Black Sea Journal of Agriculture
doi: 10.47115/bsagriculture.1844388

Open Access Journal
e-ISSN: 2618 – 6578

Research Article
Volume 9 - Issue 3 : 369-375 / May2026

PREDICTION OF ALBUMEN INDEX IN TINTED CORAL CHICKENS EGGS USING PRINCIPAL COMPONENT REGRESSION

İsmail GÖK[1]*, Kadriye KURŞUN[2], Melis ÇELİK GÜNEY[2], Nasir ABDALLAH[2], Mikail BAYLAN[2]

[1]Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Agricultural Biotechnology, 46100, Kahramanmaraş, Türkiye
[2]Çukurova University, Faculty of Agriculture, Department of Animal Science, 01330, Adana, Türkiye

Abstract: This study aimed to predict the albumen index value in Tinted Coral chicken eggs. Researchers collected 60 eggs from a flock at 82 weeks of age and measured egg weight, egg width, egg length, and shell weight. They also calculated the shape index, Haugh unit, shell thickness and albumen index.Multiple linear regression (MLR) analysis showed that the model was statistically significant (F=65.65; <0.0001) and explained 90% of the variance in albumen index (R^2=0.90). However, high correlations among the variables indicated the presence of multicollinearity problem.To address this issue, the study applied principal component regression (PCR). Three components with eigenvalues greater than 1 accounted for 84% of the total variance. PC1 represented dimensional and mass-related traits (egg length, egg weight, shell weight, shape index), PC2 represented geometric structure and internal quality (egg width, shape index, egg weight, Haugh unit), and PC3 represented shell-related and structural traits (shell thickness, shell weight, egg length, shape index). In the PCR model, all components were statistically significant. Low variance inflation factor (VIF) values (VIF<10) and high tolerance values (TV>0.1) confirmed that the multicollinearity problem was effectively eliminated.The results show that PCR provides a more reliable and stable approach for predicting albumen index in datasets with highly correlated variables. This method also offers strong potential for developing reliable prediction models in other poultry species and genotypes with similar data structures.

Keywords: Egg morphological characteristics, Multicollinearity problem, PCR analysis, Tinted Coral chickens

***Corresponding author:** Kahramanmaraş Sütçü İmam University, Faculty of Agriculture, Department of Agricultural Biotechnology, 46100, Kahramanmaraş, Türkiye
E mail:gkisoo1995@gmail.com (İ. GÖK)
İsmail GÖK https://orcid.org/0000-0002-0759-1187
Kadriye KURŞUN https://orcid.org/0000-0001-9533-7391
Melis ÇELİK GÜNEY https://orcid.org/0000-0002-6825-6884
Nasir ABDALLAH https://orcid.org/0000-0003-2701-6726
Mikail BAYLAN https://orcid.org/0000-0002-6299-5811

Received: December 18, 2025
Accepted: April02, 2026
Published: May15, 2026

Cite as: Gök, İ., Kurşun, K., Çelik Güney, M., Abdallah, N., & Baylan, M. (2026). Prediction of albumen index in tinted coral chickens eggs using principal component regression. *Black Sea Journal of Agriculture*, 9(3), 369-375.

1. Introduction

Poultry production plays a strategic role in ensuring the sustainability of the global supply of animal protein due to its short production cycle and high productivity (FAO, 2022). Within this production system, eggs represent one of the most prominent products in terms of both nutritional value and economic accessibility, and their quality characteristics directly influence production profitability and consumer preference (Roberts, 2004).

Egg quality is a multidimensional concept that requires the combined evaluation of numerous physical and internal parameters related to the shell, yolk, and albumen components. Among these, albumen occupies a central position in freshness and internal quality assessments due to its protein structure and viscosity. The albumen index is considered a sensitive indicator of albumen quality and is widely used to reflect the internal quality status of eggs (Silversides and Budgell, 2004).

Factors affecting albumen quality include a wide range of variables such as egg weight, dimensional traits, shape index, Haugh unit and shell structure (Ketta and Tůmová, 2016). However, many of these variables are inherently highly interrelated due to biological structure, and strong linear dependencies are particularly observed among morphological measurements (Ketta and Tůmová, 2016). This situation may give rise to multicollinearity problem in multiple linear regression approaches commonly employed in modeling egg quality traits, thereby limiting the statistical reliability of parameter estimates (Kutner et al., 2005).

