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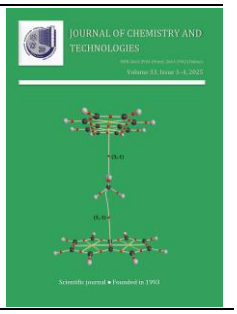

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CHEMICAL COMPOSITION AND MORPHOANATOMICAL CORRELATIONS OF THE BODY IN CERTAIN GASTROPODA SPECIES: EVIDENCE FROM THE DNIPROPETROVSK REGION

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Abstract

The correlation between morphometric parameters and chemical composition of terrestrial slugs *Limax flavus*, *Arion subfuscus*, and *Malacolimax tenellus* from the Dnipropetrovsk region was investigated as a basis for evaluating their potential as alternative protein sources. Methods. Field sampling was conducted in three cities of Dnipropetrovsk region (Dnipro, Kryvyi Rih, Pavlohrad), followed by morphometric measurements and chemical analysis of muscle, mucus, and internal organs. Pearson correlation coefficients were used to assess linear relationships among body weight, length, width, and tissue proportions. Nutrient content (moisture, protein, fat, ash, carbohydrates) was determined according to national standards. Results. 1332 specimens were analyzed. Strong positive correlations (r > 0.9) were observed between weight and body dimensions in *Limax flavus* and *Arion subfuscus*, while *Malacolimax tenellus* showed weaker trends. For example, *Arion subfuscus* had the highest protein content (15.07 %), while *Malacolimax tenellus* had the highest fat content (2.3 %). In particular, larger individuals exhibited higher meat percentage and lower mucus content, indicating adaptive metabolic patterns. As a result, species-specific nutritional profiles were established with implications for functional food use. Conclusions. The study confirms the existence of strong morphoanatomical and compositional correlations in land gastropods, supporting their potential for human consumption. Consequently, these findings may inform the development of sustainable food systems utilizing underexplored animal protein sources. The benefits of this study lie in linking morphology with biochemistry to evaluate food value and direct future biotechnological applications.

Keywords: Gastropoda; terrestrial slugs; *Limax flavus*; *Arion subfuscus*; *Malacolimax tenellus*; morphometric analysis; chemical composition; protein; Pearson correlation.

ХІМІЧНИЙ СКЛАД І МОРФОЛОГІЧНІ КОРЕЛЯЦІЇ ТІЛА У ДЕЯКИХ ВИДІВ ГАСТРОПОДІВ: ДАНІ З ДНІПРОПЕТРОВСЬКОЇ ОБЛАСТІ

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Анотація

Досліджена кореляція між морфометричними параметрами та хімічним складом наземних слимаків *Limax flavus*, *Arion subfuscus* та *Malacolimax tenellus*, зібраних у Дніпропетровському регіоні, з метою оцінки їхнього потенціалу як альтернативного джерела білка. Методи. Польовий відбір зразків здійснювався у трьох містах Дніпропетровської області (Дніпро, Кривий Ріг, Павлоград), після чого проводили морфометричні вимірювання та хімічний аналіз м'яса, слизу й нутрощів. Для оцінки лінійних зв'язків між вагою, довжиною, шириною тіла та частками тканин використовували коефіцієнт кореляції Пірсона. Вміст поживних речовин (волога, білки, жири, зола, вуглеводи) визначали згідно з національними стандартами. Результати. Проаналізовано 1332 зразки. Встановлено виражені прямі кореляції (r > 0.9) між вагою та розмірами тіла у *Limax flavus* і *Arion subfuscus*, тоді як у *Malacolimax tenellus* ці тенденції були менш вираженими. Наприклад, *Arion subfuscus* мав найвищий вміст білка (15.07 %), тоді як *Malacolimax tenellus* – найвищий вміст жиру (2.3 %). Більш того, у більших особин відзначено вищу частку м'яса та нижчий вміст слизу, що свідчить про адаптивні метаболічні особливості. В результаті були сформовані видові поживні профілі з перспективами для використання у функціональних харчових продуктах. Висновки. Дослідження підтверджує існування тісних морфоанатомічних і хімічних зв'язків у гастропод, що обґрунтовує їхній потенціал для харчового використання. Отже, отримані результати можуть бути використані для розвитку сталих продовольчих систем із залученням маловивчених джерел тваринного білка

Ключові слова: *Gastropoda*; наземні слимаки; *Limax flavus*; *Arion subfuscus*; *Malacolimax tenellus*; морфометричний аналіз; хімічний склад; білок; кореляція Пірсона.

