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Estimation of Egg Albumen Height of Hy-Line Hens Using Ridge Regression Method

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Abstract

This study aims to predict egg albumen height, one of the internal quality parameters of eggs from Hy-Line hens, using external quality traits. In the study, a high level of multicollinearity problem was detected in the multiple linear regression analysis based on the classical Least Squares Method (LSM).This negatively impacted the predictive power of the model and the reliability of the parameter estimates. To address this structural problem, the Ridge regression method was applied, which adds a penalty term to the regression coefficients and increases the model's stability by reducing the variance. In the analyses, external quality data (weight, width, length, shape index, and Haugh unit) from 150 eggs obtained from 53-week-old Hy-Line hybrid hens were used. Egg albumen height, which has a high coefficient of determination, was selected as the dependent variable. Although the R^2 value in the model generated using the Least Squares Method (LSM)was 99 %, the high VIF values indicated serious multicollinearity problem. Ridge regression analyses showed that VIF values decreased to acceptable levels, the model's predictive accuracy increased, and the parameters became more statistically significant. In conclusion, it has been demonstrated that multicollinearity problem, frequently encountered in biological data, can be effectively addressed through regularization methods such as Ridge regression. This method is considered an important tool for developing more reliable and consistent models, particularly in selection and genetic breeding studies.

Keywords: Egg Quality, Multicollinearity problem, Ridge Regression method, LSM, Hy-Line hens

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INTRODUCTION

Food safety and animal production quality have become one of the most important focal points of modern agriculture and animal husbandry. In this context, the quality of intensively consumed animal products, especially egg production, is of great importance for both production efficiency and the health of the end consumer (Geng et al., 2019). In the poultry sector, egg quality characteristics are affected by many factors, including the animal's genetic makeup, environmental conditions, and rearing practices, and accurate analysis of this variability plays a critical role in ensuring sustainable and efficient production (Aktaş and Ertekin, 2025).

Albumen height, one of the internal quality indicators of eggs, is considered a crucial parameter in the industry because it both indicates the egg's freshness and is directly related to protein quality. Egg albumen is a component that is directly observable by the consumer, has high nutritional value, and is widely used in industrial production. Albumen height decreases with the duration of storage after laying, and this change is used as one of the key criteria for determining egg freshness (Roberts, 2004). Therefore, reliable estimation of albumen height is crucial, especially during egg processing and marketing. The Hy-Line hens used in this study are a hybrid layer breed widely raised worldwide and known for their high egg production. The Hy-Line genetic line, resulting from years of breeding, stands out for its high egg production, strong shell structure, low feed consumption, and high-quality internal structure. These characteristics are among the primary reasons for the breed's preference for commercial egg production.

Egg quality is assessed under two main headings: external quality (shell thickness, shape index, weight, etc.) and internal quality (albumen height, albumen index, yolk color degree, etc.). Accurate measurement and statistical modeling of these traits not only helps assess current production conditions but also provides an important tool for guiding selection and genetic improvement practices. Indeed, the heritability of traits related to egg quality is one of the key criteria determining the potential for improvement through breeding. Internal quality traits such as albumen height generally have moderate heritability, indicating potential for genetic improvement (Tumova and Gous, 2012).

However, high correlations between variables affecting egg quality (e.g., among factors such as egg weight, shell thickness, and shape index) can lead to multicollinearity problem in classical regression analyses. This reduces the reliability of model predictions and causes biases in parameter estimates, especially in analyses based on biological data (Montgomery et al., 2012). To overcome such problems, regularizing regression methods, particularly Ridge regression, are recommended in the literature (James et al., 2021). Ridge regression reduces variance and increases the generalizability of the model by adding a penalty term to the regression coefficients (Hoerl and Kennard, 1970; Alin, 2010).

In this study, albumen height, one of the indicators of internal egg quality, was modeled with external quality parameters; The classical Least Squares Method (LSM) and the Ridge regression method are compared. Thus, the effect of Ridge regression method on model performance in biological data sets with high multicollinearity problem is demonstrated and the effectiveness of statistical modeling techniques in animal production data is discussed.