To mitigate the adverse effects of multicollinearity problem, multivariate methods based on dimensionality reduction have been proposed in the literature (Işık Taçyıldız, 2025). Among these, principal component regression (PCR)represents the original independent variables through linear combinations (principal components) that capture the highest variance in the predictors, thereby removing inter variable correlations and enabling the construction of more stable and generalizable regression models (Jolliffe and Cadima, 2016). Although PCR has been widely applied in biological research and animal studies, its use for predicting albumen quality remains limited, and most existing studies focus on different species or are based on relatively small sample sizes (Mendeş, 2009; Sarıca et al., 2012).

The present study aims to comparatively evaluate multiple linear regression (MLR) and PCR approaches in modeling the effects of morphological and shell traits on the prediction of albumen index in eggs of Tinted Coral chickens, highlighting the limitations of MLR model and the methodological advantages provided by PCR. In this respect, the study contributes to the application of multivariate approaches in modeling internal egg quality parameters and emphasizes the potential of PCR in poultry egg quality analysis.

2. Materials and Methods

In the study, a total of 60 table eggs obtained from an 82-week-old Tinted Coral flock were used. Egg length and width were measured using a digital caliper with an accuracy of ±0.01 mm, while egg weight was determined using an electronic balance with a precision of ±0.01 g. Each egg was individually broken on a glass breaking table, and albumen height, width, and length were measured using a Vernier caliper (INSIZE digital caliper, ±0.01 mm accuracy).

The shell weight was determined using an electronic balance with a sensitivity of 0.01 g after the egg's interior was cleaned. To measure shell thickness, values were recorded at three different points of the eggshell (blunt end, equatorial region, and pointed end), and the average of these measurements was taken as the eggshell thickness. Based on the collected data, the following parameters were calculated: shape index, albumen index, Haugh unit, andshell thickness (Yannakopoulos and Tserveni-Gousi, 1986; Kaya and Aktan, 2011; Olawumi and Christiana, 2017).

The shape index was calculated using the formula given in equation 1:

Shape Index = Egg Width (mm)/Egg Length (mm)x100 (1)

The albumen index was calculated as given in equation 2:

Albumen Index=Albumen Height (mm)/Average of Albumen Width and Length(mm)x100 (2)

The Haugh unit was calculated using equation 3:

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

Finally, shell thickness was calculated as given in equation 4 the average of the three measured regions:

Shell thickness (mm) = (Broad +Narrow + Middle part)/3 (4)

In the dataset, the albumen index was defined as the dependent variable, while egg weight, egg width, egg length, shape index, Haugh unit, shell weight, and shell thicknesswere considered as independent variables. To examine the relationships among these variables, MLR analysis was performed using the SPSS statistical software package (version 26).

MLR is a parametric statistical method that enables the prediction of a dependent variable based on one or more independent variables. Its general mathematical representation can be expressed as given in equation 5(Gök and Kurşun 2025a).

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

In this equation, Y denotes the dependent variable, β_0 represents the intercept, β_1–β_n are the regression coefficients, X_1–X_n denote the independent variables, and ε represents the error term (Gök and Kurşun, 2025b).

However, in MLR analyses, high correlations among independent variables may lead to multicollinearity problem (Kurşun and Gök, 2025). This situation reduces the statistical reliability of the model and complicates the interpretation of regression coefficients. Various methods have been developed in the literature to detect multicollinearity problem.

One of the primary methods is the simple correlation coefficient. A correlation coefficient of 0.75 or higher between two independent variables indicates a high risk of multicollinearity problem (Tolun, 2025). In addition, the Variance inflation factor (VIF) is used to measure the linear relationship between an independent variable and the remaining explanatory variables. A VIF value exceeding 10 is generally considered indicative of severe multicollinearity problem, and it is calculated using the following formula given in equation 6 (Yavuz, 2025):

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

The inverse of VIF value, known as the tolerance value (TV), is defined as TV=1 − R^2, where R^2 represents the coefficient of determination obtained from the regression model in which the relevant independent variable is regressed on the remaining explanatory variables. A TV below 0.1, when evaluated in conjunction with high VIF values, indicates a serious risk of multicollinearity problem (Gök and Kurşun, 2025a).

