

Phenotypic landscape of giant African land snails

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Received: November 19, 2024; Accepted: January 10, 2025; Published: January 20, 2025

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Abstract

Giant African land snails are a fascinating group of molluscs known for their impressive size and diverse phenotypic traits. This review comprehensively explores the morphological traits, characteristics and variations observed within these snails. The intricate details of shell morphology, including shape, size, composition of the shell, shell coloration and pattern, shell aperture and whorls, as well as the body characteristics, focusing on the skin coloration and body weight were considered. By synthesizing existing research and highlighting areas for future investigation, this review provides a valuable resource for researchers, conservationists, snail breeder and farmers, and enthusiasts alike, contributing to a deeper understanding of phenotypic landscape of these remarkable species.

Keywords: African; snails; shell; body; morphology

1. Introduction

Snails are hermaphroditic animals but they practice sexual reproduction and are the largest groups of molluscs, constituting the largest animal group after arthropods, with diversity in morphology and ecology [1], [2], [3], [4], [5], [6], [7]. Snails, especially the terrestrial snails, feed on different plant materials and decaying matters in the wild as they are herbivorous and non-selective scavengers that dwell naturally in forest litters [5], [7], [8], [9], [10].

Giant African land snails, especially the ones in Nigeria, usually aestivate or hibernate from November to March due to hot and dry weather conditions. During this period of hibernation or aestivation, the snails' shell aperture is temporarily closed by a calcified, whitish and fragile material called epiphragm. During this period of dryness, the snails bury themselves in the soil or hide beneath stones to keep them away from direct sunlight. The epiphragm breaks and the snails emerges out of their shells when favourable condition (raining season) returns [3], [4], [5], [11], [12], [13].

The indiscriminate hunting and deforestation reduce the abundance of snails and destroy the habitat of the land snails. Hence, rearing of the land snails as domestic animals would help to ensure the continuous survival of the snails and satisfy the demand for the meat [7], [11], [12], [14], [15], [16]. Okon and Ibom [5] observed that the morphological appearance with respect to the foot (skin) of the snail can be black, brown or white coloration. Naturally, the white-skinned (albino) snails are smaller in size than the black-skinned snails. The white-skinned snails are rarely seen in forests, rather they are found mainly in bushes around villages and cities. The forest types are relatively bigger in size than the bush types. The white-skinned snails are more aggressive in moving out of their shells [5], [7], [12], [15].

Most economical traits or characters of snails are influenced to some degree by heredity. The degree to which heredity (genetics) affects performance depends on the particular character or trait concerned. However, different ecotypes (black-skinned and white-skinned) of land snails, especially *A. marginata*, can mate freely and fertilize each other, laying fertile egg clutches that hatch into black-skinned and white-skinned snaillets in different proportions [4], [16], [17].

Interestingly, snail species have been identified and characterized based on shell morphology, anatomy of genitalia, and mantle colour, criteria are applied continuously to describe new species [14], [17]. However, species of land snails with similar morphology have ambiguous identities, especially juvenile snails, due to the great level of morphological variation observed in some snail species [18]. Morphometric or phenotypic characters or traits that have been used for characterization of snails include body weight, body shell length, body shell width, mouth shell length, mouth shell width and number of whorls, and are said to be controlled by genes [4], [5], [7], [12].

Phenotypic characterization of giant African land snails plays an essential role in understanding their ecological evolution, systematics, and potential for conservation. This review outlines key aspects of phenotypic characterization of giant African land snails, focusing on both their shells and body traits.

2. Phenotypic Characteristics of Giant African Land Snails

Morphometric or phenotypic traits are observable characteristics that are influenced by the genotype of an organism and environmental factors. Hence, Phenotype (P) = Genotype (G) + Environment (E) [12], [17]. In giant African land snails, these traits are diverse, allowing for species identification, ecological studies, and insights into evolutionary processes.

2.1 Shell characteristics

The shell of giant African land snail is prominent morphometric or phenotypic feature, and its morphology plays a vital role in identification of snails' species. Polymorphisms has been seen to be relatively common in terrestrial gastropod shells [19], [20]. These polymorphisms are maintained by different selective processes, including predation pressures [20]. The key shell characteristics are considered in the following sub-sections.

