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Morphometric Traits Differentiation and Phenotypic Diversity of Two Snail Species Ecotypes *Archachatina marginata* and *Achatina fulica* in the Western Highlands of Cameroon

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Abstract

This study was conducted from June 2021 to January 2023 to assess the genetic diversity of giant African snails in the western highlands of Cameroon. A total of 652 snails were randomly collected from the wild in three localities in the western highlands (Bafang, Bafoussam, and Santchou). The study revealed significant variations in morphobiometric characteristics both between species and localities. The predominant shell coloration was brownish with yellow zigzag stripes (65%), while the dominant coloration for shell openings was whitish (48%). Regarding foot coloration, both brown with spotted black and black with spotted brown colorations were dominant (29%). The highest recorded live weight of snails (39.33 ± 34) was found in the species *Archachatina marginata*. In terms of length measurements (in mm), the length of the right and left sides of the shell was higher in the *A. fulica* species (49.8 ± 19.7 mm and 40.07 ± 18 mm, respectively). Bafang exhibited the highest values for shell length (56 ± 11 mm) and shell width (46.52 ± 11.46 mm). *A. fulica* recorded the highest shell length (81.5 ± 27 mm), while *A. marginata* recorded the highest shell width (49.6 ± 12.1 mm), with the highest values observed in *A. fulica* from fulica having a slightly higher aperture width value (30 ± 10 mm) compared to *A. marginata*, while *A. marginata* had the highest value for aperture length measurement (54.5 ± 12 mm). *A. fulica* also exhibited the highest values for the length from apex to the first whorl and the length from left to right of the first whorl (43.2 ± 18 mm and 39 ± 19.8 mm, respectively). Strong and positive correlations were observed between the live weight of snails and body measurements regardless of species, except for the number of whorls, which showed very weak or negative correlations with other body measurements. The results of Hierarchical Cluster Analysis (HCA) revealed three distinct snail population types. These findings provide valuable insights into the phenotypic diversity of edible land snails in the western highlands of Cameroon and can be considered in improvement and conservation programs aimed at enhancing snail meat yield.

Keywords

Phenotype, Diversity, Ecotypes, Western Highlands of Cameroon

1. Introduction

Information on population sizes and genetic diversity levels of various plant and animal species is essential for the development of effective natural resource management and conservation strategies (Odey *et al.*, 2015) [1]. Giant African snails are shell-bearing invertebrate animals belonging to the phylum Mollusca. They are air-breathing and herbivorous, possessing a complex hermaphroditic reproductive system (Oyeleye *et al.*, 2012) [2]. In Cameroon, they are classified as unconventional, with wild harvesting being the primary means of exploitation [3]. However, commercial farming of these land snail species in many West African countries is gaining attention as an alternative to gathering natural populations. Unfortunately, deforestation, bush burning, and overexploitation have significantly contributed to the depletion of their biodiversity and conservation (Akinlade *et al.*, 2012; Morris, 2010) [4] [5].

Among the snail species kept and reared, *Archachatina marginata* is the most commonly kept species, followed by *Achatina achatina* in Okon *et al.* [6], and *Achatina fulica* ranking second in Cameroon. Giant African land snails produce eggs before sperm and undergo cross-fertilization to produce viable, fertile eggs (Plummer, 1975) [7]. Generally, some individuals act as males in one season and as females in the next season, while many species of freshwater snails, such as the Apple Snail and the New Zealand Mud Snail, simultaneously exhibit both roles and fertilize each other [8] [9]. This wide variation in their reproduction contributes to species continuity.

Giant African snails belong to the family Achatinidae, within which four species are classified as giant African land snails: *Achatina achatina*, *Achatina fulica*, *Archachatina marginata*, and *Limicolaria aurora*. However, only *Achatina fulica* and *Archachatina marginata* are considered to be the "truly" giant African land snails, as the largest specimens recorded by the Plant Protection and Quarantine Program (PPQ) weighed around 750 g and had a shell length of 8 inches (20.32 cm) (Smith & Fowler, 2003) [10]. The family Achatinidae has been reported to comprise more than 60 species divided into 11 genera [11] [12] [13] [14]. The identification of these species was traditionally based on morphological, anatomical, and physiological criteria [15] [16]. However, it is important to update or validate these identifications using advanced molecular techniques. Furthermore, there is a possibility of the existence of many subspecies within the predefined species that have not been clearly elucidated to date [17] [18].

There is limited information available regarding the genetic diversity of giant African land snails kept and reared in Cameroon. The difference in the color of snails brings about confusion within the Achatinidae family. Additionally, not much work has been done on the characteristics and varieties of these snails (Aluko *et al.*, 2017) [19]. Therefore, conducting morphobiometric characterization will enable us to elucidate the existence of different varieties and the genetic diversity among them. Furthermore, evaluating the snail population genetics in the western highlands of Cameroon will provide an opportunity to observe patterns of genetic change over time. By comparing populations to each other and to themselves, we will be able to see how external factors might influence the evolution of different traits as revealed in the work of Nkwendem *et al.* (2019) [20]. This study aims to contribute to the genetic characterization of giant African snails in Cameroon. Specifically, it examines the morphobiometric variation in *Archachatina marginata* and *Achatina fulica* species in the western highlands of Cameroon and determines the correlation between the weight and body measurements of the snails. Body measurements are utilized to characterize the snails and identify measurable traits that clearly distinguish between the two species' ecotypes within the Achatinidae family.

The specific snail species used in this study are represented in **Figure 1** and **Figure 2**.

2. Material and Methods

2.1. Period and Area of Study

The study was conducted in the western highlands of Cameroon, specifically in the localities of Bafoussam, Bafang, and Santchou. These localities have distinct geo-climatic conditions and agricultural practices.

