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A Novel Egg Quality Index as an Alternative to Haugh Unit Score

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Abstract

An unusually popular index reflecting the quality of the egg contents and known as the Haugh unit (*HU*) score is empirical in nature. Because of that, a number of studies appeared that contradict or try to improve this index. In this regard, we set a study that pursued several goals: (i) to trace the rationale for developing the *HU* index and give it a theoretical reassessment; and (ii) based on the assumptions of previous studies in this field, to revisit and refine the index by increasing such its components as the mathematical adequacy and information value. As a result, an alternative index was inferred that we called the Egg Quality Index (*EQI*) and described using the appropriate mathematical dependencies. This novel index, in addition to the egg weight (*W*), takes into account the physical properties of the thick albumen (by measuring its height, *H*) and yolk (by identifying its diameter, *d*, or height, *h*). We, then, compared the two indices, *HU* and *EQI*, using the simulation modelling approach. The results of comparison of the two indices as applied to a various set of parameters characteristic of chicken eggs suggested a wider potential for using *EQI* due to the inclusion of an additional parameter reflecting the yolk condition as well as a more accurate distribution of the studied eggs in quality grade groups with various gradations of consumer attractiveness.

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1. Introduction

Since the publication of the original article by Haugh (1937), an index named by the author as the Haugh unit (*HU*) has gained extraordinary popularity in assessing the quality of the contents of poultry eggs. The essence of the method is to measure the height of the thick layer of egg white (albumen) and the egg weight, followed by the *HU* computation according to the formula:

$$HU = 100\log\left(H - \frac{\sqrt{G}(30W^{0.37} - 100)}{100} + 1.9\right), \quad (1)$$

where *H* is the height of the thick albumen in millimeters, *W* is the egg weight in grams, and *G* is the gravitational constant equal to 32.2.

Later on, Eisen *et al*. (1962) simplified the above formula (1) by substituting the value of the constant and recalculating the whole equation as follows:

$$HU = 100\log(H + 7.57 - 1.7W^{0.37}), \quad (2)$$

and, as a result, the formula (2) became the main computation tool for *HU* scoring.

Nevertheless, despite the high popularity of this index, criticisms of *HU* periodically appear in scientific publications, which can be divided into the following three main subgroups.

1. Correction of the index by the egg weight is impractical.

At the time when Haugh deduced his universal formula, the poultry world used two approaches to determining the quality of albumen. First, the albumen index (*AI*) proposed by Heiman and Carver (1936) as the ratio of the height of thick albumen (*H*) to its average diameter (*D*)

$$AI = \frac{H}{D}, \quad (3)$$

which later was improved by Wilhelm and Heiman (1936) in the form of a calculation nomogram that takes into account eggs of various weights. Second, measurement of the height of thick albumen (*H*) adjusted for the egg weight (*W*) that is different from the weight of a standard two-ounce egg (Wilgus and VanWagenen, 1936). The latter authors did not give any name to their index, so we will call it here for convenience as the albumen quality (*AQ*):

$$AQ = H \cdot \frac{56.7}{W} \quad (4)$$

Thus, the scholars of that time agreed that the egg weight directly affects the calculated quality indicators of the chicken egg contents, and this was used by Haugh in developing his formula. Yet, more recent studies (Eisen *et al*., 1962; Silversides *et al*., 1993; Silversides and Villeneuve, 1994) noted that the value of *W* can be excluded from the formula (2).

2. An adjustment for the egg weight is needed, but it does not change in a power-law relationship.

In his formula, Haugh introduced the egg weight correction using the exponent 0.37 and following the nomogram of Wilhelm and Heiman (1936). Kidwell *et al*. (1964) suggested on the basis of their own studies that the dependence on *W* should be linear, thereby confirming the data of Eisen *et al.* (1962).

In his theoretical research, van Tijen (1968) explained this fact by examining a "corrective" part of the formula (2):

$$y = 1.7W^{0.37} - 7.57\,, \quad (5)$$

and substituting the *W* data in the range between 0 and 70 g. The region of the obtained curve within 40 and 70 g, i.e., the egg weight range characteristic of chicken eggs, can be conditionally assumed to be linear.

3. Modification of the Haugh formula and obtaining alternative indices.

According to Stadelman *et al*. (1957), *HU* does not provide a complete description of internal egg quality, and this, obviously, facilitated the search for new indices that would improve, as suggested by their authors, the Haugh formula and be able to more adequately calculate from a mathematical point of view an indicator of the quality of egg contents.

Kidwell *et al*. (1964), when exploring the linear nature of the variation in the height of thick albumen vs egg weight, proposed modifying *HU* and used the new name for the index, *GE*:

$$GE = 100\log(H - b(W - 56.7)) \quad (6)$$

in which b = 0.067 is the combined linear regression coefficient.

