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Managing Colllinearity in Modeling the Effect of Age in the Prediction of Egg Components of Laying Hens Using Stepwise and Ridge Regression Analysis

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ABSTRACT

The relationships between egg measurements [egg weight (EGWT), egg width (EGWD), egg shape index (EGSI), egg volume (EGV) and egg density (EGD)], and egg components [eggshell (SWT), yolk (YWT) and albumen (AWT)] were investigated in laying hens with 32, 45, and 59 weeks of age with an objective of managing multicollinearity (MC), using stepwise regression (SR) and ridge regression (RR) analyses.

There were significant correlations among egg traits that led to MC problems in all eggs. Hen age influenced egg characteristics and the magnitude of the correlations among egg characteristics. Eggs produced at older age had significantly ($p<0.01$) higher EGWT, EGWD, EGV, YWT and AWT than those produced at younger age. The SR model alleviated MC problem in eggs produced at 32 weeks, with condition index greater than 30, and one predictor, EGWT had a model fit predicted egg components with R^2 ranged from 60 to 99%. The SR model of eggs produced at 45 and 59 weeks indicated MC problem with variance inflation factors (VIF) values greater than 10, and 4 predictors; EGWT, EGWD, EGV and EGD had a model fit that significantly predicted egg components with R^2 % ranged from 76 to 99 %. The RR analysis provided lower VIF values than 10 and eliminated the MC problem for eggs produced at any age group.

It is concluded that the RR analysis provided an ideal solution for managing the MC problem and successfully predicting egg components of laying hens from egg measurements.

INTRODUCTION

The characteristics of chicken egg are important part of consumer acceptability (Bejaei *et al.,* 2011). Most eggs marketed in Saudi Arabia are sold in their shell and a consumer's first impression of any egg purchased is based on their perception of weight and shell quality (Attia *et al.,* 2014). The market requirements for egg measurements encourage the industry to pay attention to egg weight and egg components. However, no defined grades have been developed for shell eggs sold in Saudi Arabia and little attention has been focused on the characteristics of egg and its components.

Morphological characters provide useful information of characteristics and quality of egg components due to the inherent relationship among all biological characters (Olawumi & Ogunlade, 2008; Shafey *et al*., 2014). Many factors affect egg characteristics, including the age of the laying hens. It influences egg weight (Johnston & Gous, 2007; Zita *et al.*, 2009), egg shape index (Van den Brand *et al.*, 2004), yolk weight (Van den Brand *et al.*, 2004; Zita *et al.*, 2009), albumen weight (Zita *et al.*, 2009), and eggshell proportion and quality (Abrahamsson & Tauson, 1998; Wahlstrom *et al.*, 1999; Silversides &

Scott, 2001; Zita *et al.*, 2009). However, there is little detailed information on the prediction of the weight of egg components throughout the laying cycle. Much of the published information seems to predict only egg components from a set of egg measurements (Shafey *et al.*, 2014). In addition, the interrelationships among egg characteristics and layer age have been investigated to an extent, but information on the problem of collinearityis still scarce.

Collinearity or multicollinearity (MC) occurs when a regression model includes two or more highly related predictors. The MC reduces the stability of the corresponding parameter estimates, increases standard errors, and decreases power to measure effects (Kreft & de Leeuw, 1998; Harrell, 2001; Cohen *et al.*, 2003). Shafey *et al.* (2014) investigated the problem of MC in the estimation of egg components (eggshell weight, yolk weight, and albumen weight) of meat-type chicken eggs produced by 36-wk-old breeders. They found MC problems in egg weight, egg shape index and their interaction, as shown by variance inflation factor (VIF=>10), condition index (CI=>30) and high corresponding proportions of variance of egg weight, egg shape index and their interaction, respectively.

There are many statistical solutions to correct the MC problem. These include stepwise regression (Yakubu, 2009) and ridge regression analysis (Smith & Campbell, 1980; Schoeman *et al.*, 2002; Pimentel *et al.*, 2007). Stepwise regression is based on building a model by successively adding or removing collinear predictors based solely on the t-statistics of their estimated coefficients. Ridge regression improves the accuracy of a regression model by reducing the apparent magnitude of the correlations (Hoerl & Kennard, 1970a, 1970b; Hoerl *et al.,* 1975; Marquardt & Snee, 1975; Mahajan *et al.*, 1977).

Therefore, the objectives of this study were to ascertain the existence of collinearity in the estimation of egg components based on the morphological traits (egg weight, egg width, egg shape index, egg volume, and egg density) of eggs laid by 32-, 45-, and 59-wk-old of laying hens and to correct the problem, if detected, using stepwise regression and ridge regression analysis.

