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Feed Restriction and Compensatory Growth of Giant African Snails of the Species *Archachatina marginata* (Swainson, 1821)

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Abstract: Giant African snails of the species Archachatina marginata were subjected to a feed restriction for 70 days which preceded a re-feeding phase also of 70 days. The objective was to study in this species the ability to compensate for growth retardation induced by temporary dietary restriction. The study was carried out at the application farm of the Faculty of Agronomy of the University of Parakou between August 15, 2019 and January 22, 2020. In total, 90 snails, weighing on average 52.48 ± 9.03 g with an average shell length of 6.83 ± 3.38 cm, were randomly distributed into three lots of 30 subjects in semi-buried enclosures, made of cinderblock and fine mesh wire mesh. Three rations containing 20.26%, 17.18% and 14.43% crude protein and 2976 kcal; 2540 kcal and 2089 kcal of metabolizable energy per kg of dry matter were distributed ad libitum to lots 1 (control), 2 and 3 respectively. The snails showed at the end of the feed restriction period an average shell length of 8.1 ± 0.54 cm, 8.11 ± 0.43 cm and 8.13 ± 0.5 cm ($p > 0, 05$) for an average live weight of 79.6 ± 7.3 g, 68.86 ± 11.22 g and 66 ± 10.66 g ($p < 0.05$) respectively for lots 1, 2 and 3. At the end of the re-feeding phase, the shell length was 8.81 ± 0.51 cm, 8.80 ± 0.25 cm and 8.79 ± 0.46 cm ($p > 0.05$) for an average live weight of 92.59 ± 3.32 g, 88.5 ± 5.44 and 86.63 ± 7.3 g ($p < 0.05$), respectively for lots 1, 2 and 3. It emerges from this study that the weight loss observed during a feed restriction could not be fully compensated after a certain period of re-feeding in A. marginata, despite a remarkable increase in weight.

Keywords: Animal Nutrition, Feed Efficiency, Growth Performance, Benin Republic

1. Introduction

The availability and accessibility of conventional food resources of plant and animal origin are proving more and more difficult for many populations in developing countries [11]. These resources are under the influence of a double constraint: demographic and environmental. Indeed, the low productivity of production systems in these countries is crossed with increasing demographic pressure. The result is a food deficit, mainly of animal origin, which constantly worsens an already worrying food insecurity situation [21]. As a result, more and more poor households in rural areas engage in abusive harvesting practices of non-wood natural resources, thus causing some of them a real threat of disappearance. This is indeed the case for the giant African snails of the species Archachatina marginata which is a food resource highly prized by many populations in West Africa. Archachatina marginata is a gastropod mollusk whose lean flesh is particularly rich in essential amino acids and iron [7, 9, 3, 1]. The massive and excessive use of agricultural pesticides, bush fires and the collection of immature snails are all practices that have led to the scarcity of this resource [24]. However, it is established that giant African snails can be bred in captivity. Studies on the zootechnical productivity of Archachatina marginata bred in captivity have been carried out by [19]. This study shows that this snail species is perfectly capable of reproducing and ensuring regular growth in captivity. Many other authors have reported on the possibility of breeding giant African snails with rather satisfactory results [20, 10, 5, 17]. The initiative to breed the giant African snails responds to a need to preserve this resource and especially to promote its development through scientific research. This initiative also offers poor households in rural areas an alternative to conventional animal husbandry that is too demanding and too greedy in inputs. In a context of increasingly unfavorable climate change, mini-farming of species like the giant African snail may prove to be a solution to the fight against food insecurity and poverty. From this point of view, it is necessary to develop strategies which allow an efficient use of the scarce resources available and accessible at the scale of mini-breeders. Since diet is by far the most limiting factor in the expression of the zoo technical potential of farm animals [22, 18, 6], such strategies must be designed around a rationed and precision animal feed. [8] varied the levels of protein (10%, 15% and 20%) and that of calcium (0% and 10%) in the diet of giant African snails, in order to determine the best levels in the ration. The aim of the present study is to evaluate the effect of transient dietary restriction on the compensatory growth of giant African snails of the species Archachatina marginata. This is to test on this species, the ability to compensate for a growth delay following a period of undernourishment. This phenomenon has been observed on several warm-blooded animal species [12, 26, 4, 27]. These animals generally show better feed conversion as a result of an efficient use of the nutrients absorbed. However, studies of this phenomenon in cold-blooded species such as snails have never been carried out, hence the interest of this study.