2.1.1 Shell coloration and pattern

Shells can come in a variety of colours, from pale to dark shades (Figures 1a, 1 b, 1c), often with patterns such as stripes, spots, or banding. The colouration serves as camouflage, helping snails blend into their environments. Different authors have investigated on how phenotypic diversity in polymorphic snail populations are influenced by genetic traits and environmental conditions [21], [22], [23], [24]. Shell colour and pattern are highly variable in pulmonate snail species such as *Xeropicta derbentina* and *Theba pisana* [22], [23], [24], [25]. They are known for their great range of morphs, the frequency of which can be associated with different micro geographical specifics [26], [27]. Yet the combination of factors determining this diversity is still not fully understood. Several gene loci primarily control shell colour, presence or absence of shell banding, intensity of pigmentation, etc. [21], [26], [28].

Habitat structure (shaded or exposed) and ambient temperature influence the composition of phenotypes in snail populations [22], [24]. These conditions, in turn, may also be seen in their population structure (as inferred from their genotypic diversity). Thus, genes that echo a population's phylogeographical and demographic history could be informative, even though not directly coding for shell colour/pattern. This might be particularly true for populations subjected to strong bottle-necks caused by, for example, high ambient temperatures. In *T. pisana*, high temperatures emerged either as a selective force or an epigenetically acting component of the environment [22], [24] organisms possess various mechanisms to deal with high temperatures.

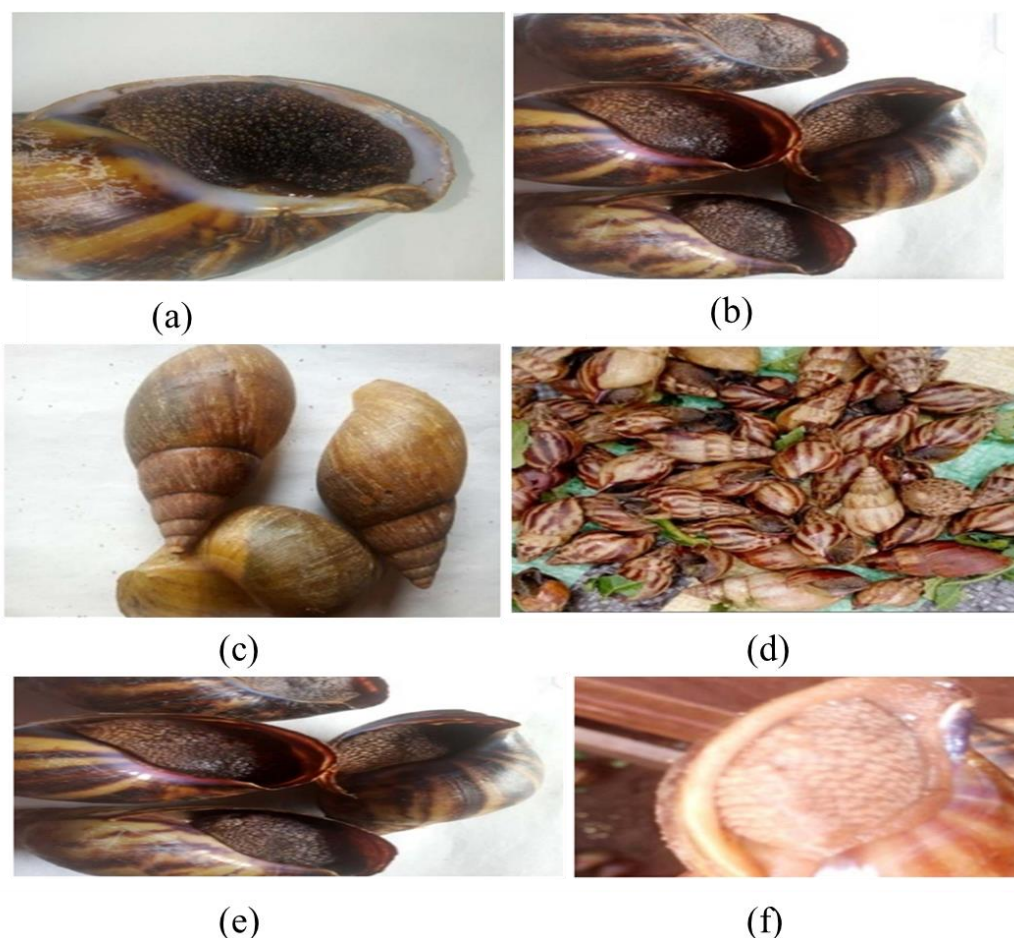


Figure 1: Variability in shell colour, pattern and aperture of selected snail species