According to the data of Robinson *et al*. (1994), the *HU* score is a weak and less appropriate quality index when the albumen heights are below 5 mm. Instead of *HU*, these authors proposed an alternative index with the correction of egg weight following a logistic model.

Another alternative index for assessing the quality of egg contents was proposed by Narushin (1997), who attempted to introduce a theoretical background for its derivation. As a result, he suggested a rationale for developing a quality index called Egg Quality (Q_e) for eggs of any poultry species, i.e., not just for chicken as suggested by Haugh for his index and mistakenly extrapolated to all varieties of poultry.

Based on the above studies, one can conclude that deeper theoretical assumptions and a more comprehensive analysis would be required to further serve as a basis for inferring an adequate quality index, and this has become the main objective of the present study. In this paper, we proposed a novel Egg Quality Index (*EQI*) and showed that, as compared with the *HU* index, *EQI* could better and in the most suitable and informative way reflect the characteristics of egg contents.

2. Methodology

2.1. Effect of the egg weight

Let us try to slightly modify the basic formula (3) for calculating *AI* using the theoretical calculations performed by Narushin (1997).

If we consider the principle of measuring the thick albumen (Fig. 1), it is obvious that the average diameter (D) can be expressed in terms of the surface area of the thick albumen (A), which can be determined by the circle area formula minus the area, which the yolk occupies. If we denote the average diameter of the yolk by *d*, then,

$$A = \frac{\pi}{4}(D^2 - d^2) \qquad (7)$$

Given that the volume of thick albumen (V_{ta}) is the product of its surface area (A) and height (H), the average diameter of thick albumen (D) can be expressed then by the following formula:

$$D = \sqrt{\frac{4V_{ta}}{\pi H} + d^2} \qquad (8)$$

In their classic book on the avian egg, Romanoff and Romanoff (1949), on the basis of numerous experimental data, proposed a graphical dependence of the albumen weight (W_a) on the total chicken egg weight (W), which we can approximate quite accurately (R^2 = 0.998) with the following linear equation:

$$W_a = 0.76W - 7.2 \qquad (9)$$

Romanoff and Romanoff (1949) also stated that the thick albumen is approximately 57.3% of the total mass of the whole egg white, so the coefficients in the equation (9) were correspondingly reduced, as a result of which the thick albumen weight (W_{ta}) can be written as

$$W_{ta} = 0.44W - 4.13 \qquad (10)$$

In order to transform the formula (10) into the volume equation (V_{ta}), the weight should be divided by the density of the thick albumen (D_{ta}), the average value of which can be taken equal to 1.04 g/cm^3 that is confirmed by several other studies (Romanoff and Romanoff, 1949; Meuer and Egbers, 1990; Punidadas and McKellar, 1999; Cameron, 2010; Kumbár *et al*., 2015). Then,

$$V_{ta} = 0.42W - 3.97 \qquad (11)$$

and

$$D = \sqrt{\frac{0.5W - 5}{H} + d^2}\ , \qquad (12)$$

so, the final formula for determining *AI* can be rewritten in the following form:

$$AI_i = \frac{H\sqrt{H}}{\sqrt{0.5W - 5 + d^2 H}} \quad (13)$$

where the values of *H* and *d* are given in centimeters, and that of *W* in grams. To avoid confusion with the albumen index (*AI*) suggested by Heiman and Carver (1936), we introduced a different parameter, the Improved Albumen Index (AI_i).

Thus, based on the formula (13), the egg weight has a direct effect on AI_i and, as a consequence, on the *HU* score.

2.2. Effect of yolk dimensions

Judging from the formula (13), the yolk diameter (*d*) also affects the AI_i value. The step of measuring the albumen index is carried out after the contents of the egg are poured on a flat surface, as a result of which the yolk takes the form of a spherical cap (Fig. 1). The yolk volume (V_y) can be determined by the appropriate formula as can be seen, for example, in Weisstein (2020):

$$V_y = \frac{\pi h}{24}(3d^2 + 4h^2) \quad (14)$$

in which *h* is the yolk height (Fig. 1).

Using the formula (14), we obtained an equation for calculating the yolk diameter (*d*):

$$d = \sqrt{\frac{8V_y}{\pi h} - \frac{4h^2}{3}} \quad (15)$$

By analogy with the above mathematical calculations of the volume of thick albumen, we tried to express the volume of the yolk (V_y) through the egg weight (*W*). At first, we also used the data from Romanoff and Romanoff (1949), approximating the graphical dependence presented by the authors for the change in the mass of the yolk (W_y) with an increasing egg weight (R^2 = 0.999):

$$W_y = 0.18W + 6.69 \quad (16)$$

The density of the yolk (D_y) was taken to be 1.035 g/cm^3, which corresponded to our data and, on average, is in good agreement with the other studies (Fromm and Gammon, 1968; Lineweaver *et al*., 1969; Meuer and Egbers, 1990; Punidadas and McKellar, 1999; Kumbár *et al*., 2015). Then,

$$V_y = 0.17W + 6.46 \quad (17)$$

Given (17), the formula (15) can be rewritten as follows:

$$d = \sqrt{\frac{0.4W + 16.5 - 1.3h^3}{h}} \quad (18)$$

Then, substituting (18) in (13), we can determine the value of AI_i using the yolk height instead of its diameter:

$$AI_i = \frac{H\sqrt{Hh}}{\sqrt{(0.5W - 5)h + (0.4W + 16.5 - 1.3h^3)H}} \quad (19)$$

where the values of H and h are taken in centimeters, and W in grams.

