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Review Article

Reproductive bioecology of the giant African land snail - a tool for breeding or control

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The Giant African Land Snail (GALS), which belongs to the Achatinidae family, comprises of over 200 species, of which the three commonest are *Achatina fulica* (recently renamed as *Lissaachatina fulica*), *Achatina achatina* and *Archachatina marginata*. *A. fulica* originated from East African coast, while *A. achatina* and *A. marginata* originated from the West African coast. About 200 years ago, *A. fulica* was introduced into other countries in the tropics and neotropics, where it appears to have evolved into a pest. The outcome of control efforts in those countries has been uncertain. Whereas in West Africa, the population of the snail has reduced significantly in the wild and unable to meet domestic demand. Hence, scientists in Africa are focusing their research on breeding the snail, while their counterparts outside the continent are focusing on developing more control measures. This study reviewed the reproductive cycle of the snail and highlighted areas that could be explored for either the control or breeding. We found out that environmental conditions particularly temperature and humidity play a key role in the reproductive cycle of the snail especially during copulation, egg laying, incubation and hatching, and growth of juveniles to maturity, which could be modulated for either control or breeding of the snail.

Keywords: *Achatinidae, fecundity, hermaphrodites, invasive species, pestiferous snail*

Introduction

The Giant African Land Snail (GALS), which belongs to the Achatinidae family, is among the largest known land snails in the world (Awodiran et al., 2015). The Achatinidae family comprises of over 200 species (Dar *et al*., 2017), of which the three commonest are *Achatina fulica* (recently renamed as *Lissaachatina fulica*), *Achatina achatina* and *Archachatina marginata* (Awodiran et al., 2015). *A. fulica* originated from East African coast, while *A. achatina* and *A. marginata* originated from West Africa coast. The snails are mostly found in the African rain forest and riparian zones in the savannahs (Ukpong, 2016). In their area of nativity in Africa, these species perform diverse ecological roles (Nnamonu et al., 2021). As detritivores and scavengers, they aid in the decomposition of organic matter and other wastes, fixing of carbon in soil, which perform the dual function of replenishing soil fertility and supporting carbon sequestration, which is important in climate change mitigation. In their quest for calcium for their shell growth, they glen calcium from several sources. Since they are part of the food web, they effectively introduce bio-calcium into food systems, when consumed by other species including humans.

These snails have been used beneficially in Africa for centuries. They are delicacies, which are used as alternative sources of animal proteins (Okorie & Ibeawuchi, 2004). Snail meat, which are popularly called ‘Congo meat’ is chewy with mushroom-like flavour. They are known to be rich in proteins including essential amino acids such as lysine and methionine, high in calcium, iron and other minerals, but low in fats and cholesterol (Babalola & Akinsoyinu, 2009; Nkansah et al., 2021). Hence, they have been used in folklore medicine for the treatment of diverse chronic conditions such as anaemia, arthritis, diabetes (Engmann et al., 2013; Ademolu et al., 2015). Their shell has been used as sources of calcium carbonate. Whole shells are used as artwork, decorative material, jewels and totems (Budha & Naggs, 2005). Milled snail shells have been used as abrasion material, for the amendment of acidic soils, and traditional medicine. The mucus from the snail has antimicrobial properties and has been demonstrated for wound healing. Mucus from the snails is used for the formulation of cosmetics and other skincare products. Both snail shell and mucus have been applied in reconstructive surgeries especially in bone grafts and tissue engineering (Ajisafe & Raichur, 2023. The snail is commonly used as instructional material in schools (Hirschenhauser & Brodesser, 2023). However, the snail has their nuisances, which are commonly overlooked perhaps because of their benefits, until recently. They spread faeces and mucus along their path, which is unpleasant (Thiengo et al., 2007). They can harbour parasites and pathogens of public health importance (Dumidae et al., 2021). GALS, especially *A. fulica*, which is herbivorous, have the tendency to become plant pests especially in disturbed ecosystems (Albuquerque et al., 2008; Dar et al., 2017).

