

Morphobiometric Characteristics and Biodiversity of Indigenous Guinea Fowl (*Numida meleagris*) in Benin

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ABSTRACT

The present study aimed to describe the morphobiometric characteristics of indigenous guinea fowl (*Numida meleagris*) populations in Benin. The current study was carried out on 1320 (529 males and 791 females) adult (at least 24 weeks old) indigenous guinea fowls from three climatic zones (Sudanian, Sudano-Guinean, and Guinean) of Benin. Each guinea fowl was subjected to a direct phenotypic description, biometric measurements, and photography. The results showed that the plumage coloration of indigenous guinea fowl in Benin was significantly diverse, but the most widespread plumage colors were pearl grey (30%), black (29.5%), and cinnamon (9.8%). The most common beak colors were grey (64.9%) and yellow-orange (24.8%). The eyes were predominantly black-white (67.1%). Grey-orange (33.7%), grey (32%), and black-orange (21%) colorations were more represented on the shanks with wattles relatively dominated by red-white (59.4%) and white-red (30.5%). The average live weight of guinea fowl was 1.34 kg in males which was 4.38% heavier than females. All the biometric measurements were significantly higher in males. The live weights of guinea fowl in the Sudanian zone (1.40 ± 0.18 kg) were higher than those of guinea fowl found in the Sudano-Guinean zone (1.27 ± 0.24 kg) and Guinean zone (1.33 ± 0.28 kg). Principal Component Analysis indicated that three distinct groups of guinea fowl can be formed based on their biometric measurements (live weight, chest circumference, body length, drumstick length, shank length, shank diameter, and wingspan). The phenotypes' diversity was relatively abundant (1-Hill: 0.69) in all climatic zones. The phenotypic biodiversity observed in the populations of indigenous guinea fowl in Benin can guide farmers to select specific phenotypes to meet consumer preferences.

Keywords: Benin, Biodiversity, Climatic zone, Indigenous guinea fowl, Phenotypic characteristic.

INTRODUCTION

Indigenous animal genetic resources represent an original and unique heritage due to the fact that they have developed particularly useful traits, in terms of production performance and adaptation qualities (Naves et al., 2011). In Benin, similar to other sub-Saharan countries, poultry production has remained dependent on family poultry farming. This form of poultry farming brings together 99% of the domestic poultry population (Chrysostome et al., 2013). This sub-sector contributes significantly to the food security, fight against poverty, and well-being of the people while requiring low levels of investment (Boko et al., 2012; Avornyo et al., 2016; Kone et al., 2018; Traoré et al., 2018; Kouassi et al., 2019). The optimal management of guinea fowl production as a rural poultry

enterprise gives farmers huge advantages as well as revenue generation through sales of live guinea fowl and eggs (Agbolosu et al., 2015).

One of the problems that farmers face in animal husbandry and particularly in guinea fowl breeding is the lack of knowledge of the characteristics of indigenous genetic resources. This problem constitutes a constraint for the adequate use of their potential, which could lead to the promotion of these indigenous genetic resources in the context of ecological constraints. The characterization and conservation of various genetic attributes of indigenous species are crucial in order to maintain the genetic biodiversity of these animals, improve the food security of the rural population, and enhance economic empowerment in developing countries (Oguntunji, 2013; Haoua et al., 2015; Ould Ahmed and N'Daw, 2015). The strong

distribution of guinea fowl is an indication of their adaptability to local environmental conditions, such as drought and high temperatures caused by climate variability (Panyako et al., 2016). Strategies for the management and enhancement of indigenous poultry resources are necessary both for rural economic development and for safeguarding biodiversity (Mahammi et al., 2014; Elkana and Gwaza, 2019). However, from these local populations of guinea fowl, some communities have conserved due to their local knowledge, types of birds with good production performance, such as varieties of guinea fowl (Chrysostome, 1995; Houndonoubo et al., 2017). However, the determination of the morphobiometric diversity of guinea fowl has not been done systematically in all the different climatic zones of Benin. The present study aimed to investigate the genetic diversity of the indigenous guinea fowl population available throughout the Beninese national territory. This knowledge would contribute to combating poverty through appropriate management and improvement of present poultry genetic resources.

MATERIALS AND METHODS

Ethical approval

All procedures were conducted in accordance with the guide for the care and use of agricultural animals in research, and approved by the department of animal production of the Faculty of Agricultural Sciences, University of Abomey-Calavi (Benin Republic).

Study areas

The study covered the Beninese national territory divided into three climatic zones which were Sudanian zone (9°45'-12°25'N), Sudano-Guinean zone (7°30'-9°45'N), and the Guinean zone (6°25'-7°30'N, Figure 1). From 1987 to 2016, the average rainfall in the Sudanian zone was less than 1000 mm in a year, and the average relative humidity during those years was 59%, and the average temperature also during those years was 28.4°C. The Sudano-Guinean zone has unimodal rainfall, from May to October with 113 days of rain, and an average annual rainfall of 900-1100 mm. The annual temperature varies between 21.2°C and 33.5°C, and the relative humidity ranges 31-98%. The Guinean zone is characterized by a bimodal rainfall with an annual average rainfall of 1200 mm; the average temperature varies

between 25°C and 31°C, and the relative humidity ranges 69-97%.

Sampling

The study was carried out on a total of 1320 adult guinea fowls on which direct observations and body measurements were taken. This sampling included 529 males and 791 females with the same number of 440 guinea fowls per climatic zone. In each climatic zone, the study area was considered by taking into account the localities where guinea fowl production was more widespread. Then, in each locality considered, the main villages involved in this activity were identified. This identification of the study localities was carried out through discussions with administrative authorities, territorial agricultural development agents, guinea fowl farmers, traders, and consumers.

The study area was large and the inclusion criteria for the sample collection from livestock and animal households entailed villages with a minimum distance of 10 km, a large number of guinea fowl farmers in the villages, ownership of at least 10 guinea fowls by each farmer. Accordingly, 16 villages on average per climatic zone were used for data collection.

Data collection and calculated indices

Qualitative and quantitative data were collected. The qualitative variables (plumage colors, colors of shanks, wattles, eyes, and beaks) were used for the morphological characterization of the guinea fowl. As for the biometric characterization, it was performed through quantitative variables which included linear body measurements (chest circumference, body length, drumstick length, shank length, shank diameter, wingspan, and live weight) of each guinea fowl. The body weights were taken using an electronic balance of 1 g precision, while the shank diameters were measured using a Vernier caliper of 0.01 mm precision, and other body measurements were performed using a tape measure. All the data were collected by the same investigator using protocols consistent with the guidelines of the Food and Agriculture Organization of the United Nations (FAO, 2013) for phenotypic characterization of animal genetic resources. The schematic representation of biometric data collection

following the recommendations of FAO (2013) is presented in Figure 2. The phenotype diversity of guinea fowl was determined by defining several indexes of biological diversity.

Shannon diversity index (1949)

$$H : -\sum_{i=1}^S p_i \log_2 p_i$$

Where, H refers to the Shannon diversity index, i is a phenotype of the study area, S denotes the phenotype richness. p_i is the proportion of a phenotype (i) in relation to the total number of phenotype (S) in the study area which was calculated by the following formula:

$$p_i : \frac{n_i}{N}; \text{ where, } n_i \text{ is the number of individuals for}$$

phenotype, and i and N indicate the total number of individuals of all phenotype combined.

Simpson index (1949)

It measures the probability that two individuals selected randomly from the sampled population belonging to the same phenotype.

$$D : \sum [n_i(n_i - 1) / N(N - 1)],$$

Where, n_i is the number of individuals for phenotype i , and N refers to the total number of individuals of all phenotypes combined.

Hill index (1973)

Hill Index is a proportional abundance measure that combines Shannon and Simpson index. It provides a more precise view of the observed diversity. It was calculated by the following equation:

$$\text{Hill} : (1/D) / e^H$$

Where, $1/D$ is the inverse of Simpson index, and e^H signifies the exponential of Shannon index.

