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REGRESSION MODELS FOR ESTIMATING CHICK HATCHLING WEIGHT FROM SOME EGG GEOMETRY TRAITS

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Abstract: The prediction of chicks' weight before hatching is an important element of selection, aimed at improving the uniformity rate and productivity of birds. With this regards, our goal was to develop and evaluate optimum models for similar prediction in two White Plymouth Rock chickens lines – line L and line K on the basis of the incubation egg weight and egg geometry characteristics – egg maximum breadth (*B*), egg length (*L*), geometric mean diameter (*Dg*), egg volume (*V*), egg surface area (*S*). A total of 280 eggs (140 from each line) laid by 40-week-old hens were randomly selected. Mean arithmetic values, standard deviations and coefficients of variation of studied parameters were determined for each line. Correlation coefficients between the weight of hatchlings and predictors were the highest for egg weight, geometric mean diameter, volume and surface area of eggs (r=0.731-0.779 for line L; r=0.802-0.819 for line K).

Nine linear regression models were developed and their accuracy evaluated. The regression equations of hatchlings' weight vs egg length had the lowest coefficient of determination (0.175 for line K and 0.291 for line L), but when egg length and breadth entered the model together, its value increased significantly up to 0.541 and 0.665 for lines L and K, respectively. The weight of day-old chicks from line L could be predicted with higher accuracy with a model involving egg surface area apart egg weight (ChW=0.513EW+0.282S - 10.345; R^2=0.620). In line K a more accurate prognosis was attained by adding egg breadth as an additional predictor to the weight in the model (ChW=0.587EW+0.566B - 19.853; R^2=0.692). The study demonstrated that multiple linear regression models were more precise that single linear models.

Key words: chick weight, egg weight, egg geometry parameters, regression models

Introduction

The avian egg is a biological system whose purpose is to guarantee the proper development of the embryo and successful hatching as a fully developed chick (*Narushin and Romanov, 2002*). *Tahir et al.* (*2011*) outlined that incubation egg weight and hatchlings' weight were important for modelling or predicting slaughter weight and economic efficiency.

Normally, the shape of avian eggs is oval. The mathematical description of egg profile allows calculation of its volume and surface area on the basis of its breath and length. The results from various experiments showed that this geometry traits could be used for prediction of the weight of hatchlings (*Narushin et al. 2002*), the weight of eggs (*Rashidi and Gholami, 2011*), internal properties and composition of eggs (*Shafey et al., 2014*), hatchability (*Narushin and Romanov, 2002*), eggshell quality (*Altuntaş and Şekeroğlu, 2008*). In comparison with these geometry traits, egg weight was more important for hatchling's weight (*Narushin et al., 2002; Sahin et al., 2009*), with specific effect of the line and breed. Numerous studies have shown that egg weight had a substantial influence on the weight of day-old chickens (*Mitrović et al., 2011*; *Traldi et al., 2011*; *Mukhtar et al., 2013*; *Ng'ambi et al., 2013*; *Mbajiorgu and Ramaphala, 2014*; *Iqbal et al., 2016; 2017*).

Egg length and breadth are traits that are easy to determine and therefore, often used in experiments with poultry eggs. They could influence the weight of day-old chicks. *Khurshid et al.* (*2003*) demonstrated that these parameters were reliable for predicting the weight of hatchling quails. *Farooq et al.* (*2001*) reported significant correlation coefficients between aforementioned dimensions and chick weight - r=0.58 with egg length and r=0.78 with egg breadth. Experiments with eggs of different fowl species (goose, quail and chicken) indicated that egg shape index (*Saatci et al., 2005*; *Yilmaz and Caglayan, 2008*; *Sahin et al., 2009; Lotfi et al., 2011*), and egg density (*Narushin et al., 2002*) did not have an effect on hatchling's weight.

To predict chickens' weight before the hatching, various models have been developed on the basis of linear and non-linear equations from which the weight is associated with incubation eggs' weight (*Tahir et al., 2011*; *Ng'ambi et al., 2013*; *Ramaphala and Mbajiorgu, 2013*; *Rashid et al., 2013*). *Rashid et al.* (*2013*) calculated that the weight of day-old chickens from three studied breeds increased by 0.595-1.361 g for every 1 g increase in egg weight.

Obviously, the weight of eggs is a more accurate parameter for day-old chickens' weight that egg geometry characteristics, but better results could be obtained when both are included in the models. This is confirmed by *Narushin et al.* (*2002*) who affirmed that the weight, volume and surface area of eggs were the best predictors of hatchlings' weight with coefficients of determination ranging between 0.26 and 0.63 according to the line.

