 102367. https://doi.org/10.1016/j.psj.2022.102367

Gogoi, A., Das, B., Phookan, A., Chabukdhara, P., Pathak, S. S., Pame, K., & Hoque, H. (2021). Evaluation of physical egg quality traits in indigenous geese of upper Assam. *International Journal of Genetics, 13*, 804–806. https://doi.org/10.9735/0975-2862

Haugh, R. R. (1937). The Haugh unit for measuring egg quality. *United States Egg & Poultry Magazine, 43*, 552–555.

Heiman, V., & Carver, J. S. (1936). The albumen index as a physical measurement of observed egg quality. *Poultry Science, 15*, 141–148. https://doi.org/10.3382/ps.0150141

Kozák, J. (2021). Goose production and goose products. *World's Poultry Science Journal, 77*, 403–414. https://doi.org/10.1080/00439339.2021.1885002

Kucharska-Gaca, J., Adamski, M., & Biesek, J. (2022). The age of the geese from the parent flock and the laying period affect the features of the eggs. *Poultry Science, 101*, Article 102094. https://doi.org/10.1016/j.psj.2022.102094

Mazanowski, A., & Adamski, M. (2006). The structure, chemical composition and time trends of egg quality characteristics in high-producing geese. *Archiv für Geflügelkunde, 70*, 127–133.

Narushin, V. G. (2001). An alternative index of measuring the quality of goose rggs. In *Proceedings of the International Workshop on Waterfowl, Halle/Wermsdorf, Germany* (p. 2).

Narushin, V. G., Romanov, M. N., & Griffin, D. K. (2021a). A novel Egg Quality Index as an alternative to Haugh unit score. *Journal of Food Engineering, 289*, Article 110176. https://doi.org/10.1016/j.jfoodeng.2020.110176

Narushin, V. G., Romanov, M. N., & Griffin, D. K. (2021b). Non-destructive measurement of chicken egg characteristics: Improved formulae for calculating egg volume and surface area. *Biosystems Engineering, 201*, 42–49. https://doi.org/10.1016/j.biosystemseng.2020.11.006

Romanov, M. N. (2018). Geese. In C. K. Baer, D. E. Ullrey, & W. G. Pond (Eds.), *Encyclopedia of Animal Science (Two-Volume Set)* (2nd ed., Vol 1, pp. 487–489). London, UK: Taylor & Francis Inc.. https://doi.org/10.1081/E-EAS2-120019645. eBook. Boca Raton, FL, USA: CRC Press Inc. ISBN: 978-1-000-00659-9.

Salamon, A., & Kent, J. P. (2013). Egg weight declines to baseline levels over the laying season in domestic geese (*Anser anser domesticus*). *International Journal of Poultry Science, 12*, 509–516. https://doi.org/10.3923/ijps.2013.509.516

Salamon, A., & Kent, J. P. (2020). The double-yolked egg: From the 'miracle of packaging 'to nature's 'mistake'. *World's Poultry Science Journal, 76*, 18–33. https://doi.org/10.1080/00439339.2020.1729671

Sari, M., Buğdayci, K. E., Akbaş, A. A., Saatci, M., & Oğuz, M. N. (2019). The effect of laying period on egg quality traits and chemical composition of Lindovskaya (Linda) geese reared under breeder conditions. *Turkish Journal of Veterinary and Animal Sciences, 43*, 662–669. https://doi.org/10.3906/vet-1811-2

Tereshchenko, A. V., Mikityuk, D. N., Ryabokon, Yu A., Ivko, I. I., Melnik, V. A., Ryabinina, E. V., Khvostik, V. P., & Gorbanev, A. P. (2008). In *Geese on the Farm and in the Courtyard* (2nd ed.). Borky, Ukraine: Ukrainian Academy of Agrarian Sciences, Poultry Research Institute.

Tilki, M., & Inal, Ş. (2004). Quality traits of goose eggs: 1. Effects of goose age and storage time of eggs. *Archiv für Geflügelkunde, 68*, 182–186.

Weisstein, E. W. (2020). *Spherical cap. MathWorld, a wolfram web resource*. Internet: http://mathworld.wolfram.com/SphericalCap.html. (Accessed 24 May 2023).

Wilhelm, L. A., & Heiman, V. (1936). The albumen index determination by nomogram. *United States Egg & Poultry Magazine, 42*, 426–429.