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Fertility, Hatchability, and Prediction of Egg Weight from Egg Quality Indices of Nigerian Indigenous and Exotic Helmeted Guinea Fowls

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Abstract: This study was conducted to compare the fertility and hatchability performance of the Nigerian indigenous and exotic helmeted guinea fowls and predict egg weight from egg indices in Nigeria. A total of 300 randomly selected 8-month-old guinea fowls, comprising 150 indigenous (30 males and 120 females) and 150 exotic birds (30 males and 120 females), were utilized in this study. Consequently, a total of 240 randomly selected eggs (120 per genotype) were used separately for the reproductive and egg quality assessments. The fertility and hatchability parameters were subjected to descriptive statistics (numbers and percentages), while the 17 egg quality parameters were analyzed using a T-test, phenotypic correlation, principal component analysis, multiple linear regression, and a CHAID decision tree. Percentages of fertility (90.0 and 73.3%) and hatchability (66.7 and 56.8%) were higher in the exotic birds compared to their indigenous counterparts. The egg quality parameters of the exotic birds were higher ($p < 0.05$) than those of the indigenous birds, with the exception of egg shell index (18.88 ± 0.79 vs. 16.41 ± 0.69) and Haugh unit (92.37 ± 3.13 vs. 91.09 ± 3.22). However, the mean yolk/albumen ratio was similar ($p > 0.05$). The phenotypic correlation coefficients between egg weight and egg quality indices in both genetic groups ranged from low to high values [−0.05–0.95 (indigenous); −0.19–0.96 (exotic birds)]. Three principal components sufficiently accounted for the variations in the egg quality traits of both genetic groups. The CHAID algorithm was more consistent in egg weight prediction, with egg width as the primary explanatory variable. The present information may guide breeding and management strategies geared towards the improvement of the reproductive and egg quality traits of the helmeted guinea fowls.

Keywords: guinea fowl; reproduction; egg quality; prediction; tropics

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Academic Editor: Marcin Wojciech Lis

Received: 3 January 2024
Revised: 19 February 2024
Accepted: 6 March 2024
Published: 24 December 2024

Citation: Jegede, P.; Yakubu, A.; Musa, I.S.; Vincent, S.T.; Shoyombo, A.J.; Alabi, O.O.; Wheto, M.; Adebambo, A.O.; Popoola, M.A. Fertility, Hatchability, and Prediction of Egg Weight from Egg Quality Indices of Nigerian Indigenous and Exotic Helmeted Guinea Fowls. *Poultry* **2025**, *4*, 1. https://doi.org/10.3390/poultry4010001

1. Introduction

Poultry production is an integral component of agriculture. It serves as the most important and quickest source of animal protein and household income, thereby improving family nutrition, health, and the livelihood of high- and low-level farmers in rural and urban communities [1–4]. In Nigeria, one of the traditional poultry species is the helmeted guinea fowl (*Numida meleagris*) [5]. Economically, guinea fowl are more attractive in the tropics due to less demand with respect to diet and better adaptation to the traditional poultry system when compared to chicken [6,7]. There is a high value for the eggs of guinea fowl because of their nutrient contents, thick shells, longer shelf life, and the premium prices they attract compared to chickens [5,8]. The bird is a seasonal bird, and its breeding activity peaks in the summer period. During this period, which coincides with the rainy season in the tropics, there are a variety of plants and insects for the birds to feed on [9,10].

In spite of the benefits derived from guinea fowl, its characterization in the tropics is poor, thereby limiting the exploitation of its full potential for sustainable economic growth and development [7]. In Nigeria, previous research and development endeavors such as the Programme for Emerging Agricultural Research Leaders (PEARL) and African Chicken Genetic Gains (ACGG) focused on chicken, while other poultry species like guinea fowl have been neglected. Also, reproductive performance (fertility and hatchability characteristics), which are crucial to guinea fowl profitability [11], and egg quality traits of guinea fowl [12–14] in the country have not been widely exploited. Such information is vital to unraveling the potential of the underutilized poultry genetic resource in order to map out appropriate selection and breeding strategies for improvement in the production and productivity of the birds. It has been reported that egg quality indices are useful for breed assessment and standardization [15]. The establishment of a relationship between traits and the prediction of egg weight from egg quality parameters is also of interest [16]. Additionally, in the poultry egg industry, egg quality parameters affect consumer preference, quality grading, price, fertility, hatchability, and weights of newly hatched birds [17]. Based on this, the current study aimed to characterize the fertility, hatchability, and egg quality parameters of indigenous helmeted and exotic guinea fowls.

2. Materials and Methods

2.1. Location of the Study

The experiment was conducted at the Guinea Fowl Improvement Unit of the Teaching and Research Farm of Landmark University, Omu-Aran, in Kwara State. The Unit is co-managed by the University of Agriculture, Abeokuta, Landmark University, and Nasarawa State University, Keffi, Shabu-Lafia Campus, to facilitate the implementation of the TETfund National Research Grant for guinea fowl improvement in Nigeria. The farm lies at latitude 8.9° N and longitude 50.61° E within the guinea savannah zone of North-Central Nigeria.

2.2. Experimental Procedure

The base population of the indigenous guinea fowl came from randomly selected birds from three agro-ecological zones of Nigeria, namely the Sudano-Sahelian, Southern Guinea Savanna, and Tropical Rainforest, as reported earlier [18]. The exotic guinea fowls were imported from the neighboring Benin Republic. After acclimatization for two weeks, a total of 300 randomly selected adult guinea fowl (8 months old) comprising 150 indigenous (30 males and 120 females) and 150 exotic birds (30 males and 120 females) were utilized in this study. Each genetic group was replicated three times in a standard poultry house using a mating ratio of 1:4, as adopted by Atawalna et al. [19]. The birds were fed a diet containing 16.0% CP and 2650 ME (Kcal/kg) from 8 months of age until the end of egg collection. Feed and clean drinking water were supplied ad libitum. Other standard rearing practices (such as daily cleaning of the feeders and water troughs; turning of the feeders periodically to ensure feeding to appetite; change of caked litter every 2 weeks; and prompt removal of dead birds) and medication were carried out, while biosecurity measures (such as restriction of human and vehicular movements to the farm, regular cleaning and disinfection of the farm and its surroundings, and adherence to biosafety regulations by staff) were taken. The entire study lasted three months (July–September 2020).