Similar predictions are important elements of selection work and therefore, for improvement of productivity of poultry. To this end, we aimed to develop and evaluate optimum models for weight prediction in two White Plymouth Rock lines – line L and line K on the basis of the incubation egg weight and egg geometry characteristics.

Materials and Methods

The experiment was performed in the Experimental base of the Agricultural Institute – Stara Zagora with 280 eggs of two White Plymouth Rock lines: L and K (140 from each line) laid by 40-week-old hens. The hens were reared in boxes in groups of 10 hens and 1 rooster on deep permanent litter of wooden shavings. Restricted feeding with daily ration compliant to the age and egg production of layers was used: metabolisable energy 1810.005 kcal/kg, crude protein – 16.012 %, crude fat – 6.836 %, crude fibre 5.889 %, lysine 0.75 %, methionine 0.38 %, calcium 3.2 %, phosphorus 0.81%.

Incubation eggs were randomly selected, and those with irregular shape or shell cracks were removed. Before the incubation, eggs were disinfected through fumigation with formaldehyde vapours. Every egg was numbered on the blunt end, weighed on a balance with precision up to 0.01 g, and its breadth and length were measured with digital caliper with precision up to 0.01 mm. On the basis of these dimensions, the geometric mean diameter (Dg), egg volume (V) and egg surface area (S) were calculated as followed:

$Dg = (LB^2)^{1/3}$ *Mohsenin (1970),*

$V = (0.6057 - 0.0018B)LB^2$ *Narushin (2005)*

$S = (3.155 - 0.013L + 0.0115B)L,$ *Narushin (2005),* where
B = egg maximum breadth; L is the egg length in mm

Egg incubation took place under optimum conditions. On the 19th day, eggs were transferred from the incubator to the hatcher and placed in wooden frames with partitions for individual hatching. After the hatch, all chicks were individually weighed with precision of 0.01 g.

Statistical methods

The means, standard deviations and coefficients of variation of studied traits were calculated for each line and evaluated by paired samples t-test. Pearson's correlation coefficients (r) between independent and dependent variables were determined. Initially, the egg weight and egg geometry traits were included to predict hatchling weight individually, and then a step-wise multiple regression was run with statistically significant predictors only in order to eliminate collinearity. problem. Collinearity was established according to VIF values, obtained as $VIF=1/1-R_i^2$, which should not exceed 10. The regression curve was determined as linear and therefore, linear models were found most appropriate to predict hatchlings' weights:

$\hat{Y} = a + b.X + \varepsilon$ (1) Simple regression model

$\hat{Y} = a + b_1.X_1 + b_2.X_2 + \ldots\ldots + b_k.X_k + \varepsilon$ (2) Multiple regression model,

where $\hat{Y}$ - dependent variable (chick weight), a – intercept, b_k – regression coefficients, X_k independent variables (egg weight, egg geometry parameters), ε - residual (error).

The significance of the regression coefficients was tested with a t-statistic while the goodness-of-fit of the regression was assessed using the coefficient of determination (R^2).

The best models were validated by incubation of 60 randomly selected eggs from each line, with preliminary determined weight and geometry traits using the described methods. The data were used for calculation of predicted weights of chickens after hatching. After the individual hatching, the weight of chicks was determined on digital balance. The differences between observed and predicted values of dependent variable were established.

Statistical analyses were performed with software SPSS (version 19.0 for Windows).

Results and Discussion

The means, standard deviations and coefficients of variations of egg weight and geometry traits in both studied lines (L and K) are shown in Table 1. For all traits, mean values were higher for line L, that could be attributed to genetic differences ($p<0.001$). The differences in egg weight and hatchling weight were 6.79 g (10.34 %) and 5.18 g (11.70 %). respectively. Our data were somewhat comparable to the results reported by *Alabi et al. (2012)*, that egg weight had an effect on egg length and volume, but not on its breadth. The presented results indicated that egg weight determined studied geometry traits (length, breadth, geometric mean diameter, volume, surface area). Unlike us, *Narushin et al. (2002)* did not established differences with regard to egg weight in three egg-laying chicken lines while egg volume, surface area, density and hatchlings' weight differed substantially. In this study, the variation of weight of day-old chicks from both lines was higher as compared to incubation eggs' weight – 6.85-7.34 vs 5.18-5.55 %, which in the view of *Shalev and Pasternak (1995)* could probably result from incubation conditions and hatchery management. Unlike us, *Tahir et al. (2011)* reported that the weight of chicks varied at a lower extent than the weight of eggs, and according to *Wolanski et al. (2007)* coefficients of variations of both were similar. They are considered to be parameters of uniformity (*Shalev and Pasternak, 1995).* The least changeable parameter was the geometric mean diameter of eggs with coefficients of variation 1.79 and 1.98 %, followed by egg breadth– 2.06 and 2.44 % for line L and K respectively. The egg volume exhibited higher coefficients of variation: 5.06 % in line L and 5.64 % for line K. In a study by *Narushin et al. (2002),* egg volume and weight were outlined as most variable parameters, as confirmed by the present study as well.

