Environ Monit Assess (2025) 197:2
https://doi.org/10.1007/s10661-024-13449-6

RESEARCH

Site properties for snail farming: the role of environmental factors and soil profiles in *Cornu aspersum* mineral content

Meryem Yeşim Çelik · Saniye Türk Çulha · Mehmet Bedrettin Duman · Can Okan Altan · Gülşen Uzun Gören · Bayram Köstekli

Received: 17 September 2024 / Accepted: 16 November 2024 / Published online: 2 December 2024

Abstract The research aims to emphasize the importance of site selection in snail farming by examining how differences in environmental variables and regional characteristics influence the mineral content of *Cornu aspersum* snails. This is achieved through a comparative analysis of the mineral contents in their muscle tissue and shells, including calcium, potassium, phosphorus, magnesium, sodium, ash, and dry matter, across two locations in the Black Sea region: Fatsa (F) and Sinop (S). The study found that snails allocate resources based on available calcium to strengthen their shells for survival. Snails in Fatsa, with high sodium intake, may be unhealthy and suffer from dehydration, and the quality of their meat appears poor due to unfavorable calcium-to-phosphorus and sodium-to-potassium ratios. In Sinop, higher calcium and inorganic content in shells provided hardness, while high calcium in meat caused toughness. These findings underscore the significance of understanding and managing soil profiles for sustainable snail farming, thereby informing site selection and optimizing conditions for growth and nutritional quality.

Keywords *Cornu aspersum* · Ground · Elemental composition · Surrounding condition

M. Y. Çelik (✉) · G. U. Gören · B. Köstekli
Department of Seafood Processing Technology, Fisheries Faculty, Sinop University, Akliman, Sinop, Turkey
e-mail: yesimcelik@sinop.edu.tr

G. U. Gören
e-mail: gulsenuzn@hotmail.com

B. Köstekli
e-mail: bkostekli@sinop.edu.tr

S. T. Çulha
Department of Hydrobiology, Fisheries Faculty, İzmir Kâtip Çelebi University, Çiğli, Izmir, Turkey
e-mail: trksanye@gmail.com

M. B. Duman · C. O. Altan
Provincial Directorate of Agriculture, Ministry of Agriculture and Forestry, Rize, Türkiye
e-mail: duman40mehmet@gmail.com

C. O. Altan
e-mail: okanaltan@hotmail.com

Introduction

The rapid growth of the human population and increasing living standards have placed great pressure on existing animal sources. In recent years, many solutions have been explored to close protein gaps while providing an environmentally friendly and cost-effective protein source. Heliculture is one of these methods and is considered an environmentally friendly production method with high nutritional value. The garden snail (*Cornu aspersum*; synonyms: *Helix aspersa*, *Cantareus aspersus*) is the most commonly cultivated species. In the 2022 report by "Global Market Insights," the valuation of the snail market was identified at 593.4 million USD, with the *Helix aspersa* species contributing almost 40% (236 million USD) of this figure. Projections estimate that from 2023 to 2032, the market will experience a compound annual growth rate (CAGR) exceeding 10.33%, driven by rising demand (GMI, 2023).

With an increasing focus on healthy and sustainable food options, snails are notable for being low in fat and high in protein, and their rich nutritional content makes them more attractive. The *Cornu aspersum* snail is highly popular in Spain as part of Mediterranean gastronomy and is known in Catalan and Spanish as the "*Caragol Bover snail*" (Mourenza 2018). In Italy, *Helix aspersa* stands out as the most economically efficient and delicious edible snail species to cultivate, considering the balance of cost and yield. Besides *Helix aspersa*, other species such as the Burgundy snail (*Helix pomatia*) and rigatella (*Helix vermiculata*) are also cultivated. From 2010 to 2019, there was a remarkable increase in snail consumption, with figures soaring by approximately 320% (Bord Bia, 2022).

Understanding the relationship between snails and their environment and assessing the impact of this relationship on the quality of livestock are important. The mineral content of the soil in the environment is a crucial criterion for land snails. The concentrations of minerals available in different soil types depend on the concentrations in the parent rock and soil chemistry. As a result, under certain conditions, herbs may be deficient or imbalanced in some trace minerals (Govasmark et al., 2005). Therefore, maintaining a mineral balance is essential for species such as *C. aspersum* whose habitat and diet are soilbound.

Numerous studies have been conducted on land snails investigating different soil parameters. Among these parameters, the calcium (Ca) content and its correlation with pH were identified as the most significant factors (Iglesias & Castillejo, 1999). The calcium concentration in food plants and surrounding soil can be assessed in land snails. Snails may actively regulate their diet to optimize calcium uptake (Chevalier et al., 2003; Kroonenberg, 1995). In natural populations, the soil is an essential part of the diet of land snails. Many studies have focused on the role of calcium in shell building, and calcium was confirmed to be the primary factor determining both the richness and density of snail populations (Iglesias & Castillejo, 1999). Land snails living in environments with low lime contents and acidic soils face limitations due to their calcium deficiency. Access to calcium is essential not only for shell formation but also for reproduction and various physiological processes, such as alkaline-acid balance and a permeable cell membrane (De Almeida Araújo et al., 2023; Iglesias & Castillejo, 1999; Otchoumou et al., 2012). The majority of the shell mass of land snails is composed of calcium carbonate, but magnesium (Mg) is also present in the crystalline structure of the shell (Fournié & Chétail, 1984). In addition to calcium and magnesium, sodium (Na) and potassium (K) are also essential for normal cellular function (Fijałek et al., 2003).

Soil moisture is a crucial factor influencing mollusc species richness, especially in arid habitats where it frequently serves as a limiting factor for most species (Martin & Sommer, 2004). Land snails are also well known as indicators of long-term habitat continuity at the landscape level, in addition to soil reactions, litter depth, dead wood, and various vegetation types (Müller et al., 2005).

Successful snail breeding requires an understanding of how environmental factors and soil structure affect snails. The soil structure significantly contributes to success. In this regard, our study emphasised the importance of site selection in snail farming by investigating several research questions related to this issue. The present study aimed to answer the following question: Do differences in soil composition cause variations in the levels of minerals such as calcium, magnesium, potassium, phosphorus, and sodium found in the meat (foot and visceral) and shells of *C. aspersum* collected from two geographical areas, Fatsa (F) and Sinop (S). By examining the mineral content of snails in environments with different characteristics, this study underscores the significance of understanding and managing soil profiles for sustainable snail farming, thereby enabling optimal site selection and farming practices.

