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APPLICATION OF MULTIVARIATE STATISTICAL ANALYSIS IN CHARACTERISING THE PHENOTYPIC VARIABILITY OF LOCALLY ADAPTED MUSCOVY DUCKS (*CAIRINA MOSCHATA*) IN NIGERIA

Osamede Henry OSAIYUWU[1]*, Opeyemi Amos ADEYINKA[1], Oluwakayode Michael COKER[2], Marvellous Olu OYEBANJO[1], Mabel Omolara AKINYEMI[3]

[1]Animal Breeding and Genetics Unit, Department of Animal Science, University of Ibadan, Ibadan, Nigeria
[2]Department of Wildlife and Ecotourism Management, University of Ibadan, Ibadan, Nigeria
[3]Department of Biological Sciences, Fairleigh Dickinson University, Madison, NJ 07940, USA

ABSTRACT

While there are studies that describe the biometric traits and phenotypic variations in Muscovy ducks in Nigeria, there are limited studies that employ a multivariate approach to depict the phenotypic variability of Muscovy ducks in Nigeria. Therefore, this study aimed to explicate genetic variabilities within *C. moschata* using qualitative and biometric traits. This study used a multivariate statistical method to phenotypically characterise locally adapted Muscovy duck populations from seven ecogeographical locations in Ibadan, Nigeria. Four qualitative traits (eye colour, bill colour, bean colour and shank colour) and eleven biometric traits (head length, neck length, body length, wings length, shank length, toe length, thigh length, bill length, breast length, breast width and bodyweight) were evaluated in 201 ducks (109 males and 92 females). To study the possible effects of geographical locations on selected phenotypes, frequency distribution, univariate analysis, stepwise and canonical discriminant analyses and cluster analysis were performed. The association between body weight (BWT) and other biometric traits was assessed using the Pearson product-moment correlation coefficient. Male ducks (drakes) were generally more abundant than female ducks (hens). The most prevalent colour traits of locally adapted Muscovy ducks were brown eye colour (70.65 %), black bean colour (62.69 %), pinkish white bill colour (45.27 %) and grey shank colour (56.22 %). Overall, ecogeographical location did not significantly affect ($p < 0.05$) the measured biometric traits. However, across all locations, the sexual dimorphism was favourable in male ducks, with respect to biometric traits. Stepwise-canonical discriminant analysis revealed a substantial intermixing of biometric traits, especially in Molete, Oje, Adogba and Ajibode ducks. Similarly, the cluster analysis, although it separated the birds into different clusters, showed some level of admixture. The small Mahalanobis distance (0.61 − 3.88) suggested that, with respect to location, there was more morphological similarity than dissimilarity between ducks. The correlation analysis revealed that the body weight of ducks can be fairly estimated from other biometric traits due to their positive, statistically significant correlation. In general, the ducks from all seven ecogeographical locations were rather homogeneous than heterogeneous.

Key words: drakes; phenotype; biometry; cluster analysis; discriminant analysis

INTRODUCTION

Poultry production is a valuable source of income for small-scale and rural farming communities and a vital source of animal protein (Mushi *et al*., 2020). In Nigeria, the livestock sector, especially the poultry industry, is densely populated with indigenous breeds, which serve as a large source of domestically generated animal protein (Oguntunji, 2017). Most of the duck breeds reared in Nigeria are raised under extensive farming systems. The breeding method used to create progenitors is largely unstandardised and

*Correspondence: E-mail: cosamede@yahoo.com
Osamede Henry Osaiyuwu, Department of Animal Science, University of Ibadan, Nigeria, 200284
Tel.: +2348064666076

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unconventional thus creating a population of ducks, whose genetic potential is left untapped.

Muscovy ducks (*Cairina moschata*) are the most popular duck breed found in Nigeria. Around the world, the meat of *C. moschata* is characterised by its minimal calorie composition, weighty breast meat, and flavour. Male ducks (drakes) grow faster and can attain a maximum weight of 4.5 – 5.5 kg, while female ducks (hens) have a much lower maximum weight of 2.3 – 2.8 kg (Sonaiya and Swan, 2004). This observed weight difference in both sexes suggests that there is sexual dimorphism in ducks (Rodenburg *et al*., 2005; Oguntunji and Ayorinde, 2014).

While there are many breeds of ducks found in Nigeria, it is generally believed that today's locally adapted Muscovy ducks are the offspring of ducks native to South American countries, such as Brazil, Mexico and Uruguay (Smith, 2022). It is generally agreed that Muscovy ducks were introduced to Nigeria after colonization (Arias-Sosa and Rojas, 2021). In Nigeria, Muscovy ducks are mainly found in the riverine regions of Southern Nigeria (Yakubu, 2013). Muscovy ducks are reared in rural farming communities, because they are a source of meat, are resistant to most poultry diseases and the breed is relatively easier to rear than chickens (Ramos, 2009; Salgado-Ubeda and López-Mendonza, 2012). The Muscovy duck eggs are rarely consumed or traded by farmers; instead, they are primarily used for breeding purposes. These ducks are excellent mothers and can lay an average of 60 to 80 eggs annually under scavenging conditions (Ikani, 2003). Unfortunately, their existence is threatened by misguided cultural beliefs that portray ducks as mysterious birds that do not require significant management attention. Similarly, the Khaki Campbell breed, predominantly found in research farms, is the second most popular duck breed in Nigeria. Although they are not highly valued for their meat, they have the potential to lay up to 300 eggs per year if they are adequately housed (Ikani, 2003).