When multicollinearity problem is detected, dimensionality reduction techniques are recommended in the literature to mitigate its effects. In this context, PCR stands out as an effective method, particularly for high-dimensional datasets exhibiting multicollinearity problem. PCR is based on principal component analysis (PCA), originally introduced by Pearson in (1901) and further developed by Hotelling in the (1933). The method represents the original independent variables using linear components with the highest variance in order to eliminate high intercorrelations and achieve dimensionality reduction. Regression models constructed using these components not only reduce multicollinearity problem but also enhance the generalizability and predictive performance of the model.

PCR is widely preferred in research fields characterized by multivariate data structures, such as animal science, biology, economics, environmental sciences, and health sciences. The fundamental mathematical expression of the method is as given in equation 7:

$$\hat{\beta} = W(T^T T)^{-1} T^t y \quad (7)$$

Here; W: The weight matrix used to obtain the principal components from the X variables, T=XW: The original data is represented with fewer dimensions and independent principal components, $(T^T T)^{-1} T^t y$ Calculates the linear relationship (regression) between the principal components and y, $\hat{\beta}$: Converts the coefficients found on the principal components to the original X variables (Jolliffe and Cadima, 2016).

3. Results and Discussion

The MLR model equation developed to predict albumen index in Tinted Coral chicken eggs is presented in equation 8.

$$\widehat{\text{Albumen Index}} = \hat{\beta}_0 + \hat{\beta}_1 \text{Egg Weight} + \hat{\beta}_2 \text{Egg Width} + \hat{\beta}_3 \text{Egg Length} + \hat{\beta}_4 \text{Shape Index} + \hat{\beta}_5 \text{Haugh Unit} + \hat{\beta}_6 \text{Shell Weight} + \hat{\beta}_7 \text{Shell Thickness} \quad (8)$$

The, the overall results of the MLR analysis in Table 1, the coefficient estimates, standard errors, t-statistics, and probability values (P) in Table 2, and the correlation (r) and coefficient of determination (R^2) in Table 3.

Table 1. Results of the MLR analysis

	Sum of Squares	df	Mean Square	F	p
Regression	198.81	10	28.40	65.65	<0.0001
Residual	22.49	49	0.43		
Total	221.31	59			

Table 2. MLR coefficients, standard errors,t-statistics, and P values

Variables	RegressionCoefficient (β)	Std. Error of theEstimate	t	p
C	-14.15	44.94	-0.31	0.75
EW	0.01	0.06	0.22	0.82
EWi	-0.37	1.03	-0.36	0.71
EL	0.12	0.76	0.16	0.86
SI	0.15	0.57	0.27	0.78
HU	0.24	0.01	17.95	<0.0001
SW	0.05	0.17	0.32	0.74
ST	-0.006	0.005	-1.20	0.23

C= constant, EW= egg weight, EWi= egg width, EL= egg length, SI= shape index, HU= Haugh unit, SW= shell weight, ST= shell thickness.

Table 3. r, R^2 and standard errors obtained from the MLR analysis

r	R^2	Std. Error of the Estimate
0.94	0.90	0.65

When Table 1 is examined, the model established through MLR analysis was found to be statistically significant (F=65.65; <0.0001).

When Table 2 is examined, examination of the regression results revealed that only the Haugh unit had a statistically significant effect on the albumen index (<0.0001). In contrast, other independent variables, such as egg dimensional measurements, shape index, and shell thickness, did not contribute significantly to the model (p>0.05). Indicating that some variables play a limited role in explaining the albumen index.

When Table 3 is examined, the R^2 of the model was calculated as 0.90, and the r reflecting the overall fit of the model was found to be 0.94. Indicating a strong linear relationship between the dependent and independent variables.

However, the lack of statistical significance for most independent variables, coupled with high intercorrelations among them, suggests the presence of multicollinearity problem. The degree of interrelation among the independent variables, as indicated by the VIF values and TV, is presented in Table 4.

