Kent Academic Repository

Narushin, Valeriy G., Romanov, Michael N., Gressier, Louis, Kent, John P. and Salamon, Attila (2024) ***Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?*** **Journal of Food Composition and Analysis, 125 (Januar). ISSN 0889-1575.**

Downloaded from

https://kar.kent.ac.uk/103670/ The University of Kent's Academic Repository KAR

The version of record is available from

https://doi.org/10.1016/j.jfca.2023.105803

This document version

Author's Accepted Manuscript

DOI for this version

Licence for this version

UNSPECIFIED

Additional information

Versions of research works

Versions of Record

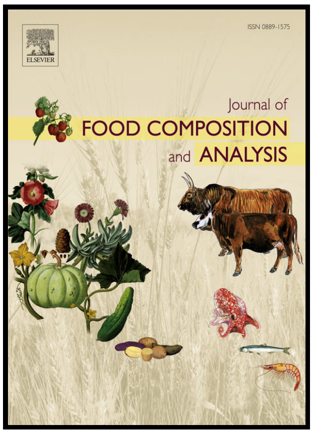
If this version is the version of record, it is the same as the published version available on the publisher's web site. Cite as the published version.

Author Accepted Manuscripts

If this document is identified as the Author Accepted Manuscript it is the version after peer review but before type setting, copy editing or publisher branding. Cite as Surname, Initial. (Year) 'Title of article'. To be published in ***Title of Journal*** , Volume and issue numbers [peer-reviewed accepted version]. Available at: DOI or URL (Accessed: date).

Enquiries

If you have questions about this document contact ResearchSupport@kent.ac.uk. Please include the URL of the record in KAR. If you believe that your, or a third party's rights have been compromised through this document please see our Take Down policy (available from https://www.kent.ac.uk/guides/kar-the-kent-academic-repository#policies).



Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?

Valeriy G. Narushin, Michael N. Romanov, Louis Gressier, John P. Kent, Attila Salamon

PII: S0889-1575(23)00677-4

DOI: https://doi.org/10.1016/j.jfca.2023.105803

Reference: YJFCA105803

To appear in: *Journal of Food Composition and Analysis*

Received date: 13 September 2023
Revised date: 29 October 2023
Accepted date: 29 October 2023

Please cite this article as: Valeriy G. Narushin, Michael N. Romanov, Louis Gressier, John P. Kent and Attila Salamon, Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?, *Journal of Food Composition and Analysis,* (2023) doi:https://doi.org/10.1016/j.jfca.2023.105803

Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?

Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?

Valeriy G. Narushin[1,2,*], Michael N. Romanov[3,4,*], Louis Gressier[5,6], John P. Kent[6], Attila Salamon[7,8]

[1] Research Institute for Environment Treatment, Zaporizhya, Ukraine

[2] Vita-Market Ltd, Zaporizhya, Ukraine

[3] School of Biosciences, University of Kent, Canterbury, UK

[4] L. K. Ernst Federal Research Center for Animal Husbandry, Dubrovitsy, Podolsk, Moscow Oblast, Russia

[5] Institut de Génie Informatique et Industriel (IG2I), Centrale Lille, Lens, France

[6] Ballyrichard House, Arklow, Co. Wicklow, Ireland

[7] Department of Ethology, ELTE Eötvös Loránd University, Budapest, Hungary

[8] ELTE NAP Canine Brain Research Group, Budapest, Hungary

Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?

Single-yolked vs double-yolked eggs in ducks and geese: how to put these in different baskets?

Valeriy G. Narushin[1,2,*], Michael N. Romanov[3,4,*], Louis Gressier[5,6], John P. Kent[6], Attila Salamon[7,8]

[1] Research Institute for Environment Treatment, Zaporizhya, Ukraine

[2] Vita-Market Ltd, Zaporizhya, Ukraine

[3] School of Biosciences, University of Kent, Canterbury, UK

[4] L. K. Ernst Federal Research Center for Animal Husbandry, Dubrovitsy, Podolsk, Moscow Oblast, Russia

[5] Institut de Génie Informatique et Industriel (IG2I), Centrale Lille, Lens, France

[6] Ballyrichard House, Arklow, Co. Wicklow, Ireland

[7] Department of Ethology, ELTE Eötvös Loránd University, Budapest, Hungary

[8] ELTE NAP Canine Brain Research Group, Budapest, Hungary

* Corresponding authors.

E-mail addresses: val@vitamarket.com.ua (V. G. Narushin); m.romanov@kent.ac.uk (M. N. Romanov)

Declarations of interest: none

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. **Louis Gressier:** investigation. **John P. Kent:** investigation, validation, writing – review & editing. **Attila Salamon:** investigation, validation, writing – original draft, writing – review & editing, project administration.

Valeriy G. Narushin: https://orcid.org/0000-0001-6799-6605, e-mail: val@vitamarket.com.ua
Michael N. Romanov: https://orcid.org/0000-0003-3584-4644, e-mail: m.romanov@kent.ac.uk
Louis Gressier: https://orcid.org/0009-0001-2601-7025, e-mail: louis.gressier0@gmail.com
John P. Kent: https://orcid.org/0000-0002-4296-3249, e-mail: j.p.kent.82@cantab.net
Attila Salamon: https://orcid.org/0009-0009-1652-6991, e-mail: dr.attila.salamon@gmail.com

Abstract

In waterfowl farms used for producing meat and eggs, a problem of discerning double-yolked (DY) and single-yolked (SY) eggs is rather actual. While in some parts of the world DY eggs are popular as a food product, DY eggs are undesired for hatcheries due to their lower fertility and poorer hatchability. After

* Corresponding authors.

E-mail addresses: val@vitamarket.com.ua (V. G. Narushin); m.romanov@kent.ac.uk (M. N. Romanov)

Declarations of interest: none

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. **Louis Gressier:** investigation. **John P. Kent:** investigation, validation, writing – review & editing. **Attila Salamon:** investigation, validation, writing – original draft, writing – review & editing, project administration.

Valeriy G. Narushin:	https://orcid.org/0000-0001-6799-6605, e-mail: val@vitamarket.com.ua
Michael N. Romanov:	https://orcid.org/0000-0003-3584-4644, e-mail: m.romanov@kent.ac.uk
Louis Gressier:	https://orcid.org/0009-0001-2601-7025, e-mail: louis.gressier0@gmail.com
John P. Kent:	https://orcid.org/0000-0002-4296-3249, e-mail: j.p.kent.82@cantab.net
Attila Salamon:	https://orcid.org/0009-0009-1652-6991, e-mail: dr.attila.salamon@gmail.com

Abstract

In waterfowl farms used for producing meat and eggs, a problem of discerning double-yolked (DY) and single-yolked (SY) eggs is rather actual. While in some parts of the world DY eggs are popular as a food product, DY eggs are undesired for hatcheries due to their lower fertility and poorer hatchability. After examining the morphological parameters of duck and goose DY and SY eggs, we determined a suite of their measured and calculated variables. We developed mathematical formulae that can be used to calculate the estimated quantity of yolks in duck or goose eggs. In this experiment, this innovative analytical approach enabled us to achieve 8.4% of erroneously placed SY eggs in a DY 'basket' for ducks and 3.2% for geese. We also considered options to increase further their identification accuracy. This study provides an instrumental prerequisite for developing respective practical analytical techniques for sorting waterfowl SY vs DY eggs.