MATERIALS AND METHODS

A total of 540 freshly-laid eggs produced by a meat-type breeder flock (Ross-Alwadi, Riyadh, Saudi Arabia) were collected when hens were 32, 45 and 59 weeks old, with 180 eggs from each age group. Eggs were candled to detect cracks, then numbered and weighed (EGWT) individually in an electronic scale at ± 0.01 g precision. Egg length (EGL) and width (EGWD) were measured using a steel vernier caliper graduated to one tenth of a millimeter. Egg shape index (EGSI) was calculated using Equation 1, according to Carter (1968):

$$EGSI = (EGWD/EGL) \times 100 \quad \text{(Eq. 1).}$$

Egg volume (EGV) was measured by the water displacement technique. The difference between the weight of an egg in the air and the weight in the water is equal to the weight of the water displaced by the egg (Archimedes' principle). The weight of the water displaced in grams is equal to the volume of the egg in milliliters (Carr, 1939) and egg density (EGD) was calculated by dividing the EGWT by EGV.

Eggs were broken and albumen and yolk separated. The yolk was then carefully rolled on a paper towel to remove extra white and chalaza. When the chalaza was not removed by this process, a razor was used to remove it from the yolk and the clean yolk was weighed (YWT). Eggshell was washed, air dried overnight and weighed (SWT) on an electronic scale. Eggshell membrane was not separated from the egg shell, thus eggshell weight includes membrane weight. All weights were measured with accuracy to the nearest 0.1 g. Albumen weight (AWT) was calculated by subtracting the total of YWT and SWT from EGWT. Also, eggshell weight percentage (SWTP) was calculated using Equation 2:

$$SWTP=SWT*100/EGWT \quad \text{(Eq. 2),}$$

yolk weight percentage (YWTP) was calculated using Equation 3:

$$YWTP=YWT*100/EGWT \quad \text{(Eq. 3)}$$

and albumen weight percentage (AWTP) was calculated using Equation 4:

$$AWTP=AWT*100/EGWT \quad \text{(Eq. 4).}$$

Measurements were made of independent variables of EGWT, EGWD, EGSI, EGV and EGD, and dependent variables of YWT, SWT and AWT.

Statistical analysis

Data were analyzed for descriptive statistics (mean, coefficient of variation, minimum and maximum values and standard deviation). Stepwise regression analyses were used with the aim of predicting egg composition of SWT, YWT and AWT from a set of explanatory variables of egg characteristics (EGWT, EGWD, EGSI, EGV and EGD). The model that describes the regression analysis (Alexopoulos, 2010) is given in Equation 5:

$$Y = a + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + e \quad \text{(Eq. 5)}$$

where, Y = dependent variable (Y_1, Y_2 or Y_3 for SWT, YWT or AWT); a = intercept; $ß'_s$ = regression coefficients; X'_s = independent variables (X_1, X_2, X_3, X_4 and X_5 for EGWT, EGWD, EGSI, EGV and EGD, respectively); and e = the error term. The level of 0.15 was chosen for the stepwise selection to place a restriction on the number of variables allowed into the regression model.

The correlation coefficients among the independent egg variables, VIF and CI were computed to investigate the existence or not of MC. The method of *VIF* of Rook *et al.* (1990) was employed as in Equation 6:

$$VIF=1 / (1-R_i^2) \quad \text{(Eq. 6)}$$

where, R_i^2 = coefficient of determination.

The CI measurement was also computed following the procedures adopted by Pimentel *et al.* (2007). In ridge regression analysis, the cross-product matrix for the independent variables (X_1 – X_5) is centered and scaled to one on the diagonal elements. The ridge constant ***k*** is then added to each diagonal element of the cross-product matrix. The ridge regression estimates for each variable are the least squares estimates obtained by using the new cross-product matrix. Let X be an n ×p matrix of the independent variables after centering the data, and let Y be an n ×1 vector corresponding to the dependent variable (Y_1, Y_2 or Y_3). Let D be a p ×p diagonal matrix with diagonal elements as in X`X. The ridge regression estimate corresponding to the ridge constant *k* can be computed as in Equation 7:

$$k = D^{-1/2}(Z`Z + kI_p)^{-1}Z`Y \quad \text{(Eq. 7)}$$

where $Z=XD^{-1/2}$ and I_p is a *pXp* identity matrix.

SAS procedure

Egg parameter results were analyzed by one-way analysis of variance using the SAS PROC ANOVA. Pearson correlation coefficients were calculated between egg variables using the SAS PROC CORR procedure. Predictive regression models were constructed using the SAS PROC REG. To test for MC in predictor variables, VIF, CI and TOL for each predictor were calculated in the analysis (PROC REG with options VIF, CI and TOL). The egg parameter were submitted to a stepwise multiple regression procedure to determine the equation that best estimates egg components (PROC REG with option stepwise). Ridge regression analysis was performed using the ridge option in the PROC REG Procedure. All analyses were performed using the SAS statistical analysis system (SAS, 2006).