2.3. AI vs HU: mathematical view

In his work, Haugh (1937) did not explain how he got his final formula, thereby only referring to the article by Wilhelm and Heiman (1936), who continued research on improving the albumen index (AI) and proposed a nomogram for its calculation based on the data of H and W. Haugh (1937) approximated the nomogram by the following equation:

$$AI = \frac{H}{\sqrt{G}} - (30W^{0.37} - 100) \quad (20)$$

in which the value of G was called the gravitational constant equal to 32.2, while the values of H were taken in millimeters and W in grams.

Nevertheless, substituting the specific values of H and W in (20) with those in the Wilhelm and Heiman (1936) nomogram, we would obtain a stably negative result that is far from the actual AI values provided in the nomogram.

To figure out exactly where the error occurred, we decided to repeat the approximation, for which we used the data from the Wilhelm and Heiman (1936) nomogram, transferring them to the Excel table, constructing similar graphical dependencies and approximating each of them with the power function $H = f(W^{0.37})$ in order to get them as close as possible to the formula (20). The results are presented in Fig. 2.

All the obtained equations have the following form:

$$H = aW^{0.37} + b \qquad (21)$$

where *a* and *b* are coefficients.

The values of both coefficients *a* and *b* in the equation (21) were approximated by the dependences $a,b = f(AI)$ that are presented in Fig. 3.

As can be seen from the diagram (Fig. 3), the function $a = f(AI)$ is a straight line parallel to the abscissa axis and, therefore, in the calculation formula, it is purposeful to use the average value of *a* equal to 1.632. The computation formula for determining the coefficient *b* is accurate enough for its use in further calculations. Substituting these data in (21), we have:

$$H = 1.632W^{0.37} + 0.0536AI - 5.0287 \qquad (22)$$

wherefrom

$$AI = 18.66H - 30.45W^{0.37} + 93.82 \qquad (23)$$

Most likely, Haugh (1937) wanted to make his formula the most convenient for calculations of that time, and due to this he slightly modified it, taking the coefficient value 30.45 equal to 30, and 93.82 to 100. We did the same in a similar way, recalculating the coefficient 18.66 that turned out to be equal to 17.6 in this case. As a result, the equation (23) was transformed into the following formula:

$$AI = 17.6H - (30W^{0.37} - 100) \qquad (24)$$

or taking into account the constant $G = 32.2$ as proposed by Haugh (1937),

$$AI = 100\frac{H}{\sqrt{G}} - (30W^{0.37} - 100) \qquad (25)$$

Thus, in the formula for *AI* (Haugh, 1937), the coefficient 100 was omitted that led to a computation error. This was due to the fact that Wilhelm and Heiman (1936) suggested using integers in the calculations: for example, instead of $AI = 0.099$, use $AI = 99$, and instead of $H = 0.76$ cm, assume $H = 76$.

The rationale of Haugh (1937) regarding the use of the gravitational constant G in his formula (20) is not entirely clear, and that caused some confusion among the authors of later works. For example, Wells (1968), introducing the Haugh formula, quite logically indicated the value of the gravitational constant G equal to 981 cm/s^2 that corresponded to its value in the measurement system given by him. However, most likely, Haugh (1937) simply tried to give his empirically derived formula some physical meaning, in connection with which he used a mixture of dimensions, proposing to determine the height of the albumen in millimeters, the egg weight in grams, and the gravitational constant in feet/s^2.

The next question is how Haugh (1937) derived his formula (1). To address this question, let us consider its sublogarithmic part and compare with the equation (25). Obviously, the Haugh formula (1) is composed from the equation (25) by simple mathematical transformations:

$$H - \frac{\sqrt{G}(30W^{0.37} - 100)}{100} + 1.9 = AI \cdot \frac{\sqrt{G}}{100} + 1.9 \qquad (26)$$

Evidently, the purpose of introducing the coefficient $\sqrt{G}/100$ was to make the calculation formula (1) more demonstrative and simpler, freeing it from the corresponding coefficient. The parameter 1.9 was added by Haugh (1937) to comply with the notion of a ‘standard egg’ previously proposed by VanWagenen and Wilgus (1935) and Wilgus and VanWagenen (1936) as an egg whose weight was 2 ounces (56.7 g), and that was entirely supported by Haugh.