Table 1. Descriptive statistics of egg weight, egg geometry parameters and chick weight at hatch used to determine models in line L and line K

Traits	Line L			Line K		
	Mean	SD	CV	Mean	SD	CV
Chick weight (ChW), g	44.26***	3.03	6.85	39.08	2.87	7.34
Egg weight (EW), g	65.68***	3.40	5.18	58.89	3.27	5.55
Egg length (L), mm	57.81***	1.52	2.63	56.12	1.92	3.42
Egg maximum breadth (B), mm	44.61***	0.92	2.06	43.06	1.05	2.44
Geometric mean diameter (D*g*), mm	48.63***	0.87	1.79	47.03	0.93	1.98
Egg volume (V), cm^3	60.47***	3.06	5.06	54.99	3.10	5.64
Egg surface area (S), cm^2	74.32***	2.52	3.39	69.75	2.64	3.78

SD – standard deviation, CV – coefficient of variation, %
Significant at ***-p<0.001

Before the regression analysis, a correlation matrix was composed with linear coefficients of correlations between the dependent and independent variables. Table 2 shows that all predictors included in the analysis had significant correlation coefficients with the weight of hatchlings ranging from moderate (with egg length and breadth: r=0.418-0.695*)* to strong (mean geometric diameter, volume, surface area and weight of eggs: r=0.731-0.819), p<0.001. The presence of significant correlations with the dependent variable indicated their suitability for inclusion in regression models. The data of *Narushin et al. (2002)* demonstrated slightly higher correlation between the hatchlings' weight and egg weight (r=0.56), than with egg volume (r=0.50) and egg surface area (r=0.50) in three egg-laying chicken lines; this was confirmed in our experiments. *Sahin et al.* (*2009*) also reported higher correlation coefficients - 0.87 (hatchling weight vs egg weight) and 0.81 (hatchling weight vs egg volume). High positive relationship (0.82) was present between hatchling weight and egg surface area (0.74 for line L and 0.80 for line K) as also reported by *El-Safty* (*2011*).

Table 2. Phenotypic correlations among chick weight at hatch, egg weight and egg geometry parameters

Traits	EW	L	B	Dg	V	S	ChW
EW		0.624 ***	0.729 ***	0.961 ***	0.965 ***	0.966 ***	0.819 ***
L	0.629 ***		-0.013	0.564 ***	0.596 ***	0.652 ***	0.418 ***
B	0.722 ***	0.211 **		0.818 ***	0.794 ***	0.749 ***	0.695 ***
Dg	0.868 ***	0.655 ***	0.877 ***		0.999 ***	0.994 ***	0.812 ***
V	0.870 ***	0.679 ***	0.861 ***	0.999 ***		0.997 ***	0.811 ***
S	0.872 ***	0.714 ***	0.835 ***	0.997 ***	0.999 ***		0.802 ***
ChW	0.779 ***	0.539 ***	0.602 ***	0.731 ***	0.733 ***	0.735 ***	

EW- egg weight, L- egg length, B- egg maximum breadth, Dg- geometric mean diameter, V- egg volume, S- egg surface area, , Ch W- chick weight
Significant at **-p<0.01, ***-p<0.001
Upper matrix: Line K
Lower matrix: Line L

Furthermore, independent variables correlate statistically significantly among, except for egg breadth and length for line K that exhibited insignificant relationship (r= -0.01), while for line L eggs, the relationship was weak but significant (0.21, p<0.01). Unlike us, *Yakubu et al.* (*2008*) reported a strong positive correlation between egg length and breadth (r=0.71).

