

In-situ morphological characterization of indigenous chicken Ecotypes in Uganda

Geoffrey Akiiki Beyihayo^{a,*}, Elly Kurobuza Ndyomugenyi^a, Richard Echodu^b, Donald Kugonza^c

^a Department of Animal Production and Range Management, Faculty of Agriculture and Environment, Gulu University, P.O Box 166, Gulu, Uganda

^b Department of Biology, Faculty of Science, Gulu University, P.O Box 166, Gulu, Uganda

^c Department of Agricultural Production, School of Agricultural Sciences, College of Agricultural and Environmental Sciences, Makerere University, P. O. Box 7062, Kampala, Uganda

ARTICLE INFO

Keywords:

Quantitative traits
Morphology
Ecological
Diversity
Selection

ABSTRACT

Genetic improvement of indigenous chickens (IC) is hindered by limited knowledge on the various chicken Ecotypes. This study characterized and assessed the genetic diversity of nine (9) IC Ecotypes based on quantitative morphological traits. A total of 576 IC (288 cocks and 288 hens) were sampled from 288 households across the 9 agro-ecological zones of Uganda. Data on linear morphological traits and live weight of IC were collected using a field guide developed by African Union Inter-African Bureau for Animal Resources (AU-IBAR, 2015). Over-all, body live weight (LWT), shank/tarsus length (SL), drumstick length (DL), thorax circumference (TC) and body length (BL) of IC varied significantly ($P < 0.05$) across Ecotypes except tarsus circumference (TAC) of cocks. Cocks and hens on average weighed 2.2 ± 0.53 and 1.6 ± 0.58 kg respectively. On average, SL, DL, TC, BL, TAC was 9.8 ± 1.23 , 4.9 ± 2.50 , 16.2 ± 1.63 , 38.4 ± 5.96 , 24.7 ± 4.93 cm for cocks and 7.8 ± 1.04 , 3.9 ± 0.53 , 13.2 ± 1.42 , 33.8 ± 5.29 , 21.3 ± 4.37 cm for hens respectively. Body weight and linear morphological traits except TAC were significantly ($P < 0.05$) influenced by Ecotype. Principal component analysis based on live body weight and morphological linear traits did not identify any distinct chicken Ecotype. The disparity in weight estimation models further emphasizes the ecologically induced variations across Ecotypes. Therefore, the current study confirms the morphological and more so genetic similarity implying genetic improvement can be achieved through selection of superior IC across Ecotypes.

1. Introduction

In Uganda, indigenous chickens (IC) account for 87.7% of the 47.6 million total chicken population and produce 80% of the 907 million eggs on the market [1]. IC are predominantly reared by subsistence resource-constrained farmers under the scavenging system, occasionally supplemented with local cereal grains and households own a flock size of 28 chickens on average [2,3]. IC continue to support the social and economic wellbeing of many rural households through provision of income, meat and are part of many other social functions [3,4]. IC play a pivotal role in nutrient utilization and recycling through scavenging and thus enhance performance of livestock-crop mixed farming systems [2]. In light of the harsh effects of climate change, indigenous chickens adapt well and over-come the challenges of water scarcity, declining feed resources, increased temperature and high incidence of diseases and

parasites. Irrespective of the harsh conditions and constraints, IC are more beneficial and their profit margins are favourable given the limited inputs under village conditions compared to commercial egg or meat type chickens [5].

In spite of the advantages associated with IC, their innate productive and reproductive performance has consistently remained low. In an attempt to increase their productivity, IC are at risk of genetic erosion resulting from their substitution or crossbreeding with imported breeds [6]. As such, the potential of IC in fighting hunger, poverty and attainment of sustainable development has not been fully exploited. In an effort to exploit the full potential of IC, the global plan of action for Animal Genetic Resources (AnGR) highlighted the need for countries to characterize, establish diversity, distribution and determination of their comparative performance as the first strategic step towards improvement of IC genetic resources [7].

* Corresponding author.

E-mail address: g.beyihayo@gu.ac.ug (G.A. Beyihayo).

<https://doi.org/10.1016/j.egg.2022.100129>

Received 27 March 2022; Received in revised form 26 May 2022; Accepted 29 May 2022

Available online 1 June 2022

2405-9854/© 2022 Elsevier Inc. All rights reserved.

Previously, African chickens were grouped into Cluster one (Northern and Central African chickens) and Cluster two (East African chickens) based on their points of origin and entry [8]. Traditionally, Ugandan IC have been categorized and identified based on the ecological zones they inhabit [4,9]. Recently, IC have been characterized on the basis of qualitative phenotypic traits, use and performance [4]. The high levels of phenotypic diversity across IC provides an opportunity for genetic improvement through identification and selection of highly performing breeding cocks and hens [4,10]. The reported phenotypic diversity of Ugandan chickens is based on data collected from within the same or a few Ecotypes and does not follow the ecological zoning approach of categorizing chickens [4,9]. To date, no comprehensive genetic or morphological studies have been carried out to confirm presence of distinct chicken Ecotypes. In addition, use of qualitative phenotypic traits is subjective and necessitates a quantitative method of assessing diversity. Therefore, the aim of this study was to characterize and assess the genetic diversity of IC Ecotypes based on quantitative morphological traits.

