

Using functional forms data analysis to assess egg quality characteristics of the West African black mud tortoise (*Pelusios castaneus*)

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ABSTRACT: This study was conducted to evaluate egg external and internal quality traits of the West African Black Mud Tortoise. A total of Eighty (80) eggs were collected from (*Pelusios castaneus*). Four model specifications (linear, double-log, semi-log and exponential functions) were evaluated to determine the best-fitting regression of egg weight on various egg traits. The data showed mean values of 18.84±1.24g, 8.02±0.26g, 28.30±2.40mm and 76.13±3.62% for egg weight (EWT), albumen weight (AWT), albumen length (ALT) and haugh unit (HU), respectively. Analysis indicated that mean yolk weight (YWT), yolk height (YHT), yolk width (YWD), yolk index (YI), shell weight (SWT) and shell thickness (STH) were 7.14±0.15g, 2.16±0.03mm, 4.07±0.13mm, 0.44±0.01, 3.68±0.13g and 0.25±0.01mm, respectively. Findings revealed mean egg length (ELT) (33.89±1.14mm), egg width (EWD) (25.79±1.41mm) and egg shape index (ESI) (1.20±0.02). EWT data demonstrated a non-linear trend. Evaluation of fit quality across four functional forms resulted in coefficient of determination (R²) values of 78.68 % (linear), 78.35% (semi-log), 65.80% (double-log), and 71.30% (exponential), respectively, indicating that the linear model provided the strongest fit. AWT was the most significant predictor of EWT. The results indicate that a linear function is the most suitable, providing the best fit for modelling the EWT curve of *Pelusios castaneus* in this study. In conclusion, data analysis shows that EWT is the key factor influencing egg quality and reproductive performance in *Pelusios castaneus*.

Keywords: Breeder, egg weight, linear function, Haugh unit, predictor, regression models.

INTRODUCTION

Functional forms data analysis for *Pelusios castaneus* focuses on predicting egg quality traits like egg weight, Haugh unit, and shell thickness using variables such as age, body weight, and management systems. Studies have shown that age and management systems significantly affect egg quality, with some findings suggesting that egg weight is a key predictor for other quality aspects like yolk and albumen percentages (Booth *et al.*, 2020; Stanford *et al.*, 2020; Phillott *et al.*, 2021; Kperegbeji and Akaine, 2025). These analyses help identify the genetic potential of the *Pelusios castaneus* for

improved egg production and quality, useful for developing superior Nigerian breeds for meat and eggs.

Age of the tortoise has a significant effect on many internal and external egg quality traits, including egg weight, length, width, and internal components like Haugh unit and yolk/albumen measurements (Phillott and Godfrey, 2020; Booth *et al.*, 2022; Mayor, 2023; Kperegbeji *et al.*, 2025). The system of management (e.g., cage vs. deep litter) also significantly influences egg traits, affecting egg weight, length, shell weight, yolk weight, and yolk height. Egg weight has been found to

significantly affect other egg quality traits, such as the shape index, shell thickness, and the percentages of yolk and albumen.

Regression models, including linear and quadratic forms, can accurately predict body weight and morphometric traits in *Pelusios castaneus*, aiding in their selection for meat and egg production. It helps identify the most important factors (independent variables) that influence desirable traits (dependent variables) like egg weight or shell quality (Hays *et al.*, 2022). Regression models allow for the prediction of egg quality traits based on easily measurable factors, which is valuable for selection programs aiming to improve Nigerian pure lines. It also helps to establish relationships between different traits, like the positive relationship between body weight and morphometric traits, or how egg weight influences other internal qualities. By understanding these relationships, researchers can select for specific traits to develop improved Nigerian breeds of tortoise with better meat and egg production potential.

Linear function is characterized by straight-line relationship between variables; constant slope (marginal effect of X on Y is constant); easy to interpret and suitable when change in Y is proportional to change in X (Ramalho and Ramalho, 2017).

Double-log (Log-Log) function is identified by both dependent and independent variables are in logarithms; coefficient *b* represents elasticity (percentage change in Y due to percentage change in X); nonlinear in original form but linear in logs and useful for modeling proportional relationships (Pakdemiril, 2024).

Semi-log function is defined as the only one variable is in logarithmic form; in log-linear: *b* shows percentage change in Y for a unit change in X; in linear-log: *b* shows change in Y for a percentage change in X and captures diminishing or increasing effects (Anatolyev, 2019).

Exponential function is marked by represents growth or decay processes; constant growth rate rather than constant change; becomes linear when transformed, and common in biological and population studies (Morris, 2015; Rubin *et al.*, 2023; Knizat, 2024).