The predictors egg volume, surface area and mean geometric diameter were very closely related in both lines (0.994-0.999). High linear relationship was reported by *Nedomova and Buchar* (*2014*) between egg volume and surface area in geese with R^2 = 0.996. A probable reason could be the involvement of the same parameters e.g. egg breadth and length in their formulas. At the same time, egg volume, surface area and mean geometric diameter correlated strongly with egg weight (0.868-0.966). The substantial relationships between egg volume and eggs in this study agreed with finding of *Malago and Baitilwake* (*2009*), *Kabir et al***.** (*2012*). The latter researchers reported coefficient of phenotypic correlation between ISA Brown and local chickens of r=0.72 and r=0.88. Strong interrelationships between egg weight, volume and surface area were communicated by *Narushin* (*1997*). A high correlation coefficient (0.99) was found out between ostrich egg weight and surface area (*El-Safty 2011*) and this was confirmed in our study as well.

Table 3 presents regression coefficients, coefficients of determination and levels of statistical significance of models predicting the weight of hatchlings on the basis of egg weight and geometry parameters in both lines. Data showed that all linear regression models were adequate as could be seen from high level of statistical significance ($p<0.001$). The comparison of models demonstrated that the coefficient of determination was useful parameters of variation of the dependent variable, explained with regression. The highest coefficients of determination in both lines were those of simple linear models which used egg weight as predictor - 0.606 for line L and 0.671 for line K, e.g 61-67 % of hatchlings' weight depended on egg weight (model 1). According to *Tserveni-Gousi and Yannakopoulos* (*1990*) 70m% of variation in the weight of pheasant chicks was attributable to egg weight which was a better predictor than shape index and shell deformity. *Tahir et al.* (*2011*) and *Ramaphala and Mbajiorgu* (*2013*) also predicted the hatching weight of chickens but reported higher coefficients of determination R^2, 0.856 and 0.995 respectively, while *Olutunmogun et al. (2017)* reported a much lower value (R^2=0.15) than our data.

Table 3. Regression coefficients, coefficients of determination and level of significance of models in lines L and K

№	Regression model	Predictors	Line	Regression coefficients			R^2	SE	F-value
				Const.	b_1	b_2			
1	Simple	EW	L	-1.360	0.695	-	0.606	1.909	229.509***
			K	-3.327	0.720	-	0.671	1.653	284.093***
2	Simple	B	L	-44.226	1.984	-	0.363	2.429	84.768***
			K	-42.467	1.894	-	0.483	2.075	129.626***
3	Simple	L	L	-17.751	1.073	-	0.291	2.562	61.166***
			K	3.999	0.625	-	0.175	2.620	29.420***
4	Simple	Dg	L	-80.183	2.559	-	0.534	2.076	170.948***
			K	-78.930	2.509	-	0.660	1.683	269.274 ***
5	Simple	V	L	0.268	0.728	-	0.537	2.070	173.025***
			K	-2.227	0.751	-	0.658	1.686	267.956***
6	Simple	S	L	-21.460	0.884	-	0.540	2.063	175.066***
			K	-21.878	0.874	-	0.643	1.724	250.191***
7	Multiple	B, L	L	-80.461	1.684	0.858	0.541	2.069	87.090***
			K	-78.969	1.909	0.639	0.665	1.675	136.930***
8	Multiple	EW, S	L	-10.345	0.513	0.282	0.620	1.883	120.502***
9	Multiple	EW, B	K	-19.853	0.587	0.566	0.692	1.607	154.75***

EW - egg weight, B- egg maximum breadth, L- egg length, Dg- geometric mean diameter, V- egg volume, S- egg surface area, R^2 – coefficient of determination, SE- standard error of estimate, ***- Significant at $p<0.001$

Linear parametric equations associating hatchlings' weight and egg length (model 3) had the lowest coefficients of determination - 0.175 (line K) and 0.291 (line L) followed by those using egg breadth as predictor (model 2). However, when both dimensions were simultaneously included in the model, coefficients of determination increased considerably to 0.541 and 0.665 for lines L and K respectively (model 7). In line K the values were comparable with those of model 1, where the independent variable was egg weight. When the geometric mean diameter (Dg), egg volume (V) and surface area (S) in both lines were used as independent predictors (models 4, 5 and 6) the values of R^2 were lower than respective values in model 1 including also egg weight, which is more pronounced in line L. Our data confirmed the findings from a previous study of *Narushin et al. (2002)*, that linear equations using as predictor egg weight were more accurate that those using egg volume and surface area independently.

The high correlation coefficients between predictors egg weight, volume, surface area and mean geometric diameter (Table 2) presumed multicollinearity as confirmed by VIF values, significantly higher than allowed ones. It is acknowledged that models based on multicollinear variables could influence the accuracy of the prognosis (*Chatterjee et al., 2000*). An option for elimination of the negative impact of multicollinearity is the elimination of some strongly correlating predictors from the model through application of stepwise regression. The calculated coefficients of determination in multiple regression models by means of stepwise regression were 0.620 for line L and 0.692 for line K (models 8 and 9). The comparison with model 1, that uses one independent variable (egg weight), shows increase in the coefficient of determination when a second predictor was included, in other words, the addition of egg surface area (model 8) and egg breadth (model 9) contributed to a greater extent for explication of the dependent variable (hatchling weight) for line L and line K.