2. Materials and Methods

2.1. Study Environment

The study was conducted at the application farm of the Agronomy's Faculty of the Parakou's University. The city of Parakou is located in the north-east of Benin at 9° 21 '00' 'north and 2° 37' 00 " east coordinates, at an average altitude of 350 m. The climate is tropical humid (South Sudanese), with a rainy season (May to October) and a dry season (November to April). Rainfall is around 1,200 mm per year, particularly abundant in July, August and September. The annual average temperature is around 27°C.

2.2. Animal Material

90 African giant snails of the species Archachatina marginata weighing an average of 52.48 ± 9.03 g with an average shell length of 6.83 ± 1.38 cm and an average diameter of 4.27 ± 0.67 cm were used in the present study. The lengths and diameters of the shells of the snails were measured using a caliper. The snails came from a private breeding site in southern Benin.

2.3. Experimental Device

Snails are fed a floury type feed. Each snail has been identified by a number inscribed on the shell using an indelible marker. For 70 days, three rations comprising 20.26%; 17.18% and 14.43% crude protein and 2976 kcal; 2540 kcal and 2089 kcal metabolizable energy per kg of dry matter were distributed at will, respectively to the snails of batches I (control), II and III. A quantity of 200 g of feed is served for each batch, twice a week (Tuesdays and Fridays) at dusk. Feed consumption is collective for the snails of each batch (see picture 1 below). Uneaten feed is weighed before a new service and after cleaning the pens. After this feed restriction phase, all batches of snails are fed for another 70 days, corresponding to the re-feeding phase, at the same level (100%) as the control batch. Drinking water is served in siphoid drinkers (see figures 1 and 2).

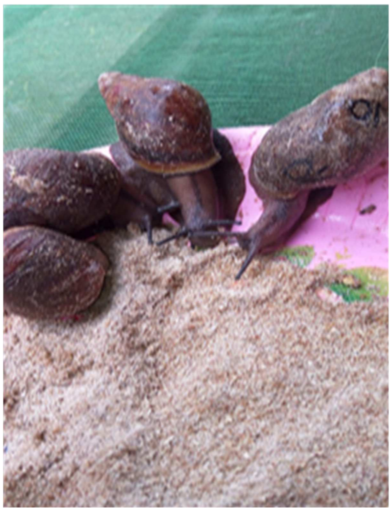

Figure 1. *Snails feeding.*

Figure 2. *Snails drinking.*

2.4. Statistical Analysis

The statistical analysis of the dependent variables selected was carried out using the GLM (Global Linear Model) procedure of the SAS (Statistical Analysis System) 9.2 software after having subjected them to the normality test. The following model was used:

$$Yijk = \mu + ai + bj + eijk$$

where:

Yijk: is an observed value of the dependent variable of interest Y;

µ: the average of the dependent variable of interest Y;
ai: the fixed effect of feed ration (i = 1, 2, 3);
bj: the fixed effect of the live weight of the snails at the end of the adaptation period (continuous variable);
eijk: variance residue.

3. Results

3.1. Feed Composition and Feed Consumption of Snails

The composition of the different rations is shown in Table 1 below.

Table 1. *Composition of the different feed rations of snails.*

Ingredients (%)	Feed rations		
	Lot 1 (control): 100%	**Lot 2: 85%**	**Lot 3: 70%**
Maize	45,00	30,00	12,00
soybean meal	17,00	08,00	02,00
Palm kernel meal	05,30	02,50	10,00
Fishmeal	05,00	03,00	--
Wheat bran	15,00	10,00	13,00
Rice bran	01,00	01,00	06,50
Corn bran	--	24,00	35,00
Malt brewery residues	--	10,00	10,00
Oyster shell	10,00	10,00	10,00
CMV	0,20	0,20	0,20
Sodium chloride	0,10	0,10	0,10
Lysine	0,60	0,50	0,50
Methionine	0,30	0,20	0,20
Di-calcium phosphate	0,50	0,50	0,50
Total	100,00	100,00	100,00
CP (%)	20,26	17,18	14,43
ME (Kcal/kg DM)	2976	2540	2089
CF (%)	5,13	8,16	11,26
Ca (%)	4,83	4,77	4,63
P (%)	0,76	0,65	0,68

CMV: Concentrated Mineral Vitamin; CP: Crude Protein; ME: Metabolizable Energy; CF: Crude Fiber; Ca: Calcium; P: Phosphor.