Among the best-studied examples for phenotypic variation in response to climate and habitat are shell pigmentation polymorphisms of helicoid land snails, which have been investigated in detail for more than 50 years [29], [30], [31]. Numerous studies on these animals have addressed single morphological features, physiological traits, or biochemical parameters that are modified by thermal stress. However, the concurrent syndromic responses to thermal stress have rarely been addressed, but are of crucial importance for mechanistic understanding of stress responses across biological levels of increasing complexity [32].

Shell markings of Achatinid land snails are in the form of streaks that run across the whorls and in common with many other pulmonates, the snails are often polymorphic for shell colour and pattern [29]. The presence of streaks on shell surface of *A. fulica* and *A. sylvatica* is associated with a dominant allele such that homozygous recessive individuals have unstreaked shells [29], [30], [31]. Unbanded and unstreaked strains of *A. fulica* are reported in Africa. Earlier studies on the species in this regard, involving variation in shell morphology in terms of size, shape and colour have been largely attributed to environmental conditions [29], [32], [33]. Fontanilla [34] and Jayashankar et al. [29] suggested that *A. fulica* should be designated under the subgenus *Lissachatina* based on conchological and anatomical features. The banding pattern on the shell of *A. fulica* snails was observed by Jayashanker et al. [29] to be highly variable among individuals from the population, and that the variation involves the colour, the intensity, number and the width of bands. The shell of *A. marginata* snail has a brownish yellow background with fairly uniformly arranged bands and zigzag lines or spots that are dark-brown or reddish brown in colour [35], [36]. The shell is generally reddish brown in colour with weak yellowish vertical markings but coloration varies with environmental conditions and diet [16], [37].

2.1.2 Aperture (Opening)

The shells of African land snails have an opening called the aperture or mouth (Figures 1a, 1b, 1e, and 1f). The size and shape of the aperture can vary from circular to ovate [4], [5], [12], [38], [39], [40], [41], [42]. The shell aperture (mouth) of *Achatina fulica* (Figure 1a) is ovate-lunate to round-lunate with a sharp, unreflected outer lip. The mantle is dark brown with rubbery skin. There are two pairs of tentacles on the head: a short lower pair and a large upper pair with round eyes situated at the tip. Narrow and rounded aperture was observed from *A. fulica* snail by Okon and Ibom [12]. On the other hand, a typical *Achatina achatina* with vinaceous-red columella has a low-spined shell and an expanded aperture (globose shape) [12]. The aperture of *A. marginata* has been reported to be white or pale blue [12], [35], [36]. The aperture of land snails can be measured using vernier caliper as reported [4], [5]. The parameters that are measured for aperture (mouth) include: mouth shell length and mouth shell width.

2.1.3 Shape

The shell shapes of *Archachatina marginata*, *Achatina fulica* and *Achatina achatina* are presented in Figure 2. The shell of *Archachatina marginata* is characterized by a wide, bulbous or dome-shaped apex, while the shell of *Achatina fulica* is broadly ovate and sub-globular with regular conical spine and narrow apex. It has a narrow, conical shell being about twice as long as its width and contains 7 to 9 whorls when fully grown, and that of *Achatina achatina* is a V-shaped at the apex, which is raised, serrated bump at the tail region of the shell. The shells can also be conical in shape and fairly pointed than other snail species [4], [5], [12], [37], [38], [40]. *Archachatina marginata* has a bulbous shell with brown stripes and a wide apex, while Aluko and Adisa [41] observed *Archachatina marginata* to have broad and wide apex. Similarly, Aluko et al. [42] observed that the shape of shell of *A. marginata marginata*, *A. marginata suturalis* and *A. marginata ovum* to be sinistral in shape (100%).