RESULTS AND DISCUSSION

Descriptive statistics of eggs laid by broiler breeders at 32, 45 and 59 weeks of age are shown in Table 1. Hen age is one of the main factors influencing egg characteristics (Van den Brand *et al.*, 2004; Rizzi & Chiericato, 2005; Johnston & Gous, 2007; Zita *et al.*, 2009). Eggs produced by older hens presented significantly (p<0.01) higher EGWT, EGWD, EGV, YWT, AWT, and SWT than those produced by younger hens(59>45>32, and 59>32>45 weeks of age, respectively). Eggs produced at 32 weeks of age had significantly (p<0.01) higher SWTP and AWTP and lower YWTP than those produced at older age (32>59>45 weeks of age). The EGD was significantly (p<0.01) lower at 45 weeks of age when compared with those produced at 32 and 59 weeks of age. EGSI was not influenced by hen age. These findings were in agreement with Van den Brand *et al.* (2004), Johnston & Gous (2007), and Zita *et al.* (2009), who reported that EGWT, YWT, AWT and YWTP increased with age of the hen, whereas AWTP and SWTP decreased with age (Rizzi & Chiericato, 2005; Zita *et al.*, 2009).

Table 1 – Measurements of Ross strain eggs produced at 32, 45 and 59 weeks of age

Egg variable[1]	Age (week)			SEM[2]
	32	45	59	
EGWT	58.37^c	61.12^b	65.93^a	0.230
EGWD	43.33^c	44.37^b	44.95^a	0.074
EGSI	0.78	0.79	0.79	0.002
EGV	53.94^c	58.09^b	61.40^a	0.216
EGD	10.07^a	10.06^b	10.07^a	0.015
SWT	5.35^b	5.28^c	5.85^a	0.022
YWT	17.08^c	19.24^b	19.91^a	0.063
AWT	35.94^c	36.60^b	40.18^a	0.160
SWTP	9.16^a	8.64^c	8.87^b	0.012
YWTP	29.30^c	31.49^a	30.19^b	0.053
AWTP	61.54^a	59.88^c	60.94^b	0.055

[1] EGWT=Egg weight (g); EGWD=Egg width (mm); EGSI=Egg shape index [egg width (mm)/egg length (mm)]; EGV=Egg volume(cm^3);EGD= Egg density(g cm^{-3}); SWT=Shell weight(g); YWT=Yolk weight(g); AWT=Albumen weight(g); SWTP=Shell weight percentage YWTP=Yolk weight percentage; AWTP=Albumen weight percentage.

[2] Standard error of mean.

The correlation coefficients among egg characteristics produced at 32, 45 and 59 weeks of age are shown in Table 2. There were significant positive correlations in eggs produced at 32, 45 and 59 weeks of age between weight of egg components (SWT, YWT and AWT) and EGWT (r =0.77-0.99, p<0.001), EGV (r =0.60-0.96, p<0.001) and EGWD (r =0.22,

Table 2 – Coefficient of correlation of the measurements of Ross strain eggs produced at 32, 45 and 59 weeks of age.

Age (week)	Egg variable[1]	EGWT	EGWD	EGSI	EGV	EGD
32	EGWD	0.262***	1			
	EGSI	-0.311***	0.532***	1		
	EGV	0.771***	0.289***	-0.551***	1	
	EGD	0.203**	-0.727***	-0.194**	-0.163*	1
	SWT	0.999***	0.263***	-0.310***	0.773***	0.203**
	YWT	0.774***	0.217***	-0.241**	0.601***	0.134
	AWT	0.995***	0.258***	-0.310***	0.766***	0.206**
	SWTP	0.708***	0.200**	-0.205**	0.593***	0.149*
	YWTP	-0.911***	-0.228**	0.283***	-0.695***	-0.202**
	AWTP	0.909***	0.227**	-0.283***	0.693***	0.201**
45	EGWD	0.741***	1			
	EGSI	0.006	0.370***	1		
	EGV	0.955***	0.799***	0.099	1	
	EGD	0.312***	-0.067	-0.293***	0.016	1
	SWT	0.988***	0.734***	0.010	0.957***	0.264***
	YWT	0.962***	0.701***	-0.015	0.893***	0.387***
	AWT	0.996***	0.742***	0.015	0.960***	0.280***
	SWTP	0.128	0.110	0.026	0.208**	-0.242**
	YWTP	-0.564***	-0.456***	-0.070	-0.619***	0.088
	AWTP	0.628***	0.507***	0.076	0.678***	-0.057
59	EGWD	0.745***	1			
	EGSI	0.012	0.372***	1		
	EGV	0.957***	0.801***	0.096	1	
	EGD	0.244**	-0.111	-0.285***	-0.048	1
	SWT	0.868***	0.580***	-0.081	0.818***	0.252***
	YWT	0.929***	0.673***	0.007	0.911***	0.151*
	AWT	0.968***	0.742***	0.031	0.916***	0.272***
	SWTP	0.061	-0.092	-0.184*	0.031	0.103
	YWTP	0.109	0.030	-0.015	0.162*	-0.174*
	AWTP	-0.110	0.007	0.075	-0.144	0.107

[1]Egg variable=see Table 1; *=p<0.05; **=p<0.01; ***p<0.001.