Statistical analysis

The data collected was encoded in a database designed on Excel 2013. Statistical analysis of the data was performed using R software (R Core Team, 2019). Descriptive statistics were used to determine the color frequencies of the plumage, eyes, and beak, as well as the colors of shanks and wattles. These frequencies were specified by sex and by climatic zone. The biometric measurements were subjected to a non-parametric Kruskal

Wallis test due to the non-normality of the distribution. The multiple comparisons procedure of the means was performed with Student Newman Keuls test when results were significant at a 5% level of probability. The variability of live weights of guinea fowl by climatic zones and sex was represented using boxplots. The Principal Component Analysis (PCA) was used to split guinea fowl with the same biometric characteristics through the FactoMineR package. In order to define more the different biometric groups of indigenous guinea fowl populations from the PCA examination, an Ascending Hierarchical Classification (AHC) was carried out with all the data made up of seven (07) variables. Hill's diversity index was used to measure the proportional abundance of guinea fowl phenotype by putting together the Shannon index (more sensitive to the numbers of rare phenotypes) and Simpson index (more sensitive to the numbers of abundant phenotypes). Accordingly, Hill index thus seems to be the most synthetic. The closer the index is to the value 1, the lower the diversity is. However, in order to facilitate interpretation, 1-Hill index was used, where the maximum diversity is represented by the value 1, and the minimum by the value 0.

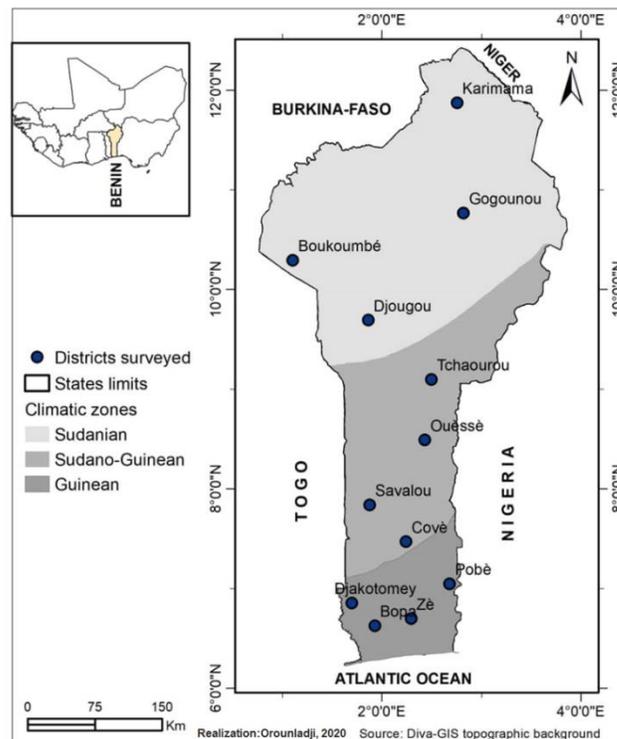


Figure 1. Materialization of the study areas.

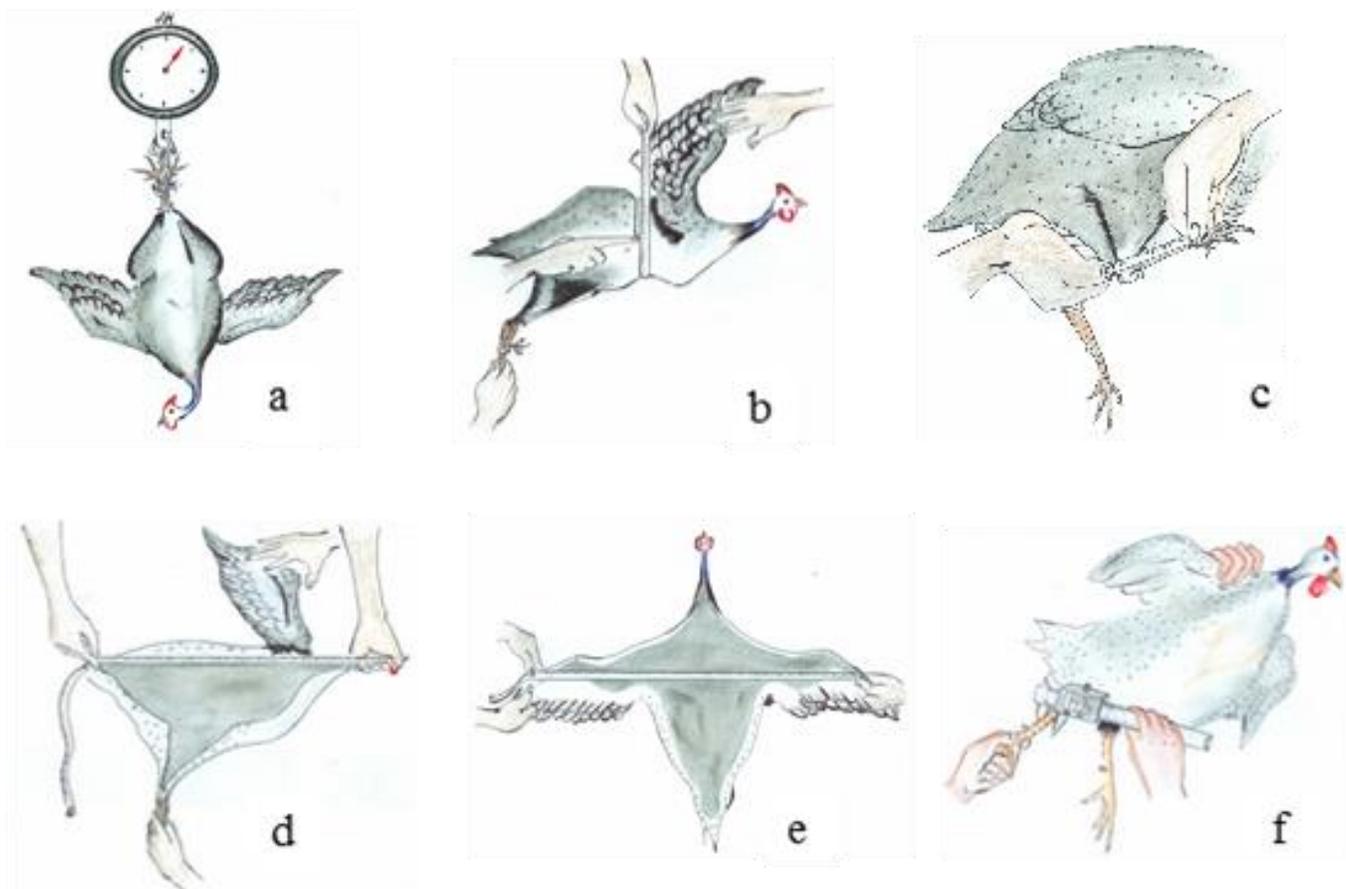


Figure 2. Body measurements; a: Live weight; b: Chest circumference; c: Shank length; d: Body length; e: Wingspan; f: Shank diameter

RESULTS

Qualitative variables describing indigenous guinea fowl populations

Descriptive appearance of guinea fowl plumage colors

Based on the colors chart of Guinea Fowl International Association (GFIA), a diversity of plumage colors was observed in the three climatic zones of Benin. A total of 12 phenotypes were identified, including pied white, white, brown, cinnamon, buff, multicolored, pearl grey, pied pearl grey, lavender, black, pastel, and royal purple (Figure 3). From the analysis of the three climatic zones, regardless of the sex of the guinea fowl, the results showed that pearl gray (30%), black (29.5%), and cinnamon (9.8%) plumages were the most represented plumage colors (Table 1). The buff, multicolored, and pastel plumages were not observed in the Guinean zone, whereas they were found in the Sudanian and Sudano-Guinean zones with pied white (3.6%), white (2.6%), brown (2.7%), pearl grey (6.8%), lavender (7.7%), and royal purple (3.4%) plumages which were under-represented.