It is well documented that any genetic improvement endeavour for livestock species must first evaluate the level of genetic diversity within the target population (Dobrzanski *et al*., 2019). Although *C. moschata* is a well-known duck breed and its economic importance is evidently demonstrated in rural communities, its phenotypic and genetic characterisation in the tropics is poor. This poor characterisation impedes the development of selection and breeding strategies. Consequently, actionable and sustainable solutions are needed – with an emphasis on meat and egg production – to properly characterise locally adapted Muscovy ducks in the tropics, especially in Nigeria. The Food and Agriculture Organisation (FAO) had itemised the steps needed in the proper characterisation of livestock (FAO, 2012). The first step involves using morphological or phenotypic characteristics – whether quantitative or qualitative – as indicators of animal genetic resources. Similarly, tolerance or vulnerability of poultry species to stressful environmental conditions could be associated with their phenotypic traits (Panyako *et al*., 2016; Kowalski, 2019; Sztandarski *et al*., 2021). Therefore, it is imperative to elucidate the phenotypic diversity that will be inherent in Muscovy ducks that have been adapted to specific local environments, as the information could prove useful for genetic improvement programmes.

In rural farming communities, where scientific expertise and tools are scarce, phenotypic diversity is best captured using biometrical traits (Shi *et al*., 2020). Furthermore, characterisation of birds using morpho-biometric features and measurements facilitates the selection of highly producing birds for breeding, as well as the conservation of indigenous animal genetic resources (Habimana *et al*., 2020; Sheriff *et al*., 2021). Nonquantifiable traits, such as eye, shank, bill and bean colours, are of importance in the physical appraisal of Muscovy ducks, to select which birds meet consumer likings for designated phenotypic traits. Also, animal breeders can develop breeding programmes to select birds with desirable nonquantifiable traits. However, biometric parameters, such as body weight, head length, breast length and toe length are important in the genetic improvement of indigenous breeds, to produce birds that meet consumer desires, for higher body weight and short maturity time (Brito *et al*. 2021). Multivariate analyses, combining biometrical traits, have been reported to better evaluate variance within individual populations, proving that it can be used in discriminant analyses of various populations (Traore *et al*., 2018; Yakubu and Ari, 2018).

While there are studies that describe the biometric traits and phenotypic variations in Muscovy ducks in Nigeria, there are limited studies that employ a multivariate approach to depict the phenotypic variability of Muscovy ducks in Nigeria. Therefore, this study aimed to explicate genetic variabilities within *C. moschata* using qualitative and biometric traits. The following hypothesis was tested:

Null Hypothesis (H0): There will be no significant phenotypic variations in locally adapted Muscovy duck populations from seven ecogeographical locations in Ibadan, Nigeria, as revealed by the multivariate analysis of qualitative and biometric traits. Additionally, geographical location will not have a significant impact on the measured biometric traits, and the ducks will exhibit a similar degree of morphological similarity across locations.

Alternate Hypothesis (H1): There will be significant phenotypic variations in locally adapted Muscovy duck populations from seven ecogeographical locations in Ibadan, Nigeria, as revealed by the multivariate analysis of qualitative and biometric traits. Additionally, we hypothesize that geographical location will have a minimal impact on the measured biometric traits, with the ducks showing a higher degree of morphological similarity than dissimilarity across locations.

The results of this study will provide useful information for the creation of sustainable breeding programmes and developing a sustainable use and conservation strategy aimed at developing highly producing Muscovy ducks in Nigeria; consequently, increasing the food security index of the nation and source of income for small-scale farmers.

MATERIAL AND METHODS

Study area and sampling size

Body measurements were recorded from adult ducks. In total, 201 birds (109 males and 92 females) were randomly sampled from locally adapted Muscovy ducks from the flocks of small farmers in the communities of Adogba, Ajibode, Apete, Egbeda, Molete, Oje and Sasa in Oyo state, Nigeria.

To effectively obtain representative samples for the analysis, the multistage cluster sampling method was used in the selection of the sampling locations. Sampling sites were selected on the basis of prior information about the availability of Muscovy ducks. Samples were collected from seven different locations: 26 samples from Adogba; 25 – from Ajibode; 11 – from Apete; 22 – from Egbeda; 49 – from Molete; 39 – from Oje; and 30 – from Sasa.

Data collection

Morphological variables and distinction were arranged according to Teguia *et al*. (2008) and Yakubu (2009). Each sex was identified by the appearance of a vent. Four qualitative traits (eye colour, bill colour, bean colour and shank colour) and 11 biometric traits were recorded for the qualitative and quantitative description of the birds. The presence or absence of a crest was also observed. The following anatomical points were used:

Head length (HL) – Measurements (in centimetres) were taken between the lacrimal bone and the most prominent point of the occipital bone;

Neck length (NL) – Considered as the length (in centimetres) between the cephalic margins of the coracoids and the occipital condyle;

Body length (BDL) – the distance (in centimetres) between the atlas and the posterior end of the ischium;

Wing length (WL) – Distance (in centimetres) between the terminal ends of the phalanx (digit III) and the starting point of the humerus (shoulder joint);

Shank length (SL) – distance (in centimetres) between the hock joint and the foot pad;

Toe length (TL) – the distance (in centimetres) between the tip of the claw or toe nail and the longest toe;

Thigh length (THL) – Measured as the distance (in centimetres) between the pelvic joint and the hock joint;

Bill length (BL) – Measured as the length (in centimetres) of the bill tip to the bill base;

Breast length (BRL) – measured as the length (in centimetres) area of the breastbone;

Breast width (BRW) – Measured as the distance (in centimetres) between both lateral caudal processes on opposite ends of the body;

Body weight (BW) – the live weight of a Muscovy duck measured in kilogrammes (kg).