p<0.01-0.74, p<0.001) and between EGD and egg components of SWT and AWT (0.20, p<0.01- 0.28, p<0.001). The high positive correlations between egg components and EGWT or EGV would suggest that EGWT and EGV are good indicators and predictors of components of eggs produced at 32, 45 and 59 weeks of age. However, results indicated that there were differences in the correlations among eggs produced at the three different ages. The correlation coefficients between egg components and EGWD or EGD ranged from 0.20 (p<0.01) to 0.74 (p<0.001) and it seems that the correlation coefficient changes with the size of the egg. The correlations between egg measures (EGWT and EGWD) and egg components (SWT, YWT and AWT) were in agreement with Olawumi & Ogunlade (2008) and Shafey *et al.* (2014), who found that the EGWT and EGWD had positive significant correlations with egg components.

The EGWT, EGV, and EGWD of the eggs produced at 32 and 45 weeks of age were positively correlated with AWTP and negatively correlated with YWTP (r =0.23-0.91, p<0.01- p<0.001). The EGD of the eggs produced at 32 and 59 weeks of age was negatively correlated with YWTP (r =0.17, p<0.05, to 0.20, p<0.01), and positively correlated with YWT (r =0.15,

Table 3 – Summary of regression analysis of measurements of Ross strain eggs produced at 32, 45 and 59 weeks of age

Age (week)	Egg variable[1]	SWT	YWT	AWT[1]	TOL[2]	VIF[3]	CI[4]
32	$ß_1$[5]	0.308	33.846	-34.154	.	0	1
	EGWT	0.098	0.283	0.6183	0.003	321.8	34.6
	EGWD	-0.023	-0.936	0.9597	0.001	1552.7	36.2
	EGSI	0.502	18.004	-18.506	0.001	655.6	103.0
	EGV	0.003	0.067	-0.0707	0.016	62.4	201.3
	EGD	-0.218	-9.816	10.0338	0.001	682.0	4698.4
	RMSE[6]	0.0079	0.2249	0.2240	-	-	-
	SSE[7]	0.0107	8.7975	8.7345	-	-	-
	RSQ[8]	0.9991	0.6049	0.9894	-	-	-
	Adj. RSQ[9]	0.9990	0.5963	0.9891	-	-	-
45	$ß_1$[5]	12.1368	-51.2441	39.1073	.	0	1
	EGWT	0.2737	-0.5444	1.2708	0.0002	4662.3	43.34
	EGWD	-0.0122	0.0579	-0.0457	0.271	3.69	80.1
	EGSI	0.01974	-0.4258	0.4061	0.691	1.445	165.1
	EGV	-0.1915	0.8314	-0.6399	0.0002	4193.1	274.7
	EGD	-11.2731	50.2752	-39.0021	0.0024	410.8	203.8
	RMSE[6]	0.0422	0.2270	0.1858	-	-	-
	SSE[7]	0.3103	8.9659	6.0056	-	-	-
	RSQ[8]	0.9800	0.9375	0.9927	-	-	-
	Adj. RSQ[9]	0.9795	0.9357	0.9925	-	-	-
59	$ß_1$[5]	18.6347	86.2314	-104.861	.	0	1
	EGWT	0.3568	1.4913	-0.8480	0.0002	5567.7	46.1
	EGWD	-0.0427	-0.1580	0.2007	0.2707	3.6944	82.0
	EGSI	-0.6514	0.5174	0.1340	0.6922	1.4446	177.7
	EGV	-0.2745	-1.2127	1.4871	0.0002	5229.9	280.7
	EGD	-15.849	-77.7525	93.5972	0.0021	470.0	406.4
	RMSE[6]	0.1692	0.3993	0.4836	-	-	-
	SSE[7]	4.9766	27.7483	40.9176	-	-	-
	RSQ[8]	0.7667	0.8764	0.9423	-	-	-
	Adj. RSQ[9]	0.7600	0.8729	0.9406	-	-	-

[1] Egg variable=See Table 1; [2] TOL=Tolerance value; [3] VIF=Variation inflation factor; [4] CI=Condition index; [5] ß=Parameter estimate; [6] RMSE=*Root Mean Square Error*, [7] SSE=sum of squared errors; [8] RSQ= R-squared; [9] Adj. RSQ=Adjusted R-squared.

p<0.05, to 0.39, p<0.001) in eggs produced at 45 and 59 weeks of age. These data demonstrate that eggs produced at 32, 45, and 59 weeks of age presented different characteristics and consequently the correlation coefficients varied among characteristics.

A summary of the regression analysis of egg measurements is shown in Table 3. Regression analysis indicated that the VIF values of EGWD and EGSI of the eggs produced at 45 and 59 weeks of age were between 1.4 and 3.7. However, the strong correlations found among egg measures led to MC problems in the in all age groups. The VIF and CI values ranged from 62 to 5568 and 35 to 4698, respectively. The VIF and CI are two of the collinearity diagnostic measures that give information about the level of MC for a reliable statistical analysis in a multiple regression analysis. The upper limits for VIF and CI are considered to be 10 and 30, respectively (Belsley, 1982; Karakus *et al.,* 2010).

