UNIVERSITY OF CAPE COAST

CHARACTERISATION OF MORPHOLOGICAL TRAITS OF INDIGENOUS DUCK POPULATIONS IN THREE AGRO-ECOLOGICAL ZONES OF GHANA

BISMARK YEBOAH

2022

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BY

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Thesis submitted to the Department of Animal Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Master of Philosophy degree in Animal Science (Genetics and Animal Breeding).

OCTOBER, 2023

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ………………………………… Date……………

Name: Bismark Yeboah

Supervisors' Declaration

I hereby declare that the preparation and presentation of the thesis was supervised following the guidelines on supervision of thesis laid down by the University of Cape Coast.

Supervisor's Signature ……………………….. Date …………………

Name: Prof. Julius Kofi Hagan

ABSTRACT

The study characterised the indigenous duck populations in three agro-ecological zones of Ghana using a primary characterisation approach involving observation and direct body measurement. Qualitative and quantitative trait data were randomly collected on 414 mature ducks, whereas data on demographic information of duck keepers were taken using a semi-structured questionnaire. The results indicated a variation in qualitative traits with plumage colour recording variants of Black and white (41.30%), Black (31.90%) and white (26.80%). The bill, bean, caruncle, shank, web, skin and eye also saw colour variations. It was observed that ducks across all agro-ecological zones laid eggs with cream shell colour. 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 (2.266) between the semi-deciduous and the rainforest duck population. The PCA had higher loadings on body weight (0.965), suggesting body weight as the trait with the highest discriminatory power among the morphometric traits. The lower rate of inbreeding (0.002) implies that the indigenous duck populations run less risk of inbreeding depression. However, the lower effective population size of 782.83 affirms that indigenous ducks are endangered. Survivability should be a trait of high priority in future breeding programmes since farmers extremely prefer it.

KEY WORDS

Indigenous Ducks

Characterisation

Morphometric traits

Agro-ecological zones

Population structure

ACKNOWLEDGEMENT

My profound gratitude goes to the supervisor of this research, Prof. Julius Kofi Hagan of the Department of Animal Science, for his guidance, constructive criticisms and encouragement and also to the Samuel and Emelia Brew-Butler-SGS/GRASSAG, UCC Research Grant Foundation for the financial support during the preparation of this work. I am sincerely grateful.

DEDICATION

To my daughter Obaapa Akosua Boatemaa Asamoah-Yeboah

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CHAPTER ONE

INTRODUCTION

This chapter provides a general overview of the research. The discussed themes in the chapter include the study's background, problem statement, justification, main objective, specific objectives, research questions, delimitations, limitations, and general organisation.

Background to the Study

Human growth in terms of population, increasing migration from rural areas to urban centers and rising incomes are fuelling the current demand for animal-derived food in developing countries. The rate of expansion of global Livestock production has been faster than any other agricultural sector (Jutzi, Otte & Wagner, 2000). The poultry sector has seen substantial growth in recent times and has contributed numerously to Ghana's economy. Prominently, the sector has contributed significantly in terms of food security and the provision of affordable animal protein to augment the nutritional adequacy in the diets of the Ghanaian populace (Aning, 2006; Mantey, Kwao & Yeboah, 2014).

Chicken production has been the driving force spearheading the poultry industry in Ghana, with duck production lagging behind guinea fowl and turkey production. Numerous concerted efforts are made to improve protein consumption in developing countries, including breeding fast-growing and prolific livestock to improve animal protein production (Ugbomeh, 2002) and providing research funds in animal production.

Despite the numerous efforts made to improve the poultry sector, one aspect of poultry production which has suffered colossal neglect in terms of attention is duck production. The contribution of duck to the meat and egg value chain in the poultry industry has always been less significant. Nevertheless, minute consideration has been given to the genetic improvement and enhancement of husbandry practices to elevate the performance of the locally adapted duck in Ghana. The duck production sub-sector saw a significant boost in the 1980s due to fundamental discoveries in management techniques, which boosted the exploitation of the species in West Africa (Alfred & Agbede, 2012); however, the specie has been in decline in recent times.

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 (Thear & Fraser, 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 (FAO, 2009; Mantey *et al.*, 2014). Again, people with no skill can successfully raise ducks on poor-quality feed in a small scale. Duck production has a profit potential by contributing significantly to household economics and enhancing protein adequacy to improve the nutritional status of the rural poor in developing countries.

Problem Statement

Animal Genetic Resources (AnGR) are those species or breeds that are economically significant and have scientific and cultural relevance to humans for sustainable food and agriculture production (Rege & Okeyo, 2006).

Empirical evidence suggests that duck rearing was high in Ghana in the past but has recently dwindled drastically to the extent that the locally adapted duck is believed to be endangered (Mantey *et al*., 2014). In other studies, Książkiewicz (2002) documented the threat of extinction of the polish ducks; Zhang *et al*. (2019) recorded a higher rate of extinction of the Zhongshan duck breed in China and Liu & Churchil (2022) also reported that sixteen duck genetic group and one Muscovy are extinct and endangered respectively in the published paper "Duck Genetics and Breeding".

Despite the tremendous abilities of the indigenous duck specie, minute or no information is available in the literature on the qualitative and morphometric characterisation of the specie. To avert the extinction of this unique AnGR and harness the full potential of the specie, there is an urgent need to characterise the specie to aid in the design of breeding programmes.

Objectives of the study

Main objective

To evaluate the morphological characteristics of the indigenous duck populations in three agroecological zones in Ghana (Coastal savanna, semi-deciduous forest and rainforest) to aid in the future breed improvement programme.

Specific objectives

The specific objectives are to;

1. Assess the variations in qualitative and quantitative traits in the indigenous duck populations as influenced by sex and agroecological zones.

2. Determine the relationships among the various morphological and morphometric traits in indigenous duck populations.
3. Describe the quantitative and qualitative traits of indigenous duck populations in the three agroecological zones using discriminant analysis and Principal Component Analysis.
4. Characterise the production systems and abilities of ducks to identify the traits preferences of farmers to aid in selection.
5. Estimate the population structure and size of ducks in the study areas to predict the rate of inbreeding.

Research Questions

1. Are there variations in the phenotypic features of indigenous ducks in Ghana?
2. What relationship exists among the phenotypic features of the specie?
3. Does location influence the differences among the specie?
4. Are the farmers keeping the specie because of a particular unique trait?
5. What is the population structure and size of the specie in the study area?

Significance of study

Phenotypic characterisation is fundamental to the accumulation of baseline data which helps the nation (Ghana) to obtain a complete inventory for its AnGR (FAO, 2012). It is a primary requirement for designing breeding programmes and breed improvement projects. The study's outcome may be used to know the status of the species (ducks) and help propose guidelines for sustainable utilisation, suitable improvement and conservation of ducks and help develop the AnGR management plans (FAO, 2011). 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. The results from the study will also go a long way to bridge the knowledge gap in the literature and add to the knowledge repository, as there is limited information on the characterisation of the Ghanaian indigenous duck in the literature.

Delimitation of the study

The research did not cover the Transitional, Sudan and Guinea savanna agro-ecological zones. Also, due to constraints of resources, the hamlet areas within the selected agro-ecological zones were not visited. Finally, financial constraints and a lack of resources did not make it possible to include molecular genetic characterisation.

Limitation

The study focused purposely on primary characterisation, which requires visiting the farm once to collect data through observations, direct body measurements, interviews and administering questionnaires rather than advanced characterisation.

Organisation of the study

The thesis has been organised into five chapters as recommended by the School of Graduate Studies, University of Cape Coast (SGS-UCC, 2016):

Chapter one: Introduction to the study

Chapter two: Literature review

Chapter three: Materials and methods

Chapter four: Results and Discussions

CHAPTER TWO

LITERATURE REVIEW

Introduction

The general overview of genetics and animal breeding programmes and a specific literature review on phenotypic characterisation considering both qualitative and morphometric traits are discussed in this chapter.

Theoretical Literature Review

Overview of Genetics and Animal Breeding

The science that studies heredity or inheritance and variation is known as genetics. The main aim of studying genetics is to discover the laws governing the differences and similarities in an organism related by descent or common ancestry. This field of study was founded on the toil of an Austrian monk named Gregor Johann Mendel in the mid-19th century, whose work was not given much attention by the scientific community until after his death. Although Mendel did not know the physical or chemical makeup of genes, his suspicion that characters were passed down in discrete units was the foundation for the current understanding of heredity. Mendel's discovery of the rules determining trait heritability is the foundation for all recent genetic studies. In 1909, Danish botanist Wilhelm Johannsen coined the term gene, hence genetics. Genetics overlaps with many fields of study, including biotechnology, medicine and agriculture.

The gene is the nucleotide sequence that may code for a particular amino acid within the genome, making a protein express a specific character or trait in an individual. As applied in animal science, genetics has three subareas: population, quantitative and molecular genetics (Falconer & Mackay, 1996).

Population genetics studies the gene (allele) and genotypic frequencies within a population and how these frequencies are predicted in future generations. The proportion of individuals in a population with a particular genotype is referred to as genotypic frequency, while the proportion of the 2n genes represented by a particular allele is called gene frequency. This branch of genetics assesses gene and genotype frequencies and the factors influencing their change within and between populations. Such factors include mutation, migration, selection and genetic drift. Quantitative genetics, on the other hand, studies the inheritance pattern of morphometric traits and how these traits correlate with one another. In contrast, molecular genetics is a more precise approach used to elucidate the genetic foundation of phenotypes at the cell level and to establish the relationship among organisms over a generation (FAO, 2011).

The critical interest of animal breeding is the application of genetic principles, thus population, quantitative and molecular genetics to improve the performance and efficiency of animal production and their health and welfare for sustainable animal protein production. The genetic principles involve a predefined set of desirable criteria that a breeder puts in place for an animal to pass to be selected to breed the next generation. This is done so that the heritable trait(s) passed from parents to offspring's, on average, will make those progenies more productive than their parents in subsequent generations (Oldenbroek & Waaij, 2015). Breeders capitalise on the natural variation in genes within a particular population to improve the performance of future generations by designing a breeding programme. A breeding programme is a well-established series of logical cycles that helps breeders genetically improve a particular trait within and or between populations (Oldenbroek & Waaij, 2015).

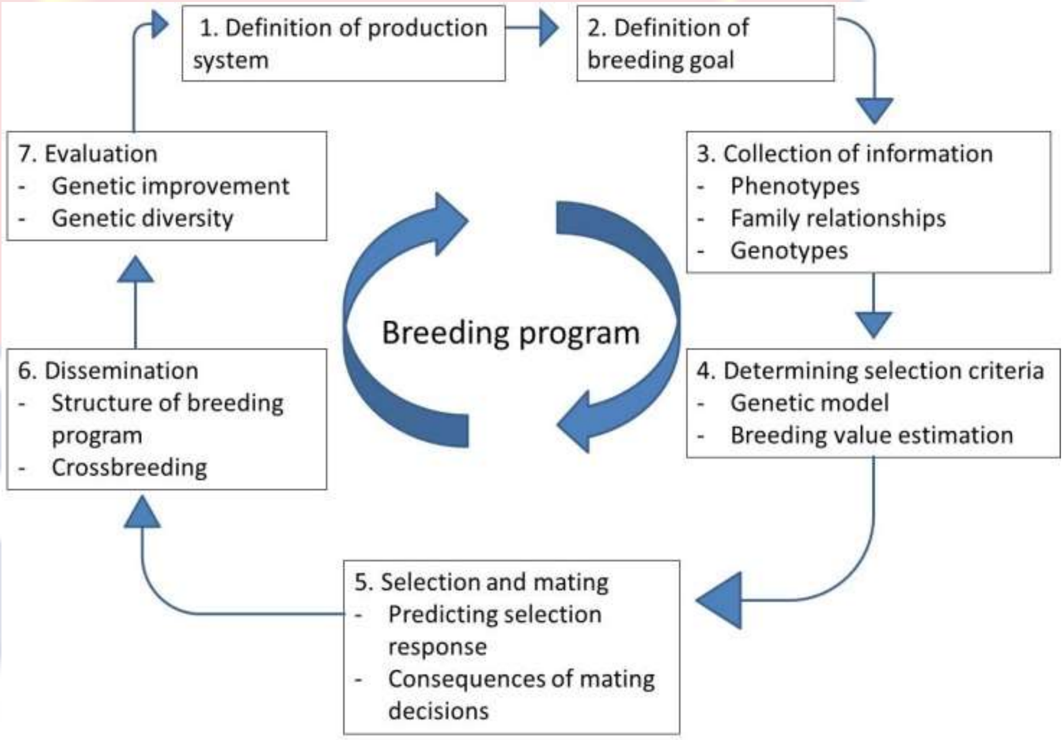

Figure 1: Breeding programme cycle (Oldenbroek & Waaij, 2015)

Description of the production system

Description of the production system is the first step a breeder considers in designing any breed improvement programme. It is vital to note that the breeder is not designing the breeding programme for his/her utmost interest but for the beneficiary farmers. The breeder considers the management systems practiced by the farmers as intensive, extensive or semi-intensive systems and analyses how the animals of interest are kept and their purpose (Annor et al., 2011). It also determines whether the beneficiary farmer is a subsistence or smallholder, small-scale commercial or large-scale commercial farmer. All these together describe the production environment to the farmer's benefit. Once the production environment is appropriately planned and identified, another aspect of equal importance is the socio-economic value of the animal, such as the role and uses of the animal.

Formulation of breeding objective/goal

The second step in designing breed improvement projects is formulating the breeding goal. Here, a statement is made about the economic worth of the animal from a genetic perspective. Emphasis is given to every trait of economic importance and challenges the breeder of the trait to improve. It gives a direction through which the desirable traits of interest are improved in a population. The breeding goal hugely depends on how well the production system is defined and is highly related to the objectives of farmers holding that animal germplasm. Generally, the breeding goal depends on how much profit is to be made upon an improvement in a trait by considering farmers' and consumers' future demands. The breeding goal is stated as an equation based on breeding and economic values. This can be calculated using a mathematical function to describe the contributions of the key aspects of the production environment to its efficiency. Assuming there is the need to improve n traits, it can be mathematically represented as described by Annor (1996) as:

$$Y = b_1K_1 + b_2K_2 + b_3K_3 \ldots \ldots \ldots \ldots + b_nK_n \ldots\ldots\ldots (1)$$

Y is the breeding goal, and b's and K's are economic and breeding values, respectively. The economic value of traits can be determined from a profit equation (P), as describe by Annor (1996) as:

$$P = I - C \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where I; is the income and C is the cost of raising a duck for meat production. The increase in efficiency of livestock production stemmed from the formulation of appropriate breeding goals is relevant to all animal product consumers, livestock farmers and the breeder. If the breeding goal is poorly chosen, it may lead to the deterioration of genetic and economic progress in a population, especially when a chosen trait of interest has a negative correlation with an important economic trait. Therefore, decisions about improving traits in a breeding programme should be purely based on economic interest regardless of how easy or difficult the trait can be measured.

Collection of information to undertake breeding decisions

After an appropriate breeding goal is formulated for economic gains, the next action is to collect relevant data to realise the breeding objective. At this stage, traditional breeders collected information based on only the appearance of the animal to identify desirable traits and determine the animals' value for the stated breeding goal. However, in recent years, technological advancement has made it possible not only to base the selection of desirable traits on phenotypes but also to dive deeper into the animal cell to collect genetic information, thus, DNA analysis (Yang et al., 2019). The phenotypic data complemented by DNA analysis can help breeders determine the offspring's pedigree with respect to their parents or ancestors. DNA analysis and the animal's externally observable features have made it possible to accurately determine how members within a particular population are genetically related (Gong et al., 2010).

Determination of selection criteria

Given that the breeding goal must positively affect the farmer's profit, it rests on the breeder to select traits to perpetuate future generations, and this is done in close association with the estimated breeding values for potential candidates whose genes will be used to produce the next generation. Assuming selection is geared towards egg production in the indigenous ducks in Ghana, or the carcass weight of drakes, the parents with higher-than-average egg-laying ability or body weight will highly improve the egg-laying rate and carcass weight of future generations. The selection of parents will have a correlative effect on the performance of progenies of the subsequent generations. Therefore, choosing selection criteria that will improve these traits is essential. Three essential factors need to be considered when selecting a trait: heritability, the correlation of the trait with other economic traits and the ability to measure the trait easily (Fayeye, 2014).

Selection and mating

The fifth step to undertake in every breeding programme is selection and mating. Selecting mating partners to perpetuate the next generation to realise the breeding goal by considering the estimated breeding values for drakes and ducks is important. For instance, when a drake with the highest estimated breeding value for 9-week body weight is chosen as sires and ducks with the highest estimated breeding value for the same trait are selected as dams, these two are mated to produce the next generation, their progenies will be heavier at 9-week than the present generation. In this case, a positive response to selection is attained. It is therefore, essential to predict genetic gains when the heritability, selection differential and phenotypic standard deviation of the trait of interest are known (Fayeye, 2014). The choice of mating which sire to which dam can also depend on the available pedigree information.

Dissemination of genetic gains

This is where the few superior animals produced are multiplied for commercial purposes. The distribution of genetic gain hinges on the structure of the breeding programme. In poultry breeding programmes, cross-breeding within the commercial breeding scheme is used. This is the mating of birds which are genetically apart from the average of the population. The limited selection of the ducks and drakes from the nucleus to the multipliers is used to take advantage of the hybrid vigour and complementarity, thus combining the characteristics of two less related breeds.

Evaluation of the breed improvement programme

The breeder asks whether the breeding objective set is achieved at this juncture. The breeder assesses whether the new generation is indeed better than their parents on average. For example, are ducks in the new generation able to produce more eggs per year than their parents, or are the 9-week body weight of drakes in the new generation heavier than the sire in the previous generation? The evaluation of the breeding goal critically reviews whether or not genetic variability increases or decreases within or among the targeted population (Bolatito & Aladele, 2019). When all these questions are answered, the breeding cycle starts again until the maximum genetic gain is attained.

Considering the aforementioned cycle of a breeding programme, little can be said about any known breed improvement programme on ducks in Ghana; however, the government of Ghana under the National Livestock

Services Project (NLSP), under the Medium Term Agricultural Development Programm (MTADP), embarked on breed development programmes like the improvement of the local chicken breeds through cockerel exchange, vaccination of layers and cockerels for crossing local hens (Ministry of Food and Agriculture, 2016).

Empirical Literature Review:

Characterisation of Animal Genetic Resources (AnGR)

AnGR are those species or breeds that are economically significant and have scientific and cultural relevance to humans for sustainable food and agriculture production (Rege & Okeyo, 2006). According to FAO (2012), "the characterisation of AnGR includes all the activities associated with the identification, qualitative and quantitative description and documentation of breed populations and structure and the natural habitats and production environment to which they are or are not adapted". Characterisation of AnGR is crucial to assess the value of breeds properly and to guide decisions made on livestock development and improvement programmes (Bolatito & Aladele, 2019).

Three types of information are needed to characterise any animal genetic resource (AnGR), including phenotypic information, genetic information, and the historical information of the breed to be characterised (FAO, 2012). Genetic characterisation also discovers the variability among populations as a result of the sequences in DNA or the modifying factors of specific genes. However, unravelling the genetic basis of a particular phenotype at the cell level and establishing the relationships among organisms from one generation to another is complemented by molecular characterisation

(FAO, 2012). The historical part of characterisation includes the description of the origin and evolution of the AnGR. The FAO Global Plan of Action for AnGR enacted in 2007 recognises that a proper understanding of breed characteristics is ideal for the sustainable utilisation of livestock, its conservation and the design of breeding programmes to improve those genetic resources.

Phenotypic Characterisation of Duck Genetic Resources

The identification of a diverse breed population of ducks in Ghana and going further to describe their external features and production environment under a particular management system considering the socio-economic factors that affect them is known as phenotypic characterisation. In Ghana, the poultry production sector is spearheaded by chicken production, with duck production given little attention. Ducks are domesticated birds that have been used for various purposes such as meat, eggs, and ornamental purposes (Aning, 2006). In Ghana, ducks play an important role in the livelihoods of rural communities as a source of income and nutrition. However, the genetic diversity of duck populations in the country is not well-documented, which makes it challenging to implement effective breeding and conservation programs (FAO, 2012).

Phenotypic characterisation involves assessing and documenting various traits such as body size, feather color, bill shape, and egg production capacity. These traits can provide valuable information about the adaptability, productivity, and genetic potential of duck populations. The study may also include evaluating traits related to disease resistance, growth rate, and reproductive performance (FAO, 2011). Data may be collected through field surveys, interviews with farmers, and direct measurements of ducks. The collected data is then analysed to determine the frequency and distribution of different traits within the population. This information can help identify unique or rare genetic variants with specific adaptive or productive advantages (Yakubu, 2011).

The phenotypic characterisation of duck genetic resources in Ghana is essential for several reasons. Firstly, it provides a baseline understanding of the existing genetic diversity, which is crucial for conservation efforts. By identifying and preserving unique genetic traits, researchers can ensure the long-term viability of duck populations and prevent the loss of valuable genetic resources. Also, the information gathered through phenotypic characterisation can guide breeding programs aimed at improving duck productivity and resilience. By selectively breeding ducks with desirable traits, such as higher egg production or disease resistance, farmers can enhance their livelihoods and contribute to food security. Lastly, phenotypic characterisation can contribute to understanding duck genetics and evolution. By studying the variations in physical traits, researchers can gain insights into the evolutionary history and genetic relationships between different duck populations (FAO, 2012).

Origin, History and Distribution of Domestic Ducks (*Cairina moschata*)

Poultry is generally used for domestic birds, such as guinea fowls, ducks, chickens, swans, geese, turkeys and pigeons, raised primarily for food (meat and eggs) and occasionally feathers. These animals are typically best at converting locally available feedstuffs like cereal, grains and grain by-products into a high-quality protein of animal origin (Tweneboah, 2002). Crawford (1990) emphasised that the present level of interest in the history and origin of these distinctive poultry species is purely academic. Notwithstanding, understanding the history and origin of ducks will be useful due to the speedy development in genetic engineering and the need to characterise these animal genetic resources to harness their potential to the fullest.