Descriptive appearance of other parts of guinea fowl

Regarding the beak, the most common color was grey (64.9%). It was accompanied successively by yellow-orange (24.8%), white (6.6%), black (3.4%), and orange (0.2%, Figure 4). As for the coloration of eyes, the major color was black-white (67.1%). Other colors, such as black-orange (12.3%), black-red (12%), and brown (8.5%) were also observed through the eyes of guinea fowl populations in all climatic zones. The wattles colorations were mainly represented by red-white (59.4%) and white-red (30.5%). White (6.4%), red (3.1%), and pink (0.7%) were other wattle colorations that were infrequent in this indigenous population of guinea fowl throughout Benin republic. The colors of shanks were more marked by grey-orange (33.7%), grey (32%), and black-orange (21%). The poorly represented colors were orange (3.9%), orange-grey (3.4%), orange-black (2.2%), grey-black (2%), black (1.1%) and pink-grey (0.8%). The black shanks were only observed in guinea fowl from the Sudanian and Sudano-Guinean zones, regardless of sex.

Quantitative variables describing indigenous guinea fowl populations

Morphobiometric measurements by climatic zones

The analysis of the variance of the biometric measurements is presented in Table 2, showing that the live weight, the drumstick length, the shank length, and the shank diameter of guinea fowl varied significantly from one climatic zone to another ($p < 0.05$). The live weights of guinea fowl in Sudanian zone (1.40 ± 0.18 kg) were higher than those of guinea fowl found in the Sudano-Guinean zone (1.27 ± 0.24 kg) and Guinean zone (1.33 ± 0.28 kg). The drumstick length was higher ($p < 0.05$) in Guinean zone (11.77 ± 1.12 cm) than those of Sudanian and Sudano-Guinean zones which were 10.48 ± 0.94 cm and 10.19 ± 0.58 cm, respectively. Guinea fowl from Sudanian zone showed higher values for shank length (6.23 ± 0.54 cm) and shank diameter (1.09 ± 0.08 cm). The other biometric measurements (chest circumference, body length, and wingspan) showed similar values ($p > 0.05$) in all climatic zones.

Morphobiometric measurements by sex

All traits measured had significantly higher values ($p < 0.05$) in males, compared to females (Table 3). Therefore, gender induced significant values of live weight, chest circumference, body length, drumstick length, shank length, shank diameter, and wingspan. Males had an average live weight of 1.37 kg, compared to 1.31 kg in females. In male guinea fowl, the values for chest circumference (32.60 ± 1.35 cm) and body length (41.71 ± 1.29 cm) were respectively higher than those observed in females (31.07 ± 2.25 cm and 40.1 ± 2.84 cm).

Morphobiometric measurements by phenotypes

All morphobiometric parameters were significantly ($p < 0.05$) influenced by phenotypes (Table 4). According to live weight, buff phenotypes (1.51 ± 0.32 kg) were heavier than all other phenotypes. The chest circumference (33.09 ± 0.09 cm) and body length (42.31 ± 0.74 cm) of buff phenotypes were also greater than those of pied pearl grey phenotypes (30.36 ± 2.29 cm and 39.38 ± 3.29 cm) and pastel phenotypes (29.33 ± 2.75 cm and 37.81 ± 3.12 cm). Pearl grey (11.04 ± 1.15 cm), multicolored (11.04 ± 1.16 cm), and lavender (11.17 ± 1.06 cm) phenotypes had a greater ($p < 0.05$) drumstick length than pied white (10.18 ± 0.71 cm) and pastel (9.45 ± 0.78 cm) phenotypes. The shank lengths of pastel (5.79 ± 0.70 cm) phenotypes were smaller ($p < 0.05$) than those of buff (6.31 ± 0.66 cm), multicolored (6.33 ± 0.65 cm), pearl grey (6.22 ± 0.59 cm), and lavender (6.28 ± 0.42 cm) phenotypes. For the shank diameter, brown (1.14 ± 0.07 cm) and multicolored (1.13 ± 0.05 cm) phenotypes showed higher values, compared to

pastel phenotypes (1.04 ± 0.08 cm). Pastel (39.12 ± 7.59 cm) phenotypes had the smallest values of wingspan compared to all other phenotypes described in the current study.

Variability of live weight by climatic zone and sex

Great variability in weights was observed within the guinea fowl populations of the Guinean zone (Figure 5). The live weight was respectively within the ranges of 0.90-2.2 kg and 0.60-2 kg in the males and females in this zone. The live weight of 50% of females in this area ranged between 1.1 and 1.5 kg, while it ranged from 1.2 to 1.65 kg in males. The Sudanian zone showed less variability. The live weights varied from 1.09 to 1.75 kg and from 1.09 to 1.76 kg, respectively, in females and males of the Sudanian zone. In 50% of males and females in the Sudanian zone, the live weight varied from 1.40 to 1.60 kg and from 1.35 to 1.45 kg, respectively. As for the males and females of the Sudano-Guinean zone, their live weights varied respectively from 0.90 to 1.8 kg and from 0.88 to 1.67 kg.

Characterization of guinea fowl populations

The cumulative contribution to the total inertia of the three axes which were retained for the interpretation of the results of the Principal Component Analysis (PCA) was 70.40% (Table 5). The dendrogram (Figure 6) and the representation of the PCA (Figure 7) were used to differentiate three biometric groups in all climatic zones of Benin. The analysis of the variance of the groups on the graphs of the AHC and the PCA allowed identifying the characteristics of each group (Table 6).

Group one contained 16.89% of the guinea fowl sampled. They had significantly lowest values ($p < 0.05$) of chest circumference (28.31 ± 1.26 cm), body length (36.13 ± 2.27 cm), drumstick length (9.44 ± 0.78 cm), shank length (5.35 ± 0.54 cm), and shank diameter (1.01 ± 0.11 cm, Table 6). The second group had a proportion of 47.5%. This group was made up of relatively half of the guinea fowl sampled. It was correlated with six biometric parameters whose values were significantly higher ($p < 0.05$) than those of group 1. These parameters were such as the chest circumference (32.19 ± 1.60 cm), body length (41.57 ± 1.22 cm), drumstick length (10.83 ± 0.86 cm), shank length (6.26 ± 0.48 cm), shank diameter (1.12 ± 0.05 cm), and wingspan (41.99 ± 1.04 cm). The third group contained 35.61% of the whole guinea fowl measured which significantly ($p < 0.05$) had the highest values of body weight (1.55 ± 0.20 kg) and drumstick length (11.44 ± 1.05 cm).

Diversity of indigenous guinea fowl populations

Of the total population considered, 12 phenotypes were identified. These 12 phenotypes were found both in the Sudanian zone and in the Sudano-Guinean zone, unlike the Guinean zone which had only 9 phenotypes (Table 7). Shannon index was similar in Sudanian (2.88) and

Sudano-Guinean (2.85) zones, and they were higher than that of Guinean zone (2.5). The values of Simpson's index (0.20) and Hill's index (0.69) were relatively high for the whole population. The geographical distribution of each phenotype is presented in Figure 8.



Figure 3. Plumage colors; pearl grey^a, black^b, cinnamon^c, lavender^d, pied pearl grey^e, pied white^f, royal purple^g, brown^h, whiteⁱ, pastel^j, buff^k and multicolored^l