The results of stepwise regression analysis are given in Table 4. Results from the stepwise regression model of eggs produced at 32 weeks of age indicated that the EGWT was the significant variable included in the model with R^2 % ranged from 60 to 99 for egg components (SWT, YWT and AWT). This finding suggests that 60 to

Table 4 – Summary of stepwise regression analysis of measurements of Ross strain eggs produced at 32, 45 and 59 weeks of age.

Age (week)	Egg variable[1]	SWT[1]	TOL[2]	VIF[3]	CI[4]	YWT[1]	TOL[2]	VIF[3]	CI[4]	AWT[1]	TOL[2]	VIF[3]	CI[4]
32	$ß_1$[5]	-0.175	-	0	1.00	11.095	-	0	1.00	-10.919	-	0	1.00
	EGWT	0.095	1.00	1.00	44.0	0.102	1.00	1.00	44.0	0.803	1.00	1.00	44.0
	RMSE[6]	0.0079	-	-	-	0.224	-	-	-	0.2234	-	-	-
	SSE[7]	0.0112	-	-	-	8.939	-	-	-	8.881	-	-	-
	RSQ[8]	0.9990	-	-	-	0.5985	-	-	-	0.9892	-	-	-
	Adj. RSQ[9]	0.9990	-	-	-	0.5963	-	-	-	0.9892	-	-	-
45	$ß_1$[5]	12.091	-	0	1.00	-50.259	-	0	1.00	38.168	-	0	1.00
	EGWT	0.273	2.2E-4	4615.13	43.50	-0.525	2.2E-4	4615.13	43.50	1.252	2.2E-4	4615.13	43.50
	EGWD	-0.012	0.35	2.84	116.99	-	0.353	2.84	116.99	-0.0367	0.3526	2.84	116.99
	EGV	-0.191	2.4E-4	4158.15	243.89	-	2.4E-4	4158.15	243.89	0.6220	2.4E-4	4158.15	243.89
	EGD	-11.229	2.4E-3	407.75	5640.27	-	2.4E-3	407.75	5640.27	-38.0907	2.4E-3	407.75	5640.27
	RMSE[6]	0.0421	-	-	-	0.226	-	-	-	0.1855	-	-	-
	SSE[7]	0.3103	-	-	-	8.9816	-	-	-	6.021	-	-	-
	RSQ[8]	0.9800	-	-	-	0.9374	-	-	-	0.9927	-	-	-
	Adj. RSQ[9]	0.9796	-	-	-	0.9359	-	-	-	0.9925	-	-	-
59	$ß_1$[5]	1.507	-	0	1.00	84.418	-	0	1.00	-48.820	-	0	1.00
	EGWT	0.104	0.44	2.244	48.42	1.460	1.8E-4	5486.54	46.27	-	0.35	2.819	50.169
	EGWD	-0.055	0.44	2.244	159.18	-0.115	0.26	2.82	128.81	0.200	-	-	-
	EGSI	-	-	-	-	-	-	-	-	-	0.39	2.79	151.12
	EGV	-	-	-	-	-1.181	0.35	5164.21	250.40	0.577	-	-	-
	EGD	-	-	-	-	-76.023	1.9E-4	464.55	6719.14	41.524	0.98	1.02	251.91
	RMSE[6]	0.1688	-	-	-	0.3984	-	-	-	0.4824	-	-	-
	SSE[7]	5.0455	-	-	-	27.7715	-	-	-	40.9542	-	-	-
	RSQ[8]	0.7636	-	-	-	0.8763	-	-	-	0.9419	-	-	-
	Adj. RSQ[9]	0.7609	-	-	-	0.8735	-	-	-	0.9409	-	-	-

[1] Egg variable=See Table 1; [2] TOL=Tolerance value; [3] Variation inflation factor; [4] Condition index; [5] ß=Parameter estimate; [6] RMSE=*Root Mean Square Error*; [7] SSE=sum of squared errors; [8] RSQ= R-squared; [9] Adj. RSQ=Adjusted R-squared.

99% of the variations in components (SWT, YWT and AWT) of eggs produced at 32 weeks of age can be explained by EGWT. However, VIF and CI values were 1.0 and 44, respectively. The slightly high CI value indicated a moderate MC problem.