2. Materials and methods

2.1. Study area

The study was conducted in nine agro-ecological zones of Uganda (Fig. 1). The agro-ecological zones and their corresponding Ecotypes were; West Nile (Madi), Acholi, Lango, Teso (Nteso), Ngisu (Bugisu), Nsoga (Busoga), Nganda (Buganda), Nyoro (Bunyoro) and Ankole.

and Busoga (Nsoga), Buganda (Nganda), Bunyoro (Nyoro) and Ankole (Ankole). In each agro-ecological zone, two districts and two sub-counties per district with the highest indigenous chicken population were selected based on the livestock census of [11]. The study was approved by Gulu University Research Ethics Committee (GUREC-2020-18). The research protocol was registered with the Uganda National Council for Science and Technology (UNCST) for final clearance (NO. A154ES).

2.2. Sampling and sample size

A total of 576 IC (288 cocks and 288 hens) were purposively sampled from 288 households across the 9 agro-ecological zones of Uganda. Eight households were selected per sub-county. History of having kept IC for a minimum of three years and ownership of a mature breeding cock were the criteria for selecting households. A minimum distance of 1 km between households was maintained along a transect drawn through the sub-county. In addition, 200 fresh fertile indigenous chicken eggs (1–5 days) per agro-ecological zone were purchased from the same households. Eggs were packed in paper trays and delivered to Gulu University poultry unit for determination of egg parameters (weight, length, breadth and volume) and subsequent artificial incubation.

2.3. Data collection

One mature breeding cock and hen per household were selected for



Fig. 1. Map of Uganda showing agro-ecological zones and the corresponding Ecotypes.

quantitative morphometric body assessment. Data on linear body measurements (shank/Tarsus Length = SL; Tarsus circumference = TAC, Drumstick length = DL, Thorax circumference = TC, Body length = BL; Wattle length = WL; Neck length (NL) = NL; Comb height = CH; Comb length = CL; Head length = HL; Wing span = WAPN; Wing length = WL and Beak length = BKL) and live-body weight = LWT were collected using a field guide developed by African Union Inter-African Bureau for Animal Resources [12] as shown in Fig. 2. A tailor's measuring tape (cm) was used to measure the quantitative linear morphometric traits [13]. Live body weight was measured in kilograms using a hanging digital scale (WeiHeng WH-A25, China). Egg weight was measured using an analytical weighing scale (Model: FA2004, China). Egg breadth and length were measured using a digital caliper (Model: DIN 862, Vogel Germany). Egg volume, V was calculated using the following formula [14]:

$$V = 2.854LB$$

Where; L is egg length in millimeters, and B is the egg maximum breadth in millimeters.

2.4. Data analysis

The effects of Ecotype, sex and their interaction on quantitative traits were assessed by the general linear model package, version R 3.5.1 [15]. Means were separated using the least significance difference at 5% level using the model below:

$$Y_{ijk} = \mu + A_i + B_j + (AB)_{ij} + e_{ijk}$$

(Y = measured variable-i; A = zone effect-i; B = sex effect-j AB = their interaction; e = residual error)

Correlations were performed using the R version 3.5.1 [15] to identify the linear morphological traits (WL, NL, TAC, SL, DL, CH, CL and BKL) with the highest Pearson's correlation coefficient with respect to body live weight (LWT) for cocks and hens under each Ecotype. The principal component factor analysis (PCA) was performed from the correlation matrix. The first two outstanding principal components (PC1 and PC2) were used to identify population clusters [15]. Linear morphological traits with the highest Pearson's coefficient with live body weight were used to derive power model equations for predicting live body weight of cocks and hens in each Ecotype [16].

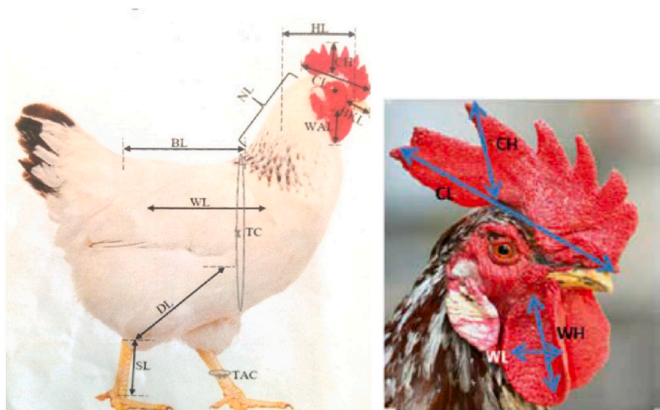


Fig. 2. Illustration of morphometric measurements (AU-IBAR, 2015)

Shank/Tarsus Length (SL) = SL; Tarsus circumference = TAC, Drumstick length = DL, Thorax circumference = TC, Body length = BL; Wattle length = WL; Neck length (NL) = NL; Comb height = CH; Comb length = CL; Head length = HL; Wing span = WAPN; Wing length = WL; Beak length = BKL and Body live weight = LWT.

3. Results

3.1. Effects of ecotype, sex or their interaction on live body weight and linear morphological traits of IC

The effects of Ecotype and sex or their interaction on body weight and the five (5) linear morphological traits of IC are presented in Table 1. The average live body weight-LWT of IC Ecotypes was 2.2 kg for cocks and 1.6 kg for hens. LWT of IC varied significantly ($P < 0.05$) across Ecotypes. Teso (2.6 kg) and Lango (2.55 kg) Ecotypes produced the heaviest cocks while Ngisu (1.68 kg), Ankole (1.71 kg) and Nteso (1.7 kg) Ecotypes produced the heaviest hens. Cocks (1.7 kg) and hens (1.31 kg) of Madi origin were the lightest Ecotype. Overall, the heaviest and lightest chicken Ecotypes originated from Teso and Madi, respectively.