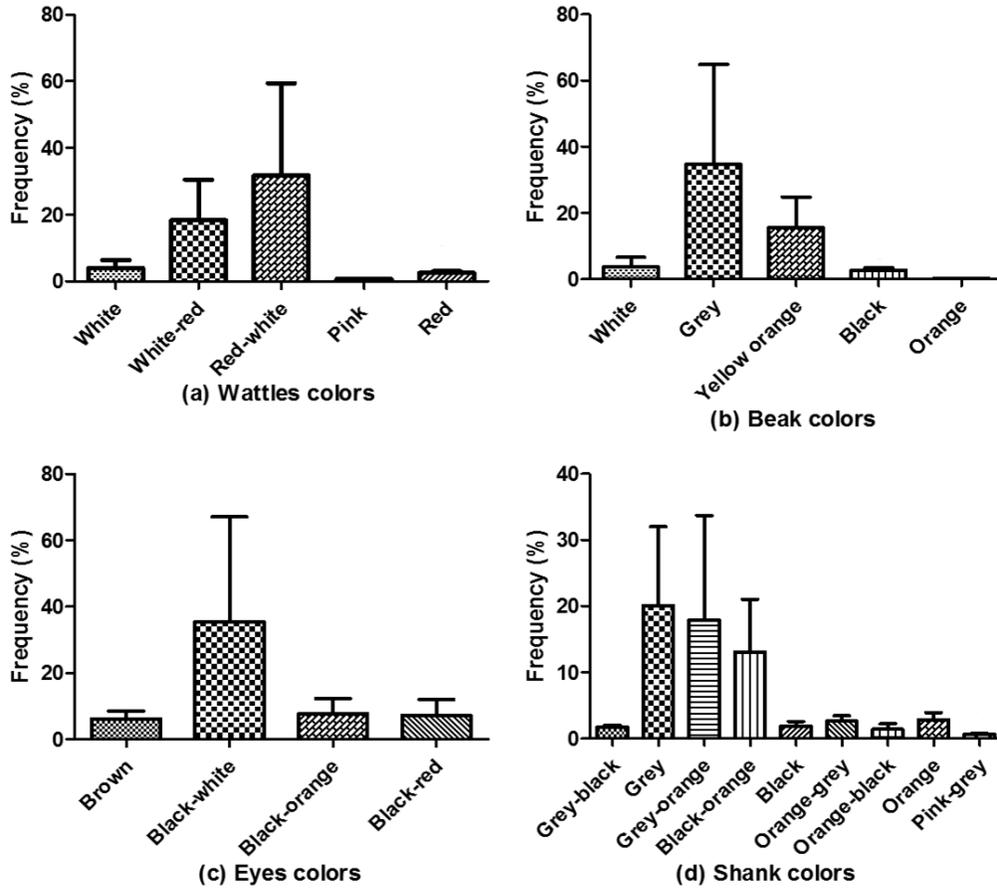


Figure 4. Morphological colors; (a) wattles, (b) beak, (c) eyes and (d) shank.

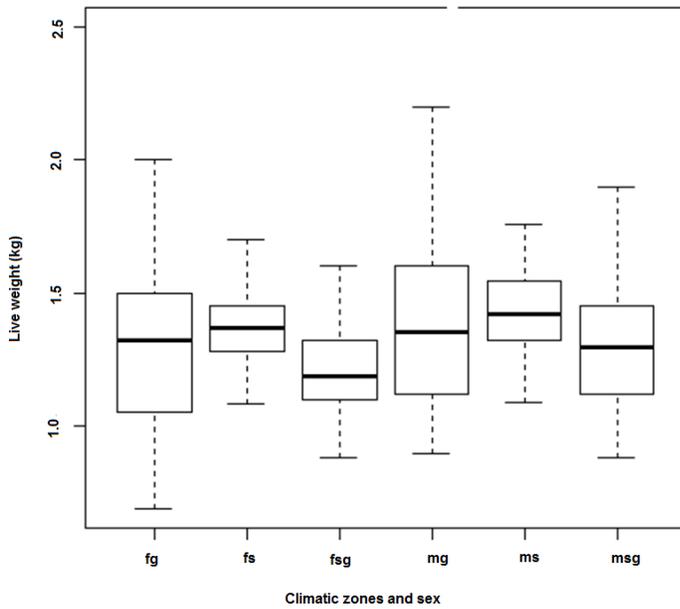


Figure 5. Variability of live weight by climatic zone and sex. fg : female of Guinean zone; fs : female of Sudanian zone; fsg : female of Sudano-Guinean zone; mg : male of Guinean zone; ms : male of Sudanian zone; msg : male of Sudano-Guinean zone.

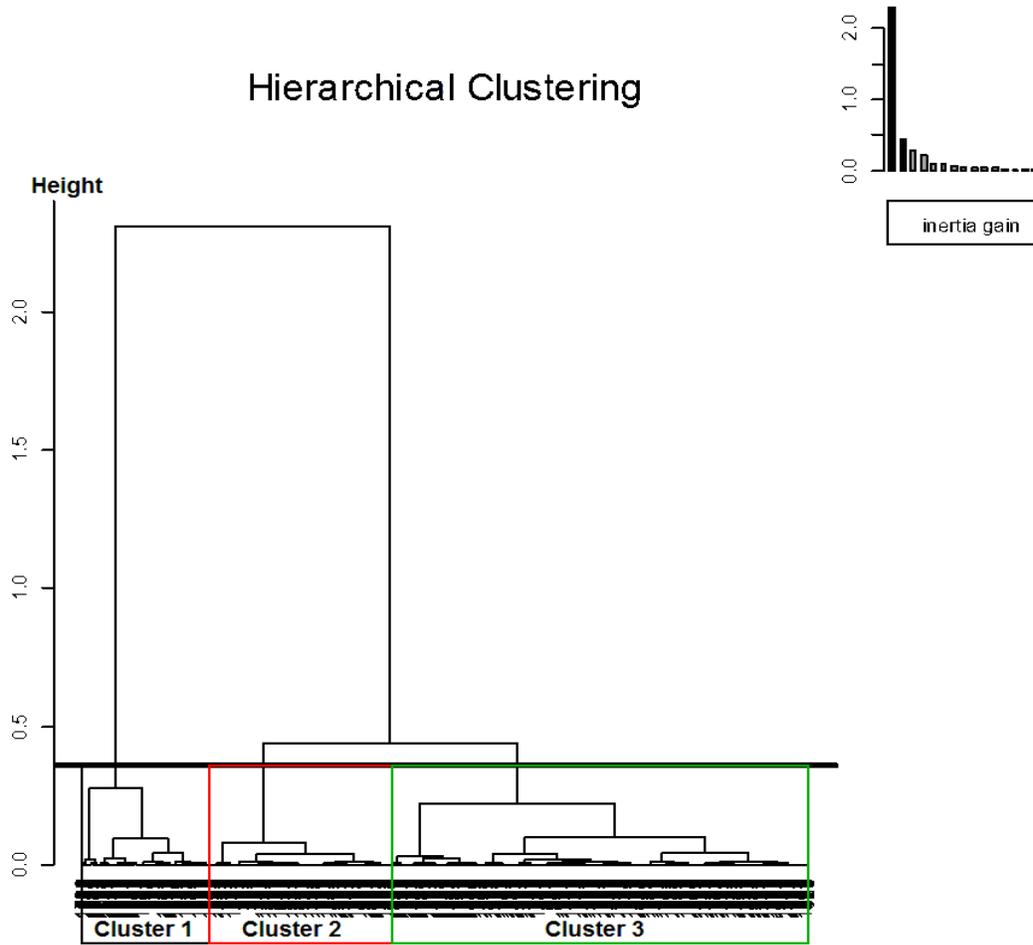


Figure 6. Dendrogram of the ascending hierarchical classification of biometric measurements

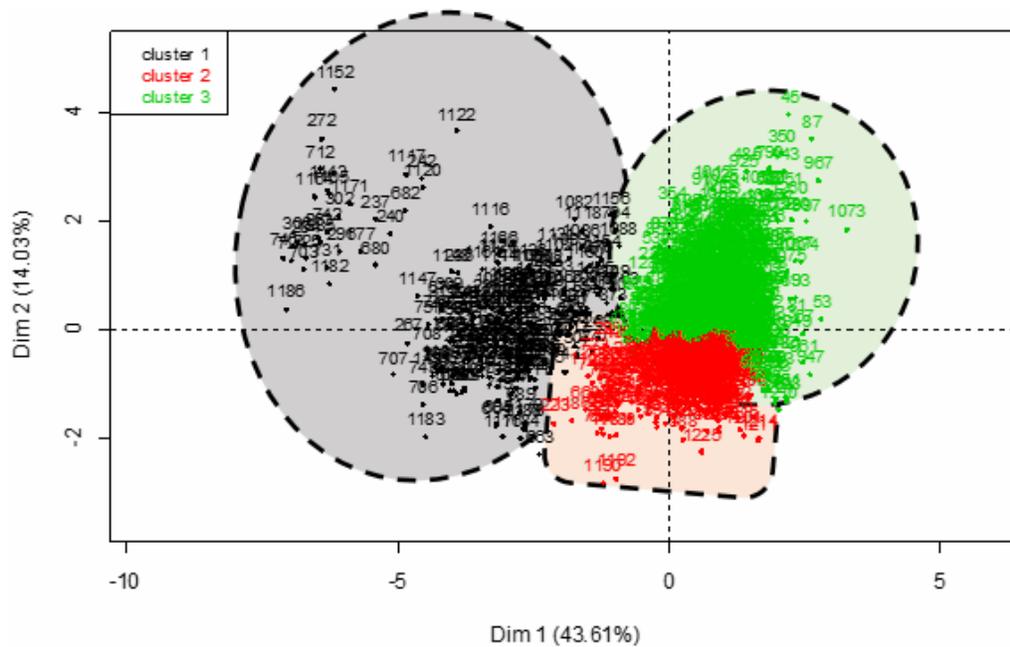


Figure 7. Graphic representation of the principal component analysis of biometric measurements