Duck is a common name for several species of waterfowl in the Anatidae family. In modern ornithology, the wild mallard (*Anas platyrhynchos*) is thought to be the ancestor of all domesticated ducks, which has experienced several crossbreeding and mutations since its domestication in China between 2000 and 3000 years ago (Zhang *et al*., 2018; Qu *et al*., 2009) except the Muscovy ducks (*Cairina moschata*) which are believed to have descended from their wild type. Regarding the domestication of *Cairina moschata*, evidence of archaeological description suggests their origination from southern America, precisely; Chile and Argentina (Stahl, Muse & Delgado-Espinoza, 2006).

The name originates from the Latin word Anas which means duck, and a combination of two Greek words, **Platus** and **rhynchos,** meaning broad and bill, respectively. According to Aning (2006), the predominant breed of ducks raised in Ghana is the Muscovy breed (*Cairina moschata*) which is widely distributed throughout the country and the Pekin duck (*Anas domesticus*) which is only found in the greater Accra region of the country (FAO, 2014).

Description of Duck species

Muscovy ducks (*Cairina moschata*) belong to the family Anatidae. Other members in the Anatidae family include; mallards, geese and swans. The head displays a pompadour-like crest with the occasional white nape.

Muscovy ducks are easily identified by their fleshy caruncles, which extend from the pale yellow to brown eyes to the base of the bill and sometimes replace some feathers on the face. The caruncles are more conspicuous in drakes (males) but drab or reduced in ducks (females). The ducklings are characterised by yellow feathers with buff-brown on the wings and tail. Other features that make Muscovy ducks stand-out from other flocks are their long broad bill, sometimes dark at the base with variable colours at the tip. The shape of the bill is spatulated with colours ranging between black, brown, red and pink. The tip of the bill is characterised by a grey nail or bean. Muscovy ducks may have a solid white, black, or blackish-brown with iridescent green reflecting a purplish tint plumage.

Muscovy ducks are quiet compared to other breeds of ducks. Muscovy ducks do not quack like mallards and those descendants from the wild mallard species. Drakes make a huff-huff sound, and ducks make a trill or coo sound. These sounds are notable during courtship as drakes pump their head and wag their tail, and ducks respond similarly. Muscovy ducks are gregarious birds which often forage and swim in pairs or small groups (Johnson & Hawk, 2009). Drakes are aggressive towards each other, but they are not territorial. A drake may breed with several ducks and guards them against other males and predators. Like other bird species, Muscovy ducks batter their opponents with their wings by flying at each other during fighting. Usually, Muscovy builds their nests in trees and sometimes on the ground. Females lay at random places from 8 to 15 eggs per clutch. The incubation of eggs takes about 35 days. Ducklings follow their mother after hatching to keep them warm, feed and protect them from predators until they are about 10 to 12 weeks. Muscovy duck species feed on a combination of plants such as seeds, grass, aquatic vegetation and roots and small animals like small insects, worms, shrimps, snails, fish and lizards. They mainly search for feed in and or around water sources (Mantey et al., 2014).

Studies on Qualitative Traits of Ducks

Describing the duck's external characteristics is the first step of the specie characterisation FAO, (2012). The phenotypic traits are a category of characters that includes the outward appearance of the animal in terms of conformation, shape, colour and the orientation of body parts. These are also known as discontinuous variations that are measured discretely or categorically. The discrete measurement of these traits is because a small proportion of genes determine them; however, categorical traits like the multiple plumage colour of birds may be influenced by a wide range of genes or are polygenic. The environment does not much influence polygenic genes and therefore are recorded and predicted accurately for a particular animal population. Some Qualitative traits of ducks may be useful for the adaptation of the birds under a particular habitat and ecological zone. Farmers and consumers may prefer such traits, while others may be important for identification (FAO, 2012).

Plumage colour and Plumage pattern of ducks

The Muscovy duck has a variety of plumage colours (Wu *et al.*, 2017). The plumage colouration of ducks is determined by three major kinds of pigments: melanin, which is synthetised by melanocytes; carotenoids and porphyrins, which are also obtained from the bird's diet (Yu *et al.*, 2004). Earlier findings indicate that ten (10) loci control the plumage colour

(Tuláček, 1990). Nevertheless, the gene controlling ducks' plumage colour remains unknown (Wu *et al*., 2017). Four candidate genes, namely the Agouti signaling protein gene (ASIP), Dopachrome tautomerase gene (DCT), Melanocortin 1 receptor gene (MC1R) and Microphthalmia–associated transcription factor gene (MITF), are thought to be responsible for the colouration of the plumage and have been investigated recently (Wu *et al*., 2017; Sultana *et al*., 2015; Zhou *et al*., 2018; Yang *et al*., 2019) to decipher their role in plumage colouration and pattern. Two autosomal loci are reported to be responsible for plumage colouration by Yang *et al*. (2019). The C and T loci are the basis of colouration in plumage and control of the biosynthesis process of melanin in ducks. The homozygous recessive allele of each locus produces a pure white plumage, as in the case of Pekin ducks and Kaiya duck breeds. Interaction of the two loci (such as CcTt * CcTt, CcTt * ccTt and ccTT * CcTt) results in ducks of different and multiple colourations from the white plumage (Gong *et al*., 2010).

Results of Oguntunji and Ayorinde (2015) revealed that the predominant plumage for Muscovy ducks was mottled (45%), followed by black (34.02%), white (10.88%), Ash (9.71%) and blue (0.39%) as the least observed plumage colour. This is similar to Chia and Momoh (2012) and Banerjee (2013), who recorded mottled as the predominant plumage colour for Muscovy ducks of Nigeria and India, respectively. In contrast, Black and multi-coloured were the predominant plumage among North West (Hassan & Mohammed, 2003) and North Eastern (Raji, Igwebuike & Usman, 2009) Nigeria Muscovy ducks, respectively.

In other studies, Ewuola, Akinyemi, Hassan, and Folaniyi (2020) reported pied (black and white) plumage as the predominant plumage for Muscovy ducks in the humid zone of Nigeria with a frequency of 69%, followed by white (31%). The results are consistent with Kadurumba *et al*. (2021), who reported Black with white patches (54.79%) as the predominant plumage colour, followed by entirely black (17.81%), completely white (10.96%), completely brown (8.22%), white with black patches (3.42%), brown with black patches (3.42%) and the least plumage colour recorded was brown with white patches (1.37%). The result is incongruent with the work of Foluke-Eunice, Charles-Adeola, Opeyemi-Akinkunmi, and Joe-Alabi (2020), who recorded black (52.50%) as the dominated plumage colour in North-central Nigeria followed by black and white (31.50%), brown (10.50%), white (4.50%) and light blue and white (1%) as the least occurring plumage colour. The results also disagree with a review by Raji *et al*. (2009), who reported four variants in plumage colour. Multicoloured (36.9%) was the predominant colour, followed by white (30.6%), black and white (26.1%) and black (6. 4%). The work of Oguntunji, Adeola, Makram, Putra, and Oriye (2020) also reported brown (34.97%) as the most subjugated plumage colour, followed by black (33.30%), green head (18.9%) and then mottled (12.80%) as the least subjugated plumage of the mallard specie in Nigeria.

For plumage colour distribution, Morduzzaman, Bhuiyan, Rana, Islam, and Bhuiyan (2015) reported a completely black plumage colour distribution on the back, neck, wing and tail. The report again recorded a white breast colour in males to be 84.62% and 93.75% white in female Nageswari ducks in Bangladesh. The head colour for ducks was wholly black, but black with white spotted in some drakes (7.69%). The results are incongruent with Kamal *et al*. (2019), who reported in the study of Desi ducks in Indonesia that head colour was a mixture of fawn and white (75%), whereas in some ducks' black (8.80%), white (8.10%) and black-white spotted head (8.10%) colour pattern was also noticed. Drake had plumage colour variants of greenish-black (55.56%) to brown (22.22%). Neck colour in males (44.44%) and females (88.29%) was white. In some drakes, brown neck colour with white ring (33.33%) and greenish colour (22.22%) was also identified, whereas chocolate was also noticed in some ducks. In drakes and ducks, the wing colour was brown/ grey and white, while the breast colour, which is consistent with the work of Morduzzaman *et al*. (2015), was identified to be predominantly white. The findings are also consistent with Tamzil Lestari and Indarsih (2018), who found that the male Muscovy ducks in Indonesia had two plumage characteristics on the body; white, and black & white (black with white spots). Both characteristics shared the same frequencies. Meanwhile, on the female ducks, the frequency of white colour was higher (62%) than that of black and white (38%).

The plumage pattern of ducks can be classified as solid, thus pure white or pure black; double coloured, thus pied or multi-coloured, which may feature three or more colours on a particular bird. In the study by Hailu *et al*. (2018), a multi-coloured plumage pattern was predominant in drakes and ducks raised in Ethiopia's Gambela and Benishangul Gumuz regions. The plumage colours recorded in most ducks in the two regions were black, white, brown and green. A similar multi-coloured plumage pattern was observed in the earlier report of Banerjee (2013) in common ducks, also known as

Desi/pati ducks, in West Bengal, India. Observation of Banerjee also saw a double plumage pattern of black and white (pied) in the study area. The results are consistent with the findings of Kamal *et al*. (2019), who also recorded a multiple plumage colouration in Desi ducks in Odisha, India, as the most dominated plumage pattern. The results disagree with the reports from Ewuola *et al*. (2020) and Kadurumba *et al*. (2021), who recorded double plumage as the most subjugated plumage pattern in Muscovy ducks in the Humid zone and Imo & Abia States of Nigeria, respectively. Also, the reports of Hailu *et al*. are incongruent with the findings of Foluke *et al*. (2020), who saw solid black as the predominant plumage pattern in Muscovy ducks in Kwara and Niger States in North-central Nigeria.

Eye Colour

In detecting the eye colour of ducks, much attention is given to the iris. The colour of the iris is said to be the colour of the eye. The colour genetics of birds cannot be deliberated wholly when the acknowledgement of the work of W. F. Hollander in 1978 is deprived. In his book, "Origins and Excursions in Pigeon Genetics”, he points out the significant genetic variations of eye colour, which he said ranges from orange, pearl and bull, particularly in pigeons. The eye plays a significant role in ducks detecting any approaching predator. The iris pigmentation allows light to pass through it and makes some ducks have varying eye colours from brown, red, blue, black, yellow etc. In a study by Banerjee (2013), the resulting eye colour was yellow in all the Muscovy ducks considered in his study in West Bengal, India. The findings are in partial consonance with Ewuola *et al*. (2020), who observed yellow (61.50%) as the predominant eye colour and 38.5% as black eye colour. It is also in partial agreement with Hailu *et al*. (2018), who identified yellow eye colour (55.3%) as the subjugated eye colour, followed by black (30.6%), black-brown (12.9%) and brown/grey (1.2%) as the least occurred eye colour. The earlier report from Morduzzaman *et al*. (2015) indicated black as the leading eye colour in both drakes and ducks, with a frequency of 88.46% and 84.37%, respectively. The remaining drakes and ducks had ash eye colour, thus 11.54% and 15.62%, respectively. The earlier report from Morduzzaman *et al*. (2015) finds partial consonance with Foluke *et al*. (2020), who recorded black, grey and orange eye colour in a ratio of 45%, 41% and 14%, respectively, when they researched 200 Muscovy ducks in Kwara and Niger states in Nigeria. The results are incongruent with the findings of Kadurumba *et al*. (2021), who reported brown as the predominant eye colour and black as the least occurring eye colour in a 76.03% and 23.97% proportion correspondingly on Muscovy ducks in the Southeast ecological zone, Nigeria.

Caruncle colour

Caruncles are fleshy bulbous growth which extends from the bill to the eyes of usually Muscovy ducks. The caruncles are prominent, well developed and conspicuous in drakes but quite rudimentary in ducks. It varies in colour from red to black, and it is thought to help Muscovy clean their feathers when they dabble in mud. In Muscovy ducks, the caruncle grows to replace most of the face feathers as the bird grows; therefore, it can be used to determine whether a duck is matured. The presence of caruncles on the face of ducks can be used to determine the breed as Muscovy, as other breeds of ducks do not have them or are less conspicuous though matured. The findings from a study by Banerjee (2013) saw 100% red-coloured caruncles in Muscovy ducks raised in West Bengal, India. This completely agrees with Kadurumba *et al*. (2021), who also reported a 100% red caruncle colour. The study is consistent with Foluke *et al*. (2020), who recorded red as the predominant caruncle colour, followed by pink and then black in a ratio of 40%, 35% and 25%, respectively, for Muscovy ducks raised in North-central Nigeria. Likewise, Ewuola *et al*. (2020) observed red (58.5%) as the predominant caruncle colour and black (41.5%) as the least subjugated caruncle colour. This is, again, in partial agreement with the earlier findings of Oguntunji and Ayorinde (2015), who identified four variants of caruncle colour thus; red, red-black, black and light yellow in a relative frequency of 83.53%, 13.92%, 2.44% and 0.88% in an orderly manner.

Bill Colour

According to Dinesh *et al*. (2008), the black bill was the predominant colour observed in Kampong Cham, Odar Meanchey and Siem Reap, whereas yellow was identified in Kampot and Rattanakiri provinces in Cambodia. Likewise, the findings of Foluke *et al*. (2020) revealed Black (51.50%) as the most subjugated colour, followed by slate-grey (33.50%) and yellow (15 %) of Muscovy ducks in North Central Nigeria. These results also agree with Maharani, Hariyono, Putra, Lee, and Sidadolog (2019), who identified black bill (77.49%), followed by yellow (16.23%) and brown (0.52 %) as the least observed bill colour among local female duck populations. The aforementioned results disagree with Banerjee (2013), who recorded slate-grey bill in black and white Muscovy ducks and yellow bill in sepia-feathered Muscovy ducks in West Bengal in Ethiopia. Kadurumba *et al*. (2021) also recorded pink-white (97.26%) as the predominant colour, while 2.74% had yellow bill colour in the local duck population in the lowland area of the rainforest agro-ecological zone of Nigeria.

The Nageswari drake populations in Bangladesh had black bill (57.69%) followed by black with yellowish tint (23.07%) and yellowish bill (19.23%), whereas ducks are composed mainly of the black bill (93.75%) and black with yellowish tint (6.25%) Morduzzaman *et al*. (2015). In contrast, Tamzil *et al*. (2018) observed an equal proportion of black-base-white-tip and reddish white with pink bill colours in males; nevertheless, females had 60% and 40% reddish white with pink bill and black-base-white-tip bill colours, respectively. Dissimilarly, drakes had prominent bill colour of yellow (44.44%) followed by yellowish green (33.33%) and greenish-black with a yellowish tint (22.22%). In the case of ducks, the prominent bill colour was yellow (52.25%), followed by black (29.73%) and green (18.02%) Kamal *et al*. (2019).

Bean/Nail Colour

Ducks have a protrusion on the tip of the upper bill called the bean or nail. The bean help ducks to root in grass and mud for food. Some species of ducks have this feature whiles others do not, and for those species that have the bean present, some may be more prominent than others with different colouration. In the work of Banerjee (2013), all the Muscovy ducks sampled from West Bengal in India had white bean colour. This is consistent with the findings of Kadurumba *et al*. (2021), who also identified white bean colour in all the local duck populations sampled from Omo and Abia State, Nigeria.

Incongruent with the aforementioned findings, Morduzzaman *et al*. (2015) sampled male and female Nageswari ducks in Bangladesh and observed only black bean colour in the study objects. Moreover, the findings of Morduzzaman *et al*. are consistent with Oguntunji *et al*. (2020), who similarly recorded black bean colour in all the 127 drakes sampled. However, there were varying colours of black (69.54%) as the predominant colour, followed by yellow-black (16.70%), brown (4.95%), yellow (4.04%), chocolate (2.75%) and yellow-brown (2.02%) in the 545 females sampled in North-west Nigeria. Hailu *et al*. (2018) identified black bean colour (77.1%) as the predominant in the Ethiopian locally adapted duck populations, followed by white (15.9%), brown (3.5%) and black brown and brown white shared equal frequency of 1.8%. Likewise, Foluke *et al*. (2020) observed black bean (35.5%) as the predominant colour, followed by slate grey (34%) and then yellow (30.5%).

Skin Colour

Ducks' skin Pigmentation is generally diverse depending on the breed, ecotype, the agro-ecological zones in which the birds are raised and many others factors. Pigment cells known as melanocytes located at the base of the epidermis produce a protein called melanin carried to the skin's surface through the keratinocytes. The duck's skin can be pigmented either yellow, black, blue-black, not pigmented and many others. The skin colour of ducks was observed to be not-pigmented, thus white, as in the case of Hailu *et al*. (2018) for all domesticated local ducks considered in his study in Gambela and Benishangul Gumuz of North-west and South-west regions of Ethiopia. This is in total agreement with the earlier findings of Morduzzaman *et al*. (2015), in which both drakes and ducks considered in his study of Nageswari ducks in Bangladesh all had a non-pigmented skin colour. It also concords with the subsequent findings of Kamal *et al*. (2019) and Oguntunji *et al*. (2020), who also identified white skin as the sole colour in both drakes and ducks in their study of Desi ducks of Odisha in India and Mallard ducks in Nigeria respectively. These reports are incongruent with the findings of Banerjee (2013), Macharia and Ommeh (2017) and Tamzil *et al*. (2018), who observed variable skin colours of white, spotted black, spotted grey, black, spotted yellow and yellow.

Shank Colour

The diversity of shank colour has been studied. Muscovy ducks were the predominant breed of ducks found in the study area of the South-east ecological zone of Nigeria. Shank colours of slate grey, black and yellow were recorded with a relative proportion of 70.55%, 26.71% and 2.74%, respectively, among the duck populations (Kadurumba *et al*., 2021). This is comparable to the earlier findings of Banerjee (2013), who noted that the black and white feathered Muscovy ducks in West Bengal, India, were all characterised by slate grey shank colour. Banerjee (2013) again identified solely yellow shank colour in sepia feathered Muscovy ducks in West Bengal. This agrees with the findings of Ewuola et al. (2020) who recorded yellow shank as the predominant shank colour followed by black with a relative prevalence of 62.5% and 37.5%, respectively. On the other hand, it was observed in Gambella and Benishangul Gumuz regions of South West and North West Ethiopia that brown-grey shank colour (62.4%) was the most occurring shank colour followed by brown-white (25.3%), white (19.4%), yellow (9.4%), black-brown (4.4%) and black shank colour being the least dominant with a proportion of 4.1% (Hailu *et al*., 2018).

In terms of sexual dimorphism in the shank colour variation, Morduzzaman *et al*. (2015) identified black shank colour as predominant in both male and female Nageswari ducks, with a relative prevalence of 73.07% and 90.63%, respectively. Additionally, males had yellowish shank colour (19.23%), and both drakes and ducks had black with a yellowish tint of 7.69% and 9.37%, proportionately. Tamzil *et al*. (2018), however, argued that yellow shank colour was predominant in both drakes and ducks, followed by black with a yellowish tint and finally black in a proportion of 49% & 48%; 34% & 38%; and 21% & 22% respectively.

Web colour

Syndactyly is typical in most birds, especially ducks. This is a condition in which two or more digits are fused. In ducks, this condition has a unique adaptation purpose that helps ducks to swim. Ducks use their webbed feet as paddles to provide a larger surface area to propel them against water when swimming. For the sake of characterisation and being aware of types, breeds and or ecotypes of ducks in the study area, assessing the web colour is of great importance. Foluke *et al*. (2020) revealed black web colour as the most common among Muscovy ducks raised in the North-central part of Nigeria, followed by slate grey and then yellow with a relative proportion of 50%, 35% and 15%, respectively. This is partly in agreement with the earlier findings of Morduzzaman *et al*. (2015), who reported black (76.93% and 87.5%) as the most predominant web colour and then black with yellowish tint (23.07% and 12.5%) as the least common web colour respectively in both drakes and ducks in Nageswari ducks in Bangladesh. Incongruently, Maharani *et al*. (2019) recorded an overall web colour to be dark brown (48.17%) when they undertook a study of six different duck populations in Indonesia, followed by light brown (24.61%) and then yellow (21.47%). However, the yellow web colour was 100% in ducks from the Alabio population, and this is similar to the previous findings of Oguntunji and Ayorinde (2015). They reported four variants of web colour (yellow, black, slate and ash) in a ratio of 60.4%, 22.92%, 13.03% and 3.92%, respectively, in Muscovy ducks in Nigeria.

Studies on Morphometric/Quantitative Traits of Ducks

Metric characters, as generally referred to, are a category of traits that includes the linear body measurement of the animals as well as the animal's body weight. These traits are usually correlated with production traits either positively or negatively. Quantitative traits are continuous variables and are controlled by numerous sets of genes. Their expression is also affected by the environment, age and sex. Therefore, in sampling animals for morphometric traits assessment, it is advisable to select matured animals kept in their typical production environment. In the case of ducks, maturity can be determined by evidence of mating, thus sexual maturity and the fleshy outgrowth of their caruncles, as in the case of Muscovy ducks.

Body weight

Sexual dimorphism regarding body weight in most duck populations reported in the literature is skewed towards drakes than ducks. In most duck populations, the females were inferior to the males in terms of body weight. It is only in a few reports that females showed superior body weight to males. A typical scenario was reported by Dinesh *et al*. (2008) where ducks had superior body weight than drakes, with a range of 2.48 kg – 2.93 kg as the overall body weight for matured Muscovy ducks in different study areas. These reports are in close agreement with the findings of Ksiazkiewicz (2002); Raji *et al*. (2009); Ogah, Momoh and Dim (2011); Yakubu (2013); Foluke *et al*. (2020) and Lan and Worowan (2020) who observed a mean body weight of 2.33 kg - 2.73 kg, for drakes raised in different environments. Likewise, Bernajee (2013) study recorded live body weights of 2.50 kg and 2.95 kg for pied and sepia-coloured Muscovy ducks raised in West Bengal, India. Nevertheless, Drouilhet *et al*. (2014), Macharia and Ommeh (2017), Hailu *et al*. (2018), Tamzil *et al*. (2018) and Ewuola *et al*. (2020) recorded 3.05kg, 3.38 kg, 3.09 kg, 3.62 kg and 3.16 kg live body weight of male Muscovy ducks from various study areas. Surprisingly, Johnson and Hawk (2009), Philip (2007) and Huang (2012) postulated a higher range of 4-7 kg, 7-10 kg, and 4.6-6.8 kg live body weight for drakes, respectively. These results are inconsistent with the findings of 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 1.66 kg, 1.80 kg and 1.73 kg respectively in drakes. For female duck populations, Lan (2020) observed a range of 5-6 kg live body weight, which disagrees with the 2.6-4.0 kg live body weight reported by the earlier findings of Johnson & Hawk (2009). Notwithstanding, the value of Johnson & Hawk aligns with the subsequent findings of Huang *et al*. (2012), who also postulated a range of 2.7-3.6 kg of body weight in ducks. Likewise, Tamzil *et al*. (2018) recorded a live body weight of 2.49 kg in Lombok Muscovy ducks raised semi-intensively in Indonesia. In contrast, the aforementioned value is higher than those reported by Raji *et al*. (2009), Yakubu (2011), Yakubu (2013), Morduzzaman *et al*. (2015), Kamal *et al*. (2019) and Kadurumba *et al.* (2021) female ducks.