Perhaps based on their perceived importance, *A. fulica* was intentionally collected from East Africa and introduced into some Indian Ocean Island nations in 1800, from where they were introduced into India in 1847. From India, they spread deeper into Asia. From Japan, they were introduced into USA in 1936, which was controlled and later from Indonesia into Brazil in1980s, from where they became spread in South America and the Caribbean (*Thiengo* et al., 2007; Fontanilla et al., 2014). Hence, the snail has now spread through most of the tropical world and neotropics with sporadic occurrences in some temperate countries (Gabetti et al., 2023). In Brazil, farming of *A. fulica* (escargot farming) was initially promoted by the government, when the snail was first imported from Indonesia (Thiengo et al., 2007). Cooperatives were established which actively promoted the breeding of the snail then. But when the business failed, snail farmers dumped their products i.e., live snails along roadsides, bushes, landfill etc, which resulted in the rapid spread of the snail in Brazil and other nearby countries (Thiengo et al., 2007). However, there are evidences that suggest multiple introductions of the snail into different countries. Achatinid snails can stowaway with agricultural products, containers and military equipment (Ayyagari & Sreerama, 2017; Dumidae et al., 2019). Recent studies have shown that the snail could have also spread through exportation of timber from Africa to other countries particularly India, China and the Middle East (Vijayan et al 2020). Besides, it has been documented that GALS were spread by Japanese soldiers during WW2 (Thiengo et al., 2007; Fontanilla et al., 2014). It is likely that all three snail species might have stowaway, but it is only *A. fulica* that has become established beyond the African continent. In most of the countries that the snail was introduced into, it evolved into pest perhaps due to lack of their natural predators (Gabetti et al., 2023). *A. fulica* outside its native range has been ranked as a major plant pest that devours over 500 different plant species, which threatens agriculture, horticulture and biodiversity (Thiengo et al., 2007). It is principally because of the generalist feeding habits and high reproductive capacity that made *A. fulica* to be classified as pest (Fontanilla et al., 2014). They also outcompete indigenous snails for habitats and food and have been observed to attack other snails and slugs (Meyer et al., 2008). They are implicated in the transmission of nematodes of veterinary and public health importance (Silva et al., 2022). Because of their foraging activities on wastes, they also harbour pathogens (Akpomie et al., 2019). They can litter peri-urban area with their faeces and mucus, which is unsightly and can cause vehicles to skid in highways (Thiengo et al., 2007). They have become destructive to building materials in their quest for calcium sources, such as paints, stucco and plaster board. Hence, outside Africa, control and eradication measures have been instituted. Various eradication measures have been tried in various countries including physical, chemical and biological methods, with uncertain level of success. Resurgence sometimes occurs in places, where they have been previously eliminated. Hence, the snail has been ranked among the world's worst 100 invasive species (Madjos & Demayo, 2017; Dumidae et al., 2021).

Meanwhile, GALS are delicacies in Africa especially West and Central Africa, but a pest everywhere else (Ohimain et al., 2024). Because of the differing effects of the snail in its native and introduced ranges, approaches and research interest on the snail also differs. The reproductive biology of the snail plays vital role in the sustenance of the snail population in the wild and adaptation to new ecosystems. In West Africa, where consumption of the snail is high, their population in the wild is diminishing, whereas in other continents, where the snail has been introduced into, their population is increasing and so is their pestiferous activities. Hence, while West Africans are doing research to domesticate and farm the snail, other countries are doing research to eradicate them. This review used the reproductive biology of the snail to address both objectives by highlighting important aspects useful for either their breeding or control.

Reproductive biology of GALS

The reproductive biology of the snail is closely linked with its ecology and ability to invade, survive and become established in diverse ecosystems. GALS are quite unique in their reproductive organs because they possess both sexes on the same individual, hence they are regarded as being hermaphroditic or diecious. Patiño-Montoya & Giraldo (2017) described these snails as protandric hermaphrodites because they develop the male gonad first. The snail carries out reciprocal copulation i.e., exchange of sperms, resulting in cross-fertilization in order to lay viable eggs, with both individuals laying the eggs (Skelley et al., 2011). Thus, doubling egg laying by a pair of organisms. But occasionally, in the absence of a partner, a single individual can self-fertilize and lay viable eggs, which can hatch into adults and potentially start a new colony. Only about 3% of the snails self-fertilize (Dickens et al., 2018). This is one of the reasons, why it is difficult to eradicate the snails once they become established in an area.