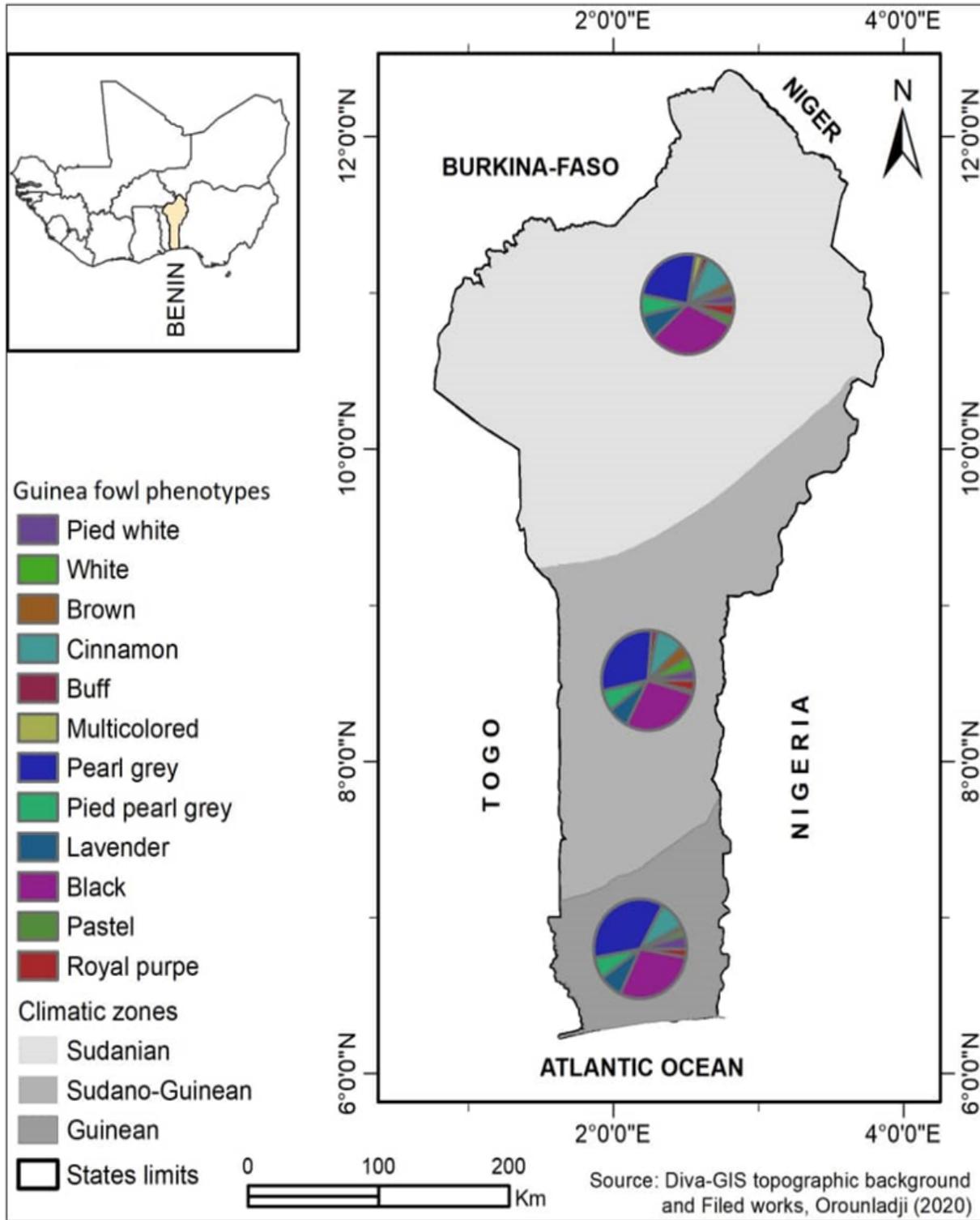


Figure 8. Geographical distribution of guinea fowl phenotypes in Benin

Table 1. Descriptive appearance of the plumage colors of guinea fowl in Benin.

Plumage colors (%)	Sudanian zone		Sudano-guinean zone		Guinean zone		Whole population		
	Male	Female	Male	Female	Male	Female	Male	Female	Overall
	151	289	208	232	170	270	529	791	1320
Pied white	1.3	4.2	5.3	1.7	5.3	3.7	4.2	3.3	3.6
White	2.0	1.0	6.2	3.0	1.2	2.2	3.4	2.0	2.6
Brown	2.6	2.4	4.3	4.3	0.6	1.9	2.6	2.8	2.7
Cinnamon	8.6	11.8	7.7	10.8	8.8	10.0	8.3	10.9	9.8
Buff	3.3	1.0	2.9	1.3	0.0	0.0	2.1	0.8	1.3
Mulicolored	4.6	1.7	1.4	0.0	0.0	0.0	1.9	0.6	1.1
Pearl grey	31.8	21.1	31.7	27.2	45.9	29.6	36.3	25.8	30.0
Pied pearl grey	4.6	8.0	5.8	7.8	4.1	8.5	4.9	8.1	6.8
Lavender	7.9	8.0	4.8	9.1	6.5	9.3	6.2	8.7	7.7
Black	25.8	33.9	24.0	31.5	27.6	30.4	25.7	32.0	29.5
Pastel	0.0	4.5	1.4	0.9	0.0	0.0	0.6	1.9	1.4
Royal purple	7.3	2.4	4.3	2.6	0.0	4.4	3.8	3.2	3.4

Table 2. Morphobiometric measurements of guinea fowl according to the climatic zones of Benin

Variables	Climatic zones		
	Sudanian zone	Sudano-guinean zone	Guinean zone
Size (n = 1320 guinea fowls)	440	440	440
Live weight (Kg)	1.40 ± 0.18 ^a	1.27 ± 0.24 ^c	1.33 ± 0.28 ^b
Chest circumference (cm)	31.71 ± 1.96	31.77 ± 2.08	31.57 ± 2.18
Body length (cm)	40.82 ± 2.49	40.75 ± 2.34	40.60 ± 2.60
Drumstick length (cm)	10.48 ± 0.94 ^b	10.19 ± 0.58 ^c	11.77 ± 1.12 ^a
Shank length (cm)	6.23 ± 0.54 ^a	6.03 ± 0.70 ^b	6.19 ± 0.54 ^a
Shank diameter (cm)	1.09 ± 0.08 ^a	1.10 ± 0.08 ^a	1.08 ± 0.08 ^b
Wingspan (cm)	41.57 ± 2.37	41.35 ± 2.37	41.58 ± 2.41

^{a, b} Means with unlike superscripts in the same row differ significantly (p < 0.05)

Table 3. Morphobiometric measurements in guinea fowl populations of Benin by sex of the individuals

Variables	Sex	
	Male	Female
Size (n = 1320 guinea fowls)	529	791
Live weight (Kg)	1.37 ± 0.25 ^a	1.31 ± 0.24 ^b
Chest circumference (cm)	32.60 ± 1.35 ^a	31.07 ± 2.25 ^b
Body length (cm)	41.71 ± 1.29 ^a	40.10 ± 2.84 ^b
Drumstick length (cm)	11.15 ± 1.10 ^a	10.59 ± 1.12 ^b
Shank length (cm)	6.30 ± 0.49 ^a	6.10 ± 0.66 ^b
Shank diameter (cm)	1.11 ± 0.10 ^a	1.08 ± 0.10 ^b
Wingspan (cm)	41.84 ± 1.07 ^a	41.28 ± 2.94 ^b

^{a, b} Means with unlike superscripts in the same row differ significantly (p < 0.05).