Breast Circumference

Several researchers have used the girth of the breast or chest as a morphometric character to determine its correlation with body weight and other morphometric traits of farm animals. Birteeb and Lomo (2015) and Hagan, Apori, Bosompem, Ankobea, and Mawuli (2012) have both used the chest girth to determine its effect on body weight and other morphostructural traits of West African Dwarf (WAD) goats in Ghana, whilst Adenaike, Jerede, Bello-Ibiyemi, and Ikeobi (2020) used it on locally adapted turkey in Abeokuta, Nigeria. The overall breast circumference of local ducks raised in the Gembela and Gumuz regions of South-west and North-west, Ethiopia as reported by Hailu *et al*. (2018), was 39.60cm, but sexual dimorphism had an impact on the trait as drakes had broader breast circumference than ducks in a proportion of 44.50cm and 35.70cm respectively. The effect of sex on the trait, as reported by Hailu *et al*., is in harmony with Tamzil *et al*. (2018) and Raji *et al*. (2009), who recorded broader breast circumference in drakes than ducks in a relative ratio of 40.90cm & 35.92cm and 40.57cm & 31.43cm respectively. Similarly, Foluke *et al*. (2020), Kadurumba *et al*. (2021), Susanti *et al*. (2016) and Yakubu (2011) all discovered a disparity in breast circumference in terms of sex in a relative prevalence of 37.46cm & 30.40cm; 33.85cm & 32.01cm; 38.30cm & 30.37cm and 38.83cm & 31.28cm respectively all in favour of drakes. However, the study by Ewuola *et al*. (2020) reported a similar trend in the effect of sex on the trait but recorded lower values as drakes had a breast circumference of 25.84cm and 20.81cm for ducks.

Body Length

The body length of ducks has been reported by several researchers in literature to ascertain its impact on other morphometric traits, more especially market body weight or body weight at slaughter. The overall body length of Muscovy ducks of three ecotypes of three ecological zones of Nigeria, namely, the dry savanna, guinea savanna and rainforest, recorded at 25.09 cm, 25.86 cm and 24.88 cm, respectively (Ogah *et al*., 2011). The results are in close coherence with the findings of Veeramani, Prabhakaran, Selvan, Sivaselvam, and Sivakumar (2014), who reported 23.74 cm as the overall body length of indigenous duck populations raised in the northern districts of Tamil Nadu, India. For the sexual dimorphism of this morphometric character, drakes showed superior body length to ducks. Raji *et al*. (2009), in their research on Muscovy ducks reared in Maiduguri, Bueno State, Nigeria, cited by Yakubu (2009), witnessed a body length of 59.25 cm and 45.51 cm for drakes and ducks, respectively. The results partially agree with the findings of Hailu *et al*. (2018) and Foluke *et al*. (2020), who indicated a body length of 56.88 cm & 47.52 cm and 54.59 cm & 49.02 cm in drakes and ducks correspondingly. In other studies, the average body length of drakes and ducks was 47.86 cm and 38.35 cm (Yakubu, 2011). The results are closely related to Kamal et al. (2019) and Kadurumba et al. (2021), who observed 42.69 cm & 41.30 and 45.04 & 42.69 cm for drakes and ducks, respectively. However, the results observed by Ewuola *et al*. (2018) thus, 21.53 cm & 17.59 cm for drakes and ducks correspondingly were lower than those reported by

Morduzzaman *et al*. (2015) and Tamzil *et al*. (2018). Again, female Muscovy ducks raised at Papua New Guinea University of Natural Resources and Environment (PNGUNRE) poultry farm from four different phenotypes, namely, chocolate, lavender, silver and white, recorded a live body length of 33.00 cm, 36.40 cm, 34.86 cm and 32.95cm, respectively (Lan and Worowan, 2020).

Neck Length

Muscovy ducks are large and heavy, with longer necks than other ducks. Many researchers have researched the neck length in ducks and its correlation with other linear body measurements. These researches are to decipher whether an improvement in the trait may positively influence other morphometric characters of interest of the specie. Ogah *et al*. (2011) conducted research to decipher how the agroecological zone impacts the length of their neck. Their findings revealed a slight influence of the production environment on the neck length. Muscovy ducks raised in the dry savanna, guinea savanna and the rain forest had varying neck lengths of 13.90cm, 14.58cm and 13.45cm for the three agroecological zones, respectively. Other findings also revealed that the sex of the duck could impact the neck length of ducks. Morduzzaman *et al*. (2015) recorded 23.49cm and 21.59cm in favour of drakes than ducks. This agrees with the earlier findings of Susanti *et al*. (2011), who recorded 23.70cm and 19.19cm for drakes and ducks, respectively. Likewise, Yakubu (2011); Kokoszyński *et al*. (2019), and Tamzil *et al*. (2018) shared similar values for drakes and ducks in a proportion of 18.10cm &14.33cm; 18.30cm & 17.50cm and 18.32cm & 14.87cm respectively. Moreover, the report from Kamal *et al*. (2019), Veeramani *et al*. (2014) and Kadurumba *et al*. (2021) slightly disagree with the findings of Susanti *et al*., Yakubu, Kokoszyński *et al*., and Tamzil *et al*., as they recorded lower values for neck length drakes and ducks in a relative proportion of 12cm & 10cm; 13.94cm & 12.43cm and 14.14cm & 13.57cm respectively. Lan and Worowan (2020), however, ascertained the impact of plumage colouration and pattern on the neck length of Muscovy ducks raised in the PNGUNRE poultry farm and saw variations in neck length as affected by plumage colour. Their findings revealed 12.42cm, 13.14cm, 13.60cm and 14.00cm for white, silver, lavender and chocolate feathered colouration.

Bill Length and Width

The ability of a duck to detect, grab and swallow food depends on the length, shape and size of the bill. Ducks use their bills to filter out excess water and inedible food items. The intended food items are gulped with less mastication though part of the bill has a teeth-like appearance. This makes the size, shape and length of the bill of ducks a great adaptive character as it helps the birds to survive within their habitat. Ducks may fall under two categories: dabblers or divers. Dabbling ducks like the Muscovy mainly feed in shallow waters by dipping their heads underneath to reach their prey. This is the point where the length of the bill becomes essential to the duck as it determines how far it can reach its prey beneath the shallow water. For this reason, animal breeders use morphometric traits like bill length to determine how adapted a particular farm animal is in its production environment or agroecological zone. Ogah *et al*. (2011) researched to ascertain the morphological traits of Muscovy ducks as influenced by three agroecological zones in Nigeria, namely the Dry savanna, Guinea savanna and the Rainforest. The findings revealed that the

Muscovy duck ecotype from the Guinea savanna had a longer bill length, followed by the Rainforest ecological zone and the Dry savanna in a relative proportion of 5.64cm, 5.42cm and 5.34cm. On the other hand, Lan and Worowan (2020) researched the bill length as influenced by plumage colour and recorded 4.86cm, 4.80cm, 4.71cm and 4.42cm sequentially for Chocolate, Lavender, Silver and White feathered Muscovy ducks raised on PNGUNRE poultry farm in Papua New Guinea. Other Animal scientists have also researched the effect of sex on the bill length. Some notable researchers, Veeramani *et al*. (2014), saw males having longer bill lengths than females in a proportion of 6.84cm and 5.76cm when they researched the zoometric traits of indigenous ducks of Tamil Nadu, India. Their findings are in harmony with Susanti *et al*. (2016), who recorded 6.20cm and 5.24cm for drakes and ducks, respectively, when they worked on "the potentials of white Muscovy as parent stock for the production of broiler ducks in Indonesia". It also agrees with Kamal *et al*. (2019), who, in their findings, recorded 6.11cm for drakes and 5.60cm for ducks when they characterised desi ducks of Odisha, Nigeria.

Moreover, other scientists also shared similar views in their findings that the influence of sex on bill length is skewed toward drakes more than ducks. However, they recorded lower values than the aforementioned researchers. Raji *et al*. (2009), Morduzzaman *et al*. (2015), Maharani *et al*. (2019) and Kadurumba *et al*. (2021) all shared similar values ranging from 5.12cm to 5.98cm for drakes and 4.67cm to 5.54cm for ducks in their studies at different locations and agro-ecological zones. The lowest of the values came from Tamzil *et al*. (2018), Foluke *et al*. (2020) and Yakubu, Kaankuka and

Ugbo (2011), who shared common values ranging from 4.13cm to 4.98cm for drakes and 3.38 to 4.10cm for ducks in their various studies.

Concerning Bill width, few reports were found in the literature; however, the width of the bill determines how wide ducks can open their mouth to gulp their prey and determines the size of feed they can swallow when competing for feed. Notwithstanding, Ogah *et al*. (2011) observed a bill width of 3.10cm, 2.63cm and 2.81cm for the ecotypes from the Dry savanna, Guinea savanna and the Rainforest, respectively, as he looked at how different agro-ecological zones may impact the trait. Maharani *et al*. (2019) reported an overall mean bill width of 2.77cm for female ducks raised in different localities of Indonesia, and Kamal *et al*. (2019) witnessed 3.70cm and 3.`46cm for drakes and ducks, respectively.

Shank Length

Various global researchers have reported some levels of variability for the shank length as a morphostructural trait and its impact on other morphological characters. Adenaike *et al*. (2020) and Bhowmik, Mia and Rahman (2014) have used the shank length to estimate the live body weight and its influence on other linear body measurements of turkey and pigeons in Nigeria and Bangladesh, respectively. The average shank length of 6.45cm for Muscovy ducks has been reported by Maharani *et al*. (2019) from varying localities such as Alabio, Magelang, Rambon, Pegagan, Pitalah and Bayang in female duck populations in Indonesia. This is in congruence with the earlier report from Morduzzaman *et al*. (2015), who documented the average shank length of female Muscovy ducks raised in Bangladesh to be 6.09cm while their male counterparts recorded 6.60cm. These results are also closely associated with Kamal *et al*. (2019), who recorded a mean shank length value for ducks to be 5.89cm and 6.21cm for drakes. The report of Maharani *et al*. contradicts the subsequent findings of Lan and Worowan (2020), who recorded lower shank lengths of chocolate, lavender, silver and white plumage-coloured 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. However, the findings of Lan and Worowan are in harmony with Kadurumba *et al*. (2021), who studied “the morphological and morphometric characterisation of local duck populations in the South-east part of Nigeria” and recorded an average shank length of 5.78cm and 5.44cm in both drakes and ducks respectively.

Similarly, Hailu *et al*. (2018) reported an overall mean for both drakes and ducks to be 5.50cm in ducks. Also, Ewuola *et al*. (2020); Ogah (2009) and Foluke *et al*. (2020) reported their findings to be 5.94cm & 3.46cm; 5.74cm & 5.56cm and 7.69cm & 5.68cm for drakes and ducks respectively. On the other hand, Ogah et al. (2011) saw some disparities in location as the researchers recorded 5.34cm, 5,64cm and 5.42cm in the dry savanna, guinea savanna and the rainforest of Nigeria. Moreover, Macharia and Ommeh (2017) witnessed a longer shank length in proportion of 8.42cm for drakes and 7.02cm for ducks. In terms of variations due to sex, it cannot be deciphered that males have longer shank lengths than females, as some ducks from different populations performed better than drakes of other populations.

Wing Length

Many researchers have reported sexual dimorphism in ducks' wing length. The findings of Tamzil *et al*. (2018) showed a higher variation in the wing length of drakes (82.81cm) and ducks (61.19cm). This is closely associated with the findings of Hailu *et al*. (2018), who reported 55.56cm and 47.70cm for drakes and ducks, respectively. The values recorded by Hailu *et al*. slightly agree with the previous findings of Kamal *et al*. (2019), who witnessed 42.73cm for drakes and 39.99cm for ducks. In terms of values, the results from Tamzil *et al*. disagrees with the earlier findings of Raji *et al*. (2009) and Susanti *et al*. (2016), who recorded shorter wing length in a relative proportion of 31.01cm & 23.99cm and 33.64cm & 26.67cm respectively for drakes and ducks. The results are also incongruent with the Yakubu (2011); Morduzzaman *et al*. (2015); Foluke *et al*. (2020), and Kadurumba *et al*. (2021), whose reports ranged between 23.65cm and 25.82cm for drakes and 16.43cm and 24.68cm for ducks. Ewuola *et al*. (2020) recorded a significantly shorter wing length of 13.38cm and 9.94cm for drakes and ducks, respectively. However, sex had a significant influence, as the already mentioned researchers reported, with drakes being superior to ducks in terms of the morphometric trait under study.

Wing Span

The wing span is measured from the tip of the longest primary feather of one wing to the tip of the longest primary feather of the other wing. This is said to be an adaptive feature in ducks as it helps them to flee from predators and determines how high a duck can fly and suspend in the air. Unfortunately, there is little or no information in the literature on the wing span of ducks. However, some researchers have used the wing span to characterise other species. Adenaike *et al*. (2020) and Bhowmik *et al*. (2014) have researched the wing span of turkey and Pigeons in Nigeria and Bangladesh, respectively, as influenced by sex and location. In other research, Brown, Alenyorege, Teye, and Roessler (2017) have studied the wingspan of the local chicken and guinea fowl in Ghana and how the trait is influenced by agroecological zone and sex. Since little or no information is found in the literature, there is a need to assess the wingspan of locally adapted Ghanaian ducks as influenced by sex and location to bridge the literature gap and add to the knowledge repository.

Correlation between body weight and linear body measurements

The correlation analysis measures the relationship between bodyweight and other linear body measurements. It helps to ascertain the direction of the association of bodyweight and linear body measurements. A positive correlation denotes that an increase in bodyweight may cause a significant increase linear body measurement and vice versa.

Hailu et al. (2018) found a positive correlation between body weight and other linear body measurements. The result showed a statistically significant ($p<0.01$) high positive correlation between body weight and chest circumference (0.739) in domesticated local ducks in Gembela and Benishangul of Ethiopia. The results are in harmony with the findings of Kadurumba *et al*. (2021), who also noted that breast circumference had a statistically significant (0.01) highest correlation (0.914) with body weight. The study also agrees with the findings of Birteeb and Lomo (2015), who also found chest girth (0.67) as the highest correlated body part with body weight in WAD goats raised in the Transitional zone of Ghana. However, the report by Ewuola *et al*. (2020) indicated that body length (0.987) had the highest statistically significant ($p<0.01$) correlation with body weight, followed by wing length (0.984) in Muscovy ducks in the humid zone of Nigeria. The study of Ewuola *et al*. 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 agrees with the reports from the study by Lan (2020), who observed body length (0.616) strongly correlated with body weight in Muscovy ducks raised in Papua New Guinea. It is also consistent 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, it strongly disagrees with the subsequent findings of Kadurumba *et al*., who did not see any significant correlation between body weight and body length. Tamzil *et al*. (2018), 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 study slightly agrees 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 regression analysis to predict the body weight of ducks

It is evidenced that linear body measurements of animals could be used to predict body weight by the simple linear regression method. Numerous research’s on different livestock species have utilized this method. Among the researchers includes Birteeb and Lomo (2015), Pesmen and Yardimci (2008), Okpeku *et al*. (2011), and many others. However, their research is skewed towards ruminants than poultry.

However, the estimation of body weight from linear body parameters of ducks is sparse in the literature. Notwithstanding the scarcity, Raji *et al*.

(2009) used a simple regression method to predict the body weight of ducks in Borno state, Nigeria. The study revealed that the regression equations and R^2 (coefficient of determination) of metric traits of local ducks ranged from 0.351 to 0.728. The results indicated that the equation (y = -1.821+0.853x) with chest girth (x) was significant statistically at P<0.01 with R^2 = 0.728. The R^2 value indicates that chest girth alone explained 72.8% of the variance in body weight (y). The results also revealed that body and wing length had a similar R^2 value of 0.704. This also shows that body length and wing length could explain 70.4% of the variance in body weight. Consistently, Sam, Ekpo, Ukpanah, Eyoh and Warrie (2016) saw R^2 value of 0.618, meaning 61.8% of the body weight variance in the two-year age group of WAD goats in Obio Akpa, Nigeria, was explained by heart girth(x) which was statistically significant at P<0.001 using the model (y= -18.10 + 1.56x). Also, the study by Ewuola *et al*. (2020) 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. The findings reported that the highest single trait predictor of body weight among the morphometric traits studied was body length with R^2 value of 0.974, indicating that body length accounted for 97.4% of the live body weight variance in the model (y = -2607.539 + 265.568x) where x = body length. Wing length, foot length and breast circumference accounted for 0.969, 0.918 and 0.869 using the model (y = -1153.662 + 320.486x; y = -1258.891 + 407.707x and y = -2263.640 + 207.765x) respectively. This shows that wing length, foot length and breast circumference explained 96.9%, 91.8% and 86.9% of the body weight variance, respectively, which were significant statistically at P<0.01. The highest R^2 (coefficient of determination) values reported by Raji *et al*. and Ewuola *et al*. clearly shows that body weight can be projected from a single and easily measurable metric trait for ducks with a higher level of accuracy using a simple regression method.

Measurement of Genetic diversity between duck populations using morphostructural attributes of ducks

Understanding the genetic variability between individual animals or the entire population aids in the conservation, improvement and sustainable use of AnGR FAO (2011). The measurement of genetic distance is the variability between two objects by describing the allelic variations or variation in nucleotide sequences between the populations, breeds or species numerically. Species with more similar alleles have less genetic distance and can be considered descending from a recent common ancestor, while those whose amino acid sequences are distantly related are genetically diverse. The reconstruction of the population history cannot be made possible when the usefulness of genetic distance is deprived. Genetic distance helps to understand the origin of animal breeds or species (Worku & Tadesse 2017).

Maintaining genetic diversity between and within livestock populations is critical to meet future adversities, including climate change, increased human populations, food security and disease epidemics. The allelic and the genotypic frequencies come into play to maintain genetic diversity. The more the variability in many alleles present, the larger the genetic diversity and vice versa (Oldenbroek & Waaij, 2015). An increase in heterozygosity of alleles within and between animal populations is significant to genetic diversity as its reduction increases homozygosity, reducing genetic variability. The reduction in heterozygosity always has a major consequence on the population structure as a deviation from expected heterozygote frequency causes inbreeding which also reduces genetic diversity. Other forces that do not conform to Hardy-Weinberg principles can increase or decrease genetic variability in a population. This includes sudden genetic changes, thus mutation that can create an alternative form of a gene that may increase genetic diversity. Also, migration can either increase or decrease genetic diversity. When new animals move into the population, there is an increasing effect; however, emigration in a small population mostly decreases genetic diversity. Again, the selection of elite breeding animals causes a decrease in gene flow as candidates with specific genetic makeup are allowed to breed the next generation at the expense of other animals. Finally, genetic drift through death, selective breeding, infertility and culling of animals causes a reduction in genetic diversity (FAO, 2011; Oldenbroek & Waaij, 2015).

Assessment of genetic diversity can be done using zoometric or morphostructural parameters, biochemical markers (enzymes, hormones, antigens and antibodies) and molecular markers (SNPs, microsatellite markers, RFLP). However, the latter has the upper hand over the former FAO (2012). Nevertheless, a proper phenotypic characterisation using zoometric traits to some extent can provide a realistic depiction of the variability among breeds and can serve as a basis for molecular genetic diversity evaluation (Dauda, Abbaya & Ebegbulem, 2018). The information gathered on zoometric traits is the first step in classifying AnGR (FAO, 2012). Analysis of variance used to be the approach to differentiating populations in the past; however, currently, multivariate analysis is the order of the day to classify populations using a cluster, principal component and discriminant analysis (Dossa, Wollny & Gauly, 2007).

According to Lix and Sojobi (2010), multivariate analysis involving cluster, discriminant and principal components analyses is suitable for assessing genetic variations within and between populations when all the traits are considered simultaneously. It explains the total variation for the group (FAO, 2012; Yakubu & Ibrahim, 2011). Mahalanobis distance determines the degree of differentiation between, within and among populations using continuous or normally distributed metric traits.

Application of discriminant analysis to differentiate and classify within and between duck populations using metric characters

Ogah *et al*. (2011) recorded a long genetic distance (54.803) between the guinea savanna and the dry savanna, followed by a distance between the dry savanna and the rain forest (35.435) and the least genetic distance (Mahalanobis distance) between the guinea savanna and the rain forest (34.120) Muscovy duck ecotypes in a study titled "Application of canonical discriminant analysis for assessment of genetic variation in Muscovy duck ecotypes in Nigeria". The higher Mahalanobis distance recorded between the guinea savanna and the dry savanna could be the result of selection and adaptation to the conditions of the production environment, whiles the lower distance recorded between the guinea savanna and the rain forest could be explained by the proximity to geographical location causing indiscriminate mating and cross-breeding among the two duck populations (Dauda, Abbaya & Ebegbulem, 2018; Yakubu & Ibrahim, 2011). The findings disagree with Oguntunji and Ayorinde (2015), who reported a shorter genetic distance ranging from 2.010 to 3.758 in the study "multivariate analysis of morphological traits of the Nigerian Muscovy ducks (*Cairina moschata)"*.

The acquisition of information on the use of Mahalanobis distance to study the degree of morphometric divergence or similarity in duck populations is scarce; however, other researchers have used other genetic distance models like the Nei's and Reynolds genetic distance to distinguish duck populations in different geographical locations. Such research includes "evaluation of genetic diversity and population structure in four indigenous duck breeds in Vietnam" (Pham *et al*., 2022), "marginal diversity analysis of conservation of Chinese domestic duck breeds" (Yang *et al*., 2019), "genetic diversity and population structure of 10 Chinese indigenous egg-type duck breeds assessed by microsatellite polymorphism" (Gong *et al*., 2010).