Materials and methods

The brown garden snail *Cornu aspersum* (synonyms: *Helix aspersa*; *Cantareus aspersus* Müller, 1774) (Gastropoda: Pulmonata) was collected from two locations in the Black Sea (Turkey): Fatsa, Kabakdağı location (40°57′31.95″N 37°32′8.39″E) in Ordu and from the center of Sinop (42°1′2.34″ N, 35° 8′4.32″ E) (Fig. 1).

The distance between the Fatsa and Sinop sites was approximately 270 km. Environmental data, including

Fig. 1 Study area

altitude, temperature, precipitation, and humidity, were sourced from climate records over several years (https://tr.climate-data.org/). At the Fatsa site, the altitude ranges from 280 to 300 m. The vegetation is characterized as sparse wild, with an average temperature of 11.60 °C, precipitation totalling 56 mm, and relative humidity at 79%. In contrast, the Sinop site is situated at a much lower altitude of 1 to 2 m. The vegetation there is denser and more diverse. The average temperature at Sinop is higher at 13.73 °C, with significantly more precipitation, measuring 112 mm. The humidity at this site is slightly lower at 76%. These environmental differences between the two locations may contribute to variations in the biometric measurements of snails observed in the study.

Sampling locations were selected based on the natural abundance or absence of snails in the region. In the natural habitat of F, no live land snails were found, but a few empty shells were found. Land snails were introduced into habitat F when they were 2 months old and were collected for analysis when they reached maturity. In contrast, habitat S contains a diverse community of land snails, and the study was conducted on the snails already present in region S. Fifty adult snails were gathered at each location, including individuals with shell lengths of 27 and 30 mm (possessing a lip shell). Adult snails were distinguished by examining their outwardly reflected apertural margins. Concurrently, soil samples were collected from the same locations where the snails were identified. The soil samples were taken from a surface depth of 3 cm, covering an area of approximately 20 cm × 20 cm. This was done in order to obtain a representative sample of the soil from the area where the snails were found. In the following collection, the snails and soils were organized based on location. The shell height, shell weight, and live weight were measured using an electronic balance. The snails were weighed to the nearest 0.001 g. After inducing mortality by storing the snails in a refrigerator at − 20 °C for several hours, the shells and meat were carefully separated.

The analysis for the ash, dry matter, and mineral (Ca, Mg, K, P, Na) contents in snail shell, meat, and soil for both F and S snails was repeated thrice, and their averages were used for data analysis. The AOAC (1993) method was employed to determine the ash and dry matter contents, while Bernhard (1976) and Yap et al. (2004) methods were utilized for the digestion process. At Izmir Kâtip Celebi University Central Research Laboratory Application and Research Center, metal measurements using microwave digestion and ICP-MS (Agilent 7700X) were carried out.

Shell hardness of the snails (sfrc-sh) was measured using the method described by Svihus et al. (2004) in a stable microsystem texture analyzer (Brookfield Texture Analyser CT3, Brookfield Engineering Lab., MA, USA). All samples were placed between the pressure piston and the bar at each site. The force required to fracture the shell was determined by progressively increasing the pressure applied by the pressure piston. A Brookfield CT3 texture analyzer from the USA was used for texture analysis. Texture profile analysis (TPA) was also conducted as part of the mechanical analysis. For the TPA, a cylindrical probe with a diameter of 2.7 cm was used. In the TPA, the device parameters were configured as follows: 60% target, 0.05 N trigger load, 0.50 mm/s test speed, 2 mm/s pretest speed, 20 points/s data rate, and a 50 kg load cell. The TPA parameters consisted of hardness (hrd-me) and cohesiveness of snail meat (coh-me).

The transfer factor (TF), also known as the bioconcentration factor or bioaccumulation factor (Adediran et al., 2003), expresses the capability to accumulate an element from the soil to snail meat or from the soil to the snail shell. The ratio of a specific element's concentration in a snail's tissue to its concentration in the soil is referred to as the "transfer factor" (TF). TFs are utilized to investigate elemental transport from the soil to the snail flesh and shell in F and S habitats. The results of the study were analyzed based on the physical condition of the snails. The formula used to calculate TF is as follows:

$$TF(\mathrm{mg/kg}) = {}^{\text{Concentration of an element in snail tissue}}\Big/_{\text{Concentration of an element in soil}} \quad (1)$$

Statistical analysis

Analysis was performed using MINITAB 19 (Minitab, Inc., State College, PA, USA) and Past 4.10 software. At a significance level of $P<0.05$, the data are expressed as the mean and standard error of the mean and were tested for variance homogeneity. One-way ANOVA was used to compare mean values between locations. Pearson's correlation test was used to examine the relationships among the minerals in the meat, shell, and soil at each location. The principal component analysis (PCA) was used to explore the dataset structure and obtain more information on the variables that mainly influence sample similarities and differences between snail tissues in the F and S habitats. The study used two different approaches to PCA: (i) for each region separately, we were able to assess the relationships between the snail and soil samples within each region, and (ii) for both regions together, we could compare regional differences and similarities.

Results

Biometric measurements

The analysis of biometric measurements (shell height, live weight, wet meat weight, and shell weight) of snails from the Sinop and Fatsa sites revealed that Sinop snails were significantly larger ($P<0.01$) with an average shell height of 30.11 mm, live weight of 7.36 g, shell weight of 1.37 g, and wet meat weight of 4.73 g than their Fatsa counterparts with an average shell height of 27.21 mm, live weight of 4.69 g, shell weight of 0.75 g, and wet meat weight of 3.04 g.

Mineral matter

The values of Ca, Na, Mg, K, P, ash, and dry matter (DM) for each station are given in Table 1. The DM and ash contents of the meat and shell of individuals from F were lower than those from S ($P<0.01$). All mineral values without Ca and K for the shell were

Table 1 The values (mg/100 g) of Ca, Na, Mg, K, dry matter of meat (%), and dry matter and ash values of soil, meat, and shell (%) are shown with standard errors

