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Research Article

Morphometric characterization and diversity of indigenous ducks in agro-ecological zones of Ghana

Bismark Yeboah, Julius Kofi Hagan, Samuel Ayeh Ofori*, Richard Asante Botwe

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Department of Animal Science, College of Agriculture and Natural Sciences, University of Cape Coast, Cape Coast, Ghana.

***Correspondence**
Samuel Ayeh Ofori
samuel.ofori@ucc.edu.gh

The study characterized the indigenous duck populations in three agro-ecological zones (AEZs) of Ghana using a primary phenotypic characterization approach involving observation and body measurement. Quantitative trait data were randomly collected on 414 matured ducks across three AEZs (138 from each AEZ). A 1:2 male-to-female selection ratio was used in each of the AEZs. Morphometric traits were subjected to analysis of variance with sex and agro-ecological zone as fixed factors using the General Linear Model. A simple and multiple regression analysis was used to estimate the relationship among morphometric traits to predict body weight. The results revealed that all morphometric traits were significantly influenced ($p<0.05$) by sex. Drakes were significantly superior ($p<0.05$) to ducks in the measured morphometric traits. A medium to high (0.593-0.945) positive correlation was observed among morphometric traits, with body length (0.894) as the best predictor of body weight. The discriminant analysis accurately classified 61.40% of ducks into their respective populations with cross-validation. The Mahalanobis distance was longer (2.27) between the Semi-deciduous and the Rain forest duck populations. The first principal component (PC1) extracted from factor analysis for the Semi-deciduous forest, Coastal savanna, Rain forest and the pooled principal component for all AEZs, explained the maximum variation among the populations with a corresponding total variance of 80.49%; 81.35, 82.93 and 80.59%. The PC1 had higher loadings on body weight (0.965), suggesting that body weight is the trait with the highest discriminatory power among the morphometric traits. A medium to high communality was observed for all morphometric characters measured, indicating that those traits could be used to explain the overall variability in the body dimensions of ducks.

Key words: *ducks, morphometric diversity, quantitative trait, discriminant analysis, mahalanobis distance, variability*

Introduction

Phenotypic characterization detects and defines variability within and between different breeds in a particular location under specific management, considering the socio-economic elements that affect them (FAO, 2012). It precedes other characterization approaches and serves as a foundation for genetic and molecular characterization (Hassan et al., 2019; Ali et al., 2021; Ofori & Hagan, 2021; Botwe et al., 2023). It is fundamental to accumulating baseline data, which helps the nation (Ghana) obtain a complete inventory of its animal genetic resources (AnGR) and is a primary requirement for designing breeding programmes and breed improvement projects (FAO, 2012). Duck genetic resources have economic significance and cultural relevance to Ghana's rural poor and promote sustainability for food and agriculture. Duck produces more meat than local chicken and guinea fowl weighing between 2.48 and 2.93 kg at 8-9 weeks old, and some breeds of ducks, like Khaki Campbell, lay more and bigger eggs than chicken (Ugbomeh, 2002). Ducks are tough and good scavengers, which are easier and more cheaply managed than chicken. They adapt quickly and easily to tropical environments, can withstand many common poultry diseases like Newcastle and do not necessarily need expensive compounded feed (Mantey et al., 2014). Again, people with no skill can successfully raise ducks on poor-quality feed on a small scale. Despite the tremendous abilities of ducks, there is no information available in the literature on the phenotypic characterization of the indigenous duck populations in Ghana. Therefore, there is a need to characterize the indigenous ducks in Ghana to aid in designing breeding programmes. The study will also bridge the knowledge gap in the literature and add to the knowledge repository. The study's outcome may be used to know the status of the species (ducks) and help propose guidelines for sustainable utilization, suitable improvement and conservation of ducks and help develop the AnGR management plans (FAO, 2012). There is no known duck improvement programme in Ghana, and the study will serve as a foundation for future breed improvement programmes. Future improvement of ducks may serve as an alternative source of cheaper and affordable protein to augment protein inadequacy and malnutrition in Ghana.

Materials and methods

Description of the study area

The study was conducted in three (3) agro-ecological zones of Ghana, namely, the Coastal savanna, Semi-deciduous forest and Rain forest. These three agro-ecological zones have the highest poultry populations in Ghana hence, their inclusion in the study. The Coastal savanna lies between latitude 05^{0}07N and longitude 001^{0}17W. The average relative humidity, rainfall, and temperature of this AEZ are 70-85%, 600-1200mm, and 24-30^{0}C respectively. The Semi-deciduous forest also lies between latitude 06^{0}14N and longitude 07^{0}36W with annual rainfall, temperature, and humidity range of 1200-1600mm, 24-31^{0}C, and 60-80%, respectively. Also, the Rain forest AEZ lies between latitude 04^{0}59N and longitude 01^{0}29W with annual rainfall, temperature, and humidity of 800-2800mm, 25-29^{0}C, and 65-85%, respectively.

Study approach and sampling

The study adopted the survey approach as well as purposive and snowballing sampling techniques to select households and farms raising ducks. A sample of 414 matured ducks was randomly selected from a population of 1744 ducks found in selected households and farms within the three AEZs (138 from each AEZ) following the FAO (2012) breed descriptor tool for phenotypic characterization studies. A 1:2 male-to-female selection ratio was used in each AEZ. Different duck farmers practiced different management systems, including intensive, semi-intensive and extensive systems. Those that raised ducks intensively fed the birds twice daily and provided ad libitum potable water, while supplementary feed was offered to ducks raised semi-intensively and extensively. The formula used to estimate the sample size for the respondent households and farms was adopted from FAO (2012) as described below;

$$n = \left(\frac{z}{m}\right)^2 p(1-p)$$

$$n = \left(\frac{1.96}{0.05}\right)^2 0.05(1-0.50) = 384$$

Where n = sample size; z = the z value for 95% confidence level = 1.96; m = the margin of error (the confidence interval of ±5%) =0.05; and p is the estimated value for 50% proportion of the sample that will respond a given way to a survey question, p = 0.50.

Data collection for morphometric traits

The duration of the collection of the data spanned from November 2021 to May 2022. Measurements of morphometric features were recorded as defined by FAO (2012). The body weight and linear body characters were taken with a 10kg digital hanging weighing scale, digital calipers and measuring tape as follows:

Body weight (BW): Live adult ducks were restrained and hanged on a digital measuring scale, and their total body weight was recorded.