Keywords: Double-yolked eggs; Duck eggs; Goose eggs; Egg sorting; Egg parameters; Non-destructive testing

1. Introduction

Ducks and geese provide meat, eggs, foie gras and fat for human consumption, both as regular and functional foods (Romanov, 1997, 2018; Kozák, 2021), especially in East and South-East Asia, with a fast growth in their production (Pingel, 2011). A notable phenomenon in waterfowl, as well as in other poultry species and game birds, is multiple-yolking, i.e., two or more yolks enclosed within one egg (Salamon & Kent, 2016a, 2020), with double-yolked (DY) eggs being the most common (Romanoff & Romanoff, 1949). Few factors are known to affect the generation of DY eggs, including nutrition, light, female age, and genetics (Salamon, 2020a). For example, Dunn et al. (2001a,b) found association of the gonadotropin-releasing hormone receptor gene with the DY trait in broiler breeders. DY eggs are quite popular in some parts of the world as a food product (Ma et al., 2017), being more expensive than single-yolked (SY) eggs (Li et al., 2009). Fertile DY eggs accidentally incubated are considered an undesirable loss due to their lower fertility and hatchability (Fasenko et al., 2000; Salamon & Kent, 2014, 2016b, 2020), thus eventually affecting yield of waterfowl products used for food. Therefore, hatcheries remove DY eggs before incubation, as they are a waste of space and energy in the incubators (Zhang et al., 2014; Salamon, 2015).

DY eggs are heavier, longer, wider and have a higher shape index than SY eggs (Curtis, 1914; Salamon & Kent, 2013a, 2017, 2020). DY eggs are removed before incubation – or selected for research – based on their larger size. However, Salamon & Kent (2016b) showed that this is not sufficient, as 42.73% of DY duck eggs fell within the normal egg weight (W) range, i.e., 75 to 105 g. Possible solutions to overcome this problem are egg candling or usage of computer vision to distinguish DY duck eggs from SY eggs (Ma et al., 2017; Li et al., 2019; Intarakumthornchai & Kesvarakul, 2020; Chen et al., 2022).

Ma et al. (2017) created the Fisher's linear discriminant (FLD) and convolutional neural network (CNN) models for discriminating DY vs SY eggs, although this required a greater hardware capacity (Ma et al., 2017). Li et al. (2019) also extracted the yolk shapes as binary images and used the convex hull algorithm (Duan et al., 2016) and determined the convexity defects that were much larger for DY eggs than for SY eggs. Chen et al. (2022) used a Raspberry Pi small single-board computer and an industrial USB camera to take the images of SY and DY eggs, using CNN and the proposed Resnet50* model. These studies all utilized a refined image to train and test the machine learning to classify SY and DY duck eggs (Ma et al., 2017; Li et al., 2019; Chen et al., 2022). Intarakumthornchai & Kesvarakul (2020) used geometric and weight indicators to separate SY and DY chicken eggs by employing the computer vision, although this approach was not satisfactory for similar sized SY and DY eggs.

Undoubtedly, the use of innovative techniques is a promising avenue for separating duck and goose DY vs SY eggs. However, a number of practical aspects should be taken into account that may impede a potential analytical/technological justification for sorting DY and SY eggs as follows:

(i) The computer vision applications are economically feasible in large hatcheries. The incubation of duck and goose eggs is usually undertaken either in a farm or a specialized hatchery, with a sorting line being uneconomical for smaller quantities of eggs. Nevertheless, selected DY eggs in waterfowl farms can be sold as table eggs (Li et al., 2009; Ma et al., 2017), and their separation from SY eggs would reduce the cost of incubating only SY eggs.

(ii) Waterfowl eggs have a thicker shell and their background color can be maculated, unlike chicken eggs, which complicates the use of candling technologies.

For developing innovative solutions, the morphological parameters of eggs can be taken as a basis. Waterfowl DY eggs are heavier, longer, wider and have a greater shape index than SY ones (Salamon & Kent, 2013a, 2017, 2020). Intarakumthornchai & Kesvarakul (2020) combined several morphological indicators into a complex index for dividing eggs into three categories: (1) DY eggs, (2) SY eggs, and (3) a mixed set of DY and SY eggs. Thus, further separation of a much smaller egg sample of the third category will be beneficial for incubation. A certain amount of DY eggs remaining there would represent an irreversible loss, although being less than that for the entire batch of eggs incubated without prior sorting. Therefore, a successful analytical/technological solution should be focused on minimizing the number of eggs in the third category.

Intarakumthornchai & Kesvarakul (2020) used *W* and the shape index, i.e., the ratio of egg length (*L*) to maximum breadth (*B*), as distinguishing parameters that we will refer here to as DY/SY indicators. Harms & Abdallah (1995) expanded a list of these indicators with shell characteristics, including shell weight and percentage shell. Surely, determination of DY/SY indicators should comply with the principle of non-destructive measurement, and shell parameters are unlikely to meet this criterion. Harms & Abdallah (1995) also suggested a relative index, i.e., shell weight per unit of surface. According to our previous work on non-destructive egg quality testing (Narushin, 1998a,b; Narushin et al., 2004, 2023), such indices can provide a much higher level of prediction than single variables.

The aforementioned studies were aimed at developing the analytical/technological solutions for chicken eggs and, to a lesser extent, for duck eggs from Asian breeds only. However, this problem has a broader relevance in waterfowl eggs (Salamon & Kent, 2014, 2016b, 2020) and deserves a special study. In this regard, we set the goal of developing innovative, simpler, alternative analytical methods for separating duck and goose eggs into DY and SY 'baskets' that can be efficiently implemented in small farms and/or hatcheries. Herewith, the problem of minimizing a mixed sample of eggs can be solved by searching for a set of indicators that allow the most accurate non-destructive identification of DY and SY eggs. To achieve this objective, a series of experiments was undertaken as outlined below.