The lengths and widths were measured using a graduated flexible tape, while the body weight was determined using a weighing scale that impacted no pain or discomfort on the birds.

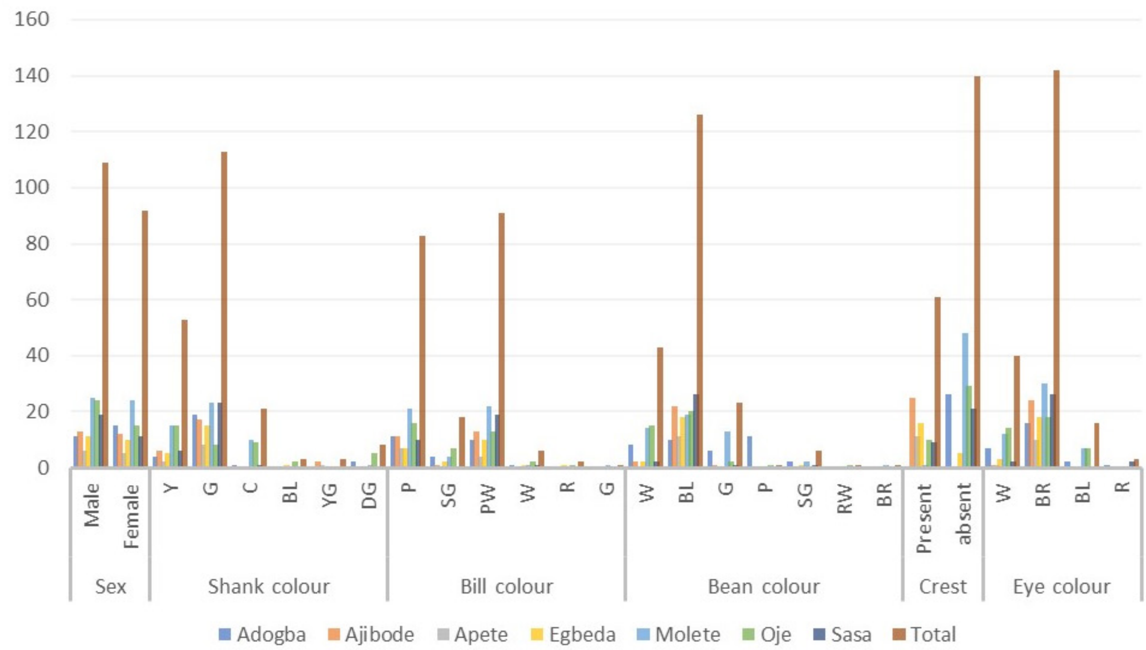
Statistical analysis

Descriptive statistics for each biometric trait was done by the PROC MEANS procedure of SAS 9.4 (2002), while PROC FREQ was used to compute the frequencies for sex and qualitative traits. The GLM procedure of the same software was used to estimate the fixed effect of geographical locations on male and female ducks and both sexes. The separation of means was carried out using the Turkey test. PROC CORR was used to evaluate the degree of association among the biometric traits studied. Discriminant analyses (stepwise and canonical) and cluster analysis were used for multivariate evaluation in this study were. To determine which of the biometric variables had the most discriminating power, the stepwise discriminant statistical procedure (PROC STEPDISC) was used. The comparative importance of biometric variables in separating birds in each geographical location was analysed using Wilk's lambda, F value and partial R2. Canonical discriminant analysis (using PROC CANDISC) was performed to estimate the Mahalanobis distance among the different geographical locations of the ducks. Cluster analysis was performed to examine the level of biometrical similarity or divergence among ducks in different locations using the PROC CLUSTER command. For cluster analysis, Ward's method with the MACRO SHOW option was used to initiate the FREQ procedure, thus displaying a cross-tabulated result of the clusters and locations.

RESULTS

Frequency distribution of qualitative traits, sex and crest

The frequency distribution, which encapsulates the colour variation in locally adapted Muscovy ducks, is shown in Figure 1. There was no observable pattern of variation in each class of qualitative traits among the seven geographical locations. In Oyo State, Nigeria, the most frequent colour phenotypes of locally adapted Muscovy ducks were grey shank colour (56.22 %), pinkish white bill colour (45.27 %), black bean colour (62.69 %) and brown eye colour (70.65 %). Similarly, male (54.22 %) was the most common sex. The absence of the crest (69.65 %) was also frequent.



Y: Yellow; G: Grey; C: Cream; BL: Black, YG: Yellowish grey; DG: Dark grey; P: Pink; SG: Slate grey; PW: Pinkish white; W: White; R: Red; BR: Brown; and RW: Reddish white

Figure 1. Frequency distribution of colour traits, crest and sex of locally adapted Muscovy ducks based on geographical location

The fixed effect of geographical location on biometric traits of ducks (male, female and both)

The effect of geographical location on the biometric traits of male ducks is presented in Table 1, while the results for female ducks and both sexes combined are shown in Tables 2 and 3, respectively. Overall, there were little or no significant difference ($p < 0.05$) in the biometric traits of ducks reared in different locations.