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Introduction

Actuality and problem statement. In the context of the current global food crisis and the shortage of high-quality protein products, the search for alternative sources of complete protein is becoming increasingly relevant [1]. Traditional animal-based protein sources – such as beef, poultry, and fish – require substantial natural resources; including water, feed, and arable land, and exert a considerable impact on the global ecological balance [2]. As a result, there is growing interest in non-traditional protein sources, among which mollusks of the class *Gastropoda* occupy a significant position.

Terrestrial gastropod mollusks represent a numerous group of invertebrates widely distributed across various ecosystems and exhibiting a high degree of adaptability to environmental conditions [3]. However, despite their considerable bioresource potential, their chemical composition – particularly that of slugs – remains insufficiently studied in the context of potential use as a food resource. In contrast, marine gastropods and terrestrial snails have been relatively well researched [4; 5]. The results of long-term studies on the biology and ecology of the latter have laid the foundation for a food-related concept known as heliciculture [6].

At present, knowledge about terrestrial mollusks in the Dnipropetrovsk region is virtually nonexistent. Therefore, a scientific and practical challenge arises in determining the qualitative and quantitative composition of key nutrients in the meat of terrestrial gastropods, assessing its nutritional value, and evaluating the prospects for its application in the food industry. Studying the chemical composition of these organisms will make it possible to determine their potential as a source of complete protein and will open new avenues for the development of food products with enhanced biological value.

The *aim* of this study is to establish correlations between various body components and parameters of the slugs *Limax flavus*, *Arion subfuscus*, and *Malacolimax tenellus*, as well as to determine their chemical composition.

To achieve this aim, the following objectives were set:

1. To conduct a morphometric analysis of external and internal body parameters of the studied slug species;
2. To determine correlation relationships between the main morphometric parameters and specific body components;
3. To investigate the chemical composition of the tissues of the studied species;
4. To analyze potential differences in chemical composition and morphometric characteristics among *Limax flavus*, *Arion subfuscus*, and *Malacolimax tenellus*;
5. To assess the influence of ecological factors on the morphofunctional characteristics and chemical composition of the studied species, as well as to evaluate the prospects for using these organisms in the food industry and restaurant sector.

The issue of snail processing technologies, including stages of cultivation, purification, and treatment, is intended to be addressed in separate publications, based on the morphoanatomical and biochemical characteristics presented in the current study.

Research methods. The study was conducted in the Dnipropetrovsk region, located in the geographical center of Ukraine. The region experiences a temperate continental climate, with an average annual temperature ranging from +8 to +10 °C. Summers are warm, with average temperatures around +23 to +25 °C, while winters are cold, with temperatures that can drop to –5 °C or lower. The area exhibits clearly defined seasonal changes: the warm period lasts from May to September, with peak temperatures typically in July and August, whereas the cold season extends from November to March. The average annual precipitation is approximately 400–500 mm, with peaks occurring during the spring and autumn months. The summer season is characterized by moderate rainfall, while the winter period tends to be relatively dry. The region receives an average annual solar insolation of approximately 1,600–1,700 hours [7].

Slug collection was carried out in toponyms of two district centers (Pavlohrad and Kryvyi Rih) and one regional center (Dnipro) within the Dnipropetrovsk region. After collection, specimens were identified according to their respective localities. Species identification was based on the morphological characteristics of the individuals, including body coloration, pigmentation of the mantle, size, and number of eggs laid [8; 9]. To determine the proportion of various morphological features and the chemical composition of the meat and mucus, samples consisting of 60 individuals per locality were formed. Sample preparation for analysis followed methodologies described in [10]. Slugs and their body components (mucus, meat, internal organs) were weighed using “Camry” electronic scales

(model: EK2151HK) with a maximum capacity of 5 kg and an accuracy of 1 g. For laboratory analyses, "Sartorius" electronic balances with a capacity of 500 g and an accuracy of 0.1 g were used.