Moreover, some researchers have also used the approach to cluster other poultry species. Adenaike *et al*. (2020) conducted a study on "multifunctional discriminant analysis of morphostructural traits in Nigerian locally adapted turkeys" and found a larger Mahalanobis distance (415.16) between the male white major and female white major. Adeyemi and Oseni (2017) reported a longer Mahalanobis distance (57.595) between the white and lavender plumage, while the least distance (6.745) was recorded between black and lavender plumage colour when he applied canonical discriminant analysis to study the biometric data of Nigerian indigenous turkey. In contrast, Ogah (2013) and Melesse *et al*. (2021) recorded lower Mahalanobis distance between the range of (3.371 & 4.620) and (4.39 & 23.90) on "canonical discriminant analysis of morphometric traits in indigenous chicken genotypes" and "assessing the morphological diversity of Ethiopian indigenous chickens using multivariate discriminant analysis of morphometric traits for sustainable utilization and conservation" respectively. The results reported by Ogah and Melesse *et al*. show a closer relationship among the chicken population studied and can be thought of as originating from a common ancestor.

Principal Component Analysis (PCA)

Principal component analysis helps to assess the total variance and defines the characters with greater discriminatory effects between cluster groups. Maharani *et al*. (2019) extracted two to four principal components from a factor analysis with varimax rotation from a study conducted on "the phenotypic characterisation of local female ducks in Indonesia" considering five duck populations from Alabio, Magelang, Pegagan, Pitalah and Rambon. The study revealed that the PC1 accounted for much of the variability in the duck populations from the duck populations studied. Maharani et al. (2019) recorded that PC1 had higher loadings on beak length (0.778) in Alabio duck populations suggesting beak length as the traits with the highest discriminatory ability. The results of the study are comparable to the findings of Yakubu *et al*. (2011) on ducks Egena, Ijaiya, Ogah, & Aya (2014); Dahloum, Moula, Halbouche, and Mignon-Grasteau (2016) on chickens and Ogah (2011) on turkeys. The medium to high communalities observed in the study for beak width, beak length, neck diameter and neck length indicates that those morphometric traits can be used to explain the total variation in body dimensions of poultry species. However, the lower communalities observed for claw length in the Alabio duck populations show how weak claw length explains the overall variance in body measurements. These explanations are affirmed by Mendes (2011), Ogah (2009) and Yakubu, Kuje and Okpeku (2009).

Population structure and the rate of inbreeding in the indigenous duck populations

The duck population in Ghana is a unique animal genetic resource estimated to be around 300 000 (FAO, 2014). The comparative advantage of other poultry species, like chicken and guinea fowl over ducks, threatens the patronage leading to the endangerment of the specie (Mantey *et al*., 2014). The lower estimated population size and a drastic decline in recent years might exacerbate the rate of inbreeding within the limited population. The population size may significantly influence population dynamics (Ogah & Ari, 2012). The tendency of inbreeding depression resulting from the escalated rate of inbreeding may be high, considering the limited population size. Inbreeding depression could lead to declining reproductive efficiency and fitness in a population and consequently hinder population growth. Several studies on the effect of inbreeding in livestock and poultry have been carried out in other countries (Thompson *et al*., 2000; Ogah & Ari, 2012). However, there is no attempt to deliberately improve the performance of the indigenous ducks in Ghana despite its significance in alleviating the poverty of the rural poor. Therefore, assessing the current population structure to predict the rate of inbreeding of indigenous ducks in Ghana is justified.

Production abilities of Ducks

Egg colour

Ducks produce eggshells with diverse colouration such as white, cream, blue, bluish green and charcoal grey; however, white and bluish-green are ducks' two main eggshell pigmentation phenotypes (Bai *et al*., 2019). The eggshell colour is determined by the proportion of biliverdin to protoporphyrin content in the shell (Hargitai, Boross, Nyiri and Eke, 2016) and its relatedness to the age and breed of the laying duck (Bi *et al*., 2018). The shell colour may have distinct functions such as adaptation to prevent predation, strengthening of shell structure (Samiullah, Roberts & Chousalkar, 2016) and reducing microbial contamination (Ishikawa *et al*., 2010; Bai *et al*., 2019). It may also play a role in facilitating the filtration of harmful solar radiations and regulating temperature to maintain embryonic development (Westmoreland, Schmitz & Burns, 2007; Maurer *et al*., 2015; Liu *et al*., 2021). Consumers use eggshell colours to determine the quality and usually prefer some colours to others. In Asia, bluish-green eggshell colours are mostly preferred (Jonchère *et al*., 2010; Bai *et al*., 2019; Ren *et al*., 2022). The empirical literature on the eggshell colour of ducks is relatively scarce; however, Morduzzaman *et al*. (2015) reported 100% bluish colouration in Nageswari ducks in Bangladesh.

Egg weight

The average egg weight of Dumyati and Muscovy ducks was reported by Ahmed (2011) to be 61.42±1.06 and 69.55±1.52g, respectively, when the research was conducted on "comparative study on the mechanical properties and ultrastructural eggshell traits for Dumyati and Muscovy ducks" in Egypt. The results agree with Popoola, Alemede, Aremu and Ola (2015), who recorded the average egg weight of 67±3.03g for Muscovy ducks in Osun State, Nigeria. The result again conforms to Morduzzaman *et al*. (2015), whose report revealed the average egg weight of Nageswari ducks in

Bangladesh to be 67.32±0.82g. It is also within the range of 60-90g reported by Huan and Lin (2011). However, a slightly lower egg weight of 61.22g was recorded for Sudani (Egyptian Muscovy) ducks (Makram, Galal and El-Attar, 2021) and 58.23±2.33g for white Muscovy (Susanti *et al*., 2016). In other studies, relatively heavier eggs were recorded by Lase, Rukmiasih, Hardjosworo, Lestari, & Sinabang (2021) to be 71.10±3.6g for Muscovy ducks in Indonesia. The work of Etuk, Ojewola, Abasiekong, Amaefule and Etuk (2012) also revealed a higher egg weight of 70.80±0.35g, 76.27±0.49g and 76.35±0.34g for Muscovy ducks raised in Semi-intensive, intensive-system with wallow and intensive-system without wallow in Akwa Ibom, Nigeria. The report of Yuan *et al*. (2013) on the normal and striped Pekin egg weight was 94.60±3.71g and 97.31±4.99g, respectively. Furthermore, Mazanowski, Kisiel and Adamski (2005) documented egg weights of 142.70g, 143.20g, 145.40g and 149.20g for the Podkarpacka goose, Kielecka goose, Suwalska goose and Kartuska goose, respectively in Poland. These findings are relatively higher than the findings of Ahmed (2011).

Egg length and width

Popoola *et al*. (2015) documented egg length of 63.10±0.05mm and egg width of 41.10±0.11mm for Muscovy duck eggs in Osun State, Nigeria. These results are consistent with those reported by Harun, Veeneklaas, Visser and van Kampen *et al*. (2001) and Lase *et al*. (2021), who recorded average egg length and width of 62.60±1.90mm & 46.70±1.10mm and 60.45±1.50mm & 42.43±1.60mm respectively. The results also agree with the findings of Etuk *et al*. (2012), who recorded egg length and width of 60.56±0.44mm & 46.15±0.26mm, 61.10±0.40mm & 46.15±0.26mm and 60.89±0.41mm &

44.89±0.20mm for Muscovy ducks raised in Semi-intensive, the intensive system with wallow and intensive system without wallow in Akwa Ibom, Nigeria. Likewise, Makram *et al*. (2021) and Pandian *et al*. (2012) documented a similar result for egg width of 42.70mm and 45.12±0.42mm; however, their reported egg length of 58.32mm and 59.80±0.54mm, was slightly lower than what was recorded by Popoola *et al*. (2015).

Egg shape and shape index

The shape of the egg, when visually assessed, is constrained more by width than length (Salamon & Kent, 2017), and the shape index calculated from the dimensions of an egg is the ratio of egg width to egg length expressed in percentages (Panda, 1996 cited by FAO, 2012). Nishiyama (2012) outlined four basic shapes of eggs thus; circular or round, elliptical, oval and conical. A study by Salamon and Kent (2017) saw 17.24% conical shape, 10.88% elliptical shape and 4.31% oval shape in single-yolked duck eggs (*Anas platyrhynchos domesticus*). The visual appraisal of duck egg shape is limited in the literature; however, most researchers use the shape index to characterize the egg shape of ducks.

The egg shape index for Muscovy ducks' eggs originating from Indonesia's Cirebon region was 76.57% (Widianingrum, Widjastuti, Anang & Setiawan, 2020). The results are in line with Etuk *et al*. (2012), who reported a 76% shape index for Muscovy ducks raised semi-intensively in the humid tropical region of Nigeria. The results are similar to Pandian *et al*. (2012), who recorded a 75.50% shape index for eggs collected from intensively raised ducks in India. The current findings are higher than those of Makram *et al*. (2021), who recorded a shape index of 73.26% in sudani ducks in Egypt. A lower average shape index (72.24%) was recorded for mallard ducks, and a significantly lower shape index was recorded for the pekin ducks in the same study (Al-Obaidi & Al-Shadeedi, 2016). Ipek and Soczu (2017) also witnessed a 72% shape index for a lightweight egg from pekin ducks in Bursa, Turkey.

Percentage hatchability of eggs

One trait of economic importance in domestic poultry production is the hatchability of eggs (Abd El-Hack *et al*., 2019). It is usually affected by genetics, age of breeding stock, nutrition, storage, conditions for incubation and shell parameters (Kamanli, Durmus and Demir, 2010; Yuan *et al*., 2013). Other environmental factors such as ventilation, egg turning during incubation, relative temperature and humidity significantly influence hatchability (Archer, Jeffrey & Tucker, 2017; Ramli *et al*., 2017). The percentage hatchability recorded by Widianingrum *et al*. (2020) was 72.90%, 76.00%, 78.20% and 81.60% for Muscovy ducks raised in Cirebon, Kuningan, Indramayu and Majalengka regions of Indonesia. The results slightly agree with Yuan *et al*. (2013), who reported a percentage hatchability of 76.44±10.45% and 86.83±3.76% for stripe and normal Pekin eggs, respectively. The results are slightly harmonious with the findings of Nageswara, Ramasubba-Reddi and Ravindra-Reddy (2005), who reported an average hatchability percentage of 71.00±0.14% for indigenous ducks and 68.40±0.12% for Khaki Campbell ducks' eggs in India. The findings slightly agree with Makram *et al*. (2021), who recorded a hatchability percentage of 73.30% for Sudani (Egyptian Muscovy); however, a decreased hatchability percentage of 47.30% and 36.90% was reported for a cross between Muscovy & Sudani and Pekin & Sudani ducks' eggs respectively in the same study.

Again, Rashid, Kawsar, Miah and Howlider (2005) recorded slightly decreased hatchability of 54.21% and 62.91% for Muscovy and the pekin duck eggs correspondingly in Bangladesh whilst Susanti (2021) also reported the lowest hatchability of 14.60% in Muscovy ducks in Indonesia. Nickolova (2005) on the other hand reported the highest percentage hatchability of 95.48% for Muscovy ducks when an experiment was conducted to study the impact of temperature regime in the incubation of Muscovy duck eggs in Bulgaria.

Age at first egg and total egg production per year (TEPY)

Nageswara *et al*. (2005) reported the age at first egg (AFE) for indigenous ducks and Khaki Campbell ducks to be 139±7.40 and 147±5.10 days, respectively. The findings are incongruent with those of Widianingrum *et al*. (2020), who documented 194.60, 208.40, 169.60 and 167.40 days for AFE of Muscovy ducks raised in Cirebon, Indramayu, Majalengka and Kuningan regions of Indonesia respectively. The results also disagree with Morduzzaman *et al*. (2015), who recorded 168.48±3.53 days for age at first egg for Nageswari ducks in Bangladesh.

For total egg production per year (TEPY) per duck, Morduzzaman *et al*. (2015) reported an average of 173.63±3.39 eggs for On-station and 201.00±0.52 eggs at Farmer’s level for Nageswari ducks in Bangladesh. The results are higher than the findings of Widianingrum *et al*. (2020), who reported 130.40, 79.20, 126.00, and 127.00 for on-station Muscovy ducks originating from Cirebon, Indramayu, Majalengka and Kuningan regions of Indonesia. Likewise, Mazanowski, Bernacki and Kisiel (2005) recorded a lower TEPY of 177 and 129 for A44 and A55 paternal strains and 135, 134 and 121 for P66, P77 and K11 maternal strains on the Waterfowl Breeding Farm Dworzyska, Poland.

Hatching window of eggs

Ipek and Sozcu (2015) reported an ideal incubation period of 672 h (approximately 28 days) for pekin ducks in Bursa, Turkey. This report was affirmed by Pereira *et al*. (2021) for the same breed of ducks raised in Araquari, Santa Catarina, Brazil. The results were again confirmed by Ipek and Sozcu (2017) for the pekin ducks; however, some eggs hatched as early as 637 h (26.54 days) this time. In contrast, Arias-Sosa and Rojas (2021) recorded an incubation period of 34 days in their review of the productive potential of Muscovy ducks. Likewise, Widianingrum *et al*. (2020) reported 33.45 days for Muscovy ducks originating from different regions of Indonesia.

Farmers trait preferences

The indigenous duck populations in Ghana represent a valuable animal germplasm that needs to be conserved for sustainable utilization. The specie has improved the livelihood of the many poor farmers in rural areas and has played a significant role in attaining global food security (Aning, 2006). In Ghana, duck production is constrained by biological, environmental and socioeconomic factors (Agbolosu & Aawona, 2021). There is no known breed improvement programme for indigenous ducks in Ghana, which affirms the specie's neglect in academic research and development in Ghana. The understanding of ducks' genetic potentials and associated productive factors is insufficient, which has hampered the development of ducks in Ghana. Studying the socioeconomic features and farmer's trait preferences of ducks is critical for preserving and conserving the species' tremendous genetic abilities.

Understanding farmers' socioeconomic characteristics and traits preferences aids in selecting beneficial traits to be included in breeding goals in breed improvement programmes. Farmers keeping objectives and trait preferences form a significant component of phenotypic characterisation (FAO, 2012).

Chapter Summary

This chapter reviewed both the theoretical and empirical literature on ducks. This chapter dived deeper into the empirical review of ducks' characterisation. The empirical review provided vital information on the phenotypic and morphometric characteristics and the correlation among these traits. This information forms the foundation of the present study.

CHAPTER THREE

MATERIALS AND METHODS

Study Location

The study was conducted in three (3) agroecological zones of Ghana, namely, the Coastal savanna, Semi-deciduous forest and Rainforest.

Table 1: Description of the study area

Characteristics	**Agro-ecological zone**		
	Semi Deciduous Forest	Rainforest	Coastal Savannah
Climate			
-Temperature	24-31°C	25-29°C	24-30°C
-Relative Humidity	60-80%	65-80%	70-85%
-Rainfall	1200-1600mm	800-2800mm	600-1200mm
-Longitude	001°29'-001°40'W	001°59'-001°02'W	000°09'-002°02'W
-Latitude	06°14'-06°36'N	04°59'-05°00'N	05°00'-05°45'N
-Elevation	260-400m	150-380m	75-140m
-Slope	Very variable (hilly, undulating, steep and mountainous)	Very variable (hilly, undulating and mountainous)	Very variable (hilly, flat, undulating and mountainous)
-Soil type	Sandy-loamy	Loamy	Clayey-loam
-Soil pH	Neutral (pH between 5.5 and 8.5)	Neutral (pH between 5.5 and 8.5)	Neutral (pH between 5.5 and 8.5)
-Surface condition (main substrate on which animals are generally maintained)	Variable substrate types (sandy, natural vegetation)	Variable substrate types (sandy, natural vegetation)	Variable substrate types (sandy, natural vegetation)
Land cover or vegetation	Presence of tall trees interspersed with evergreen undergrowth	Dense vegetation with major tall tropical trees like iroko, mahogany, silk cotton, etc.	Coastal shrubs in the upland interspersed with grasses
Land use	Cultivation of cash crops (cocoa, oil palm, teak), arable crops (maize, cassava, cowpea) and rearing of livestock	Cultivation of cash crops, arable crops (maize, cassava, vegetables) and rearing of livestock	Cultivation of cash crops (pineapple, cocoa, orange), arable, crops, vegetables) and rearing of livestock

Sources: Field Data, (2022); MoFA, (2010); FAO, (2012); Ofori *et al*. (2021)

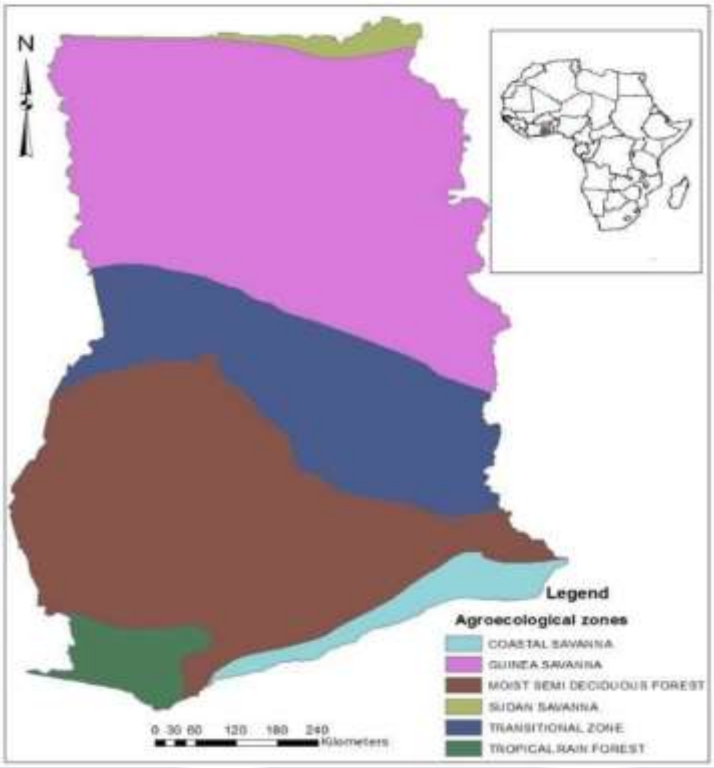

Figure 2: A map depicting the study areas

Sampling technique

A multistage purposive sampling and snowballing technique were adopted for the study. Four stages of sampling were used; agroecological zone, district, community and household. Districts, communities and households were chosen purposively based on the evidence of ducks.

Population and Sample size

A total of 414 mature ducks aged 1-3 years old were randomly selected from the duck populations in the three agroecological zones. The study used 138 males and 276 females with 46 males and 92 females from each agroecological zones. The sample size was taken following the FAO (2012) breed descriptor tool for phenotypic characterisation studies. Information on the quantitative traits of eggs were assessed on 450 eggs; 150 eggs from each agro-ecological zone. The formula for choosing the minimum sample size is described below;

$$n = \left(\frac{z}{m}\right)^2 p(1-p) \text{ ……………………… (3)}$$

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.

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

Data collection method and duration

A primary characterisation approach and survey method involving observation and direct body measurements were adopted. The duration of the collection of the data spanned from November 2021 to May 2022.

Household qualitative data collection

A semi-structured questionnaire was used to engage ninety (90) duck farmers to collect demographic data, objectives of keeping ducks, traits preferences, management system, flock size and structure, socio-economic challenges, resource availability and disease epidemics as well as the production performance of ducks. The questionnaire used is included in Appendix B.

The Global Positioning System (GPS) Store Coordinates App was downloaded from google Playstore and installed on Android OS smartphones to take GPS coordinates of the geographical location of places where data were collected.

Data collection for phenotypic and genetic differentiation of qualitative traits

Identification of eight qualitative traits for phenotypic differences like bill colour, bean colour, web colour, shank colour, plumage colour, plumage pattern, skin colour and eye colour were assessed by visual appraisal. The information gathered on the qualitative traits of ducks aided in the description of the duck populations in the three agroecological zones studied.

Data collection for Morphometric traits

Measurements of morphometric characteristics were recorded as defined by FAO (2012). The body weight and other linear body characters were taken with a 10kg digital hanging weighing scale, digital caliper 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 end of the caudal tail without feathers with a measuring tape.
- ✓ **Wing span (WS)**: Using a tape measure, the length between the wingtips was measured to the nearest centimeters when the wings were outstretched.
- ✓ **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 regiotarsalis was measured to the nearest centimeters on the right limb using a pair of caliper.
- ✓ **Bill length (BLL)**: Bill length was measured to the nearest centimeters from the base of the bill to the tip using a pair of caliper.
- ✓ **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.

The same instruments were used to collect quantitative data on egg length, width and weight. Figures indicating the various morphometric measurements can be seen in Appendix A.

Statistical Data Analysis

Statistical analysis of qualitative phenotypic traits

The frequencies of duck populations showing a particular phenotype of qualitative traits were computed by descriptive statistics using IBM SPSS 25.0 statistical software.

The degree of differentiation between the three duck populations from the three corresponding agro-ecological zones were obtained by estimation of the genetic distance between the populations as follows;

$$d^2 = (P_1 - P_2)^2 \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Where; $d^2 =$ the estimated genetic distance between any two populations

P_1 = Gene frequency of a given trait in population 1

P_2 = Gene frequency of a given trait in population 2

Statistical analysis of quantitative (morphometric/morphostructural) traits

Analysis of Variance (ANOVA)

Morphometric traits were subjected to analysis of variance with sex and agroecological zones as fixed factors using the General Linear Model (GLM) of Minitab 19. Mean separation for traits exhibiting significant differences was done using the Tukey HSD 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;

$$Y_{ij} = \mu + S_i + E_j + e_{ij} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (5)$$

Y_{ij} = individual observation of each body trait;

μ = overall mean;

S_i = fixed effect of ith sex (i = male, female);

E_j = fixed effect of j^{th} agroecological zone (j = Semi Deciduous-1, Rainforest-2 and Coastal Savannah-3);

e_{ij} = random error associated with each record

The estimated standard deviation was done as follows;

$$\sigma = \sqrt{\frac{\sum_i^n (x_i - \bar{x})^2}{n-1}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

Where; σ=sample standard deviation

x_i = observed values of a sample item

$\bar{x}$ = mean of the observations

n = number of observations

Pearson correlation matrix was estimated for the measured morphometric traits using IBM SPSS 25.0 statistical package as follows;

$$r\,(xy) = \frac{cov(xy)}{\sqrt{var(x).var(y)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

Symbolically,

$$r_{xy} = \frac{\sum(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum(x_i - \bar{x})^2 \sum(y_i - \bar{y})^2}} \ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

Where,

cov(xy) = the covariance between traits x and y

var(x) = the variance for trait x

var(y) = variance for trait y

$r_{(xy)}$: the correlation coefficient of the linear relationship between the traits x and y

x_i = the measured values of trait x

$\bar{x}$ = the mean of the values of trait x

y_i = the measured values of trait y

$\bar{y}$ = the mean of the values of trait y

A simple and multiple regression analysis was used to estimate the relationship among morphometric traits to predict body weight using IBM SPSS 25 statistical package as follows.

$$LW = \beta_0 + \beta + \varepsilon \ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where,

LW = live weight,

β_0 = the intercept of the regression equation,

β = partial regression coefficient of the linear body trait retained in the model,

ε is the random error.