Body length (BL): The body length was measured from the tip of the bill over the head through the body trunk to the tip of the caudal tail without feathers with a measuring tape.
Wing span (WS): The length between the wingtips was measured to the nearest centimetres when the wings were outstretched using a tape measure.

Wing length (WL): This was measured to the nearest centimeters from the scapula to the tip of the longest primary feathers using a tape measure.

Shank length (SL): The length between the hock joint and the regio tarsalis was measured to the nearest centimeters on the right limb using a pair of calipers.

Bill length (BLL): Bill length was measured to the nearest centimeters from the base of the bill to the tip using a pair of calipers.

Bill width (BLW): the width of the bill was measured at the base of the bill using a digital caliper.

Breast circumference (BC): The circumference of the breast was measured from the top of the pectus (hind breast) with a measuring tape.

Neck length (NL): The length of the axial skeleton from the first to the last cervical vertebrae was measured using a measuring tape.

Statistical analysis of quantitative (morphometric) traits

Analysis of variance (ANOVA)

Morphometric traits were subjected to analysis of variance with sex and agro-ecological zones as fixed factors using the General Linear Model (GLM) of Minitab 19 (Minitab, 2020). The mean separation of traits exhibiting significant differences was done using the Tukey's HSD (honestly significant difference) test. The sex and agro-ecological zone effect on body weight and other linear body characters were tested using the model used by Yakubu (2011) as follows;

$$Y_{ij} = \mu + S_i + E_j + e_{ij}$$

Y_{ij} = individual observation of each body trait;
μ = overall mean;
S_i = effect of i^{th} sex (i = male, female);
E_j = effect of j^{th} agro-ecological zone (j = Semi-deciduous forest-1, Rain forest-2 and Coastal savannah-3);
e_{ij} = random error associated with each record

A simple and multiple regression analysis were used to estimate the relationship among morphometric traits to predict body weight using SPSS version 25 (IBM SPSS, 2017) statistical package as follows:

$$LW = \beta_0 + \beta X + \varepsilon$$

Where,
LW = live weight,
β_0 = the intercept of the regression equation,
βX = partial regression coefficient of the linear body trait retained in the model (X),
ε is the random error.

Multivariate analysis (discriminant and principal component analysis)

Discriminant analysis was used to classify and differentiate the three duck populations from the three corresponding agro-ecological zones using Minitab 19 (Minitab, 2020) statistical package based on Mahalanobis distance using the model (Ofori et al., 2021):

$$D^2 = (x - m)^T \cdot C^{-1} \cdot (x - m)$$

Where,
D^2–: the Mahalanobis squared distance
x–: the vector of observation of morphometric trait (row in a dataset)
m–: the vector of mean values of independent morphometric variables (mean of each column)
T–: superscript: Transposed matrix (a new matrix whose rows are the columns of the original)
C^{-1}–: the inverse covariance matrix of independent morphometric variables

The canonical plot depicting a pictorial representation of the distribution of the duck populations was generated by GenStat 12th edition (VSNI, 2012).

Principal Component Analysis (PCA) was done by extracting principal components from factor analysis to determine the morphometric trait with the highest discriminatory power. The representation of the linear combination of available data into components or factors was first determined distinctly for each agro-ecological zone and then a pooled component for all three duck populations was determined. The indicators used to determine whether the partial correlations among morphometric traits were low included the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity (Shrestha, 2021). A KMO value of 0.50 and above was considered suitable (Shrestha, 2021), whereas a non-significant Bartlett's test of sphericity for morphometric traits for a particular duck population was excluded for PCA. According to Everitt et al. (2011), "Principal Component Analysis is a method of transforming variables in a multivariate data set, $x_1, x_2, \ldots x_p$ into new uncorrelated variables $y_1, y_2, \ldots y_p$ which account for decreasing proportions of the total variance in the original variables defined as

$y_1 = a_{11}x_1 + a_{12}x_2 + \ldots + a_{1p}x_p.$
$y_2 = a_{21}x_1 + a_{22}x_2 + \ldots + a_{2p}x_p.$
$y_p = a_{p1}x_1 + a_{p2}x_2 + \ldots + ap_px_p.$

The principal components $y_1, y_2, \ldots y_p$ account for decreasing proportions of the total variance in the original variables $x_1, x_2, \ldots x_p$. Variance maximizing orthogonal rotation was used in the linear transformation of the factor pattern matrix to make interpreting the extracted principal components easier". The PCA was done using SPSS version 25 (IBM SPSS, 2017)

Results and discussion

Characterization, correlation and regression analysis of morphometric traits of ducks in Ghana

The descriptive statistics of quantitative (morphometric) traits as affected by sex and agro-ecological zone are presented in Table 1. Generally, sex highly influenced (*p<0.05*) all the traits and agro-ecological zone significantly affected all the morphometric traits except body length.

Table 1. Means ± standard deviations of morphometric traits as affected by sex and agro-ecological zone

Traits/Factor		Sex			
		Males (*n=138*)		**Females** (*n=276*)	
BWT (kg)		2.59±0.01[a]		1.80±0.00[b]	
BL (cm)		58.50±0.16[a]		46.99±0.11[b]	
SL (cm)		6.15±0.03[a]		5.26±0.02[b]	
NL (cm)		18.99±0.10[a]		15.52±0.07[b]	
BLL (cm)		5.70±0.03[a]		4.95±0.02[b]	
BLW (cm)		2.54±0.01[a]		2.29±0.00[b]	
BC (cm)		41.19±0.13[a]		35.75±0.09[b]	
WL (cm)		53.51±0.12[a]		42.31±0.09[b]	
WS (cm)		116.51±0.26[a]		93.10±0.19[b]	
AEZ		**Semi-deciduous forest**	**Coastal savanna**	**Rain forest**	**N**
BWT (kg)	Male	2.66±0.18[a]	2.58±0.19[ab]	2.51±0.15[b]	46