The average shank length -SL across IC Ecotypes was 9.8 cm for cocks and 7.8 cm for hens. Shank length varied significantly across Ecotypes. Lango (11.3 cm) and Acholi (10.7 cm) cocks had the longest SL, Madi and Nyoro Ecotype cocks had the shortest SL of 9.4 and 9.3 cm, respectively. Acholi (8.2 cm) and Lango (8.4 cm) hens had the longest SL, followed by Ngisu (10.1 cm), Nganda (7.6 cm) and Nyoro (7.5 cm) Ecotype had the shortest SL. Over-all, Lango, Acholi and Nteso chickens had longer ($P < 0.05$) SL compared to Nsoga, Nganda, Ankole, Madi and Nyoro Ecotypes.

Over-all, tarsus circumference -TAC of IC Ecotypes was 4.9 cm for cocks and 3.9 cm for hens. Unlike cocks, the tarsus circumference of hens significantly ($P < 0.05$) varied across Ecotypes. Nyoro hens exhibited the largest tarsus circumference (4.3 cm) followed Ankole (4.2 cm) and Nganda (4.09 cm) Ecotype. On the other hand, Madi hens exhibited the least tarsus circumference (3.4 cm). On average, tarsus circumference was highest in the Nsoga, Ankole and Nyoro Ecotypes and lowest in Madi Ecotype.

Over-all, drumstick length -DL of IC Ecotypes was 16.2 cm for cocks and 13.2 cm for hens and varied significantly across Ecotypes ($P < 0.05$). DL of cocks was highest among Acholi, Ngisu and Nteso and lowest for Nyoro and Madi Ecotypes ($P < 0.05$). Nsoga, Ngisu and Nteso hens had the highest ($P < 0.05$) DL.

Generally, thorax circumference -TC of Indigenous chicken Ecotypes was 38.4 cm for cocks and 33.8 cm for hens and varied significantly ($P < 0.05$) across Ecotypes. The Ngisu and Nteso cocks and hens had larger ($P < 0.05$) TC compared to other Ecotypes. Ngisu and Teso had the largest TC followed by Nsoga, while Ankole Ecotype had the least ($P < 0.05$) TC.

Over-all, body length-BL of IC was 24.7 cm for cocks and 21.3 cm for hens and varied significantly ($P < 0.05$) across Ecotypes. Lango, Acholi, Nganda, Ankole and Nyoro had longer bodies (23.42, 22.6, 26.0, 25.91, 25.9 cm) compared to Nteso and Ngisu Ecotypes (19.2 and 18.87 cm) respectively.

The effect of sex on body weight and the five (5) linear morphological traits was significant ($P < 0.05$) across all Ecotypes. Cocks dominated hens in all the six measured traits (LWT, SL, TAC, DL, TC and BL). The effect of Ecotype on body weight and linear morphological traits except TAC was significant ($P < 0.05$) across all Ecotypes.

The Ecotype-sex (E X S) interaction was only significant ($P < 0.05$) for LWT, DL and TC ($P < 0.01$). Shank length, tarsus circumference and body length were not influenced ($P > 0.05$) by the Ecotype-sex interaction. The Nteso cocks and hens were the heaviest and Madi being the lightest (1.5 kg) Ecotype produced the lightest cocks. Ngisu and Nteso Ecotype cocks and hens had longer DL but Madi chickens specifically cocks exhibited shorter DL. Ngisu and Nteso Ecotypes had similar but large thorax circumference for both cocks and hens while Ankole Ecotype had the lowest TC.

3.2. Egg weight and geometry of selected indigenous chicken Ecotypes

The weight and geometry of indigenous chicken eggs from selected ecologies are presented in Table 2. Over-all, indigenous chicken eggs

Table 1

The effect of Ecotype (E), sex (S) or their interaction (E X S) on body weight and linear morphological traits of nine (9) IC Ecotypes.