2. Materials and Methods

For this study, fertile duck eggs (N = 1289 SY, 1302 DY) and goose eggs (N = 31 SY, 31 DY) were obtained from Ballyrichard Farm (Arklow, Ireland; 52°50'5" N, 6°7'49" W) using Aylesbury duck and Legarth goose flocks. The appropriate housing and management conditions were followed as described elsewhere for ducks (Salamon & Kent, 2016b) and geese (Kent & Murphy, 2003; Salamon & Kent, 2013b, 2016c).

The eggs were weighed, and their values of L and B were measured with a vernier caliper. Based on the measurements of L and B, the egg volume (V) and surface area (S) were calculated using the formulae from Narushin et al. (2021):

$$V = 0.5202LB^2 - 0.4065, \tag{1}$$

$$S = 0.933B(B + 2.343L), \tag{2}$$

where L and B are the egg length and maximum breadth.

Egg density (D) was calculated as a ratio of W to V. In addition to the above parameters, the following ratios were used as potential DY/SY indicators: B/L, V/S, and W/S. Quantity of yolks (QY) in eggs was determined using their candling. The STATISTICA 5.5 program (StatSoft, Inc./TIBCO, Palo Alto, CA, USA) and computational Microsoft Excel tools were used to process the results.

3. Results and Discussion

The appropriate measured and calculated DY and SY duck/goose egg variables are given in Tables 1 and 2.

Analyzing the data of Tables 1 and 2, it seems that DY and SY eggs differed by their parameters so that it was not a problem to recognize them and separate one group from another. These differences were obvious especially for goose eggs, in which even the D values were significantly different, contrary to the similar indicator in duck eggs. Nonetheless, it was not so easy to arrange the eggs into different baskets depending on QY as can be seen from visualizing the data of morphological measurements of DY and SY eggs in Fig. 1. Hereby, we focused on three fundamental measurements, W, L and B, whose values formed the basis for calculating all other parameters.

The graphical representation in Fig. 1 shows that a certain part of the eggs can be classified for sure as either DY (higher values of the measured parameter) or SY (lower values of the parameter). On the other hand, there were some overlapping areas in which both SY and DY eggs were present. While this area was relatively small for the goose eggs, for the duck eggs it covers around 50% of the entire sample. In addition, even if we are talking about separating at least a guaranteed part of the eggs that go beyond the overlapping area, there is no criterion by which it would be possible to evaluate the boundaries of this area. What can be a key value of the measured parameter, whose mode of exceeding or subceeding would allow automatic classification into one or another group? To answer this question, we performed a correlation analysis of the egg parameters presented in Table 1 and 2 relative to QY which we expressed mathematically as 1 (for SY) and 2 (for DY). The respective Pearson’s correlation coefficients of the measured and calculated egg parameters are presented in Table 3.

As the data analysis showed (Table 3), the correlation between the morphological parameters and *QY* was higher in goose eggs than in duck eggs. This result was quite predictable, judging from the graphical dependencies presented in Fig. 1. Due to the observed differences, further approaches to the development of an analytical methodology for putting DY and SY eggs into different baskets will be considered below separately for duck and goose eggs.

3.1. Duck Eggs

Most of the variables demonstrated very similar correlation (Table 1), suggesting an equivalent effect on *QY*. Taking the set of parameters (*W*, *L*, *B*, *V*, *S*) in different combinations including single and multiple functions, we chose the following recalculating formulae that showed the best results:

$$QY = 0.0171W - 0.2285, \tag{3}$$

with R^2 = 0.325;

$$QY = 0.0173V - 0.1411, \tag{4}$$

with R^2 = 0.307;

$$QY = 0.025S - 1.0772, \tag{5}$$

with R^2 = 0.329;

$$QY = 0.6246L - 3.0149 \tag{6}$$

with R^2 = 0.432;

$$QY = 1.1537 \cdot 10^{-14} \cdot W^{4.0688} \cdot V^{-14.542} \cdot S^{17.2335} \tag{7}$$

with R^2 = 0.441;

$$QY = 0.0591W^{4.1007} \cdot L^{-1.2077} \cdot B^{-8.2412} \tag{8}$$

with R^2 = 0.447.

In Eqns 3 to 8, the values of *W* are taken in g, *V* in cm^3, *S* in cm^2, and *L* and *B* in cm.

To represent the obtained single parametric equations (Eqns 3 to 6) graphically (Fig. 2), we can assume that a certain S-curve will be a more convenient for the approximation.

The corresponding approximation of the data with a sigmoid (Fig. 2) resulted in the following functions:

$$QY = 1 + \frac{1}{1 + e^{-10(W - W_{av})}}, \tag{9}$$

with $R^2 = 0.173$,

where W_{av} is an average of the egg weight that in our case was equal to 101.12 g;

$$QY = 1 + \frac{1}{1 + e^{-10(V - V_{av})}}, \tag{10}$$

with $R^2 = 0.316$,

where V_{av} is an average of the egg volume, which in our case equaled 94.93 cm^3;

$$QY = 1 + \frac{1}{1 + e^{-10(S - S_{av})}}, \tag{11}$$

with $R^2 = 0.333$,

where S_{av} is an average of the egg surface area, equaling 102.98 cm^2 in our case;

$$QY = 1 + \frac{1}{1 + e^{-4.82(L - L_{av})}}, \tag{12}$$

with $R^2 = 0.490$,

where L_{av} is an average of the egg length, being in our case equal to 7.225 cm.

The best prediction of *QY* was observed when being predicted by the sigmoid using *L* (Eqn12). Nevertheless, the only worthy option for choosing the right way of egg detection was to compare a number of correctly and/or incorrectly determined eggs among the SY and DY sets. Accordingly, choosing the formulae for the best results of the *QY* recalculations, the number of the correctly and incorrectly detected eggs was determined (Table 4).

Analyzing the results of Table 4, we assumed that Eqn8 provided the best prediction, resulting in a total of 430 incorrectly detected eggs, or 16.6% of the whole set (2591 eggs). In the case of Eqn8, three measurements, i.e., *W*, *L* and *B*, were involved in such a prediction.

Furthermore, we considered the following hypothesis as a goal for a decision-making process: the SY eggs are much worthy than DY ones. Therefore, the only criterion for the pre-incubational sorting is to detect the SY eggs as accurate as possible since they are the mostly valuable product. That means, if there are two sets resulted from such detection, we need to minimize a quantity of the SY eggs being mistakenly placed into the DY basket. In this case, Eqn7 seemed to be more precise as it conformed to a lesser quantity of the incorrectly detected SY eggs as compared to Eqn8 (108 vs 111). Thus, within the framework of our experimental dataset, we saved three more valuable SY eggs when using Eqn7. On the other hand, this also resulted in putting five more DY eggs into an incubator, but the loss would be much less due to such a mistake. Only the incubation space would be used ineffectively. Nevertheless, even this can be improved with the help of Eqn8, but the obtained results should only be used for the SY egg group. Therefore, we may recommend both formulae: Eqn7 with its three basic egg variables, *W*, *V* and *S*, and Eqn8 with *W*, *L* and *B* as the most efficient predictors for defining SY and DY eggs.