	Female	1.84±0.08^{a}	1.82±0.10^{a}	1.75±0.10^{b}	92
BL (cm)	Male	58.87±1.34^{a}	58.45±1.28^{ab}	58.16±1.15^{b}	46
	Female	46.90±2.23^{a}	47.34±1.96^{a}	46.71±2.22^{a}	92
SL (cm)	Male	6.08±0.40^{a}	6.25±0.33^{a}	6.11±0.33^{a}	46
	Female	5.17±0.40^{b}	5.42±0.40^{a}	5.19±0.42^{b}	92
NL (cm)	Male	19.14±1.39^{ab}	19.28±1.21^{a}	18.55±1.30^{b}	46
	Female	16.09±1.22^{a}	15.46±1.03^{b}	15.00±1.18^{c}	92
BLL (cm)	Male	5.73±0.33^{a}	5.70±0.35^{a}	5.68±0.29^{a}	46
	Female	5.05±0.30^{a}	4.94±0.36^{ab}	4.87±0.41^{b}	92
BLW (cm)	Male	2.53±0.06^{b}	2.53±0.06^{b}	2.57±0.6^{a}	46
	Female	2.30±0.06^{a}	2.26±0.09^{b}	2.31±0.07^{a}	92
BC (cm)	Male	41.75±1.67^{a}	41.27±1.57^{ab}	40.53±1.51^{b}	46
	Female	36.49±1.35^{a}	35.66±1.52^{b}	35.10±1.71^{c}	92
WL (cm)	Male	53.59±1.37^{a}	53.26±1.25^{a}	53.70±1.19^{a}	46
	Female	42.50±1.51^{a}	42.02±1.55^{a}	42.40±1.48^{a}	92
WS (cm)	Male	115.32±3.24^{b}	117.57±2.62^{a}	116.66±3.57^{ab}	46
	Female	93.17±3.03^{ab}	92.28±3.18^{b}	93.86±2.88^{a}	92

BWT=Body weight; BL=Body length; SL=Shank length; NL=Neck length; BLL= Bill length; BLW=Bill width; BC= Breast circumference; WL=Wing length; WS= Wing span. Means within a subclass in a row that does not share common superscripts are significantly different ($p<0.05$); see appendix for actual P values.

Body weight

The average body weight recorded for drakes and ducks from the three agro-ecological zones were 2.59kg and 1.80kg, respectively; however, males from the Semi-deciduous forest (2.66kg) had higher body weight than the Coastal savanna (2.58kg), and then the males from the Rain forest (2.51kg) had the least body weight. The overall body weight of males recorded in the present study agrees with Banerjee (2013), who reported 2.50kg for pied feathered Muscovy drakes in West Bengal State of India. Also, the results from the present study are in close association with the reports from Książkiewicz (2002), Raji et al. (2009), Ogah et al. (2011), Foluke et al. (2020) in addition to Lan & Worowan (2020) who observed a mean body weight of 2.47kg, 2.71kg, 2.41kg, 2.73kg, 2.33kg and 2.73kg respectively for drakes raised in different environments. The average body weight observed in the present study is slightly lower than the 4-7kg (Johnson & Hawk, 2009; Lan, 2020) as well as 3.05kg, 3.38kg, 3.09kg, 3.62kg and 3.16kg reported by Drouilhet et al. (2014), Hailu et al. (2018), Tamzil et al. (2018) and Ewuola et al. (2020) respectively. The current research however, recorded a higher body weight than those reported by Morduzzaman et al. (2015), Kamal et al. (2019) and Kadurumba et al. (2021) who recorded relatively lower body weight in Nageswari ducks in Bangladesh, Desi ducks of Odisha, India and local duck population in South-east ecological zone, Nigeria of 1.66kg, 1.80kg and 1.73kg respectively for drakes. The present study recorded an overall average body weight of 1.80kg for females. In contrast, within the population, body weight followed a similar trend as that of their male counterparts, where the higher body weight was recorded from the Semi-deciduous forest, followed by the Coastal savanna and then the Rain forest in a prevalence of 1.84kg, 1.82kg and 1.75kg respectively. The overall body weight recorded for females in the present research is higher than the findings of Kamal et al. (2019), Raji et al. (2009), Morduzzaman et al. (2015), and Yakubu (2013) who witnessed a live body weight of 1.41kg, 1.44kg, 1.46kg, 1.51kg, 1.52kg and 1.58kg respectively. In contrast, Tamzil et al. (2018) recorded a higher body weight of 2.49kg, whiles Johnson & Hawk (2009), Huang et al. (2012) and Lan (2020) also reported a range of 2.6-4.0kg, 2.7-3.6kg and 5-6kg respectively.

Compared to other studies, the lower body weight recorded in the present study may be attributed to the influence of genetics, the production environment and the differences in management systems and practices (Ofori & Hagan, 2020). Most of the farms and households studied practice semi-intensive and extensive management systems with less or no supplementary feeding, and most of the farms used less veterinary treatment for their birds. However, those studies that recorded higher body weight resulted from the intensive management system and better routine management and veterinary practices.

Body length

The males from the Semi-deciduous forest had a longer body length than their counterparts in the Coastal savanna and the Rain forest with a corresponding mean value of 58.87cm, 58.45cm and 58.16cm. In divergence, the Coastal savanna recorded the longest body length for females, followed by the Semi-deciduous forest and then the Rain forest with values of 47.34cm, 4.90cm and 46.71cm, respectively. The overall mean body length recorded for the present study, 58.50cm for males and 46.99cm for females, finds partial agreement with Raji et al. (2009), Hailu et al. (2018) and Foluke-Eunice et al. (2020), who reported a body length of 59.25cm & 45.51cm; 56.88cm & 47.52cm and 54.59cm & 49.02cm for males and females respectively. The results are however, closely associated with the findings of Kamal et al. (2019) and Kadurumba et al. (2021), who recorded 47.86cm & 38.35cm, 42.69cm & 41.30cm and 45.04cm & 42.69cm for drakes and ducks respectively. Comparatively, shorter body length of 21.53cm & 17.59cm and 26.27cm & 23.79cm were recorded by Morduzzaman et al. (2015) for drakes and ducks, respectively. The variation in the body length between the present study and other previous studies can be attributed to genetic and environmental influence, as the previous studies were conducted on different breeds and ecotypes of ducks raised in different production environments. It can also be due to the measurement accuracy and how the body length was taken, as the present study measured the body length from the tip of the beak to the caudal tail without feathers. Some researchers may have a different approach to measuring body length hence the variations.

