Direct and Indirect Effects of Egg Quality Traits on Egg Weight of Potchefstroom Koekoek Chicken Genotype

Victoria Rankotsane Hlokoe and Thobela Louis Tyasi*

School of Agricultural and Environmental Sciences, Department of Agricultural Economics and Animal Production, University of Limpopo, Private Bag X1106, Sovenga 0727, Limpopo, South Africa

*Corresponding author: louis.tyasi@ul.ac.za

Article History: 21-279

Received: 10-Feb-21

Revised: 26-Feb-21

Accepted: 01-Mar-21

ABSTRACT

Path analysis is the statistical tool used to assess the direct and indirect effects of independent variables on the dependent variables. This study was done to examine the association among egg weight (EWt) and egg quality traits, including egg length (EL), egg width (EWD), yolk weight (YW), shell weight (SW), shell ratio (SR), shell index (SI), albumen weight (AW), albumen ratio (AR) and yolk ratio (YR), and assess the direct and indirect influences of egg quality traits on egg weight. Three hundred eggs of Potchefstroom Koekoek chicken genotype were used in the study to determine egg weight and egg quality traits. Pearson's association and path coefficient analysis were utilised for analysing data. The findings of association showed that EWt had positively high statistically significant association ($P < 0.01$) with EL ($r = 0.79$), EWD ($r = 0.55$), YW ($r = 0.45$), AW ($r = 0.48$), and AR ($r = 0.38$). Path analysis results revealed that YR (-1.98) followed by YW (1.72) made the biggest direct influence on the EWt, while AR followed by SW displayed the highest indirect effect on EWt via YR and YW. Correlation findings recommend that improving EL, EWD, YW, AW and AR might result in increased EWt. The results of path analysis indicate that YR and YW could be selected during breeding to improve EWt of Potchefstroom Koekoek chicken genotype. Chicken farmers may use the outcomes of the current study to predict EWt using egg quality traits.

Key words: Direct effect, Indirect effect, Egg weight, Egg length, Yolk weight.

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INTRODUCTION

The Potchefstroom Koekoek is the chicken genotype which was bred through crossing of Black Australorp, White Leghorn and Barred Plymouth Rock (Grobbelaar et al. 2010; Tyasi et al. 2019). The genotype is adapted well to the tropical areas, have good self-sustainment, disease resistant, have brilliant temperament and suitable for free-range production system (Dessie and Gatachew 2016; Heit 2017). Potchefstroom Koekoek is a free-range dual-purpose chicken genotype used in communal farms in rural areas for meat and egg production (Mtileni et al. 2012; Idowu et al. 2018). However, the egg weight of this chicken genotype is low, hence, the egg quality traits require genetic improvement in order to enhance the egg weight (Mutibvu et al. 2019). According to Thakur and Bhardwaj (2017), path analysis is the statistical technique used to assess the cause-effect association among dependent and independent variables. Mendes et al. (2005) reported that path analysis analyses the direct and indirect impact of the

independent variables on the dependent variables. Egg quality traits have been shown as important predictors of egg weight during breeding in South-eastern Nigeria local chicken (Adeolu and Oleforuh-Okoleh 2011), three varieties of Japanese quail (Chimezie et al. 2017) and Isa Brown egg layer chickens in Nigeria (Ukwu et al. 2017) and. However, based to our knowledge, the information on the prediction of egg weight from egg quality traits using path analysis in Potchefstroom Koekoek chickens genotype is not enough. Therefore, the objectives of the study were: 1) to determine the association between egg weight and egg quality traits, including egg length, egg width, yolk weight, shell weight, shell ratio, shell index, albumen weight, albumen ratio and yolk ratio using Pearson's correlation analysis, and 2) to determine the direct and indirect influences of egg quality traits on egg weight with path coefficient analysis. This research is going to assist Potchefstroom Koekoek chicken genotype farmers to select best egg quality traits that can be used to increase egg weight during breeding.