The average daily feed consumption during the entire trial period is shown in figure 3 below. It emerges from this figure that the average daily feed consumption of snails follows a tendency inversely proportional to the energy and protein concentration of the ration. The snails from lots 2 and 3 consumed with 1.09 ± 0.13 g and 1.13 ± 0.14 g on average, during the feed restriction phase, respectively 4.6% and 8% more feed than those in the control group. However, this difference was not found to be significant ($p > 0.05$). During the re-feeding phase, where all batches of snails are fed at the same level as the control batch, the average daily feed consumption was found to be almost identical between all batches, with 1.48 ± 0,17g, 1.49 ± 0,17g and 1.49 ± 0,17g, respectively for control batches, 2 and 3.

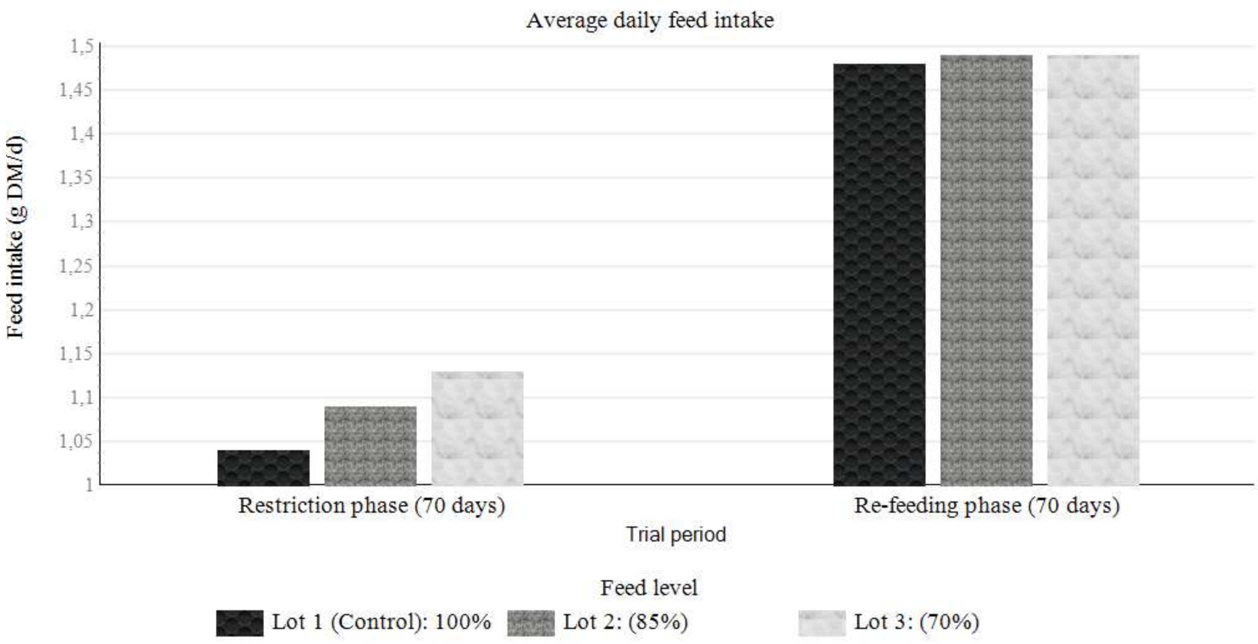

Figure 3. *Feed consumption of snails during the trial period.*

3.2. Weight Growth of Snails

The average daily weight gain of the snails during the test period is shown in Figure 4. It can be seen from this figure that during the feed restriction phase, the rate of daily growth of snails is directly proportional to the level of feed to which they are subjected. With respectively 0.25 g and 0.18 g, snails of Lots 2 and 3 showed a significantly lower daily weight gain ($p < 0.01$) of 32.43% and 51.35% to those of the control. The re-feeding phase was marked by a spectacular acceleration in the average daily weight gain of snails previously subjected to feed restriction. The snails of batches 2 and 3 which had been fed respectively with 85% and 70% of the feed level of the control batch, recorded with 0.27g and 0.28g a respective mean daily gain of 50% and 55% significantly ($p < 0.05$) greater than the control batch.