MATERIALS AND METHODS

The animal material of the study consisted of Hy-Line native layer hybrid hens developed by the Ankara Poultry Research Institute. Data obtained from internal and external egg quality analyses of 150 eggs obtained from 53-week-old Hy-Line hybrid hens reared in cage system No. 3 at the Çukurova University Research and Application Farm were used in the study. Egg quality analyses were conducted in the Poultry Laboratory of the Animal Science Department of the Faculty of Agriculture, Çukurova University. Egg width and length measurements were taken using a digital caliper with a sensitivity of ±0.01 mm. Egg weights were determined using an electronic scale with a sensitivity of 0.01 g. Each egg was individually broken on a glass breaking bench, and the height, width, and length measurements of the yolk and albumen were recorded using a digital caliper with a sensitivity of ±0.01 mm. The egg albumen was also collected in a separate Petri dish and weighed using an electronic scale with a sensitivity of 0.01 g. Through these collected measurement data, quality indicators such as shape index, albumen index, yolk index and Haugh unit were calculated using the following formulas (Yannakopoulos and Tserveni-Gousi, 1986; Kaya and Aktan, 2011; Olawumi and Christiana, 2017).

$$\text{Shape Index} = \frac{\text{Egg Width (mm)}}{\text{Egg Length (mm)}} \text{x}100 \quad (1)$$

$$\text{Albumen Index} = \frac{\text{Albumen heigth (mm)}}{\text{Average of Albumen Width and Length (mm)}} \text{x}100 \quad (2)$$

$$\text{Haugh unit} = 100 \log (\text{Albumen Height} + 7.57 - 1.7 \text{ x Egg Weight}^{0.37}) \quad (3)$$

$$\text{Yolk Index} = \frac{\text{Yolk heigth (mm)}}{\text{Yolk Width (mm)}} \text{x}100 \quad (4)$$

Within the scope of the study, a prediction model was developed considering one dependent variable (egg albumen height) and five independent variables (egg weight, width, length, shape index, and Haugh unit). Multiple regression analysis was applied to assess the model's performance and fit quality; these analyses were conducted using the SPSS 26 statistical package.

Multiple regression analysis is a statistical method that allows a dependent variable to be estimated using more than one independent (explanatory) variable. The basic regression equation used in this analysis is expressed as follows:

$$Y = \beta_0 + \beta_1 X_1 + \cdots + \beta_n X_n + \varepsilon \quad (5)$$

In this equation, Y represents the dependent variable, β_0 represents the constant coefficient, β_0–β_n represents the regression coefficients, $X_1 - X_n$ represents the independent variables, and ε represents the error term (Üçkardeş et al., 2012).

Examining the relationship between independent variables is crucial for ensuring model reliability. High levels of correlation between explanatory variables can lead to multicollinearity problems (Maxwell, 2000; Montgomery et al., 2001).

The main methods commonly used to detect this problem are listed below:

Simple Correlation Coefficient: If the correlation coefficient between two variables is 0.75 or above, it should be considered that there may be a multicollinearity problem.

VIF: It is an indicator that measures the relationship between each independent variable and other variables. When the VIF value is 10 or higher, the risk of multicollinearity is considered high. The VIF value is calculated using the following formula (Albayrak, 2005):

$$VIF = 1 / (1 - R^2) \quad (6)$$

Tolerance Value (TV): It is defined as $1 - R^2$. Small tolerance values, together with high VIF, may be indicative of a multicollinearity problem (Albayrak, 2005).

Because each of these methods assesses multicollinearity from different perspectives, their combined use in determining the presence of this problem provides more reliable results. Various solutions have been proposed in the literature to mitigate the multicollinearity problem; these include variable removal, combining correlated variables, adding a new variable to the model, Principal Component Regression, and Ridge Regression method. In this study, the Ridge regression method was chosen to address the multicollinearity problem.

Ridge regression method is a statistical technique developed by Hoerl and Kennard (1970) to overcome the multicollinearity problem and used as an alternative to the classical LSM. The LSM method can reduce the reliability of the model by causing large variances in the estimates when there is a high correlation between independent variables. Ridge regression method, on the other hand, addresses this problem by adding a small positive constant, the Ridge coefficient (k), to the diagonals of the covariance matrix used to estimate the regression coefficients. This practice increases the model's stability by reducing the estimated variance, but it also introduces a partial bias in the estimates. However, this balance between low variance and acceptable bias is widely preferred in statistical modeling applications because it improves the overall performance of the model (Albayrak, 2005; Kurşun and Gök, 2025).

In Ridge regression method, in order to determine the initial parameter of Ridge coefficient (k) and the appropriate model variance lag length, the stationarity point of the regression can be calculated with the Augmented Dickey Fuller (ADF) unit root test, and the model variance lag length can be calculated with the help of the Vecto Auto Regressive (VAR) model.