Bafoussam has a tropical wet and dry or savanna climate. The average annual temperature in this locality is 23.71˚C (74.68˚F). Bafoussam receives an average precipitation of approximately 137.51 millimeters (5.41 inches) and has 211.88 rainy days per year, accounting for 58.05% of the time [21].

Bafang experiences a wet season characterized by oppressive and overcast conditions, while the dry season is humid and mostly cloudy. The temperature in Bafang varies from 58˚F to 82˚F throughout the year, rarely falling below 55˚F or exceeding 86˚F. The dry season lasts for approximately 4.2 months, from November 12th to March 17th. January has the fewest wet days in Bafang, with an average of 2.0 days receiving at least 0.04 inches of precipitation. Bafang is located in the South-West of Bangou Mountain [21].

Santchou subdivision has a dry and humid climate with pseudo-tropical rainfall patterns. The annual average temperature is 23˚C, and the yearly precipitation is approximately 1662.7 mm. The driest months are January and February [22].

Figure 1. *Achatina fulica*.

Figure 2. *Archachatina marginata*.

Santchou is located between 9˚50' and 10˚06' North latitude and between 5˚20' and 5˚12' East longitude, with soil types primarily consisting of reddish ferralitic melanized soils found on the volcanic hills in the eastern part of West Cameroon [23].

In the western highlands, continuous cultivation is practiced in various localities, with some utilization of fertilizers. The main crops cultivated in this region include maize, cocoyams, potatoes, peanuts, beans, and yams. The predominant soil types found are ferralsols and nitosols. Erosion hazards are prevalent, often exacerbated by the lack of dense vegetation cover [24].

2.2. Sampling Techniques and Experimental Design

The study was conducted in the western highlands of Cameroon from June 2021 to January 2023. A total of 652 snails, locally known as "Escargot" or "Congo meat", were randomly harvested from the wild during the rainy season, which is the period of abundance for both species. These snails were collected from three different localities: Bafang, Bafoussam, and Santchou. The experimental snails were randomly organized according to 2 × 3 imbalanced factorial design (two species all present in three localities).

Identification and sorting of the snails obtained from farmers into species were conducted using the appropriate profile and template, following the methods described by Raut and Barker [25], Okon *et al.* [26], Memel *et al.* [27], and Nkwendem *et al.* [20]. Two breeds of snails were selected for the experiment: *Archachatina marginata* and *Achatina fulica*.

Table 1 shows the number of snails collected per locality, with Bafang, Bafoussam and Santchou with both species represented.

Table 1. Proportion of snails collected per locality.

Locality	Number	Species
Bafang	45	*A. marginata*
	68	*A. fulica*
Bafoussam	186	*A. marginata*
	117	*A. fulica*
Santchou	141	*A. marginata*
	95	*A. fulica*
Total	**652**	

2.3. Morphobiometric Characteristics

The snails collected for the study exhibited varying numbers of whorls, with the *Archachatina marginata* species having 4 - 5 whorls and the *Achatina fulica* species having 6 - 7 whorls to minimize age-related effects. The live weight of the snails ranged from 16 g to 185 g for both species, and no injuries were observed on the animals.

Various phenotypic characteristics of the snails were recorded, including Shell Length (SL), Shell Width (SW), Length of Left Side (LLS), Length of Right Side (LRS), Length from Apex to First Whorl (LAFW), Length from Left to Right Side of the First Whorl (LLRSFW), Snail Live Weight (SLW), Aperture Length (AL), Aperture Width (AW), Foot Coloration (FC), Shell Coloration (SC), Number of Whorls (NW), and Opening of Shell Coloration (OSC). These measurements were obtained using conventional methods, with the snails positioned straight, apex downward, and larger part upward, while gloves were used to handle the live animals. The measurement techniques were based on the methods described by Memel *et al.* [27] and Nkwendem *et al.* [20].

The dimensional shell parameters, such as Shell Length (SL), Aperture Length (AL), Aperture Width (AW), and Length from Apex to First Whorl (LAFW), were measured using a Vernier Caliper. Weight measurements were obtained using an electronic balance with 0.01 g sensitivity, while the shell shape, number of whorls, foot, shell and opening of shell colorations were observed using naked eyes. The collected data, including the measurements of Shell Length, Aperture Length, Aperture Width, and Length from Apex to First Whorl (LAFW), can be found in **Figure 3**. Additionally, measurements of Shell Width (SW), Length of Left Side of the Shell (LLS), Length of Right Side of the Shell (LRS), and Length from Left to Right of the First Whorl (LLRSFW) are presented in **Figure 4**.

2.4. Statistical Analysis

The Analysis of Variance (ANOVA) was conducted to assess the impact of factors such as species and locality on the various measurements and body weight. If significant effects were found, Duncan's test was used to determine differences between the means. The statistical model used for the ANOVA was as follows:

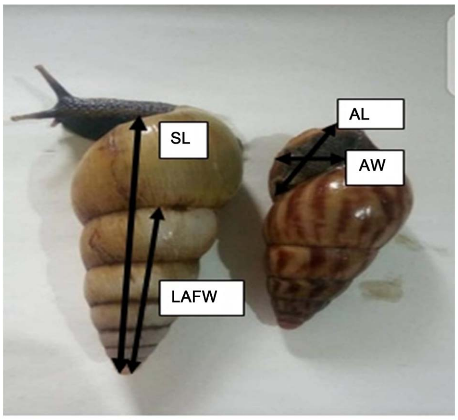

Figure 3. Measurements of Shell Length (SL), Aperture Length (AL), Aperture Width (AW) and Length from Apex to First Whorl (LAFW).