Table 4. Morphobiometric measurements of guinea fowl by phenotypes in Benin

Phenotypes	Size (n = 1320 guinea fowls)	Live weight (Kg)	Chest circumference (cm)	Body length (cm)	Drumstick length (cm)	Shank length (cm)	Shank diameter (cm)	Wingspan (cm)
Pied white	48	1.25 ± 0.27 ^b	31.99 ± 1.96 ^{ab}	40.72 ± 2.83 ^{abc}	10.18 ± 0.71 ^b	6.07 ± 0.54 ^{ab}	1.11 ± 0.09 ^{ab}	41.48 ± 2.70 ^a
White	34	1.29 ± 0.21 ^b	31.68 ± 1.74 ^b	40.84 ± 3.08 ^{abc}	10.48 ± 0.91 ^{ab}	6.11 ± 0.78 ^{ab}	1.05 ± 0.11 ^{bc}	40.52 ± 3.07 ^a
Brown	36	1.28 ± 0.21 ^b	31.46 ± 2.02 ^b	41.31 ± 1.92 ^{ab}	10.57 ± 0.78 ^{ab}	5.92 ± 0.80 ^{ab}	1.14 ± 0.07 ^a	41.12 ± 1.81 ^a
Cinnamon	130	1.30 ± 0.23 ^b	31.28 ± 2.28 ^b	39.99 ± 2.75 ^{bc}	10.54 ± 1.08 ^{ab}	5.99 ± 0.67 ^{ab}	1.08 ± 0.08 ^{bc}	41.24 ± 2.23 ^a
Buff	17	1.51 ± 0.32 ^a	33.09 ± 0.09 ^a	42.31 ± 0.74 ^a	10.58 ± 0.18 ^{ab}	6.31 ± 0.66 ^a	1.05 ± 0.15 ^{bc}	41.81 ± 0.67 ^a
Multicolored	15	1.29 ± 0.12 ^b	32.06 ± 1.47 ^{ab}	41.02 ± 2.06 ^{ab}	11.04 ± 1.16 ^a	6.33 ± 0.65 ^a	1.13 ± 0.05 ^a	41.45 ± 1.10 ^a
Pearl grey	396	1.33 ± 0.25 ^b	31.86 ± 1.99 ^{ab}	41.09 ± 2.07 ^{ab}	11.04 ± 1.15 ^a	6.22 ± 0.59 ^a	1.10 ± 0.06 ^{abc}	41.62 ± 2.54 ^a
Pied pearl grey	90	1.29 ± 0.21 ^b	30.36 ± 2.29 ^c	39.38 ± 3.29 ^c	10.41 ± 1.21 ^{ab}	5.92 ± 0.58 ^{ab}	1.07 ± 0.06 ^{bc}	41.43 ± 2.40 ^a
Lavender	102	1.30 ± 0.19 ^b	32.44 ± 1.20 ^{ab}	41.68 ± 1.33 ^{ab}	11.17 ± 1.06 ^a	6.28 ± 0.42 ^a	1.10 ± 0.05 ^{abc}	41.72 ± 1.14 ^a
Black	389	1.38 ± 0.26 ^b	31.72 ± 2.08 ^b	40.60 ± 2.49 ^{bc}	10.87 ± 1.18 ^{ab}	6.19 ± 0.58 ^{ab}	1.09 ± 0.10 ^{abc}	41.61 ± 2.10 ^a
Pastel	18	1.22 ± 0.12 ^b	29.33 ± 2.75 ^d	37.81 ± 3.12 ^d	9.45 ± 0.78 ^c	5.79 ± 0.70 ^b	1.04 ± 0.08 ^c	39.12 ± 7.59 ^b
Royal purple	45	1.34 ± 0.20 ^b	32.09 ± 1.95 ^{ab}	41.08 ± 2.21 ^{ab}	10.66 ± 0.87 ^{ab}	6.20 ± 0.61 ^{ab}	1.09 ± 0.06 ^{abc}	41.86 ± 0.79 ^a

^{a, b, c, d} Means with unlike superscripts in the same column differ significantly ($p < 0.05$).

Table 5. Cumulative contribution to the total inertia of the factorial axis

Factorial axis	Inertia (%)	Cumulative inertia (%)
1	43.61	43.61
2	14.03	57.64
3	12.76	70.40

Table 6. Variables describing the Principal Component Analysis groups of guinea fowl in Benin based on their morphobiometric traits

Variables	Group 1	Group 2	Group 3
Size (n : 1320 guinea fowls)	223	627	470
Live weight (Kg)	1.24 ± 0.20 ^b	1.20 ± 0.16 ^c	1.55 ± 0.20 ^a
Chest circumference (cm)	28.31 ± 1.26 ^b	32.19 ± 1.60 ^a	32.62 ± 1.15 ^a
Body length (cm)	36.13 ± 2.27 ^b	41.57 ± 1.22 ^a	41.78 ± 0.87 ^a
Drumstick length (cm)	9.44 ± 0.78 ^c	10.83 ± 0.86 ^b	11.44 ± 1.05 ^a
Shank length (cm)	5.35 ± 0.54 ^b	6.26 ± 0.48 ^a	6.39 ± 0.46 ^a
Shank diameter (cm)	1.01 ± 0.11 ^c	1.12 ± 0.05 ^a	1.09 ± 0.07 ^b
Wingspan (cm)	38.99 ± 4.67 ^b	41.99 ± 1.04 ^a	42.04 ± 0.80 ^a

^{a, b} Means with unlike superscripts in the same row differ significantly (p < 0.05).

Table 7. Diversity index of indigenous guinea fowl populations of Benin by climatic zone

Diversity index	Sudanian zone	Sudano-guinean zone	Guinean zone	Whole population
Number of guinea fowl	440	440	440	1320
Phenotypic richness	12	12	9	12
Shannon	2.88	2.85	2.5	2.78
Simpson	0.18	0.19	0.24	0.20
1-Hill	0.70	0.69	0.65	0.69

DISCUSSION

The strong distribution of plumage colors within the genetic resources of indigenous guinea fowl in Benin probably indicates the existence of genetic variability. A total of 12 plumage colors were identified with the dominance of pearl grey and black colors in the present study. Agbolosu et al. (2015) identified nine plumage colors in Ghana, and eight were observed in Cameroon by Meutchieye et al. (2017), while seven were observed in Ghana (Brown et al., 2017) as well as in Benin (Houndonougbo et al., 2017). This higher number (12) of phenotypes observed, compared to the results of Chrysostome (1995) and Houndonougbo et al. (2017), would be due to the large-scale of the study area considered. The presence of major effect genes and the interactions among several of them were plausibly at the

basis of this color diversity. The multiple crossbreeding that have not been controlled for several decades, among the birds with different plumage colors, give rise to other combinations, probably those existing in low proportion (Akouango et al., 2004). This multi-coloration of guinea fowl plumage observed in the current study was similar to the results of some authors (Chrysostome, 1995; Ogah, 2013; Fajemilehin, 2014; Agbolosu et al., 2015; Panyako et al., 2016; Houndonougbo et al., 2017). The dominance of pearl grey colors shows the color by which guinea fowl is recognized from its origin. However, the colors that were found in low proportions, notably buff, multicolored and pastel plumages, in the total population in the present study may indicate a relatively high level of gene dilution across all-round crosses. The absence of buff, multicolored, and pastel plumages in the Guinean zone may be due to the interaction between genotype and

environment (Santoni *et al.*, 2000; Bahy *et al.*, 2003). The higher pearl grey color recorded in the current study was in agreement with the observation reported earlier in Ghana (Agbolosu *et al.*, 2015; Brown *et al.*, 2017), Nigeria (Fajemilehin, 2014), Benin (Chrysostome, 1995; Houndonougbo *et al.*, 2017), and in Burkina-Faso (Bouda, 2017). Apart from the varieties of guinea fowl listed by Houndonougbo *et al.* (2017), other plumage colors were identified during this study, as documented by the Guinea Fowl International Association color chart (GFIA, 2009).