2.1.4 Size

Raut and Barker [43] reported that *Achatina achatina* when fully grown can have up to 20 cm in height, and 10 cm in maximum diameter in their shell. Sexual maturity in snails has been recorded in various reports: 7-11 months [2]; 7-12 months for poorly-managed snails or snails under extensive management or in the wild, and 5-6months for intensively-managed snails [44]; 9-10 months [3]; 8-12 months [45]; 6.32 -7.02 months [4]; 7-10months [12]). On the other, Etukudo et al. [46] reported the measurements of body shell lengths, body shell widths, mouth shell lengths, and mouth shell widths of *Achatina achatina* snails at maturity from Osun, Ondo, and Oyo states in Nigeria. The recorded values were as follows: body shell lengths (12.77 cm, 12.70 cm, and 13.13 cm), body shell widths (6.67 cm, 6.87 cm, and 6.93 cm), mouth shell lengths (6.90 cm, 7.13 cm, and 6.93 cm), and mouth shell widths (4.70 cm, 4.47 cm, and 4.37 cm), respectively. Okon et al. [16] and Etukudo et al. [7] reported shell parameters for *Achatina achatina* snail at maturity to be 4.763 cm, 1.732 cm, 9.258 cm, 4.063 cm, 1.979 cm, 0.705 cm for aperture length, aperture width, body shell length, body shell width, spiral length, and spiral width, respectively. Okorie and Ibeawuchi [40] observed that the body shell lengths of *Archachatina marginata* ranged from 8.70 - 11.60 mm at 2days of age, 43.20 - 52.40 mm at 5 months of age, 76.50 – 104.60 mm at 14 months of age. Shell width was also observed by the same author to be ranged from 0.55 – 0.64 mm, while the length of shell aperture ranged from 0.54 – 0.69 mm at 14 months of age.

Etukudo et al. [46] recorded the measurements of body shell lengths, body shell widths, mouth shell lengths, and mouth shell widths of *Archachatina marginata* snails at maturity from Osun, Ondo, and Oyo states in Nigeria. The recorded values were as follows: body shell lengths (14.43 cm, 16.07 cm, and 15.97 cm), body shell widths (8.07 cm, 8.63 cm, and 8.83 cm), mouth shell lengths (8.97 cm, 9.00 cm, and 8.87 cm), and mouth shell widths (5.50 cm, 5.47 cm, and 5.70 cm), respectively. For *Achatina fulica* snails. Etukudo et al. [46] recorded the following measurements of shell parameters from mature snails collected in Osun, Ondo, and Oyo states, Nigeria: body shell lengths (8.17 cm, 7.93 cm, and 7.83 cm), body shell widths (4.40 cm, 4.30 cm, and 4.73 cm), mouth shell lengths (4.93 cm, 4.97 cm, and 4.83 cm), and mouth shell widths (2.87 cm, 2.57 cm, and 2.73 cm), respectively. Etta et al. [47] reported shell parameters for mature *Achatina fulica* snails as follows: body shell length (10.440 mm), body shell width (5.087 mm), aperture length (5.291 mm), and aperture width (2.990 mm). Additionally, Okon et

al. [16] and Etukudo et al. [48] provided shell measurements for mature *A. fulica* snails, recording aperture length (3.243 cm), aperture width (1.061 cm), body shell length (6.786 cm), body shell width (2.661 cm), spiral length (1.118 cm), and spiral width (0.261 cm). These findings from body shell sizes for the three snail breeds were not in line with the views of Nisbet [49] and Plummer [50] that the largest land gastropod is *Achatina achatina*. The findings, however, align with previous reports [51], [52], which identified *Archachatina marginata* as the largest known land snail in Nigeria.