2.3. Collection of Eggs for Hatching

Eggs laid in the third week of August were collected, which comprised 120 each from the indigenous guinea fowl and the exotic birds. The eggs were labeled with the code given at the time of collection based on genotype. A total of 240 eggs were set in an automatic incubator. The incubation temperature was set at 37.5 °C while the humidity was 45–70% [45–55% (Day 1–25) at egg setting and 65–70% (Day 26–28) at egg hatching]. The essence was to guarantee good embryonic development and maximum hatchability [20]. The turning device was adjusted in accordance with the manufacturer's recommendations. Candling was performed on the 7th, 14th, and 18th days of incubation. The hatching of eggs was conducted on the 28th day of incubation.

2.4. Reproductive Assessment

Eggs' fertility was determined using the following equation:

$$\text{Fertility} = \frac{\text{No. of fertile eggs}}{\text{No of eggs set}} \times 100$$

Hatchability of fertile eggs was calculated as indicated below:

$$\text{Hatchability} = \frac{\text{No. of keets hatched}}{\text{No. of fertile eggs}} \times 100$$

2.5. Egg Quality Assessment

A total of 240 clean eggs with no defects, comprising 120 each from the indigenous guinea fowl and the exotic birds, were utilized for the egg quality assessment. The seventeen egg quality parameters assessed included egg weight, egg length, egg width, shell thickness, shell weight, egg shell index, egg shape index, yolk weight, yolk height, yolk diameter, yolk ratio, yolk index, albumen weight, albumen height, albumen diameter, yolk/albumen ratio, and Haugh unit. Egg weight was taken using a sensitive scale with ±0.01 g accuracy [17,21]. Egg length and egg width were measured using a digital caliper to the nearest 0.01 mm [22]. The egg shape index was determined as the ratio of egg width to egg length multiplied by 100 [23]. The shell thickness was taken as the average of the thicknesses of the blunt, middle, and sharp points of the egg and was measured using a micrometer gauge [12]. Shell weight, after drying at room temperature for one day [24], was determined using a sensitive scale with ±0.01 g accuracy [25]. The egg shell index was obtained from the ratio of shell weight to egg weight multiplied by 100 [26].

Albumen height and yolk height were measured by a tripod micrometer (accuracy of 0.01 mm) after the albumen of the broken eggs was carefully separated from the yolk [11,22]. Yolk weight was measured using a sensitive scale [21], while albumen weight was calculated as: Albumen weight (g) = Egg weight − (yolk weight + shell weight) [24]. Albumen and yolk diameters were determined using a digital caliper with 0.01 mm accuracy [21]. The yolk index was taken as the ratio of yolk height to yolk diameter multiplied by 100 [24]. The yolk ratio was calculated as the ratio of yolk weight to egg weight [27]. The yolk/albumen ratio was determined as the ratio of yolk weight to albumen weight [24]. The Haugh unit [21,28] was calculated using the following equation by Raymond Haugh in 1937:

$$\text{HU} = 100 \times \log(\text{H} + 7.57) - (1.7 \times \text{W}0.37)$$

where,

HU = Haugh unit; H = Albumen height (mm); W = Egg weight (g)

2.6. Statistical Analysis

Descriptive statistics (numbers and percentages) were computed for fertility and hatchability parameters. In order to find the differences between the indigenous guinea fowl and the exotic birds, egg parameters were subjected to a *t*-test. Significant differences were declared at $p < 0.05$. The egg quality parameters of local and exotic guinea fowl were subjected to Pearson's product-moment correlation. Principal component analysis (PCA) was carried out to explore the hidden relationship between egg quality traits [29]. This was to permit appropriate grouping of the guinea fowl based on genotype. The criterion used for the extraction of the principal components (PCs) was Eigenvalues greater than 1 [18]. Egg weight (a dependent variable) of the local and exotic guinea fowls was predicted from independent egg traits (egg length, egg width, shell thickness, shell weight, egg shell index, egg shape index, yolk weight, yolk height, yolk diameter, yolk ratio, yolk index, albumen weight, albumen height, albumen diameter, yolk/albumen ratio, and Haugh unit) using a multiple linear regression model [16,30,31]. Also, egg weight was predicted from the principal component (PC) factor scores of the independent egg traits. The multiple linear regression was performed in two stages. The first stage involved the use of the stepwise option of the ordinary least squares (OLS) method (where the predictors were: i. the egg traits and ii. the PC factor scores of the egg traits). The second stage involved the use of the ridge method (only the egg traits were used as predictors). In the ridge regression, the regularized CATREG procedure was used. The conditions were set at: supplementary object = 17, validation type = crossvalidation (10-folds), convergence = 0.0001, and maximum iterations = 100. Egg weight prediction was also achieved without PC scores of the egg traits using a decision tree model [Chi-square automatic interaction detection (CHAID)] as described by Orhan et al. [32] and Portillo-Salgado et al. [16]. The Bonferroni adjustment and ten-fold crossvalidation were applied in CHAID [18]. All analyses were conducted using IBM SPSS [33].