The stepwise regression models for the prediction of components of eggs produced at 45 weeks of age indicated MC problems with VIF and CI ranged from 2.84 to 4615, and 43 to 5640, respectively. The variables included in the model were EGWT, EGWD, EGV and EGD with R^2 % ranged from 93 to 99%. This finding suggested that 93 to 99% of the variations in components of the eggs produced at 45 weeks of age can be explained by EGWT, EGWD, EGV and EGD. On the other hand, the stepwise regression models for the prediction of components of the eggs produced at 59 weeks of age indicated MC problems with VIF and CI ranged from 1.02 to 5486, and 46 to 6719, respectively. The variables included in the model were EGWT and EGWD; EGWT, EGWD, EGV and EGD; and EGWT, ESI and EGD for the prediction of SWT, YWT and AWT, respectively. These variables explain about

Table 5 – Summary of Ridge regression analysis of measurements of Ross strain eggs produced at 32, 45 and 59 weeks of age

Age (week)	Egg variable [1]	SWT [1]	YWT [1]	AWT [1]	VIF[2]
32	$ß_1$[3]	-1.325	11.724	-22.234	0
	EGWT	0.084	0.110	0.703	5.22
	EGWD	0.043	-0.020	0.444	8.20
	EGSI	-0.742	0.207	-8.170	5.20
	EGV	3.0E-4	0.00	-0.019	6.25
	EGD	0.485	-0.307	4.921	4.89
	Riddge[4]	0.004	0.004	0.004	-
	RMSE[5]	0.00829	0.22642	0.22512	-
	SSE[6]	0.01381	8.9203	8.8181	-
	RSQ[7]	0.9987	0.59939	0.9893	-
	Adj. RSQ[8]	0.9970	0.3410	0.9780	-
45	$ß_1$[3]	-1.227	-12.485	-15.758	0
	EGWT	0.052	-0.10	0.364	8.71
	EGWD	-0.009	0.054	-0.029	3.57
	EGSI	-0.038	-0.317	0.133	1.42
	EGV	0.042	0.15	0.315	8.14
	EGD	1.133	13.948	12.252	1.77
	Riddge[4]	0.0025	0.0025	0.0025	-
	RMSE[5]	0.04359	0.22915	0.19104	-
	SSE[6]	0.33061	9.1367	6.3503	-
	RSQ[7]	0.9787	0.93627	0.992	-
	Adj. RSQ[8]	0.9570	0.8730	0.9840	-
59	$ß_1$[3]	-1.067	1.557	-32.5102	0
	EGWT	0.058	0.208	0.250	4.14
	EGWD	-0.038	-0.139	0.197	3.53
	EGSI	-0.739	0.143	0.315	1.40
	EGV	0.045	0.161	0.308	4.10
	EGD	2.438	0.861	26.251	1.32
	Riddge[4]	0.0035	0.0035	0.0035	-
	RMSE[5]	0.16968	0.40339	0.48610	-
	SSE[6]	5.00968	28.1339	41.1150	-
	RSQ[7]	0.76527	0.8739	0.94166	-
	Adj. RSQ[8]	0.5740	0.7570	0.8830	-

[1] Egg variable=See Table 1; [2] Variation inflation factor; [3] ß=Parameter estimate; [4] Ridge point; [5] RMSE=*Root Mean Square Error*; [6] SSE=sum of squared errors; [7] RSQ= R-squared; [8] Adj. RSQ=Adjusted R-squared.

76 to 94% of the variation in SWT, YWT and AWT of the eggs produced at 59 weeks of age.

The results of ridge regression analysis are shown in Table 5 and Figures 1, 2, and 3 for eggs produced at 32, 45 and 59 weeks of age, respectively. The VIF values produced by ridge regression ranged from 4.9 to 8.2, 1.4 to 8.7 and 1.3 to 4.1 for eggs produced at 32, 45 and 59 weeks of age, respectively, all of which were lower than 10. These findings suggested that ridge regression analysis provided an ideal solution for managing the moderate and severe MC problems and successfully predicting egg components (SWT, YWT and AWT) from measurements (EGWT, EGWD, EGSI, EGV and EGD) of eggs produced at 32, 45 and 59 weeks of age. This study is in agreement with earlier studies, which indicated that the use of ridge regression eliminated the problem of MC (Schoeman *et al.*, 2002; Pimentel *et al.*, 2007).