Shank length

Drakes had longer shank than ducks in the present study across all the agro-ecological zones (Table 1). The overall average shank length recorded for drakes (6.15cm) and ducks (5.26cm) is similar to the 6.21cm and 5.89cm reported by Kamal et al. (2019). It is however, lower than what was recorded by Morduzzaman et al. (2015), who witnessed a shank length of 6.60cm for drakes and 6.09cm for ducks in Bangladesh. Likewise, the recorded shank length in the present work is lower than the overall shank length (6.45cm) reported by Maharani et al. (2019); the 7.69cm for drakes and 5.68cm for ducks witnessed by Foluke-Eunice et al. (2020) and the 8.42cm for drakes and 7.02cm for ducks reported by Macharia et al. (2017). In contrast, the values of the present study are higher than those reported by Ewuola et al. (2020), Hailu et al. (2018) and Ogah et al. (2011). It is also higher than what was reported by Lan and Worowan (2020), who recorded lower shank lengths of chocolate, lavender, silver and white plumage-clouded female Muscovy ducks in PNGUNRE poultry farm in Papua New Guinea in a ratio of 4.86cm, 5.20cm, 4.71cm and 5.05cm respectively.

Neck length

Both sex and agro-ecological zone had a significant influence on neck length. The Coastal savanna recorded the longest neck length of 19.28cm, followed by the Semi-deciduous forest (19.14cm), and then the Rain forest recorded 18.55cm for drakes. On the other hand, the Semi-deciduous forest recorded the longest neck length of 16.09cm, followed by the Coastal savanna (15.46cm) and, finally, the Rain forest (15cm) for ducks. This agrees with Ogah et al. (2011), who observed variation in neck length among duck populations raised in Nigeria's dry savanna, guinea savanna and rain forest. The mean neck length recorded across the study area is 18.99cm for drakes and 15.52cm for ducks. The sexual dimorphism in the overall mean length agrees with Morduzzaman et al. (2015), Kokoszyński et al. (2019), Tamzil et al. (2018), Veeramani et al. (2014), Kamal et al. (2019) and Kadurumba et al. (2021), who stressed that there is a sexual dimorphism associated with the trait. However, the values recorded for the present study are lower than the 23.49cm & 21.59cm and, 23.70cm & 19.19cm recorded by Morduzzaman et al. (2015) and Susanti et al. (2016) for drakes and ducks, respectively. In contrast, the results of the present study are higher than those observed in the work of Kokoszyński et al. (2019), and Tamzil et al. (2018), who recorded 18.10cm &14.33cm; 18.30cm & 17.50cm and 18.32cm & 14.87cm for drakes and ducks respectively. Additionally, the values reported by Kamal et al. (2019), Veeramani et al (2014) and Kadurumba et al. (2021) are also lower than what was recorded in the present study as they recorded a neck length for drakes and ducks in a relative proportion of 12cm & 10cm, 13.94cm & 12.43cm and 14.14cm & 13.57cm respectively.

Bill length

The current study's findings revealed a significant influence (*$p<0.05$*) of sex and agro-ecological zone on the bill length of ducks. Drakes and ducks from the Semi-deciduous forest had the longest bill of 5.73cm and 5.05cm, respectively, followed by the Coastal savanna, recording 5.70cm and 4.94cm, then the Rain forest with 5.68cm and 4.87cm. The current research finds agree with the work of Ogah et al. (2011), who documented that location or agro-ecological zones have a significant effect on the bill length of ducks as they found that birds from the guinea savanna had longer bill length, followed by the rainforest and finally the dry savanna in a relative proportion of 5.64cm, 5.42cm and 5.34cm. The present study saw drakes recording longer bills than ducks in a proportion of 5.70cm and 4.95cm correspondingly. This is in harmony with the works of Raji et al. (2009), Veeramani et al. (2014), Susanti et al. (2016), Kamal et al. (2019), Maharani et al. (2019), Tamzil et al. (2018) and Kadurumba et al. (2021) who shared a common view that drakes have longer bills than ducks in their various researches. It also falls within the range of drakes (5.12-5.5.98cm) and ducks (4.67-5.54cm) reported by Morduzzaman et al. (2015), Maharani et al. (2019), Kadurumba et al. (2021) and Raji et al. (2009). Notwithstanding, the present results are lower than what was previously reported by Kamal et al. (2019), Veeramani et al. (2014) and Susanti et al. (2016) who recorded 6.11cm & 5.60cm, 6.84cm & 5.76cm and 6.20cm & 5.24cm for drakes and ducks respectively. However, it is higher than the range of drakes (4.13-4.98cm) and ducks (3.38-4.10cm) reported by Tamzil et al. (2018) and Foluke-Eunice et al. (2020) .

Bill width

The overall bill width recorded for the present work was 2.54cm for drakes and 2.29cm for ducks. Drakes from the Rain forest recorded the widest bill of 2.57cm, while their counterparts from the Semi-deciduous forest and the Coastal savanna shared a similar bill width of 2.53cm. The widest bill for ducks was also recorded from the Rain forest followed by Semi-deciduous forest and then the Coastal savanna in a proportion of 2.31cm, 2.30cm and 2.26cm, respectively. This slightly agrees with Ogah et al. (2011), who also witnessed varying bill width from different agro-ecological zones; however, the overall mean recorded for drakes and ducks are lower than the earlier findings of Kamal et al. (2019), who witnessed 3.70cm and 3.46cm for drakes and ducks respectively. Also, ducks from the present study recorded a lower bill width than their counterparts in Indonesia, who recorded a 2.77cm bill width, as reported by Maharani et al. (2019).