Cite This Article as: Hlokoe VR and Tyasi TL, 2021. Direct and indirect effects of egg quality traits on egg weight of Potchefstroom Koekoek chicken genotype. International Journal of Veterinary Science 10(4): 280-285. <https://doi.org/10.47278/journal.ijvs/2021.053>

MATERIALS AND METHODS

Ethical Approval

This research was conducted following the standard operation procedures of the Animal Research and Ethics Committee (AREC) at the University of Limpopo, South Africa.

Experimental Area

The research was conducted at the University of Limpopo experimental farm. Brown and Ng'ambi (2019) explained the latitude, longitude, location, rainfall and ambient temperatures.

Experimental Birds and Data Collection

Eggs of Potchefstroom Koekoek chicken genotype were used in the study. A total of three hundred (300) eggs were collected and used for determining egg weight and egg quality traits. Egg weight was measured using a sensitive digital weighing balance (Mettler Toledo, PL203 CE) with accuracy of 0.001g. Egg length and egg width were taken using a Vernier calliper. Egg length (EL), egg width (EWD), yolk weight (YW), albumen weight (AW), shell weight (SW), shell index (SI), shell ratio (SR) and albumen ratio (AR) were measured and computed as described by Ukwu et al. (2017).

Data Analysis

Statistical Package for Social Sciences (IBM SPSS 2019) version 26 was employed for analysis of data. Descriptive statistics involving the coefficient of variation (CV), mean and standard error of EWt were measured and computation of independent variables was done. Statistical Analysis System version 9.4 (SAS 2019) was used to plot the boxplot. To evaluate the relationship among measured traits, Pearson's correlation was used. Multiple regression was utilised to construct a formula for estimation of EWt using egg quality traits. The multiple linear regression model below was used:

$$Y = a + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_4 X_4 + b_5 X_5 + b_6 X_6 + b_7 X_7 + b_8 X_8 + b_9 X_9$$

Where

Y = dependent variable (EWt),

a = intercept,

$b_1 - b_9$ = regression coefficient,

$X_1 - X_9$ = independent variables (egg quality traits).

Path coefficient analysis method was employed to determine the direct and indirect influence of independent variables on the dependent variable as explained by Mendes et al. (2005). Path coefficient analysis was briefly calculated using the following formulas:

$$Py_{xi} = \frac{biS_{xi}}{Sy}$$

Where

Py_{xi} = coefficient of path analysis from X_i to Y (i = EL, EWD, YW, SW, SI, AW, AR, SR and YR)

b_i = partial coefficient of regression,

S_{xi} = standard deviation (σ) of X_i and

$S_y = \sigma$ of Y.

Indirect effects of egg quality traits on EWt via direct influence were computed using the following formula:

$$IE_{yxi} = rx_{ij}Py_{xj}$$

Where

IE_{yxi} = direct influence of egg quality traits through a direct influence on egg weight,

rx_{ij} = coefficient of correlation (r) among i th and j th egg quality traits, and

Py_{xj} = path analysis coefficient that shows the direct influence of j th egg quality trait on egg weight.

RESULTS

Descriptive Statistics

The summary about egg weight in Potchefstroom Koekoek chicken has been presented in Fig. 1. The egg weight values of all four quartiles i.e., 25th (first quartile), 50th (median) 75th (third) and 100th (maximum) have already been overviewed. Boxplot of EWt revealed minimum values greater than 50g, first quartile of 55g, median less than 60g, third quartile greater than 60g, and the maximum higher than 70g, respectively. The boxplot description showed that the data concerning EWt in Potchefstroom Koekoek had one outlier which was greater than 75g.

Fig. 1: Boxplot showing the median, minimum, maximum, 25th and 75th percentile values of egg weight of Potchefstroom Koekoek chicken.