The multiplicity of ornamental details, such as the coloration of the beak, wattle, and shank, also indicates the diversity of the genetic resources of indigenous guinea fowl in the three climatic zones of Benin. Guinea fowl with grey beaks and black-white eyes predominate among the phenotypes. The diversity of eye color could be attributed to genes of an animal influencing blood supply and melanin levels, environmental effect in terms of availability of carotenoids, as well as the interaction among blood supply, melanin, and carotenoids (Ngeno *et al.*, 2014). The red-white color was the relatively predominant coloration of the wattles. As color plays an important role in the absorption and reflection of solar radiation, the wattles' color also plays a role in thermoregulation (Agbolosu *et al.*, 2015). As for the shank, their colorations were more marked by grey-orange, grey, and black-orange.

As for body measurements, the average live weights of guinea fowl obtained were comparable to those of Bouda (2017) in Burkina Faso. On the other hand, they were higher than the live weights reported in Ghana (Agbolosu *et al.*, 2015; Brown *et al.*, 2017) and lower than those obtained in Nigeria (Ogah, 2013). The body lengths of guinea fowl observed in the current study were similar to those reported in an intensive production system of indigenous guinea fowl in Botswana (Tjetjoo *et al.*, 2013) and Ghana (Brown *et al.*, 2017).

The significantly higher values obtained in males agreed with the findings of Bouda (2017). These values were also different from the measurements obtained by Brown *et al.* (2017). These differences in the results relating to the biometric variables reflecting sexual dimorphism can be explained by the breeding conditions of the birds (guinea fowl) studied. Moreover, intrinsic factors, such as the genotype, age of the animal, and its physiological state (in the female) could influence the results. According to Keambou *et al.* (2007), the dimorphism in favor of males suggests that a breeding program for meat production would be more advantageous with males than with females, primarily for traits of

economic importance, such as weight, drumstick development, and shank diameter. However, care should be taken to maintain the reproductive capacity of these animals.

Buff phenotypes were heavier than all other phenotypes (pied white, white, pearl grey, pied pearl grey, multicolored, brown, cinnamon, black, pastel, royal purple, and lavender), and buff phenotypes would be the most useful phenotype for improving growth performance. These results could be explained by the small number of observations on buff phenotypes, and most of them were mature. These observations differ from the findings of Duodu *et al.* (2018) who reported a higher live weight in the pearl grey phenotype, compared to the lavender, white, and black guinea fowl.

Live weight depends on the biotope and the condition of the animals. It is, therefore, an important attribute of farm animals, and thus, it forms the basis not only for assessing growth and feed efficiency but also for making economic decisions (Fajemilehin, 2014). It has been reported by Nwosu *et al.* (1985) that live weight is the best parameter for making management, health, production, and marketing decisions. The differences in body weight revealed in the present study indicated the inherent genetic makeup of each phenotype of guinea fowl depending on the climate variability of the areas. Variation in body weight could be useful in determining overall adaptive genetic diversity (Toro and Caballero, 2005).

Three groups were categorized on the basis of quantitative variables. While the first and the second groups respectively had low values and averages of the biometric variables, the third group constituted the category of guinea fowl to prioritize in a process of genetic improvement of the species through its high values. Thus, to promote indigenous guinea fowl in Benin, studies on the production performance of the third group can be used to produce labeled indigenous guinea fowl by seeking to strengthen their diet with unconventional food resources such as maggots, termites, etc.

The diversity of phenotypes within the three climatic zones was relatively maximal in the analysis of the value of Hill index which constitutes a compromise between the Shannon and Simpson index. This indicates the strong diversity of the guinea fowl in Benin. These results are similar to the values obtained by Kerboub *et al.* (2017). However, diversity was more abundant in Sudanian and Sudano-Guinean zones than in the Guinean zone. This difference is probably linked to the climatic conditions which vary between these three climatic zones, but with higher rainfall in the Guinean zone, and which are not too

favorable to the proliferation of guinea fowl within this zone. Some factors, such as physiological state, age of the guinea fowl, climate and genetic variabilities, measurements techniques, management practices, and the interaction among all these factors could explain the discrepancy in the morphobiometric parameters observed by the authors in diverse areas of tropical Africa.

CONCLUSION

The current study showed great variability in the genetic resources of indigenous guinea fowl in Benin both in its phenotypic and in their biometric characteristics. Within the population of these guinea fowls, pearl grey plumage color was more widespread, regardless of the climatic zone. Guinea fowl with grey beaks and black-white eyes predominated among the phenotypes. The red-white color was the relatively predominant coloration of the wattles. As for the shanks, their colorations were more marked by grey-orange, grey, and black-orange. Sexual dimorphism for weight growth, as for the other biometric variables considered, was in favor of males. These quantitative variables were used to distinguish three groups of guinea fowl. The great biological diversity observed during the present study can constitute a basis for the establishment of hardy and more efficient phenotypes through genetic improvement programs integrating selection and controlled breeding. At the same time, improved breeding conditions would significantly increase the productivity of the indigenous guinea fowl as a source of quality protein, particularly in rural areas.

DECLARATIONS

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Competing interests

The authors reported no conflict of interest regarding the publication of this article.

Authors' contributions

This work was carried out by the collaboration of all authors. OBM conceptualized the work, collected and

analyzed data, and wrote the manuscript. TSK and CCAAM conceptualized and supervised the work and, corrected the manuscript. All authors read and approved the final version of the manuscript.

REFERENCES

- Agbolosu AA, Ahunu BK, Aboagye GS, Naazie A and Kayang BB (2015). Variation in some qualitative traits of the indigenous guinea fowl in Northern Ghana. *Global Journal of Animal Scientific Research*, 3(1): 396-401. Available at: <http://archives.giasr.com/index.php/GJASR/article/view/114/327>
- Akouango F, Mouangou F and Ganongo G (2004). Phénotypes et performances d'élevage chez les populations locales de volailles du genre *Gallus gallus* au Congo Brazzaville. *Cahiers d'Etudes et de Recherches Francophones/Agricultures*, 13(3): 257-262. Available at : <https://revues.cirad.fr/index.php/cahiers-agricultures/article/view/30444>
- Avornyo FK, Salifu S, Panyan EK, Al-Hassan BI, Ahiagbe M and Yeboah F (2016). Characteristics of guinea fowl production systems in northern Ghana. A baseline study of 20 districts in northern Ghana. *Livestock Research for Rural Development*, 28(8): 1-12. Available at: <http://www.lrrd.org/lrrd28/8/avor28134.html>
- Bahy AA, Mohammed MMA and Osama MA (2003). Relationship between genetic similarity and some productive traits in local chicken strains. *African Journal of Biotechnology*, 2(2): 46-47. DOI: <https://doi.org/10.5897/AJB2003.000-1008>
- Boko KC, Kpodekon TM, Dahouda M, Marlier D and Mainil JG (2012). Contraintes techniques et sanitaires de la production traditionnelle de pintade en Afrique subsaharienne. *Annales de Médecine Vétérinaire*, 156(1): 25-36. Available at : www.facmv.ulg.ac.be/amv/articles/2012_156_1_02.pdf
- Bouda S (2017). Caractérisation zootechnique et morphobiométrique des écotypes de pintades (*Numida meleagris*) du Sahel et du Centre-Ouest du Burkina Faso''. Mémoire de fin de cycle en vue de l'obtention du diplôme d'ingénieur du développement rural, Université Nazi Boni, Burkina-Faso, p. 98. Available at: <https://cutt.ly/oj4kmS3>
- Brown MM, Alenyorege B, Teye GA and Roessler R (2017). Phenotypic diversity, major genes and production potential of local chickens and guinea fowl in Tamale, northern Ghana. *Asian-Australas Journal of Animal Science*, 30(10): 1372-1381. DOI: <https://doi.org/10.5713/ajas.17.0145>
- Chrysostome CAAM (1995). Méthodologie de développement de la pintade au Bénin. Thèse de doctorat. Institut national Agronomique de Grignon, Paris, France, p. 190. Unpublished.
- Chrysostome CAAM, Houndonougbo MF, Houndonougbo V, Dossou J and Zohoun R (2013). Caractéristique des poulets selon le point de vue des éleveurs. Dixièmes Journées de la Recherche Avicole et Palmipèdes à Foie Gras, La Rochelle, du 26 au 28 mars 2013, pp. 524-529. Available at: https://orbi.uliege.be/bitstream/2268/203809/1/Caract%C3%A9ristique_Poulet_Eleveurs_2013JRA126.pdf
- Duodu A, Annor SY, Kagya-Agyemang JK and Kyere CG (2018). Influence of strain on production and some other traits of indigenous guinea fowls (*Numida meleagris*) in Ghana. *Current Journal of Applied Science and Technology*, 30: 1-7. DOI: <https://doi.org/10.9734/CJAST/2018/44123>
- Elkana H and Gwaza DS (2019). Evaluation of loss in vigour of the dual purpose french guinea fowl and their mixed genetic grade in Katsina, Nigeria. *Universal Journal of Agricultural Research*, 7(4): 148-154. DOI: <https://doi.org/10.13189/ujar.2019.070402>