3. Results

3.1. Reproductive Performance

The fertility and hatchability values of the Nigerian indigenous guinea fowls and their exotic counterparts are shown in Table 1. Percentage fertility (90.0 vs. 73.3%) and hatchability (66.7 vs. 56.8%) were higher in the exotic birds compared to their indigenous counterparts.

Table 1. Hatchability and fertility characteristics of Nigerian indigenous and exotic guinea fowls.

Parameters	Indigenous Guinea Fowls	Exotic Guinea Fowls
Number of incubated eggs	120.0	120.0
Number of fertile eggs	88.0	108.0
Number of unfertile eggs	32.0	12.0
Percentage of fertile eggs	73.3	90.0
Percentage of unfertile eggs	26.7	10.0
Number of keets hatched	50	72.0
Percentage hatchability	56.8	66.7

3.2. Egg Quality Parameters

The egg quality traits of the Nigerian indigenous and exotic guinea fowls are presented in Table 2. Higher values ($p < 0.05$) were obtained in exotic birds with the exception of egg shell index, where the values were higher in their indigenous counterparts (18.88 ± 0.79 vs. 16.41 ± 0.69) and Haugh unit (92.37 ± 3.13 vs. 91.09 ± 3.22).

Table 2. Effect of genetics on egg quality parameters of the Nigerian indigenous and exotic guinea fowls.

	Genetic Group	
Traits	**Indigenous**	**Exotic**
Egg weight (g)	34.09 ± 1.69 ^{a}	41.50 ± 1.77 ^{a}
Egg length (mm)	45.48 ± 2.31 ^{b}	50.91 ± 2.31 ^{a}
Egg width (mm)	32.73 ± 1.54 ^{b}	37.86 ± 1.54 ^{a}
Shell thickness (mm)	0.67 ± 0.06 ^{b}	0.71 ± 0.06 ^{a}
Shell weight (g)	6.44 ± 0.55 ^{b}	6.82 ± 0.52 ^{a}
Egg shell index (%)	18.88 ± 0.79 ^{a}	16.41 ± 0.69 ^{b}
Egg shape index (%)	72.08 ± 3.97 ^{b}	74.46 ± 3.53 ^{a}
Yolk weight (g)	10.30 ± 0.73 ^{b}	13.08 ± 0.71 ^{a}
Yolk height (mm)	12.97 ± 0.71 ^{b}	14.88 ± 0.71 ^{a}
Yolk diameter (mm)	33.20 ± 0.98 ^{b}	36.31 ± 0.98 ^{a}
Yolk ratio	30.18 ± 0.92 ^{b}	31.50 ± 0.69 ^{a}
Yolk index (%)	39.10 ± 2.63 ^{b}	41.01 ± 2.43 ^{a}
Albumen weight (g)	16.41 ± 1.01 ^{b}	20.77 ± 0.97 ^{a}
Albumen height (mm)	7.11 ± 0.58 ^{b}	7.34 ± 0.58 ^{a}
Albumen diameter (mm)	51.54 ± 1.76 ^{b}	57.66 ± 1.76 ^{a}
Yolk/Albumen ratio	0.63 ± 0.02 ^{a}	0.63 ± 0.02 ^{a}
Haugh unit	92.37 ± 3.13 ^{a}	91.09 ± 3.22 ^{b}

Table 2. *Cont.*

Means within rows with different superscripts are significantly different ($p < 0.05$).

3.3. Relationships between Egg Quality Traits

The phenotypic correlation coefficients of the egg quality parameters of the Nigerian indigenous and exotic guinea fowls are shown in Table 3. In the indigenous birds, egg weight (EW) was highly ($p < 0.01$) correlated with EWD (0.97), SW (0.95), YW (0.93), AW (0.92), ST (0.90), ESI (0.76), and EL (0.60). With regard to the exotic birds, the correlation (0.96) between EW and EWD was also significantly ($p < 0.01$) highest, followed by AW (0.94), YW (0.92), SW (0.90), EL (0.89), and ST (0.88). The correlations among other egg parameters range from high to low and from positive to negative values in both genetic groups.

Table 3. Phenotypic correlations of egg quality parameters of Nigerian indigenous and exotic guinea fowls.

Traits	EW	EL	EWD	ST	SW	ESI	ESPI	YW	YH	YD	YR	YI	AW	AH	AD	Y/A	HU
EW		0.60 **	0.97 **	0.90 **	0.95 **	0.76 **	0.29 **	0.93 **	0.36 **	−0.05 ns	0.52 **	0.32 **	0.92 **	0.07 ns	−0.14 ns	0.28 **	−0.11 ns
EL	0.89 **		0.60 **	0.56 **	0.56 **	0.45 **	−0.57 **	0.54 **	0.08 ns	0.17 ns	0.28 **	−0.02 ns	0.52 **	0.17 ns	0.03 ns	0.21 **	0.06 ns
EWD	0.96 **	0.91 **		0.91 **	0.92 **	0.75 **	0.32 **	0.91 **	0.35 **	−0.11 ns	0.52 **	0.34 **	0.91 **	0.11 ns	−0.14 ns	0.25 **	−0.07 ns