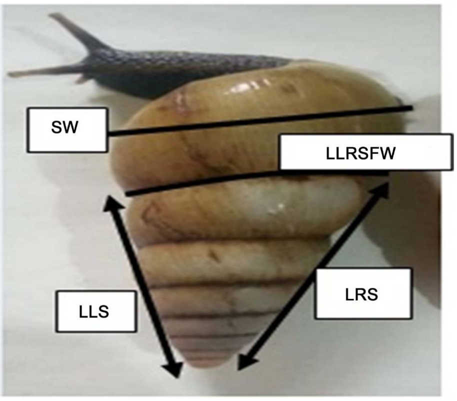

Figure 4. Measurement of Shell Width (SW), Length of Left Side (LLS) and Length of Right Side (LRS) and Length from Left to Right of the First Whorl (LLRSFW).

$$Y_{ijk} = \mu + \alpha_i + \beta_j + \varepsilon_{ijk}$$

with Y_{ijk} = Body weight or measurement on animal *k* of locality *j* of species *I*;

μ = mean of the population;

α_i = effect of species *i*;

β_j = effect of locality *j*;

ε_{ijk} = residual error on individual k of species *i* of locality *j*.

The Pearson's Chi-square test was used to evaluate the association between the qualitative variables at 5% significance level, specifically the color of the foot, coloration of shell opening and shell [28].

3. Results

3.1. Phenotypic Colorations of Snails

Results of the Pearson's Chi-squared test revealed significant variations ($p < 0.001$) in body coloration of snails across different species and localities in the study area. This indicates that the body coloration of the snails differed significantly depending on the species and the locality they were collected from.

Regarding foot coloration, a diverse range of colors was observed, and the proportions varied across different categories. The category "black with spotted brown (BlsBr)" had the highest proportion (29%), indicating that a significant number of snails exhibited this color pattern. Conversely, the category "Whitish foot with black dots (Wbd)" had the smallest proportion (14%), suggesting that fewer snails displayed this particular color pattern.

In terms of the opening of the shell coloration, the highest proportion (48%) was observed in the category "pink coloration (Pk)", indicating that a significant number of snails had a pink-colored opening of the shell. The second-highest proportion (46%) was observed in the category "Whitish", suggesting that a similar number of snails had a whitish-colored opening of the shell.

Regarding shell coloration, the dominant pattern was "brown with yellow zigzag stripes (BrwYz)", accounting for 68% of the snails. This indicates that a significant majority of snails had a shell with this color pattern.

These findings highlight significant variations in body coloration, foot coloration, opening of shell coloration, and shell coloration among the snail species and localities studied in the western highlands of Cameroon ($p < 0.001$). Table 2 reveals a detailed overview of the color variation of the snails according to the studied localities in the western highlands of Cameroon.

Figure 5 and Figure 6 reveal the different shell, foot and opening of shell colorations of the snails in the localities of Bafoussam, Bafang and Santchou of the western highlands of Cameroon. Figure 5 gives a general view of the different percentages of the snails colorations while Figure 6 indicates some specifiic colorations of the snails.

3.2. Shell Measurements of the Snails

Table 3 represents the morphobiometric characteristics of three parameters: LLRSFW (Length from Left to Right Side of the First Whorl), LRS (Length of the Right Side of the Shell), and LLS (Length of the Left Side of the Shell).

The LLRSFW values showed significant variation based on both the species and the locality (see Table 3). The mean LLRSFW value for *A. fulica* collected in Bafoussam was 26 ± 19.6d mm. The mean LLRSFW value for *A. fulica* collected in Bafang was 50 ± 13.4a mm, which was significantly higher.

The length of the right side was significantly influenced by both the species and the locality. *A. fulica* had a higher mean length of the right side (49.8 ± 19.7a mm) compared to *A. marginata* (39.7 ± 11b mm). The highest value was observed in the locality of Santchou (49.8 ± 19.7a mm), and the lowest value was observed in the same locality (38.7 ± 11b mm).

The length of the left side also varied significantly based on both the species and the locality. For *A. fulica*, the mean length of the left side was 46.52 ± 11.46a mm in Bafang and 45.64 ± 14.9a mm in Santchou. *A. fulica* had a higher mean

Table 2. Color distribution of edible snails in different localities of the western highlands of Cameroon.

Coloration	Modalities	Localities (%)			Total	X^2
		Bafang	Bafoussam	Santchou		
	BrwG	0.0	0.0	11	4	
Shell color	BrwYz	88	71	58	69	***
	YwBrz	12	29	2.1	16	
	Br	0.9	0.0	29	11	
	Bl	0.0	27	0.0	13	
	BlSBr	18	29	35	29	
	Br	35	17	3.4	15	***
Opening of shell coloration / And foot colorations	BrSBl	48	27	21	29	
	Wbd	0.0	0.0	40	15	
	Pk	87	42	40	49	
	Vl	0.0	11	0.0	5	***
	Wtsh	13	48	60	46	

Note: ***: $p < 0.001$, **: $p < 0.01$, *: $p< 0.05$, BrwG = brown with greenish parts, BlSBr = black with spotted brown spots, Wtsh = whitish, Pk = pink, Vl = violet, Wbd = whitish with black dack spots, Br = brown, Bl = black, BrwYz = brown with yellowish zigzag points, YwBrz = yellow with brown zigzag stripes.