Most studies use simple correlation or linear regression, while more advanced models that consider maternal and environmental factors are lacking. This study aims to identify the best predictor of egg weight from twelve egg characteristics using four regression models.

MATERIALS AND METHODS

Experimental site

The research was conducted at the Department of Animal Production Research Farm (DAPRF), Southern Delta University (SDU), Ozoro. Latitude 5°32' N and Longitude 6°15' E of Greenwich meridian place the center in mid-western Nigeria's rainforest. Rainfall averages 2500-3000 mm per year and 27.4°C and 85% are the mean

temperature and relative humidity, respectively (SDU, 2025).

Experimental animal and management practices

Adult female tortoises are sourced from rural farmers/markets in Isoko Local Government Area, Delta State, Nigeria. They were managed under an Intensive system, and were fed *ad libitum*. The study periods typically lasted for 12 months (January to December, 2025), covering the peak laying seasons. Twenty (20) females are managed, often with ten (10) males in a 1:2 mating ratio.

Egg data collection and measurements

Eighty (80) eggs collected from heaps of sharp sand, where females are encouraged to dig and lay. The traits investigated were egg weight, egg length, egg width, egg shape index, yolk weight, yolk height, yolk diameter, shell weight, shell thickness, Albumen height, Albumen weight and haugh unit. Egg shell weight, Albumen and Yolk weight were measured on the triple beam balance (OHAUS, 2610g), lengths and widths of eggs and yolks were measured with Vernier caliper (in mm). Egg index was taken as the ratio of egg height to Egg width, while the yolk index (YI) was taken as the ratio of Yolk height to Yolk weight. Shell thickness (in mm) was taken as the mean of measurements taken with micrometer screw gauge at the broad-end, middle portion and narrow-end of shells. Albumen height was recorded by measuring the height of the content of each in a tripod micrometer. Haugh unit was obtained from Albumen height and Egg weight using the procedure of Card and Nesheim (1975).

Statistical analysis

The data were subjected to Statistical Analysis System (SAS, 2018). Mean, standard deviation and coefficient of variation (CV%) of each variable were obtained. Egg weight curve was obtained by plotting the corresponding weight on age per month. Different mathematical functions like Linear, Double-log, Semi-log and Exponential functions were used to describe the variability in the egg weight of the animals. The functions were fitted to average weekly weight. The implicit model was of the form:

$$Q = f (X_1, X_2, X_3, \dots, X_{12}, \mu)$$

Where: Q = egg weight (g), X_1 = albumen weight (g), X_2 = albumen height (mm), X_3 = Haugh unit (%), X_4 = yolk weight (g), X_5 = yolk height (mm), X_6 = yolk width (mm), X_7 = yolk index, X_8 = shell weight (g), X_9 = shell thickness (mm), X_{10} = egg length (mm), X_{11} = egg width (mm), X_{12} = egg index, μ = error term that is assumed that to be normally distributed with mean equal to zero and a constant variance.

Table 1. Descriptive Statistics (minimum, maximum, mean \pm standard deviation, and coefficient of variation) of egg quality traits in *Pelusios castaneus*.

Traits	Min.	Max.	Mean (\pm SD)	Coefficient of Variance (CV%)
EWT (g)	17.14 \pm 0.04	21.23 \pm 1.02	18.84 \pm 1.24	6.58
AWT (g)	7.08 \pm 0.13	9.05 \pm 1.07	8.02 \pm 0.26	3.24
ALT (mm)	23.38 \pm 1.25	44.06 \pm 2.53	28.30 \pm 2.40	8.48
HU (%)	73.63 \pm 2.63	83.04 \pm 3.63	76.13 \pm 3.62	4.75
YWT (g)	6.74 \pm 0.07	8.06 \pm 1.24	7.14 \pm 0.15	2.10
YHT (mm)	1.67 \pm 0.01	12.04 \pm 1.63	2.16 \pm 0.03	1.39
YWD (mm)	4.08 \pm 0.03	36.80 \pm 2.64	4.07 \pm 0.13	3.19
YI	0.41 \pm 0.01	0.46 \pm 0.01	0.44 \pm 0.01	2.27
SWT (g)	3.32 \pm 0.02	4.12 \pm 0.04	3.68 \pm 0.13	3.53
STH (mm)	0.23 \pm 0.01	0.33 \pm 0.01	0.25 \pm 0.01	4.00
EWD (mm)	26.64 \pm 1.05	31.21 \pm 0.53	25.79 \pm 1.41	5.47
ELT (mm)	31.82 \pm 1.15	38.50 \pm 1.20	33.89 \pm 1.14	3.36
ESI	1.19 \pm 0.01	1.23 \pm 0.02	1.20 \pm 0.02	1.67