The summary of EWt and egg quality traits including EL, egg EWD, YW, SW, SI, SR, AW, AR and YR is presented in Table 1. Descriptive statistics indicated that SI (73.56 ± 1.02) had greater mean values than all the other egg quality traits in Potchefstroom Koekoek chicken genotype, followed by EWt (59.71 ± 0.32), AR (56.67 ± 0.14), EL (55.56 ± 0.12) and EWD (43.45 ± 0.07), respectively. The results further showed that SW (9.60 ± 0.37) had the lowest mean numerical value than all the traits. The mean was divided with the standard deviation to calculate the coefficient of variance and the findings displayed a range of 3.71%-66.25%.

Table 1: Descriptive statistics for egg weight and egg quality traits of the Potchefstroom Koekoek chicken genotype

Traits	N	Mean±SE	CV (%)
EW (g)	300	59.71±0.32	9.14
EL (mm)	300	55.56±0.12	3.71
EWD (mm)	300	43.45±0.07	2.83
YW (g)	300	17.48±0.07	7.21
SW (g)	300	9.60±0.37	66.25
SI (%)	300	73.56±1.02	24.13
SR (%)	300	12.57±0.20	27.53
AW (g)	300	32.11±0.35	18.78
AR (%)	300	56.67±0.14	4.39
YR (%)	300	29.86±0.12	7.17

EW=egg weight, EL=egg length, EWD=egg width, YW=yolk weight, SW=shell weight, SI=shell surface index, SR=shell ratio, AW=albumen weight, AR=albumen ratio, YR=yolk ratio, SE=Standard error and CV=coefficient of variance.

Phenotypic Correlations Between Measured Traits

Pearson's association was employed to examine the relationship among EWt, and egg quality traits of Potchefstroom Koekoek chicken genotype and the findings are presented in Table 2. The results indicated that EWt had a positively high statistically significant correlation ($P<0.01$) with EL ($r=0.79$), EWD ($r=0.55$), YW ($r=0.45$), AW ($r=0.48$), and AR ($r=0.38$), and a negatively high statistically significant association ($P<0.01$) with YR ($r=-0.49$) and no significant correlation ($P>0.05$) with SW ($r=0.04$), SI ($r=0.01$) and SR ($r=0.09$). These findings further displayed that EL had a positively high statistical relationship ($P<0.01$) with EWD ($r=0.49$), YW ($r=0.57$), AW ($r=0.42$), and AR ($r=0.19$), and a negatively high statistically significant association ($P<0.01$) with YR ($r=-0.36$) but not significantly associated ($P>0.05$) with SW ($r=0.08$) and SI ($r=-0.05$). The outcomes also indicated that EWD had a positively high statistically significant association ($P<0.01$) with YW ($r=0.28$), AW ($r=0.47$), and AR ($r=0.60$), and a negatively high statistically significant correlation ($P<0.01$) with YR ($r=-0.64$) but had no significant association with SW ($r=0.08$), SI ($r=0.05$) and SR ($r=0.03$). The findings also showed that YW had a positively high statistically significant association ($P<0.01$) with YR ($r=0.38$), and AW ($r=0.13$) and a negatively high statistically significant association ($P<0.01$) with AR ($r=-0.43$) but not statistically associated with SW ($r=0.05$), SI ($r=-0.03$) and SR ($r=0.09$). The outcomes further showed that SI had a positively high statistically significant correlation ($P<0.01$) with SR ($r=0.94$), and AW ($r=0.81$) and no statistical significant correlation ($P>0.05$) with AR ($r=0.06$) and YR ($r=-0.03$). SR had a positively high statistically significant association ($P<0.01$) with AW

($r=0.77$), a negatively high statistical significant association ($P<0.01$) with AR ($r=-0.11$) and not significantly associated ($P>0.05$) with YR ($r=0.04$). AW had a positively high statistically significant association ($P<0.01$) with AR ($r=0.44$), and a negatively high statistically significant association ($P<0.01$) with YR ($r=-0.46$). Furthermore, AR had a negatively high statistically significant association ($P<0.01$) with YR ($r=-0.93$).