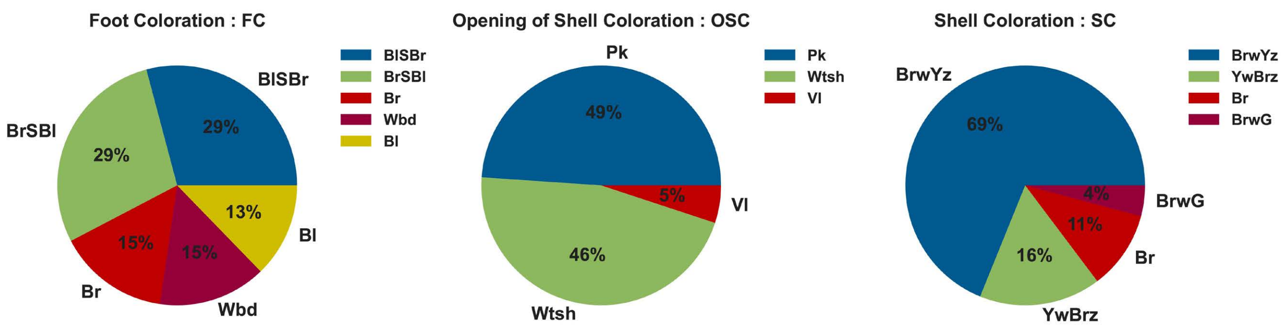

Figure 5. General coloration of snails in the western highlands of Cameroon.

(a) (b)

(c)

(d)

(e)

(f)

Figure 6. Different colorations of snails in the western highlands of Cameroon. (a) BLsBr, Wtsh, BlSBr (black with spotted brown), Wtsh (whitish shell opening); (b) BrSBl (brown with spotted black skin), Pk (Pk = pink shell opening); (c) BrwG (BrwG = brown shell with greenlike portions); (d) YwBz (yellow shell with brown zigzag stripes); (e) BrwYz (brown shell with yellow zigzag stripes); (f) Br (brown foot).

Table 3. Morphobiometric characteristics (in mm) of edible land snails in three localities of the western highlands of Cameroon.

Locality	Species	LLRSFW			LRS		LLS	
		N	$\mu \pm s$	CV (%)	$\mu \pm s$	CV (%)	$\mu \pm s$	CV (%)
Bafang	*A. fulica*	68	50 ± 13.4^{a}	26.8	56 ± 11^{a}	19.6	46.52 ± 11.46^{a}	24.6
	A. marginata	45	40 ± 11.4^{b}	24.7	42 ± 10^{b}	23.8	40.51 ± 13.3^{a}	32.83
Bafoussam	*A. fulica*	117	26 ± 19.6^{d}	75.3	39 ± 31^{a}	49.48	31.79 ± 20.22^{b}	63.6
	A. marginata	186	36 ± 12^{c}	33.33	39.7 ± 11^{b}	27.7	29.94 ± 15.18^{c}	50.7
Santchou	*A. fulica*	95	47 ± 14^{a}	29.7	58.7 ± 16^{a}	27.2	45.64 ± 14.9^{a}	32.6
	A. marginata	141	34.3 ± 12^{c}	34.9	38.7 ± 11^{b}	28.4	35.06 ± 15.9^{b}	45.35
Total	*A. fulica*	280	39 ± 19.8^{a}	50.7	49.8 ± 19.7^{a}	49.8	40.07 ± 18^{a}	44.92
	A. marginata	372	35.6 ± 11.8^{b}	33.14	39.7 ± 11^{b}	27.7	8.78 ± 27^{b}	30.7

Note: *A. fulica* = *Achatina fulica*, *A. marginata* = *Archachatina marginata*, LLRSFW= Length from Left to Right Side of the First Whorl, μ ± s = mean ± standard deviation, CV (%) = Coefficient of Variation, n = number of individuals by locality, LRS = Length of Right Side, LLS = Length of Left Side. a, b, and c in the same column, values with the same letter are not significantly different (p > 0.05).

length of the left side compared to *A. marginata*, with values of 40.07 ± 18a mm and 8.78 ± 27b mm, respectively. The Coefficient of Variation (CV) for the length of the left side was 40.41, indicating moderate variability.

In the above descriptions, a, b, and c in the same column represent values that are not significantly different (p > 0.05). For *A. fulica*, the mean length of the left side was 46.52 ± 11.46a mm in Bafang and 45.64 ± 14.9a mm in Santchou. *A. fulica* had a higher mean length of the left side compared to *A. marginata*, with values of 40.07 ± 18a mm and 8.78 ± 27b mm, respectively. The length of the left side also varied significantly based on both the species and the locality. For *A. fulica*, the mean length of the left side was 46.52 ± 11.46a mm in Bafang and 45.64 ± 14.9a mm in Santchou. *A. fulica* had a higher mean length of the left side compared to *A. marginata*, with values of 40.07 ± 18a mm and 8.78 ± 27b mm, respectively.

In the above descriptions, a, b, and c in the same column represent values that are not significantly different (p > 0.05). For *A. fulica*, the mean length of the left side was 46.52 ± 11.46a mm in Bafang and 45.64 ± 14.9a mm in Santchou. *A. fulica* had a higher mean length of the left side compared to *A. marginata*, with values of 40.07 ± 18a mm and 8.78 ± 27b mm, respectively.

Table 4 shows the Morphobiometric characteristics with respect to the number of whorls, aperture length and aperture width of the snails in the locality of Bafang, Bafoussam and Santchou of the western highlands of Cameroon.

The results presented in Table 4 provide information on the average number of whorls, aperture length, and aperture width. It can be observed that the number of whorls varied between 7.2 ± 0.5a and 4.2 ± 0.5e. The species *A. fulica* had a higher number of whorls (7.29) compared to *A. marginata* (5.74). Depending on the locality, the highest values were recorded in the locality of Bafoussam, while the lowest values were observed in the locality of Bafang.