The ADF unit root test is a widely used test to determine the stationarity of time series data. A stationary time series is one in which statistical properties such as mean, variance, and covariance remain constant over time. The ADF unit root test tests whether the series contains a unit root. A unit root indicates that the time series is non-stationary and indicates a trend or tendency in the series. The absence of a unit root indicates that the time series is stationary. The mathematical model for the ADF unit root test is generally expressed as follows:

$$\Delta Y_t = \alpha + \beta_t + \gamma Y_t - 1 + \sum_{i=1}^{p} \delta_i \Delta Y_{t-i} + \varepsilon_t \qquad (7)$$

Here, Y_t = Time series data, ΔY_t = Time series change, α = Constant term, β= Trend coefficient, γ= Unit root coefficient, δ_i= Coefficients of lagged values, p: Lag length, ε_t= Error term (Dickey Fuller, 1979).

The VAR model: In econometric analyses, the use of simultaneous equation systems becomes important when there are complex and reciprocal relationships between independent variables. In such systems, considering the interactions of each variable with other variables yields more accurate and reliable results. One of the most commonly used methods for solving simultaneous equation systems is the VAR model. The VAR model is a powerful tool for examining dynamic relationships and interactions in time series analysis, enabling modeling using the past values of each endogenous variable in conjunction with all other endogenous variables.

The mathematical formula of the VAR model with a lag length of p is expressed as follows:

$$y_t = A_1 y_{t-1} + \cdots + A_p y_{t-1} + B_{x_t} + \varepsilon_t \qquad (8)$$

Here, $y_t p \times 1$ dimensional value vector, $x_t d \times 1$ dimensional deterministic variables, $A_p p \times p$ dimensional parameter matrices and the error terms vector (Johansen, 1995).

RESULTS AND DISCUSSION

In analyses conducted on a dataset of internal and external quality traits of eggs from Hy-Line hens, egg albumen and yolk indices, as well as height parameters, were evaluated to determine the dependent variable. Based on the modeling studies, egg albumen height with a coefficient of determination (R^2) of 0.75 or higher was selected as the most appropriate dependent variable. Therefore, it was determined that external quality measurements significantly predicted egg white height, and the appropriate regression model was constructed as follows.

$$\hat{Y} = \widehat{\beta_0} + \widehat{\beta_1} X_1 + \widehat{\beta_2} X_2 + \widehat{\beta_3} X_3 + \widehat{\beta_4} X_4 + \widehat{\beta_5} X_5 + \hat{e} \qquad (9)$$

$\hat{Y}$ = Egg albumen height
X_1 = Egg weight
X_2 = Egg width
X_3 = Egg length
X_4 = Shape index
X_5 = Haugh unit

The linear relationship between egg albumenheight and external egg quality parameters was analyzed using the multiple linear regression model obtained using the LSM. The findings regarding this relationship are detailed in Table 1. The overall statistical significance of the model is evaluated in Table 2.

n addition, the estimated values of the parameters in the regression model and the significance levels of these estimates are presented in Table 3. Furthermore, in order to detect possible multicollinearity problems that may exist among the independent variables, VIF and TV analyses were performed, and the relevant results are given in Table 4.

Table 1. Goodness of fit (R^2, Adjusted R^2) and standard error values of the multiple linear regression model created with the LSM.

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.998	0.995	0.995	0.072

Table 2. Variance analysis results of the multiple linear regression model obtained with the LSM.

	Sum of Squares	df	Mean Square	F	Sig.
Regression	154.646	5	30.929	5872.069	0.000
Residual	0.758	144	0.005		
Total	155.404	149			

Table 3. Parameter estimates of the multiple linear regression model obtained by the LSM and the statistical significance levels of these estimates.

	Regression Coefficient	Std. Error of the Estimate	t	p
$\widehat{\beta_0}$	-10.451	3.719	-2.810	0.006
$\widehat{\beta_1}$	0.053	0.004	12.955	0.000
$\widehat{\beta_2}$	0.046	0.090	0.511	0.610
$\widehat{\beta_3}$	-0.038	0.065	-0.582	0.561
$\widehat{\beta_4}$	-0.24	0.051	-0.470	0.639
$\widehat{\beta_5}$	0.193	0.001	168.137	0.000

Table 4. VIF values and TV for the evaluation of multicollinearity between independent variables in the multiple linear regression model created with the LSM.