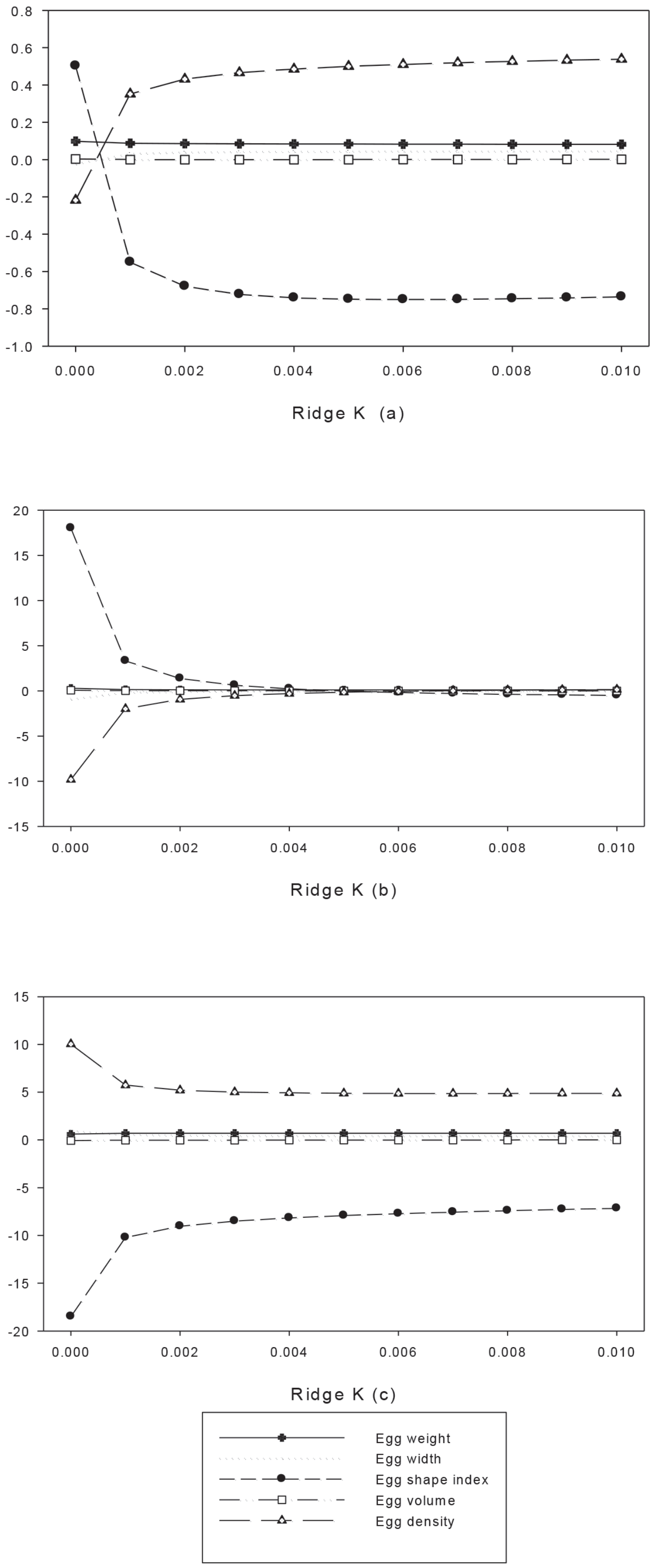

Figure 1 – Ridge trace plots of K value for eggshell weight (a), yolk weight and albumin weight (c) of eggs produced at 32 weeks age