In contrast, the aperture width exhibited significant variation, ranging from 43.4 ± 11a mm to 14.4 ± 15 mm. The highest aperture width was observed in the locality of Bafang, while the lowest was recorded in the locality of Bafoussam. It should be noted that *A. fulica* had a slightly greater aperture width compared to *A. marginata*.

On the other hand, the aperture length showed variation ranging from 54.5 ± 12a mm to 49.2 ± 23b mm. *A. marginata* exhibited a higher aperture length compared to *A. fulica*, with values of 54.5 ± 12a mm and 49.2 ± 23b mm, respectively.

It is worth mentioning that the letters a, b, and c in the same column indicate values that are not significantly different (p > 0.05).

Table 5 presents the results of the comparison of the means from the apex to the last whorl, shell length and width and the live weight of the snails according to the species and the locality.

From the information provided in Table 5, it is evident that the total shell length varied depending on the species. *A. fulica* had a total shell length of 81.5 ± 27a mm, while *A. marginata* had a slightly smaller length of 77.5 ± 16b mm. Among the *A. fulica* specimens, those collected in the locality of Bafoussam exhibited the shortest length (60 ± 22d mm), whereas the longest length was observed in *A. fulica* specimens from the locality of Santchou (101.7 ± 21.6a mm).

Table 4. Morphobiometric characteristics (in mm) of snails according to the number of whorls, aperture length and width of the shell.

Locality	Species	NW			AW		AL	
		N	$\mu \pm s$	CV (%)	$\mu \pm s$	CV (%)	$\mu \pm s$	CV (%)
Bafang	*A. fulica*	68	6 ± 0.2[c]	3.3	43.4 ± 11[a]	25.3	65.1 ± 11[a]	16.8
	A. marginata	45	4.2 ± 0.5[e]	11.9	35 ± 11[c]	31.4	56.4 ± 12[b]	21.4
Bafoussam	*A. fulica*	117	7.2 ± 0.5[a]	6.9	14.4 ± 15[e]	3.47	28 ± 16.4[c]	58.5
	A. marginata	185	4.4 ± 0.5[d]	11.3	30.1 ± 11[d]	2.32	54.5 ± 12[b]	22
Santchou	*A. fulica*	95	6.4 ± 0.49[b]	7.6	39.4 ± 13[b]	32.9	64 ± 14.6[a]	22.8
	A. marginata	141	4.5 ± 0.5	11.11	28.5 ± 10[d]	35.0	54 ± 12[b]	22.2
Total	*A. fulica*	280	6.6 ± 0.6[a]	9.0	30.1 ± 10[a]	33.2	49.2 ± 23[b]	46.7
	A. marginata	372	4.4 ± 0.5[b]	11.3	29.9 ± 18.9[a]	63.2	54.5 ± 12[a]	22

Note: AW = Aperture Width, CV (%) = Coefficient of Variation, n = number of individuals per locality, $\mu \pm s$: mean ± standard deviation, NW: Number of Whorls, AL = Aperture Length. a, b, and c in the same column, values with the same letter are not significantly different ($p > 0.05$).

Table 5. Morphobiometric characteristics (in mm) of the shell length and width, length from apex to the last whorl and the live weight of the snails in the western highlands of Cameroon.

Locality	Species	SL			LAFW		SW		LIVE WEIGHT	
		N	$\mu \pm s$	CV	$\mu \pm s$	CV	$\mu \pm s$	CV	$\mu \pm s$	CV
Bafang	*A. fulica*	68	90.3 ± 12[b]	13.33	50 ± 12[a]	24	60.8 ± 11.2[b]	18.42	31.29 ± 12.9[C]	41
	A. marginata	45	76.1 ± 18.6[c]	24.44	34.6 ± 11[b]	31.7	52 ± 13[e]	25	44 ± 42[b]	95
Bafoussam	*A. fulica*	117	60 ± 22[d]	36.6	33.3 ± 20[b]	60.0	30.4 ± 19[a]	62.5	13.6 ± 4.8[d]	35
	A. marginata	186	77.5 ± 16.6[c]	21.41	32.3 ± 11[b]	34.0	35 ± 12[a]	32.2	49.3 ± 34[ab]	68
Santchou	*A. fulica*	95	101.7 ± 21.6[a]	21.23	50.5 ± 16[a]	31.6	59.6 ± 16[ab]	26.84	55.4 ± 30[a]	54
	A. marginata	141	78 ± 16[c]	20.51	32 ± 11[b]	34.3	48.7 ± 11.7[c]	24.02	51 ± 31[ab]	60
All localities	*A. fulica*	280	81.5 ± 27[a]	33.12	43.2 ± 18[a]	41.6	47.7 ± 21.9[a]	45.9	31.1 ± 36[b]	85
	A. marginata	372	77.5 ± 16[b]	20.64	32.3 ± 10[b]	31.0	49.6 ± 12.1[b]	24.3	39.33 ± 34[a]	86

Note: *A. fulica* = *Achatina fulica*, *A. marginata* = *Archachatina marginata*, SL = Shell Length, μ ± s = mean ± standard deviation, CV (%) = Coefficient of Variation, n = number of individuals by locality, LAFW = Length of the Apex at the First Whorl, SW = Shell Width, LIVE Weight = Weight of the Living Snail. a, b, and c in the same column, values with the same letter are not significantly different ($p > 0.05$).

The length from the apex to the first whorl ranged from 50.5 ± 16a mm for *A. fulica* to 32 ± 11b mm for *A. marginata*. The shortest and longest lengths were both observed in the locality of Santchou.