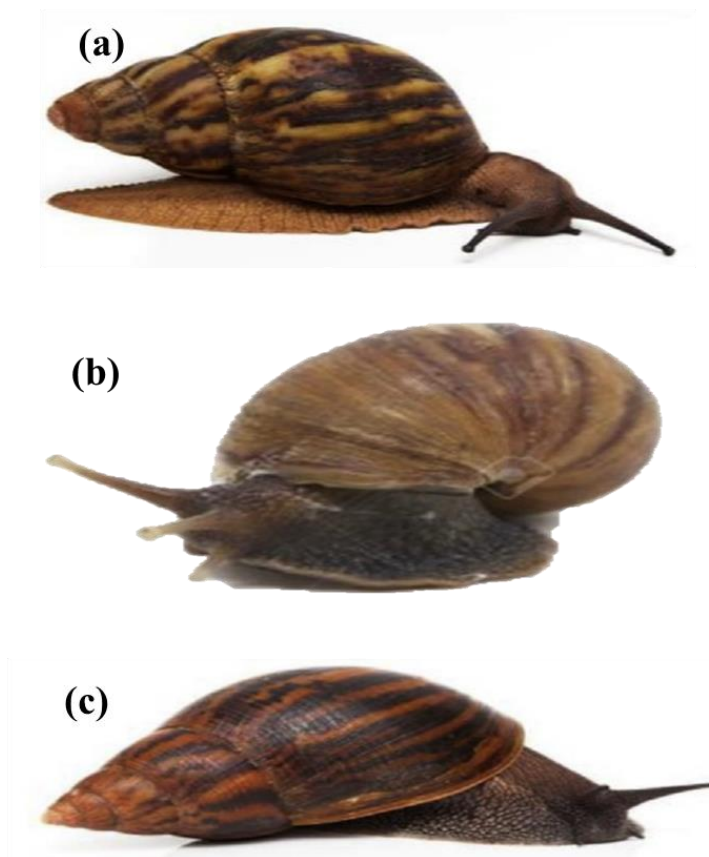


Figure 2: Variability in shapes of the shell of snails

2.1.5 Composition of the shell

The shell of giant African land snails (*Archachatina marginata*, *Achatina achatina* and *Achatina fulica*) are made of calcium carbonate, which gives the snails its hard and rigid structure. This component helps protect the snails from predators and environmental factors [6], [7]. The shell of *A. marginata* snail was reported to have the following major constituents in their shell: K_2O , Fe_2O_3 , CaO , P_2O_5 , Al_2O_3 , ZnO , SrO , Cr_2O_3 , TiO_2 and MnO . Metals concentration in the snails' shell has been observed to be in decreasing order: $Ca > K > Na > Mg > Fe > Zn$ [53], [54], [55]. Higher concentrations of calcium in the shell of snail confirmed that $CaCO_3$ is the main component in the shell of molluscs [56], [57]. The following mineral elements: Mg^{2+} , Ca^{2+} , Fe^{2+} , Na^+ , K^+ , and Cl^- has been reported to be present in the shell of *A. marginata* snails [58], [59], [60], [61].

2.1.6 Whorl

A whorl is a single, complete 360° revolution or turn in the spiral or whorled growth of a mollusc shell [62]. The number of whorls depends on mathematical factors in the geometric growth that exist in an adult shell of a particular species [63]. The whorl of any giant African land snail is the spiral-shaped structure of its shell, that consists of many coiled layers that form as the snail grows or increases in size. Each new whorl is larger than the old or the previous one, and the spiral formation gives strength and protection for the snail. The whorls can differ with respect to number, shape, and size depending on the

snails' species [43]. *A. fulica* is one of the smallest among the giant land snails of the world, growing with a long and greatly swollen body whorl [37].

Qualitative characterization of *Archachatina marginata* varieties (*Archachatina marginata marginata* (Amm), *Archachatina marginata saturalis* (Ams), *Archachatina marginata ovum* (Amo)) in the derived savannah zone of Ogun State, Nigeria was studied by Aluko et al. [42] and they discovered that the three varieties of *Archachatina marginata* snail possessed whorls that ranges from 4 to 6. Also, Ademolu et al. [60], examined shell whorls morphometrics of *A. marginata* (Swainson), *A. achatina* (Linnaeus) and *A. fulica* (Bowdich) using snails of 12 months of old with 6 whorls from the same farm, they discovered that in all three species, the degree of shell mineralization decreased from the apical (oldest) to the body (youngest) whorl, thus depending entirely on the whorl's age.

Okon et al. [64] evaluated and compared phenotypic traits and correlations of three breeds of giant African land snails (*A. marginata*, *A. achatina* and *A. fulica*) with different number of whorls on the shell. Their results showed high significant ($p < 0.01$) breed effects on phenotypic traits as *A. marginata* snails with four (288.700 g) and 5 (394.500 g) whorls were phenotypically and genotypically heavier, larger and wider than *A. achatina* (127.0 g and 182.000 g) and *A. fulica* (48.850 g and 65.050 g) with four and five whorls. They observed only one strong, negative, and significant ($p < 0.01$) phenotypic correlation (r) between shell length and aperture with the first spiral ($r = -0.650$) for *A. achatina* snails with four whorls. In contrast, *A. achatina* snails with five whorls exhibited a few strong, negative, and significant ($p < 0.01$) phenotypic correlations, including body weight and shell width ($r = -0.613$), shell length and aperture with the first spiral ($r = -0.641$), and shell width and aperture length ($r = -0.602$). Similarly, *A. fulica* snails with four whorls recorded a few strong, negative, and significant ($p < 0.01$) phenotypic correlations, such as body weight and shell width ($r = -0.627$), shell length and aperture with the first spiral ($r = -0.639$), and shell width and aperture width ($r = -0.657$). For *A. fulica* snails with five whorls, only one strong, negative, and significant ($p < 0.01$) phenotypic correlation was observed between shell length and aperture with the first spiral ($r = -0.605$).