Despite the obtained results, there were still lots of incorrectly determined eggs in both baskets (~8% for SY and 25% for DY). Therefore, an additional analysis was undertaken to evaluate the distribution of the measurements of various egg variables, splitting them into correctly and incorrectly detected eggs. It was established that *L* in Eqn8 was the best parameter from the point of a well-defined border between the correct and incorrect results (Fig. 3).

In other words, Fig. 3a demonstrates the eggs classified with the parameter *L* and appeared in the basket for the DY eggs correctly (blue dots) and mistakenly (purple dots). Herewith, the eggs of a lower length (e.g., 7 cm and less in our case) can be removed and used further for the incubation as potentially SY ones. For sure, it is rather difficult to guarantee that another batch of the eggs will have the same boundary (7 cm). Nevertheless, even the rejection of several eggs of the lowest length and moving these into the SY basket can help in saving worthy eggs from being wasted.

The situation was similar regarding the SY egg basket (Fig. 3b). The purple dots represented the DY eggs mistakenly detected as SY ones. We can undertake a similar procedure, just to reject the eggs of the highest length, as potentially DY ones.

3.2. Goose Eggs

As for the results of the correlation analysis (Table 2), a sufficiently large number of goose egg parameters can be used as the basis for calculating *QY*. This met the goal of this study to define a way to make such a prediction as accurate as possible. As for the results of the measurements (Fig. 1b), the SY and DY goose eggs were absolutely similar within the interval of around 205–230 g. In other words, if *W* fell within such an interval, it was impossible to predict if it was a SY or a DY egg. In our case, there were 10 DY and 3 SY eggs within this interval meaning that around 22% of the eggs could be detected mistakenly.

In this respect, the following single and multi-parametric formulae showed the best prediction:

$$QY = 0.0082W - 0.3079, \tag{13}$$

with R^2 = 0.685;

$$QY = 0.008V - 0.1024, \tag{14}$$

with R^2 = 0.692;

$$QY = 0.0142S - 0.9212, \tag{15}$$

with R^2 = 0.720;

$$QY = 0.3978L - 2.4119, \tag{16}$$

with R^2 = 0.771;

$$QY = 30690037W^{-0.9848} \cdot V^{9.704} \cdot S^{-14.4846} \cdot L^{5.0451}, \tag{17}$$

with R^2 = 0.765;

$$QY = 0.00404W^{-0.06077} \cdot L^{2.43582}, \tag{18}$$

with R^2 = 0.759.

In Eqns 13 to 18, the values of *W* are taken in g, *V* in cm^3, *S* in cm^2, and *L* in cm.

The highest correlation (R^2 = 0.771) was identified when only one parameter, *L*, was used for the prediction. Similar to what we did for the duck eggs, the prediction function for *QY* depending on *L* was approximated with the sigmoid:

$$QY = 1 + \frac{1}{1 + e^{-10(L - L_{av})}}, \tag{19}$$

with R^2 = 0.840,

where L_{av} is the average number of the egg length, which in our case was equal to 9.83 cm.

All the deduced equations (13–19) were checked under a number of correctly and incorrectly determined eggs. The recalculated *QY* values were rounded for integers, and the results are shown in Table 5.

Using the recalculation results (Table 5), it is possible to conclude that the most valuable predictor for the identification of DY/SY goose eggs was *L*. Using the *L* values, it is possible to define the eggs according to the formula (16) or (19). Although Eqn19 was more accurate (R^2 = 0.840), it resulted in the same two wrong results as the linear function (Eqn16). However, the advantage of both predicting formulae was in getting only one valuable SY egg into the basket where DY goose eggs were collected. Such a recalculation enabled reducing the prediction error to 3.2%. Only two eggs of 62 were confused in their identification.

We cannot completely exclude the fact that the investigated sample of goose eggs was significantly inferior in size relative to the number of duck eggs involved in the experiment. Perhaps, similar to duck eggs, it makes sense to use more parameters to identify *QY* for goose eggs, too. However, in our opinion, another hypothesis would also be valid. Amongst the poultry species, geese have been subject to artificial selection to the smallest extent and least influenced by breeders. As a result, domestic geese are, for instance, still seasonal layers (Shi et al., 2008) and tend to lay an egg every second day (Romanov, 1999; Kent & Murphy, 2003). In this regard, they maintain certain common characteristics with the wild species and have a greater variation of parameters than ducks. Therefore, it is rather obvious to hypothesize that the use of the parameter *L* as the DY/SY indicator may be justified for a much larger set of goose eggs.

Another nuance that we considered necessary to check was how significant the calculation results would be if there would be no DY eggs in a sample at all. After all, our experimental sample was compiled artificially. It is quite obvious that, in the conditions of an ordinary goose farm, such a high percentage of DY eggs is simply impossible. In this regard, we randomly selected 80 goose eggs, which we carefully analyzed with an ovoscope, making sure that they all contained one yolk. Using the same methodology for measuring and calculating the main parameters, we determined the variability of these indicators that were within the following limits (mean ± SD): $W = 155.1 \pm 20.5$, $V = 145.6 \pm 19.3$, $S = 138.5 \pm 12.0$, $L = 8.7 \pm 0.4$.

The use of formula (19), when only *L* is involved in the calculation, revealed that in our sample there would be only 38 SY eggs and the remaining 42 were DY eggs, being, therefore, subject to discarding. Naturally, such an output cannot in any way be considered economically feasible and acceptable. However, using Eqn17 with a full set of parameters (*W*, *V*, *S* and *L*) demonstrated extremely accurate results. All 80 eggs from this sample were SY eggs and can be successfully used for incubation.

Thus, when identifying the number of yolks in both duck and goose eggs, it is advisable to use the maximum set of parameters so as not to be “hostages” of a possible erroneous and/or random tendency of one individual measurement. What is meant? For example, different age categories, in both ducks and geese, lay eggs whose sizes cannot be clearly predicted (Salamon, 2015, 2020b). In domestic ducks, some studies showed increasing *W* early in the laying period that reached a plateau followed by a subsequent reduction at the laying period end (e.g., Applegate et al., 1998; Mazanowski et al., 2005), while others found a linear growth in *W* over the whole laying period (e.g., Adamski et al., 2005; Kokoszynski et al., 2007). In contrast, *W* in domestic geese declines over the first half of the laying season and reaches a baseline weight which is maintained until the laying season end (Salamon, 2015; Mroz & Lepek, 2003). Also, it was found in several studies that *W* of two years old geese were greater than that in one year old geese (Brun et al., 2003; Juodka et al., 2012; Salamon & Kent, 2013b; Adamski et al, 2016). *W* continued to increase up to 4–5 years of age and then declined (Salamon & Kent, 2013b; Adamski et al, 2016). Since flocks of different ages are often kept together on waterfowl farms, certain contradictions may arise with respect to the sizes of SY and DY eggs. For instance, ducks or geese laying smaller eggs produce a DY egg, the size of which is smaller or the same as that of a SY egg for that part of the flock that lays larger eggs. It is precisely such uncertainties that can be solved by applying greater number of indicators involved in the calculation. The more parameters are used, the greater the likelihood of obtaining an adequate result.