Correlation Matrix							
Veriables	Egg Weight	Egg Width	Egg Length	Shape Index	Haugh Unit	TV	VIF
Egg Weight	1					0.059	16.861
Egg Width	0.924**	1				0.002	503.816
Egg Length	0.856**	0.702**	1			0.001	699.463
Shape Index	-0.142	0.160	-0.590**	1		0.003	371.513
Haugh Unit	-0.146	-0.150	-0.159	0.052	1	0.967	1.034

When Table 1 is examined, the multiple linear regression model generated using the LSM. successfully reflects the effect of egg external quality traits on albumen height with a 99% explanatory factor ($R^2 = 0.99$). This relatively high coefficient of determination demonstrates the strong influence of external quality parameters on albumen height. However, the risk of multicollinearity problem in the model cannot be ignored.

The variance analysis results in Table 2 reveal that the model is generally statistically significant ($p < 0.01$). This indicates that the explanatory power of the model is not random and that the independent variables together create a significant effect. An examination of Table 3 reveals that half of the independent variables included in the model made statistically significant contributions ($p < 0.05$).

Furthermore, considering the VIF and TV in Table 4, it was observed that some variables, particularly egg width and length, had high VIF while their TV were low. This suggests strong linear relationships between the relevant variables and, consequently, that the model may be experiencing multicollinearity. As is widely accepted in the literature, a VIF value of 10 or higher indicates a risk of multicollinearity

In order to clarify this situation more clearly;

$$\text{VIF, } C_{ij}\ \frac{1}{1-R_{ij}} \tag{10}$$

with the help of the formula,

$$\text{VIF, } C_{ij} = \frac{1}{1-0.99} = \frac{1}{0.01} = 100 \tag{11}$$

calculated.

In the estimation model in which the egg albumen height was the dependent variable, the VIF value between the variables was 10 or higher ($Cij \geq 10$), clearly demonstrating the presence of a multicollinearity problem in the model. To eliminate this structural problem and obtain more reliable model estimates, it became necessary to examine the stationarity properties of the time series data.

Accordingly, the ADF unit root test was applied using the EViews package program to test the stationarity of the variables. The ADF unit root test analyzed whether the series were stationary at the level or after differencing. After establishing the stationarity of the variables, the VAR model was chosen to determine the appropriate lag length to be used in the forecasting models. The findings obtained from these analyses are detailed in Tables 5 (ADF unit root test result) and 6 (lag criteria results for the VAR model), respectively.

Table 5. ADF unit root test result.

ADF-t statistics	Critical Values			Level	
	% 1	% 5	% 10	t- statistics	Probability (p)
Egg Albumen Height	-3.474	-2.880	-2.577	-10.573	0.000
Egg Weight	-3.474	-2.880	-2.577	-19.706	0.000
Egg Width	-3.474	-2.880	-2.577	-18.154	0.000
Egg Length	-3.474	-2.880	-2.577	-13.881	0.000
Shape Index	-3.474	-2.880	-2.577	-12.206	0.000
Haugh Unit	-3.474	-2.880	-2.577	-10.583	0.000

Table 6. VAR model lag length result.

Lag	LogL	LR	FPE	AIC	SC	HQ
0	-970.934	NA	0.028	13.474	13.983	13.525
1	-909.258	117.397	0.020	13.120	13.598	13.471
2	-875.306	61.814	0.021	13.149	14.750	13.799
3	-853.698	37.554	0.025	13.347	15.687	14.298
4	-837.758	26.383	0.033	13.624	16.703	14.875
5	-811.558	41.196	0.039	13.759	17.577	15.310

LR: sequential modified LR test statistic (each test at 5% level) FPE: Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan-Quinn information criterion.

As a result of examining Tables 5 and 6, the t-statistic values obtained within the scope of the ADF test (-10.573, -19.706, -18.154, -13.881, -12.206, -10.583) are smaller (in absolute terms greater) than the absolute sum of the critical value to which they are compared, which is -8.931, indicating that the series are stationary at the level. This finding is a positive indicator of the stability of the model in time series analysis.

Furthermore, the optimal lag length for the data set was determined to be one; this was supported by both the stationarity analyses and all comparison criteria (Akaike Information Criterion - AIC, Schwarz Criterion - SC, Hannan-Quinn - HQ) used within the VAR model. These information criteria yielded their lowest values at the first lag. Therefore, not only are the series stationary at the first lag level, but the external egg quality traits no longer have a significant effect on the albumen index after the first lag level in the model.