The same authors reported that *A. marginata* snails with four whorls exhibited only one strong, negative, and significant ($p < 0.01$) phenotypic correlation between body weight and shell length ($r = -0.720$). Additionally, they identified two low, positive, and significant ($p < 0.05$) phenotypic correlations: between aperture with the first spiral and aperture width ($r = 0.544$), and between spiral length and diagonal length ($r = 0.583$) for *A. marginata* snails with four and five whorls, respectively. The authors concluded that the breed type and the number of whorls on snail shells strongly influence phenotypic trait estimates and correlation coefficients of giant African land snails in Nigeria. They also stated that correlation estimates for mature snails with higher numbers of whorls (four and five) are rarely strong, positive, and significant. Furthermore, Okon et al. [64] confirmed that *A. marginata* snails are phenotypically and genotypically heavier, larger, and wider than *A. achatina* and *A. fulica* snails with four and five whorls.

Etukudo et al. [65] opined that genetically, *A. achatina* species of snails are heavier and larger than the *A. fulica* counterpart with the same number of whorls (5). At hatch, the hatchlings have very brittle shells that have 1-2 complete whorls, while adults' snails can have up to 10 whorls [4], [5], [12].

2.2 Body Characteristics

The foot/skin of a land snail has many distinctive characteristics that help the snail to survive in its environment. These features are tied closely to the snail's need for moisture, movement, and protection. The key aspects of a land snail's skin/foot are discussed in the following sections.

2.2.1 Skin coloration

The skin colour of giant African land snails can differ depending on the species (*A. marginata* (Figures 1a, 1f, and 2a); *A. achatina* (Figure 2c); *A. fulica* (Figures 2b and 3a)) and the environment or habitat, but it is usually brown (Figure 1f), black (Figures 1e, 2 and 3a) and white/albino (Figures 3b, 3c, and

3d). The texture of the foot is always smooth, although it can be slightly rough or wrinkled sometimes especially when dry. The body of the snail tends to be a mottled brown colour, while the albino individuals will have a paler coloured shell with a white body. The genes of a snail determine its basic body colour, while environmental factors such as habitat and diet can influence the intensity and variation of that colour. Additionally, some snails have body colours that help them blend into their surroundings, providing camouflage from predators. Variations in natural populations have been studied extensively. [4], [5], [12], [66], [67].