Thus, the *HU* score is a somewhat modernized formula for calculating the modified albumen index based on the nomogram proposed by Wilhelm and Heiman (1936), which implies that the alternative equations (13) and (19) we derived here can also be used for practical purposes.

3. Results and Discussion

3.1. Introducing EQI

For convenience and by analogy with what proposed by Wilhelm and Heiman (1936), we can multiply the equations (13) and (19) by 100. Also, fully agreeing with Haugh (1937) that the logarithm of the resulting function would make its use more convenient, due to changes in the data on linear dependence, and multiplying again the logarithm by 100 to get rid of the decimal places after the logarithm operation, we will get the final expression for defining the quality of the chicken egg contents that, in order not to cause confusion with the previous indices, we called here Egg Quality Index (*EQI*):

$$EQI = 100\log\left(\frac{100H\sqrt{H}}{\sqrt{0.5W - 5 + d^2H}}\right) \tag{27}$$

or

$$EQI = 100\log\left(\frac{100H\sqrt{Hh}}{\sqrt{(0.5W-5)h + (0.4W + 16.5 - 1.3h^3)H}}\right) \tag{28}$$

3.2. HU vs EQI: simulation modelling

In view of the fact that in reality it is sometimes difficult to select a sample of chicken eggs whose qualitative characteristics are widely variable, we undertook evaluation of the obtained *EQI* values using simulation modelling methods. This made it possible to take into account all possible combinations of various values of the three parameters, *H*, *W*, and *h*, as were applicable to chicken eggs and used in the formula (28).

The simulation modelling included the following steps. Based on the data from Heiman and Carver (1936), Wilgus and VanWagenen (1936), Wilhelm and Heiman (1936) and Haugh (1937) that served as the basis for the creation of the *HU* score, plus more recent works on the

HU estimation (Eisen *et al*., 1962; van Tijen, 1968; Silversides *et al*., 1993; Silversides and Villeneuve, 1994), the *H* values were taken in the range between 2 and 11 mm and divided into classes with an increment of 1 mm, whereas the range of the *W* values was set between 42 and 70 g and split into classes with an increment of 2 g. Since the above authors, unlike us, did not use the size of the yolk in their models, variation in the yolk height was derived from the data of Keener *et al*. (2006), Sarica *et al*. (2012), Ogunwole *et al*. (2015), Rath *et al*. (2015) and Feddern *et al*. (2017), with the range of the *h* values being taken between 6 and 20 mm and with a 2-mm increment for dividing into classes. All possible simulation modelling combinations of the *H*, *W* and *h* values were substituted into the formulae (28) and (1), thus obtaining a dataset of 1280 variants. The interrelation between *HU* and *EQI* values computed for each of the simulation variants are presented in the form of a graphical dependence (Fig. 4).

The values of both *HU* and *EQI* indices vary widely: from 11 to 107 for *HU*, and from 12 to 133 for *EQI*, so we can suggest that the *EQI* quality index more fully reflects the nuances of changes in the qualitative characteristics of chicken eggs.

3.3. HU vs EQI: egg quality grading

In order to carry out a deeper qualitative analysis of the *EQI* index in comparison with *HU*, let us use the United States Standards, Grades, and Weight Classes for Shell Eggs (USDA, 2000) that include the following egg quality grades: AA, with *HU* values of 72 and higher; A, with *HU* values of 60 to 71; and B, with *HU* values less than 60. This classification, however, was recently amended with the grading data from the other sources, e.g., ORKA (2019) and Pius and Olumide (2017) that suggested to define the B quality grade if the *HU* score ranges between 31 and 59, while eggs with *HU* values of 30 and less should be included in the C grade. Schematically, the distribution of the *HU* and *EQI* indices according to the above four quality grades is shown in Fig. 5.

A more detailed analysis of the results showed that based on the *HU* data, 816 simulation modelling combinations (simulation variants) of egg parameters were included in the AA grade group. However, if we analyze the simulation dataset using the *EQI* index, 3 eggs fell into this group falsely, since their index calculated by the formula (28), which also takes into account the yolk height, was lower than 72. A more pronounced discrepancy between the two simulation datasets obtained with *HU* and *EQI* was observed for the A grade group: of the 144 simulation combinations identified for this grade category using *HU*, 8 eggs should be placed into a lower category B if they were evaluated using *EQI*, while 60 eggs of the lower A grade should be transferred to a higher category AA. A similar mismatch was observed in the B grade group. This category had 256 simulation combinations using *HU*, although, when calculated according to *EQI*, 60 eggs should be put into a lower category C, and 36 eggs to a higher category A. Simulation modelling combination of the lowest C grade included 64 conditional eggs that coincided when using *HU* vs *EQI*. Thus, even if we use the above four grades that reflect quite a rough consumer attractiveness scale for the qualitative assessment of eggs, we can conclude that, despite the rather high correlation between the two studied indices (r = 0.981), *HU* cannot cope properly with all possible combinations of qualitative egg characteristics and that the middle grade groups A and B are especially affected because almost up to half of all eggs in them did not correspond to their appropriate category based on *EQI*. Moreover, these inconsistencies can be exacerbated when using *HU* for research purposes where variation of egg quality parameters can be much greater, and the results of an entire experiment can depend on the exact assignment of eggs to the correct grade categories.