Multivariate Analysis

A multivariate analysis study is suitable for assessing genetic variations within and between populations when all the traits are considered simultaneously (Lix & Sojobi 2010). Principal Component Analysis was done by extracting the principal components from factor analysis to determine the morphometric trait with the highest discriminatory power.

Discriminant analysis was used to classify and differentiate the three duck populations from the three corresponding agro-ecological zones using Minitab 19 statistical package based on Mahalanobis distance using the formula;

$$D^2 = (x - m)^T \cdot C^{-1} \cdot (x - m) \quad \text{.............................} (10)$$

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.

The effective population size and the inbreeding coefficient were estimated using the formula given as follows;

$N_e = \frac{4(N_m x N_f)}{N_m + N_f}$ and $\Delta F = 1/2N_e$

Where N_e = Effective population size

N_m= number of breeding drakes

N_f = Number of breeding ducks

ΔF = inbreeding coefficient

Chapter Summary

The study used a primary characterisation approach and a survey method to collect data on 414 matured ducks across three (3) agroecological zones of Ghana. Ninety (90) duck keepers were engaged in the study. Ten (10) qualitative traits were assessed by a visual appraisal, and nine (9) morphometric traits were taken with the help of a digital weighing scale, digital calipers and measuring tape. Descriptive statistics involving frequency and percentages were used to analyze qualitative data, whereas inferential statistics involving ANOVA, discriminant and principal component analysis were used to analyze quantitative data.

CHAPTER FOUR

RESULTS AND DISCUSSIONS

Phenotypic differentiation in qualitative characteristics of duck populations

The distribution of qualitative characteristics of ducks with agroecological zones and sex as factors are presented in Tables 2 and 3, respectively. The studied traits exhibited differences across the three agro-ecological zones.

Table 2: Distribution of Morphological Traits of Indigenous Duck Populations as Influenced by Agro-Ecological Zones

Trait	Colour	Agroecological Zones (%) Semi-deciduous Forest (N=138)	Coastal Savanna (N=138)	Rain Forest (N=138)	Overall (%) (N=414)
Plumage colour	White	26.80	29.70	23.90	26.80
	Black	27.50	30.40	37.70	31.90
	Black & White	45.70	39.90	38.40	41.30
Plumage pattern	Single colour	26.8	29.70	31.20	29.20
	Double colour	66.70	66.70	59.40	64.30
	Multi-colour	6.50	3.60	9.40	6.50
Bill colour	Yellow	4.30	3.60	0.70	2.90
	White	0.70	0.70	0.70	0.70
	Pink	58.00	54.30	52.20	54.80
	Black	18.80	24.60	27.50	23.70
	Black & Pink	18.10	16.70	18.8	17.90
Bean colour	White	15.90	17.40	15.20	16.20
	Black	66.70	71.70	71.00	69.80
	Black & White	17.40	10.90	13.80	14.00
Caruncle colour	Red	59.40	58.00	56.50	58.00
	Black	7.20	9.40	11.60	9.40
	Red & Black	33.30	32.60	31.90	32.60
Shank colour	Yellow	55.80	52.20	52.90	53.60
	Black	42.80	47.10	46.40	45.40
	Slate	1.40	0.70	0.70	1.00
Web colour	Yellow	52.90	56.50	58.00	55.80
	Black	12.30	13.80	9.40	11.80
	Black & Yellow	34.80	29.70	32.60	32.40
Skin colour	Yellow	24.60	19.60	22.50	22.20
	White	42.00	47.80	43.50	44.40
	Pink	33.30	32.60	34.1	33.30
Eye colour	Brown	26.10	21.00	24.60	23.90
	Yellow	59.40	59.40	62.30	60.40
	Black	14.50	19.60	13.00	15.70
Egg colour	Cream	100	100	100	100

N= Sample size

Table 3: Distribution of Morphological Traits of indigenous Duck Populations as influenced by sex

Trait	Colour	Sex (%)	
		Drakes (N=138)	Ducks (N=276)
Plumage colour	White	42.00	26.80
	Black	30.40	31.90
	Black & White	27.50	41.30
Plumage pattern	Single colour	35.50	26.10
	Double colour	61.60	65.60
	Multi-colour	2.90	8.30
Bill colour	Yellow	5.80	1.40
	White	2.20	0.00
	Pink	60.10	52.20
	Black	14.50	28.30
	Black & Pink	17.40	18.10
Bean colour	White	6.50	21.00
	Black	76.80	66.30
	Black & White	16.70	12.70
Caruncle colour	Red	53.60	60.10
	Black	11.60	8.30
	Red & Black	34.80	31.50
Shank colour	Yellow	51.40	54.70
	Black	45.70	45.30
	Slate	2.90	0.00
Web colour	Yellow	53.60	56.90
	Black	10.90	12.30
	Black & Yellow	35.50	30.80
Skin colour	Yellow	26.10	20.30
	White	39.10	47.10
	Pink	34.80	32.60
Eye colour	Brown	30.40	20.70
	Yellow	54.30	63.40
	Black	15.20	15.90

N= Sample size

Plumage colour and Plumage pattern

The results of the current study revealed that the predominant plumage colour of ducks in Ghana is black and white (41.30%), followed by black (31.90%) and, finally, white plumage (26.80%) colour. However, drakes were dominant in white plumage (42%), whiles ducks mainly appeared in black and white plumage (41.30%). The present study finds agreement with Kadurumba *et al*. (2021), who observed black with white patches (54.79%) to predominate in the south-east agroecological in Nigeria, followed by black (17.81%), white (10.96%) with brown (1.37%) as the least dominated plumage colour. The results of the current study reaffirm the report of Ewuola *et al*. (2020), who recorded Pied (Black and White) plumage as the predominant plumage colour for Muscovy ducks in the humid zone of Nigeria with a frequency of 69%, followed by white (31%). The results of the current study disagree with the earlier findings of Chia and Momoh (2012), Banerjee (2013) and Oguntunji and Ayorinde (2015). The current work further disagrees with Foluke *et al*. (2020), Raji *et al*. (2009) and Oguntunji *et al*. (2020). The current study observed double colour (64.30%) as the subjugated plumage pattern in the study area followed by solid colour (29.20%), i.e., either solid white or solid black and then multi-colour (6.50%) across the three agro-ecological zones. Likewise, both drakes and ducks had a double colour pattern, as evidenced in Table 3. The plumage pattern recorded in the current study compares well with the earlier findings of Ewuola *et al*. (2020), who identified double as the predominant pattern and the solid white pattern as the least in a relative proportion of 69% and 31%, respectively. The results also agree with the report of Kadurumba *et al*. (2021).

Bill colour

Four variants were recorded for bill colour in the three agroecological zones studied. The predominant colour was pink (54.80%), followed by black (23.70%), black-pink (17.90%), yellow (2.90%) and white (0.70%). Table 3 revealed no sexual dimorphism in bill colour, as both drakes and ducks had a prominent pink bill. The results from the present study slightly agree with Kadurumba *et al*. (2021), who recorded Pink-white (97.26%) as the predominant colour while 2.74% had yellow bill colour in local duck population in the lowland area of the rainforest agro-ecological zone of Nigeria. However, the current study disagrees with Maharani *et al*. (2019), who identified Black bill (77.49%) as predominant, followed by Yellow (16.23%) and brown (0.52 %) as the least observed bill colour among local female duck populations in Indonesia. Likewise, the present study is incongruent with the findings of Banerjee (2013), who recorded slate-grey bill in black and white Muscovy ducks and yellow bill in sepia-feathered Muscovy ducks in West Bengal in Ethiopia. Moreover, it is in contrast to the report of Morduzzaman *et al*. (2015), who recorded black bill (57.69%) followed by black with yellowish tint (23.07%) and yellowish bill (19.23%) for drakes, whereas ducks were composed mainly of a black bill (93.75%) and black with yellowish tint (6.25%) in Nageswari duck populations. Furthermore, the present study disagrees with Tamzil *et al*. (2018), who observed an equal proportion of black-base-white-tip and reddish white with pink bill colours in males; nevertheless, females had 60% and 40% reddish white with pink bill and black-base-white-tip bill colours respectively. Also, Kamal *et al*. (2019) reported yellow, yellowish green and green black with a yellowish tint in the relative prevalence of 44.44%, 33.33% and 22.22%, respectively, for drakes, whereas ducks recorded 52.25%, 29.73% and 18.02% for yellow, black and green in successive order.

Bean colour

The present findings revealed in Table 2 that black (69.80%) was the predominant bean colour, followed by white (16.20%) and then black and white (14.00%) across the three agroecological zones. Table 3 on the other hand showed that 76.80% of drakes and 66.30% of ducks had black bean. The results are harmonious with the findings of Hailu *et al*. (2018), who identified black bean (77.10%) as the predominant in the Ethiopian locally adapted duck populations, followed by white (15.9%), brown (3.5%) and black brown and brown white shared equal frequency of 1.8%. The study partially agrees with Oguntunji *et al*. (2020), who similarly documented black bean (69.54%) as the frequently occurring bean colour in ducks, whereas all drakes had black bean from North-west Nigeria. Morduzzaman et al. (2015) consistently reported 100% black bean colour from Nageswari duck in Bangladesh. The current findings disagree with Banerjee (2013) and Kadurumba *et al*. (2021), who recorded all-white bean colour from duck populations in West Bengal, India and Omo & Abia states in Nigeria, respectively.

Caruncle colour

The present study observed three colour variants (red, red-black and black) for caruncles across the study area. Red caruncle prevails as the dominant, followed by red-black and black in a proportion of 58.00%, 32.6% and 9.40%, correspondingly. The findings partially agree with Oguntunji and Ayorinde (2015), who identified four colour variants for caruncle: red, red-black, black and light yellow, in a frequency of 83.53%, 13.92%, 2.44% and 0.88% in orderly manner. The study again finds partial consonance with Foluke *et al*. (2020), who recorded red as the predominant caruncle colour followed by Pink and then Black in a ratio of 40%, 35% and 25%, respectively, for Muscovy ducks raised in North-central Nigeria. Similarly, Ewuola *et al*. (2020) observed red (58.50%) as the predominant caruncle colour and black (41.50%) as the least subjugated caruncle colour. Also, Banerjee (2013) and Kadurumba *et al*. (2021) recorded 100% red caruncle colours in Muscovy ducks raised in West Bengal, India and Abia state of Nigeria, respectively. Both drakes and ducks had predominant red caruncles in a proportion of 53.60% and 60.10%, correspondingly.

Shank colour

Three variants were recorded for shank colour in the present work. Yellow, black and slate appeared in a proportion of 53.60%, 45.40% and 1.00%, respectively. The findings align with Ewuola *et al*. (2020), who identified two variants that is yellow and black, with a frequency of 62.50% and 37.50% respectively, it is comparable with Tamzil *et al*. (2018), who witnessed yellow (49%) in drakes and 48% in ducks as the predominant colour in Lombok, Indonesia followed by black with yellowish tint (34 %) for drakes and 38% for ducks and then black being the minor colour recorded in a proportion of 21% and 22% in drakes and ducks respectively. The current study finds partial consonance with Banerjee (2013), who identified solely yellow shank colour in sepia feathered Muscovy ducks; however, all black and white feathered Muscovy ducks were characterized by slate grey shank colour in west Bengal, India. On the contrary, Hailu *et al*. (2018) reported that brown-grey shank colour was the most occurring shank colour, followed by brown-white, white, yellow, black-brown and black shank as the least dominant, it further disagrees with Morduzzaman *et al*. (2015), who witnessed black (73.07% and 90.63%) as the subjugated shank colour for drakes and ducks respectively then followed by black with yellowish tint recording 7.69% for drakes and 9.37% for ducks. The shank colour differentiation by sex saw drakes and ducks both dominant in yellow shanks, followed by black, as shown in Table 3.

Web colour

Three variants were recorded for web colour from the study area. Yellow (55.80%) web was the common colour, followed by black with a yellowish tint (32.40%) and then black (11.80%). The current study finds partial agreement with Oguntunji and Ayorinde (2015), who reported four variants of web colour (yellow, black, slate and ash) in a ratio of 60.4%, 22.92%, 13.03% and 3.92%, respectively, in Muscovy ducks in Nigeria. The present study slightly agrees further with Maharani *et al*. (2019), who recorded yellow web in all the Alabio duck populations in Indonesia; however, Maharani *et al*. further reported dark brown, light brown, and yellow web colour in a relative prevalence of 48.17%, 24.61% and 21.47% in a successive order when all six duck populations studied were pooled together. The present findings are in contrast to the findings of Foluke *et al*. (2020), who identified black web colour as the most common among Muscovy ducks raised in the North-central part of Nigeria, followed by slate grey and then yellow with a relative proportion of 50%, 35% and 15% respectively. Likewise, the present study contradicts the earlier report of Morduzzaman *et al*. (2015), who reported black (76.93% and 87.5%) as the most predominant web colour and then black with yellowish tint (23.07% and 12.5%) as the minor web colour respectively in both drakes and ducks in Bangladesh. The effect of sex was not significant as both drakes and ducks shared similar web colours.

Skin colour

The present work observed white (44.40%) as the predominant skin colour, followed by pink (33.30%) and yellow (22.20%). The current study agrees with Banerjee (2013), Macharia and Ommeh (2017) and Tamzil *et al*. (2018), who observed different colour variants in the skin. However, the present work is not consistent with the findings of Hailu *et al*. (2018), Morduzzaman *et al*. (2015), Kamal *et al*. (2019) and Oguntunji *et al*. (2020), who recorded non-pigmented skin in their various studies.

Eye colour

The eye colour observed in the current study revealed yellow as the predominant eye colour, followed by brown and black with a relative prevalence of 60.40%, 23.90% and 15.70%, respectively. The effect of sex revealed a similar trend as both drakes and ducks had a predominant yellow eye colour. The results from the present study are in congruence with the findings of Banerjee (2013), who recorded yellow eye colour for all the Muscovy ducks considered in his study area. It is also consistent with the report of Ewuola *et al*. (2020), who observed yellow (61.50%) as the subjugated eye colour and black (38.50%). The study partially finds consonance with Hailu *et al*. (2018), who identified yellow eye colour (55.30%) as the most frequent colour, followed by black (30.6%), black-brown (12.9%) and brown/grey (1.2%) as the least occurred eye colour. In contrast to the present study, Morduzzaman *et al*. (2015) observed black as the leading eye colour in both drakes and ducks, with a frequency of 88.46% and 84.37%, respectively. The remaining drakes and ducks had ash eye colour, thus 11.54% and 15.62%, respectively. The results are incongruent with the findings of Kadurumba *et al*. (2021), who reported brown as the predominant eye colour and black as the least occurring eye colour in a 76.03% and 23.97% proportion correspondingly on Muscovy ducks in the Southeast ecological zone, Nigeria. It also disagrees with Foluke *et al*. (2020), who recorded Black, grey and orange eye colour in a ratio of 45%, 41% and 14%, respectively.

Egg colour

The present work witnessed 100% cream eggshell colour across the study area; however, the results are incongruent with Morduzzaman *et al*. (2015), who reported bluish eggshell colour in Nageswari ducks in Bangladesh.

Phenotypic characterisation, correlation matrix and regression analysis of morphometric traits of ducks in Ghana

The descriptive statistics of quantitative (morphometric) traits as affected by sex and agroecological zone are presented in Tables 4 and 5. Generally, sex highly influenced ($p<0.05$) all the traits and agroecological zone significantly affected all the morphometric traits except body length.

Table 4: Means ± SEM of Body Weight and Linear Body Measurement as affected by Sex

Traits/Factor	SEX	
	Males *(N=138)*	**Females** *(N=276)*
BWT (kg)	$2.59{\pm}0.01^{a}$	$1.80{\pm}0.00^{b}$
BL (cm)	$58.50{\pm}0.16^{a}$	$46.99{\pm}0.11^{b}$
SL (cm)	$6.15{\pm}0.03^{a}$	$5.26{\pm}0.02^{b}$
NL (cm)	$18.99{\pm}0.10^{a}$	$15.52{\pm}0.07^{b}$
BLL (cm)	$5.70{\pm}0.03^{a}$	$4.95{\pm}0.02^{b}$
BLW (cm)	$2.54{\pm}0.01^{a}$	$2.29{\pm}0.00^{b}$
BC (cm)	$41.19{\pm}0.13^{a}$	$35.75{\pm}0.09^{b}$
WL (cm)	$53.51{\pm}0.12^{a}$	$42.31{\pm}0.09^{b}$
WS (cm)	$116.51{\pm}0.26^{a}$	$93.10{\pm}0.19^{b}$

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 row that does not share common superscripts are significantly different (p<0.05); see appendix for actual P values N=Sample size

Table 5: Means ± SEM of Body Weight and Linear body Measurements as affected by agroecological zone

Traits/Factor		AEZ			
		Semi-deciduous forest *(N=138)*	Coastal savanna *(N=138)*	Rain forest *(N=138)*	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	47.34±1.96	46.71±2.22	92
SL(cm)	Male	6.08±0.40	6.25±0.33	6.11±0.33	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	5.70±0.35	5.68±0.29	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	53.26±1.25	53.70±1.19	46
	Female	42.50±1.51	42.02±1.55	42.40±1.48	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 N=Sample size.

Body weight

The average body weight recorded for drakes and ducks from the three agroecological 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 feather Muscovy drakes in West Bengal. The results from the present study are in close association with the reports from Ksiazkiewicz (2002), Raji *et al*. (2009), Momoh (2011), Yakubu (2013), Foluke *et al*. (2020) and Lan and

Worowan (2020) who observed a mean body weight of 2.47 kg, 2.71 kg, 2.41 kg, 2.73 kg, 2.33 kg and 2.73 kg respectively for drakes raised in different environments. The average body weight observed in the present study is slightly lower than the 3.05kg, 3.38 kg, 3.09 kg, 3.62 kg and 3.16 kg reported by Drouilhet *et al*. (2014); Macharia and Ommeh (2017); Hailu *et al*. (2018); Tamzil *et al*., (2018) and Ewuola *et al*. (2020) respectively. However, Johnson and Hawk (2009); Philip (2007), cited by Lan (2020) and Huang (2012), postulated a higher range of 4-7 kg, 7-10 kg, and 4.6-6.8 kg live body weight for drakes respectively, and this highly supersede the current findings whereas the present findings 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 1.66 kg, 1.80 kg and 1.73 kg respectively in 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), Kadurumba *et al*. (2021), Raji *et al*. (2009), Morduzzaman *et al*. (2015), Yakubu (2011) 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, while 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. Most of the farms 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 relative incidence of 58.87cm, 58.45cm and 58.16cm. In contrast, the coastal savanna recorded the longest body length for females, followed by the semi-deciduous forest and then the rain forest with a prevalence 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 *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. It is closely associated with the findings of Yakubu (2011), 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. A relatively shorter body length of 21.53cm & 17.59cm and 26.27cm & 23.79cm were recorded by Ewuola *et al*. (2018) and 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 bean 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 agroecological zones, as can be seen in Table 2. 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 *et al*. (2020) and the 8.42cm for drakes and 7.02cm for ducks reported by Macharia and Ommeh (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-coloured female Muscovy ducks in PNGUNRE poultry farm in Papua New Guinea in a frequency of 4.86cm, 5.20cm, 4.71cm and 5.05cm respectively.

The variations in shank length could be due to habitat characteristics and foraging strategies. Different agroecological zones have different types of vegetation, water availability and differences in habitat structure. Ducks may need longer shank to stride through deeper water to reach for aquatic plants or invertebrates or navigate through dense vegetation.

Neck length

Both sex and agroecological 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 witnessed 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), Kokoszynski *et al*. (2019); Tamzil *et al*. (2018); Veeramani *et al*. (2014); Kamal *et al*. (2019) and Kadurumba *et al*. (2020), 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*. 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

Yakubu (2011); Kokoszyński *et al*., and Tamzil *et al*., who recorded 18.10cm &14.33cm; 18.30cm & 17.50cm and 18.32cm & 14.87cm for drakes and ducks respectively. Additionally, the report from Kamal *et al*., Veeramani *et al*. and Kadurumba *et al*. 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.

The differences in neck length recorded from the present and previous studies could be attributed to the predation pressure in different agroecological zones. Ducks with longer necks could detect potential threats easily and escape from predators. This could lead to the evolution of longer necks in some populations.

Bill length and width

The current study's findings revealed a significant influence (P<0.05) of sex and agroecological zone on the bill length of ducks. Drakes and ducks from the semi-deciduous forest had the longest bill of 5.73cm & 5.05cm, respectively, followed by the coastal savanna, recording 5.70cm & 4.94cm, then the rain forest with 5.68cm & 4.87cm. The current research finds agreement with the work of Ogah *et al*. (2011), who documented that location or agroecological zones have a significant effect on the bill length of ducks as they found 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); Morduzzaman *et al*. (2015); Tamzil *et al*. (2018) and Kadurumba *et al*. (2021) who shared a common view that drakes have longer bills than ducks in their various research. It also falls within the range of drakes (5.12-5.5.98cm) and ducks (4.67-5.54cm) reported by Morduzzaman *et al*., Maharani *et al*., Kadurumba *et al*., and Raji *et al*. Notwithstanding, present result is lower than what was previously reported by Kamal *et al*., Veeramani *et al*. and Susanti *et al*. 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*., Foluke *et al*. (2020) and Yakubu *et al*. (2011).