In terms of shell width, it varied between 60.8 ± 11.2 mm and 30.4 ± 19 mm, with *A. fulica* showing the widest width. Among the different localities, the highest shell width was observed in Bafang, while the smallest was observed in Bafoussam.

The live weight of the snails ranged from 31.1 ± 36b g for *A. fulica* to 39.33 ± 34a g for *A. marginata*. The lowest live weight was recorded for *A. fulica* specimens harvested in Bafoussam (13.6 ± 4.8d g), whereas the highest live weight was observed in *A. marginata* specimens from Santchou (55.4 ± 30a g).

Figure 7 represents the general morphobiometric variation observed within the snail's population in the western highlands of Cameroon.

3.3. Phenotypic Correlations between Weight and Body Measurements of the Snails

The phenotypic correlations between body weight and body measurements are presented in **Figure 8**. Strong and positive correlations were observed between the live weight of snails and most body measurements, regardless of species, except for the number of whorls, which exhibited either a weak or negative correlation with other body measurements. The correlations varied in strength, ranging from very strong (0.98) to weak (0.11). Notably, there was a weak correlation between the length of the right side and the length of the left side, as well as between shell length and the number of whorls. **Figure 8** depicts the phenotypic correlations observed in the snail populations of the western highlands of Cameroon. The significance level was set at ($p > 0.05$). The abbreviations used in the figure are as follows: NW = number of whorls, AL = aperture length, AW = aperture width, LLRSFW = length from left to right side of the first whorl, LRS = length of the right side, LLS = length of the left side, LAFW = length from apex to the first whorl, SW = shell width, Live weight = weight of the living snail, SL = length of the shell.

Table 6 shows the results of FAMD (factor analysis of mixed data) while **Figure 9** reveals the Distinctive clusters of snail's populations in the western highlands of Cameroon.

Within the snail population, 55.34% of variability was observed. Factors such as shell width, length of the left side, length of the right side, length from aperture to the first whorl, and length from left to right side of the first whorl contributed the most to the diversity within the snail population, accounting for 34.6% of the variation. Shell length, aperture length, and width were the second and third factors, explaining 20.66% of the variability within the snail population respectively (**Table 6**).

There are thirteen variables with two categories, and these variables, along with the first three dimensions of FAMD (Factor Analysis of Mixed Data), were used to perform Hierarchical Cluster Analysis (HCA). The results of HCA revealed three distinct snail population types, as shown in **Figure 9**. Within the snail population, 55.34% of variability was observed. Factors such as shell width, length of the left side, length of the right side, length from the apex to the first whorl, and length from the left to right side of the first whorl contributed the most to the diversity within the snail population, accounting for 34.6% of the variation. Shell length, aperture length, and aperture width were the second and

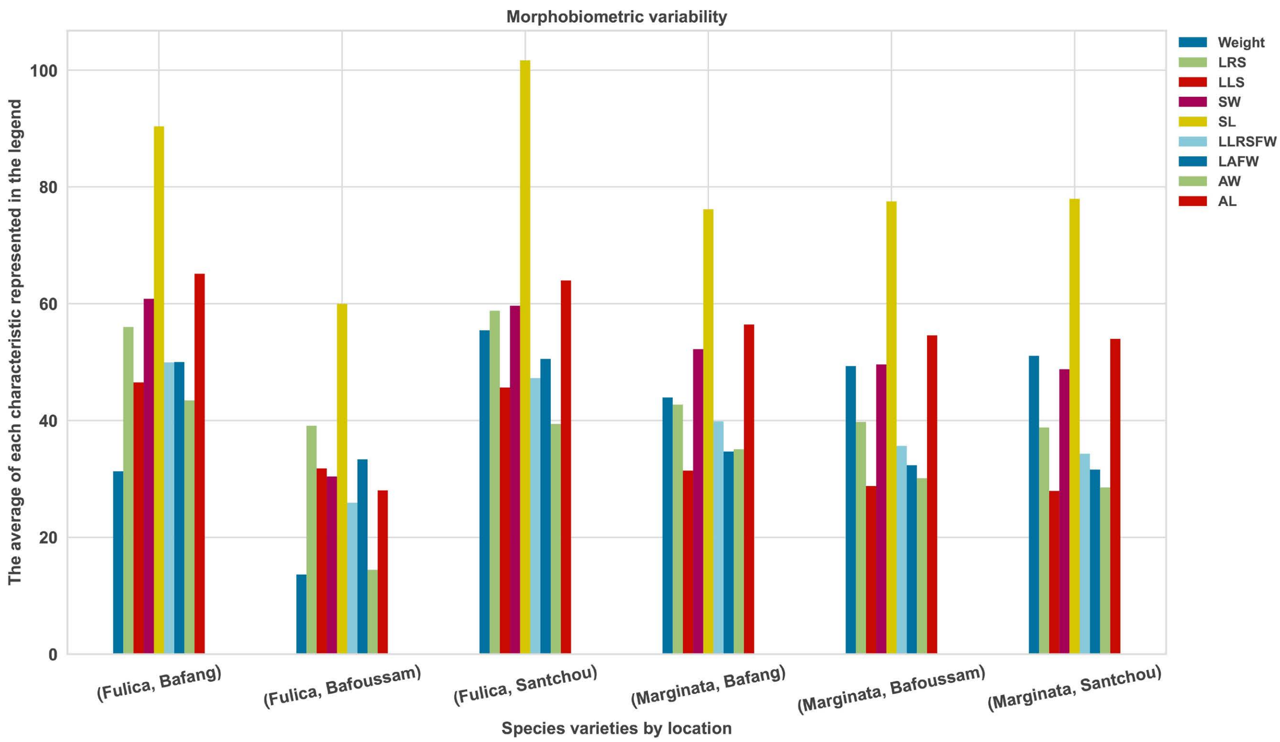

Figure 7. Morphobiometric expressions as compared to localities and species.