Despite the wide usage of *HU*, many researchers still continue to additionally evaluate the quality of egg contents using the albumen and yolk indices. Earlier studies aimed at revealing the relationship of these indices did not identify clearly this relationship between them. For example, Sauter *et al*. (1951) found a close relationship between the albumen and yolk indices at a correlation level of 0.945 and suggested an empirical formula for their computation. On the other hand, Wesley and Stadelman (1959) confirmed that the relationship between the yolk index and the diameter of the thick albumen, which they used instead of the albumen index, only at the level of 0.17, and that between the yolk index and *HU* 0.39, and concluded that it would be advisable to use all three indicators for a more adequate assessment of the quality of the chicken egg contents. However, there were previously no attempts to combine different egg quality parameters into one index. In this connection, we developed here the novel index, *EQI*, and suggest that this can be a good alternative to a comprehensive assessment of the egg quality.

3.4. Conclusions

Our theoretical and computational studies enabled to derive the novel index for assessing the quality of the contents of chicken eggs, which is a function of the height of the thick albumen, the average diameter or the height of the yolk, and the egg weight. Based on the analysis performed by means of the simulation modelling, this novel indicator, the Egg Quality Index (*EQI*), has a much higher potential for a qualitative assessment of the eggs in view of a wider range of measurements, the inclusion of an additional parameter characterizing the condition of the yolk, and a more accurate distribution of the studied eggs in quality groups with a different gradation of consumer appeal. We suggest the novel index to be a promising and useful tool for further application in food and poultry industries.

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Figure captions

Fig. 1. Scheme for measuring egg quality parameters of the thick albumen (NABEL, 2016).

Fig. 2. Graphical representation of Wilhelm and Heiman (1936) chart used to demonstrate the dependence of the albumen heights on the egg weights.

Fig. 3. The results of approximating the values of the coefficients *a* and *b* by the functions *f*(*AI*).

Fig. 4. Variations of *HU* and *EQI* values computed on the base of the simulation modelling data for the qualitative characteristics of chicken eggs.

Fig. 5. Distribution of the *HU* and *EQI* values in accordance with the four egg quality grade groups, AA, A, B and C.