Spatial representation of duck biometric data

Based on Wilk's lambda (0.5888 – 0.8768), F-value (2.06 – 4.54) and the partial R^2 (0.0612 – 0.1232), neck length, head length, body weight, wing length and toe length were the most important parameters or discriminant variables required for duck separation in the seven geographical locations (Table 4). Furthermore, these variables were useful in calculating the Mahalanobis distance between the ducks that exist in different

Table 1. Effect of geographical location on biometric traits of drakes (male ducks)

	Locations						
Traits	Adogba	Ajibode	Apete	Egbeda	Molete	Oje	Sasa
HL (cm)	6.246^{ab}	5.969^{ab}	5.683^{ab}	5.963^{ab}	5.984^{ab}	6.504^{a}	5.521^{b}
NL (cm)	5.691^{b}	6.739^{ab}	6.700^{ab}	7.227^{a}	6.284^{ab}	6.550^{ab}	6.947^{a}
BDL (cm)	31.700^{ab}	33.100^{ab}	34.533^{a}	34.491^{a}	30.516^{b}	32.708^{ab}	32.095^{ab}
WL (cm)	12.355^{a}	13.169^{a}	13.533^{a}	12.734^{a}	12.500^{a}	12.242^{a}	13.574^{a}
SL (cm)	11.436^{a}	6.692^{ab}	5.583^{a}	7.745^{ab}	6.964^{ab}	6.954^{ab}	6.884^{ab}
TL (cm)	7.655^{a}	7.436^{a}	7.517^{a}	8.346^{a}	8.224^{a}	8.329^{a}	7.505^{a}
THL (cm)	7.918^{b}	8.785^{ab}	9.500^{a}	8.491^{ab}	8.104^{b}	8.650^{ab}	8.778^{ab}
BL (cm)	5.345^{a}	6.023^{a}	6.583^{a}	5.891^{a}	5.836^{a}	7.663^{a}	6.272^{a}
BRL (cm)	10.018^{ab}	9.954^{ab}	11.283^{a}	11.055^{a}	9.188^{b}	10.438^{ab}	9.853^{ab}
BRW (cm)	5.700^{a}	6.639^{ab}	7.433^{a}	6.655^{ab}	5.780^{b}	5.917^{b}	6.890^{a}
BW (kg)	2.176^{c}	2.639^{ab}	2.867^{a}	2.670^{a}	2.197^{c}	2.588^{bc}	2.420^{abc}

^{abc} Means within the same row for different location having different superscripts are significantly different ($p < 0.05$). Means with the same superscript are not significantly different from each other. HL: Head length; NL: Neck length; BDL: Body length; WL: Wing length; SL: Shank length; TL: Toe length; THL: Thigh length; BL: Bill length; BRL: Breast length; BRW: Breast width; and BW: Body weight.

Table 2. Effect of geographical location on biometric traits of hens (female ducks)

	Locations						
Traits	Adogba	Ajibode	Apete	Egbeda	Molete	Oje	Sasa
HL (cm)	5.533^{a}	5.575^{a}	5.240^{a}	5.520^{a}	5.588^{a}	5.293^{a}	4.782^{a}
NL (cm)	4.533^{c}	5.392^{abc}	5.740^{ab}	5.800^{a}	5.163^{abc}	4.780^{bc}	5.964^{a}
BDL (cm)	25.627^{a}	28.700^{a}	28.180^{a}	27.630^{a}	28.667^{a}	27.547^{a}	28.982^{a}
WL (cm)	10.713^{a}	11.650^{a}	11.280^{a}	11.200^{a}	10.871^{a}	11.360^{a}	11.636^{a}
SL (cm)	5.567^{a}	6.083^{a}	6.300^{a}	6.320^{a}	5.829^{a}	5.887^{a}	5.946^{a}
TL (cm)	6.933^{a}	6.858^{a}	7.500^{a}	7.410^{a}	7.025^{a}	7.153^{a}	7.236^{a}
THL (cm)	6.673^{b}	7.200^{ab}	7.260^{ab}	7.710^{a}	7.104^{ab}	6.947^{ab}	7.336^{ab}
BL (cm)	4.953^{a}	5.467^{a}	5.320^{a}	5.090^{a}	5.075^{a}	5.153^{a}	5.318^{a}
BRL (cm)	8.787^{a}	8.517^{a}	8.240^{a}	8.270^{a}	9.167^{a}	9.093^{a}	8.236^{a}
BRW (cm)	4.760^{a}	5.192^{a}	4.800^{a}	5.450^{a}	5.117^{a}	5.200^{a}	5.218^{a}
BW (kg)	1.437^{b}	1.536^{ab}	1.354^{b}	1.362^{b}	1.621^{ab}	1.900^{a}	1.336^{b}

^{abc} Means within the same row for different location having different superscripts are significantly different ($p < 0.05$). Means with the same superscript are not significantly different from each other. HL: Head length; NL: Neck length; BDL: Body length; WL: Wing length; SL: Shank length; TL: Toe length; THL: Thigh length; BL: Bill length; BRL: Breast length; BRW: Breast width; and BW: Body weight.

locations (Table 5). It is noteworthy that there was substantial spatial amalgamation of biometric traits among birds in Molete, Oje, Adogba and Ajibode (Figure 2).