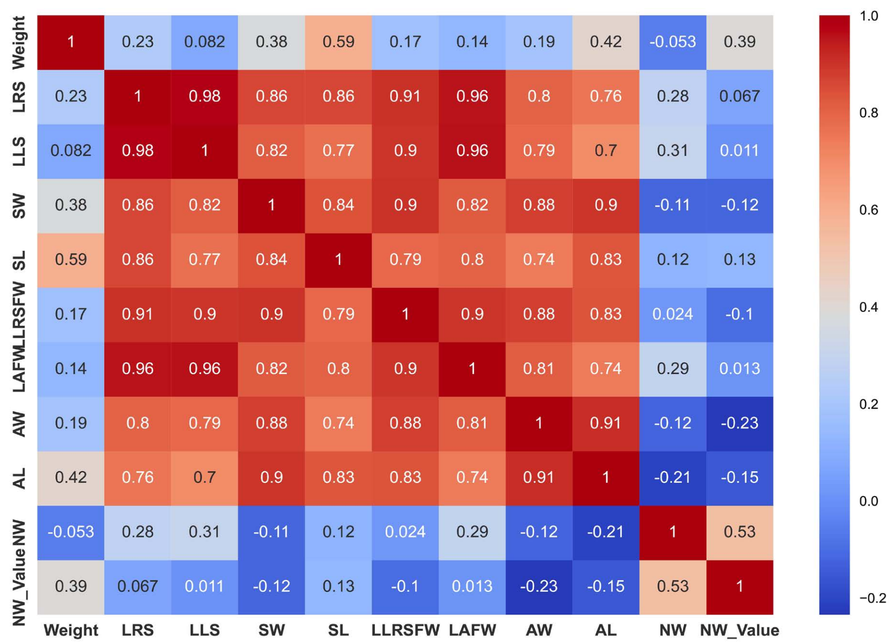

Figure 8. Phenotypic correlation between weight and body measurements of the snail species in the western highlands of Cameroon.

third factors, explaining 20.66% of the variability within the snail population, respectively (**Table 6**).

Thirteen variables with two categories were used, along with the first three dimensions of FAMD (Factor Analysis of Mixed Data), to perform Hierarchical

Table 6. Result of FAMD factors loading.

Variables	Dim 1	Dim 2
LLRSFW	0.93	−0.08
LRS	0.95	0.17
LLS	0.92	0.21
NW	0.11	0.95
AW	0.89	−0.23
AL	0.88	−0.34
SL	0.90	−0.001
LAFW	0.93	0.18
SW	0.92	−0.23
Live weight	0.31	−0.14
Eigen value	8.66	5.16
Percentage of variance	34.6	20.66
Percentage of cumulative variance	34.6	55.34

Note: Body measurements are in millimeters and live weight in gram, variance and cumulative variance are in percentages.

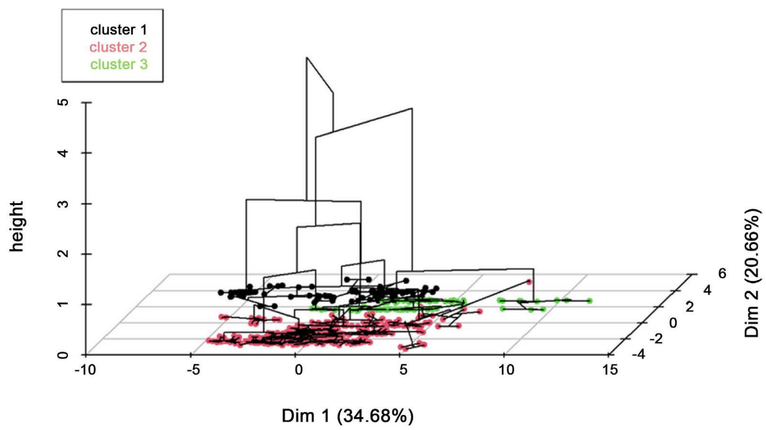

Figure 9. Distinctive clusters of snail's populations in the western highlands of Cameroon.

Cluster Analysis (HCA). The results of HCA revealed three distinct snail population types, as depicted in Figure 9. It was observed from Figure 9 that Clusters 2 and 3 are admixed according to the two dimensions indicating phylogenetic relationship between the animals with more than half of Cluster 2 present in Dimension 1. Clusters 1 and 3 are closer and are fully observed in Dimension 2, while Clusters 1 and 2 are separated. From Table 6 above, it is observed that LRS (Length of Right Side), LLRSFW (Length from Left to Right of the First Whorl), LAFW (Length from Apex to First Whorl), LLS (Length of Left Side) and SW (Shell Width) greatly contribute for the genetic variability in Dimension 1 (0.95), 0.93 and 0.92) respectively and NW (Number of Whorls) accounts for the great variability observed in Dimension 2 (0.95). This indicates that the above parameters could be used in the genetic improvement of these animals according to their various dimensions.

4. Discussion

In the western highlands of Cameroon, there was a significant color variation within the snail population. The dominant foot coloration was black with spotted brown (29%), predominantly observed in the localities of Santchou and Bafang. Brown with spots was the second most common foot coloration, while black foot coloration had the lowest occurrence (13%). Bafang had the highest occurrence of brown and brown spotted black foot coloration (35% and 48%, respectively).