		Ca	*Na*	*Mg*	*K*	*P*	*Ash (%)*	*DM (%)*
Soil	*S*	1374.66 ± 181.48^{a}	458.79 ± 8.37^{b}	272.39 ± 4.36^{b}	637.85 ± 13.36^{b}	992.00 ± 24.05^{b}	92.69 ± 0.07^{a}	99.18 ± 0.10^{a}
	F	554.24 ± 19.30^{b}	223.54 ± 3.72^{a}	31.27 ± 0.40^{a}	282.75 ± 3.97^{a}	23.33 ± 4.04^{a}	83.95 ± 0.02^{b}	98.28 ± 0.06^{b}
Meat	*S*	1796.03 ± 69.25^{a}	459.90 ± 6.87^{a}	243.36 ± 2.62^{a}	601.25 ± 9.08^{a}	853.38 ± 10.28^{a}	95.31 ± 0.05^{a}	17.94 ± 0.02^{a}
	F	165.20 ± 11.69^{b}	1316.07 ± 12.50^{b}	130.02 ± 1.89^{b}	490.98 ± 8.81^{b}	512.97 ± 11.64^{b}	94.18 ± 0.00^{b}	18.46 ± 0.08^{b}
Shell	*S*	$33{,}931.21 \pm 643.05^{a}$	59.66 ± 0.87^{a}	10.57 ± 0.32^{a}	66.72 ± 1.33^{a}	————	8.89 ± 0.04^{a}	99.73 ± 0.03^{a}
	F	$33{,}061.13 \pm 404.34^{a}$	49.52 ± 0.45^{b}	12.38 ± 0.17^{b}	66.08 ± 0.86^{a}	————	8.04 ± 0.01^{b}	99.64 ± 0.03^{b}

Superscript letters indicating the difference between stations were evaluated separately for meat, shell, and soil. Different superscript letters in the same line are significantly different ($P<0.001$). *Abbreviations*: The letters "*S* and *F*" represent the Sinop and Fatsa groups, respectively significantly different for each location ($P < 0.001$). Many studies on the Ca, Mg, K, Na, and P contents of snail meat shells are listed in Table 2.

Transfer factors

The results for the soil-to-snail tissue (meat and shell) factor in F and S snails are summarized in Table 3. High transfer factor values were found for Ca in the snail shells of the S and F habitats, with average values above unity of 24.99 ± 2.88 and 60.29 ± 7.66, respectively. Considering the minerals that enter snail meat, the P and Mg levels in the F habitat are quite high.

Table 2 Mean concentrations (mg/100 g) of Na, Mg, K, Ca, and P in snail meat and shells as reported in the literature (*A. marginata*, *Archachatina marginata*; *A. achatina*, *Achatina achatina*; *A. fulica*, *Achatina fulica*; *P. globosa*, *Pila globosa*; *P. ampullacea*, *Pila ampullacea*; *C. aspersum*, *Cornu aspersum*; *H. aspersa*, *Helix aspersa*; *C. sulcata*, *Cookia sulcata*; *B. spirata*, *Babylonia spirata*; *T. militaris*, *Turbo militaris*; *L. undulata*, *Lunella undulata*; *L. torquata, Lunella torquata*)

	mg/100 g	Snail species	Na	Mg	K	Ca	P
Adeyeye (1996)	Meat	*A. marginata*	196.24	46.33	44.18	212.38	0.64
		Achatina sp.	181.87	37.79	49.88	188.96	215.48
		Limicolaria sp.	53.83	18.91	72.82	22.24	183.35
Fagbuaro et al. (2006)	Meat	*A. marginata*	50.80	45.59	192.78	201.08	123.43
		A. achatina	60.94	46.15	193.74	204.63	131.38
		Limicolaria spp.	65.10	45.99	197.57	28.75	153.84
Babalola and Akinsoyinu (2009)	Meat	*A. marginata*	-	25.01	-	126.40	22.91
		A. achatina	-	19.28	-	106.30	19.01
		A. fulica	-	15.13	-	66.30	14.79
		Limicolaria spp.	-	5.28	-	36.20	8.98
Obande et al. (2013)	Meat	*P. ampullacea*	0.04	31.19	71.13	129.18	60.52
Mason et al. (2014)	Meat	*C. sulcata*	410.00	310.00	280.00	70.00	90.00
Akinnusi et al. (2018)	Shell	*A. marginata*	27.56	139.78	125.75	260.75	196.27
Nkansah et al. (2021)	Meat	*A. marginata*	67.64	308.70	111.43	701.79	268.53
		A. achatina	58.09	304.62	114.65	656.90	241.90
		A. fulica	73.38	301.20	111.02	402.29	61.29
	Shell	*A. marginata*	5.92	50.09	24.95	13,716.09	-
		A. achatina	6.82	65.06	22.32	14,118.53	-
		A. fulica	21.83	119.71	26.41	14,375.28	-
Moniruzzaman et al. (2021)	Meat	*P. globosa*	300.00	25.70	2020	1739.00	245.00
Aouji et al. (2023)	Meat	*H. aspersa*	83.10	187.79	597.11	432.47	577.28
Lusnic et al. (2023)	Meat	*C. aspersum*	51.32	-	-	-	-
Rygało-Galewska et al. (2023)	Meat	*C. aspersum*	5915.44	2948.14	7097.36	1.36	11,109.90
	Shell		1198.09	508.48	806.19	37.99	896.51

Table 3 Transfer factor in snails; element in snail shell or meat (mg/kg)/element in soil (mg/kg)

		Na	*Mg*	*P*	*K*	*Ca*
S	**Shell**	0.13 ± 0.01	0.039 ± 0.00	———	0.01 ± 0.01	24.99 ± 2.88
F		0.22 ± 0.01	0.40 ± 0.02	———	0.23 ± 0.01	60.29 ± 7.66
S	**Meat**	1.01 ± 0.09	0.90 ± 0.06	0.86 ± 0.07	0.95 ± 0.09	1.34 ± 0.29
F		0.22 ± 0.01	4.16 ± 0.02	22.61 ± 4.44	1.74 ± 0.14	0.30 ± 0.03

Abbreviations: The letters "*S* and *F*" represent the Sinop and Fatsa groups, respectively

Texture analyses and strength of shell

The results of shell hardness as a shear force (sfrc-sh) were 39.11 ± 4.35 N in Sinop and 19.12 ± 2.02 N in Fatsa. The difference in the means between stations was statistically significant ($P < 0.001$). Texture profile analysis (TPA) revealed that the hardness and cohesiveness of the snail meat were 8.21 ± 0.11 and 0.22 ± 0.01 in S and 7.33 ± 0.30 and 0.16 ± 0.01 in F. The results are significantly different ($P < 0.001$).

Correlation and PCA results

The correlation table (Table 4) illustrates the statistical relationships present in the large dataset. In the S and F habitats, a strong relationship was indicated by correlation values of 0.9.