Mahalanobis distance

The distance presented in Table 5 is the Mahalanobis distance between the ducks reared at different geographical

Table 3. Effect of geographical location on biometric traits of ducks irrespective of sex

Traits	Locations						
	Adogba	Ajibode	Apete	Egbeda	Molete	Oje	Sasa
HL (cm)	5.835^{ab}	5.780^{ab}	5.482^{ab}	5.738^{ab}	5.790^{ab}	6.039^{a}	5.250^{b}
NL (cm)	5.023c	6.092^{ab}	6.264^{ab}	6.548^{ab}	5.735^{bc}	5.869^{ab}	6.587^{a}
BDL (cm)	28.196^{b}	30.988^{a}	31.645^{a}	31.224^{a}	29.610^{ab}	30.723^{ab}	30.953^{a}
WL (cm)	11.408^{b}	12.440^{ab}	12.509^{ab}	12.019^{ab}	11.702^{b}	11.903^{ab}	12.863^{a}
SL (cm)	8.050^{a}	6.400^{a}	5.909^{a}	7.067^{a}	6.408^{a}	6.544^{a}	6.540^{a}
TL (cm)	7.239^{a}	7.168^{a}	7.509^{a}	7.900^{a}	7.637^{a}	7.877^{a}	7.407^{a}
THL (cm)	7.200^{b}	8.024^{ab}	8.482^{a}	8.119^{a}	7.614^{ab}	7.995^{ab}	8.231^{a}
BL (cm)	5.119^{a}	5.765^{a}	6.009^{a}	5.510^{a}	5.463^{bc}	6.700^{a}	5.910^{a}
BRL (cm)	9.308^{a}	9.264^{a}	9.900^{a}	9.729^{a}	9.178^{a}	9.921^{a}	9.260^{a}
BRW (cm)	5.158^{c}	5.994^{ab}	6.236^{a}	6.081^{ab}	5.455^{bc}	5.641^{abc}	6.277^{a}
BW (kg)	1.750^{b}	2.109^{ab}	2.179^{ab}	2.047^{ab}	1.915^{ab}	2.323^{a}	2.022^{ab}

^{abc} Means within the same row for different location having different superscripts are significantly different ($p < 0.05$). Means with the same superscript are not significantly different from each other. HL: Head length; NL: Neck length; BDL: Body length; WL: Wing length; SL: Shank length; TL: Toe length; THL: Thigh length; BL: Bill length; BRL: Breast length; BRW: Breast width; and BW: Body weight.

Table 4. Summary of stepwise selection*

Traits	Partial R^2	F-Value	Pr > F	Wilks' Lambda	Pr < Lambda
Neck length	0.123	4.540	0.0002	0.8768	0.0002
Head length	0.153	5.790	<.0001	0.7430	<.0001
Body weight	0.083	2.900	0.0099	0.6812	<.0001
Wing length	0.079	2.740	0.0140	0.6272	<.0001
Toe length	0.061	2.060	0.0593	0.5888	<.0001

*Note that only significant discriminant variables from the PROC STEPDISC analysis and variables with partial R^2 values ≥ 0.01 were used in the final discriminant model.

Table 5. Mahalanobis distance among locally adapted Muscovy ducks in different locations

Traits	Adogba	Ajibode	Apete	Egbeda	Molete	Oje	Sasa
Adogba	0	1.29*	1.96*	2.12**	0.47	0.99*	3.88***
Ajibode		0	0.34	0.97	0.71	1.38**	1.14*
Apete			0	0.61	0.83	1.43	0.61
Egbeda				0	0.61	1.57**	1.17
Molete					0	0.62	2.20***
Oje						0	3.80**
Sasa							0

*Note: *$p < 0.01$, **$p < 0.001$, and ***$p < 0.0001$.

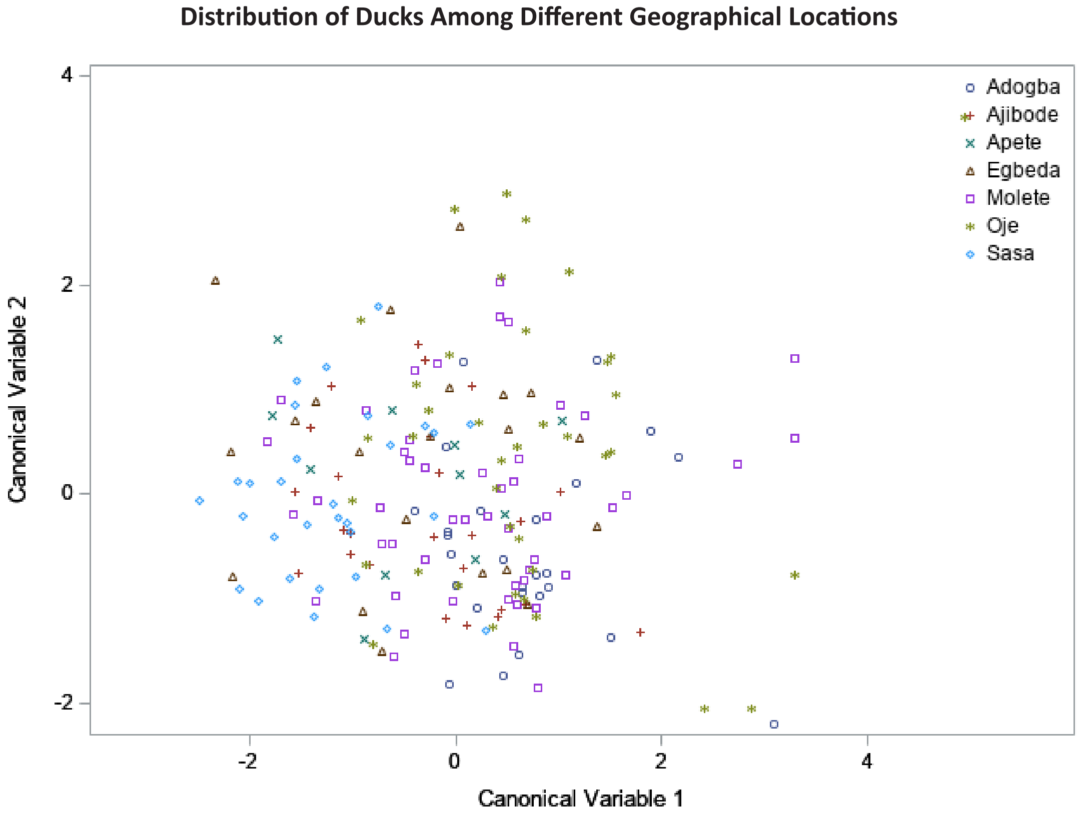


Figure 2. Canonical discriminant variables illustrating the distribution of Muscovy ducks among different geographical locations

locations. The squared distance between Sasa and Adogba was significantly higher ($p < 0.0001$) than other locations, followed by the squared distance between Sasa and Oje ($p < 0.001$) and the squared distance between Sasa and Molete ($p < 0.0001$). Overall, there was a more significant difference ($p < 0.01, 0.001, 0.0001$) in the squared distance between Sasa and other locations, followed by Oje.