Proponents of using the maximum set of egg parameters to determine the number of yolks in them were also Intarakumthornchai & Kesvarakul (2020), who showed that the usage of the variables *W*, *V*, *S*, *L* and *B* as the DY/SY indicators allow the significant reduction of the mixed category of DY and SY eggs.

Therefore, we can recommend for farms and small hatcheries to implement our findings in daily practice. For further analytical/technological developments, such a technology for segregating eggs into different baskets using the results of the mathematical calculations will minimize the number of eggs inside the third mixed category. Thus, their further identification with a more sophisticated analytical technique can make such a process incomparably cheaper. At the same time, the use of alternative approaches will eliminate the possible errors inherent in each method, thereby increasing the likelihood of correctly identifying the number of yolks inside the egg.

4. Conclusions

Based on the current innovative analysis of the morphological parameters of duck and goose DY and SY eggs, the following practical recommendations can be proposed for detecting and distinguishing DY and SY eggs:

For duck eggs:

1. To analyze the egg batch by measuring and/or calculating the variables *W*, *L*, *B*, *V* and *S*.
2. To recalculate *QY* with Eqns7 and 8, the obtained *QY* values being rounded to integers (1 or 2).
3. The eggs with *QY* = 1 according to Eqn7 are considered as SY and should be moved to the SY basket. The eggs with *QY* = 2 according to Eqn8 are considered as DY and moved to the DY basket.

4. The eggs from the SY basket having the highest length are considered as DY and should be moved to the DY basket.
5. The eggs from the DY basket having the lowest length are considered as SY and moved to the SY basket.

For goose eggs:

1. To analyze the egg batch by measuring their L values.
2. To recalculate the QY values with either Eqns 16 or 19. The obtained QY values should be rounded to integers (1 or 2).
3. The eggs with $QY = 1$ are considered as SY being moved to the SY basket. The eggs with $QY = 2$ are considered as DY and moved to the DY basket.

Declaration of Competing Interest

The authors declare no conflicts of interest.

Data Availability

Data will be made available upon request.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Compliance with ethical standards

None.

References

Adamski, M., Bernacki, Z., & Kużniacka, J. (2005). Changes in the biological value of duck eggs defined by egg quality. *Folia Biologica (Kraków)*, *53*(Suppl.), 107–114. https://doi.org/10.3409/173491605775789335

Adamski, M., Kucharska-Gaca, J., Kuźniacka, 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*. https://doi.org/10.1399/eps.2016.148

Applegate, T. J., Harper, D., & Lilburn, M. S. (1998). Effect of hen production age on egg composition and embryo development in commercial Pekin ducks. *Poultry Science*, *77*, 1608–1612. https://doi.org/10.1093/ps/77.11.1608

Brun, J. M., Delaunay, I., Sellier, N., Alletru, B., Rouvier, R., & Tixier-Boichard, M. (2003). Analysis of laying traits in first cycle geese in two production systems. *Animal Research*, *52*, 125–140. https://doi.org/10.1051/animres:2003010

Chen, W., Du, N., Dong, Z., & Yang, Z. (2022). Double yolk nondestructive identification system based on Raspberry Pi and computer vision. *Journal of Food Measurement and Characterization*, *16*, 1605–1612. https://doi.org/10.1007/s11694-021-01269-y

Curtis, M. R. (1914). Studies on the physiology of reproduction in the domestic fowl. VI. Double and triple-yolked eggs. *Biological Bulletin*, *26*, 55–83. https://doi.org/10.2307/1536071

Duan, Y., Wang, Q., Li, X., & Tang, Y. (2016). High-throughput online detection method of egg size and shape based on convex hull algorithm. *Transactions of the Chinese Society of Agricultural Engineering*, *32*, 282–288.

Dunn, I. C., Miao, Y.-W., Morris, A., Romanov, M. N., Wilson, P. W., Waddington, D., & Sharp, P. J. (2001a). Candidate genes and reproductive traits in a commercial broiler breeder population, an association study. *Journal of Animal Science*, *79*(Suppl. 1, Vol. 2), 43.

Dunn, I. C., Miao, Y.-W., Morris, A., Romanov, M. N., Waddington, D. W., Wilson, P. W., & Sharp, P. J. (2001b). Association between candidate genes and reproductive traits in a commercial broiler breeder population. *British Poultry Science*, *42*(Suppl. 1), S113–S114. https://doi.org/10.1080/00071660152681692

Fasenko, G. M., Robinson, F. E., Danforth, B. L., & Zelter, I. (2000). An examination of fertility, hatchability, embryo mortality, and chick weight in double versus single-yolked broiler breeder eggs. *Canadian Journal of Animal Science*, *80*, 489–493. https://doi.org/10.4141/A99-090

Harms, R. H., & Abdallah, A. G. (1995). A comparison of eggshell weight from double- and single-yolked eggs. *Poultry Science*, *74*, 612–614. https://doi.org/10.3382/ps.0740612

Intarakumthornchai, T., & Kesvarakul, R. (2020). Double yolk eggs detection using fuzzy logic. *PLoS One*, *15*, e0241888. https://doi.org/10.1371/journal.pone.0241888

Juodka, R., Kiskiene, A., Skurdeniene, I., Ribikauskas, V., & Nainiene, R. (2012). Lithuanian vishtines goose breed. *World's Poultry Science Journal*, *68*, 51–62. https://doi.org/10.1017/S0043933912000062

Kent, J. P., & Murphy, K. J. (2003). Synchronized egg laying in flocks of domestic geese (*Anser anser*). *Applied Animal Behaviour Science*, *82*, 219–228. https://doi.org/10.1016/S0168-1591(03)00063-7

Kokoszyński, D., Bernacki, Z., & Korytkowska, H. (2007). Eggshell and egg content traits in Peking duck eggs from the P44 reserve flock raised in Poland. *Journal of Central European Agriculture*, *8*, 9–16.