The present study used two different approaches to PCA: (i) for each region separately, we were able to assess the relationships between the snail and soil samples within each region, and (ii) for both regions together, we could compare regional differences and similarities. The basic patterns were captured by the biplots of this study (Fig. 2), as observed by Kroonenberg (1995). The S biplot exhibited the most significant variations in sfrc-sh, hrd-me, coh-me, and Ca, while the F biplot showed variations in sfrc-sh, hard-me, coh-me, Ca, and K, as indicated by the respective vector lengths. The patterns of the F and S biplots are nearly the same without Na and K.

The most prominent relationships revealed by these biplots are (i) the strong positive association between sfrc-sh and Ca (between Mg, P, Na, and K for the S biplot) and the positive association between sfrc-sh and Ca (between Mg, P, and K for the F biplots), as indicated by the acute angles between their vectors; (ii) the negative association between Ca and K, Ca being closely correlated with sfrc-sh, as indicated by the large obtuse angles for the F biplot; and a negative association between Ca and K, being closely correlated with Na and Ca being closely correlated with sfrc-sh for the S biplot. In addition, the comparison of regional differences and similarities was facilitated by conducting PCA for sites S and F together. At both sites, a strong positive relationship was found between the SFRC and Ca concentrations in the snail shells. Mg and P levels were significantly greater and correlated with snail meat in both regions (Fig. 2).

The total variation for the F and S sites was separately derived from two principal component axes, whereas the total variation for both sites together was derived from five principal components.

The eigenvalues, variability values (%), and cumulative values (%) are shown in Table 5. The eigenvalues of all three evaluations for PC1 are greater than 1, indicating that the evaluated principal component weight values are reliable (Mohammadi & Prasanna, 2003). The magnitude of the loading values indicates which variables or features have a greater or lesser impact on key components. According to the F loading data, in the first principal component, Ca, Mg, Na, K, and P had the highest coefficients, whereas hrd-me, coh-me, and sfc-sh had the highest coefficients in PC2 for the F loading data. When the S loading data were analyzed, Mg, Na, K, and P had the highest values in PC1, and Ca, hrd-me, coh-me, and sfc-sh had the highest coefficients in PC2. However, when evaluating the sites together, the highest coefficients were for hrd-me and coh-me in PC2, for Mg and Ca in PC3, for Na in PC4, and for sfrc-sh in PC5.

However, there was a variation of more than 80% for each PC1 value. It could be argued that some of the loads are highest on PC3, PC4, and PC5, which better reflects the relationships between these variables within the general dataset. However, for differences less than 3%, the relationships were considered insignificant.

Discussion

Land snails are capable of evaluating calcium concentrations in both their food sources and soil (Chevalier et al., 2003). They actively regulate their diet to optimize calcium absorption (Kroonenberg, 1995). Soil plays a crucial role in the diet of snails in natural populations (Baur et al., 2009). In the present study, the stations selected for the research were located in areas with different climatic structures, vegetation, and soil qualities. The vegetation at Fatsa station (F) comprises sparse wild grasses. It has been noted that there are no living land snails in their natural habitat, and only a few lifeless land snails have been found. The calcium content of the F soil (554 mg/100 g) was 73.53% lower than that of the soil at the Sinop station (S). Moreover, the Mg content was 86% lower than that

Table 4 The relationships between the results of correlation analyses

Sinop				Fatsa			
Sample 1	Sample 2	Correlation	*P* value	Sample 1	Sample 2	Correlation	*P* value
Na-me	Na-sh	−0.595	0.025	K-sh	Na-sh	0.805	0.001
Mg-me	Na-sh	−0.854	0.000	Na-me	Mg-sh	−0.569	0.034
P-me	Na-sh	−0.755	0.002	Mg-me	Mg-sh	−0.641	0.014
Ca-so	Na-sh	0.820	0.000	K-me	Mg-sh	−0.554	0.040
Coh-me	Na-sh	−0.642	0.013	P-me	Mg-sh	−0.878	0.000
DM-so	Na-sh	0.542	0.045	DM-me	Mg-sh	−0.852	0.000
Ca-sh	Mg-sh	0.857	0.000	Ca-sh	K-sh	0.578	0.030
Na-me	Mg-sh	−0.896	0.000	Ca-me	Ca-sh	−0.759	0.002
K-me	Mg-sh	−0.911	0.000	Ca-so	Ca-sh	−0.850	0.000
Ca-me	Mg-sh	−0.920	0.000	P-so	Ca-sh	−0.519	0.057
Ca-me	K-sh	−0.557	0.039	Mg-me	Na-me	0.530	0.051
K-so	K-sh	0.631	0.016	K-me	Na-me	0.607	0.021
Hrd-me	K-sh	0.564	0.036	P-me	Na-me	0.615	0.019
DM-me	K-sh	0.753	0.002	DM-me	Na-me	0.651	0.012
Na-me	Ca-sh	−0.778	0.001	DM-so	Na-me	0.704	0.005
K-me	Ca-sh	−0.645	0.013	K-me	Mg-me	0.965	0.000
Ca-me	Ca-sh	−0.753	0.002	P-me	Mg-me	0.912	0.000
Na–so	Ca-sh	0.850	0.000	P-so	Mg-me	−0.646	0.012
Mg-so	Ca-sh	0.634	0.015	Coh-me	Mg-me	0.517	0.058
Ca-so	Ca-sh	0.660	0.010	DM-me	Mg-me	0.614	0.020
Sfrc-sh	Ca-sh	−0.655	0.011	DM-so	K-me	0.540	0.046
Mg-me	Na-me	0.580	0.030	Mg-so	Ca-me	−0.628	0.016
K-me	Na-me	0.937	0.000	Ca-so	Ca-me	0.946	0.000
Ca-me	Na-me	0.719	0.004	P-so	Ca-me	0.837	0.000
Ca-so	Na-me	−0.761	0.002	P-so	P-me	−0.528	0.052
P-me	Mg-me	0.929	0.000	DM-me	P-me	0.832	0.000
Ca-so	Mg-me	−0.746	0.002	Mg-so	Na–so	0.891	0.000
P-so	Mg-me	−0.552	0.041	K-so	Na–so	0.905	0.000
Sfrc-sh	Mg-me	0.628	0.016	K-so	Mg-so	0.656	0.011
Ca-me	K-me	0.812	0.000	P-so	Mg-so	−0.617	0.019
Ca-so	K-me	−0.574	0.032	P-so	Ca-so	0.639	0.014
Ca-so	P-me	−0.546	0.043	DM-so	DM-sh	0.616	0.019
P-so	P-me	−0.720	0.004	Ash-me	DM-sh	0.998	0.000
Mg-so	Na–so	0.891	0.000	Ash-shl	DM-sh	0.996	0.000
Hrd-me	Na–so	−0.536	0.048	Ash-so	DM-sh	−0.851	0.000
Sfrc-sh	Na–so	−0.752	0.002	Ash-me	DM-so	0.659	0.010
K-so	Mg-so	0.682	0.007	Ash-shl	DM-so	0.548	0.042
P-so	Mg-so	−0.617	0.019	Ash-so	DM-so	−0.938	0.000
Hrd-me	Mg-so	−0.493	0.073	Ash-shl	Ash-me	0.990	0.000
P-so	K-so	−0.676	0.008	Ash-so	Ash-me	−0.879	0.000
Coh-me	K-so	0.549	0.042	Ash-so	Ash-shl	−0.804	0.001
DM-so	Ca-so	0.744	0.002				
Sfrc-sh	Hrd-me	0.658	0.011				
Ash-me	DM-sh	−0.954	0.000				