Keys: EWT = Egg weight; AWT = Albumen weight; ALT = Albumen length; HU = Haugh Unit; YWT = Yolk weight; YHT = Yolk height; YWD = Yolk width; YI = Yolk index; SWT = Shell weight; STH = Shell thickness; EWD = Egg width; ELT = Egg length; ESI = Egg shape index

The functional forms used in the regression analysis are:

a. Linear function: $Y = b_0 + b_1X_1 + b_2X_2 + \dots + b_{12}X_{12} + \mu$ (Knizat, 2024).....Eq. (1)

b. Double-log function: $\log y = \log b_0 + b_1 \log x_1 + b_2 \log x_2 + \dots + b_{12} \log x_{12} + \mu$ (Pakdemiril, 2024).....Eq. (2)

c. Semi-log function: $y = \log b_0 + b_1 \log x_1 + b_2 \log x_2 + \dots + b_{12} \log x_{12} + \mu$ (Anatolyev, 2019).....Eq. (3)

d. Exponential function: $\log y = b_0 + b_1X_1 + b_2X_2 + \dots + b_{12} \log x_{12} + \mu$ (Morris, 2015)...Eq. (4)

Where: Y = egg weight, x_1 to x_{12} = explanatory variables, μ = error term that is normally distributed.

With constant variance with expectation equals zero, the criteria used in selecting the functional form that gave the best fit for regression was based on:

- The magnitude of the coefficient of multiple determination
- The F-ratio
- The significance of the individual explanatory variables
- The appropriateness of the regression coefficients.

The efficiency of these functional forms was compared by using the value of coefficient of determination (R^2)

RESULTS AND DISCUSSION

Mean values (\pm SD) for egg quality traits are presented in Table 1. The egg weights ranged from 17.14g to 21.23g with mean value of 18.84 g. The mean egg weight of

Pelusios castaneus was good compared to 17.03g obtained by Stemle, (2022) and Guedes *et al.* (2023). The mean egg weight of *Pelusios castaneus* obtained in this study showed a true reflection of the flock egg weight. Odiko *et al.*, (2024) in Western Nigeria also reported similar good performance. However, as earlier stated good management practices can be enhanced for such good performance because the mean egg weight obtained was a typical of *Pelusios castaneus* breed that was well managed. The coefficient of variation ranged between 1.39% to 8.48% respectively. The range of the value coupled with the obtained coefficient of variation for these traits suggest adequate nutrition in the management practices. Such adequacy, which may have risen from adequate feeding of the animals, accounted for such good results of little range of over 1.81g. Corresponding values for albumen weights and lengths were 8.02g and 28.30mm respectively. Rugiero, 2021 had also reported higher albumen weight (9.04g) and yolk weight (8.61g) in Pancake tortoise, this may be due to the comparatively smaller size of the eggs of *Pelusios castaneus*. Haugh unit ranged between 73.63% and 83.04%, yolk weight varied from 6.74 g to 8.06 g. The slightly lower Haugh unit in this study compared with the value (78%) submitted for by Hunter *et al.* (2021) may indicate genetic variations between the eggs from different species. Yolk height was between 1.67 mm and 12.04 mm while the yolk index ranged between 0.41 and 0.46.

According to Blake *et al.* (2024), yolk index varies with the month of measurement. The yolk index in the present report is almost the same range with the value of 0.40 and 0.47 reported respectively by Gatto and Reina, (2022) and Eustace *et al.*, (2020) reported yolk index of 0.26 to 0.54 for the *Pelusios niger*.