The life cycle of the snail consists of several stages such as egg laying and hatching into juveniles, which grow to become adults (Figure 1). Equal sizes of the snail typically copulate with reciprocal transfer of sperm, but when they are unequal, the smaller one acts as male. They can lay eggs within a short time i.e., about 1 to 2 weeks after mating (Skelley et al., 2011). They can store exchanged sperms in their body in viable forms for up to 2 years and can produce new fertile eggs every 2-3 months (Hoffman & Pirie, 2014). After a single mating, gravid snails can lay from 100-500 eggs at a time, which they do several times within a year cumulating to 1800 eggs or more (Skelley et al., 2011; Roda et al., 2016). About 5% of the Achatina snail population is gravid all year round (Roda et al., 2016). The clutches are usually laid in clusters in moist soil, under leaf litter or other debris, where they incubate. Their incubation period is rather short, ranging from 2 – 4 weeks (Kumar et al., 2021), depending on environmental conditions particularly temperature and humidity. Hatching occurs at temperatures higher than 15^{o}C (Hoffman & Pirie, 2014). At higher temperatures and humidity, the eggs hatch even faster. Hatchability is quite high ranging from 75 - 86% (Akanni & Akinnusi, 2021). Eggs are hatched directly into juveniles (without larval stages), which are typically miniature or smaller versions of the adult. The juvenile consumes detritus and vegetation and grow rapidly and can attain sexual maturity within 6 months (Skelley et al., 2011; Dickens et al., 2018). Under laboratory conditions, Kumar et al. (2021) reported three juvenile stages of the snail before maturity, which was based on the number of rings. The first juvenile stage (J1) with one ring appearing within 25 -30 days, two rings (J2) from 33 -40 days and three rings (J3) from 44 – 48 days, developing into adults within 65 – 70 days, with a total duration of 150 – 160 days. Typically, sexual maturity can occur from 5-15 months, again depending on environmental conditions. Typically, their life span is 3-5 years (Roda et al., 2016), but could prolong to 10 years as a result of dormancy (Skelley et al., 2011; Aluko et al., 2017). Their high rate of fecundity also contributes to the difficulty of eradicating them.

Environmental conditions can have significant effects on the reproduction of the snail. For instance, the breeding season often coincides with the monsoon, when temperatures and humidity are high (Aluko *et al*., 2017; Akanni and Akinnusi 2021). For instance, there are more gravid snails during high humidity. The optimum humidity and temperature for the reproduction of the snail are >80% (Kumar et al., 2021) and 22 - 32^{o}C (Gabetti et al., 2023) respectively. During the periods of unfavourable weather conditions, whether extreme heat /drought and cold/winter, the snail can become dormant inside the shell sealed with calcareous matter and mucus under reduced metabolic activity, which is typically referred to as estivation (summer sleep) and hibernation (winter sleep) respectively (Skelley et al., 2011; Gabetti et al., 2023). Hoffman & Pirie (2014) reported that *A. fulica* is adapted to broad environmental conditions including temperate conditions and can aestivate when the temperature exceeds 30^{o}C and hibernate when it is below 2^{o}C. Hence, the ongoing climate change is therefore having differing impacts on the snails, possibly contributing to their decline in West Africa and their increase especially in the countries they have been introduced into (Roda et al., 2016; Patiño-Montoya et al., 2022a, 2022b).

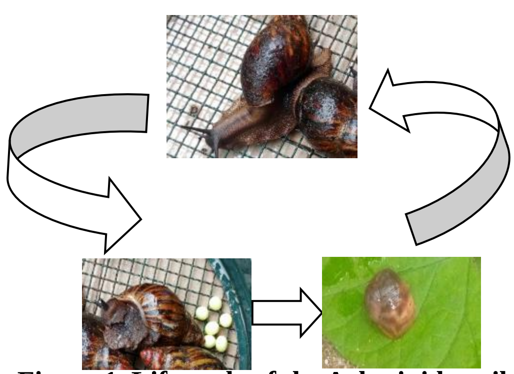

Figure 1. Life cycle of the Achatinid snail

Control approach

In countries and regions where the snails have been introduced, they unfortunately developed into an intractable pest. Hence, research priority was focused on the eradication of the species. It is because of the high prolificity of the snail that made it difficult to control (Rekha et al., 2015; Roda et al., 2016). Control efforts including physical, chemical and biological methods and/or their combinations backed by policies, legislations and eradication programs, have been tried in different countries with uncertain outcomes (Ohimain et al., 2024).