Trait	Sex	Ecotypes										Ecotype (E)	Sex (S)	E X S	R ² _{adj}
		Acholi	Ngisu	Nsoga	Nganda	Lango	Ankole	Nteso	Madi	Nyoro	All				
LWT/ kg	C	2.39 ± 0.53 ab	2.44 ± 0.46 ab	2.17 ± 0.57bc	2.29 ± 0.46bc	2.55 ± 0.47a	2.13 ± 0.49c	2.6 ± 0.51a	1.7 ± 0.36d	2.2 ± 0.41bc	2.2 ± 0.53	***	***	*	0.33
	H	1.57 ± 0.30 ab	1.68 ± 0.38a	1.57 ± 0.27 ab	1.52 ± 0.33 ab	1.59 ± 0.25 ab	1.71 ± 0.21a	1.7 ± 0.40a	1.31 ± 0.23b	1.5 ± 0.31 ab	1.6 ± 0.58				
	Aver.	1.9 ± 0.64abcd	2.1 ± 0.56abc	1.9 ± 0.53cd	1.9 ± 0.55cd	2.1 ± 0.61 ab	1.9 ± 0.95bcd	2.1 ± 0.64a	1.5 ± 0.36e	1.9 ± 0.48d					
	C	10.7 ± 1.12 ab	10.1 ± 0.94bc	9.7 ± 1.29cd	9.6 ± 1.11cd	11.3 ± 0.94a	9.3 ± 1.00d	10.0 ± 0.87c	9.4 ± 0.97d	9.3 ± 1.13d	9.8 ± 1.23	***	***	.	0.54
SL/ cm	H	8.2 ± 1.03a	8.04 ± 0.67abc	7.6 ± 0.56bc	7.6 ± 1.00c	8.4 ± 0.91a	7.59 ± 0.88bc	8.1 ± 1.60	7.6 ± 1.13bc	7.5 ± 1.12c	7.8 ± 1.04			na	
	Aver.	9.49 ± 1.68b	9.07 ± 1.32bc	8.63 ± 1.436d	8.56 ± 1.48d	9.91 ± 1.70a	8.41 ± 1.28d	9.02 ± 1.59c	8.5 ± 1.38d	8.34 ± 1.44d					
	C	4.98 ± 0.76	4.67 ± 0.64	4.47 ± 0.57	4.88 ± 0.69	4.83 ± 0.57	4.95 ± 0.64	4.73 ± 0.48	4.3 ± 0.78	4.95 ± 0.62	4.9 ± 2.50	na	***	na	0.07
	H	3.67 ± 0.35cd	3.74 ± 0.30c	3.68 ± 0.35c	4.09 ± 0.49b	3.74 ± 0.60c	4.21 ± 0.47 ab	3.76 ± 0.38c	3.4 ± 0.47d	4.3 ± 0.50a	3.9 ± 0.53				
	Aver.	4.32 ± 0.88 ab	4.21 ± 0.69 ab	4.56 ± 0.48a	4.47 ± 0.71 ab	4.30 ± 0.80 ab	4.57 ± 0.67a	4.2 ± 0.65	3.9 ± 0.78b	4.6 ± 0.64a					
	C	16.92 ± 1.59a	17.13 ± 0.90a	16.35 ± 1.40 ab	15.9 ± 1.81bc	16.71 ± 1.22 ab	16 ± 1.71bc	17 ± 1.24a	15.3 ± 1.47c	15.6 ± 1.86c	16.2 ± 1.63	***	***	*	0.53
DL/ cm	H	12.9 ± 1.31 ab	13.8 ± 0.78a	13.7 ± 1.91a	12.8 ± 1.28b	12.7 ± 1.65b	13.2 ± 1.28 ab	13.7 ± 1.57a	12.9 ± 1.76 ab	13.2 ± 1.51 ab	13.2 ± 1.42				
	Aver.	14.9 ± 2.47 ab	15.4 ± 1.91a	14.9 ± 1.87 ab	14.3 ± 2.22cd	14.8 ± 2.48abc	14.6 ± 2.05bcd	15.4 ± 2.18a	14.1 ± 1.97d	14.4 ± 2.04cd					
	C	38.9 ± 4.47c	44.9 ± 3.99a	42.2 ± 3.72b	34.2 ± 4.16c	40.4 ± 6.24bc	34.5 ± 3.51c	45.9 ± 3.20a	39.5 ± 2.95c	35.3 ± 3.77c	38.4 ± 5.96	***	***	**	0.52
	H	34.2 ± 3.44b	38.7 ± 2.40a	37.4 ± 6.22a	31.2 ± 3.46cd	33.6 ± 3.80bc	31.6 ± 3.06cd	38.1 ± 7.21a	35.2 ± 2.78b	31.8 ± 3.51cd	33.8 ± 5.29				
	Aver.	36.59 ± 4.61c	41.80 ± 4.50a	39.77 ± 5.64b	36.65 ± 4.01c	37.10 ± 6.19c	31.01 ± 3.57d	42.0 ± 6.80a	37.39 ± 3.57c	36.5 ± 4.03c					
	C	24.4 ± 4.71a	20.3 ± 2.60b	19.9 ± 4.46b	27.9 ± 4.18bc	25.1 ± 3.88a	27.9 ± 3.80bc	21.0 ± 2.14b	23.2 ± 3.07a	27.7 ± 3.38bc	24.7 ± 4.93	***	***	na	0.50
BL/ cm	H	20.84 ± 6.69a	17.47 ± 1.82b	16.86 ± 2.36	24.3 ± 3.04bc	21.61 ± 2.87a	24.04 ± 3.18bc	17.4 ± 2.01b	20.30 ± 2.84a	24.4 ± 2.24bc	21.3 ± 4.37				
	Aver.	22.6 ± 6.00 ab	18.87 ± 2.63c	18.38 ± 3.86	26.0 ± 4.06 ab	23.42 ± 3.83a	25.91 ± 3.99 ab	19.2 ± 2.75c	21.74 ± 3.27b	25.9 ± 3.27 ab					

C = Cock; H = Hen; Body live weight = LWT; Tarsus/shank Length = SL; Tarsus circumference = TAC, Drumstick length = DL, Thorax circumference = TC, Body length = BL; E X S = Ecotype-Sex interaction; na=not significant; ***p < 0.001; **p < 0.01; *p < 0.05.

Table 2

Egg weight and geometry of selected indigenous chicken Ecotypes.

Egg parameters	Ecotypes					All	SEM	P-Value
	Nteso	Nsoga	Acholi	Lango	Madi			
Weight/g	42.73a	42.61a	41.65a	40.23b	38.99b	41.13	0.23	5.83×10^{-8}
Length L/mm	52.29	52.22	52.11	52.14	51.91	52.13	0.12	0.911
Breadth/mm	38.44 ab	38.64a	38.11b	38.44 ab	37.11c	38.17	0.08	2.23×10^{-10}
Volume V/mm ³	5740a	5768a	5672a	5723a	5503b	5684	21.36	3.39×10^{-4}

weighed 41.13g. Egg weights were highest ($P < 0.05$) in Nteso (42.73) while the Madi Ecotype (38.99g) produced the lightest eggs. All indigenous chicken Ecotypes produced eggs with similar volume except the Madi (5503 mm³) Ecotypes which produced eggs with the lowest volume ($P < 0.05$). Egg length was similar across all Ecotypes ($P > 0.05$). Egg breadth varied across Ecotypes with Nteso, Nsoga and Lango

producing large eggs compared to Madi Ecotype ($P < 0.05$).