Table 4. Level of relationships among independent variables, VIF values, and TV

	Correlation Matrix								
V	EW	EWi	EL	SI	HU	SW	ST	VIF	TV
EW	1							19.65	0.05
EWi	0.82$^{**(H)}$	1						147.97	0.006
EL	0.88$^{**(H)}$	0.24$^{(L)}$	1					297.89	0.003
SI	-0.02$^{(L)}$	0.81$^{**(H)}$	-0.87$^{**(H)}$	1				337.42	0.002
HU	0.04$^{(L)}$	0.13$^{(L)}$	0.30$^{*(M)}$	0.75$^{**(H)}$	1			1.41	0.70
SW	0.47$^{**(M)}$	0.22$^{(L)}$	0.71$^{*(H)}$	-0.17$^{(L)}$	-0.18$^{(L)}$	1		12.91	0.07
ST	0.01$^{(L)}$	-0.21$^{(L)}$	0.01$^{(L)}$	-0.16$^{(L)}$	-0.18$^{(L)}$	0.60$^{**(M)}$	1	12.28	0.08

V=variables, EW= egg weight, EWi= egg width, EL= egg length, SI= shape index, HU= Haugh unit, SW= shell weight, ST= shell thickness, L= low 0.00–0.29, M=medium 0.30–0.69, H=high 0.70–1.00, *P<0.05, **P<0.01.

When Table 4 is examined, evaluation of the r indicates a pronounced multicollinearity problem in the constructed model. In particular, the high positive correlations observed between egg weight and egg width (r=0.82) and between egg weight and egg length (r=0.88), as well as the strong negative correlation between egg length and shape index (r=-0.87), demonstrate substantial linear dependence among the independent variables. These strong relationships are considered one of the main reasons why the regression coefficients did not yield statistically significant results.

The presence of multicollinearity problem at a structural level in the model was further confirmed by the VIF values and TV. The VIF values for shape index (VIF=337.42), egg length (VIF=297.89), and egg width (VIF=147.97) far exceed the commonly accepted threshold in the literature (VIF>10). Indicating a high degree of shared variance in the model and a severe reduction in the reliability of parameter estimates (Yavuz, 2025). The corresponding TV below 0.1 for these variables also support the existence of this structural problem.

In contrast, variables such as Haugh unit (VIF=1.41), shell weight (VIF=12.91), and shell thickness (VIF=12.28) exhibited relatively lower VIF values and higher TV, suggesting that these variables contribute more independently to the model. Notably, the variables with low statistical significance also showed high VIF values and low TV, confirming that the multicollinearity problem is not only theoretical but also statistically substantiated.

Accordingly, to mitigate the adverse effects of multicollinearity problem, achieve dimensionality reduction, and enhance the reliability of regression coefficient estimates, PCR was applied. Analyses were conducted using the SAS statistical software package, and the eigenvalues from the PCR analysis are presented in Tables 5.

Table 5. Eigenvalues of the correlation matrix obtained from the PCR analysis

PC	Eigenvalues of the Correlation Matrix			
	Eigenvalue	Difference	Proportion	Cumulative
PC1	2.53	0.52	0.36	0.36
PC2	2.01	0.65	0.28	0.65
PC3	1.36	0.60	0.19	0.84
PC4	0.75	0.50	0.10	0.95
PC5	0.25	0.18	0.03	0.99
PC6	0.06	0.06	0.009	0.99
PC7	0.001	-	0.0002	1.00

When Table 5 is examined, three principal components with eigenvalues greater than 1 (PC1, PC2, and PC3) were identified. These three components account for 84% of the total variance. Indicating that a substantial portion of the information in the dataset can be represented through these components. In terms of explained variance, PC1 accounts for 36% of the total variance, PC2 for 28%, and PC3 for 19%. Components with eigenvalues less than 1 carry less variance compared to the original variables and were therefore considered secondary in the component selection process. The eigenvectors derived from the PCR analysis are presented in Table 6.

Table 6. Eigenvectors obtained from the PCR analysis

	Eigenvectors						
Variables	PC1	PC2	PC3	PC4	PC5	PC6	PC7
EW	0.48	0.41	-0.04	0.04	0.17	-0.74	0.009
EWi	0.27	0.60	-0.03	-0.22	0.16	0.53	-0.43
EL	0.53	-0.10	-0.40	0.15	0.11	0.35	0.61
SI	-0.32	0.49	0.34	-0.30	0.009	0.03	0.65
HU	-0.22	0.35	0.05	0.90	-0.01	0.09	0.007
SW	0.44	-0.02	0.50	0.06	-0.72	0.08	0.008
ST	0.20	-0.27	0.67	0.12	0.63	0.10	0.003

EW= egg weight, EWi= egg width, EL= egg length, SI= shape index, HU= Haugh unit, SW= shell weight, ST= shell thickness.