The dominant shell coloration was brown with yellow zigzag stripes (69%), primarily observed in the locality of Bafang (88%). Yellow with brown zigzag stripes (16%) were mostly observed in the locality of Bafoussam (29%). Pink coloration was dominant for the opening of the shell (49%), primarily observed in the locality of Bafang (87%). Whitish coloration was highly observed in the locality of Santchou (60%).

These variations in body coloration can be attributed to genetic variation among the snails, soil types, and climatic conditions of the study area, or interactions among these factors. Santchou experiences a dry and humid climate with pseudo-tropical rainfall, an average temperature of 23˚C, and an annual precipitation of 1662.7 mm, while Bafang has a predominantly cloudy and humid climate with warm temperatures year-round. The soil types in Santchou are reddish ferrallitic melanized soils found on the volcanic hills of the eastern part of West Cameroon [23]. These results differ from those reported by Nkwendem *et al.* [20] and Tsayo *et al.* [29], who both reported black coloration with yellowish stripes and red tips in the species *A. marginata* in the coastal and equatorial forest urbanized areas of Cameroon, respectively.

Regarding the different body measurements of the shell and its sides, significant differences were observed ($p < 0.05$), with the species *A. fulica* having higher values for the length of the right and left sides compared to *A. marginata* (49.8 and 40.07 mm) and (39.7 and 8.78 mm), respectively.

The highest values for the length of the right side were observed in the localities of Santchou (58.7 ± 16a) and Bafang (56 ± 11a) for *A. fulica*, respectively. The length of the left side of the shell was also higher in *A. fulica* compared to *A. marginata* (40.07 ± 18a and 8.78 ± 27b), respectively. These findings are consistent with the results reported by Nkwendem *et al.* [20], who found higher values for the length of the shell's left and right sides in *A. fulica* (39.06 ± 7.07 mm and 28.54 ± 5.32 mm) compared to *A. marginata*. Memel *et al.* [27] also reported similar results, with *Achatina achatina* displaying greater lengths of the right and left sides compared to *Archachatina ventricosa* (38.8 ± 7.4 mm and 29.5 ± 5.7 mm) and (33.8 ± 6.2 mm and 24.3 ± 6 mm), respectively.

These differences in shell measurements can be attributed to genetic variations among the snail species, feeding rate, growth rate, and environmental conditions in the different study areas of the species [24] and Aluko *et al.* [30].

A. fulica exhibited a higher shell length (81.5 ± 27a mm) compared to *A. marginata* (77.5 ± 16b mm), and the highest value was obtained in the locality of Santchou (101.7 ± 21.09a mm). The highest shell width value was observed in the species *A. marginata* (49.6 ± 12.1b mm) compared to *A. fulica* (47.7 ± 21.9a mm). These findings align with the results reported by Nkwendem *et al.* [20], where *A. fulica* had the highest value for shell length (71.16 ± 16.06 mm), and *A. marginata* had the highest value for shell width (39.82 ± 4.70 mm). However, these results differ from those reported by Etta *et al.* [31], who obtained smaller values (10.440 mm and 5.087 mm) for shell length and width in *A. marginata,* although their study specifically focused on *A. marginata* snails fed with Phyllanthus amarus. The variation can be explained by the distinct shape of the different species, as *A. fulica* has a more conical and elongated shell, while *A. marginata* has a domed shape and is less elongated. It could also be explained by the feeding variation of the snails and climatic conditions, as well as the interaction between genetic makeup and the environment [32].

The average weight was highest in *A. marginata* breeds, with Santchou having the highest value (55.4 ± 30a g) compared to *A. fulica* (31.1 ± 36b g). The Length from Apex to First Whorl (LAFW) and length from left to right of the first whorl (LLRSFW) showed the lowest values in the species *A. marginata* (32.3 ± 10b mm and 35.6 ± 11.8b mm), respectively, while *A. fulica* exhibited higher values for Length from Apex to First Whorl (LAFW) and Length from Left to Right of the First Whorl (LLRSFW). The highest values were observed in *A. fulica* (43.2 ± 18a mm and 39 ± 19.8a mm), respectively, in the localities of Santchou and Bafang.

The values of aperture length and width (AW) were highest in the species *A. fulica* (54.5 ± 12a mm and 30 ± 10a mm), respectively, compared to *A. marginata* (49.2 ± 23b and 29.9 ± 18.9a). These results differ from those reported by Okon *et al.* [26], who obtained higher values for aperture length and width in *Achatina achatina* species compared to *A. fulica* species with four and five whorls. This disparity can be attributed to the difference in species used in the studies and variations in the environmental conditions of the study areas. The number of whorls also varied greatly between the species, with *A. fulica* having an average number of whorls of (6.6 ± 0.6a) compared to *A. marginata* (4.4 ± 0.6a). These results are similar to those of Nkwendem *et al.* [20] and Tsayo *et al.* [29], who also reported a higher number of whorls in *A. fulica* species compared to *A. marginata*.

Three genetic groups of snails were found in the western highlands of Cameroon. This indicates the importance of giant African snails in the lives of Cameroon inhabitants and neighboring countries. No significant challenges were observed during this study. The future perspectives of this study will include the extension of molecular genetic diversity analysis of African giant snails in Central Africa in order to conserve these snail species, which have high genetic potential.

5. Conclusion

This study highlights the potential of combining metric values and morphological characters to enhance the identification of species ecotypes within *A. marginata* and *A. fulica.* To further enhance our understanding of snail characteristics, including Achatinidae, it would be advantageous to incorporate a comprehensive approach that combines morphological characters, metric values, and molecular analysis. Such an integrated approach would provide valuable insights into the distinct characteristics of snails, enabling genetic improvement strategies and informed decision-making processes regarding snail production and meat yield.

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Conflicts of Interest

The authors declare no conflict of interest.

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