Breast circumference

Results from the present study revealed that sex and agro-ecological zone significantly (*$p<0.05$*) influenced breast circumference. The mean breast circumference of the indigenous duck populations recorded in the present study is 41.19cm for drakes and 35.75cm for ducks. The results showed that drakes and ducks from the Semi-deciduous forest had the broadest breast (41.75cm & 36.49cm), followed by Coastal savanna (41.27cm & 35.66cm) and then the Rain forest (40.53cm & 35.10cm). The sexual dimorphism in the trait is expected and agrees with the previous findings (Hailu et al., 2018; Tamzil et al., 2018; Foluke-Eunice et al., 2020; Kadurumba et al., 2021; Ewuola et al., 2020; Susanti et al., 2016), who recorded a broader breast for drakes than ducks. Also, the overall mean values recorded for drakes and ducks in the current work concord with Hailu et al. (2018), who documented 44.50cm for drakes and 35.70cm for ducks. It also finds harmony with Tamzil et al. (2018), who recorded 40.91cm and 35.92cm for drakes and ducks, respectively. The values recorded for the present study, however, are slightly higher than those recorded by Raji et al. (2009), Foluke-Eunice et al. (2020), Kadurumba et al. (2021) and Susanti et al. (2016) who discovered a disparity in breast circumference in terms of sex in a relative occurrence of 40.57cm & 31.43cm, 37.46cm & 30.40cm, 33.85cm & 32.01cm, 38.30cm & 30.37cm and 38.83cm & 31.28cm for drakes and ducks respectively. On the contrary, Ewuola et al. (2020) recorded values that are relatively lower than the findings of the present study for drakes (25.84cm) and ducks (20.18cm).

Wing length

The mean values of 53.51cm and 42.31cm recorded for wing length in the present study for drakes and ducks, respectively, finds little congruence with the work of Hailu et al. (2018), who reported 55.56cm and 47.70cm for drakes and ducks respectively. The values in the current work somehow agree with the earlier findings of Kamal et al. (2019), who noticed 42.73cm for drakes and 39.99cm for ducks but disagree with Tamzil et al. (2018) who reported higher values of 82.81cm for drakes and 61.19cm for ducks. Contrariwise, the current research recorded longer wings than the previous findings of Raji et al. (2009) and Susanti et al. (2016), who witnessed shorter wings of 31.01cm & 23.99cm and 33.64cm & 26.67cm for drakes and ducks correspondingly. The results of the present work are also incongruent with Yakubu (2011), Foluke-Eunice et al. (2020), Kadurumba et al. (2021), whose reports ranged between 23.65cm and 25.82cm for drakes and 16.43cm and 24.68cm for ducks. Likewise, Ewuola et al. (2020) recorded a very short wing length of 13.38cm and 9.94cm for drakes and ducks, respectively, which are not in harmony with the present study. The difference in the wing length can again be attributed to the effect of breed genetics and the production environment. It can also be ascribed to the measurement method as the present study measured the wing length from the scapula to the tip of the longest primary feathers of live birds; other researchers may have measured from the scapula to the tip of the terminal phalanx of slaughtered birds.

Wing span

Sex and agro-ecological zone significantly influenced the wing span. The overall average for the trait favoured drakes more than ducks, as drakes recorded 116.51cm for the trait and ducks recorded 93.10cm. Drakes from the Coastal savanna had the longest wing span of 117.57cm, followed by Rain forest recording 116.66cm, and then drakes from the Semi-deciduous forest measured 115.32cm long for the trait. On the contrary, ducks from the Rain forest recorded the longest wing span of 93.86cm, followed by the Semi-deciduous forest witnessing 93.17cm and the Coastal savanna, recorded 92.28cm. Adenaike et al. (2020) and Bhowmik et al. (2014) have conducted research to determine the wing span of turkey and Pigeons in Nigeria and Bangladesh, respectively, as influenced by sex and location, whereas Brown et al. (2017) have studied the wingspan of both the local chicken and guinea fowl in Ghana and how the trait is influenced by agro-ecological zone and sex. However, there is no information on the wing span of ducks in the literature. Therefore, the present work can help bridge this gap in the literature and serve as the basis for future research.

Pearson correlation among morphometric traits measured

The phenotypic correlations among morphometric traits (body weight and linear body measurements) are presented in Table 2. The results revealed medium to high, statistically significant positive values (*p<0.05*).

Table 2. Correlation among morphometric traits measured

	BWT	BL	SL	NL	BLL	BLW	BC	WL
BWT								
BL	0.945**							
SL	0.734**	0.731**						
NL	0.815**	0.795**	0.645**					
BLL	0.742**	0.723**	0.593**	0.660**				
BLW	0.802**	0.816**	0.646**	0.685**	0.619**			
BC	0.875**	0.852**	0.689**	0.788**	0.709**	0.744**		
WL	0.925**	0.925**	0.707**	0.781**	0.701**	0.829**	0.831**	
WS	0.920**	0.920**	0.705**	0.781**	0.704**	0.826**	0.828**	0.982**

**Correlation is significant at p<0.05

The results from the present study revealed a higher (0.734-0.945) positive correlation between body weight and morphometric traits such as body length, shank length, neck length, bill length, bill width, breast circumference, wing length and wing span. This indicates that these morphometric traits have a higher contribution to body weight, hence, a good predictor of body weight. Additionally, it implies that the selection for improvement of one of these traits may significantly improve the live body weight of the indigenous duck populations in Ghana, provided these higher correlations result from genetic factors rather than the influence of the production environment. The current work showed that body length (0.945) had the highest correlation with body weight, followed by wing length (0.925), wing span (0.920), breast circumference (0.875), neck length (0.815), bill width (0.802), bill length (0.742) and finally shank length (0.734). The present findings are consistent with Ewuola et al. (2020), who indicated that body length (0.987) had the highest correlation with body weight, followed by wing length (0.984) in Muscovy ducks in the humid zone of Nigeria. It further agrees with Raji et al. (2009), who also observed that body length (0.87) had the highest correlation with body weight, followed by chest girth (0.85). It also finds consonance with the reports of Lan (2020), who observed that body length (0.616) strongly correlates with body weight in Muscovy ducks. It is also in congruence with Adenaike et al. (2020), whose discriminant analysis of morphostructural parameters in locally adapted turkeys in Nigeria revealed a higher correlation between body length (0.91) and body weight. However, the work of Hailu et al. (2018) demonstrated that breast circumference (0.739) had the highest correlation with body weight. Likewise, Kadurumba et al. (2021) also observed that breast circumference (0.914) had the highest correlation with body weight in Muscovy ducks. The present study does not agree well with Tamzil et al. (2018), who, on the other hand, saw wing length as the highest correlating trait with body weight in both drakes (0.81) and ducks (0.80) in Muscovy ducks raised semi-intensively in Lombok Island, Indonesia. The current work slightly disagrees with Bhowmik et al. (2014), whose work on Pigeons revealed that wing span (0.750) had the highest correlation with body weight, followed by body length (0.741).