When Table 6 is examined, the interpretation of the principal components was based on the eigenvector loadings. PC1 exhibited high loadings for egg length, egg weight, shell weight, and shape index, representing the overall dimensional characteristics and mass of the eggs.

PC2 was associated with egg width, shape index, egg weight, and Haugh unit, reflecting the geometric structure and internal quality traits of the eggs. PC3 showed high loadings for shell thickness, shell weight, egg length, and shape index, representing the eggshell structure, potential durability, external appearance, and geometric properties. The parameters predicted by PCR, along with standard errors, t-statistics, p-values, VIF values, and TV, are detailed in Table 7.

Table 7. Estimated parameters, standard errors, t-statistics, p-values, VIF values, and TV obtained from the PCR analysis

	RegressionCoefficient (β)	Std. Error of the Estimate	t	p	VIF	TV
C	9.13	0.08	-	-	-	-
PC1	-0.49	0.05	-9.12	<0.0001	1.21	0.82
PC2	0.64	0.06	10.77	<0.0001	1.11	0.90
PC3	0.06	0.07	0.92	<0.0001	1.12	0.89
PC4	1.58	0.09	16.07	0.36	1.04	0.96
PC5	-0.18	0.16	-1.09	0.28	1.09	0.91
PC6	0.01	0.33	0.06	0.95	1.66	0.60
PC7	0.58	2.30	0.26	0.79	1.01	0.99

When Table 7 is examined, the regression coefficients, standard errors, VIF values, and TV obtained from the PCR analysis are presented. According to the regression results, PC1 (β=−0.49, <0.0001), PC2 (β=0.64, <0.0001), and PC3 (β=0.06, <0.0001) had statistically significant effects on the dependent variable. In contrast, PC4, PC5, PC6, and PC7 did not contribute significantly (P>0.05).

For all components included in the model, VIF values were well below 2 (maximum VIF=1.66), and the TV were relatively high (TV≥0.60). These findings indicate that the PCR approach effectively mitigated multicollinearity problem and allowed the regression coefficients to be estimated reliably.

In conclusion, considering the eigenvalue structure, the proportion of explained variance, and the statistical significance of the regression coefficients, the PCR model incorporating PC1–PC3 provides a statistically robust, stable, and interpretable framework. Accordingly, the PCR model for predicting the dependent variable can be expressed as in equation 9:

$$\text{Albumen Index} = 9.13 - 0.49\text{PC1} + 0.64\text{PC2} + 0.06\text{PC3} \quad (9)$$

Literature shows that researchers widely use MLR to predict egg quality traits (Albayrak, 2005; Sarıca et al., 2012; Duman et al., 2016). However, high correlations among independent variables limit model reliability. Strong relationships among egg quality create multicollinearity problem and reduce the interpretability of regression coefficients (Kebede et al., 2022; Işık Taçyıldız, 2025). In particular, correlations between egg weight and other quality indicators negatively affect model performance (Abdulraheem et al., 2024; Jegede et al., 2024). Findings highlight limitations of linear regression approaches when researchers analyze highly correlated datasets.

Dimensionality reduction methods offer a solution to multicollinearity problem. PCA and PCR remove correlations among variables and help researchers build more stable and reliable models. Previous studies show that these methods explain a large proportion of total variance with a limited number of components and produce effective results in biological datasets (Sanad et al., 2021; Kebede et al., 2022; Abdulraheem et al., 2024; Abdelhady and Abdellatif, 2025). PCR reduces multicollinearity problem and improves prediction accuracy (Mendeş, 2009). However, some studies indicate that alternative methods may perform better depending on data structure (Akyürek and Akkol, 2018).