Multiple Linear Regression

Multiple linear regression analysis was used to compute preliminary equations, and the results are described in Tables 3. The results showed that YW (8.274) had the greatest single contribution ($P<0.05$) to the EWt of Potchefstroom Koekoek chicken genotype followed by SR (0.196) with $R^2=0.82$ and $MSE=5.65$. The outcomes also displayed that 82% of the differences in EWt was described by the model. The model of multiple regression was constructed as $EWt = 302.87 - 0.45 EL - 2.37 EWD + 8.27 YW - 1.68 SW - 0.24 SI + 0.20 SR - 1.38 AW + 0.04 AR - 6.22 YR$. The findings showed that SR and AR in the model were statistically not significant ($P>0.05$).

Path Analysis

The value of regression coefficient from analysis of multiple regression was utilised as a direct effect of egg quality traits on EWt and an indirect influence was calculated with path coefficient analysis method. Path coefficient analysis results are presented in Tables 4. The direct and indirect effects of egg quality traits on EWt of Potchefstroom Koekoek chicken genotype are shown in Table 4. The results showed that seven egg quality traits (EL, EWD, YW, SW, SI, AW and YR) were statistically significant as direct influences on EWt of Potchefstroom Koekoek chicken genotype. However, YR (-1.98) followed by YW (1.72) made the biggest direct influence on the EWt, while AR followed by SW displayed the highest indirect influence on EWt through YR and YW.

Optimum Regression Model

The best regression equation for estimation of EWt from egg quality traits of Potchefstroom Koekoek chicken was established. The findings of path analysis showed that coefficients of SR (0.20) and AR (0.04) were statistically non-significant, whereas EL (-0.33), EWD (-2.50), YW (8.21), SW (-1.59), SI (-0.17), AW (-1.38) and YR (-6.19) were statistically significant on the EWt. The statistically non-significant egg quality traits on the EWt were removed from the multiple linear regression model. The R^2 and MSE

Table 2: Phenotypic correlation among measured egg quality traits

Egg quality traits	EW	EL	EWD	YW	SW	SI	SR	AW	AR	YR
EW (g)										
EL (mm)	0.79**									
EWD (mm)	0.55**	0.49**								
YW (g)	0.45**	0.57**	0.28**							
SW (g)	0.04 ^{ns}	0.08 ^{ns}	0.08 ^{ns}	0.05 ^{ns}						
SI (%)	0.01 ^{ns}	-0.05 ^{ns}	0.05 ^{ns}	-0.03 ^{ns}	-0.98**					
SR (%)	0.09 ^{ns}	0.11*	-0.03 ^{ns}	0.09 ^{ns}	-0.93**	0.94**				
AW (g)	0.48**	0.42**	0.47**	0.13**	-0.77**	0.81**	0.77**			
AR (%)	0.38**	0.19**	0.60**	-0.43**	-0.00 ^{ns}	0.06 ^{ns}	-0.11*	0.44**		
YR (%)	-0.49**	-0.36**	-0.64**	0.38**	-0.05 ^{ns}	-0.03 ^{ns}	0.04 ^{ns}	-0.46**	-0.93**	

EW=egg weight, EL=egg length, EWD=egg width, YW=yolk weight, SW=shell weight, SI=shell surface index, SR=shell ratio, AW=albumen weight, AR=albumen ratio, YR=yolk ratio, ns=not significant, *significant ($P<0.05$) and **significant ($P<0.01$).

Table 3: Multiple linear regression analysis for Potchefstroom Koekoek chicken genotype

Regression Parameters	Egg quality traits								
	EL	EWD	YW	SW	SI	SR	AW	AR	YR
Coefficient (B)	-0.45	-2.37	8.27	-1.68	-0.24	0.20	-1.38	0.04	-6.22
SE	0.22	0.33	0.95	0.50	0.11	0.41	0.38	0.46	1.08
P- value	0.04	0.00	0.00	0.00	0.03	0.63	0.00	0.94	0.00

Intercept (a) = 302.87, Coefficient of determination (R^2) = 0.82, MSE = 5.65

EL=egg length, EWD=egg width, YW=yolk weight, SW=shell weight, SI=shell surface index, SR=shell ratio, AW=albumen weight, AR=albumen ratio, YR=yolk ratio.