Figure 1

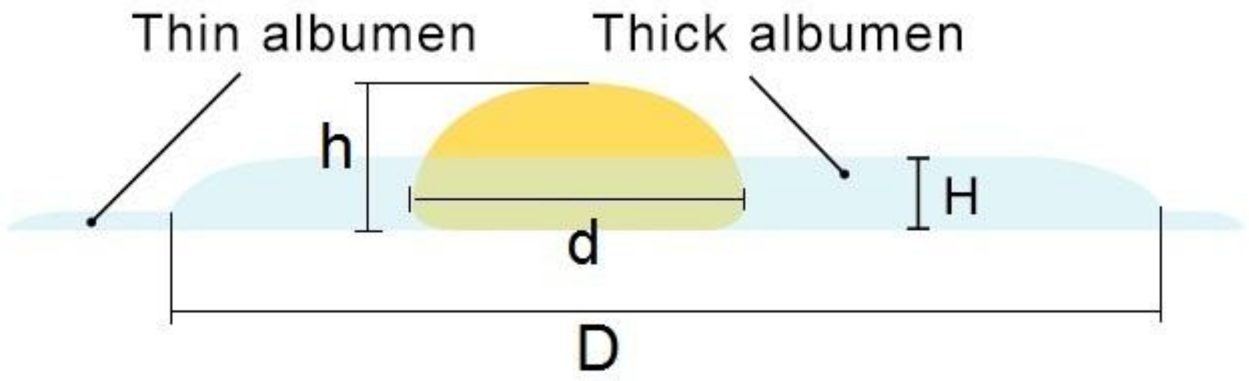