The overall bill width recorded for the present was 2.54cm for drakes and 2.29cm for ducks. Drakes from the rainforest 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 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 agroecological 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 agroecological 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 it is significant in mate attraction, reproduction and resource acquisition. The present work agrees with the previous findings (Hailu *et al*., 2018; Tamzil *et al*., 2018; Foluke *et al*., 2020; Kadurumba *et al*., 2021; Ewuola *et al*., 2020; Susanti *et al*., 2016 and Yakubu, 2011) who recorded a broader breast for drakes than ducks. Also, the overall mean values recorded for drakes and ducks in the current work concords with Hailu *et al*., who documented 44.50cm for drakes and 35.70cm for ducks. It also finds harmony with Tamzil *et al*., 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 *et al*.; Kadurumba *et al*.; Susanti *et al*., and Yakubu who discovered a disparity in breast circumference in terms of sex in a relative prevalence 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*. 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. Incongruently, Tamzil *et al*. (2018) reported higher values of 82.81cm for drakes and 61.19cm for ducks. Unlike the results of Tamzil *et al*., 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 the Yakubu (2011); Morduzzaman *et al*. (2015); Foluke *et al*. (2020), and 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 agroecological zone significantly influenced the trait. The overall average wing span 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 witnessed 115.32cm long of the trait. On the contrary, ducks from the rain forest recorded the longest wing span of 93.86cm, trailed 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 metric traits measured

The phenotypic correlations among morphometric traits (body weight and linear body measurements) are presented in Table 6. The results revealed medium to high, statistically significant positive values (p<0.05).

Table 6: Correlation among morphometric traits measured

	BWT	BL	SL	NL	BLL	BLW	BC	WL
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**

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; **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) revealed that breast circumference (0.739) had the highest correlation with body weight. Likewise, Kadurumba *et al*. (2021) also witnessed 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 7 and 8, respectively.

Table 7: 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 8: 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 & Lomo (2015), Pesmen and Yardimci (2008) and Okpeku *et al*. (2011). 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 or traits 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 at ($p>0.05$). 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 7. 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. The result of Ewuola *et al*. saw body length as 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 $p>0.01$.

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 traits for ducks with a higher level of accuracy using a simple regression equation.

A multiple regression analysis was further performed to determine the pooled predictive ability of the morphometric traits, and the results are presented in Table 8. 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.

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

Multivariate analysis is suitable for assessing genetic variability within and between the indigenous duck populations in Ghana when all metric characters are considered simultaneously (Yakubu & Ibrahim, 2011). 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 9 and Figure 2.

Table 9: Matrix of Mahalanobis distance between duck populations based on morphometric traits

Population (P)	P1	P2	P3
P1 (Semi-Deciduous Forest)		1.46198	2.26615
P2 (Coastal Savanna)			1.29968
P3 (Rain Forest)			

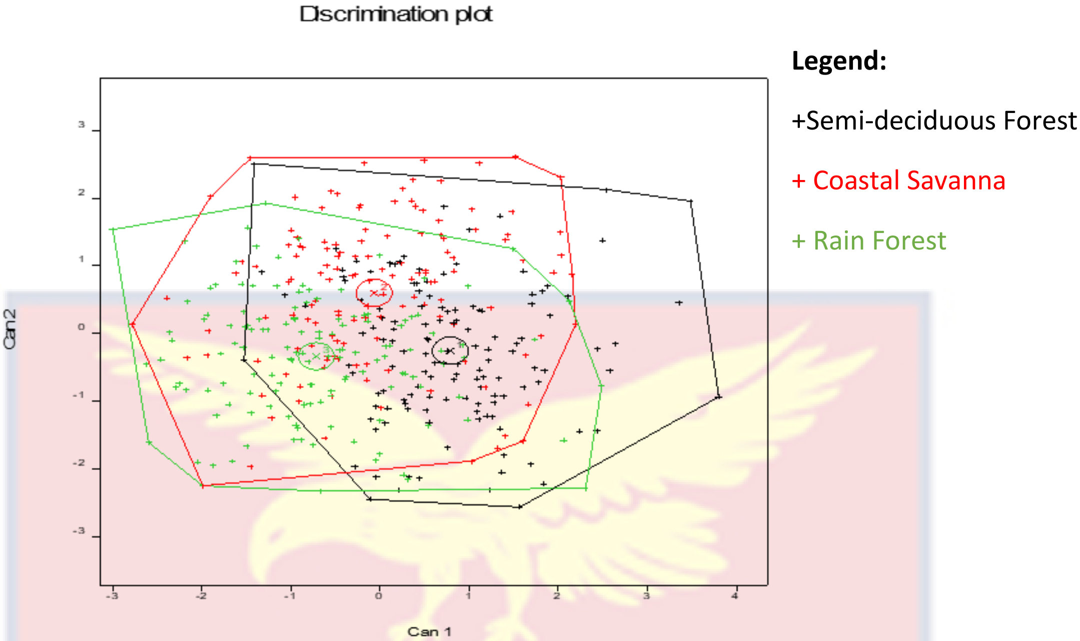

Figure 3: Canonical plot for the three duck populations

From Table 9, the populations were significantly distant ($p<0.05$) from each other. The longest (2.26615) distance was between the duck populations from the semi-deciduous forest (P1) and the rainforest (P3), whereas the shortest (1.29968) distance was observed between the duck populations from the coastal savanna (P2) and rainforest (P3). The shortest Mahalanobis distance observed between the duck populations from the coastal savanna and the rainforest could be attributed to high intermingling or genetic exchange of germplasm within the two populations over time due to the closeness of the two populations. As suggested by the shorter Mahalanobis distance, the similar genetic identity shared between P2 and P3 could be curbed by obtaining breeding stock from more expansive geographical areas. The longer Mahalanobis distance between P1 and P3 might be subjected to natural and artificial selection and environmental adaptation. Thus, the creation of the genetic 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 and improve on these traits of economic importance to harness the full potential of this unique germplasm. The findings of the current work are comparable to Ogah (2013), who recorded a Mahalanobis distance between the range of (3.371 & 4.620). It also agrees with Oguntunji and Ayorinde (2015), who reported a shorter Mahalanobis distance ranging from 2.010 to 3.758 for Nigerian Muscovy duck populations. However, Ogah *et al*. (2011) recorded a long genetic distance (54.803) between the guinea savanna and the dry savanna, followed by a distance between the dry savanna and the rain forest (35.435) and the least genetic distance (Mahalanobis distance) was between guinea savanna and the rain forest (34.120) Muscovy duck ecotypes in Nigeria. Also, Adenaike *et al*. (2020) saw 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 10.

Table 10. 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** **64.49**	22 15.94	26 18.84
P2 (Coastal Savanna)	32 23.19	**79** **57.25**	26 18.84
P3 (Rain Forest)	17 12.32	37 26.81	**86** **62.32**
Error level for populations	35.51	42.75	37.68
Prior probability (Priors)	0.333	0.333	0.333

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 10, based on the Mahalanobis distance (Table 9). The current work revealed the highest relatedness among duck populations from the semi-deciduous forest (64.49%), followed by duck populations from the rainforest (62.32%), whereas the slightest similarity was found within the populations in the coastal savanna (57.25%). The results further showed that 23.19% and 12.32% of P1 (semi-deciduous forest) were misclassified into P2 (coastal savanna) and P3 (rainforest), respectively. Also, 15.94% and 26.81% of P2 were misclassified to P1 and P3, respectively. Again, 18.84% of duck populations within the rainforest 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; Batubara *et al*., 2011; Traore *et al*., 2008; Yakubu & Ibrahim, 2011; Yakubu *et al*., 2010; and Ofori *et al*., 2021) have used the approach to demonstrate high classification success in goat populations.

Principal Component Analysis (PCA)

The eigenvalues of the total variance, unrotated component loadings and communalities of all morphometric traits in the studied duck populations are presented in Table 11.

Table 11: Eigenvalue, Percentage of Total Variance, Unrotated Components Loadings and Communalities of Morphometric Traits Observed in Indigenous Ghanaian Duck Populations

Traits *(N=414)*	**PC1**	**Communalities**
BWT	0.965	0.931
BL	0.959	0.919
SL	0.795	0.632
NL	0.861	0.742
BLL	0.795	0.632
BLW	0.865	0.748
BC	0.908	0.825
WL	0.956	0.915
WS	0.954	0.910
Eigenvalue	7.2527	7.2527
Percentage of the total variance (%)	80.60	80.60

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; N=sample size.

The PCA of the current work revealed one principal component extracted from the factor analysis without varimax rotation. The principal component extracted accounted for 80.60% of the total variance in the original variables measured with an eigenvalue of 7.2527. 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 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*. extracted two to four principal components. His results revealed 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.*, 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 saw 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.

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 Yakubu *et al*. (2011), 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 indicates that those traits could be used to explain the overall variability in body dimensions of ducks (Maharani *et al*., 2019; Mendes, 2011; Ogah, 2009; and Yakubu *et al*., 2009).

Production performance of indigenous ducks in Ghana.

The production and reproductive ability of the indigenous ducks raised in Ghana are presented in Table 12. The study revealed that agroecological zones had no significant (P>0.05) effect on measured production traits. See actual p-values in Appendix H.

Table 12: Mean ± SD of production performance of Indigenous Ducks in Ghana

	Agro-Ecological Zone			
Indices	**SDF**	**CS**	**RF**	**Overall**
Egg weight (g)	60.26±2.18	60.23±2.06	60.42±2.20	60.30±2.14
Egg length (mm)	60.02±2.01	59.82±2.08	60.12±2.16	59.98±2.08
Egg width (mm)	44.92±1.78	44.65±1.75	44.98±1.80	44.85±1.78
Egg shape index (%)	74.84	74.64	74.82	74.77
Hatching window (days)	33.70±2.00	33.90±1.35	33.63±1.38	33.74±1.59
Percentage hatchability	82.27±8.09	83.33±9.03	83.80±9.81	83.13±8.93
AFM (months)	11.43±0.73	11.13±0.73	11.26±0.74	11.28±0.73
AFE (months)	8.50±0.68	8.53±0.68	8.63±0.72	8.56±0.69
Egg per clutch	15.60±3.92	15.83±2.80	16.07±3.23	15.83±3.32
TEPY	38.13±14.17	38.73±11.97	40.13±13.82	39.00±13.23

AFE=Age at first egg; AFM=Age at first mating; TEPY=Total egg per year; SDF=Semi-deciduous forest; CS=Coastal Savanna; RF=Rain Forest

The study revealed that agroecological zones had no significant (P>0.05) effect on measured production traits. See actual P-values in Appendix H. Moreover, from Table 12, the present work recorded 60.30±2.14g for egg weight across the three agroecological zones studied. The results are comparable to the findings of Makram *et al*. (2021) and Susanti *et al*. (2016), who reported the egg weight to be 61.22g and 58.23g for Egyptian Muscovy and white Muscovy, respectively. The current work again agrees with Ahmed (2011), who recorded 61.42g of egg weight for Dumyati ducks in Egypt. It also falls within the 60-90g reported by Huan and Lin (2011). The current report slightly differs from that of Popoola *et al*. (2015), Morduzzaman *et al*. (2015); Lase *et al*. (2021) and Etuk *et al*. (2012), who witnessed a slightly higher egg weight of 67.00±3.03g; 67.32±0.82g; 71.10±3.60g and

76.27±0.49g correspondingly. The current results are relatively lower than what was recorded by Yuan *et al*. (2013), who saw a very high egg weight of 97.31±4.99g for striped Pekin eggs. The significant differences observed in the egg weight in the aforementioned literature are attributable to breed genetics, management systems, location and differences in quality of feed and feeding regimes.

The present study revealed the egg length and egg width to be 59.98±2.08mm and 44.85±1.78 respectively, which is closely associated with the findings of Popoola *et al*. (2015), who recorded egg length of 63.10±0.05mm and egg width of 41.10±0.11mm for Muscovy duck egg in Nigeria. It is also in line with Harun *et al*. (2001) and Lase *et al*. (2021), who recorded average egg length and width of 62.60±1.90mm & 46.70±1.10mm and 60.45±1.50mm & 42.43±1.60mm. The results also agree with the findings of Etuk *et al*. (2012), who recorded egg length and width of 60.56±0.44mm & 46.15±0.26mm, 61.10±0.40mm & 46.15±0.26mm and 60.89±0.41mm & 44.89±0.20mm for Muscovy ducks raised in Semi-intensive, the intensive system with wallow and intensive system without wallow in Akwa Ibom, Nigeria. Likewise, Makram *et al*. (2021) and Pandian *et al*. (2012) documented similar egg length and width results of 58.32mm & 42.70mm and 59.80±0.54mm & 45.12±0.42mm.

The egg shape index for the present work was calculated from the dimensions of an egg is the ratio of the average egg width to the average egg length expressed as percentages (Anderson, Tharrington, Curtis & Jones, 2004 and FAO, 2012). The egg shape index in the current work was 74.77%. The result is higher than that of Makram *et al*. (2021) and Al-Obaidi and Al-

Shadeedi (2016), who witnessed a shape index of 73.26% and 72.24%, respectively. It is also higher than the 72% Ipek and Soczu (2017) reported for lightweight pekin duck eggs in Bursa, Turkey. However, Widianingrum *et al*. (2020); Etuk *et al*. (2012), and Pandian *et al*. (2012) reported a higher shape index of 76.57%; 76% and 75.50% than the present work. The egg shape index is significant to the extent that it affects the egg-crushing strength (Anderson *et al*., 2004; Blanco *et al*., 2014; Sarica *et al*., 2012) and correlates with shell thickness. The egg shape index of 74.77% indicates that the egg produced by the indigenous Ghanaian duck populations have a normal oval shape (Sarica & Erensayin, 2009; Tunsisa & Berihun, 2022).

Results from the farmers revealed that the average hatching window or incubation period is 33.74±1.59 days for the indigenous duck populations in Ghana, as shown in Table 12. The findings are in congruence with the report of Arias-Sosa and Rojas (2021), who observed an incubation period of 34 days in their review of the productive potential of Muscovy ducks. Likewise, it agrees with Widianingrum *et al*. (2020), who reported 33.45 days for Muscovy ducks originating from different regions of Indonesia. Moreover, results from the present work saw a more extended incubation period than the 28 days reported by Ipek and Soczu (2015). Also, Ipek and Soczu (2017) recorded a lower hatching window of 26.54 days than the current work.

The percentage hatchability for the present study is 83.13±8.93%, as shown in Table 12. The higher percentage hatchability from the present study aligns with the findings of Yuan *et al*. (2013), who documented 86.83±3.76% for Pekin eggs. It also agrees with Nickolova (2005), who recorded a high hatchability of 95.48% for Muscovy duck eggs in Bulgaria. However, Makram *et al*. (2021) reported a hatchability of 73.30%, which a lower than the present work. Likewise, Rashid *et al*. (2005) also recorded a slightly decreased hatchability of 54.21% and 62.91% for Muscovy and Pekin duck eggs correspondingly raised in Bangladesh.

Furthermore, Nageswara *et al*. (2005) also witnessed a slightly lower hatchability of 71.00±0.14% for indigenous ducks and 68.40±0.12% for Khaki Campbell ducks' eggs in India. Also, the lowest percentage hatchability was reported by Susanti (2021) who recorded 14.60% hatchability in Muscovy ducks in Indonesia. The higher hatchability recorded for the indigenous duck populations in Ghana indicates higher prolificacy and fertility of the species. The differences in hatchability success are attributable to the duration of storage of eggs, incubator temperature management and setting, egg weight, egg turning during incubation, breed genetics and age and other environmental factors.

Farmers reported the age at first mating for drakes in the study area to be 11.28±0.73 months, whereas the age at first egg was reported to be 8.56±0.69 days (Table 12). The current findings contrast the report of Widianingrum *et al*. (2020), who documented 194.60, 208.40, 169.60 and 167.40 days for AFE of Muscovy ducks raised in Cirebon, Indramayu, Majalengka and Kuningan regions of Indonesia respectively. The current work does not align well with Nageswara *et al*. (2005), who testified that the age at first egg (AFE) for indigenous ducks and Khaki Campbell ducks are 139±7.40 and 147±5.10 days, respectively. It also disagrees with the earlier findings of Morduzzaman *et al*. (2015), who recorded 168.48±3.53 days for age at the first egg for Nageswari ducks in Bangladesh. The longer period taken for the local duck populations to reach sexual maturity may be attributed to the lack of selection of the species.

From Table 12, egg per clutch was recorded to be 15.83±3.32, and the average total egg per year (TEPY) was 39.00±13.23. The present findings are lower than Mazanowski *et al*. (2005), who reported TEPY of 177 and 129 for A44 and A55 paternal strains and 135, 134 and 121 for P66, P77 and K11 maternal strains on the Waterfowl Breeding Farm Dworzyska, Poland. It is also lower than what was documented by Morduzzaman *et al*. (2015), who reported an average of 173.63±3.39 eggs for On-station and 201.00±0.52 eggs at the Farmer's level for Nageswari ducks in Bangladesh. Likewise, Widianingrum *et al*. (2020) reported 130.40, 79.20, 126.00, and 127.00 for On-station Muscovy ducks originating from Cirebon, Indramayu, Majalengka and Kuningan regions of Indonesia which is higher than the result from the present study. The present work's lower average total egg per year informs breeders of the need to design a breed improvement program for this indigenous germplasm.

Demographic information of indigenous duck farmers

The study consulted ninety (90) duck farmers from three agroecological zones of Ghana. Thirty (30) farmers were selected from each agroecological zone. The information gathered from the farmers included their gender, level of education, profession, years they have been engaging in duck production, their purpose of keeping the species, and many more. The results are presented in Tables 13 - 22.

Table 13: Demographic Information of Indigenous Duck Farmers

Demographic characteristics		Percentage (%)			
		SDF	**CS**	**RF**	**Overall**
Gender	Male	30.50	35.60	33.90	65.60
	Female	38.70	29.00	32.30	34.40
Age	< 20 years	0.00	0.00	0.00	0.00
	20-40 years	30.80	61.50	7.70	14.40
	41-60 years	38.30	31.70	30.00	66.70
	>60 years	17.60	17.60	64.70	18.90
Education	No formal education	44.40	33.30	22.20	20.00
	Primary education	27.30	36.40	36.40	36.70
	Middle/JHS	36.40	27.30	36.40	24.40
	Secondary/Technical	30.00	40.00	30.00	11.10
	Tertiary	28.60	28.60	42.90	7.80
Profession	Farmer	30.40	31.90	37.70	76.70
	Salaried worker	33.33	33.33	33.33	23.30
	Other	0.00	0.00	0.00	0.00
Purpose of keeping ducks	Fun or hobby	0.00	0.00	0.00	0.00
	Own consumption	32.40	35.30	32.30	37.80
	Food and income	38.50	28.20	33.30	43.30
	For sale only	23.50	41.20	35.30	18.90
	Religious or traditional	0.00	0.00	0.00	0.00
Years of duck production	< 1 Year	44.40	38.90	16.70	20.00
	1-5 Years	34.80	30.40	34.80	25.60
	6-10 Years	37.50	25.00	37.50	26.70
	11-15 Years	18.80	37.50	43.80	17.80
	16-20 Years	33.30	33.30	33.30	6.70
	>20 Years	0.00	66.70	33.30	3.30
Any Government supports?	Yes	0.00	0.00	0.00	0.00
	No	33.33	33.33	33.33	100
Contribution of duck products to household nutrition (PRIORITY)	Lowest	0.00	0.00	0.00	0.00
	Low	0.00	0.00	0.00	0.00
	Medium	28.80	30.80	40.40	57.80
	High	39.50	36.80	23.70	42.20
	Highest	0.00	0.00	0.00	0.00

SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Table 13 shows that males (65.60%) engaged in duck production, whereas females were well represented by 34.40%. The male-to-female ratio could be attributed to how males are more involved in poultry production than females and the gender disparities in roles and activities arising from customary rules (Ekpo, Oke, Osseyi, Dossou & Chrysostome, 2020; FAO, 2013; Agbolosu & Aawona, 2021). However, it is encouraging to see most women engaged in poultry especially duck production, in the study area as it can help to increase household income.

It is interesting to know that majority (81.10%) of duck keepers were within their young age (21-60). This indicates that a more significant proportion of farmers engaged in duck production are in their economically active age, which is more encouraging for duck production and the poultry sector. The results find consonance with Dei, Alenyorege, Apalibe, Okai, and Larbi (2014), who indicated that farmers involved in duck production in Northern Ghana are at a young and economically active age. It further agrees with Agbolosu and Aawona (2021), who studied the health and disease management of indigenous ducks in the Tamale metropolis of Ghana and found that the majority of farmers are in their economically active age. Also, the present study aligns well with Ekpo *et al*. (2020), who reported that 90% of poultry farmers in Benin are in their young age.

Notably, 80% of the farmers in the current study had formal education from the primary to the tertiary level, whereas the remaining 20% had no formal education. This indicates that rendering training and resource services to this active economic force will not go waste but could boost their interest in duck production, which could go a long way to foster the potential of the specie to be harnessed. It can also be seen from Table 13 that majority (76.70%) of the farmers engaged in the study were full-time farmers, whereas 23.30% were salaried workers raising ducks as their part-time business. Since the more significant proportion of the farmers is into full-time poultry production, the necessary attention when given to them, in the form of training and provision of resources such as equipment, income in the form of grants and loans could boost their interest to channel all their energy and attention into commercial duck production.

To eradicate poverty and global food insecurity, the government of Ghana, through the Ministry of Food and Agriculture (MoFA), could include duck production in the rearing for food and jobs campaign to provide self-employment for the youth and the Ghanaian populace. This is affirmed by the results from the present study, which is shown in Table 13 that predominantly, the farmer's primary purpose of raising ducks was not for fun or hobby but mainly for food and income, which represent 43.30% of the total response, followed by consumption only (37.80%) and finally for sale only (18.90%).

Moreover, it was revealed by the present study that products from ducks (meat and eggs) played a significant role in household nutrition by serving as an alternative source of animal protein due to its medium to high priority in the contribution to household nutrition. The results from the present study align with Yakout, Kosba and Thieme (2009), who also witnessed medium to the highest priority for ducks' contribution to household nutrition in Egypt. The present findings mean that duck production is a source of livelihood and an alternative source of cheap animal protein, which can also improve the standard of living and the income level of the Ghanaian youth and when given the needed attention, can bridge the gap between the poor and the rich in society and also improve the protein deficiency in the rural poor and the Ghanaian populace at large.