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

Li, H.-F., Zhu, W.-Q., Chen, K.-W., Zhang, T.-J., & Song, W.-T. (2009). Association of polymorphisms in the intron 1 of duck prolactin with egg performance. *Turkish Journal of Veterinary and Animal Sciences*, *33*, 193–197. https://doi.org/10.3906/vet-0709-4

Li, L., Wang, Q., Weng, F., & Yuan, C. (2019). Nondestructive visual inspection method of double-yolked duck egg. *International Journal of Pattern Recognition and Artificial Intelligence*, *33*, 1955006. https://doi.org/10.1142/S0218001419550061

Ma, L., Sun, K., Tu, K., Pan, L., & Zhang, W. (2017). Identification of double-yolked duck egg using computer vision. *PLoS One*, *12*, e0190054. https://doi.org/10.1371/journal.pone.0190054

Mazanowski, A., Bernacki, Z., & Kisiel, T. (2005). Comparing the structure and chemical composition of duck eggs. *Annals of Animal Science*, *5*, 53–66.

Mroz, E., & Lepek, G. (2003). A biological evaluation of hatches in different phases of goose egg production. *Polish Journal of Natural Sciences*, *13*, 115–123.

Narushin, V. G. (1998a). Mathematical algorithm for quality control in egg production. *Acta Horticulture*, *476*, 345–348. https://doi.org/10.17660/ActaHortic.1998.476.40

Narushin, V. G. (1998b, June). *Shell Strength as an Indicator of Egg Quality: Methods for Estimation*. In Proceedings of the 10th European Poultry Conference (Vol. 2, pp. 684–687), World's Poultry Science Association, Jerusalem, Israel.

Narushin, V. G., van Kempen, T. A., Wineland, M. J., & Christensen, V. L. (2004). Comparing infrared spectroscopy and egg size measurements for predicting eggshell quality. *Biosystems Engineering*, *87*, 101–107. https://doi.org/10.1016/j.biosystemseng.2003.12.006

Narushin, V. G., Romanov, M. N., & Griffin, D. K. (2021). 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

Narushin, V. G., Kent, J. P., Salamon, A., Romanov, M. N., & Griffin, D. K. (2023). Density of egg interior: Looking inside an egg while keeping it intact. *Innovative Food Science & Emerging Technologies*, *87*, 103387. https://doi.org/10.1016/j.ifset.2023.103387

Pingel, H. (2011). Waterfowl production for food security. *Lohmann Information*, *46*(2), 32–42.

Romanoff, A. L., & Romanoff, A. J. (1949). *The avian egg*. John Wiley & Sons Inc., New York.

Romanov, M. N. (1997). Impact of genotype, nutrition and management systems on goose production efficiency. In *Proceedings of 11th European Symposium on Waterfowl* (pp. 33–41). Nantes, France: Association Groupe Francais de la WPSA (French Branch).

Romanov, M. N. (1999). Goose production efficiency as influenced by genotype, nutrition and production systems. *World's Poultry Science Journal*, *55*, 281–294. https://doi.org/10.1079/WPS19990021

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; eBook) (Vol. 1, pp. 487–489). London, UK: Taylor & Francis Inc.; Boca Raton, FL, USA: CRC Press Inc. https://doi.org/10.1081/E-EAS2-120019645

Salamon, A. (2015). Maternal investment – and its constraints – in the egg of domestic waterfowl. Ph. D. thesis, University College Dublin.

Salamon, A. (2020a). Factors affecting the production of double-yolked eggs. *World's Poultry Science Journal*, *76*, 815–826. https://doi.org/10.1080/00439339.2020.1830011

Salamon, A. (2020b). Fertility and hatchability in goose eggs: A review. *International Journal of Poultry Science*, *19*, 51–65. https://doi.org/10.3923/ijps.2020.51.65

Salamon, A., & Kent, J. P. (2013a). Double and single yolked duck eggs: their contents and dimensions compared and the mechanical stimulation hypothesis for albumen secretion is supported. *International Journal of Poultry Science*, *12*, 254–260. https://doi.org/10.3923/ijps.2013.254.260

Salamon, A., & Kent, J. P. (2013b). 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. (2014). Changes during incubation within double-yolked duck (Anas platyrhynchos domesticus) eggs: yolk position, mortality, hatchability and the importance of an optimal egg size. *International Journal of Poultry Science*, *13*, 695–702. https://doi.org/10.3923/ijps.2014.695.702

Salamon, A., & Kent, J. P. (2016a). Triple-yolked eggs in domestic ducks: a rare occurrence. *Poultry Science*, 95, 1179–1181. https://doi.org/10.3382/ps/pew004

Salamon, A., & Kent, J. P. (2016b). Yolk size and ovulation order determine fertility within double-yolked duck (Anas platyrhynchos domesticus) eggs. *Reproduction, Fertility and Development*, *28*, 440–445. https://doi.org/10.1071/RD14059

Salamon, A., & Kent, J. P. (2016c). Manual egg turning is necessary for optimal hatching in geese. *International Journal of Poultry Science*, *15*, 57–61. https://doi.org/10.3923/ijps.2016.57.61

Salamon, A., & Kent, J. P. (2017). Egg shape is constrained more by width than length, evidence from double-yolked duck eggs. *International Journal of Poultry Science*, *16*, 387–392. https://doi.org/10.3923/ijps.2017.387.392

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

Shi, Z. D., Tian, Y. B., Wu, W., & Wang, Z. Y. (2008). Controlling reproductive seasonality in the geese: a review. *World's Poultry Science Journal*, *64*, 343–355. https://doi.org/10.1017/S0043933908000081

Zhang, W., Pan, L., Tu, K., Zhang, Q., & Liu, M. (2014). Comparison of spectral and image morphological analysis for egg early hatching property detection based on hyperspectral imaging. *PLoS One*, *9*, e88659. https://doi.org/10.1371/journal.pone.0088659

Figure captions

Fig. 1 Visualization of the distribution of the parameters *W*, *L* and *B*. (**a**) Duck eggs (blue points indicate the DY eggs, and yellow ones the SY eggs); (**b**) goose eggs (dark blue points indicate the DY eggs, and purple ones the SY eggs)