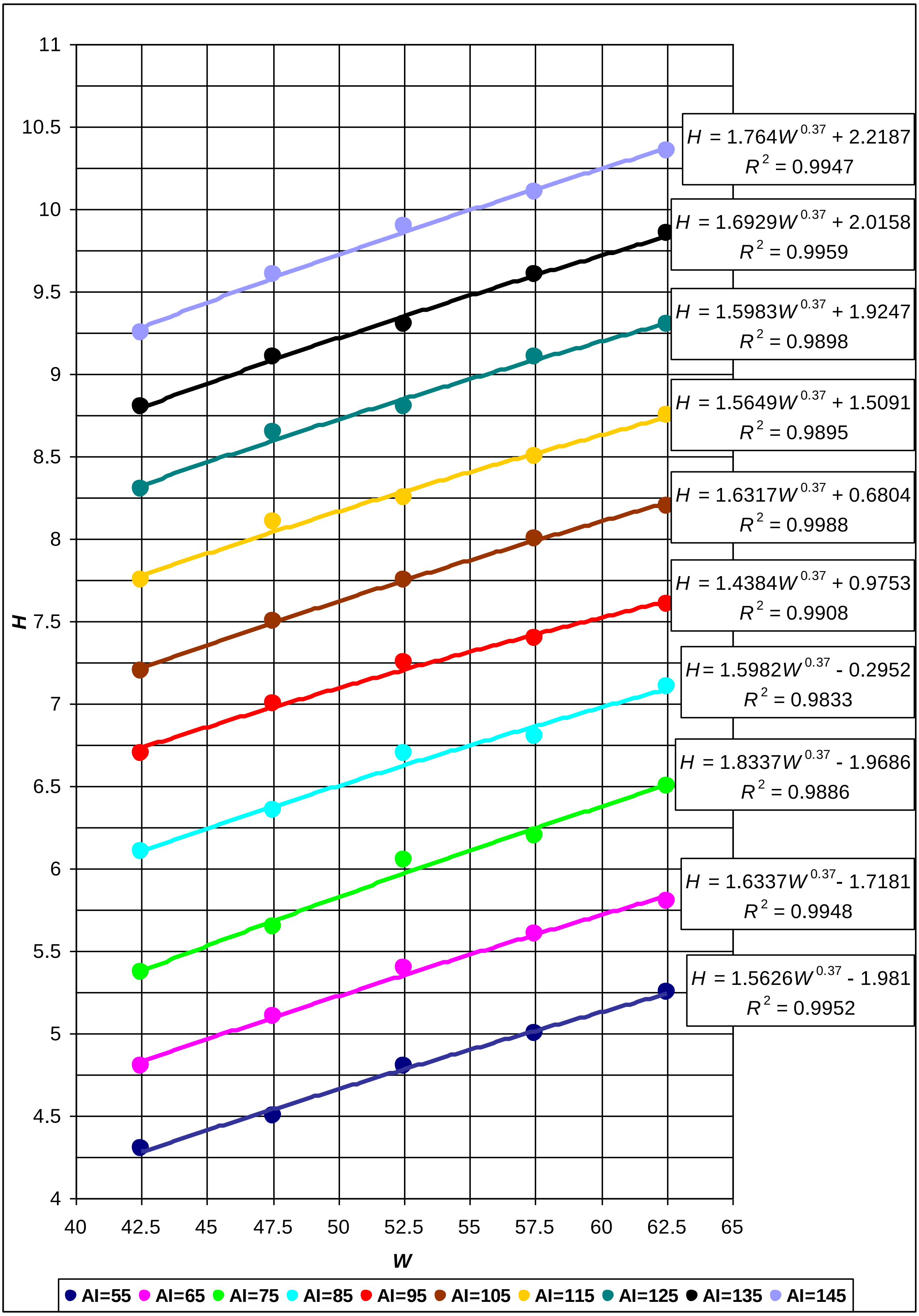
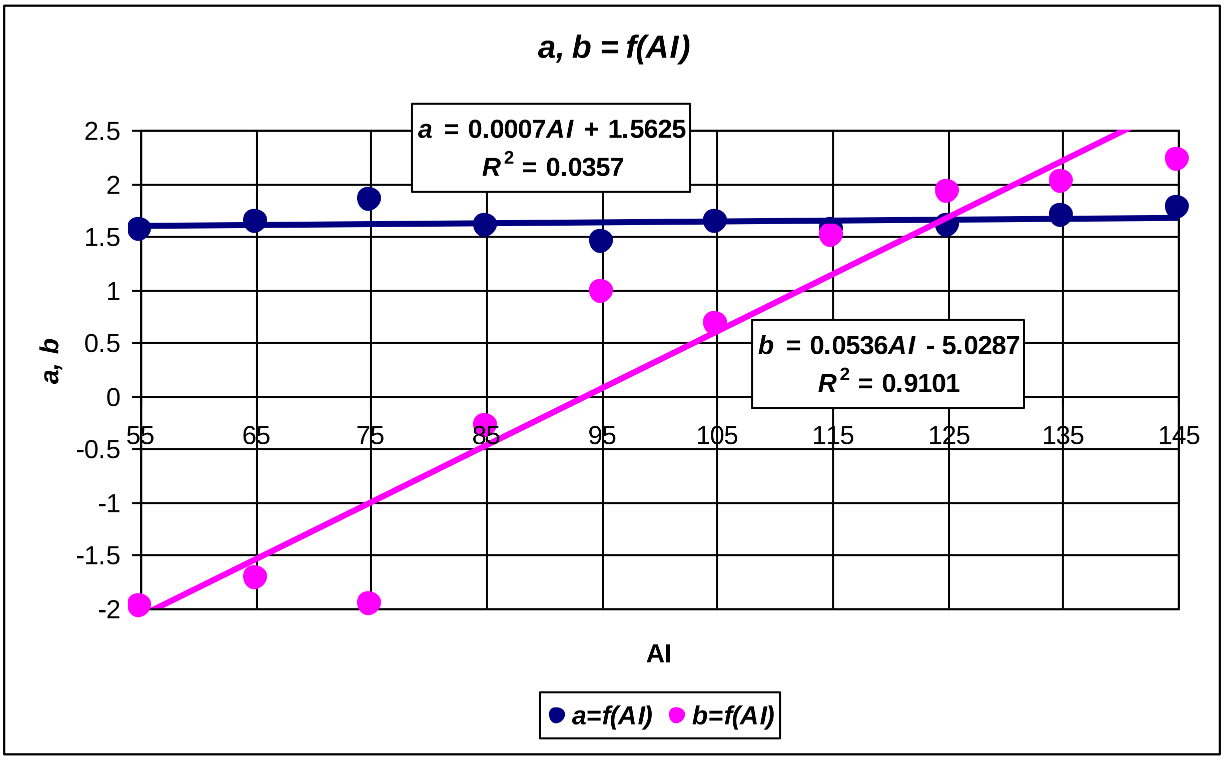