Table 3. *Cont.*

Traits	EW	EL	EWD	ST	SW	ESI	ESPI	YW	YH	YD	YR	YI	AW	AH	AD	Y/A	HU
ST	0.88 **	0.84 **	0.89 **		0.82 **	0.62 **	0.28 **	0.84 **	0.31 **	−0.05 ns	0.47 **	0.27 **	0.78 **	0.06 ns	−0.15 ns	0.35 **	−0.11 ns
SW	0.90 **	0.80 **	0.90 **	0.77 **		0.93 **	0.28 **	0.89 **	0.31 **	0.00 ns	0.51 **	0.26 **	0.91 **	0.09 ns	−0.13 ns	0.21 **	−0.09 ns
ESI	0.66 **	0.58 **	0.69 **	0.55 **	0.90 **		0.24 **	0.72 **	0.21 **	0.06 ns	0.42 **	0.15 ns	0.77 **	0.10 ns	−0.10 ns	0.08 ns	−0.04 ns
ESPI	0.69 **	0.48 **	0.76 **	0.62 **	0.68 **	0.57 **		0.29 **	0.26 **	−0.30 **	0.20 **	0.35 **	0.33 **	−0.09 ns	−0.18 ns	0.01 ns	−0.14 ns
YW	0.92 **	0.81 **	0.90 **	0.82 **	0.81 **	0.55 **	0.68 **		0.41 **	−0.05 ns	0.80 **	0.35 **	0.90 **	0.12 ns	−0.16 ns	0.48 **	−0.05 ns
YH	0.39 **	0.26 **	0.40 **	0.32 **	0.34 **	0.20*	0.48 **	0.45 **		−0.16 ns	0.34 **	0.89 **	0.37 **	0.01 ns	−0.05 ns	0.18*	−0.06 ns
YD	−0.09 ns	−0.03 ns	−0.13 ns	−0.11 ns	−0.09 ns	−0.08 ns	−0.20*	−0.10 ns	−0.08 ns		−0.03 ns	−0.59 **	−0.05 ns	−0.11 ns	0.08 ns	−0.02 ns	−0.10 ns
YR	0.37 **	0.33 **	0.38 **	0.36 **	0.30 **	0.15 ns	0.33 **	0.67 **	0.31 **	−0.04 ns		0.29 **	0.59 **	0.17 ns	−0.14 ns	0.65 **	0.07 ns
YI	0.33 **	0.19 **	0.36 **	0.26 **	0.30	0.18 *	0.50 **	0.37 **	0.88 **	−0.50 **	0.24 **		0.33 **	0.06 ns	−0.07 ns	0.15 ns	−0.01 ns
AW	0.94 **	0.82 **	0.90 **	0.76 **	0.84 **	0.60 **	0.64 **	0.86 **	0.39 **	−0.09 ns	0.33 **	0.33 **		0.12 ns	−0.06 ns	0.05 ns	−0.05 ns
AH	0.02 ns	0.08 ns	0.05 ns	0.03 ns	0.06 ns	0.09 ns	0.01 ns	0.05 ns	0.01 ns	−0.08 ns	0.13 ns	0.09 ns	−0.01 ns		0.14 ns	0.03 ns	0.98 **
AD	−0.13 ns	−0.09 ns	−0.16 ns	−0.16 ns	−0.11 ns	−0.07 ns	−0.21 *	−0.18 ns	−0.10 ns	0.001 ns	−0.20 *	−0.06 ns	−0.09 ns	0.06 ns		−0.25 **	0.18 ns
Y/A	0.29 **	0.29 **	0.31 **	0.39 **	0.25 **	0.13 ns	0.30 **	0.54 **	0.18 *	−0.01 ns	0.77 **	0.13 ns	0.07 ns	0.09 ns	−0.22 *		−0.02 ns
HU	−0.19 *	−0.11 ns	−0.15 ns	−0.14 ns	−0.13 ns	−0.05 ns	−0.13 ns	−0.14 ns	−0.08 ns	−0.07 ns	0.04 ns	0.02 ns	−0.20 *	0.97 **	0.11 ns	0.01 ns	

EW = Egg weight, EL = Egg length, EWD = Egg width, ST= Shell thickness, SW = Shell weight, ESI = Egg shell index, ESPI = Egg shape index, YW = Yolk weight, YH = Yolk height, YD = Yolk diameter, YR = Yolk ratio, YI = Yolk index, AW = Albumen weight, AH = Albumen height, AD = Albumen diameter, Y/A = Yolk/Albumen ratio; HU = Haugh unit. Upper matrix = Indigenous birds; Lower matrix = Exotic birds. *, ** Significant at $p < 0.05$ and $p < 0.01$, respectively; ^{ns} Not significant.

3.4. Variables' Contributions to Variation and Loadings on the Principal Components

The eigenvalues, percentages of the total variance, and communalities of the egg quality traits of the Nigerian indigenous and exotic guinea fowls are presented in Table 4. The communalities ranged from 0.574 to 0.978 and 0.590 to 0.987, respectively, in the indigenous and exotic birds. Three principal components (PCs) were extracted from the indigenous guinea fowls with eigenvalues of 5.949 (PC1), 2.148 (PC2), and 1.825 (PC3), accounting for 82.7% of the total variance. In their exotic counterparts, three PCs were also extracted with eigenvalues of 5.739 (PC1), 2.164 (PC2), and 1.799 (PC3), explaining 80.8% of the generalized variance. The reliability of the PCA was confirmed using the Kaiser–Meyer–Olkin (KMO) Measure of Sampling Adequacy (KMO = 0.66 and 0.64, respectively, for indigenous and exotic birds) and Bartlett's Test of Sphericity (chi-square = 2993.944 and 2944.584; $p < 0.01$, respectively, for indigenous and exotic birds).

Table 4. Eigenvalues and share of total variance along with rotated factor loadings and communalities of the egg quality traits of Nigerian indigenous and exotic guinea fowls.