Based on these findings, the VIF calculations were based on the first lag level, and the Ridge regression method, frequently recommended in the literature, was applied to address the multicollinearity issue identified in the model. Ridge regression method were conducted using the NCSS 12 statistical package.

The linear relationship between egg external quality traits and albumen height was re-evaluated in the multiple linear regression model, which was re-estimated using the Ridge regression method. The primary reason for choosing this method was to mitigate the multicollinearity issue observed in the classical regression model and to obtain more reliable estimates.

The findings of the new model are presented in Table 7. The overall statistical significance level of the model is detailed in Table 8. Furthermore, the regression coefficients included in the model, along with their statistical significance levels, along with the VIF and TV, are presented in detail in Table 9. Furthermore, the VIF graph, created to visually monitor the level of multicollinearity between variables after the Ridge regression model, is shown in Figure 1.

Table 7. Goodness of fit (R^2, Adjusted R^2) and standard error values of the multiple linear regression model obtained by the Ridge regression method

R	R Square	Adjusted R Square	Std. Error of the Estimate
0.891	0.890	0.885	1.293

Table 8. Variance analysis results of the multiple linear regression model estimated by the Ridge regression method.

	Sum of Squares	df	Mean Square	F	Sig.
Regression	5106.994	5	1021.399	610.880	0.000
Residual	240.769	144	1.672		
Total	5347.76	149	35.891		

Table 9. Parameter estimates, statistical significance levels, VIF values and TV of the multiple linear regression model estimated by the Ridge regression method.

	Regression Coefficient	Std. Error of the Estimate	VIF	TV
$\widehat{\beta_0}$	-1.395	-	-	-
$\widehat{\beta_1}$	2.010	0.192	7.2	0.002
$\widehat{\beta_2}$	0.593	0.139	9.3	0.001
$\widehat{\beta_3}$	-0.128	0.109	5.5	0.003
$\widehat{\beta_4}$	-1.059	0.100	9.7	0.0001
$\widehat{\beta_5}$	5.572	0.512	9.4	0.0001

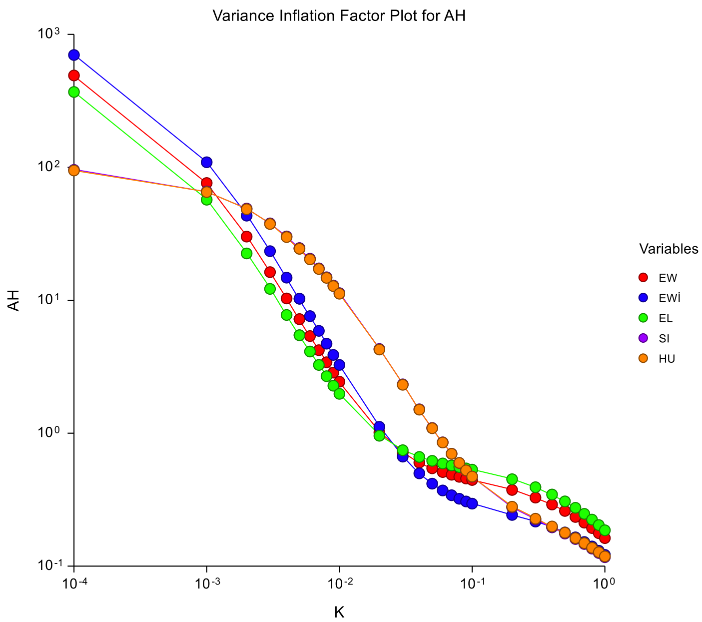

Figure 1. VIF graph. AH: Egg Albumen Height, EE: Egg Weight, EWI: Egg Width, EL: Egg length, SI: Shape Index, HU: Haugh Unit

An evaluation of Tables 7, 8, and 9 reveals that the parameter estimates obtained with the Ridge regression method differ significantly from those obtained with the LSM. By limiting the size of the parameter coefficients thanks to the penalty term integrated into the model, Ridge regression method significantly alleviates the problem of high standard errors, which is frequently encountered, especially in cases of multicollinearity.

This method both increases the model's estimation reliability and improves its predictive accuracy. In contrast, issues such as multicollinearity and overfitting in the LSM reduce the precision of the estimates and can lead to increased parameter standard errors. Ridge regression method's ability to offset these disadvantages allows the model to achieve a more robust and statistically consistent structure.