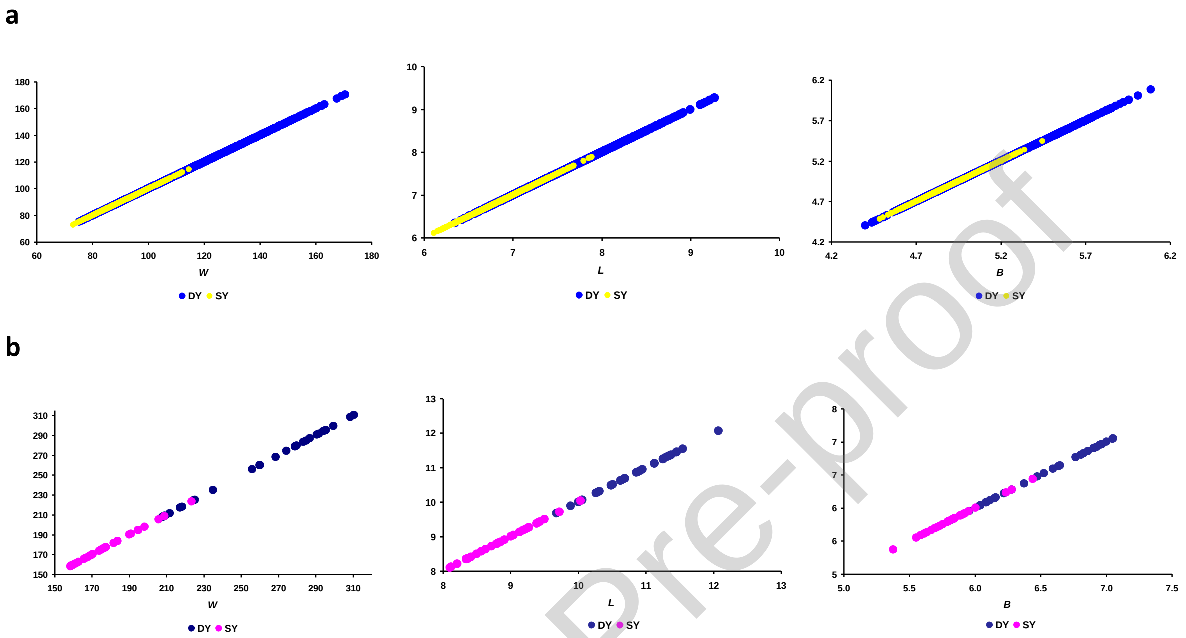
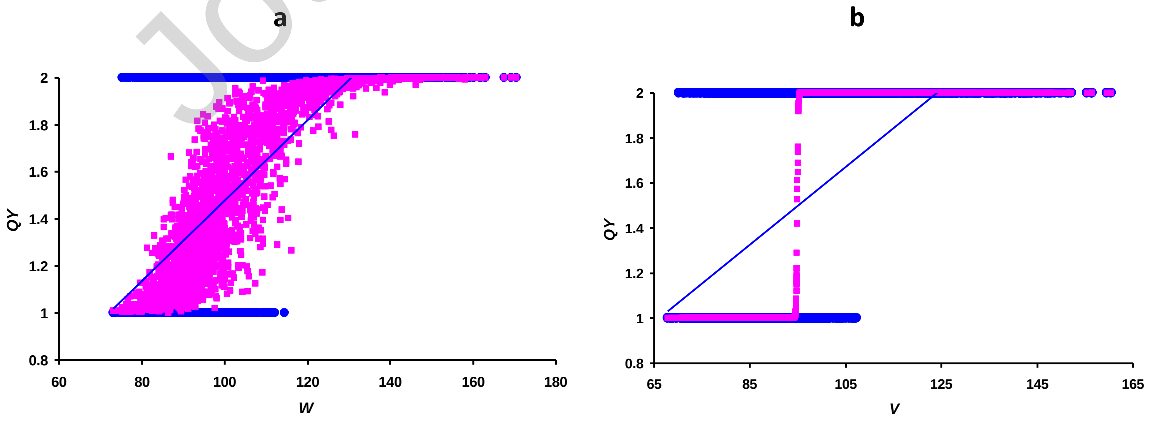


Fig. 2 A graphical visualization of the linear (blue line) and sigmoid (purple line) approximation of the dependences of the quantity of yolks (*QY*) relative to the duck egg weight, *W* (**a**); volume, *V* (**b**); surface area, *S* (**c**); and length, *L* (**d**)



c

d

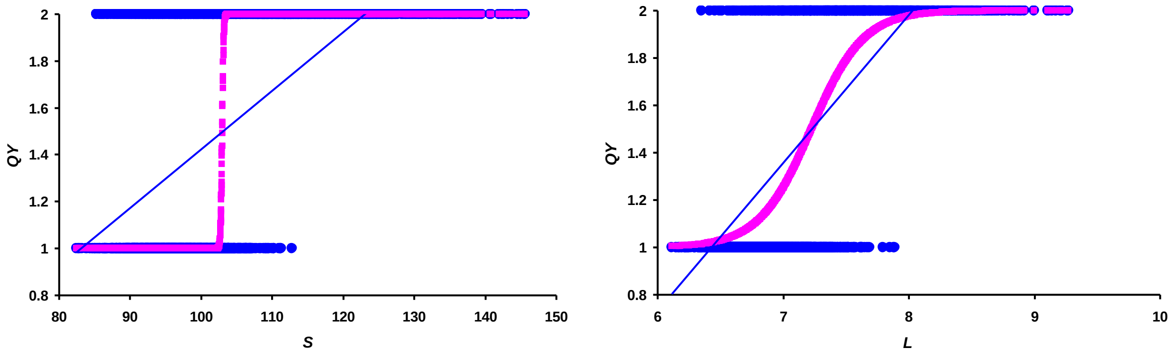


Fig. 3 Correct (blue dots) and incorrect (purple dots) results of detecting DY (**a**) and SY (**b**) duck eggs using Eqn8