PCR approach in the present study effectively handles high correlations among independent variables and enables reliable prediction of albumen index. Results show that egg weight and dimensional traits influence albumen index through derived principal components. Low VIF values and high TV indicate successful handling of multicollinearity problem in the model. Overall, results support PCR as an effective analytical tool for datasets with high inter variable correlations.

4. Conclusion

In this study, the factors affecting the albumen index were investigated using MLR and PCR method. Although the MLR model exhibited a high explanatory power, most regression coefficients were not statistically significant due to strong interrelationships among the independent variables, thereby limiting the reliability of parameter estimates. This limitation was effectively addressed through PCR analysis, which yielded a more reliable and stable model characterized by low VIF values and high TV.

The evaluation based on principal components indicated that the albumen index is shaped by the combined effects of egg dimensional traits, shell structure, external appearance, and quality related parameters. These findings demonstrate that egg quality exhibits a multidimensional structure and highlight the importance of employing multivariate approaches in similar studies.

Author Contributions

The percentages of the authors' contributions are presented below. All authors reviewed and approved the final version of the manuscript.

	İ.G.	K.K.	M.Ç.G.	N.A.	M.B.
C	20	20	20	20	20
D	20	20	20	20	20
S	20	20	20	20	20
DCP	20	20	20	20	20
DAI	20	20	20	20	20
L	20	20	20	20	20
W	20	20	20	20	20
CR	20	20	20	20	20
SR	20	20	20	20	20
PM	20	20	20	20	20
FA	20	20	20	20	20

C= concept, D= design, S= supervision, DCP= data collection and/or processing, DAI= data analysis and/or interpretation, L= literature search, W= writing, CR= critical review, SR= submission and revision, PM= project management, FA= funding acquisition.

Conflict of Interest

The authors declared that there is no conflict of interest.

Ethical Consideration

Ethics committee approval was not required for thisstudy because of there was no study on animals orhumans.

References

Abdelhady, M., & Abdellatif, M. A. (2025). Identifying predictive components of egg weight in two lines of Dandarawi chicken using principal component analysis. *Egyptian Poultry Science Journal, 45*(2), 115–124. https://doi.org/10.21608/epsj.2025.436828

Abdulraheem, A. O., Aremu, J. O., Mohammed, A., Allamin, H., Shettima, M. M., Aliyu, J., & Raji, A. O. (2025). Genetic relationship between external and internal egg quality traits of Japanese quails. *Nigerian Journal of Animal Science and Technology, 8*(3), 10–16. https://www.njast.com.ng/index.php/home/article/view/449

Akyürek, S., & Akkol, S. (2018). Prediction of inner quality characteristics of eggs using partial least squares regression and comparison with principal component regression. *YYÜ Journal of Agricultural Sciences, 28*(4), 473–481. https://doi.org/10.29133/yyutbd.448697

Albayrak, A. S. (2005). Alternative bias estimation techniques to the least squares technique in multicollinearity and an application. International Journal of Management Economics and Business, 1(1), 105-126.

Duman, M., İekeroğlu, A., Yıldırım, A., Eleroğlu, H., & Camcı, Ö. (2016). Relation between egg shape index and egg quality characteristics / Zusammenhang zwischen Formindex des Eies und Eiqualitätsmerkmalen. *European Poultry Science, 80*, 1–9. https://doi.org/10.1399/eps.2016.117

FAO. (2022). Food and Agriculture Organization: The state of food and agriculture 2022: Revealing the true cost of food to transform agri-food systems.

Gök, İ., & Kurşun, K. (2025a). Comparative estimation models of egg albumen index in Atak-S hens with ridge and principal component regression methods. *Turkish Journal of Agriculture Food Science and Technology, 13*(9), 2615–2622. https://doi.org/10.24925/turjaf.v13i9.2615-2622.7699

Gök, İ., & Kurşun, K. (2025b). Prediction model of albumen index and height in Japanese quail eggs via external quality characteristics. *International Journal of Agriculture Environment and Food Sciences, 9*(2), 493–501. https://doi.org/10.31015/2025.2.22

Hotelling, H. (1933). Analysis of a complex of statistical variables into principal components. *Journal of Educational Psychology, 24*(6), 417–441. https://doi.org/10.1037/h0071325

Işık Taçyıldız, S. Ş. (2025). Prediction of albumen height based on egg quality traits by principal components regression. *Black Sea Journal of Statistics, 1*(2), 41–46. https://doi.org/10.5281/zenodo.18234774