Table 4 (continued)

Sinop				Fatsa			
Sample 1	Sample 2	Correlation	*P* value	Sample 1	Sample 2	Correlation	*P* value
Ash-shl	DM-sh	0.944	0.000				
Ash-so	DM-sh	0.979	0.000				
Ash-shl	Ash-me	−0.801	0.001				
Ash-so	Ash-me	−0.995	0.000				
Ash-so	Ash-shl	0.857	0.000				

Abbreviations: me, meat; *sh*, shell; *so*, soil; *hrd*, hardness; *DM*, dry matter; *sfrc*, shear force; *coh*, cohesiveness

in the S soil. The K and especially the P content in the soil at F was found to be lower than that at S. This result could be an indication of soil acidity at F and support the argument that land snails are absent from their natural habitat. Yan and Hou (2018) reported that low Mg and Ca contents in soil affect the amount and quality of vegetation in the environment. Low soil levels (or high acidity) may exclude *Cantareus aspersus* snails from some habitats or limit the fecundity of resident populations (Crowell, 1973). In contrast to calcium-poor soils, calcium-rich soils typically exhibit greater snail abundance, species diversity, and biomass, as reported by various studies (Iglesias & Castillejo, 1999; Ondina, 2004). In the present study, the snails in F were believed to have a lower meat weight and greater adult size because they did not find much greenery in the area where they eat. Thus, it was concluded that the snails may have consumed more soil to provide the mineral reserves they needed. The growth of *H. aspersa* is significantly influenced by the vegetation and soil conditions consumed, as demonstrated by Egonmwan's findings (Egonmwan, 2008). Soil carbonates and calcium support snail growth, whereas high levels of exchangeable calcium and magnesium in soil are favorable. Okpeku and Omueti (2003) reported that snails grow better when calcium is obtained from the soil than from other sources.

In our current study, it is thought that snails growing in low-calcium soils primarily use the calcium they absorb from soil and food to develop their shells. There was no significant difference in the amount of calcium in the shells of the S and F snails. However, the difference in the amount of calcium in their meat was 90%. These differences are thought to arise primarily from the need for snails to allocate resources between the shell and soft tissue, depending on resource availability and the costs and benefits of growth in both components.

Based on our transfer factor analysis, we found that the rate of calcium transfer from soil to snail flesh in the F region was 60.29, which was significantly greater than that in the S region (24.99). The transfer factor data from snails in the F region, characterized by low soil calcium levels, indicate that these snails have evolved to efficiently concentrate calcium, emphasizing its critical role in their survival. Specifically, the findings highlight that strengthening shells is a primary concern for *Helix aspersa* snails, and they adjust their resource allocation strategies based on the amount of available calcium. Shelled gastropods strongly depend on calcium (Ca), a major macronutrient constituent of their body (Dallinger et al., 2001). In addition to reinforcing the shell, Ca is critical for various functions in soft tissue metabolism and reproduction (Porcel et al., 1996). In calcium-rich environments, rapid growth is desirable to support soft tissues, whereas in calcium-poor environments, shell formation is prioritized, and soft tissues may be depleted (Beeby & Richmond, 2007; Müller et al., 2005).

Interestingly, in the present study, the Na concentration in the soil of the F site was significantly lower than that in the control site, whereas the Na concentration in the snail meat was significantly greater at the F site. The reasons for this phenomenon are as follows, as explained by Greenaway (1970): (i) There was a significant initial loss of sodium when the snails were placed in an environment with a low external sodium concentration. This initial loss of sodium triggered the increased activity of the sodium uptake mechanism. This led to a period of net sodium intake in which the snails absorbed more sodium