Simple and multiple regression analysis

The simple and multiple regression analysis for predicting live body weight from morphometric traits of indigenous duck populations in Ghana is presented in Tables 3 and 4, respectively.

Table 3. Prediction equations of simple regression analysis

Trait	Prediction Equation	Adj. R^2	Sig.
BL	**BWT=-1.212+0.06BL**	**0.894**	***
SL	BWT=-0.688+0.49SL	0.539	***
NL	BWT=-0.516+0.15NL	0.664	***
BLL	BWT=-0.971+0.58BLL	0.550	***
BLW	BWT=-3.325+2.27BLW	0.642	***
BC	BWT=-2.175+0.11BC	0.765	***
WL	BWT=-0.983+0.06WL	0.855	***
WS	BWT=-1.105+0.03WS	0.845	***

*BWT=Body weight; BL=Body length; SL=Shank length; NL=Neck length; BLL= Bill length; BLW=Bill width; BC= Breast circumference; WL=Wing length; WS= Wing span; R^2=Coefficient of determination; Adj. =Adjusted; Sig. =Significant*** (p<0.05).*

Table 4. Prediction equations of multiple regression models

Prediction Equation	Adj. R^2	Sig.
BWT=-1.693+0.050BL+0.033BC	0.911	***
BWT=-1.632+0.034BL+0.027BC+0.020WL	0.922	***
BWT=-1.605+0.033BL+0.023BC+0.019WL+0.016NL	0.924	***
BWT=-1.665+0.031BL+0.021BC+0.019WL+0.015NL+0.047BLL	**0.926**	***

*BWT=Body weight; BL=Body length; NL=Neck length; BLL= Bill length; BC= Breast circumference; WL=Wing length; R^2=Coefficient of determination; Adj. =Adjusted; Sig. =Significant*** (p<0.05).*

It is evidenced that linear body measurements of animals could be used to predict body weight by simple and multiple linear regression methods. Numerous researchers on different livestock species have utilized these methods. Among the researchers includes Birteeb and Lomo (2015), Pesmen & Yardimci (2008), Okpeku et al. (2011) and Ofori et al. (2021). However, their research is skewed towards ruminants than poultry. A simple regression analysis was performed on all the morphometric traits measured to ascertain the most significant trait, which could be used to predict the body weight of the indigenous duck populations in Ghana. The simple regression model revealed medium to high prediction accuracies (0.539-0.894), which were all statistically significant ($p<0.05$). The study indicated that body length with prediction equation (y=-1.212+0.06BL) is the best predictor of body weight with R^2=0.894 followed by wing length, wing span, breast circumference, neck length, bill width, bill length and then shank length with R^2=0.855; 0.845; 0.765; 0.664; 0.642; 0.550 and 0.539 respectively with their corresponding prediction equation in Table 3. The R^2 (coefficient of determination) values indicate that body length alone could explain 89.40% of the total variance in body weight, whereas 85.5%; 84.5%; 76.5%; 66.4%; 64.2%; 55%, and 53.9% of the variance in body weight could be explained by wing length, wing span, breast circumference, neck length, bill width, bill length and shank length respectively. The current findings are in harmony with the work of Ewuola et al. (2020), who revealed a higher coefficient of determination values, which ranged from 0.869 to 0.974 in Muscovy ducks raised in the humid region of Nigeria. Again, the results of the present work further confirms that of Ewuola et al. (2020), who indicated that body length is the highest single trait predictor of body weight with R^2 value of 0.974. The present study, however, slightly disagrees with Raji et al. (2009), who found the best single trait predictor of body weight to be breast circumference with $R^2 = 0.728$, which was statistically significant at $p<0.05$. The highest R^2 (coefficient of determination) values reported by the present study, together with the earlier findings of Raji et al. (2009) and Ewuola et al. (2020), clearly show that body weight can be predicted from a single and easily measurable metric trait for ducks with a higher level of accuracy using a simple regression method. A multiple regression analysis was further performed to determine the pooled predictive ability of the morphometric traits, and the results are presented in Table 4. The results revealed high (0.911-0.926) prediction accuracies, which were all statistically significant ($p<0.05$). This implies that a combination of two or more morphometric traits in a model can improve the prediction of body weight (see highlighted equation in Table 4).

Differentiation and classification of indigenous duck populations in Ghana using discriminant analysis of morphometric characters

Multivariate analysis is suitable for assessing variability within and between the indigenous duck populations in Ghana when all metric characters are considered simultaneously (Yakubu & Ibrahim, 2011; Ofori et al., 2021; Botwe et al., 2023). In the present study, the degree of differentiation of the indigenous duck population in Ghana was achieved using the Mahalanobis distance, as shown in Table 5 and Figure 1.

Table 5. Matrix of mahalanobis distance between duck populations based on morphometric traits

Population (P)	P1	P2	P3
P1 (Semi-deciduous forest)		1.46	2.27
P2 (Coastal savanna)			1.30
P3 (Rain forest)			