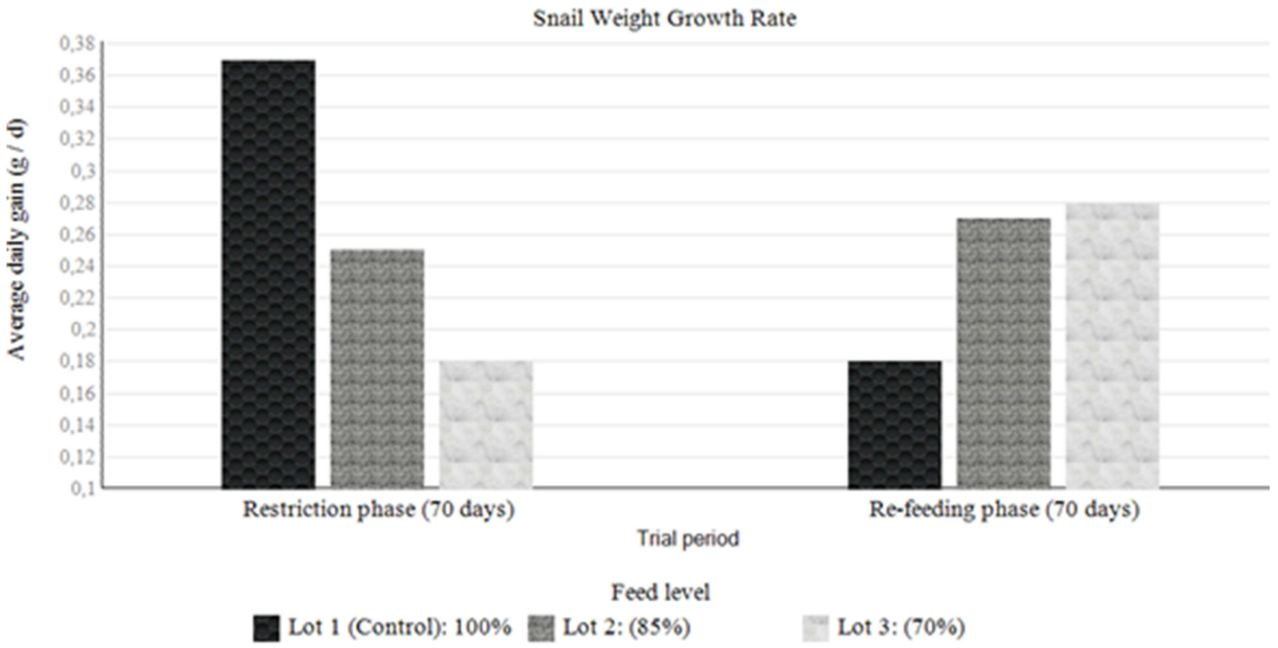

Figure 4. *Average daily weight gain per snails (n= 30) during the trial period.*

3.3. Snail Shell Measurement

The values for the length and diameter of the snail shell during the test period are reported in Table 2. It emerges from this table, that a feed restriction, of the order of 15% and 30%, applied to giant African snails of the species *Archachatina marginata* for a period of 10 weeks, did not allow to record a significant difference ($p > 0.05$), between the lengths and diameters of their shell. Snails increased their shell length by 17.39%, 18.22% and 18.68%, respectively for control lots, 2 and 3. In the same order, the shell diameter increased by 14.55%, 14.42% and 14.68%. During the re-feeding phase where all batches of snails are fed at the same level as the control batch, the increase in measurements was less obvious and still without significant difference ($p > 0.05$) between the different batches. The mean increase in shell length was 8.77%, 8.51% and 8.12% for control lots, 2 and 3, respectively. In the same order, that of the diameter of the shell was 7.74%, 9.55% and 9.4%. However, there is a slight superiority (of more than a point and a half), although not significant ($p > 0.05$), in the diameter of the shell in snails previously subjected to feed restriction. The increase in length and diameter of the snail shell was found to be significantly less during the re-feeding phase than during the feed restriction phase. Shell development was slowed by approximately 50% between the feed restriction phase and the re-feeding phase.

Table 2. *Measurement of the shell of giant African snails of the species Archachatina marginata.*

Feed level	**Test phases**											
	Restriction phase (10 weeks)						**Re-feeding phase (10 weeks)**					
	Length (cm)			**Diameter (cm)**			**Length (cm)**			**Diameter (cm)**		
	L_0	**L_{10}**	**%**	**D_0**	**D_{10}**	**%**	**L_{10}**	**L_{20}**	**%**	**D_{10}**	**D_{20}**	**%**
Lot1 (100%)	$6.9^a±0.49$	$8.1^a±0.54$	17.4^a	$4.4^a±0.24$	$5.04^a±0.27$	14.55^a	$8.1^a±0.54$	$8.8^a±0.51$	8.77^a	$5.04^a±0.27$	$5.43^a±0.26$	7.74^a
Lot2 (85%)	$6.86^a±0.46$	$8.11^a±0.43$	18.2^a	$4.3^a±0.28$	$4.9^a±0.32$	14.42^a	$8.11^a±0.43$	$8.8^a±0.25$	8.51^a	$4.9^a±0.32$	$5.4^a±0.31$	9.55^a
Lot3 (70%)	$6.85^a±0.51$	$8.13^a±0.5$	18.7^a	$4.4^a±0.26$	$5^a±0.29$	14.68^a	$8.13^a±0.5$	$8.8^a±0.46$	8.12^a	$5^a±0.29$	$5.5^a±0.3$	9.4^a