Table 4: Path coefficient analysis of egg quality traits and egg weight

Egg quality traits	Correlation coefficient with EW	Direct effect	Indirect effect								
			EL	EWD	YW	SW	SI	SR	AW	AR	YR
EL (mm)	0.79**	-0.20*		-0.26	0.98	-0.11	0.05	0.04	-0.46	0.04	0.71
EWD (mm)	0.55**	-0.54*	-0.10		0.48	-0.12	-0.05	-0.01	-0.51	0.13	1.26
YW (g)	0.45**	1.72*	-0.11	-0.15		-0.07	0.03	0.03	-0.15	-0.10	-0.76
SW (g)	0.04 ^{ns}	-1.41*	-0.02	-0.04	0.08		0.86	-0.36	0.84	0.00	0.11
SI (%)	0.01 ^{ns}	-0.87*	0.01	-0.03	-0.05	1.39		0.37	-0.88	0.01	0.06
SR (%)	0.09 ^{ns}	0.39 ^{ns}	-0.02	0.01	0.15	1.31	-0.82		-0.83	-0.03	-0.07
AW (g)	0.48**	-1.09*	-0.09	-0.25	0.23	1.09	-0.71	0.30		0.10	0.90
AR (%)	0.38**	0.22 ^{ns}	-0.04	-0.32	-0.75	0.00	-0.06	-0.04	-0.47		1.84
YR (%)	-0.49**	-1.98*	0.07	0.34	0.66	0.08	0.03	0.01	0.50	-0.20	

EW=egg weight, EL=egg length, EWD=egg width, YW=yolk weight, SW=shell weight, SI=shell surface index, SR=shell ratio, AW=albumen weight, AR=albumen ratio, YR=yolk ratio, ns=not significant, *significant ($P<0.05$) and **significant ($P<0.01$).

in the regression model were changed by the removal of statistically not significant egg quality traits. Table 5 presents the best regression models for estimation of EWt from egg quality traits of Potchefstroom Koekoek. The remaining egg quality traits were evaluated again with the multiple linear regression approach to estimate EWt after the exclusion of non-significant egg quality traits (SR and AR). The model of EL, EWD, YW, SW, SI, AW and YR was statistically significant ($P<0.05$) with $R^2=0.82$ and $MSE=5.63$. The equation of regression was constructed as $EWt=300.59 - 0.33 EL - 2.50 EWD + 8.21 YW - 1.59 SW - 0.17 SI - 1.38 AW - 6.19 YR$. This indicates that 82% of the variation in EWt was described by the model.

DISCUSSION

The egg quality traits are the best parameters in animal breeding for improvement of egg weight in chickens (Ukwu et al. 2017; Khaskheli et al. 2020). The boxplot was used to summarise the data for all studied traits and the results showed that the Potchefstroom Koekoek had egg weight of about 58g. Descriptive statistics further indicated that SI had greater mean values than other egg quality traits in Potchefstroom Koekoek chicken genotype, followed by EWt, AR, EL and EWD, respectively. The results were higher than that of Nonga et al. (2010) in Tanzania free-range local chickens, Mohammed et al. (2005) in Sudanese indigenous chicken ecotypes, Saroj et al. (2020) in indigenous Sakini chicken and Dzungwe et al. (2018) in French broiler Guinea fowl. The differences may be due to breed variations. This study firstly used Pearson's correlation to examine the relationship among EWt and egg quality traits namely, EL, EWD, YW, SW, SI, AW, AR, SR and YR in Potchefstroom Koekoek. The results indicated that EL, EWD, YW, AW and AR had a positively high statistically significant relationship with EWt. The results of this study showed that by enhancing EL, EWD, YW, AW and AR might result in improved EWt. Therefore, EL, EWD, YW, AW and AR might be involved in the criteria for selection during breeding to enhance EWt