After evaluation of regression models, the most accurate (those with highest R^2 values) were selected – models 1 and 7 for both lines, model 8 (line L) and model 9 (line K) for validation of their prediction power. They served for calculation of predicted weights of day-old chicks for 60 randomly selected eggs from each line set for incubation. Table 4 presents the expected and observed values for weights of hatchlings. The differences between predicted ($\hat{Y}$) and observed (Y) values were small and for line L ranged between 0.04-0.48 g, while for line K - between 0.24-0.34 g, corresponding to 0.09-1.09 % and 0.63-0.86 % from respective real values.

Conclusion

On the basis of data, it could be concluded that the best prediction was obtained with an additional predictor when apart egg weight as followed: egg surface area for line L (*ChW*=0.513*EW*+0.282*S*-10.345) and egg maximum breadth for line K (*ChW*=0.587*EW*+0.566B -19.853). Models on the basis of main egg dimensions – breadth and length could be also used for tentative determination of hatchlings'' weight from both lines. According to the study, multiple regression models were more efficient than single linear models.

Table 4. Mean of actual and predicted values, difference and percent difference for the models generated to predict the chick weight at hatch in line L and line K

Line	Chick weight (g)					Difference							
	Actual (Y) *	Predicted				(Y-$\hat{Y}_1$)		(Y-$\hat{Y}_7$)		(Y-$\hat{Y}_8$)		(Y-$\hat{Y}_9$)	
		Model 1 ($\hat{Y}_1$)	Model 7 ($\hat{Y}_7$)	Model 8 ($\hat{Y}_8$)	Model 9 ($\hat{Y}_9$)	g	%	g	%	g	%	g	%
L	44.18	43.70	44.14	43.83	-	0.48	1.09	0.04	0.09	0.35	0.79	-	-
K	39.52	39.27	39.18	-	39.28	0.25	0.63	0.34	0.86	-	-	0.24	0.61

*- chick weight was measured by digital balance

Regresijski modeli za procenu mase pilića na izleganju na osnovu određenih geometrijskih karakteristika jajeta

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Rezime

Predviđanje telesne mase pre izleganja je važan element selekcije, čiji je cilj poboljšanje uniformnosti i produktivnosti živine. S tim u vezi, naš cilj bio je da razvijemo i procenimo optimalne modele za slično predviđanje u dve linije pilića: White Plymouth Rock - linija L i linija K, na osnovu težine jaja u inkubaciji i geometrijskih karakteristika jajeta - maksimalna širina jajeta (B), dužina jajeta (L), geometrijski srednji prečnik (Dg), volumen (V) i površina jajeta (S). Ukupno 280 jaja (140 iz svake linije) koja su izlegle kokoši uzrasta od 40 nedelja su odabrana nasumično. Za svaku liniju su određene aritmetičke vrednosti, standardna odstupanja i koeficijenti varijacije proučavanih parametara. Korelacioni koeficijenti između mase izleglih pilića i prediktora bili su najviši za težinu jajeta, geometrijski srednji prečnik, zapreminu i površinu jajeta (r=0,731-0,779 za liniju L; r=0,802-0,819 za liniju K).

Izrađeno je devet modela linearne regresije i procenjena njihova tačnost. Regresijske jednačine težine izleglih pilića prema dužini jajeta imale su najmanji koeficijent determinacije (0,175 za liniju K i 0,291 za liniju L), ali kada su dužina i širina jajeta ušla u model zajedno, vrednost koeficijenta se značajno povećala na 0,541 i 0,665 za linije L i K, respektivno. Masa jednodnevnih pilića iz linije L mogla se predvideti sa većom preciznošću sa modelom koji uključuje površinu jajeta u odnosu na masu jajeta (ChW=0,513EW+0,282S – 10,345; R^2=0,620). U liniji K, postignuta je preciznija prognoza dodavanjem širine jajeta kao dodatnog prediktora za masu u modelu (ChW=0,587EW+0,566V -19,853; R^2=0,692). Studija je pokazala da su višestruki linearni regresioni modeli bili precizniji od pojedinačnih linearnih modela.

Ključne reči: masa pilića, masa jajeta, geometrijski parametri jajeta, regresijski modeli

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