3.3. Principal component analysis

The relationship among ecotypes based on body weight and linear morphological traits was visualised using the principal component

analysis. The percentage variation explained by PC1 and PC2 was 63.3% and 10.2% respectively. The first two outstanding principal components (PC1 and PC2) indicates overlapping among Ugandan chicken Ecotypes (Fig. 3).

3.4. Ecotype diversity and live weight estimation models

The linear morphometric traits exhibiting the highest Pearson's correlation coefficient with respect to live weight and the derived estimation models are presented in Table 3. Live body weight and selected linear morphometric traits had positive and strong associations across Ecotypes with Pearson's coefficients ranging from 0.554 to 0.852. The traits for estimating live weight varied across Ecotypes and sex of chicken. However, tarsus circumference (TAC) was the dominant trait for estimating live weight across Ecotypes and sex. Power model equations for predicting live weight varied across sex and Ecotype of the chicken. R-squared values ranged from 81.07% to 100% thus, indicating the high accuracy of estimating live weight using the derived power models equations.

4. Discussion

4.1. Live body weight and linear morphometric traits across ecotypes

The average live body weights of 2.2 ± 0.53 and 1.6 ± 0.58 kg in the current study are similar to values of 2.3 and 1.6 kg for indigenous cocks and hens respectively reported by Ref. [16]. Previously [4], reported slightly lower values of 2.1 and 1.4 kg for indigenous cocks and hens respectively. The high values of body length, drumstick length and thorax circumference reported by Ref. [16], was a result of a study involving only Nganda chicken. The disparity in linear morphometric trait values observed between this study and others could be attributed to differences in field guidelines used in taking measurements. In the current study, ecological zones significantly affected live body weight and morphometric traits of indigenous chickens except tarsus circumference. Recently [17], also reported significant ecological effect on body weight and linear body traits except back length. Significant ecological effect on live body weight and morphometric traits has also been reported in indigenous chicken Ecotypes of Algeria [18] and Ethiopia [19,20]. Indigenous chicken Ecotypes from three agro-ecological zones of Ethiopia had significant variations in body weight, wing span, comb length, beak length, breast angle and keel bone length [19]. In a related study, chicken reared in highlands were reported to be heavier at maturity and their survivability was higher than their counterparts in lowland ecologies. However, their egg production

traits were not influenced by the agro-ecologies [21]. In an evaluation study of three indigenous chicken Ecotypes [22], reported low hatchabilities and survival rates in lowlands. However, body weight and egg production traits were not affected by the elevation above sea level. On the contrary [23], reported higher live body weight and more chances of survival for dual-purpose breeds reared in lowland agro-ecologies.

The effect of ecology on body weight and morphometric traits is probably influenced by the variety of scavengeable feed resources, which are largely influenced by the climate, vegetation and farming systems practiced in the different zones [24,25]. The variation in body weight and linear morphometric traits observed among indigenous chickens can also be attributed to the breed and ecology or their interaction [18,26]. Origin of chicken Ecotypes could be another source of variation in body weight. The Madi Ecotype, inhabiting the Western part of the River Nile, which most likely belongs to Cluster one of African chickens, is the highest of all the Ecotypes and this can be attributed to its origin [8]. The Madi Ecotype is likely to have originated from the Indus valley of Asia and entered Uganda along the River Nile to Nubia and finally into Uganda [27].

4.2. Egg weight and geometry across Ecotypes

The Madi Ecotype consistently produce eggs with the least weight, volume and breadth amongst all Ecotypes. The weight of Madi chicken eggs corresponds to the low weight of chickens from the same ecology. Egg weight and geometry have been reported to influence hatching weight and post-hatch performance. Senbeta [28] reported higher hatching weights, body weight gain, feed intake and survival rates with increasing egg size. Apart from predicting hatchability and chick weight, egg geometry has an application in comparison of chicken morphology and diversity across ecologies [29]. In the current study, the variation in egg size could be an indicator of genetic variability especially between Madi and other Ecotypes.

4.3. Principal component analysis

Overlapping of Ecotypes based on the first two principal components is evidence of absence of distinct chicken Ecotypes. The variations observed across the chicken Ecotypes are probably ecologically induced. As a result of human activities including trade and migration, the variation across chicken clusters reported by Ref. [8] have reduced due to planned or unplanned cross breeding. The absence of distinct chicken Ecotypes is as a result of social, economic and cultural interactions among communities across the different ecologies [30]. Crossbreeding and ecological effect are responsible for the creation of new sub-groups and phenotypic diversity among chicken Ecotypes [4,10]. On the basis of Principal Component Analysis-PC, indigenous chickens in Kenya were clustered into two distinct Ecotypes [30]. Previously [31], grouped Tanzanian indigenous chickens into three distinct populations with PC1 and PC2 explaining 89.9 and 5.13% of the variation respectively.