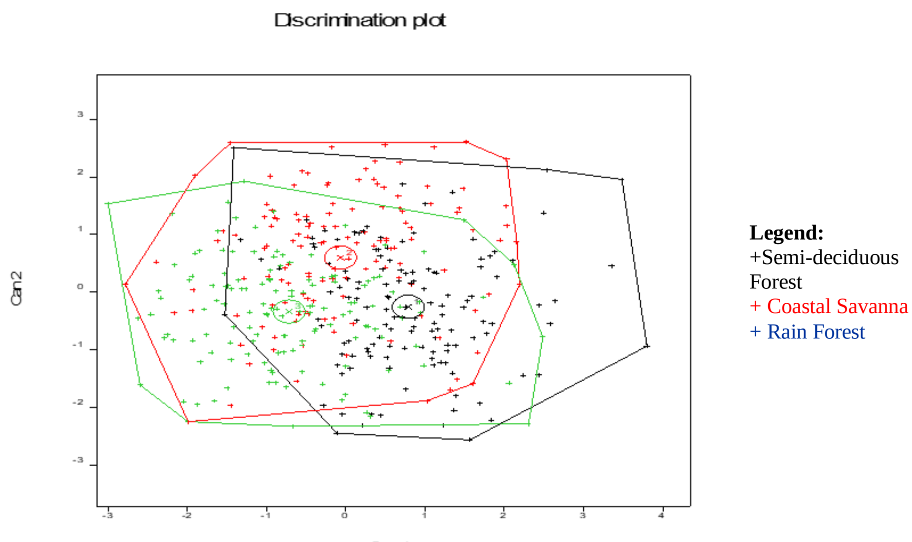

Figure 1. Canonical plot for the three duck populations

From Table 5, the populations were significantly distant (*p<0.0001*) from each other. The longest (2.27) distance was between the duck populations from the Semi-deciduous forest (P1) and the Rain forest (P3), whereas the shortest (1.30) distance was observed between the duck populations from the Coastal savanna (P2) and Rain forest (P3). The shortest Mahalanobis distance observed between the duck populations from the Coastal savanna and the Rain forest could be attributed to high intermingling or genetic exchange between the two populations over time due to the ecological closeness of the two populations. As suggested by the shorter Mahalanobis distance, populations P2 and P3 may share similar genes which could lead to inbreeding depression; it is accordingly advisable for farmers to subsequently curb the situation by obtaining new duck breeding stock from different and more expansive geographical areas.

The longer Mahalanobis distance between P1 and P3 might be due to natural and artificial selection and environmental adaptation. Thus, the creation of the variability as observed between P1 and P3 can be caused by geographical isolation, which agrees with Gizaw et al. (2007). From the present work, it is imperative to conserve the genetic diversity found between the duck populations from the Semi-deciduous forest (P1) and the Rain forest (P3) and use it as the basis to design a breeding programme to improve on the weight and other traits of economic importance to harness the full potential of indigenous ducks. The findings of the current work are comparable to Ogah (2013), who recorded a Mahalanobis distance in the range of 3.37-4.62 for Nigerian native chicken genotypes. It also agrees with Oguntunji & Ayorinde (2015), who reported a shorter Mahalanobis distance ranging from 2.01 to 3.76 for Nigerian Muscovy duck populations. However, Ogah et al. (2011) recorded a long Mahalanobis distance (54.80) between the guinea savanna and the dry savanna, followed by a distance between the dry savanna and the rain forest (35.44) and the least Mahalanobis distance was between guinea savanna and the rain forest (34.12) Muscovy duck ecotypes in Nigeria. Also, Adenaike et al. (2020) noticed a longer Mahalanobis distance that ranged between 303.58 and 415.16 for locally adapted Nigerian turkeys.

Classification of duck populations

The relatedness and differences between individuals within the three duck populations are shown in Table 6. The discriminant analysis in the present study was able to classify appropriately 61.4% of individual ducks into their respective populations with cross-validation, as presented in Table 6, based on the Mahalanobis distance (Table 5). The current work revealed the highest relatedness among duck populations from the Semi-deciduous forest (64.49%), followed by duck populations from the Rain forest (62.32%), whereas the slightest similarity was found within the populations in the Coastal savanna (57.25%). The considerable relatedness or similarity within the populations implies that within population selection should be discouraged among duck farmers within the respective agro-ecological zones. The results further showed that 23.19% and 12.32% of P1 (Semi-deciduous forest) were misclassified into P2 (Coastal savanna) and P3 (Rain forest), respectively.

Table 6. Classification matrix with cross-validation of the number of observations and percentage classified (misclassified) into populations of ducks based on morphometric trait

Population (P)	P1	P2	P3
P1 (Semi-deciduous forest)	**89**	22	26
	64.49	15.94	18.84
P2 (Coastal savanna)	32	**79**	26
	23.19	**57.25**	18.84
P3 (Rain forest)	17	37	**86**
	12.32	26.81	**62.32**
Error level for populations	35.51	42.75	37.68
Prior probability (Priors)	0.333	0.333	0.333

Also, 15.94% and 26.81% of P2 were misclassified to P1 and P3, respectively. Again, 18.84% of duck populations within the Rain forest were wrongly assigned to the Semi-deciduous forest and the Coastal savanna. Classification of duck populations using this method is rare in the literature. However, some researchers (Dossa et al., 2007; Traore et al., 2008; Yakubu et al., 2010; Batubara et al., 2011; Yakubu & Ibrahim, 2011; Ofori et al., 2021) have used the approach to demonstrate high classification success in sheep and goat populations.

Most discriminating traits by Principal Component Analysis (PCA)

The eigenvalues of the total variance, un-rotated component loadings and communalities for all morphometric traits in the studied duck populations are presented in Table 7. In the current work, the first principal component (PC1) was extracted from the factor analysis for each of the three duck populations without varimax rotation because PC1 explained maximum variation among the populations. The Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy was found to be 0.933, 0.938 and 0.942 for Semi-deciduous forest, Coastal savanna and Rain forest duck populations respectively, whereas the three agro-ecological zones pooled together had KMO measure of 0.946. The correlation matrices tested with Bartlett's test of sphericity for all morphometric traits were statistically significant (P< 0.0001) for all agro-ecological zones with chi-square of x^2 =1858.87; x^2 = 1883.30 and x^2 =1882.79 for Semi-deciduous forest, Coastal savanna and Rain forest duck populations respectively. The KMO measurement and the Bartlett's test of sphericity provided validity for the factor analysis of the data sets.