Several physical measures have been used by different countries for the control of the snail, of which the commonest is manual collection techniques such as handpicking especially during their period of dormancy, setting of baits and traps, which is typically followed by their destruction through crushing. Habitat modifications were also considered, which involved making the habitat to be inhospitable for the snail to inhabit and reproduce. Habitat modification can involve the removal of potential hiding places such as detritus, wood, stones, mulches, debris etc. Modifying the habitat by keeping it clean and avoiding dampness was also considered since moisture facilitates egg laying and hatchability (Subedi, 2014). These methods are only effective in small or localized areas such as gardens and small farms. But physical methods can be tedious and limited in scope. Any eggs or snails missed can potentially hatch or grow, self-fertilize, if there are no partners to form a new colony (Capinera, 2020). Besides, most of the habitat control measures are impractical and can also impact the ecosystem negatively. Hence, physical methods will need to be carried out several times at specified intervals for it to be effective in the long hull.

Chemical methods involve the use of various chemicals for the control of the snail ranging from repellents to pesticides such as molluscicides. Some salts either repel or kill the snails such as sodium chloride, iron phosphate, copper sulphate, etc. The commonest chemical molluscicides used in combatting the snail is metaldehyde, which is usually applied as baits in diverse forms such as pellets, granules, and liquids. Other pesticides such as methiocarb is applied as bait while chlorpyrifos are sprayed (Subedi, 2014). Some synthetic chemical agents such as methiocarb, copper sulphate, iron phosphate and extracts of natural substances of biological origin such as *Azadirachta indica* (neem), *Allium sativum* (garlic), *Cymbopogon citratus* (lemongrass) and *Jatropha curcas* mode of action is by disrupting the reproductive cycles of the snail. Sometimes, mixtures of different chemicals are used to increase their potency. The major problem with the chemical approach is its non-selective nature and potential toxicity to non-target organisms including domestic animals, wildlife and humans. In Brazil for example, the indiscriminate use of metaldehyde resulted in the loss of wildlife including bats, rodents, lizards, and skunks, some of which are the natural predators of the snail (Thiengo et al., 2007). However, molluscicides of biological origin can be environmentally friendly.

Biological approaches involved the use of natural enemies or predators, parasites, and pathogens to control the snail's population. Several vertebrate predators especially in the native range of the snail are known to feed on the snails especially their juveniles including avian species (turkeys, ducks, grouse, thrushes), mammals especially rodents, pigs and humans. Juveniles of the snails have been used as live feed for cultured catfish in Nepal. Some predatory snails such as *Euglandina rosea*, *Gonaxis quadrilateralis*, *G. kibweziensis*, and *Edentulina ovoidea*), have been introduced to counter *A. fulica* in the wild. Other groups of animals such as nematodes, helminths, arthropods, crabs, turtles also prey on the snails (Davis & Butler 1964; Raut & Goshe 1984; Civeyrel & Simberloff 1996). Pathogens such as fungi (*Paecilomyces lilacinus, Phytophthora palmivora*) and bacteria (*Aeromonas hydrophilia*) have also been considered for the control of the snail (Dean et al., 1970; Raut & Goshe 1984). Predators have the disadvantage of affecting indigenous snail species and were reported to cause their extinction in Hawaii and the Pacific Islands without controlling the snail (Thiengo et al., 2007; Civeyrel & Simberloff, 1996). Pathogens used to control the snail can also cause disease in humans. The outcome of control efforts was ambivalent in most cases. Notwithstanding, control measures were effective in the eradication of the snail in some countries like USA, Australia and Japan (Fontanilla et al., 2014), but there are cases of sporadic resurgence in the USA in 2011, 2022, 2023, 2024 (Thiengo et al., 2007; Fontanilla et al., 2014; Ohimain et al., 2024). Some countries like Nepal, experienced successes initially, but the snails rebound when control programs were abandoned (Budha & Naggs, 2005).