To analyze the correlation between various components of the studied slugs, the Pearson correlation coefficient (r) was used, which indicates the degree of linear relationship between two parameters [11]. The correlation coefficient ranges from –1 to +1, where +1 indicates a strong positive correlation, -1 indicates a strong negative correlation, and 0 indicates no correlation at all [12].

Chemical analyses of the slugs' meat and mucus were conducted at the Testing and Research Center for Food and Industrial Products of the State Enterprise "Dniprostandartmetrologiya" in accordance with current regulatory documents for testing methods.

Moisture content was determined by the drying method (DSTU 8029:2015) using a SHS-80 drying oven; ash content – according to DSTU 8718:2017 using a SNOL-8.2 muffle furnace; protein content – by the Kjeldahl method (DSTU 8030:2015) on a Kjeltec 2300 automatic analyzer; fat content – by the Soxhlet extraction method (DSTU 8718:2017) using a BÜCHI B-811 laboratory apparatus.

Subjects of the study are correlation relationships between the morphometric parameters of the body of *Limax flavus*, *Arion subfuscus*, and *Malacolimax tenellus*, and the characteristics of their chemical composition.

Objects of the study are terrestrial gastropod mollusks of the species *Limax flavus, Arion subfuscus,* and *Malacolimax tenellus.*

Analysis of scholarly publications on the research topic

Currently, the study of slug diversity and distribution encompasses both the discovery of new species and the assessment of anthropogenic impacts on ecosystems. For example, on Montecristo Island, a newly described species, *Weltersia obscura*, has sparked discussions regarding its endemic versus alien origin [13]. Meanwhile, in the cool-temperate forested wetlands of Nova Scotia, invasive *Arion* species have been found to dominate due to their adaptation to logging roads and clear-cuts, whereas native species such as *Deroceras laeve* and *Prophysaon dorsalis* persist in various forest microhabitats [14]. In England and Ireland, more than 20 % of the slug fauna remains undiscovered or undescribed, highlighting the ongoing risk of undetected biological invasions [15]. Ecological studies have further demonstrated that close-to-nature forestry supports stenotopic species, while exotic slugs – particularly *Arion lusitanicus* – thrive in areas of intense forest disturbance [16]. In Italy's Brescia province, eight new slug species records have been confirmed, including *Milax nigricans* and *Tandonia simrothi* [17]. Systematic revisions of the subfamily Oopeltinae have supported the need for a distinct taxonomic status for *Oopelta*, and have provided updated data on *Limax nyctelius* and *Deroceras reticulatum* [18]. In North America, the exotic *A. subfuscus* sensu stricto, detected in California, likely originates from the northeastern United States rather than directly from Europe [19]. In Poland, a newly defined distributional boundary for *Deroceras invadens* suggests ongoing colonization from Germany [20], while in Québec *A. fuscus* has been identified as the dominant representative of the *A. subfuscus* s.l. complex, reflecting varied introduction pathways and histories [21].

Genetic studies of arionids in the British Isles have revealed three distinct clusters, formed on the basis of genetic structure and reproductive systems. Intensive hybridization between polymorphic and monogenic lineages contributes to genetic variability within populations [22]. Comparative analyses of genes and allozymes between *A. urbiae* and *A. anguloi* suggest a conspecific origin, while *A. subfuscus* likely comprises two distinct species with notable genetic divergence [23]. Molecular and morphological investigations of the *A. subfuscus/fuscus* complex in continental northwestern Europe have uncovered cryptic taxonomic diversity; gonad type has been proposed as a key morphological marker to distinguish the two species in this region [24]. Overall, the genetic structure of the family Limacidae remains relatively stable, whereas reproductive strategies and modes of reproduction still require more detailed examination, opening avenues for further systematic research [25].