in Potchefstroom Koekoek chicken genotype. The findings of this study are in agreement with previous studies on South-eastern Nigeria local chicken (Adeolu and Oleforuh-Okoleh 2011), Isa Brown egg layer chickens in Nigeria (Ukwu et al. 2017), French broiler Guinea fowl (Dzungwe et al. 2018) and indigenous Sakini chicken Saroj et al. (2020). The results were dissimilar to those of Dayanidhi et al. (2016) in indigenous Hansli chickens, and the variations may be due to breed differences. Naskar et al. (2005) and Tyasi et al. (2017) reported that the coefficient of association only assists in specifying the size of relations without determining the cause effect relationship among the traits. Therefore, the use of path coefficient analysis method helps in examining the direct and indirect influences of the egg quality traits on EWt of Potchefstroom Koekoek.

Multiple linear regression analysis was used to calculate the path coefficient for egg quality traits. The equation of regression was constructed using the findings of multiple regression and all the measured egg quality traits were involved in the equations. However, EL, EWD, YW, SW, SI, AW and YR were statistically significant. The regression results agree with the study of Orhan et al. (2016) in commercial white layer hybrids of Isparta. The results show that EL, EWD, YW, SW, SI, AW and YR were statistically significant as direct influences on EWt of Potchefstroom Koekoek chicken genotype. Path coefficient analysis technique was employed to predict the indirect influence of egg quality traits on EWt. The findings revealed that YR followed by YW made the biggest direct influence on the EWt, while AR followed by SW displayed the highest indirect influence on EWt through YR and YW of Potchefstroom Koekoek chicken genotype. These results explain that YR and YW made the greatest influence on EWt of Potchefstroom Koekoek chicken genotype. The path analysis findings suggest that EWt could be estimated using YR and YW in Potchefstroom Koekoek chicken genotype. The egg quality traits that were not significant were excluded for construction of optimum regression model. Following the elimination of not significant egg

quality traits from the model, EL, EWD, YW, SW, SI, AW and YR were included in the regression model. Based to the previous information, there are limited path analysis studies evaluating the relationship among EWt and egg quality traits in chickens. Nevertheless, most research of path coefficient analysis in chickens were focusing on enhancement of body weight in Chinese indigenous Dagou male chickens (Tyasi et al. 2018), indigenous Nigeria chickens (Egena et al. 2014), Taishan chickens (Qiao et al. 2017) and Zambian indigenous free-range chickens (Liswaniso et al. 2020). Other studies can use path analysis to investigate the cause effect association between EWt and egg quality traits in other chicken breeds.

Conclusion

The findings showed that there is correlation among egg quality traits. It is concluded that EL, EWD, YW, AW and AR had a high positive association with EWt of Potchefstroom Koekoek chicken genotype. Path analysis showed that YR and YW made the greatest direct effect on the EWt, while AR and SW made the biggest indirect influence on EWt through YR and YW of Potchefstroom Koekoek chicken genotype. This means that YR and YW made the highest contribution to EWt. The established regression model can be employed by chicken farmers to predict EWt. The study may help Potchefstroom Koekoek chicken farmers with traits to use as selection criterion during breeding to enhance egg weight. Additional studies are required to examine the association among egg weight and egg quality traits in larger sample of similar or varying chicken genotypes.

Acknowledgements

Authors wish to express their gratitude to the Farmworkers at the University of Limpopo Experimental for their support during data collection and Department of Agricultural Economics and Animal Production, the University of Limpopo for financial support.

Author's Contribution

TLT and HVR designed the experiment, analyzed the data the manuscript. HVR performed fieldwork and wrote the manuscript. TLT revised, read, edited and approved the final manuscript.

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