Cluster Analysis

The cluster analysis produced three clusters (Figure 3), showing that the ducks at each location belonged to distinct ecogeographical populations. However, these populations share similarities.

Correlation coefficients among biometric traits of ducks

The correlation coefficients between body weight and body measurements of locally adapted male and female Muscovy ducks are presented in Table 6. The correlation coefficients for the measured biometric traits were mostly significant positive ($p < 0.05, 0.01$ and 0.001). The highest significant correlation coefficient ($p < 0.001$; 0.74) was for female ducks between body weight and body length. Similarly, for male ducks, body weight and body length had the highest statistically significant correlation coefficient ($p < 0.001$; 0.54).

DISCUSSION

Without a proper understanding of the existing phenotypic variations in a specific local livestock population, it will be impossible to holistically capture animal genetic resources; consequently, impeding future attempts at genetic improvement geared towards conservation and sustainable breeding (Sztandarski *et al.*, 2021). The biometric characterisation of livestock is an effective indicator of phenotypic variability within a population. Furthermore, biometrical characterisation could be useful in poultry management.

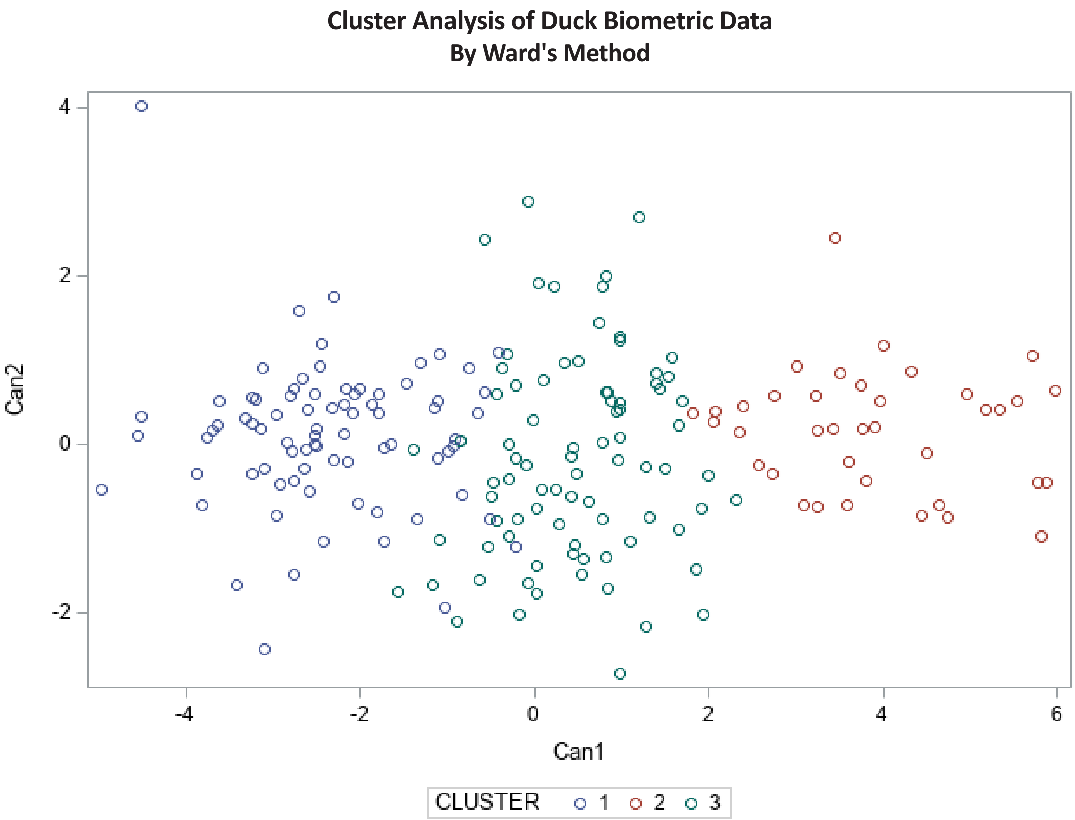


Figure 3. Differentiation of ducks in different locations based on biometric data using cluster analysis