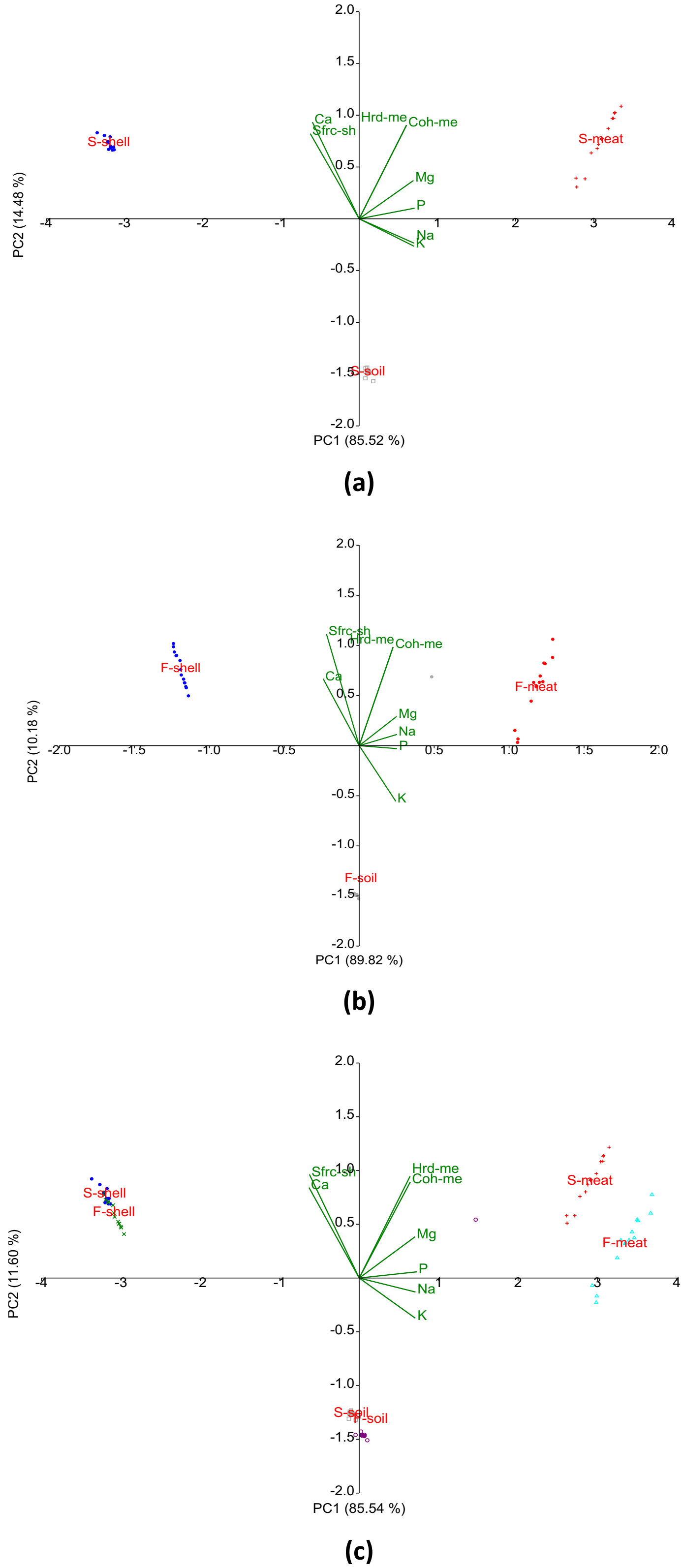

Fig. 2 The distributions of Ca, Mg, P, K, Na, Sfrc-sh, and Coh-me for regions S (**a**) and F (**b**) individually and together (**c**) according to the principal component analysis (PCA) biplots

Table 5 PCA results as eigenvalues, percent variance, and cumulative values of PCA loading of the Ca, Mg, Na, K, and P contents of the examined snail tissues (meat and shell) and soil samples, depending on S and F location, separately and together

	Fatsa		Sinop		Fatsa and Sinop				
	PC 1	PC 2	PC 1	PC 2	PC1	PC2	PC3	PC4	PC5
Eigenvalue	7.185	0.815	6.841	1.159	6.842	0.928	0.210	0.012	0.006
% variance	89.819	10.181	85.518	14.482	85.535	11.601	2.632	0.158	0.074
Cumulative	*89.819*	*100.000*	*85.518*	*100.000*	*85.535*	*97.136*	*99.768*	*99.926*	*100.000*
Na	0.372	0.055	0.378	0.126	0.371	0.068	0.460	0.597	0.447
Mg	0.369	0.145	0.373	0.198	0.368	0.201	0.399	0.110	0.053
K	0.361	0.276	0.377	0.142	0.370	0.195	0.321	0.402	0.388
Ca	0.355	0.332	0.321	0.502	0.331	0.441	0.547	0.356	0.490
P	0.373	0.014	0.381	0.055	0.379	0.030	0.222	0.228	0.148
Hrd-me	0.334	0.490	0.325	0.486	0.335	0.496	0.016	0.237	0.126
Coh-me	0.334	0.490	0.325	0.486	0.337	0.468	0.280	0.245	0.216
Sfrc-sh	0.323	0.554	0.336	0.442	0.328	0.504	0.310	0.415	0.565

than they could otherwise. (ii) This may be due to increased sodium in the body and decreased body water because of dehydration.

This research allowed us to assess the quality of snail meat by analyzing the mineral content at different locations. The calcium-to-phosphorus ratio was 2.10 in region S and 0.32 in region F. According to Nieman et al. (1992), a ratio above 1 is considered "good," while a ratio below 0.50 is considered "poor." Therefore, the snails in F had a poor Ca/P ratio, indicating poor meat quality. In addition, the sodium/potassium ratio in snail meat was evaluated and found to be 0.76 in region S and 2.68 in region F. Potassium is involved in regulating the body's water content. It has a close relationship with Na and water because of its hygroscopic and fluid-regulating ability. Nieman et al. (1992) recommended a Na/K ratio of 0.60 for the prevention of high blood pressure. Hence, the snails in F do not have a recommendable meat quality.

In our current study, there was a positive relationship between potassium, magnesium, and phosphorus in the meat of snails from stations F and S. Baaij et al. (2015) emphasized the metabolic relationship between potassium, phosphorus, and magnesium in animals. According to the study, P is positively correlated with K and Mg because it is related to their occurrence in animal organisms. K and Mg are the most abundant cations in the intracellular environment and are involved in several metabolic processes. Magnesium is the second most abundant cation in the cell after potassium and plays an important role in biology (Romani, 2007).

The hardness of the snail shell in S was greater than that in F. Although there was no difference in the amount of calcium in the shell between these two sites, it can be assumed that all the inorganic matter in the shell contributes to the strength of the shell. The ash content of a snail shell represents the amount and proportion of inorganic components and carbon compounds in the form of oxides and salts (Ameh, 2006). Many studies have reported the effects of Ca minerals on snail shell strength. Resistance to fragmentation depends on shell strength (Zuschin & Stanton, 2001) which is associated with several intrinsic properties, such as mineralogy, magnesium, and organic content (Martin & Sommer, 2004), and shell size and thickness (Cristini et al., 2021). The scarcity of Ca may result in thinner and more brittle shells (Voelker, 1959). Heavily calcified shells increase shell strength (Beeby & Richmond, 2007). The main component of the shell is calcium carbonate, although magnesium is also a major component of the crystalline structure of the shells. These mineral components are deposited through a reinforcing process (Fournié & Chétail, 1984).

The current study revealed that the hardness and toughness of snail meat from S were greater than those from the other samples. The high calcium content in the meat of the snails in the S region may have caused this situation, which can directly affect the strength and cohesion of the meat. Similarly, De Almeida Arajo et al. (2023) reported that meat texture parameters are strongly related to available Ca levels.

Conclusion

The study points to the crucial role that the environment plays in influencing mineral levels and meeting the physiological needs of snails. The health and nutritional quality of snails are closely linked to the characteristics of their habitat, which directly impacts their growth and development. The main conclusions are briefly presented below:

- The absence of snails may be due to the low calcium and magnesium contents in the soil in the F habitat.
- *Helix aspersa* snails allocate their resources between their shell and soft tissue based on the availability of resources and the costs and benefits of growth. The primary concern for these snails is to strengthen their shells, so they adjust their resource allocation strategies based on the amount of available calcium.
- A study suggested that a very high Na content in snail meat may indicate unhealthy and dehydrated snails.
- The study hypothesized that the quality of snail meat in the F habitat would be poor according to the calcium-to-phosphorus ratio and sodium-to-potassium ratio.
- The higher calcium and total inorganic contents of the shells in the S habitat may have provided a hard shell.
- The high calcium content in the meat of the snails in the S habitat may have caused the hardness and toughness of the snail meat.