4.4. Ecotype diversity and live weight estimation models

The traits and models for estimating live body weight varied across Ecotypes and sex of chicken. Similarly [19], reported varying traits and models for estimating live weight of chicken Ecotypes across three agro-ecological zones of Ethiopia. In the present study, comb height and length were the best estimators of live weight for cocks and hens respectively for the Nganda chicken Ecotype. However [16], reported thorax circumference as the best predictor of live weight for mature Nganda chicken Ecotype. Although chicken live body weight was generally predictable by breast angle, body length and shank circumference were specific to hens and cocks respectively [19]. Recently [32], also indicated that body length is the best estimator of live weight among hens. High correlation coefficients of 0.70 and 0.64 between body weight and thorax circumference have been reported among

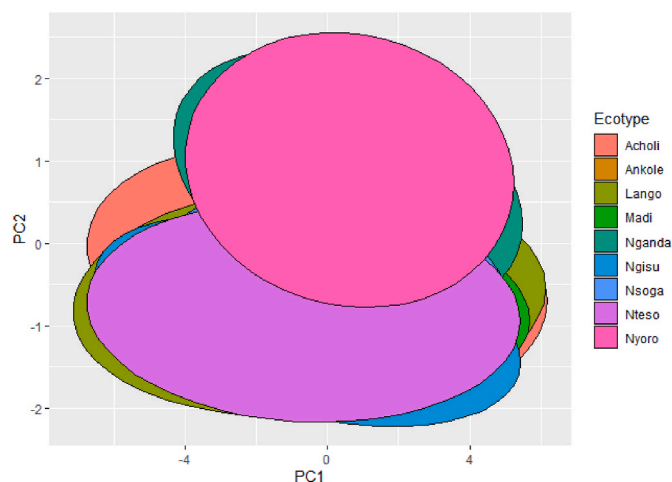


Fig. 3. Principal component analysis of nine (9) IC ecotypes based on 9 linear morphological traits (PC1 = 63.3% and PC2 = 10.2%).

Table 3

Live weight estimation of indigenous chicken Ecotypes based on linear morphometric traits.

Correlation of traits and live weight				Derived power model equations			
Ecotype	Sex	Trait	Pearson's coefficient ^b	Live weight (y) estimator across Ecotypes ^c	R _{adj} ^a	SE	Significance
Acholi	C	TAC	0.852	y = 318.99(TAC) ^{1.2512}	0.9995	77.94	***
	H	SL	0.572	y = 249.94(SL) ^{0.8731}	0.9999	78.18	Na
Lango	C	DL	0.579	y = 38.505(DL) ^{1.4882}	0.9996	64.54	**
	H	TAC	0.747	y = 615.14(TAC) ^{0.7222}	0.9992	57.94	***
Madi	C	TAC	0.801	y = 431.85(TAC) ^{0.9402}	0.9999	57.94	***
	H	CH	0.663	y = 1279(CH) ^{0.1668}	0.8107	41.65	***
Ngisu	C	CL	0.820	y = 663.65(CL) ^{0.6179}	0.9973	35.81	***
	H	TAC	0.561	y = 217.51(TAC) ^{1.5492}	0.9998	283.02	*
Nsoga	C	TAC	0.733	y = 264.85(TAC) ^{1.3927}	0.9992	97.23	***
	H	BKL	0.598	y = 327.08(BKL) ^{1.2812}	0.9998	123.28	***
Nteso	C	CL	0.807	y = 647.12(CL) ^{0.6557}	0.9950	31.84	***
	H	TAC	0.655	y = 214.8(TAC) ^{1.546}	0.9994	158.74	***
Nganda	C	CH	0.617	y = 1374(CH) ^{0.4239}	0.9802	58.59	***
	H	CL	0.713	y = 879.78(CL) ^{0.4867}	0.9889	33.1	***
Nyoro	C	WL	0.657	y = 1381.3(WL) ^{0.3501}	0.9730	44.38	***
	H	CL	0.554	y = 912.14(CL) ^{0.4767}	0.9882	65.46	***
Ankole	C	TAC	0.686	y = 301.62(TAC) ^{1.2209}	0.9998	85.61	***
	H	TAC	0.601	y = 332.43(TAC) ^{1.0698}	1.0000	78.5	***

C = Cock; H = Hen; Tarsus circumference = TAC; Tarsus/shank Length = SL; Drumstick length = DL; Wattle length = WL; Comb length = CL; Comb height = CH; Beak length = BKL; ^bPair-wise Pearson's correlation coefficient, traits with the highest coefficient with live weight (y) were selected; ^cPower model equations based on a trait with the highest Pearson's coefficient; ^dAdjusted R-squared values to evaluate the power model equations; SE = Standard Error; ^{na}not significant; ***p < 0.001; **p < 0.01; *p < 0.05.

Bangladesh and Ethiopian indigenous chickens [20,33] respectively. It is a common occurrence to have different studies presenting different traits as the best live weight estimators for one or both sexes. The potential sources of disparity in weight estimation models is the use of different guidelines in morphometric studies.

4.5. Ecotype-ecology interaction

In the current study, linear morphometric traits for estimating live weight varied across Ecotypes and sex of chicken. However, tarsus circumference was the dominant trait across Ecotypes for estimating live weight of either cocks or hens. This is because tarsus circumference did not vary significantly across Ecotypes as compared to other traits. In a statistical modelling study, body weight and the length of linear body traits except back length were influenced by the agro-ecologies the chicken inhabit thus confirming Ecotype-ecology interaction [32]. Therefore, in the present study, apart from estimating body weight, the diversity in the weight estimation models is an indicator of wide morphological and consequently genetic variation within and across the chicken Ecotypes. The observed morphological variations across Ecotypes provides an opportunity for genetic improvement of indigenous chicken through selection [32].