- Fajemilehin SOK (2014). Morphological and genetic characterization of domesticated guinea fowl in Sokoto state, Nigeria. PhD thesis, University of Ibadan, Nigeria, p. 160. Available at: <https://ir.library.ui.edu.ng/handle/123456789/223>
- Food and Agriculture Organization (FAO) (2013). Caractérisation phénotypique des ressources génétiques animales. Directives FAO sur la production et la santé animales No. 11. Rome. p. 151. Available at: <http://www.fao.org/docrep/019/i2686f/i2686f.pdf>
- Guinea Fowl International Association (GFIA) (2009). Color chart of Guinea Fowl International Association. Available at: <http://www.guineafowlinternational.org>
- Haoua MT, Poutougnigni MY, Keambou TC and Manjeli Y (2015). Morphobiometrical diversity of the indigenous chicken's population in the Sudano-sahelian zone of Cameroon. *Scientific Journal of Animal Science*, 4(11): 133-154. DOI: <https://doi.org/10.14196/sjas.v4i11.2016>
- Hill MO (1973). Diversity and evenness: A unifying notation and its consequences. *Ecology*, 54(2): 427-432. DOI: <https://doi.org/10.2307/1934352>
- Houndonoubo PV, Chrysostome CAAM, Mota RR, Hammami H, Bindelle J and Gengler N (2017). Phenotypic, socio-economic and growth features of Guinea fowls raised under different village systems in West Africa. *African Journal of Agricultural Research*, 12(26): 2232-2241. DOI: <https://doi.org/10.5897/AJAR2017.12411>
- Keambou TC, Manjeli Y, Tchoumboue J, Teguia A and Iroume RN (2007). Caractérisation morphobiométrique des ressources génétiques de poules locales des hautes terres de l'ouest Cameroun. *Livestock Research for Rural Development*, 19(8): 1-13. Available at: <https://www.lrrd.org/lrrd19/8/keam19107.htm>
- Kerboub Y, Benabria A, Adamou Djarbaoui M, Fentrouci B and Gaouar SBS (2017). Morphometric characterization of some species of bats in Western Algeria. *Genetics and Biodiversity Journal*, 1(1): 71-80. Available at: <https://ojs.univ-tlemcen.dz/index.php/GABJ/article/view/276>
- Kone GA, Kouassi GF, Kouakou NDV and Kouba M (2018). Diagnostic of guinea fowl (*Numida meleagris*) farming in Ivory Coast. *Poultry Science*, Pp. 1-7. DOI: <https://dx.doi.org/10.3382/ps/pey290>
- Kouassi GF, Koné GA, Good M and Kouba M (2019). Factors Impacting Guinea Fowl (*Numida meleagris*) Production in Ivory Coast. *The Journal of Applied Poultry Research*, Pp. 1-7. DOI: <https://www.dx.doi.org/10.3382/japr/pfz079>
- Mahammi FZ, Gaouar SBS, Tabet-Aoul N, Tixier-Boichard M and Saïdi-Mehtar N (2014). Caractéristiques morpho-biométriques et systèmes d'élevage des poules locales en Algérie occidentale (Oranie). *Cahier Agricultures*, 23: 382-392. DOI: <https://doi.org/10.1684/agr.2014.0722>
- Meutchieye F, Djiosa FD, Sindze AT and Manjeli Y (2017). Polymorphisme visible chez la pintade locale (*Numida meleagris*) en zone soudano-sahélienne du Cameroun. *Communications en Aviculture Familiale*, 26: 5-14. <https://cutt.ly/Pk2hzU1>
- Naves M, Alexandre G, Mathieu M, Gouridine JL and Mandonnet N (2011). Les races animales locales : bases du développement innovant et durable de l'élevage aux Antilles. *Innovations Agronomiques*, 16: 193-205. Available at: <https://www6.inrae.fr/ciag/content/download/3716/35876/file/Vol16-15-Naves.pdf>
- Ngeno K, van der Waal EH, Kahi AK and van Arendonk JAM (2014). Morphological features of indigenous chicken ecotype populations of Kenya. *Animal Genetic Resources*, 55: 115-124. DOI: <https://dx.doi.org/10.1017/S2078633614000356>
- Nwosu CC, Aklionbere FN and Ibou JE (1985). Characterization of phenotypes of cattle in Nigeria: Body measurements. *Beitrage Zur tropische chen landiovtchaff und Veterinor Medish*, 23(1): 89-97. Available at: <https://europepmc.org/article/med/4015613>
- Ogah DM (2013). Variability in body shape characters in an indigenous guinea fowl (*Numida meleagris* L.). *Slovak Journal of Animal Science*, 46(3): 110-114. Available at: <https://sjas.ojs.sk/sjas/article/view/254/242>
- Oguntunji AO (2013). Phenotypic and biochemical characterization of the Nigerian Muscovy ducks. Bowen University, Iwo, Osun State, Nigeria. Ph.D. Thesis, p. 371.
- Ould Ahmed M and N'Daw A (2015). Caractérisation de l'élevage familial de la poule locale (*Gallus gallus*) dans la région de Trarza en Mauritanie. *Animal Genetic Resources*, 57: 89-97. DOI: <https://doi.org/10.1017/S2078633615000284>
- Panyako PM, Imboma T, Kariuki DW, Makanda M, Oyier PA, Malaki P, Ndiema EK, Obanda V, Agwanda B, Ngeiywa KJ et al. (2016). Phenotypic characterization of domesticated and wild helmeted Guinea fowl of Kenya. *Livestock Research for Rural Development*, 28(9): 1-10. Available at: <http://lrrd.cipav.org.co/lrrd28/9/omme28158.html>
- R Core Team (2019). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at: <https://www.R-project.org/>
- Santoni S, Faivre-Rampant P, Prado E and Prat D (2000). Marqueurs moléculaires pour l'analyse des ressources génétiques et l'amélioration des plantes. *Cahier Agricultures*, 9(4): 311-327. Available at: <https://revues.cirad.fr/index.php/cahiers-agricultures/article/view/30253>
- Shannon CE (1949). Communication Theory of Secrecy Systems. *Bell System Technical Journal*, 28(4): 656-715. DOI: <https://doi.org/10.1002/j.1538-7305.1949.tb00928.x>
- Simpson EH (1949). Measurement of diversity. *Nature*, 163: 688. DOI: <https://dx.doi.org/10.1038/163688a0>
- Tjetjoo SU, Moreki JC, Nsoso SJ and Madibela OR (2013). Growth performance of guinea fowl fed diets containing yellow maize, millet and white sorghum as energy sources and raised under intensive system. *Pakistan Journal of Nutrition*, 12(4): 306-312. Available at: <https://cutt.ly/Jj4gPpO>
- Toro MA and Caballero A (2005). Characterization and conservation of genetic diversity in subdivided populations. *Philosophical Transactions of the Royal Society B Biological Sciences*, 360: 1367-1378. DOI: <https://doi.org/10.1098/rstb.2005.1680>
- Traoré FG, Traoré A, Bayala B, Dayo GK, Tapsoba AS, Soudré A, Sanou M, Tindano K and Tamboura HH (2018). Characterization and typology of guinea fowl (*Numida meleagris*) farming systems in Burkina Faso. *International Journal of Advanced Research*, 6(1): 6-21. DOI: <https://dx.doi.org/10.21474/IJAR01/6177>