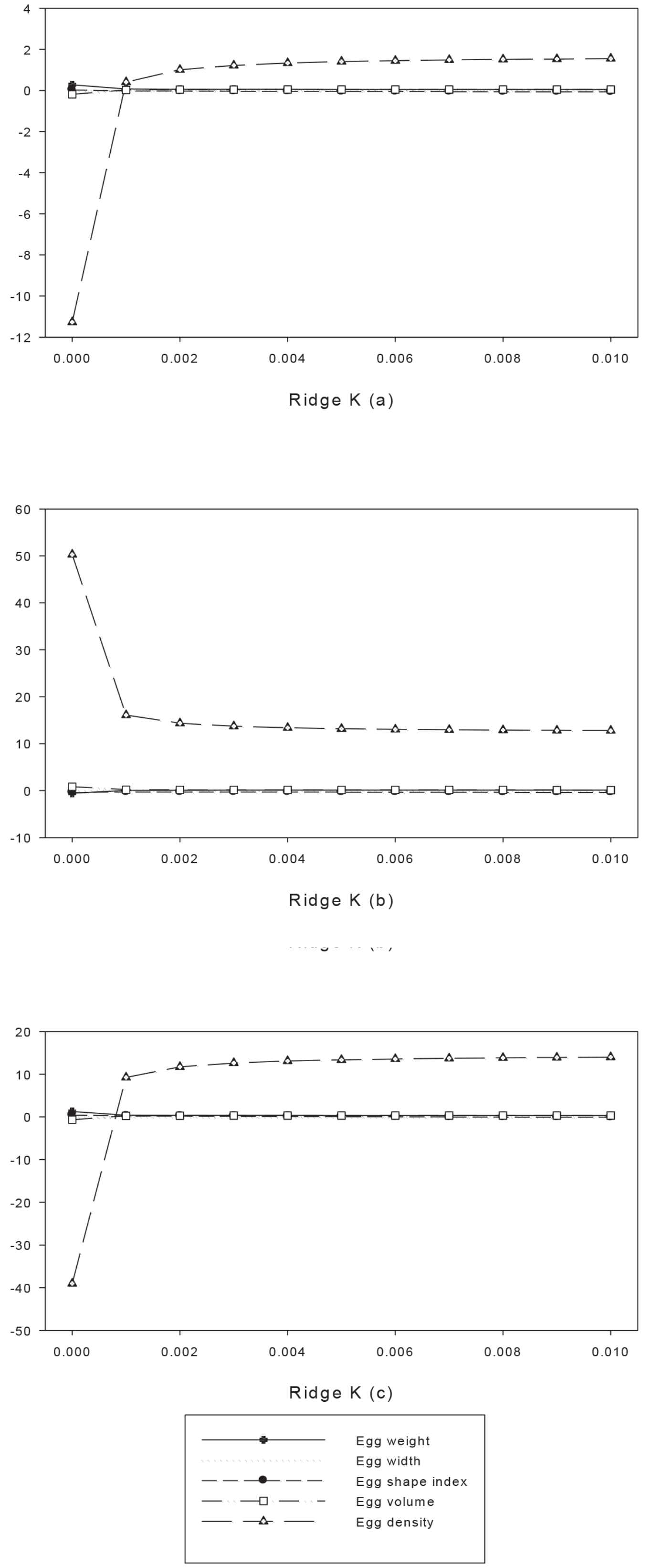

Figure 2 – Ridge trace plots of K value for eggshell weight (a), yolk weight and albumin weight (c) of eggs produced at 45 weeks age

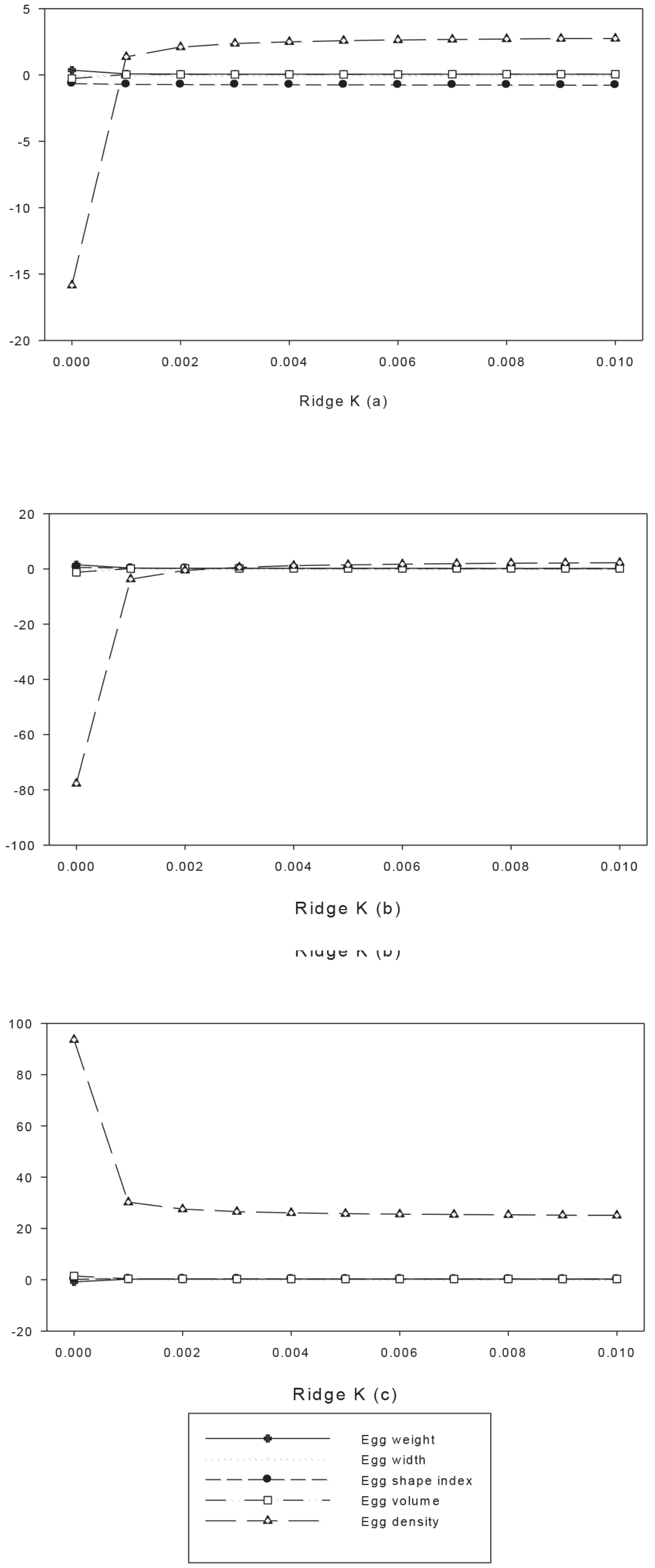

Figure 3 – Ridge trace plots of K value for eggshell weight (a), yolk weight and albumin weight (c) of eggs produced at 59 weeks age

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CONCLUSIONS

The objectives of this study were to determine the presence of collinearity in the estimation of egg components from morphological characters of eggs and get the best model to describe the components of eggs produced by hens at 32, 45 and 59 weeks of age. In the present study, MC problems were found in the data collected from eggs produced by hens of the three age groups. The ridge regression analysis provided better solution of the MC problem than the stepwise regression when predicting components of SWT, YWT and AWT of eggs.

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