Population History and Population Structure

The population history providing information on the breed of duck, source of farmers breeding stock, type of holding, reproductive strategy and the population size and structure are presented in Tables 14 and 15.

Table 14: Population History and Reproduction

Population history		Percentage (%)			
		SDF	**CS**	**RF**	**Overall**
Breed of duck	Local breed	28.40	35.80	35.80	74.40
	Exotic breed	0.00	0.00	0.00	0.00
	Both	47.80	26.10	26.10	25.60
Source of breeding stock	Local farmers	32.10	34.50	33.30	93.30
	Breeding center	0.00	0.00	0.00	0.00
	Institutional farms	0.00	0.00	0.00	0.00
	Imported	50.00	16.70	33.30	6.70
Type of holding	Subsistence	37.90	28.80	33.30	73.30
	Commercial farmer	20.80	45.80	33.33	26.70
	Breeding center	0.00	0.00	0.00	0.00
	Experimental station	0.00	0.00	0.00	0.00
Reproduction strategy	Controlled mating	0.00	0.00	0.00	0.00
	Uncontrolled mating	33.33	33.33	33.33	100.00
Type of reproduction	Natural incubation	34.20	32.90	32.90	81.10
	Artificial incubation	29.40	35.30	35.30	18.90
Reproduction season	March – July	38.20	41.20	20.60	37.80
	Sept – November	32.10	25.00	42.90	31.10
	Dec – February	100.00	0.00	0.00	2.20
	All-season	23.10	34.60	42.30	28.90
Brooding per year	Once	33.30	35.90	30.80	52.10
	Two Times	34.30	31.40	34.30	47.90
	Three Times	0.00	0.00	0.00	0.00
	Four Times	0.00	0.00	0.00	0.00

SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Table 14 shows that the more significant proportion (74.40%) of the farmers raised the indigenous local breed of duck which is closely related to the Muscovy (*Cairina moschata*). In contrast, the remaining 25.60% raised both the local and exotic breed, thus the pekin. This agrees with Aning (2006) and Mantey et al. (2014), who mentioned that most of the duck populations raised in Ghana are Muscovy ducks. It is shown in Table 14 that most (93.30%) duck keepers obtained their breeding stock from local farmers around their locality, and few (6.70%) farmers had their breeding stock imported from European countries like Holland. It is important to stress that none of the farmers obtained their breeding stock from either a breeding center or an experimental station. It is worth noting that farmers did not receive any government or NGO support for duck production. This affirms that ducks are neglected from the poultry value chain in Ghana hence the need for stakeholders to be concerned and inculcate this unique germplasm into the value chain, given the considerable economic importance of the specie. The results agree with the work of Mantey *et al*. (2014), who asserted that there is no certified breeding source for domestic ducks in Ghana. It was also revealed that the majority (73.30%) of the farmers were into subsistence farming, where ducks are raised to consume within the household with little sales for income when the need arises. It is encouraging to know that a notable proportion (26.70%) were into commercial farming of ducks which operates with the sole interest of making a profit. This category of farmers is essential due to their direct linkage to the market output they provide and their contribution to the gross domestic product (GDP). The lower proportion of commercial duck keepers to the subsistence farmers for duck production is comparable to the findings of Mantey *et al*. (2014), Yakout *et al*. (2009), and MoFA (2016). It is evidenced in Table 14 that all farmers employed an uncontrolled mating strategy. In this case, all males were given a chance to contribute their genes to the next generation. This can result in mating between dam and son, sire and daughter, and siblings of common ancestry. Uncontrolled mating can increase the inbreeding rate, resulting in inbreeding depression over time.

As shown in Table 14, the results revealed that most farmers (81.10%) employed the natural incubation method, where ducks sit on their eggs and hatch them, whereas 18.90% used the artificial incubation method with the help of an incubator. This corroborates the subsistence holding as reported by WWFC (2009). The reproductive season of ducks was assessed, and the response from farmers revealed that ducks lay mostly from March-July (37.80%), followed by September-November (31.10%), and a notable group responded that ducks could lay all season (28.90%) and finally, 2.20% of the respondents reported December -February as laying season. This agrees with the assertion by Mantey *et al*. (2014) that ducks in Ghana can have three laying seasons or lay all year round, depending on the management system. Farmers gave varying responses concerning the number of times ducks brood in a year. The majority of the respondents representing, 52.10%, revealed that ducks brood once a year, whereas the remaining proportion (47.90%) stated that ducks brood twice a year. This report does not agree with Mantey et al., who emphasized that 78.70% of ducks raised in the southern part of Ghana brood thrice a year, whereas 17.30% brood once. Notwithstanding, farmers reported that brooding in ducks depends on the weaning length and feeding of the bird. The farmers reported that ducks on the extensive and semi-intensive system of management do not wean their ducklings early hence the delay in brooding.

Table 15: Population Structure

Population structure	Frequency				Percentage (%)
	SDF	CS	RF	Overall	
Drakes	78	106	80	264	15.14
Ducks	214	309	234	757	43.40
Pullets	73	127	86	286	16.40
Ducklings	112	179	146	437	25.06
Total population size	477	721	546	1744	100
Average flock size/household	15.90	24.03	18.20	19.37	

The population structure from Table 15 revealed that ducks were the dominant population (757), representing 43.40%, followed by ducklings (437), pullets (286) and drakes (264) in a relative proportion of 25.06%, 16.40% and 15.14%, respectively. The overall population size was recorded to be 1744. The coastal savanna had the largest population size and dominated the average flock size per household. The effective population size and the rate of inbreeding are given as follows;

$N_e = \frac{4(N_m x N_f)}{N_m + N_f}$ and $\Delta F = 1/2N_e$; Where N_e = Effective population size; N_m= number of breeding drakes; N_f = Number of breeding ducks; ΔF = rate of inbreeding.

Table 16: Population Structure and Predicted Inbreeding Rate for Indigenous Ducks in Ghana

Year	Population	N	N_m	N_f	N_m/N_f	N_e	N_e/N	ΔF
2022	Semi-deciduous	292	78	214	0.36	228.66	0.78	0.002
	Coastal savanna	415	106	309	0.34	315.70	0.76	0.002
	Rain forest	314	80	234	0.34	238.47	0.76	0.002
	Overall	**1021**	**264**	**757**	**0.35**	**782.83**	**0.77**	**0.001**

N= Number of breeding animals; N_e = Effective population size; N_m= number of breeding drakes; N_f = Number of breeding ducks; N_m/N_f = male to female ratio; Ne/N = ratio of breeders contributing effective genes; ΔF = inbreeding coefficient.

Table 16 presents the estimated effective indigenous duck population size from Ghana's three agroecological zones. The coastal savanna (315.7) had the highest effective population size, followed by rain forest (238.47) and, finally, the semi-deciduous forest (228.66). The effective population size (N_e) contributes to the rate of change in the variance of gene frequencies witnessed within a particular population (Wright, 1996; Ogah, Ari & Campus, 2012). It is useful in measuring the long-term performance of the duck populations in terms of variation and inbreeding (Fernández, Villanueva, Pong-Wong & Toro, 2005) and also aids in assessing the status of the specie (Duchev, Distl & Groeneveld, 2006). The estimated population size gives a clear overview of the population of ducks in Ghana hence, could serve as a census population size. Considering the lower effective population size (Ne = 782.83), the study finds agreement with Mantey *et al*. (2014), who stressed that the indigenous ducks in Ghana are at the risk of endangerment. As shown in Table 16, the assumed inbreeding rates are relatively low (0.002) despite the lower effective population size. Simon and Bachnaeur (1993), cited by Ogah *et al*., emphasized that an inbreeding rate <5% runs less risk of extinction. Considering the lower inbreeding rate, as shown in Table 16, it can be said that the indigenous duck populations in Ghana run less risk of inbreeding depression. This affirms that the genetic diversity of the duck's genetic resources is intact. Hence selection of superior birds to breed future generations is not compromised. To sustainably maintain the indigenous ducks in Ghana for present and future utilization, a breeding programme geared towards reducing inbreeding depression and extinction of the specie is needed. This can be done by introducing new members to contribute to the gene pool.

The production environment of indigenous ducks in Ghana

The routine management practices of duck producers are presented in Table 17. It is evidenced from Table 17 that ducks are mainly raised under the semi-intensive system of management, representing 51.10% of the total response, followed by the intensive system recording 33.30%, then the extensive management system (15.60%). The results slightly agree with the report by Agbolosu and Aawona (2021), who recorded 65% for the semi-intensive system, 33% for the extensive and 2% for the intensive management system for the three northern regions of Ghana. The larger number of farmers raising ducks under the intensive management system could be due to the locations where data was taken, as the study did not consider much of remote areas and hamlets owing to financial constraints.

The study's findings revealed that the majority (54.40%) of farmers supplemented their birds' diet, 33.30% provided their birds with all the needed feed, and 12.20% did not feed their ducks. In that case, ducks were left to scavenge for themselves every day. Farmers who provided all feed for the ducks fed them twice daily. The findings from the current study compare well with Mantey *et al*. (2014), who also witnessed a greater proportion of farmers from the southern part of Ghana feeding their birds twice daily.

For farmers that supplemented the diet of ducks and those that provided all feed for the ducks, 39.20% fed ducks with kitchen waste, 38% fed ducks with compounded feed, 21.50% fed ducks with a combination of kitchen waste and the remaining 1.30% used leafy vegetables to feed ducks. It must be emphasized that all farmers whose birds were in confinement fed their ducks with compounded feed. Furthermore, ad libitum portable drinking water was provided by 84.40% of farmers, 4.40% provided occasional drinking water, and the remaining 11.10% did not specifically provide drinking water for their birds, with the notion that birds can find their source of drinking water. Ducks are water-loving species; occasionally, Muscovy breeds may want to exhibit their swimming behaviour. Therefore, farmers were assessed on the provision of wallows, and 63.30% of the farmers provided wallows, while 36.70% did not. This implies that most of the farmers had the welfare of the birds at heart.

Table 17: Production Environment of indigenous ducks in Ghana

Production environment		Percentage (%)			
		SDF	CS	RF	Overall
Management system	Intensive system	33.30	40.00	26.70	33.30
	Semi-intensive system	32.60	32.60	34.80	51.10
	Extensive system	35.70	21.40	42.90	15.60
Feeding	All feed provided	33.30	40.00	26.70	33.30
	Farmer supplement feed	30.60	30.60	38.80	54.40
	no feed provided	45.50	27.30	27.30	12.20
Number of times feed is provided	Once	0.00	0.00	0.00	0.00
	Twice	33.33	33.33	33.33	100.00
	Ad libitum	0.00	0.00	0.00	0.00
Type of feed provided	Compounded feed	33.30	40.00	26.70	38.00
	Kitchen waste	38.70	25.80	35.50	39.20
	Leafy vegetables	0.00	0.00	100	1.30
	Compounded feed + kitchen waste	17.60	41.20	41.20	21.50
	Combination of all	0.00	0.00	0.00	0.00
Watering	Ad libitum	32.90	35.50	31.60	84.40
	Occasional water provided	75.00	0.00	25.00	4.40
	Animals find their own water	20.00	30.00	50.00	11.10
Provision of wallows	Yes	29.80	33.30	36.80	63.30
	No	39.40	33.30	27.30	36.70

SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Health and medication

Information on the preventive and curative measures taken by farmers is presented in Table 18.

It can be seen from Table 18 that 45.60% of farmers regularly vaccinated ducks, 31.10% were never vaccinated, and 23.30% provided occasional vaccination to ducks. Additionally, 58.90% of farmers subjected birds to regular preventive endo and ectoparasite control measures, 23.30% occasionally prevented ducks from endo and ectoparasite, and 17.80% did not. Moreover, 53.30% gave occasional veterinary treatment to sick birds, 31.10% subjected sick birds to regular traditional treatment, and 15.60 gave regular veterinary treatment to sick birds.

Table 18: Health and Medication

Management practice	Indices	Percentage (%)			
		SDF	CS	RF	Overall
Vaccination	Never	35.70	25.00	39.30	31.10
	Occasionally	14.30	28.60	57.10	23.30
	Regularly	41.50	41.50	17.00	45.60
Endo and ectoparasite control	Never	37.50	18.80	43.80	17.80
	Occasionally	23.80	23.80	52.40	23.30
	Regularly	35.80	41.50	22.60	58.90
Treatment given to sick bird	Never	0.00	0.00	0.00	0.00
	Occasional vet. Treatment	18.80	41.70	39.60	53.30
	Regular veterinary treatment	71.40	28.60	0.00	15.60
	Occasional tradition treatment	0.00	0.00	0.00	0.00
	Regular traditional treatment	39.30	21.40	39.30	31.10
	Traditional + veterinary treatment	0.00	0.00	0.00	0.00

SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Socioeconomic Information of duck producers

It is apparent from Table 19 that majority (44.40%) of farmers raised ducks for Market and own consumption, 36.70% ventured into duck production purposely for subsistence, and 18.90% are fully market-oriented, where they raise ducks purposely for profit. Notwithstanding the notable proportion of fully market-oriented farmers, the target market for the farmers was the local market within their locality. There was no established niche market and market for breeding animals specifically where duck producers could market duck products like meat and egg and breeding stock for starters to buy from. The leading roles and uses of the indigenous ducks were for food, as reported by farmers. Most duck farmers had no idea that ducks could be used for research, biological pest control and exhibitions and raised purposely for their plumage for decorations. This affirms the lower patronage of duck production in the study area.

Table 19: Socioeconomic Information of duck producers

Socioeconomic parameter	Indices	Percentage (%)			
		SDF	CS	RF	Overall
Market orientation	Fully market-oriented	35.30	41.20	23.50	18.90
	Market and subsistence	30.00	30.00	40.00	44.40
	Subsistence oriented	36.40	33.30	30.30	36.70
Target market	Local	33.33	33.33	33.33	100.00
	National	0.00	0.00	0.00	0.00
	Regional	0.00	0.00	0.00	0.00
	International	0.00	0.00	0.00	0.00
Presence of niche market	Yes	0.00	0.00	0.00	0.00
	No	33.33	33.33	33.33	100.00
Presence of market for breeding animals	Yes	0.00	0.00	0.00	0.00
	No	33.33	33.33	33.33	100.00
Main uses of breed	Food	33.33	33.33	33.33	100.00

SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Adaptive Ability

Farmers reported the adaptive behaviour of ducks to be docile, very adapted to the tropical climate and highly resistant to most poultry diseases, especially Newcastle, as evidenced by Table 20. As reported by farmers, the highly resistant nature of ducks to diseases finds congruence with the work of Van der Meulen and den Dikken (2004). The docility of ducks makes handling easier hence, cheaply managed. It is worth noting that the highly resistant ability of ducks to most poultry diseases encouraged some farmers not to vaccinate and give preventive endo and ectoparasite control medications.

Table 20: Adaptive Ability

Trait	Indices	Percentage (%)			
		SDF	CS	RF	Overall
Behaviour	Very aggressive	0.00	0.00	0.00	0.00
	Aggressive	0.00	0.00	0.00	0.00
	Moderately aggressive	0.00	0.00	0.00	0.00
	Docile	31.90	29.80	38.30	52.20
	Very docile	34.90	37.20	27.90	47.80
Adaptation to climate	Very adapted	36.50	30.80	32.70	57.80
	Adapted	28.90	36.80	34.20	42.20
	Moderately adapted	0.00	0.00	0.00	0.00
	Not adapted	0.00	0.00	0.00	0.00
	Highly susceptible	0.00	0.00	0.00	0.00
Resistance to common poultry diseases, e.g. Newcastle	Highly resistant	27.50	41.20	31.40	56.70
	Resistant	41.00	23.10	35.90	43.30
	Moderately resistant	0.00	0.00	0.00	0.00
	Not resistant	0.00	0.00	0.00	0.00
	Highly susceptible	0.00	0.00	0.00	0.00

SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Trait preferences of duck keepers

Duck farmers were tasked to select the five most preferred traits from a pool of traits provided by the researcher and rank each on a five-point Likert scale with one (5) as extremely preferred, two (4) as Very highly preferred, three (3) as highly preferred, four (2) as preferred and five (1) moderately preferred. As a result, farmers selected survivability, early maturity, disease resistance, docility and carcass weight for drakes, whiles survivability, early maturity, egg laying rate, hatchability and broodiness were selected for ducks. The assigned ranks are shown in Tables 21 and 22.

Table 21: Farmer's Trait Preferences for Drakes

	Mean Rank			
Trait	**SDF**	**CS**	**RF**	**Overall**
Survivability	4.53±0.81	4.43±0.86	4.73±0.58	4.57±0.77
Early maturity & Body weight	4.10±0.48	4.03±0.62	3.80±0.55	3.98±0.56
Disease resistance	3.37±0.67	3.50±0.78	3.47±0.73	3.44±0.72
Carcass weight	1.50±0.51	1.57±0.50	1.60±0.50	1.56±0.50
Docility	1.53±0.51	1.43±0.50	1.40±0.50	1.46±0.50
Carcass quality	***	***	***	***
Mating ability	***	***	***	***
Plumage colour	***	***	***	***

*** Farmers did not rank trait; Mean rank 1= Extremely preferred; 2=Very highly preferred; 3=Highly preferred; 4=Preferred;5=Moderately preferred; SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

Table 22: Farmer's Trait Preferences for Ducks

	Mean rank			
Trait	**SDF**	**CS**	**RF**	**Overall**
Survivability	4.67±0.71	4.60±0.72	4.43±0.86	4.57±0.77
Early maturity & Body weight	4.00±0.53	3.93±0.52	4.00±0.64	3.98±0.56
High egg-laying rate	3.37±0.67	3.47±0.78	3.50±0.73	3.44±0.72
Hatchability of eggs	1.63±0.49	1.53±0.51	1.67±0.48	1.61±0.49
Broodiness	1.33±0.48	1.47±0.51	1.33±0.48	1.38±0.49
Egg size	***	***	***	***
Egg weight	***	***	***	***
Eggshell thickness	***	***	***	***
Disease resistance	***	***	***	***
Plumage colour	***	***	***	***
Docility	***	***	***	***

*** Farmers did not rank trait; Mean rank 1= Extremely preferred; 2=Very highly preferred; 3=Highly preferred; 4=Preferred;5=Moderately preferred; SDF=Semi-deciduous forest; CS= coastal savanna; RF= Rainforest

The findings from the current work disclosed that survivability and early maturity was “extremely preferred” and “very highly preferred” trait among duck keepers for both drakes and ducks, whereas disease resistance, docility and carcass weight were highly preferred, preferred and moderately preferred respectively by duck producers for drakes. Additionally, for ducks, egg-laying ability, hatchability, and broodiness were “highly preferred”, “preferred” and moderately preferred. These trait preferences by duck farmers have practical significance since it forms the basis for the definition of breeding goals for designing the first breeding programme for ducks in Ghana. In the design of the breeding programme for ducks, breeders will focus on improving on these traits of choice by duck producers; hence, the breeding goal for ducks breeding programme may be an increase in survival, early maturity, egg laying rate, hatchability and broodiness in ducks.

Chapter Summary

The study revealed variations in the qualitative traits across the three agroecological zones. Sex and agroecological zone had no significant ($P<0.05$) effect on the qualitative traits, however, there was a significant ($P<0.05$) influence of sex on all the morphometric traits measured where drakes showed significant superiority over ducks. A medium to high (0.593-0.945) positive correlation was observed among the morphometric traits, and body length (0.894) was the best predictor of body weight. The discriminant analysis revealed a longer Mahalanobis distance (2.266) between the semi-deciduous and rainforest duck populations. The principal component analysis revealed that body weight had the highest discriminatory power among the morphometric traits. Duck keepers practiced subsistence farming under the semi-intensive management system, and ducks were allowed to mate indiscriminatory. Survivability was the extremely preferred trait by the farmers.

CHAPTER FIVE

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

The study purposively focused on the qualitative and quantitative characterisation of duck populations in Ghana. The study's results could be used to design a breeding programme and breed improvement project for ducks in Ghana to enable the species' sustainable utilization and conservation of the specie. A primary characterisation approach, a survey method involving morphometric traits measurements, and the description of duck keeper's traits preferences with the production environment, population structure, and size were assessed. The effective population size was calculated to predict the rate of inbreeding for the present and the future. A snowball and a simple random sampling technique were adopted for the study. A questionnaire was administered to ninety (90) farmers for the research, with thirty (30) from each agroecological zone. In total, 414 matured birds were randomly selected for quantitative and qualitative data, with 138 birds from each agroecological zone involving 92 ducks and 46 drakes.

Conclusions

In line with the specific objectives of the study, the study revealed the following findings;

1. There is an existence of variation in qualitative traits as the study revealed three plumage colours for ducks in the study area with variants of Black and White (pied), Black and then White. The study also revealed different variants in the colour of the bill, bean, caruncle, shank, web, skin and eye. It was observed that ducks across all

agroecological zones laid eggs with cream shell colour, suggesting that the indigenous ducks across all agroecological zones may be of the same breed.

2. 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, the agroecological zone significantly ($p<0.05$) influenced 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, without a weighing scale, body length could be used to select birds with the highest body weight accurately.
3. The discriminant analysis accurately classified 61.40% of ducks into their respective populations with cross-validation. The Mahalanobis distance showed a longer distance (2.266) between the semi-deciduous duck populations 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 breed. 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.
4. The assessment of the production environment revealed that farmers are holding a breed closely related to the Muscovy duck in predominantly subsistence farming under the semi-intensive management system with uncontrolled mating. Mostly, the birds' feed

is supplemented by farmers with usually compounded feed, and kitchen waste. Water is served ad libitum. Among the traits selected by farmers, survivability was the extremely preferred trait by duck keepers; hence, the need to include these traits in future breeding programmes while considering the production environment of duck keepers.

5. The lower rate of inbreeding obtained implies that the indigenous ducks in Ghana are genetically diverse and run a lower risk of inbreeding depression.

Recommendations

1. An additional investigation should be conducted using the advanced characterisation approach complemented with molecular genetic characterisation to validate the identity of the indigenous duck breeds.
2. Survivability and early maturity should be the trait of high interest and priority for drakes, whereas selection decisions in breeding programmes should also favour survivability, early maturity and high egg-laying rate in ducks to stimulate farmers' interest in raising ducks on a large scale for sustainable utilization of the specie.