5. Conclusion

The observed variation in body weight and linear morphological traits across Ecotypes is ecologically induced. Despite the similarity across Ecotypes, the Madi chicken weighs less and correspondingly lays eggs with the least weight, volume and breadth. On the basis of live weight and linear morphological traits, principal component analysis provides no evidence of distinct IC Ecotypes. The difference in weight estimation models further emphasizes the ecologically induced morphological variations across Ecotypes. Therefore, genetic improvement can be achieved through selection of superior chickens across Ecotypes.

Funding

This study was funded by African Union (AU) through the Native Chicken Project (AURG II-2-115-2018).

Data

Genetic data and codes are available as supplementary files.

CRediT authorship contribution statement

Geoffrey Akiiki Beyihayo: Conceptualization, Formal analysis, Writing – original draft, Data collection, analysis, Compilation of initial manuscript draft. **Elly Kurobuza Ndyomugenyi:** Writing – review & editing, Review, Editing, and, Supervision. **Richard Echodu:** Writing – review & editing, Review, Editing, and, Supervision. **Donald Kugonza:** Supervision, Funding acquisition, and, Project administration.

Declarations of interest

None.

Acknowledgements

African Union (AU) is acknowledged for financing this study under the Native Chicken Project (Contract number: AURG II-2-115-2018). We are also grateful to the farmers in the participating agro-ecological zones for allowing us to use their chickens in the study.

All authors read and approved the final manuscript.

References

- [1] Uganda Bureau of Statistics, Uganda Bureau of Statistics Statistical, 2014, pp. 1–305 [Online]. Available: http://www.ubos.org/onlinefiles/uploads/ubos/statistical_abstracts/Statistical Abstract 2014.pdf. (Accessed 15 August 2016).
- [2] J.T. Wong, et al., Small-scale poultry and food security in resource-poor settings: a review, *Global Food Secur.* 15 (2017) 43–52, <https://doi.org/10.1016/j.gfs.2017.04.003>. March.
- [3] C. Lubandi, S. Lwasa, D. Kugonza, B.M. Brian, G. Nadiope, M.W. Okot, Analysis of indigenous chicken value chain in Uganda, *African J. Rural Dev.* 3 (3) (2019) 895–912.
- [4] E.M. Ssewanyana, A. Ssali, T. Kasadha, Dhikusooka, P.L. Kasoma, J. Kalema, B. A. Kwatotyot, Aziku, On-farm characterization of indigenous chickens in Uganda, *J. Anim. Plant Sci.* 1 (2) (2008) 33–37 [Online]. Available: <http://www.m.elewa.org/JAPS/2008/1.2/1.pdf>.
- [5] M.K. Padhi, Importance of Indigenous Breeds of Chicken for Rural Economy, vol. 2016, 2016.
- [6] F. Semahoro, D.R.D. Kugonza, B.M.B.M. Babigumira, S. Walusimbi, G. Nadiope, M. W.M.W. Okot, Growth performance of chicken genotypes based on indigenous