	Genetic Group							
	Indigenous				**Exotic**			
Traits	**PC1**	**PC2**	**PC3**	**Communality**	**PC1**	**PC2**	**PC3**	**Communality**
Egg length	0.737	−0.421	0.174	0.751	0.730	−0.453	0.140	0.758
Egg width	0.944	0.228	0.002	0.944	0.953	0.208	−0.010	0.951
Shell thickness	0.875	0.180	−0.042	0.799	0.883	0.157	−0.060	0.807
Shell weight	0.957	0.167	−0.025	0.945	0.931	0.183	0.034	0.901

Table 4. *Cont.*

	Genetic Group							
	Indigenous				**Exotic**			
Traits	**PC1**	**PC2**	**PC3**	**Communality**	**PC1**	**PC2**	**PC3**	**Communality**
Egg shell index	0.836	0.090	−0.005	0.708	0.750	0.141	0.110	0.594
Egg shape index	0.102	0.723	−0.201	0.574	0.100	0.741	−0.175	0.590
Yolk weight	0.907	0.262	0.023	0.893	0.897	0.234	0.004	0.860
Yolk height	0.236	0.795	0.059	0.692	0.244	0.775	0.044	0.663
Yolk index	0.167	0.861	0.107	0.781	0.185	0.845	0.097	0.757
Albumen weight	0.904	0.254	0.017	0.883	0.896	0.217	−0.022	0.851
Albumen height	0.099	0.001	0.983	0.976	0.111	−0.007	0.985	0.984
Haugh unit	−0.075	−0.041	0.985	0.978	−0.049	−0.042	0.991	0.987
Eigenvalue	5.949	2.148	1.825		5.739	2.164	1.799	
% of total variance	49.58	17.90	15.21		47.82	18.03	14.99	

PC1 = Principal component 1, PC2 = Principal component 2, and PC3 = Principal component 3.

3.5. Principal Component Factor Score Coefficients

The principal component factor score coefficients of the Nigerian indigenous and exotic guinea fowls are presented in Table 5. These factor scores could be used instead of the original interdependent egg quality traits in estimating the egg weight of guinea fowl.

Table 5. Principal component factor scores coefficients for the prediction of egg weight of Nigerian indigenous and exotic guinea fowls.

	Genetic Group					
	Indigenous			**Exotic**		
Traits	**PC1**	**PC2**	**PC3**	**PC1**	**PC2**	**PC3**
Egg length	0.188	−0.272	0.057	0.194	−0.289	0.032
Egg width	0.167	0.013	−0.009	0.177	0.004	−0.023
Shell thickness	0.159	−0.004	−0.032	0.169	−0.016	−0.048
Shell weight	0.177	−0.019	−0.025	0.174	−0.004	−0.001
Egg shell index	0.160	−0.043	−0.016	0.139	−0.004	0.040
Egg shape index	−0.050	0.332	−0.076	−0.050	0.344	−0.061
Yolk weight	0.156	0.034	0.003	0.163	0.023	−0.014
Yolk height	−0.035	0.362	0.053	−0.029	0.355	0.045
Yolk index	−0.057	0.402	0.080	−0.050	0.396	0.076
Albumen weight	0.156	0.031	0.000	0.165	0.014	−0.027
Albumen height	0.001	0.026	0.487	−0.003	0.024	0.486
Haugh unit	−0.030	0.023	0.490	−0.033	0.023	0.492

PC1 = Principal component 1, PC2 = Principal component 2, and PC3 = Principal component 3.

3.6. Egg Weight Prediction Using Stepwise Multiple Linear Models

The prediction models of egg weight based on original egg quality traits and their principal component factor scores in Nigerian indigenous and exotic guinea fowls are presented in Table 6. Four models were obtained in the indigenous birds from the stepwise regression of egg weight using the original egg indices as predictors. Egg width was the sole predictor in the first model; egg width and shell weight were the explanatory variables in the second model; egg width, shell weight, and egg shell index were the independent variables in the third model; and egg width, shell weight, and egg shell index yolk/albumen ratio were the predictors in the fourth model. The respective coefficients of determination (R^2) to estimate the reliability of the models were 0.936, 0.958, 0.999, and 0.999. Two principal component models (PC1; PC1 and PC2) were obtained to predict egg weight with R^2 values of 0.908 and 0.953, respectively. In exotic birds, however, three models were obtained for the estimation of egg weight from original egg indices. The first model solely contained egg width as the predictor; egg width and shell weight were the independent variables extracted to predict egg weight in the second model, while the third model contained egg width, shell weight, and yolk/albumen ratio. The R^2 values were 0.927, 0.948, and 0.959, respectively. Here, three principal component models (PC1; PC1 and PC2; PC1, PC2, and PC3) were obtained to predict egg weight with R^2 values of 0.913, 0.950, and 0.952.

Table 6. Stepwise multiple regression of egg weight on original egg indices and on their principal component (PC) factor scores in Nigerian indigenous and exotic guinea fowls.

Model	Predictors	Intercept	Regression Coefficient	Standard Error	R^2
	Indigenous				
	(i) Original egg indices as predictors				
1	Egg width	−0.797	1.066	0.026	0.936
2	Egg width	4.340	0.676	0.054	0.958
	Shell weight		1.185	0.151	
3	Egg width	31.458	0.067	0.014	0.999
	Shell weight		4.996	0.072	
	Egg shell index		−1.682	0.029	
4	Egg width	32.751	0.060	0.013	0.999
	Shell weight		5.072	0.068	
	Egg shell index		−1.719	0.028	
	Yolk/Albumen ratio		−1.391	0.307	
	(ii) Orthogonal traits as predictors				
1	PC1	34.087	1.613	0.047	0.908
2	PC1	34.087	1.613	0.034	0.953
	PC2		0.360	0.034	
	Exotic				
	(i) Original egg indices as predictors				
1	Egg width	−0.531	1.110	0.029	0.927
2	Egg width	−0.230	0.778	0.054	0.948
	Albumen weight		0.591	0.086	
3	Egg width	−6.842	0.602	0.058	0.959
	Albumen weight		0.837	0.089	
	Yolk/Albumen ratio		12.967	2.359	
	(ii) Orthogonal traits as predictors				
1	PC1	41.498	1.693	0.048	0.913
2	PC1	41.498	1.693	0.037	0.950
	PC2		0.343	0.037	
3	PC1	41.498	1.693	0.036	0.952
	PC2		0.343	0.036	
	PC3		−0.081	0.036	