Figure 2



H = 1.764W^0.37 + 2.2187
R^2 = 0.9947
H = 1.6929W^0.37 + 2.0158
R^2 = 0.9959
H = 1.5983W^0.37 + 1.9247
R^2 = 0.9898
H = 1.5649W^0.37 + 1.5091
R^2 = 0.9895
H = 1.6317W^0.37 + 0.6804
R^2 = 0.9988
H = 1.4384W^0.37 + 0.9753
R^2 = 0.9908
H= 1.5982W^0.37 - 0.2952
R^2 = 0.9833
H = 1.8337W^0.37 - 1.9686
R^2 = 0.9886
H = 1.6337W^0.37- 1.7181
R^2 = 0.9948
H = 1.5626W^0.37 - 1.981
R^2 = 0.9952
H
W
AI=55 AI=65 AI=75 AI=85 AI=95 AI=105 AI=115 AI=125 AI=135 AI=145

Figure 3



a, b = f(AI)
a = 0.0007AI + 1.5625
R2 = 0.0357
b = 0.0536AI - 5.0287
R2 = 0.9101
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
a, b
55
65
75
85
95
105
115
125
135
145
AI
a=f(AI)
b=f(AI)

Figure 4 (corrected)

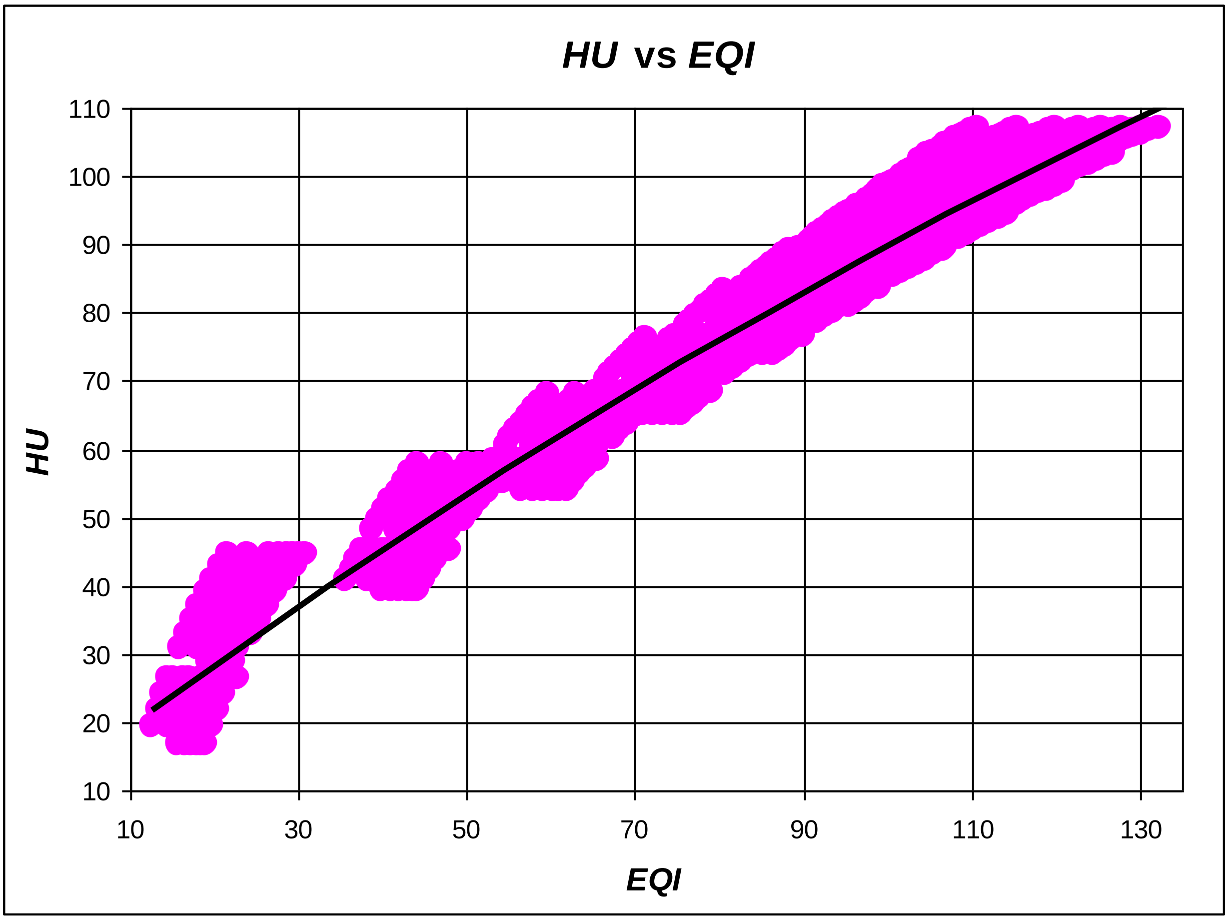
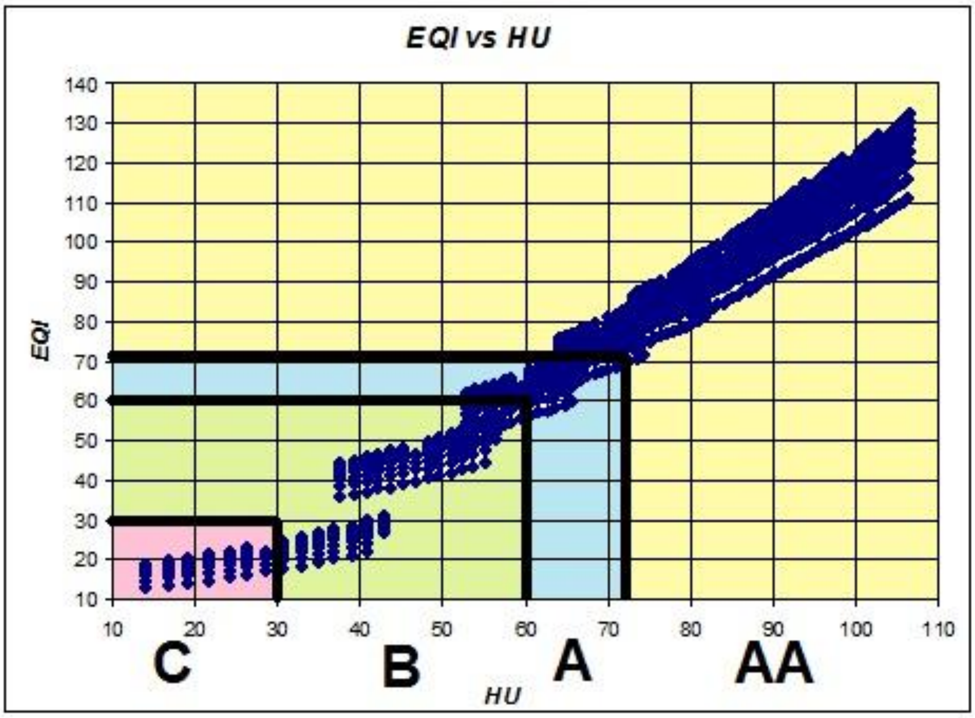


Figure 5


EQI vs HU
EQI
140
130
120
110
100
90
80
70
60
50
40
30
20
10
10
20
30
40
50
60
70
80
90
100
110
HU
C
B
A
AA

Highlights

- Haugh unit score (*HU*) is a conventional predictor of the quality of egg interior.
- We propose a new score, Egg Quality Index (*EQI*), using mathematical dependencies.
- Two indices, *HU* and *EQI*, were compared using the simulation modelling approach.
- *EQI* has a stronger potential due to an additional parameter for egg yolk condition.

Credit Author Statement

VGN: Conceptualization; Investigation; Methodology; Roles/Writing - original draft; Writing - review & editing.

MNR: Conceptualization; Investigation; Roles/Writing - original draft; Writing - review & editing.

DKG: Project administration; Resources; Supervision; Writing - review & editing.

***Conflict if Interest form**

A Novel Egg Quality Index As an Alternative to Haugh Unit Score

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Conflicts of interest

The authors have no conflict of interest to declare.