Values in the same column with the same superscript letters are not significantly different at the 5% threshold

L0: Length at the start of the restriction; L10: Length at end of restriction (10 weeks); D0: Diameter at the start of the restriction; D10: Diameter at the end of the restriction (10 weeks); L20: Length at the end of re-feeding (20 weeks); D20: Diameter at the end of re-feeding (20 weeks); %: Increase.

4. Discussion

Giant African snails of the species *Archachatina marginata* subjected to qualitative dietary restriction in a controlled environment showed variable performance in relation to the level of diet. The main zoo technical parameters recorded, such as food consumption, weight and shell growth have been shown to be more or less in line with those obtained with other authors.

4.1. Feed Consumption

The feed consumption of snails was found to be inversely proportional to the energy and protein concentration of the ration. The more the ration is deficient in energy and protein, the more the snails tend to consume feed, which ultimately improves their ability to ingest. This ingestion capacity may have been favoured by the relatively high crude fibber content of the low protein and energy rations. As [27] on broilers, a ration rich in vegetable fibbers participates in the development of the gastrointestinal complex, thus improving the feed ingestion capacity of animals. By trying to ingest more feed, snails thus try to fill the nutritional deficit to which they are subjected. The strategy of qualitative feed restriction thus offers the advantage of enhancing feed resources of low nutritional value while increasing the capacity of animals to ingest more feed, guaranteeing high performance. It is known that monogastric animal species orient their feed consumption according to the energy and protein density of the ration. Giant African snails, mainly phytophagous, nevertheless need balanced diets rich in energy, proteins and minerals to ensure optimal and regular production [2, 23, 19]. The average daily feed intake recorded in the present study was found to be almost double that obtained by [20] on subjects of the *Achatina Achatina* species weighing on average 52 g and fed a concentrated ration in the form of flour containing 12% calcium. In fact, the authors obtained an average daily intake of 0.6 g against 1.2 g for the control batch without nutritional restriction in the present study. For their part, [14] recorded on juvenile *Archachatina marginata* weighing on average 10 g and fed with feed concentrate over a period of 18 weeks, an average daily intake of 0.22 g. The relatively high dietary intake in the present study may have been boosted by the drinking water permanently made available to the snails. Drinking water is indeed one of the factors that greatly influences feed intake. Its prolonged deprivation can lead to complete cessation of feed intake in snails [15]. For their part, [23] recorded an ingestion of feed concentrate of between 0.78 and 1 g in adult subjects of the *Achatina fulica* species. During the re-feeding phase, the average daily feed intake was, at approximately 1.5 g, almost identical for all batches of snails. Those previously subjected to dietary restriction ended up adjusting their consumption to the energy and protein density of the ration during the re-feeding phase. The ingestion capacity forged during the feed restriction phase was maintained during the first few weeks of the re-feeding phase. Similar feeding behaviors have been observed by [13] on ruminants. Ultimately, it appears that over the entire period of the test, the feed intake of the re-fed snails, although tending to be higher than that of the control snails, did not in any way generate more energy and protein expenditure in the ration.