In this context, it was concluded that the model generated using the Ridge regression method offers both statistical reliability and a higher predictive power. The estimated Ridge regression method model is presented below.

$$\hat{Y} = -\widehat{1.395} + \widehat{2.010}X_1 + \widehat{0.593}X_2 - \widehat{0.128}X_3 - \widehat{1.059}X_4 + \widehat{5.572}X_5 + \hat{e} \quad (12)$$

According to the LSM results presented in Tables 1, 2, and 3, half of the parameters in the estimated regression model were found to be statistically significant ($p < 0.05$). However, the standard error calculated for the model's constant term (β_0) was relatively higher compared to the other parameters. This indicates a higher uncertainty in the estimation of the constant term.

These findings are consistent with studies conducted by Aktan (2004) and Akçay and Sarıözkan (2015) in the literature and support observations regarding the predictive behavior of the LSM when similar data structures are used. An examination of Table 4 reveals significant findings regarding the relationships between independent variables. Specifically, positive and statistically significant ($p < 0.05$) correlations were found at 92 % between egg weight and egg width, and 85 % between egg weight and egg length. These results demonstrate a high level of linear correlation between physical egg measurements.These findings are consistent with studies conducted in the literature by Akbaş et al. (1996), Kul and Şeker (2004), Alkan et al. (2010), and Gök et al. (2023) and support the relationships observed in similar data structures.

In the analyses related to the prediction model presented in Tables 5 and 6, a high level of multicollinearity problem was observed among the variables. To prevent this structural problem from negatively affecting the predictive power and reliability of the model, the Ridge regression method, widely recommended and applied in the literature, was chosen. In the Ridge regression application, the lag length was set to "1" to preserve the dynamic structure of the model, consistent with the literature, and multicollinearity levels were re-evaluated by calculating VIF values accordingly.The applied method and the obtained findings are largely consistent with the results obtained in similar studies conducted by Gök et al. (2022), Gök and Şahin (2023), Gök and Şahin (2023), Gök and Şahin (2024), Gök and Şahin (2024), and Gök and Şahin (2025).

According to the results in Tables 7, 8, and 9, the Ridge regression analysis applied to address the multicollinearity problem observed in the model yielded lower regression coefficients, a lower VIF value (9.09), and a higher TV compared to the OLS method. These results demonstrate that Ridge regression method effectively reduces the multicollinearity problem and increases the statistical reliability of the model. The findings obtained are compatible and equivalent with the studies in the literature such as Albayrak (2005), Topal et al. (2010), Rathert et al. (2011), Üçkardeş et al. (2012), Akçay and Sarıözkan (2015), Çiftsüren (2017), Yalçınöz and Şahin (2020), Demir et al. (2021), Tolun et al. (2023), Yavuz et al. (2023), Çetenak et al. (2024), Tolun et al. (2024) and Gök and Kurşun (2025).

CONCLUSION

This study examined the effects of egg external quality traits on egg albumen height and identified a multicollinearity problem in the model generated using the classical LSM. It was determined that high correlation between variables negatively impacted the reliability of parameter estimates and the generalizability of the model. The Ridge regression method, implemented to overcome this structural problem, increased the model's stability by reducing multicollinearity problem and yielded more consistent estimates. The results obtained with Ridge regression method indicate that this method provides more meaningful and reliable estimates, particularly in biological datasets containing multicollinearity method. Ridge regression method has been shown to be a more appropriate approach than classical methods for modeling egg albumen height with external quality parameters such as egg weight, shape index, width, and length. In this context, the use of regularization methods such as Ridge regression method is recommended for statistical modeling of egg quality, particularly in the development of decision support mechanisms within the context of genetic breeding and selection studies. This method not only increases the predictive power of the model but also provides more robust and applicable results by controlling the complexity of the relationship between variables. In future research, comparatively evaluating different penalized regression techniques (e.g., Lasso or Elastic Net) could contribute to improving the model's variable selection capacity. Furthermore, diversifying the variables included in the model and experimenting with nonlinear modeling approaches could further deepen statistical analyses of egg quality and increase their generalizability. In this respect, Ridge regression method is considered an important tool for analyzing biological data, and its more widespread use in such studies would significantly contribute to the literature.

Compliance with Ethical Standards

Peer Review

This article has been peer-reviewed by independent experts in the field using a double-blind review process.

Conflict of Interest

The author declares that there is no conflict of interest.

Author Contribution

The author solely conceived, designed, and conducted the study, analyzed the data, and wrote the manuscript.

Ethics Committee Approval

Ethical approval was not required for this study.

Consent to Participate / Publish

Not applicable.

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Data Availability

Not applicable.

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