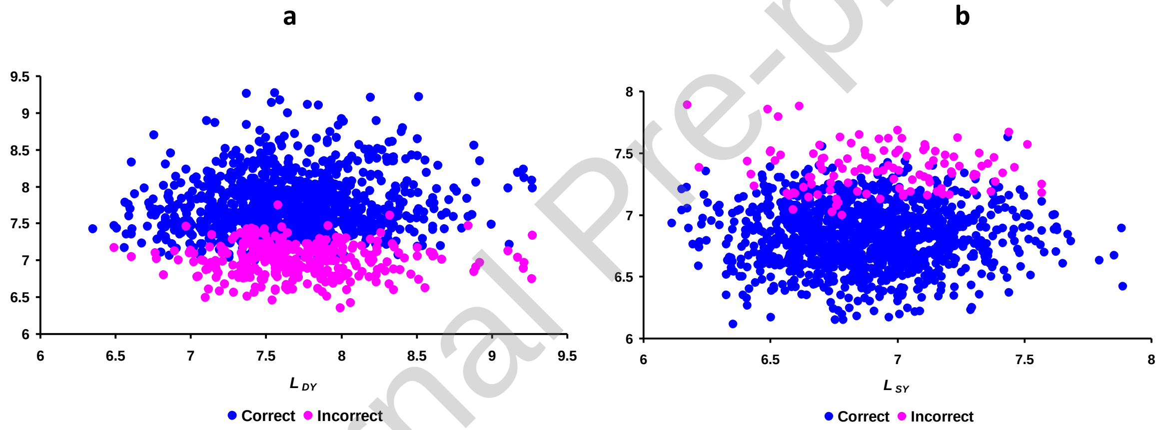


Table 1 Data of measured and calculated DY and SY duck egg variables

Parameters	Minimum value		Maximum value		Mean		Standard deviation	
	SY	DY	SY	DY	SY	DY	SY	DY
Egg weight, *W* (g)	73.0	75.3	114.5	170.5	91.7^a	110.67^a	6.99	18.14
Length, *L* (cm)	6.1	6.3	7.9	9.3	6.9^a	7.6^a	0.28	0.49
Max breadth, *B* (cm)	4.5	4.4	5.4	6.1	4.9^a	5.1^a	0.15	0.30
Egg density, *D* (g/cm^3)	1.011	0.953	1.132	1.137	1.065	1.066	0.015	0.016
Egg volume, *V* (cm^3)	67.8	70.2	107.2	160.4	86.1^a	103.9^a	6.86	17.66
Surface area, *S* (cm^2)	82.4	85.2	112.8	145.6	96.4^a	109.6^a	5.13	12.29
Volume to surface ratio, *V*/*S*	0.82	0.82	0.97	1.10	0.89^a	0.94^a	0.02	0.05
Weight to surface ratio, *W*/*S*	0.87	0.87	1.03	1.22	0.95^a	1.00^a	0.02	0.05

Shape index, *B*/*L*	0.63	0.57	0.82	0.79	0.71[a]	0.68[a]	0.03	0.03

[a] $p < 0.05$; the values without any index are insignificant

Table 2 Data of measured and calculated DY and SY goose egg variables

Parameters	Minimum value		Maximum value		Mean		Standard deviation	
	SY	DY	SY	DY	SY	DY	SY	DY
Egg weight, *W* (g)	158.4	207.8	223.4	321.0	177.9[a]	261.0[a]	16.38	37.09
Length, *L* (cm)	8.1	9.7	10.0	12.1	8.9[a]	10.8[a]	0.50	0.57
Max breadth, *B* (cm)	5.4	5.8	6.4	7.1	5.8[a]	6.6[a]	0.21	0.39
Egg density, *D* (g/cm^3)	1.051	1.040	1.202	1.115	1.139[a]	1.078[a]	0.039	0.022
Egg volume, *V* (cm^3)	132.5	189.6	198.6	304.4	156.5[a]	242.6[a]	16.35	37.96
Surface area, *S* (cm^2)	128.9	165.3	168.5	229.1	144.7[a]	195.2[a]	10.12	20.25
Volume to surface ratio, *V/S*	1.02	1.13	1.18	1.33	1.08[a]	1.24[a]	0.04	0.07
Weight to surface ratio, *W/S*	1.13	1.25	1.33	1.40	1.23[a]	1.33[a]	0.04	0.06
Shape index, *B/L*	0.58	0.54	0.72	0.66	0.66[a]	0.61[a]	0.04	0.03

[a] $p < 0.05$; the values without any index are insignificant

Table 3 Correlation between measured/calculated egg variables and the quantity of yolks (*QY*) in duck and goose eggs

Parameters	Correlation with *QY* in duck eggs	Correlation with *QY* in goose eggs
Egg weight, *W* (g)	0.570[a]	0.827[a]
Length, *L* (cm)	0.657[a]	0.878[a]
Max breadth, *B* (cm)	0.411[a]	0.760[a]
Egg density, *D* (g/cm^3)	0.037	-0.696[a]
Egg volume, *V* (cm^3)	0.554[a]	0.832[a]
Surface area, *S* (cm^2)	0.574[a]	0.849[a]
Volume to surface ratio, *V/S*	0.522[a]	0.823[a]
Weight to surface ratio, *W/S*	0.555[a]	0.727[a]
Shape index, *B/L*	-0.497[a]	-0.616[a]

[a] $p < 0.05$; the values without any index are insignificant

Table 4 The results of *QY* recalculations in the duck eggs

Incorrectly defined eggs with the following equations	SY eggs appeared in the basket for DY ones (*QY* = 2)		DY eggs appeared in the basket for SY ones (*QY* = 1)		Total	
	No. of eggs	Per cent to total number	No. of eggs	Per cent to total number	No. of eggs	Per cent to total number
Eqn3 (*W*)	120	9.31	444	34.10	564	21.77
Eqn4 (*V*)	131	10.16	460	35.33	591	22.81
Eqn5 (*S*)	131	10.16	441	33.87	572	22.08
Eqn6 (*L*)	127	9.85	332	25.50	459	17.72
Eqn7 (*W*, *V*, *S*)	108	8.38	324	24.88	432	16.67
Eqn8 (*W*, *L*, *B*)	111	8.61	319	24.50	430	16.60
Eqn9 (*W*)	305	23.66	515	39.55	820	31.65
Eqn10 (*V*)	131	10.16	462	35.48	593	22.89
Eqn11 (*S*)	135	10.47	437	33.56	572	22.08
Eqn12 (*L*)	133	10.32	325	24.96	458	17.68

Table 5 The results of *QY* recalculations in the goose eggs

Incorrectly defined eggs with the following equations	SY eggs appeared in the basket for DY ones (*QY* = 2)		DY eggs appeared in the basket for SY ones (*QY* = 1)		Total	
	No. of eggs	Per cent to total number	No. of eggs	Per cent to total number	No. of eggs	Per cent to total number
Eqn13 (*W*)	8	25.8	1	3.2	9	14.5
Eqn14 (*V*)	7	22.6	0	0	7	11.3
Eqn15 (*S*)	6	19.4	0	0	6	9.7
Eqn16 (*L*)	1	3.2	1	3.2	2	3.2
Eqn17 (*W*, *V*, *S*, *L*)	2	6.5	1	3.2	3	4.8
Eqn18 (*W*, *L*)	2	6.5	1	3.2	3	4.8
Eqn19 (*L*)	1	3.2	1	3.2	2	3.2

CRediT authorship contribution statement

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. **Louis Gressier:** investigation. **John P. Kent:** investigation, validation, writing – review & editing. **Attila Salamon:** investigation, validation, writing – original draft, writing – review & editing, project administration.

Declaration of Interest Statement

The authors declare that they have no conflicts of interest.

Highlights

- Being food products, duck/goose eggs are subject to math and engineering research.
- Quantity of yolks in them can be predicted based on their physical characteristics.
- We introduce here an innovative approach to predict single- and double-yolked eggs.
- The formulae are applicable in areas of food research and emerging technologies.