Jegede, P., Yakubu, A., Vicent, S. T., Musa, I. S., Shoyombo, A. J., Alabi, O. O., Wheto, M., Adebambo, A. O., & Popoola, M. A. (2024). Fertility, hatchability, and prediction of egg weight from egg quality parameters using principal components and regression methods. *Poultry, 4*(1), 1–15. https://doi.org/10.3390/poultry4010001

Jolliffe, I. T., & Cadima, J. (2016). Principal component analysis: a review and recent developments. *Philosophical transactions of the royal society A: Mathematical, Physical and Engineering Sciences, 374*(2065), 20150202. https://doi.org/10.1098/rsta.2015.0202

Kaya, E., & Aktan, S. (2011). Flock age and hatching egg storage period in Japanese quail: 1. Effects on dark albumen traits. *Süleyman Demirel University Journal of Agriculture Faculty, 6*(2), 30–38.

Kebede, K., Getachew, A., & Urge, M. M. (2022). Principal components regression of internal egg quality traits in two exotic chicken breeds in haramaya. *Journal of Food Chemistry*

& Nanotechnology, 8(3), 102-107. https://doi.org/10.17756/jfcn.2022-132

Ketta, M., & Tumová, E. (2016). Eggshell structure, measurements, and quality-affecting factors in laying hens: A review. *Czech Journal of Animal Science, 61*(7), 299–309. https://doi.org/10.17221/46/2015-CJAS

Kurşun, K., & Gök, İ. (2025). Prediction model of albumen index in duck eggs via external egg quality characteristics in case of multicollinearity. *Black Sea Journal of Agriculture, 8*(4), 525–532. https://doi.org/10.47115/bsagriculture.1655436

Kutner, M. H., Nachtsheim, C. J., Neter, J., & Li, W. (2005). *Applied linear statistical models* (5th ed.). McGraw-Hill/Irwin.

Mendeş, M. (2009). Multiple linear regression models based on principal component scores to predict slaughter weight of broiler chickens. *European Poultry Science, 73*(2), 139–144. https://doi.org/10.1016/S0003-9098(25)00852-5

Olawumi, S., & Chiristiana, B. (2017). Phenotypic correlations between external and internal egg quality traits of Coturnix quails reared under intensive housing system. *Journal of Applied Life Sciences International, 12*(3), 1–6. https://doi.org/10.9734/JALSI/2017/33802

Pearson, K. (1901). Principal components analysis. *The London, Edinburgh, and Dublin Philosophical Magazine and Journal of Science, 6*, 559.

Roberts, J. R. (2004). Factors affecting egg internal quality and eggshell quality in laying hens. *Journal of Poultry Science, 41*(3), 161–177. https://doi.org/10.2141/jpsa.41.161

Sanad, S. S., Gharib, M. G., Ali, M. A. E., & Farag, A. M. (2021). Prediction of milk production of Holstein cattle using principal component analysis. *Journal of Animal and Poultry Production*. https://doi.org/10.21608/jappmu.2021.149198

Sarıca, M., Önder, H., & Yamak, U. S. (2012). Determining the most effective variables for egg quality traits of five hen genotypes. *International Journal of Agriculture & Biology, 14*(2), 235–240.

Silversides, F. G., & Budgell, K. (2004). The relationships among measures of egg albumen height, pH, and whipping volume. *Poultry Science, 83*(10), 1619–1623. https://doi.org/10.1093/ps/83.10.1619

Tolun, T. (2025). Comparative evaluation of some penalty regression techniques in the multicollinearity problem. *Turkish Journal of Agricultural and Natural Sciences, 12*(4), 1166–1174. https://doi.org/10.30910/turkjans.1757995

Yannakopoulos, A. L., & Tserveni-Gousi, A. S. (1986). Quality characteristics of quail eggs. *British Poultry Science, 27*, 171–176. https://doi.org/10.1080/00071668608416870

Yavuz, E. (2025). Estimation of egg albumen height of Hy-Line hens using ridge regression method. *International Journal of Agriculture Environment and Food Sciences, 9*(3), 841–849. https://doi.org/10.31015/2025.3.23