- populations of Eastern Uganda, *Proc. World Congr. Genet. Appl. to Livest. Prod.* (2018). Electronic, no. 1c, p. 557, <https://pdfs.semanticscholar.org/f898/801fe122ca812b38b2bb8f7218ed7015f5eb.pdf%0Ahttp://www.wcgalp.org/system/files/proceedings/2018/growth-performance-chicken-genotypes-based-indigenous-populations-eastern-uganda.pdf> [Online]. Available.
- [7] FAO Commission on Genetic Resources for Food and Agriculture Assessments, Global plan of action for animal genetic resources and the Interlaken declaration, *World's Poult. Sci. J.* (2007) 286 [Online]. Available: http://www.journals.cambridge.org/abstract_S0043933909000245.
 - [8] S.A.M. Osman, T. Yonezawa, M. Nishibori, Origin and genetic diversity of Egyptian native chickens based on complete sequence of mitochondrial DNA D-loop region, *Poultry Sci.* 95 (6) (2016) 1248–1256, <https://doi.org/10.3382/ps/pew029>.
 - [9] E. Ssewanyana, Strategies for management of animal genetic resources in Uganda, *Uganda J. Agric. Sci.* 9 (1) (2004) 888–892.
 - [10] D.S. Fleming, et al., Genomic analysis of Ugandan and Rwandan chicken ecotypes using a 600 k genotyping array, *BMC Genom.* 17 (1) (2016) 1–16, <https://doi.org/10.1186/s12864-016-2711-5>.
 - [11] UBOS, "Uganda Bureau of Statistics, The 2018 Statistical Abstract, 2018, p. 315 [Online]. Available: https://www.ubos.org/wp-content/uploads/publications/05_2019STATISTICAL_ABSTRACT_2018.pdf.
 - [12] Au-Ibar, *Pictorial Field Guide for Linear Measurements of Animal Genetic Resources*, 2015.
 - [13] T.L. Tyasi, et al., Multivariate adaptive regression splines data mining algorithm for prediction of body weight of hy-line silver Brown commercial layer chicken breed, *Adv. Anim. Vet. Sci.* 8 (7) (2020) 794–799, <https://doi.org/10.17582/journal.aavs/2020/8.8.794.799>.
 - [14] V.G. Narushin, M.N. Romanov, Egg physical characteristics and hatchability, *World's Poult. Sci. J.* 58 (3) (2002) 297–303, <https://doi.org/10.1079/WPS20020023>.
 - [15] "RStudio" R Core Team, A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, 2021. URL: <https://www.R-project.org/>.
 - [16] J. Semakula, P. Lusembo, D.R. Kugonza, D. Mutetikka, J. Ssenyonjo, M. Mwesiwa, Estimation of live body weight using zoometrical measurements for improved marketing of indigenous chicken in the Lake Victoria basin of Uganda, *Livest. Res. Rural Dev.* 23 (8) (2011).
 - [17] B.M. Zone, A. Tadele, Statistical Modelling of Indigenous Chicken with Body Weight and Linear Body Measurements in, 2019, pp. 63–67, <https://doi.org/10.19080/IJESNR.2019.22.556083>.
 - [18] L. Dahloun, N. Moula, M. Halbouche, S. Mignon-Grasteau, Phenotypic characterization of the indigenous chickens (*Gallus gallus*) in the Northwest of Algeria, *Arch. Anim. Breed.* 59 (1) (2016) 79–90, <https://doi.org/10.5194/aab-59-79-2016>.
 - [19] D. Negassa, A. Melesse, S. Banerjee, Phenotypic characterization of indigenous chicken populations in southeastern Oromia regional state of Ethiopia, *Anim. Genet. Resour. génétiques Anim. génétiques Anim.* 55 (2014) 101–113, <https://doi.org/10.1017/s2078633614000319>, December 2017.
 - [20] H. Assefa, A. Melesse, Morphological and morphometric characterization of indigenous chicken populations in sheka zone, south western Ethiopia, *Poultry, Fish. Wildl. Sci.* (2018), <https://doi.org/10.4172/2375-446x.1000200>, 06, 02.
 - [21] F.S. Guni, S.H. Mbagi, A.M. Katule, E.H. Goromela, Performance evaluation of Kuroiler and Sasso chicken breeds reared under farmer management conditions in highland and lowland areas of Mvomero district, Eastern Tanzania, *Trop. Anim. Health Prod.* 53 (2) (2021) 53–59, <https://doi.org/10.1007/s11250-021-02693-4>.
 - [22] S. Markos, B. Belay, T. Dessie, On farm carcass performance evaluation of three local chicken ecotypes in western zone of Tigray, Northern Ethiopia, *J. Biol. Agric. Healthc.* 4 (23) (2014) 154–161.
 - [23] F.O. Ajayi, et al., Production performance and survivability of six dual-purpose breeds of chicken under smallholder farmers' management practices in Nigeria, *Arch. Anim. Breed.* 63 (2) (2020) 387–408, <https://doi.org/10.5194/aab-63-387-2020>.
 - [24] F.C. Muchadeyi, C.B.A. Wollny, H. Eding, S. Weigend, S.M. Makuza, H. Simianer, Variation in village chicken production systems among agro-ecological zones of Zimbabwe, *Trop. Anim. Health Prod.* 39 (6) (2007) 453–461, <https://doi.org/10.1007/s11250-007-9050-0>.
 - [25] M. De Kinderen, *Genotype by Environment Interactions of Chickens Tested in Ethiopia Two Traits Analysed*, 2020. September.
 - [26] B. Kassa, Y. Tadesse, W. Esatu, T. Dessie, On-farm comparative evaluation of production performance of tropically adapted exotic chicken breeds in western Amhara, Ethiopia, *J. Appl. Poultry Res.* 30 (4) (2021), 100194, <https://doi.org/10.1016/j.japr.2021.100194>.
 - [27] D.N. Edwards, Chickens in Africa: the importance of qasr ibrim, *Antiquity* 67 (256) (1993) 584–590, <https://doi.org/10.1017/S0003598X00045786>.
 - [28] E.K. Senbeta, Effect of egg size on hatchability and subsequent growth performance of fayoumi chicken, *J. Agric. Sci.* 9 (7) (2017) 116, <https://doi.org/10.5539/jas.v9n7p116>.
 - [29] V.G. Narushin, Egg geometry calculation using the measurements of length and breadth, *Poultry Sci.* 84 (3) (2005) 482–484, <https://doi.org/10.1093/ps/84.3.482>.
 - [30] O.N. Okumu, et al., Genetic diversity of indigenous chickens from selected areas in Kenya using microsatellite markers, *J. Genet. Eng. Biotechnol.* 15 (2) (2017) 489–495, <https://doi.org/10.1016/j.jgeb.2017.04.007>.
 - [31] C.M. Lyimo, A. Weigend, U. Janßen-Tapken, P.L. Msoffe, H. Simianer, S. Weigend, Assessing the genetic diversity of five Tanzanian chicken ecotypes using molecular tools, *S. Afr. J. Anim. Sci.* 43 (4) (2013) 499–510, <https://doi.org/10.4314/sajas.v43i4.7>.
 - [32] H.O. U, V.M.O. O, R.J. N, Statistical modelling of body weight and linear body measurements in Nigerian indigenous chicken, *IOSR J. Agric. Vet. Sci.* 7 (1) (2014) 27–30, <https://doi.org/10.9790/2380-07152730>.
 - [33] F. Tabassum, M. Hoque, F. Islam, C. Ritchil, M. Faruque, A. Bhuiyan, Phenotypic and Morphometric characterization of indigenous chickens at Jhenaigati upazila of Sherpur district in Bangladesh, *SAARC J. Agric.* 12 (2) (2015) 154–169, <https://doi.org/10.3329/sja.v12i2.21927>.