Acknowledgements This study was carried out in parallel with project 2021-GAP-SUÜF-0021. No funding influenced the study.

Author contribution Meryem Yeşim Çelik was responsible for the conception and design of the study. Mehmet Bedrettin Duman carried out the sampling. Can Okan Altan, Gülşen Uzun Gören, and Bayram Köstekli conducted the analysis. Meryem Yeşim Çelik and Saniye Türk Çulha performed the data analysis and were involved in drafting the manuscript. All authors reviewed and approved the final manuscript.

Data availability No datasets were generated or analysed during the current study.

Declarations

Ethical approval Each author has read the Instructions for Authors' statement on the "Ethical Responsibilities of Authors" and complied with it as appropriate.

Competing interest The authors declare no competing interests.

References

Adediran, J. A., De Baets, N., Mnkeni, P. N. S., Kienkens, L., Muyima, N. Y. O., & Thys, A. (2003). Organic waste materials for soil fertility improvement in the border region of the eastern cape, South Africa. *Biological Agriculture and Horticulture, 20*, 283–300. https://doi.org/10.1080/01448765.2003.9754974

Adeyeye, E. I. (1996). Waste yield, proximate and mineral composition of three different types of land snails found in Nigeria. International journal of food sciences and nutrition, 47(2), 111-116.

Akinnusi, F. A. O., Oni, O. O., & Ademolu, K. O. (2018). Mineral composition of giant African land snail's (Archachatina marginata) shells from six south West States Nigeria. *Nigerian Journal of Animal Science, 20*(4), 485–489.

De Almeida Araújo, C., Magalhães, A.L.R., De Araújo, G.G.L., Campos, F.S., Gois, G.C., Dos Santos, K.C., De Matos, M.H.T., Do Nascimento, D.B., & Santos, N.S. (2023). Correlation between mineral profile, physical-chemical characteristics, and proximate composition of meat from Santa Ines ewes under water restriction. *Semina: Ciências Agrárias* 44(2),529–548. https://doi.org/10.5433/1679-0359.2023v44n2p529.

Ameh, U. (2006). Standard operating procedure National Agency for Food and Drug Administration and Control (NAFDAC) Boriki, Port Harcourt, Nigeria.

AOAC. (1993). *Official methods of analysis of the association of official analytical chemists* (16th ed.). Association of Official Analytical Chemists.

Aouji, M., Imtara, H., Rkhaila, A., Bouhaddioui, B., Alahdab, A., Parvez, M. K., ... & Bengueddour, R. (2023). Nutritional composition, fatty acids profile, mineral content, antioxidant activity and acute toxicity of the flesh of Helix aspersa Müller. Molecules, 28(17), 6323.

Baaij, J. H. F., Hoenderop, J. G. J., & Bindels, R. J. M. (2015). Magnesium in man: Implications for health and disease. *Physiological Reviews, 95*(1), 1–46. https://doi.org/10.1152/physrev.00012.2014

Babalola, O. O., & Akinsoyinu, A. O. (2009). Proximate composition and mineral profile of snail meat from different breeds of land snail in Nigeria. *Pakistan Journal of Nutrition, 8*(12), 1842–1844.

Baur, A., Nicole, M., & Bruno, B. (2009). Effects of soil type and adult size on mating propensity and reproductive output in two populations of the land snail *Arianta* *arbustorum* (Linnaeus). *Malacologia, 51*(1), 1–11. https://doi.org/10.4002/040.051.0101

Beeby, A., & Richmond, L. (2007). Differential growth rates and calcium-allocation strategies in the garden snail *Cantareus aspersus*. *Journal of Molluscan Studies, 73*(1), 105–112. https://doi.org/10.1093/mollus/eym002

Bernhard, M. (1976). Manual of methods in aquatic environment research. Part 3. Sampling and analysis of biological material, FAO Fish Tech Pap FIRI/ T, Rome, No:158, pp: 123.

Bord Bia, The Irish Food Board. (2022). Global snail market overview. Official Irish Food Board Reports. https://assets.gov.ie/245417/2f1a5c20-4372-483c-829b-097bd4659fc5.pdf Accessed 21 March 2024.

Chevalier, L., Le Coz-Bouhnik, M., & Charrier, M. (2003). Influence of inorganic compounds on food selection by the brown garden snail *Cornu aspersum* (Muller) (Gastropoda: Pulmonata). *Malacologia-Philadelphia., 45*(1), 125–132.

Cristini, P. A., Frontini, P. M., & Ballarre, J. (2021). Shell strength of freshwater molluscs and its implication on preservation potential. *Historiacal Bşology., 33*(11), 2668–2682. https://doi.org/10.1080/08912963.2020.1822355

Crowell, H. (1973). Laboratory study of calcium requirements of the brown garden snail, *Helix aspersa* Müller. *Proc Malacological Soc London., 40*, 491–503. https://doi.org/10.1093/oxfordjournals.mollus.a065244

Dallinger, R., Berger, B., Triebskorn Kohler, R., & Kohler, H. (2001). Soil biology and ecotoxicology. In: Barker, G.M. (ed.). The biology of terrestrial molluscs. CAB International, Wallingford, U.K. 489–525. https://doi.org/10.1079/9780851993188.0489.

Egonmwan, R. I. (2008). Effects of dietary calcium on growth and oviposition of the African land snail *Limicolaria flammea* (Pulmonata: Achatinidae). *Revista De Biologia Tropical, 56*(1), 333–343. https://doi.org/10.15517/rbt.v56i1.5528

Fagbuaro, O., Oso, J. A., Edward, J. B., & Ogunleye, R. F. (2006). Nutritional status of four species of giant land snails in Nigeria. Journal of Zhejiang University Science B, 7, 686-689

Fijałek, Z., Sołtyk, K., Lozak, A., Kominek, A., & Ostapczuk, P. (2003). Determination of some micro- and macroelements in preparations made from peppermint and nettle leaves. *Die Pharmazie, 58*(7), 480–482.

Fournié, J., & Chétail, M. (1984). Calcium dynamics in land gastropods. *American Zoologist, 24*, 857–870.