3.7. Egg Weight Prediction Using the Ridge Regression

The estimation of egg weight using the ridge regression model in Nigerian indigenous and exotic guinea fowls is presented in Table 7. In the indigenous birds, nine variables (egg length, egg width, shell thickness, shell weight, egg shell index, egg shape index, yolk weight, albumen weight, and yolk index) were found to be significant ($p < 0.05$; $p < 0.01$) in predicting egg weight. However, in the exotic birds, the significant ($p < 0.05$; $p < 0.01$) explanatory variables were egg length, egg width, shell thickness, shell weight, egg shape index, yolk weight, albumen weight, yolk ratio, and yolk/albumen ratio. The coefficient of determination (R^2) for both predictors was 0.959.

Table 7. Prediction of egg weight of Nigerian indigenous and exotic guinea fowls using ridge regression.

Predictors	Standardized Regression Coefficient	Standard Error	p-Value	R^2
Indigenous				
Egg length	0.146	0.015	0.01 **	0.959
Egg width	0.128	0.010	0.01 **	
Shell thickness	0.118	0.013	0.01 **	
Shell weight	0.151	0.009	0.01 **	
Egg shell index	0.094	0.013	0.01 **	
Egg shape index	0.049	0.015	0.01 **	
Yolk weight	0.140	0.011	0.01 **	
Yolk height	0.016	0.021	0.43 ^{ns}	
Yolk diameter	−0.027	0.021	0.21 ^{ns}	
Albumen weight	0.139	0.011	0.01 **	
Albumen height	−0.006	0.020	0.75 ^{ns}	
Albumen diameter	−0.021	0.027	0.64 ^{ns}	
Yolk ratio	−0.012	0.031	0.71 ^{ns}	
Yolk/Albumen ratio	0.036	0.028	0.20 ^{ns}	
Yolk index	0.021	0.011	0.04 *	
Haugh unit	0.010	0.021	0.65 ^{ns}	
Exotic				
Egg length	0.149	0.071	0.01 **	0.959
Egg width	0.156	0.019	0.01 **	
Shell thickness	0.123	0.021	0.01 **	
Shell weight	0.179	0.023	0.01 **	
Egg shell index	−0.019	0.058	0.74 ^{ns}	
Egg shape index	0.067	0.021	0.01 **	
Yolk weight	0.149	0.019	0.01 **	
Yolk height	0.027	0.028	0.34 ^{ns}	
Yolk diameter	−0.018	0.028	0.67 ^{ns}	
Albumen weight	0.185	0.022	0.01 **	
Albumen height	0.049	0.033	0.12 ^{ns}	
Albumen diameter	0.016	0.034	0.81 ^{ns}	
Yolk ratio	−0.053	0.019	0.01 **	
Yolk/Albumen ratio	0.056	0.030	0.04 *	
Yolk index	0.018	0.027	0.66 ^{ns}	
Haugh unit	−0.014	0.037	0.87 ^{ns}	

*, ** Significant at $p < 0.05$ and $p < 0.01$, respectively; ^{ns} Not significant.

3.8. Egg Weight Prediction Using the CHAID Model

The CHAID model for the prediction of egg weight is shown in Figures 1 and 2, respectively. In the indigenous guinea fowls, egg width (>33.50 mm) was found to be the most important variable to estimate egg weight, and together with albumen weight (>17.36 g) in terminal node 8, it made a better prediction (optimal egg weight was 36.23 g). The resubstitution estimate (0.20) and standard error (0.03) were low, while the prediction accuracy was high (R^2 = 0.930). With regard to the exotic birds, egg width (>38.63 mm) was also found to be the most important variable to estimate egg weight, and together with albumen weight (>21.75 g) in terminal node 8, it made a better prediction (optimal egg weight was 43.87 g). The resubstitution rate (0.26) and standard error (0.04) were also low, while the prediction accuracy was high (R^2 = 0.917).