Breeding approach

The high reproductive prolificity of the snail contributes to their rapid population growth in the wild. But in West and Central Africa, where their harvesting, consumption and demand are high, their population has reduced significantly. Besides human consumption, other factors have been reported to contribute to the decline in the population of the snail in the wild including urbanization, deforestation and wood logging, agriculture especially shifting cultivation and the use of agrochemicals especially pesticides, bush burning, environmental pollution, construction of roads and dams (Nyameasem & Borketey-La, 2014; Aluko et al., 2017). Hence, the priority of researchers in West and Central Africa is on the breeding and domestication of the snail to meet domestic demand.

Snail breeding is done for several purposes such as research, food production, medicinal and cosmetic applications. In countries where the snails were introduced to, including India, Japan, Indonesia and Brazil, they were initially farmed.

Whereas, Africans depended on wild stocks to meet their needs until recently when the snail population in the wild declined significantly. Animal scientists in West and Central Africa now focus on the domestication, breeding and cultivation of the snail. Snail farming involves carefully controlling their environmental conditions particularly humidity and temperature, reproduction cycle, and health to ensure optimal productivity. Among the three commonest Achatinid snails, *A. fulica* is the most prolific in oviposition, tolerance to broader environmental conditions including temperatures ranging 0 – 45ºC (Capinera, 2020), sturdy, with diverse dietary requirements and have become adapted to disturbed places like farms, garden and peri-urban areas (Ogunjinmi et al., 2009; Madjos & Demayo 2017). Hence, this species is easier to cultivate with little maintenance costs. Environmental conditions suitable for the cultivation of the snail include warm temperatures (25°- 30°C) and humid conditions (humidity above 80%). The ambient weather conditions in West Africa coast due to their high humidity and temperature are favourable for the proliferation of the snails. Snail breeding in West Africa is quite easy, but still at the infancy stage. It involves collecting pairs of snails from the wild or purchasing them from the open market, placing them in a damp pen with sterile soil, and supplying them with feeds, which include commercial snail feeds, decaying organic matter, vegetables and calcium sources such as crushed eggshells or limestone. Diverse food and fruit wastes including leftovers are also used to feed snails. Eggs laid in the pen are collected aseptically and incubated in incubation boxes at optimum temperature and humidity until they hatch. The juvenile snails are raised in a clean environment while optimizing temperature, humidity and their diet. Juvenile snails can be raised in tanks or trays secured by using nets to prevent their escape and provide protection from predators. The pens are cleaned regularly to prevent disease. Compared to wild snails, cultured snails have been found to possess fewer parasites and pathogens (Parlapani et al., 2014), hence are healthier to consume. For instance, Nyoagbe *et al*. (2016) found significantly lower populations of microbes (total bacterial counts, coliforms, Shigella-Salmonella, *Pseudomonas*, *Staphylococcus* and *Bacillus*) in snail meat of *A. achatina* and *A. marginata* obtained from farms compared to the wild. Hence, snail breeding can create opportunities to develop “clean” snails.

Conclusion

The commonest species of GALS, which are *A. fulica*, *A. achatina* and *A. marginata* are used in West and Central Africa as food, with medicinal, cosmetics and cultural benefits. Of these, only *A. fulica* was intentionally introduced into other countries, while all three species might have been unintentionally introduced via the export of agricultural products and timber. As of today, only *A. fulica* has become established beyond the African continent and has evolved into an intractable pest. The success of the physical, chemical and biological control measures deployed in several countries is uncertain. Here we reviewed the reproduction cycle of the snail highlighting areas of vulnerability that can be exploited for the control of the snail in those countries where it is branded as a pest. But in West Africa, where their population in the wild is declining and unable to meet domestic demand, we also highlighted prospects for their breeding. Since, cultured snails typically contain fewer parasites and pathogens than wild snails, breeding could reduce the public health risk of the snails.

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None

Author contributions

The first author conceived and designed the study and wrote the first draft, while all authors revised the draft and approved the final version.

Conflict of interests

The authors declare no conflict of interest.

Ethics approval

Not applicable.

AI tool usage declaration

The authors declare that no AI and associated tools were used for writing scientific content in the manuscript.

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