GMI, Global Market Insights. (2023). Snail market size - By snail type (*Helix aspersa, Helix pomatia, Achatina fulica, Otala lactea, Cornu aspersum*), form (fresh snails, canned snails, frozen snails, dried snails), distribution channel, application, regional outlook & global forecast, 2023 – 2032. Report ID: GMI7103, Published Date: October 2023. https://www.gminsights.com/industry-analysis/snail-market Accessed 22 March 2024.

Govasmark, E., Steen, A., Bakken, K., Strøm, T., & Hansen, S. (2005). Factors affecting the concentration of Zn, Fe and Mn in herbage from organic farms and in relation to dietary requirements of ruminants. *Acta Agriculture Scandinavica Section B, 55*(2), 131–142. https://doi.org/10.1080/09064710510008586

Greenaway, P. (1970). Sodium regulation in the freshwater mollusc *Limnaea stagnalıs* (L.) (Gastropoda: Pulmonata). *Journal of Experimemtal Biology* 53(1), 147–163. https://doi.org/10.1242/jeb.53.1.147.

Iglesias, J., & Castillejo, J. (1999). Field observations on feeding of the land snail *Helix aspersa* Müller. *Changes*. 411–23.

Kroonenberg, P.M. (1995). Introduction to biplots for GxE tables. Department of Mathematics, Research Report 51, University of Queensland.

Lušnic Polak, M., Polak, T., Brglez, N., & Demšar, L. (2023). Snail meat, a newly discovered old source of protein in the human diet. *MESO: Prvi hrvatski časopis o mesu*, *25*(2.), 124–134.

Martin, K., & Sommer, M. (2004). Relationships between land snail assemblage patterns and soil properties in temperate-humid forest ecosystems. *Journal of Biogeography, 31*(4), 531–545.

Mason, S. L., Shi, J., Bekhit, A. E. D., & Gooneratne, R. (2014). Nutritional and toxicological studies of New Zealand Cookia sulcata. *Journal of Food Composition and Analysis, 36*(1–2), 79–84.

Mohammadi, S. A., & Prasanna, B. M. (2003). Analysis of genetic diversity in crop plants salient statistical tools and considerations. *Crop Science, 43*(4), 1235–1248. https://doi.org/10.2135/cropsci2003.1235

Moniruzzaman, M., Sku, S., Chowdhury, P., Tanu, M. B., Yeasmine, S., Hossen, M. N., ... & Mahmud, Y. (2021). Nutritional evaluation of some economically important marine and freshwater mollusc species of Bangladesh. *Heliyon*, *7*(5).

Müller, J., Christian, S., & Torsten, H.(2005). Habitat factors for land snails in European beech forests with a special focus on coarse woody debris. *European Journal of Forest Research* 124(3),233–42. https://doi.org/10.1007/s10342-005-0071-9

Nieman, D. C., Butterworth, D. E., & Nieman, C. N. (1992). *Nutrition* (pp. 237–312). Brown Publishers, Dubuque, USA.

Nkansah, M. A., Agyei, E. A., & Opoku, F. (2021). Mineral and proximate composition of the meat and shell of three snail species. *Heliyon*, *7*(10).

Obande, R. A., Omeji, S., & Isiguzo, I. (2013). Proximate composition and mineral content of the Fresh water snail (Pila ampullacea) from River Benue, Nigeria. *Journal of Environmental Science, toxicology and food technology, 2*, 43–46.

Okpeku, M., & Omueti, J.O. (2003). The role of calcium supplement in the diet of reared snails. Paper presented at 25th Annual Conference of the Nigeria Society for Animal Production Abeokuta, Nigeria. March 22–26, 28:324–326.

Ondina, P., Hermida, J., Outeiro, A., & Mato, S. (2004). Relationships between terrestrial gastropod distribution and soil properties in Galicia (NW Spain). *Applied Soil Ecology, 26*(1), 1–9. https://doi.org/10.1016/j.apsoil.2003.10.008

Otchoumou, A., Dupont-Nivet, M., & Dosso, H. (2012). Effects of diet quality and dietary calcium on reproductive performance in *Archachatina ventricosa* (Gould, 1850), Achatinidae, under indoor rearing conditions. *International Journal of Intervertebrate Reproduciton, 56*(1), 14–20. https://doi.org/10.1080/07924259.2011.588013

Porcel, D., Bueno, J. D., & Almendros, A. (1996). Alterations in the digestive gland and shell of the snail

Helix aspersa Müller (Gastropoda, Pulmonata) after prolonged starvation. *Comparative Biochemical and Physiology, 115*, 11–17. https://doi.org/10.1016/0300-9629(95)02069-1

Romani, A. (2007). Regulation of magnesium homeostasis and transport in mammalian cells. *Archives of Biochemistry and Biophysics, 458*(1), 90–102.

Rygało-Galewska, A., Zglińska, K., Roguski, M., Roman, K., Bendowski, W., Bień, D., & Niemiec, T. (2023). Effect of different levels of calcium and addition of magnesium in the diet on garden snails' (Cornu aspersum) condition, production, and nutritional parameters. Agriculture, 13(11), 2055.

Svihus, B., Juvik, E., Hetland, H., & Krogdahl, A. (2004). Causes for improvement in nutritive value of broiler chicken diets with whole wheat instead of ground wheat. *British Poultion Science, 45*, 55–60. https://doi.org/10.1080/00071660410001668860

Voelker, J. (1959). Der chemische einfluss von kalziumkarbonat auf wachstum, entwicklung und gehäusebau von *Achatina fulica* Bowdich (Pulmonata). *Mitteilungen Aus Dem Hamburgi- Schen Zoologischen Museum und Institut der Universität Hamburg, 57*, 37–78.

Yan, B., & Hou, Y. (2018). Effect of soil magnesium on plants: A review. In IOP Conference Series: Earth and *Environmental Science* (Vol. 170, p. 022168). IOP Publishing. https://doi.org/10.1088/1755-1315/170/2/022168.

Yap, C. K., Ismail, A., & Tan, S. G. (2004). Heavy metal (Cd, Cu, Pb and Zn) concentrations in the green-lipped mussel *Perna viridis* (Linnaeus) collected from some wild and aquacultural sites in the west coast of Peninsular Malaysia. *Food Chemistry, 84*(4), 569–575. https://doi.org/10.1016/S0308-8146(03)00280-2

Zuschin, M., & Stanton, R. J. (2001). Experimental measurement of shell strength and its taphonomic interpretation. *Palaios, 16*(2), 161–170.