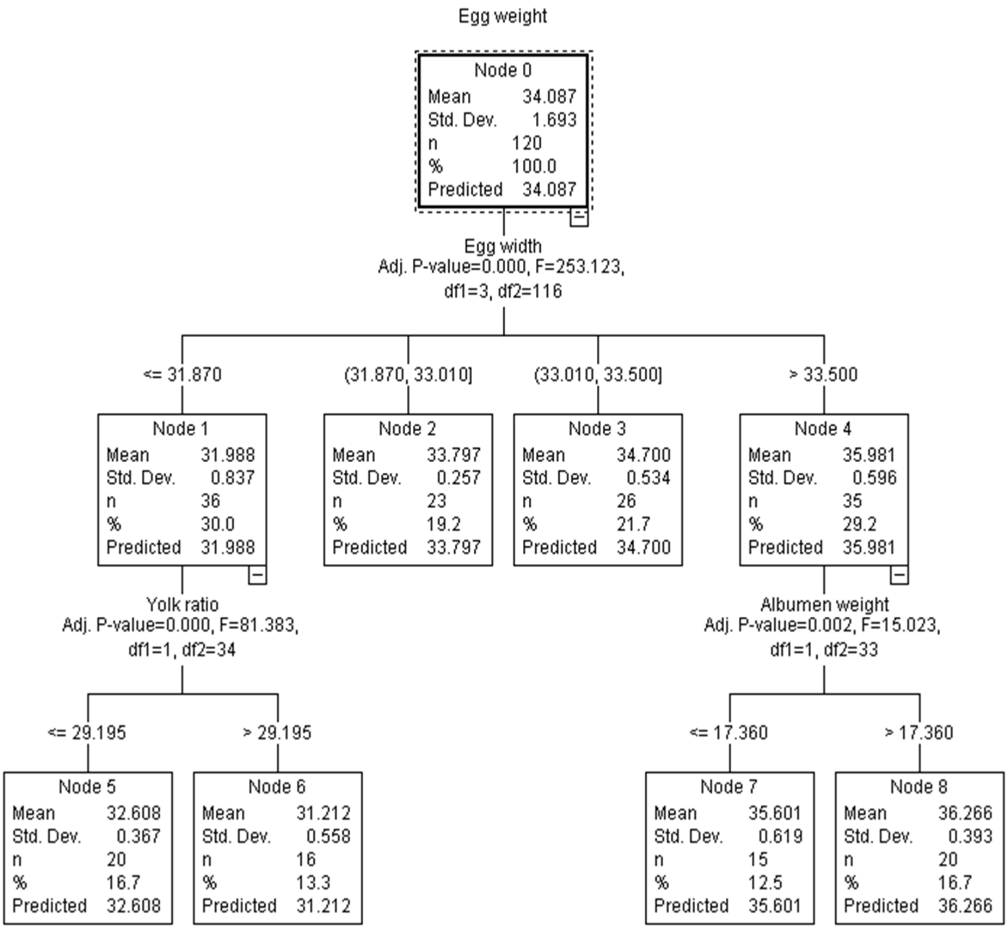

Figure 1. Egg weight prediction of Nigerian indigenous guinea fowls using the CHAID algorithm.

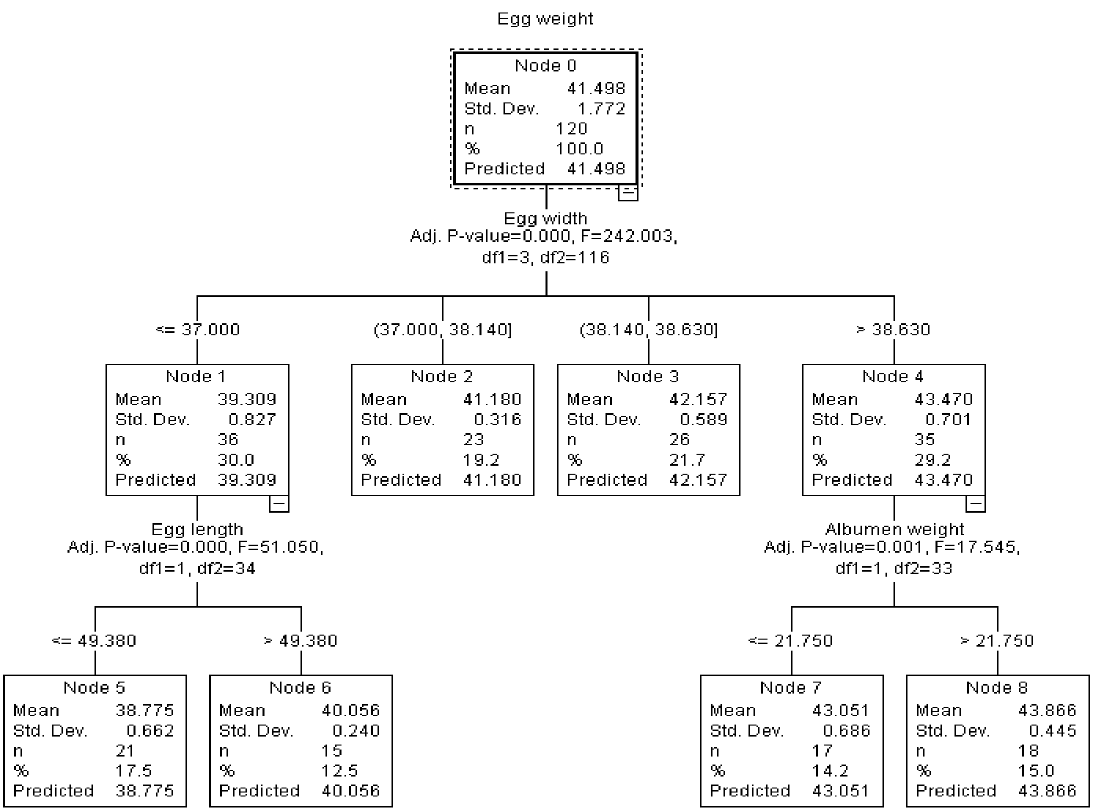

Figure 2. Egg weight prediction of the exotic guinea fowls using the CHAID algorithm.

4. Discussion

The exotic birds performed better than their indigenous counterparts in terms of hatchability and fertility. This may be a result of a differential genetic constitution. According to Zeleke et al. [13], the differences among genetic groups of guinea fowl in terms of fertility and hatchability could be a reflection of previous interventions on selection and breeding. However, the values obtained in the indigenous stock are comparable to the hatchability range of 58.9–76.7% and fertility rate of 49.2–70.0% reported by Obike et al. [34]. In the current study, the fertility value of the Nigerian indigenous stock was higher than the values of 55.97% [35] and 57% reported by Zeleke et al. [13]. Also, the indigenous stock had a higher hatchability value compared to the 50.4% reported by Atawalna et al. [36]. However, a lower hatchability percentage was obtained in comparison with the hatching rates of 72.92 and 82.2% reported by Yakubu et al. [35] and Adu-Aboagye [37], respectively. In other studies, the fertility of guinea fowl eggs has been reported to range from 70 to 85% [38,39], while hatchability ranges from 72 to 80% [40,41]. The observed variations in the indigenous guinea fowls of Africa could possibly be due to environmental factors (as they were reared in different agro-ecosystems), varying management systems, health status, sex structure, age and weight of guinea hens, egg size, and incubator conditions. Also, the guinea fowls of the current study were naturally mated; there is every possibility that if artificial insemination is adopted, better results would be obtained. This is congruous with the submission of Hudson et al. [42] that artificial insemination is a veritable tool in the improvement of guinea fowl's fertility and hatchability.