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APPENDICES

Appendix A: Images of qualitative and quantitative traits

Figure 4: Instruments used for morphometric data collection

Figure 5: Demonstration of variations in plumage colour and pattern

Figure 6: Measurement of bill width and length

Figure 7: Assessment of shank length and colour

Figure 8: Variations in caruncle colour

Figure 9: Measurement of neck length

Figure 10: Measurement of wing span and wing length

Figure 11: Measurement of body length

Figure 12: Measurement of body weight

Appendix B

Questionnaire for Data Collection on Characterisation of Ducks

ID	SECTION A: DEMOGRAPHIC INFORMATION (A1-A3)	
A1	**The farm**	GPS coordinates: AEZ: District: Town:
A2	**Farmer or proxy**	**Sex:** Male **[ ]** Female **[ ]** **Age:** < 20 **[ ]** 20-40 **[ ]** 41-60 **[ ]** > 60 **[ ]** **Education:** No formal **[ ]** Primary education **[ ]** Middle/JSS **[ ]** Secondary/Technical **[ ]** University **[ ]** **Profession:** Farmer **[ ]** Salaried worker **[ ]** Other work **[ ]** **Duration for raising ducks:** <1 **[ ]** 1-5 **[ ]** 6 -10 **[ ]** 10-15 **[ ]** 16-20 **[ ]** >20 **[ ]** **Support by government or NGO?** Yes **[ ]** No **[ ]**
A3	**Purpose of keeping ducks**	Fun or hobby **[ ]** Own consumption only **[ ]** Food and income **[ ]** For sale only **[ ]** Religious or traditional purpose **[ ]**
A4	**PRIORITY:** **How important does duck meat and eggs contribute to household nutrition and livelihood?**	Lowest [ ] Low [ ] Medium [ ] High [ ] Highest [ ]

SECTION B: POPULATION HISTORY (B1-B4)		
B1	**Breed of Duck**	Local (Muscovy) [ ] Exotic [ ] Both [ ]
B2	**Source of breeding stock**	Local farmers **[ ]** Breeding centers **[ ]** Experimental stations **[ ]** Imported **[ ]**
B3	**Type of holding:**	Subsistence **[ ]** Commercial farmer **[ ]** Breeding center **[ ]** Experimental station **[ ]**
SECTION C: FLOCK MANAGEMENT (C1-C9)		
C1	**Population structure** **Number of;**	Drakes: [ ] Ducks: [ ] Pullets: [ ] Ducklings: [ ]
C2	**Total population size**	Estimated: Counted:
C3	**Trend of population size over the past five years**	Stable **[ ]** Increasing **[ ]** Decreasing **[ ]**
C4	**Reproduction strategy**	Controlled mating **[ ]** Uncontrolled mating **[ ]**
C5	**If controlled, what method**	Hand mating **[ ]** Artificial insemination **[ ]**
C6	**Type of reproduction**	Natural incubation **[ ]** Artificial incubation **[ ]**
C7	**Reproductive season** **(egg laying season)**	Major raining season **[ ]** Minor rainy season **[ ]** Dry season **[ ]** All seasons **[ ]**
C8	**Number of Brooding per year**	One [ ] Two [ ] Three [ ] Four [ ]
C9	**Production**	Age at first egg (months) ………………………… Egg colour: White [ ] Blue [ ] Cream [ ] Dark grey [ ] Egg shape: Round [ ] Oval [ ] Elliptical [ ] Conical [ ] Storage period ………………………………….. Egg per clutch …………………………………….. Total egg per year ………………………………… Egg weight (g)…………………………………….. Egg width (cm)

		…………………………………… Egg length (cm) …………………………………... Length of incubation (days): ……………………… Percentage hatchability (%) ………………………. AFM ……………………………………
SECTION D: PRODUCTION ENVIRONMENT (D1-D7)		
D1	**System of rearing**	Intensive **[ ]** Semi-intensive **[ ]** Extensive **[ ]**
D2	**Feeding**	All feed provided by farmer **[ ]** Farmer supplement feed **[ ]** No feed provided **[ ]**
D3	**If all feeds are provided by the farmer, how many times per day?**	One [ ] Two [ ] Three [ ] Ad libitum [ ]
D4	**Type of feed provided**	Compounded feed [ ] Kitchen waste [ ] Leafy vegetables and or grains [ ] Compounded feed + kitchen waste [ ] Combination of all [ ]
D5	**Watering**	Ad libitum portable water provided **[ ]** Occasional drinking water provided **[ ]** Animals find their own source of water **[ ]**
D6	**Wallows**	Are birds provided with water for wallowing? Yes **[ ]** No **[ ]**
D7	**Health and medication**	Are birds Vaccinated? Never **[ ]** Occasionally **[ ]** Regularly **[ ]** Are birds subjected to preventive endo and ecto-parasite control? Never **[ ]** Occasionally **[ ]** Regularly **[ ]** Treatment given to sick birds? Never **[ ]** Occasional veterinary treatment **[ ]** Regular veterinary treatment **[ ]** Occasional traditional treatment **[ ]** Regular traditional treatment **[ ]** Traditional and veterinary treatment **[ ]**

SECTION E: SOCIOECONOMIC INFORMATION (E1-E6)		
E1	**Market orientation**	Fully market oriented **[ ]** Market and subsistence oriented **[ ]** Subsistence oriented **[ ]**
E2	**Target market**	Local **[ ]** National **[ ]** Regional **[ ]** International **[ ]**
E3	**Products targeted at niche market?**	Yes **[ ]** No **[ ]**
E4	**Established market for breeding animals and genetic materials?**	Yes **[ ]** No **[ ]**
E5	**Main uses and roles of breed**	Food **[ ]** Research **[ ]** Pest control **[ ]** Medical purposes **[ ]** Plumage **[ ]** Manure **[ ]** Prestige **[ ]** Social and /religious ceremonies **[ ]**
	If the main use is food, specify…	Eggs **[ ]** Meat **[ ]**
E6	**ADAPTIVE ABILITY** **Behaviour**	Very aggressive **[ ]** Aggressive **[ ]** Moderately aggressive [ ] Docile **[ ]** Very docile [ ]
	Adaptation to climate	Very adapted **[ ]** Adapted [ ] Moderately adapted **[ ]** Not adapted **[ ]** Highly susceptible [ ]
	Resistance to common poultry disease like Newcastle and Avian Influenza	Highly resistant **[ ]** Resistant [ ] Moderately resistant **[ ]** Not resistant **[ ]** Highly susceptible [ ]

Trait preference of farmers (criteria for selection of birds)

Trait Preferences for Drakes			Trait Preferences for Ducks	
Trait		Rank	Trait	Rank
	Early maturity, Body Weight and Early slaughter weight		Early maturity and Body weight	
	Survivability		Survivability	
	Docility		Docility	
	Carcass quality		Broodiness	
	Carcass weight		Hatchability of eggs	
	Mating capability		Egg size	
	Plumage colour		Egg weight	
	Disease resistance		Egg shell thickness	
			High egg laying rate	
			Disease resistance	
			Plumage colour	

Appendix C

Pooled analysis of variance for morphometric traits

Analysis of Variance: BWT

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.9109	0.4554	28.68	0.000
SEX	1	56.1914	56.1914	3538.93	0.000
Error	410	6.5100	0.0159		
Lack-of-Fit	2	0.0667	0.0334	2.11	0.122
Pure Error	408	6.4433	0.0158		
Total	413	63.6123			

Tukey pairwise comparison: AEZ

AEZ	N	Mean	Grouping		
1	138	2.24525	A		
2	138	2.20728		B	
3	138	2.13236			C

Means that do not share a letter are significantly different.

Tukey pairwise comparison: sex

SEX	N	Mean	Grouping
1	138	2.58572	A
2	276	1.80420	B

Means that do not share a letter are significantly different.

Analysis of Variance: BL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	19.3	9.6	2.68	0.070
SEX	1	12182.3	12182.3	3388.22	0.000
Error	410	1474.2	3.6		
Lack-of-Fit	2	11.6	5.8	1.62	0.200
Pure Error	408	1462.6	3.6		
Total	413	13675.8			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
2	138	52.9614	A
1	138	52.8092	A
3	138	52.4469	A

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	58.4928	A	
2	276	46.9855		B

Means that do not share a letter are significantly different.

Analysis of Variance: SL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	4.327	2.1636	14.15	0.000
SEX	1	72.737	72.7368	475.68	0.000
Error	410	62.693	0.1529		
Lack-of-Fit	2	0.163	0.0814	0.53	0.588
Pure Error	408	62.531	0.1533		
Total	413	139.757			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
2	138	5.84740	A	
3	138	5.64479		B
1	138	5.61863		B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	6.14819	A	
2	276	5.25902		B

Means that do not share a letter are significantly different.

Analysis of Variance: NL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	59.17	29.59	20.35	0.000
SEX	1	1110.26	1110.26	763.73	0.000
Error	410	596.04	1.45		
Lack-of-Fit	2	9.51	4.75	3.31	0.038
Pure Error	408	586.53	1.44		
Total	413	1765.47			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping		
1	138	17.6877	A		
2	138	17.3109		B	
3	138	16.7667			C

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	18.9920	A	
2	276	15.5181		B

Means that do not share a letter are significantly different.

Analysis of Variance: BLL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	1.375	0.6875	5.64	0.004
SEX	1	51.590	51.5901	423.17	0.000
Error	410	49.985	0.1219		
Lack-of-Fit	2	0.288	0.1442	1.18	0.307
Pure Error	408	49.697	0.1218		
Total	413	102.950			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	138	5.40430	A	
2	138	5.31959	A	B
3	138	5.26415		B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	5.70377	A	
2	276	4.95493		B

Means that do not share a letter are significantly different.

Analysis of Variance: BLW

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.12486	0.06243	12.54	0.000
SEX	1	5.75834	5.75834	1156.40	0.000
Error	410	2.04161	0.00498		
Lack-of-Fit	2	0.02891	0.01446	2.93	0.054
Pure Error	408	2.01269	0.00493		
Total	413	7.92480			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
3	138	2.43445	A	
1	138	2.41764	A	
2	138	2.39220		B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	2.53986	A	
2	276	2.28967		B

Means that do not share a letter are significantly different.

Analysis of Variance: BC

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	122.87	61.44	25.69	0.000
SEX	1	2719.20	2719.20	1137.14	0.000
Error	410	980.42	2.39		
Lack-of-Fit	2	1.91	0.96	0.40	0.671
Pure Error	408	978.50	2.40		
Total	413	3822.49			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping		
1	138	39.1489	A		
2	138	38.4351		B	
3	138	37.8155			C

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	41.1848	A	
2	276	35.7482		B

Means that do not share a letter are significantly different.

Analysis of Variance: WL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	15.6	7.8	3.79	0.023
SEX	1	11556.9	11556.9	5618.65	0.000
Error	410	843.3	2.1		
Lack-of-Fit	2	0.7	0.4	0.18	0.838
Pure Error	408	842.6	2.1		
Total	413	12415.8			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	138	48.0636	A	
3	138	48.0310	A	B
2	138	47.6368		B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	53.5145	A	
2	276	42.3065		B

Means that do not share a letter are significantly different.

Analysis of Variance: WS

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	64.9	32.4	3.30	0.038
SEX	1	50420.8	50420.8	5126.45	0.000
Error	410	4032.5	9.8		
Lack-of-Fit	2	168.5	84.3	8.90	0.000
Pure Error	408	3864.0	9.5		
Total	413	54518.1			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
3	138	105.362	A	
2	138	104.610	A	B
1	138	104.456		B

Means that do not share a letter are significantly different.

Tukey Pairwise Comparisons: SEX

SEX	N	Mean	Grouping	
1	138	116.514	A	
2	276	93.104		B

Means that do not share a letter are significantly different.

Appendix D: Analysis of variance for Drakes

Analysis of Variance: BWT

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.5104	0.25519	8.39	0.000
Error	135	4.1076	0.03043		
Total	137	4.6180			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	46	2.66130	A	
2	46	2.58348	A	B
3	46	2.51239		B

Means that do not share a letter are significantly different.

Analysis of Variance: BL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	11.63	5.817	3.66	0.028
Error	135	214.36	1.588		
Total	137	225.99			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	46	58.8696	A	
2	46	58.4457	A	B
3	46	58.1630		B

Means that do not share a letter are significantly different.

Analysis of Variance: SL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.7705	0.3853	3.07	0.049
Error	135	16.9159	0.1253		
Total	137	17.6864			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
2	46	6.25239	A
3	46	6.11130	A
1	46	6.08087	A

Means that do not share a letter are significantly different.

Analysis of Variance: NL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	13.81	6.904	4.05	0.020
Error	135	229.99	1.704		
Total	137	243.80			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
2	46	19.2826	A	
1	46	19.1413	A	B
3	46	18.5522		B

Means that do not share a letter are significantly different.

Analysis of Variance: BLL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.0570	0.02850	0.27	0.766
Error	135	14.4286	0.10688		
Total	137	14.4856			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
1	46	5.73065	A
2	46	5.69913	A
3	46	5.68152	A

Means that do not share a letter are significantly different.

Analysis of Variance: BLW

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.04908	0.024542	6.30	0.002
Error	135	0.52611	0.003897		
Total	137	0.57520			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
3	46	2.56652	A	
2	46	2.52696		B
1	46	2.52609		B

Means that do not share a letter are significantly different.

Analysis of Variance: BC

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	34.61	17.304	6.89	0.001
Error	135	338.93	2.511		
Total	137	373.54			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	46	41.7500	A	
2	46	41.2717	A	B
3	46	40.5326		B

Means that do not share a letter are significantly different.

Analysis of Variance: WL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	4.710	2.355	1.46	0.236
Error	135	217.761	1.613		
Total	137	222.471			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
3	46	53.6957	A
1	46	53.5870	A
2	46	53.2609	A

Means that do not share a letter are significantly different.

Analysis of Variance: WS

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	118.0	58.98	5.88	0.004
Error	135	1354.5	10.03		
Total	137	1472.5			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
2	46	117.565	A	
3	46	116.663	A	B
1	46	115.315		B

Means that do not share a letter are significantly different.

APPENDIX E

Analysis of variance for Drakes

Analysis of Variance: BWT

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.4672	0.233611	27.30	0.000
Error	273	2.3357	0.008556		
Total	275	2.8029			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	92	1.84185	A	
2	92	1.82380	A	
3	92	1.74696		B

Means that do not share a letter are significantly different.

Analysis of Variance: BL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	19.24	9.620	2.10	0.124
Error	273	1248.20	4.572		
Total	275	1267.44			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
2	92	47.3424	A
1	92	46.9022	A
3	92	46.7120	A

Means that do not share a letter are significantly different.

Analysis of Variance: SL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	3.720	1.8598	11.13	0.000
Error	273	45.615	0.1671		
Total	275	49.334			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
2	92	5.42261	A	
3	92	5.18924		B
1	92	5.16522		B

Means that do not share a letter are significantly different.

Analysis of Variance: NL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	54.87	27.436	21.01	0.000
Error	273	356.54	1.306		
Total	275	411.41			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping		
1	92	16.0924	A		
2	92	15.4565		B	
3	92	15.0054			C

Means that do not share a letter are significantly different.

Analysis of Variance: BLL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	1.606	0.8032	6.22	0.002
Error	273	35.268	0.1292		
Total	275	36.874			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
1	92	5.05391	A	
2	92	4.94261	A	B
3	92	4.86826		B

Means that do not share a letter are significantly different.

Analysis of Variance: BLW

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	0.1047	0.052345	9.61	0.000
Error	273	1.4866	0.005445		
Total	275	1.5913			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
3	92	2.30587	A
1	92	2.30087	A
2	92	2.26228	B

Means that do not share a letter are significantly different.

Analysis of Variance: BC

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	90.18	45.088	19.25	0.000
Error	273	639.57	2.343		
Total	275	729.75			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
1	92	36.4891	A
2	92	35.6576	B
3	92	35.0978	C

Means that do not share a letter are significantly different.

Analysis of Variance: WL

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	11.60	5.799	2.53	0.081
Error	273	624.83	2.289		
Total	275	636.43			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
1	92	42.5000	A
3	92	42.3967	A
2	92	42.0228	A

Means that do not share a letter are significantly different.

Analysis of Variance: WS

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	115.4	57.707	6.28	0.002
Error	273	2509.5	9.192		
Total	275	2624.9			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping	
3	92	93.8587	A	
1	92	93.1739	A	B
2	92	92.2793		B

Means that do not share a letter are significantly different.

APPENDIX F

Simple Regression Analysis

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.945[a]	.894	.894	.12796

a. Predictors: (Constant), BL

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	56.866	1	56.866	3473.065	.000[b]
	Residual	6.746	412	.016		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), BL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.734[a]	.539	.538	.26670

a. Predictors: (Constant), SL

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	34.307	1	34.307	482.329	.000[b]
	Residual	29.305	412	.071		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), SL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.815[a]	.665	.664	.22751

a. Predictors: (Constant), NL

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	42.286	1	42.286	816.923	.000[b]
	Residual	21.326	412	.052		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), NL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.742[a]	.551	.550	.26340

a. Predictors: (Constant), BLL

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	35.028	1	35.028	504.863	.000[b]
	Residual	28.585	412	.069		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), BLL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.802[a]	.643	.642	.23487

a. Predictors: (Constant), BLW

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	40.886	1	40.886	741.199	.000[b]
	Residual	22.727	412	.055		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), BLW

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.875[a]	.765	.765	.19029

a. Predictors: (Constant), BC

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	48.694	1	48.694	1344.829	.000[b]
	Residual	14.918	412	.036		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), BC

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.925[a]	.855	.855	.14946

a. Predictors: (Constant), WL

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	54.409	1	54.409	2435.807	.000[b]
	Residual	9.203	412	.022		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), WL

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.920[a]	.846	.845	.15445

a. Predictors: (Constant), WS

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	53.785	1	53.785	2254.753	.000[b]
	Residual	9.828	412	.024		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), WS

APPENDIX G

Multiple Regression Analysis

Model Summary[f]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.945[a]	.894	.894	.12796	
2	.955[b]	.912	.911	.11696	
3	.961[c]	.923	.922	.10937	
4	.962[d]	.925	.924	.10784	
5	.963[e]	.927	.926	.10685	1.945

a. Predictors: (Constant), BL

b. Predictors: (Constant), BL, BC

c. Predictors: (Constant), BL, BC, WL

d. Predictors: (Constant), BL, BC, WL, NL

e. Predictors: (Constant), BL, BC, WL, NL, BLL

f. Dependent Variable: BWT

ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	56.866	1	56.866	3473.065	.000[b]
	Residual	6.746	412	.016		
	Total	63.612	413			
2	Regression	57.990	2	28.995	2119.569	.000[c]
	Residual	5.622	411	.014		
	Total	63.612	413			
3	Regression	58.708	3	19.569	1635.929	.000[d]
	Residual	4.904	410	.012		
	Total	63.612	413			
4	Regression	58.856	4	14.714	1265.291	.000[e]
	Residual	4.756	409	.012		
	Total	63.612	413			
5	Regression	58.954	5	11.791	1032.721	.000[f]
	Residual	4.658	408	.011		
	Total	63.612	413			

a. Dependent Variable: BWT
b. Predictors: (Constant), BL
c. Predictors: (Constant), BL, BC
d. Predictors: (Constant), BL, BC, WL
e. Predictors: (Constant), BL, BC, WL, NL
f. Predictors: (Constant), BL, BC, WL, NL, BLL

APPENDIX H: Analysis of Variance of Production Traits

Analysis of Variance: egg weight

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	3.30	1.650	0.36	0.699
Error	447	2059.80	4.608		
Total	449	2063.10			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean Grouping
3	151	60.4219 A
1	150	60.2580 A
2	149	60.2268 A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	6.76	3.381	0.78	0.460
Error	447	1945.02	4.351		
Total	449	1951.78			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean Grouping
3	151	60.1152 A
1	150	60.0167 A
2	149	59.8201 A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ	2	9.30	4.649	1.47	0.232
Error	447	1417.37	3.171		
Total	449	1426.66			

Tukey Pairwise Comparisons: AEZ

AEZ	N	Mean	Grouping
3	151	44.9795	A
1	150	44.9167	A
2	149	44.6477	A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ2	2	1.156	0.5778	0.22	0.799
Error	87	223.967	2.5743		
Total	89	225.122			

Tukey Pairwise Comparisons: AEZ

AEZ2	N	Mean	Grouping
2	30	33.9000	A
1	30	33.7000	A
3	30	33.6333	A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ2	2	37.07	18.53	0.23	0.796
Error	87	7059.33	81.14		
Total	89	7096.40			

Tukey Pairwise Comparisons: AEZ

AEZ2	N	Mean	Grouping
3	30	83.8000	A
2	30	83.3333	A
1	30	82.2667	A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ2	2	1.356	0.6778	1.26	0.288
Error	87	46.700	0.5368		
Total	89	48.056			

Tukey Pairwise Comparisons: AEZ

AEZ2	N	Mean	Grouping
1	30	11.4333	A
3	30	11.2667	A
2	30	11.1333	A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ2	2	0.2889	0.1444	0.30	0.742
Error	87	41.9333	0.4820		
Total	89	42.2222			

Tukey Pairwise Comparisons: AEZ

AEZ2	N	Mean	Grouping
3	30	8.63333	A
2	30	8.53333	A
1	30	8.50000	A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ2	2	3.267	1.633	0.15	0.865
Error	87	975.233	11.210		
Total	89	978.500			

Tukey Pairwise Comparisons: AEZ

AEZ2	N	Mean Grouping
3	30	16.0667 A
2	30	15.8333 A
1	30	15.6000 A

Means that do not share a letter are significantly different.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
AEZ2	2	63.2	31.60	0.18	0.838
Error	87	15514.8	178.33		
Total	89	15578.0			

Tukey Pairwise Comparisons: AEZ

AEZ2	N	Mean Grouping
3	30	40.1333 A
2	30	38.7333 A
1	30	38.1333 A

Means that do not share a letter are significantly different.

APPENDIX I: Principal Component Analysis

Factor Score Coefficients

Variable	Factor1
BWT	0.133
BL	0.132
SL	0.110
NL	0.119
BLL	0.110
BLW	0.119
BC	0.125
WL	0.132
WS	0.132