Table 7. Eigenvalue, Percentage of Total Variance, Un-rotated Components Loadings and Communalities of Morphometric Traits Observed in Indigenous Ghanaian Duck Populations

	SDF PCA		**CS PCA**		**RF PCA**		**Pooled PCA**	
Traits	**PC1**	**Comm.**	**PC1**	**Comm.**	**PC1**	**Comm.**	**PC1**	**Comm.**
BWT	0.970	0.940	0.961	0.924	0.971	0.942	0.965	0.931
BL	0.955	0.913	0.965	0.932	0.961	0.924	0.959	0.919
SL	0.807	0.651	0.792	0.627	0.833	0.695	0.795	0.632
NL	0.835	0.698	0.884	0.781	0.877	0.769	0.861	0.742
BLL	0.779	0.606	0.784	0.615	0.820	0.672	0.795	0.632
BLW	0.889	0.791	0.856	0.732	0.894	0.800	0.865	0.748
BC	0.908	0.824	0.913	0.834	0.919	0.845	0.908	0.825
WL	0.953	0.908	0.966	0.934	0.957	0.915	0.956	0.915
WS	0.956	0.913	0.971	0.943	0.950	0.902	0.954	0.910
Eigenvalue	7.244		7.321		7.464		7.253	
% Total variance	80.49		81.35		82.93		80.59	

SDF=Semi-deciduous forest; CS= Coastal savanna; RF= Rain forest; PCA=Principal component analysis; Comm.= Communalities; *BWT=Body weight; BL=Body length; SL=Shank length; NL=Neck length; BLL= Bill length; BLW=Bill width; BC= Breast circumference; WL=Wing length; WS= Wing span*

The PC1 accounted for 80.49%, 81.35% and 82.93% of the total variances for Semi-deciduous forest, Coastal savanna and Rain forest duck populations respectively with a corresponding eigenvalue of 7.244, 7.321 and 7.464. In Semi-deciduous ducks, PC1 had higher loading on body weight (0.970), wingspan (0.956), body length (0.955) and WL (0.953). A higher loading was identified on WS (0.971), WL (0.966), BL (0.965) and BWT (0.961) for Coastal savanna duck populations whereas in Rain forest ducks, PC1 had higher loadings on BWT (0.971), BL (0.961), WL (0.957) and WS (0.950). The principal component extracted from the pooled agro-ecological zones accounted for 80.59% of the total variance in the original variables measured with an eigenvalue of 7.253. The PC1 had higher loadings on body weight (0.965) followed by body length (0.959), wing length (0.956), wing span (0.954), breast circumference (0.905), bill width (0.865), neck length (0.861) whereas bill length and shank length shared a similar loading of 0.795. The present results imply that BW had the highest discriminatory power followed by BL, WL, WS, BC, BLW, NL, BLL and SL which agrees with Ogah (2013). This further suggests that body weight and body length are priority traits for discriminating duck populations. The results of the current work are comparable to Maharani et al. (2019), who used principal component analysis to determine the degree of discrimination in duck populations in India. However, Maharani et al. (2019) extracted two to four principal components. Their results revealed that PC1 accounted for 40.19%, 34.57%, 34.82%, 37.51% and 32.42% for Alabio, Magelang, Pegagan, Pitalah and Rambon duck populations with a corresponding eigenvalue of 3.125, 2.766, 2.786, 3.001 and 2.594, which are relatively lower than what was recorded in the present work. In the work of Maharani et al. (2019), PC1 had higher loadings on beak length (0.778), neck diameter (0.758) and foot width (0.797) for Alabio duck populations. The Magelang populations had PC1 recording higher loadings on beak width (0.776) and foot width (0783). Also, the duck populations from Pegagan recorded higher loadings on all traits measured for PC1. A higher loading was recorded on shank length (0.843) for PC1 in the Pitalah duck populations, whereas in the Rambon duck populations, a higher loading was observed on beak width (0.857) and foot width (0.860) for PC1. The present findings align with Mendes (2011), Udeh & Ugbu (2011) as well as Yakubu et al. (2009) who reported that PC1 has higher loadings on morpho-structural traits of poultry. The detected morphometric features loaded in the same principal component were clustered in the same group suggesting a similar genomic location for their heredity. It also infers a possible underlying biological relationship between the identified morphometric traits.

A medium to high communality (0.632 – 0.931) was also recorded for all traits in the present study, which is comparable to the findings of Egena et al. (2014) and Dahloum et al. (2016) who worked on chickens and Ogah (2011) on turkeys. The medium to high communalities observed in the current work for all the morphometric characters measured indicate that those traits could be used to explain the overall variability in body dimensions of ducks (Ogah, 2013; Mendes, 2011; Maharani et al., 2019). The consistency of the higher communalities observed for body weight, body length, wing span and wing length which ranged between 0.902 and 0.943 across the three duck populations in the present study shows that these traits could highly explain the diversity of morphological and morphometric dimensions of ducks in Ghana.

Conclusion

The present study revealed that sex had a significant ($p<0.05$) influence on all the morphometric traits measured, and drakes were significantly ($p<0.05$) superior to ducks in all the morphometric traits measured. Moreover, agro-ecological zone had a significant ($p<0.05$) influence on all morphometric traits except body length. The study further revealed a medium to high (0.593-0.945) positive correlation among morphometric traits with body length (0.894) as the best predictor of body weight; hence in the absence of a weighing scale, body length could be used to select birds with highest body weight with much accuracy. The discriminant analysis accurately classified 61.40% of ducks into their respective populations with cross-validation. The Mahalanobis distance showed a longer distance (2.27) between the semi-deciduous duck population and the rainforest duck population, and this was aided by a pictorial representation from a canonical plot. The distance between the two duck populations may suggest a distinction in the indigenous duck populations. The principal component analysis had a higher loading (0.965) on body weight, implying that body weight has the highest discriminatory power among the morphometric traits, hence, a significant trait for discriminating duck populations. Additional investigation could consider using an advanced characterization approach complemented by molecular genetic characterization to validate the identity of the indigenous duck populations in Ghana.

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Author contributions

Conceptualization: [Bismark Yeboah, Julius Kofi Hagan, Samuel Ayeh Ofori, Richard Asante Botwe]; *Methodology*: [Bismark Yeboah, Julius Kofi Hagan, Samuel Ayeh Ofori, Richard Asante Botwe]; *Formal analysis and investigation*: [Bismark Yeboah, Julius Kofi Hagan, Samuel Ayeh Ofori, Richard Asante Botwe]; *Writing - original draft preparation*: [Bismark Yeboah, Samuel Ayeh Ofori]; *Writing - review and editing*: [Bismark Yeboah, Julius Kofi Hagan, Samuel Ayeh Ofori, Richard Asante Botwe]; *Funding acquisition*: [Bismark Yeboah]; Resources: [Bismark Yeboah, Richard Asante Botwe]; *Supervision*: [Julius Kofi Hagan, Samuel Ayeh Ofori]

Data availability

The data could be made available by the authors upon a reasonable request.

Consent to participate

Not applicable.

Conflict of interest

The authors declare no conflict of interest.

Ethics approval

Not applicable.

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