4.2. Weight Growth

As might be expected, the energy and protein nutritional restriction applied to snails clearly affected their weight growth. The more severe this restriction, the slower the snails gained weight. Not being able to find enough protein and energy in their ration to ensure optimal synthesis of organic tissues, these snails were forced to a much more moderate growth rate compared to that of the controls. An energy and protein restriction in the order of 30% caused a weight growth retardation of more than 50% after 10 weeks of feeding. The energy and protein value of the ration is thus found to be decisive in the diet of *Archachatina marginata* snails for optimal and regular weight growth. Like all monogastric animal species, the giant African snails of the species *Archachatina marginata* depend on a diet rich and balanced in essential nutrients to fully express their production potential. [16] showed that in *Archachatina ventricosa* snails, the feed concentrate rich in protein and energy gave better weight and reproductive performance compared to a diet exclusively based on fruit and vegetables. Lack of essential nutrients, such as energy and protein, especially essential amino acids, in the ration, causes a slowdown in basic metabolic activities. This results in a reduction in energy expenditure, thus limiting the synthesis of organic tissues. According to [13], the decrease in overall energy expenditure can be explained by a decrease in the size and weight of tissues and / or a decrease in metabolic activity per unit of weight for all or part of the tissues. [14] highlighted the importance of a feed concentrate rich in energy and protein on the weight performance of *Archachatina marginata*. These authors recorded average daily weight gains of 0.22 g versus 0.10 g in subjects fed exclusively on papaya. The average daily gain of regularly fed snails in the present study was found to be slightly higher, for a fairly similar ration energy density and a slightly higher crude protein content, compared to the study conducted by the above-mentioned authors. This provides information on the ability of snails of the species *Archachatina marginata* to express their growth potential in captivity, if the breeding conditions, in particular the feed and nutritional conditions are satisfactory. Diet and environmental conditions, in particular relative humidity, are factors that may hinder the weight growth of *Archachatina marginata*. A slowdown in the weight growth of *Archachatina marginata* can occur naturally, if the animals go through a period of aestivation in which maintenance energy expenditure is kept to a minimum. It is possible that the slowing of weight growth in relation to the severity of the nutritional restriction reaches a critical threshold detrimental to the viability of snails if the duration of the restriction should be prolonged beyond the limit ensuring an energy and protein balance positive. The resumption of a satisfactory diet that meets the physiological needs of snails is accompanied almost spontaneously by an accelerated rate of weight growth. This growth is all the more accelerated as the extent of the previous nutritional restriction had been significant. The basal energy metabolism of the snails, which had remained low throughout the period of nutritional restriction, gradually recovered during the period of re-feeding. This transitional phase has proven to be favourable for an efficient use of the nutrients contained in the feed ration. Indeed, for an equivalent feed intake, the re-feeded snails showed significantly higher weight gains than the regularly fed controls. This phenomenon known as compensatory growth observed in many animal species is used as a strategy to obtain better feed and nutritional efficiency.

4.3. Shell Measurement

The different energy and protein concentrations of the ration did not have a remarkable effect on the development of the shell of *Archachatina marginata* snails as was the case with weight growth after ten weeks of testing. The shell, however, experienced an almost identical increase over time in all batches of snails despite the different rations ingested. Obviously, the shell growth of *Archachatina marginata* depends on the calcium content of the feed available to them. The different feed rations with fairly similar calcium contents in the present study produced shells with almost identical measurements. This study showed that *Archachatina marginata* showed significantly greater shell growth during the first 10 weeks of testing, regardless of feeding level. Shell growth during the second period of the trial was found to be less important. Thus, we can see that the *Archachatina marginata* proceed to an acceleration of their shell growth during their young age. The same observation was reported by [25]), according to whom, *Archachatina marginata* performs most of the extension of its shell before sexual maturity. Snail shell length grew faster than diameter during the first period of feed restriction. This morphometric dimorphism was considerably reduced during the second period of testing, to the point where, in the re-feeded subjects, the shell diameter increased more significantly compared to that of the control subjects. This more or less bulbous form of the shell is characteristic of the species *Archachatina marginata*. As the snail shell is composed almost exclusively of calcium carbonate, the process of its enlargement is mainly based on the level of availability of calcium in the feed but also in the substrate. According to [2], snails get about 40% of their calcium requirements from the soil they live in using their foot sole. The influence of the calcium content of the feed and that of the substrate on the shell growth of snails of the species *Archachatina marginata* and *Achatina achatina* was tested respectively by [2] and [5]. The authors showed that beyond a certain level, the shell growth of snail can stop or even regresses. As for [20], they reported that at a ration calcium content greater than 12.02% *Achatina achatina* produced more shell than edible flesh. The calcium content of between 4 and 5% in the different rations used during the present study, did not cause any disturbance in the development of the shell of *Archachatina marginata.*

5. Conclusion

The qualitative and periodic dietary restriction of giant African snails of the species *Archachatina marginata* reared in a controlled environment has shown to be a promising strategy for the efficient use of the increasingly scarce feed resources. The more severe the restriction, the more the snails exhibited a significantly higher growth rate during subsequent re-feeding. However, a ten-week re-feeding period was clearly not enough to fully compensate for a delay in weight growth induced by a diet highly deficient in protein and energy. A dietary restriction of around 15% and 30% in protein and energy allowed the snails to achieve only a respective weight compensation of 61.92% and 48.23% compared to the controls.

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