The regression analysis involving the four functional

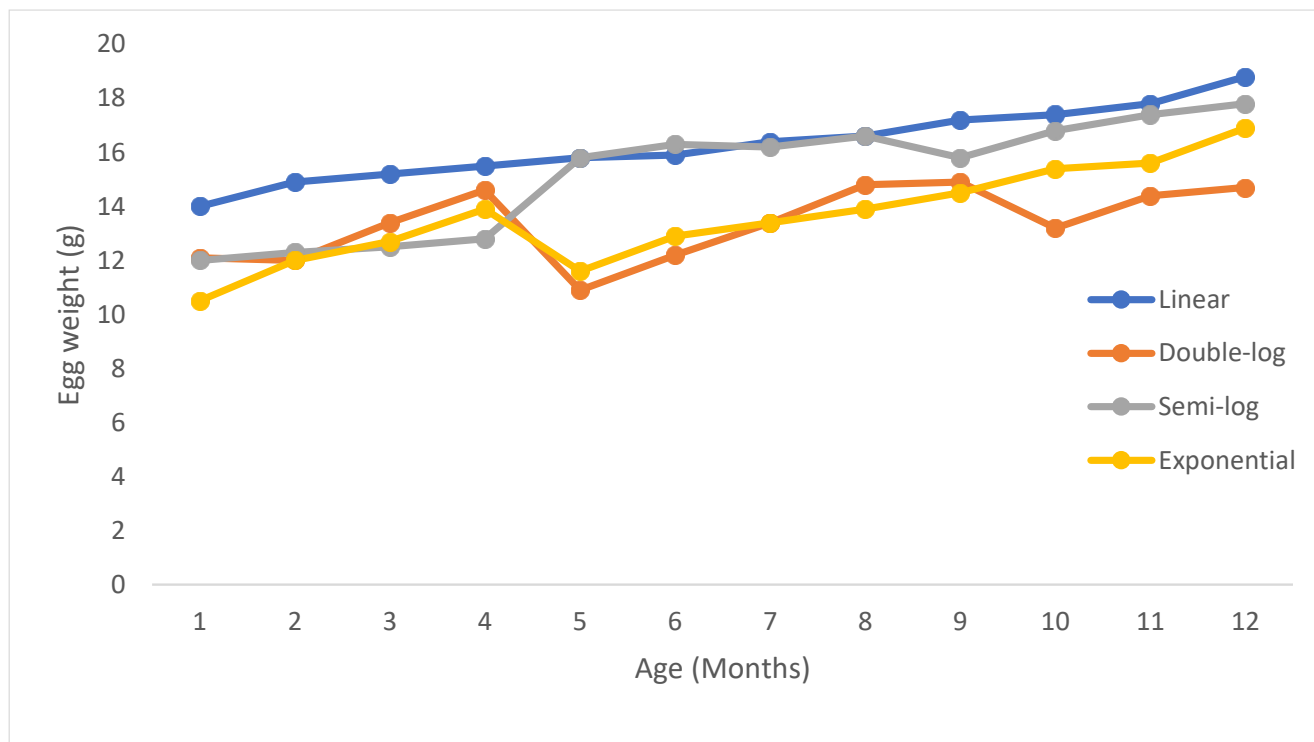


Figure 1. Egg weight curve of *Pelusios castaneus* tortoises for 12 months.

Table 2. Parameter estimates, standard error and coefficient of determination value (R^2) for the function forms fitted to egg quality traits.

Functional forms	Constant A	b^1	b^2	Standard Error (SE)	R^2 (%)
Linear	0.36	1.05 ± 0.01	-	0.31	78.68
Double-log	5.73	7.48 ± 1.62	-	0.58	65.80
Semi-log	0.28	1.16 ± 0.02	-0.003	0.10	78.35
Exponential	1.39	0.26 ± 0.01	-	0.26	71.30

forms showed a significant ($p < 0.05$) relationship between EWT and AWT. The semi-log and double-log forms indicated a significant association ($p < 0.05$) when EWT was regressed on AHT and HU. Only the exponential functional form indicated a significant association ($P < 0.05$) between EWT and EWD. The present results showed that AWT is the most important determinant of EWT. This may be due to the fact that albumen constitute the largest portion of total EWT.

The egg weight curve of the flock is shown in Figure 1. The curve was not completely linear and analysis of the curve fitting using linear, double-log, semi-log and exponential functions had coefficient of determination (R^2) of 78.35, 65.80, 78.68 and 71.30% respectively (Table 2). These estimates indicated good reliability of the results. From the result, negligible difference can be said to exist between Linear and Semi-log functions in accounting for the variance observed in the egg weight of *Pelusios castaneus* over time (78.35 Vs 78.68%). Similarly, slight

difference existed between Double-log and Exponential functions (65.80 Vs 71.30%). R^2 values have been used by other workers to assess the predictability value of different mathematical functions (Morris, 2015; Anatolyev, 2019; Rubin *et al.*, 2023; Knizat, 2024 and Pakdemiril, 2024). Therefore, with the relatively high R^2 values for Linear and Semi-log functions. These functions can be said to have reasonably predicted the egg weight of *Pelusios castaneus* used in the study. Examination of the result revealed that these functions estimated egg quality traits. Conversely, Double-log and Exponential functions did not explain the ascending phase of egg weight curves and thus their use in predicting egg weight could be misleading.

Conclusion

Based on data analysis applied to the evaluation of egg

quality characteristics in *Pelusios castaneus* (West African Black mud tortoise), linear regression models slight demonstrate that EWT is the critical significant determinants of overall egg quality and reproductive performance.

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