The prevalence of male ducks (drake) in this study could be explained by the *modus operandi* of small-scale duck farmers: male birds are usually preferred over females because they grow faster and, therefore, sold to generate income. It was observed that the absence of the crest (69.65 %) was greater than the presence of the crest (30.35 %). Kadurumba *et al*. (2021), on the other hand, reported 100 % crest absence in Muscovy ducks sampled from South-East Nigeria. The predominant brown eye colour (70.65 %) of ducks within Oyo ecogeographical locations is similar to those of the lowland region of the rainforest agro-ecological zone in south-east Nigeria (Kadurumba *et al*., 2015, 2021) and those of Cambodia (FAO, 2009). The predominant grey shank colour (56.22 %) in this study is corroborated by the reports of Chia and Momoh (2012) and Kadurumba *et al*. (2021). However, contrary to the results of this study, Oguntunji and Ayorinde (2015) reported the slate, black, ash and yellow shank colours, with yellow being widespread, for Muscovy ducks in western Nigeria. Pink-white was observed as the ubiquitous bill colour in this study, which is consistent with the findings of Hassan and Mohammed (2003) and Kadurumba *et al*. (2021). On the other hand, Chia and Momoh (2012) reported that black-yellow is the popular bill colour for ducks in north-central Nigeria. Similarly, Oguntunji and Ayorinde (2015) found that black was the predominant bill colour in the southern part of Nigeria. Black bean colour was predominant in this study and was corroborated by the reports of FAO (2009). However, Kadurumba *et al*. (2021) reported an absence of pigmentation; that is, white as the predominant bean colour. Furthermore, white, brown and red bean colours were noted for their non-appearance among Muscovy ducks in western Nigeria, according to Oguntunji and Ayorinde (2015). A plausible explanation for this variation in colour traits could be sampling coverage. However, a maxim in evolutionary biology is that polymorphism of qualitative traits, such as colour, within the same species could surprisingly cause discernible phenotypic variations (Brock *et al*., 2020). Therefore, the observed variation in colour traits could be attributed to polymorphism (Birteeb and Boakye, 2020), which could have evolved in locally adapted Muscovy ducks as an adaptive mechanism. Furthermore, it is necessary for livestock reared in the tropics to develop resistance to undesirable climatic elements while maintaining production performance (Getachew *et al*., 2021).

Body weights (BWT) observed in this study (2.17 − 2.87 kg for drakes and 1.33 − 1.90 kg for hens) were higher than those reported by Kadurumba *et al*. (2021) for the agroecological zone of the South-East of Nigeria. However, they were within the range reported by Yakubu (2011, 2013). The difference in BWT values could be explained by age, geographical location, management system, health status and physiological state of the birds. Univariate analysis showed that there were little to no significant differences in biometric traits among ducks reared at different locations. Therefore, it can be expected that these geographical locations may not play a role in the evolutionary history or adaptation of Muscovy ducks. Furthermore, the univariate analysis affirmed the sexual dimorphism observed in locally adapted Muscovy ducks, with drakes having higher values for biometric traits than hens. The sexual dimorphism observed in this study corroborates the reports of Teguia *et al*. (2007), Yakubu (2011) and Oguntunji and Ayorinde (2014). The sexual dimorphism observed in this study is emblematic of the various natural and sexual selection pressures experienced by male and female birds. Evidently, in this study, for most biometric traits, sexual dimorphism favoured male ducks. Therefore, this result agrees with the scientific literary consensus that in birds, males are known to have larger body sizes than females (Ganbold *et al*., 2019). This difference in body weight and measurements could be due to the male ducks having a higher feed conversion efficiency than their female counterparts. The ducks used in this study are presumably not the result of any selective breeding programme; consequently, the high rate of indiscriminate breeding in the different populations sampled could also explain the presence of sexual dimorphism in biometric traits (Morales *et al*., 2020). Furthermore, the phenotypic variations, observed in the biometric traits recorded, suggest a corollary genetic variation, which could induce a positive selection response when such traits are selected. Similarly, this observed variation between male and female ducks for sexually dimorphic traits means that different selection strategies should be used for each sex during breeding.

Table 6. Correlation matrices of biometric traits in female and male ducks

	HL (cm)	NL (cm)	BDL (cm)	WL (cm)	SL (cm)	TL (cm)	THL (cm)	BL (cm)	BRL (cm)	BRW (cm)	BW (kg)
HL (cm)		0.1719^{ns}	0.0975^{ns}	0.0613^{ns}	0.2716**	0.2385*	0.0921^{ns}	0.3777***	0.2450*	0.1811^{ns}	0.3075***
NL (cm)	0.3855***		0.4276***	0.4611^{ns}	0.4186^{ns}	0.4141***	0.4110^{ns}	0.4650***	0.2314*	0.4433***	0.2777**
BDL (cm)	0.4638***	0.5962***		0.4230^{ns}	0.4041^{ns}	0.0802^{ns}	0.2432*	0.3464***	0.4530***	0.3538***	0.5361***
WL (cm)	0.3954***	0.4992***	0.3897***		0.4766^{ns}	0.3757^{ns}	0.3549***	0.5093^{ns}	0.4074^{ns}	0.4839^{ns}	0.5139^{ns}
SL (cm)	0.0763ns	-0.0160^{ns}	0.0704^{ns}	-0.0077^{ns}		0.3811^{ns}	0.2521*	0.4581^{ns}	0.5276^{ns}	0.3370***	0.5855^{ns}
TL (cm)	0.4905***	0.3790***	0.3057***	0.3234***	-0.2931***		0.2494*	0.4023^{ns}	0.1354^{ns}	0.2393*	0.3498***
THL (cm)	0.4908^{ns}	0.5381^{ns}	0.4576^{ns}	0.5660^{ns}	-0.0536^{ns}	0.3351^{ns}		0.3917^{ns}	0.1968^{ns}	0.2171*	0.3202**
BL (cm)	-0.1506^{ns}	0.0001^{ns}	0.1004^{ns}	-0.0552^{ns}	-0.0137^{ns}	-0.0406^{ns}	-0.1217^{ns}		0.3921^{ns}	0.3883^{ns}	0.4924^{ns}
BRL (cm)	0.4183***	0.4000***	0.5445***	0.2321*	0.1031^{ns}	0.1743^{ns}	0.3896***	-0.0112^{ns}		0.3302***	0.6986^{ns}
BRW (cm)	0.2431**	0.4394***	0.3703***	0.3997***	-0.0256^{ns}	0.1006^{ns}	0.3794***	-0.0372^{ns}	0.4474***		0.4015^{ns}
BW (kg)	0.4246***	0.6444***	0.7387***	0.4610***	0.0402^{ns}	0.3093***	0.3592***	0.1528^{ns}	0.6240***	0.3711***	

Note: $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$. female ducks upper diagonal and male ducks lower diagonal.
HL: Head length; N: Neck length; BDL: Body length; WL: Wing length; SL: Shank length; TL: Toe length; THL: Thigh length; BL: Bill length; BRL: Breast length; BRW: Breast width; and BW: Body weight.