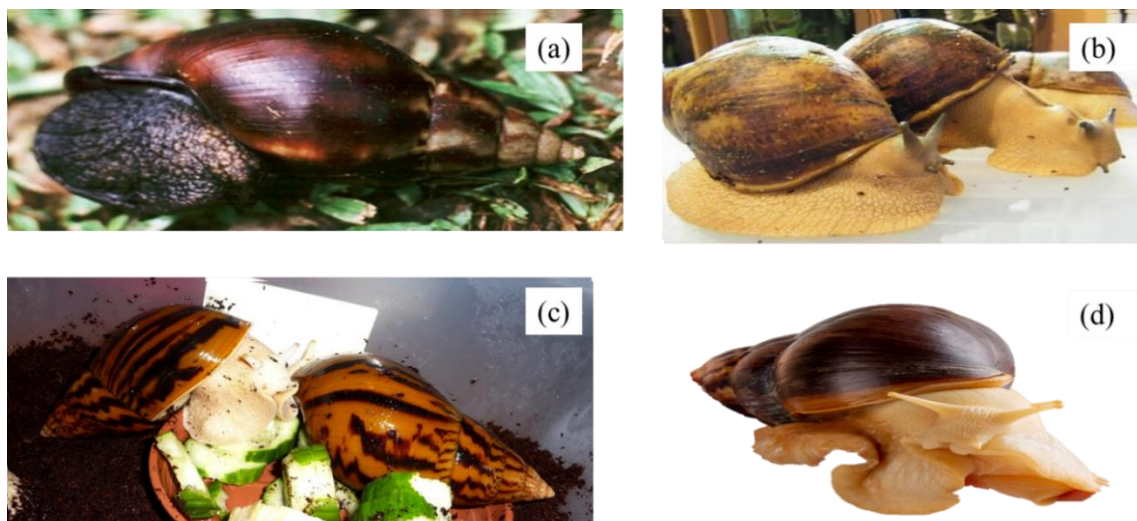


Figure 3: Snail's skin colouration (a): Aperture of *A. fulica* snail [68]; (b): White-skinned (Albino) *A. marginata* snail [7]; (c): White-skinned (Albino) *Achatina achatina* [69]; (d): White-skinned (Albino) *Achatina fulica* [70]

2.2.2 Body weight

Body weight of any land snails can differ widely depending on the size, species and environmental factors (diet, stocking density, genetic, hydration, activity level, etc.). Body weight of land snail is measured in grams or kilograms using electronic scale. The body weight of an adult *A. fulica* snails has been reported by several authors to be up to 32 grams in weight [4], [5], [12]. Body weights of *A. fulica* based on five (5) whorls has also been reported to be (59.58 g, 61.20 g, 65.05 g) [4], [5], [12], [48]. The body weights of *Achatina achatina* and *Achatina fulica* snails with 4 whorls ranged from 83.00 to 180.50 g (average 156.90 g) and from 30.60 to 85.20 g (average 49.70 g), respectively. That for *Achatina achatina* and *Achatina fulica* snails with 5 whorls ranged from 132.70 to 272.80 g (average 138.95 g) and from 50.60 to 119.30 g (average 59.58 g), respectively [16]. Ibom et al. [71] had earlier reported higher mean body weights of 93.70 g, 109.70 g and 73.00 g for *A. fulica* snails from central agro-ecological zone, northern agro-ecological zone and southern agro-ecological zone of Delta state, respectively. But, further recorded low mean body weights of 120.90 g, 107.50 g and 72.00 g for *A. achatina* snails from central agro-ecological zone, northern agroecological zone and southern agro-ecological zone of Delta state. On the other hand, mean body weights of 138.60 g for *A. fulica* snails with 4 whorls was reported by Okon et al. [14]. The mean body weights of 127.20 g and 48.85 g were recorded for *A. achatina* and *A. fulica* snails with 4 whorls by Etim [72], and 182.00 g and 65.05 g for *A. achatina* and *A. fulica* snails with 5 whorls by the same author. Etta et al. [47] reported a higher mean body weight of 137.50 g for *A. fulica* snails with 4 whorls.

Body weights of *Archachatina marginata* have been recorded based on number of whorls (2, 3, 4 and 5) to be 1.210 g, 4.238 g, 96.410 g, and 124.141 g respectively [7], [17]. Higher mean body weights of 6.9812 g and 10.2962 g were recorded for black-skinned and white-skinned ectotype of *A. marginata* snails with 2 whorls [7]. Similarly, body weight of black-skinned *A. marginata* has also been reported to range from 4.24 g to 7.93 g (for 50 adult snails) [4], [5], [7], [12].

3. Conclusion

The phenotypic variation of giant African land snails is a testament to their remarkable adaptability, survivability and evolutionary success. Through a comprehensive exploration of their morphological traits, valuable insights have been gained into the factors shaping their phenotypic landscape. Shell morphology, in particular, exhibits a wide range of variations, influenced by genetic, environmental, and ecological factors. The body characteristics, encompassing vital traits like body colour and body weights, also displays significant diversity, contributing to their ecological niches and behavioural adaptations. Understanding the phenotypic landscape of these snails is crucial for several reasons. It can help us to better understand the evolutionary processes that have shaped their diversity, identify populations with unique adaptations, and inform conservation efforts for these important species. While considerable progress has been made, further research is needed to fully unravel the complex interplay between genetics and environment in shaping the phenotypic landscape of giant African land snails. By combining genomic studies with detailed ecological observations, deeper insights can be gained into the mechanisms underlying their phenotypic variability and better appreciate the remarkable adaptations of these fascinating creatures.

Acknowledgements

None.

Funding

None.

Conflict of Interests

The authors declare that they have no conflict of interest.

Author Contributions

All authors have read and approved the final version of the manuscript.

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