Guinea fowls are highly valued for their eggs because of their nutritional and health benefits. On average, eggs from the exotic birds seemed to be better than those from their indigenous counterparts in most parameters investigated. The superior edge in egg quality characteristics of the exotic birds, especially egg weight, is not surprising considering the fact that the birds have been subjected to artificial selection. According to Krunt et al. [15], higher egg weight is a product of the selective process involving birds of superior advantage in terms of performance. Therefore, there is every possibility that if the indigenous birds are upgraded using the exotic gene pool, there may be an improvement in the egg quality parameters, with an emphasis on egg weight, which has been reported as a crucial indicator for breed standardization, quality grading, and consumer evaluation [43,44]. The mean egg weight value of 41.50 g in exotic birds is comparable to the value of 40.37 g reported for French Broiler Guinea Fowl guinea fowl strain in Kastina State, Nigeria [45], but less than 43.44 g and 51.68 g reported by Krunt et al. [15], and Kouame et al. [46], respectively. The egg weight value of 34.1 g in indigenous birds is lower than the 37.3 and 37.5 g reported for guinea fowl in Sarki and Birnin Kebbi, Nigeria, by Idowu et al. [14]. However, apart from genetics, other non-genetic factors such as age, nutrition, and the system of management can influence egg quality parameters [47,48].

The estimates of correlation are comparable to those reported in similar studies [16,24,49,50]. The strong and positive association of egg weight with egg width, egg length, shell, yolk and albumen weights, and shell thickness is in consonance with the submissions of earlier workers [24,27]. The negative correlation between egg weight and haugh unit is consistent with the findings of Bernacki et al. [27] and Khaleel [28]. The strong relationship existing between egg weight and some egg parameters may be useful as a selection criterion, as it is possible that they have the same gene action. This, therefore, provides a basis for the genetic manipulation and improvement of the indigenous guinea stock for better egg quality traits. High correlation coefficients among the variables also make it possible to predict egg weight from egg quality parameters.

Three principal components were extracted (out of a total of sixteen original independent variables), which were able to account for a good percentage of the generalized variance in the egg quality parameters investigated. These, according to Malfatti et al. [51], can be used to assess the relationship between the different egg quality indices as well as their assignment into various groups. The stepwise regression revealed the importance, especially of egg width, in the prediction of egg weight. However, due to the problem of multicollinearity, the ordinary least squares method (stepwise regression) estimates may be biased compared to estimates from the principal component factor scores and ridge regression [30,52]. Also, in the CHAID model, egg width alone and in combination with albumen weight were the best predictors of egg weight in indigenous and exotic guinea fowls. The CHAID model, which is non-parametric, does not impose assumptions on the independent variables compared to multiple linear regression. In this study, the CHAID model was more consistent in the estimation of egg weight in both genetic groups. Therefore, it might be an indispensable tool in the poultry industry with regard to egg quality classification. This is in accordance with earlier reports [32,53]. Egg width can easily be measured. This becomes imperative as this information could be exploited in estimating egg weight where resources are limited. The prediction of egg weight from other egg quality parameters has been reported [16]. Albumen weight, as observed in the present study, has also been reported to be a good indicator of egg weight [27].

5. Conclusions

The exotic birds performed better than their indigenous counterparts in terms of hatchability and fertility. The percentage of fertility and hatchability were higher in the exotic birds compared to their indigenous counterparts. Three principal components sufficiently accounted for the variations in the egg quality traits of both genetic groups. The multiple linear regression and CHAID models revealed the importance, especially of egg width, in the prediction of egg weight. The indigenous stock performance can be improved in terms of egg quality parameters, especially egg weight, by upgrading the exotic guinea fowls. However, populations of indigenous guinea fowl should be maintained in conservation and breeding centers for future use, considering their genetic adaptation to the local environments. The obtained CHAID model with egg width as the sole predictor can be used to estimate egg weight where there is no availability of a digital weighing scale.

Author Contributions: Conceptualization, A.Y. and P.J.; methodology, A.Y., P.J., and I.S.M.; software, A.Y. and I.S.M.; validation, S.T.V. and A.J.S.; formal analysis, A.Y.; investigation, P.J.; resources, P.J., A.Y., A.O.A., A.J.S., M.W., M.A.P. and O.O.A.; data curation, P.J., A.Y. and S.T.V.; original draft preparation, P.J.; review and editing, A.Y., M.A.P., A.O.A., A.J.S., M.W., S.T.V. and O.O.A.; visualization, P.J.; supervision, A.Y. and I.S.M.; project administration, A.Y., A.O.A. and A.J.S.; funding acquisition, A.Y., A.O.A., A.J.S., M.W., O.O.A. and M.A.P. All authors have read and agreed to the published version of the manuscript.

Funding: This study was financed by the competitive National Research Fund of the Tertiary Education Trust Fund (TETFUND) of the Federal Republic of Nigeria through grant no. TEF/DR&D/CE/NRF/UNI/ABEOKUTA/STI/VOL.1.

Institutional Review Board Statement: The project was approved by the postgraduate review board of Nasarawa State University, Keffi, Shabu-Lafia Campus, Lafia, Nigeria (4 November 2022).

Informed Consent Statement: Not applicable.

Data Availability Statement: The data will be made available through the corresponding author based on request.

Acknowledgments: The first author received M.Sc. sponsorship from the Nigerian Guinea Fowl Project, which is greatly appreciated.

Conflicts of Interest: The authors declare no conflicts of interest.

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