Although the univariate analysis indicated differences in biometric traits of male and female ducks from different locations, the multivariate analyses provided information on which trait is most useful for differentiating the birds. Five out of all the variables in the data set were found to have potential discriminatory power. These variables were used to develop discrimination models in both the CANDISC and CLUSTER procedures. Clustering or cluster analysis is a type of unsupervised learning technique used to find commonalities between data elements that are otherwise unlabelled and uncategorized. The goal of clustering is to find distinct groups or "clusters" within a data set. The cluster analysis indicated that all seven locations can be arranged into three groups. This further supports the results that the populations were not very distinct one from another. The variables that were found to have discriminatory power were body weight, neck length, wing length, head length and toe length, with neck length having the highest power. The results obtained here are similar to those of Yakubu (2011). The low Mahalanobis distance (0.61 – 3.88) obtained for ducks from different geographical locations suggests that there was a high degree of morphological similarities among ducks from different locations. Thus, the ducks used in this study are not genetically distinct breeds. Furthermore, the canonical distribution (Figure 2) shows intermixing among ducks from several locations, demonstrating an innate relationship among duck populations and that they are of the same breed. Similarly, the cluster analysis, although it successfully segregated the duck populations using their biometric traits, showed intermingling among the populations. Therefore, the Muscovy ducks in Ibadan (Nigeria) are largely unselected. The observed intermixing was considerably higher among ducks in Molete, Oje, Adogba, and Ajibode, and this intermixing could be due to unintentional human action. For instance, when duck farmers migrate to new locations, they take long for their flocks to resettle. This migration could result in exchange or mating of birds between existing members of the new location and new settlers. Another explanation for the intermixing is that household duck farmers purchase ducks to repopulate their flock from another location or neighbouring duck markets. Additionally, the loss of biodiversity in one location could be the result of market undercurrents in another location (Benton *et al*., 2021). The mobility of duck owners and their flock could have substantial effects on genetic erosion and dictate the distribution pattern of the duck population.

The phenotypic correlation coefficients (*r*) among the biometric traits are shown in Table 6. For male ducks, *r* was in the range of -0.29 – 0.74, with the highest statistically significant ($p < 0.001$; 0.74) value recorded for the association between BWT and body length (BDL). On the other hand, for female ducks, *r* ranged between 0.06 and 0.70. Similarly, to its male counterpart, the association between BWT and BDL had the highest significant *r* value ($p < 0.001$; 0.54) for female ducks. Additionally, the varying *r* values obtained for male and female ducks are indicative of the different genetic structure that exists in both sexes. The correlation coefficients obtained in this study are similar to those in the reports of Yakubu (2011) and Kadurumba *et al*. (2021). The positive and statistically significant correlation coefficients between some biometric traits suggest that they are controlled by the same gene (Ogah and Kabir, 2013). Furthermore, this association implies that the body weight of ducks can be estimated using body measurements that are highly correlated with it.

A holistic look at the statistical algorithms used in this study shows, that Muscovy ducks from different eco-geographical locations in Ibadan, Nigeria, are rather similar than different, with respect to the biometric traits studied. Consequently, Muscovy ducks in these locations could be useful in the development of purebreds or crossbreeding programmes.

CONCLUSION

Although the frequency distribution indicated a difference in qualitative traits among the locations, there is no discernible pattern across all locations. For all biometric traits, univariate analyses revealed no significant differences in measured traits, implying that geography had no influence on bird adaptation. However, sexual dimorphism was observed between male and female ducks, with males being superior for all biometric traits. Canonical discriminant and cluster analyses showed intermixing among the ducks from different locations. Lastly, it can be inferred that the Muscovy ducks from studied ecogeographical locations belonged to an indigenous population and possessed a low amount of phenotypic diversity.

AUTHOR'S CONTRIBUTIONS

Conceptualization: Osaiyuwu, O. H., Akinyemi, M. O.

Methodology: Osaiyuwu, O. H, Adeyinka, O. A., Coker, O. M., Oyebanjo, M. O., Akinyemi, M. O.

Investigation: Adeyinka, O. A., Oyebanjo, M. O.

Data curation: Osaiyuwu, O. H., Adeyinka, O. A., Oyebanjo, M. O.

Writing-original draft preparation: Osaiyuwu, O. H., Oyebanjo, M. O.

Writing-review and editing: Osaiyuwu, O. H., Adeyinka, O. A., Coker, O. M., Oyebanjo, M. O., Akinyemi, M. O.

Project administration: Osaiyuwu, O. H., Adeyinka, O. A., Coker, O. M., Oyebanjo, M. O., Akinyemi, M. O.

All authors have read and agreed to the published version of the manuscript.

DATA AVAILABILITY STATEMENT

The data presented in this study are available on request from the corresponding author.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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