Numerous scholarly works have focused on the feeding behavior and nutrient assimilation of gastropod mollusks. Nutrient utilization efficiency in slugs largely depends on food quality and the age category of individuals. Juvenile slugs exhibit significantly higher assimilation capacity compared to adults, indicating an intensified metabolic rate during growth phases [26]. Field studies conducted in orchards have shown that slugs predominantly consume non-nutritive parts

of plants, and their activity levels and population density vary depending on temperature, humidity, and species identity. For instance, some species, such as *Deroceras reticulatum*, remain active even at lower temperatures, whereas others significantly reduce their activity [27]. Research on *A. subfuscus* has confirmed selective feeding behavior: this species shows a marked preference for *Brassica napus* seedlings, along with lower abundance on other plant species and notable phytoselectivity towards *Chelidonium maius*, *Euphorbia helioscopia*, and *Plantago lanceolata* [28].

In the modern world, slugs are not only invasive agricultural pests but also serve as model laboratory animals and producers of biologically active mucus with adhesive and cohesive properties for applications in medicine, the food industry, and biotechnology. In recent years, it has been established that mucus from various slug species possesses considerable medical potential. Specifically, the mucus of *L. maximus* and *A. rufus* has been shown to suppress the metabolic activity of human keratinocytes and melanoma cells, resulting in a reduced number of these cells and suggesting potential antitumor properties of these extracts [29]. The yellow mucus of *L. flavus* has been used as a model for assessing the irritant potential of surface disinfectants employed against SARS-CoV-2: a unique pigmentation reaction involving the accumulation of yellow pigment in the mucus allows for clear identification of irritants and evaluation of formulation safety [30]. At the molecular level, whole-body transcriptomic analysis of *L. flavus* has identified a range of genes encoding potential antimicrobial peptides and proteins, thereby supporting its traditional use in Chinese medicine [31]. Furthermore, three antimicrobial peptides with proven antifungal and antibacterial activity have been isolated from the mucus of *L. flavus*, opening promising avenues for the development of novel pharmaceuticals targeting drug-resistant pathogens [32].

Studies of the secretions of *A. subfuscus* have revealed principles underlying the formation of ultra-strong biopolymeric hydrogels. It has been demonstrated that the protective secretions of this slug form a double-network hydrogel, whose strength results from the synergistic action of two polymolecular networks, allowing these secretions to serve as prototypes for synthetic adhesives [33]. Recombinant proteins derived from this secretion successfully replicate the gel's reinforcing function and are considered potential biomimetic materials for sutureless surgical closures [34]. Further research confirmed that the double-network hydrogel of *A. subfuscus* achieves maximal strength due to interactions between two independent matrices [35]. At the cellular level, analyses of secretory cells have highlighted the role of microgels in forming a fast-curing and rupture-resistant adhesive [36]. Finally, it was established that the primary cross-linking of the gel occurs not via metals but through oxidative protein reactions, complicating control over this process and opening new avenues for investigating the mechanisms of adhesion [37].

Mucosal reactions of slugs are used as a biological model to assess the safety of chemical substances. In particular, *L. flavus* has demonstrated high sensitivity to surface disinfectants against SARS-CoV-2, accompanied by intense yellow pigmentation of the mucus, allowing for rapid and non-harmful evaluation of irritant effects [30]. However, to standardize and enhance the universality of this test, optimization is required: the current methodology classifies substances into three categories of eye irritation but needs validation for other species, notably *A. lusitanicus*, to ensure accuracy and transferability of results across different mollusk species [38].

Despite the demonstrated potential of the aforementioned bioproducts, debates continue regarding the safety of gastropods in the context of parasitic interactions involving their mucus and chemotaxis. A series of studies on nematode interactions with mollusk mucus have revealed important mechanisms of parasitism. *Phasmarhabditis papillosa* exhibits a pronounced chemotactic response to the mucus of *L. maximus* and *Helix pomatia* at elevated temperatures (above 20°C), indicating a thermosensitive attraction of the parasite to the mucus [39]. Another nematode, *P. hermaphrodita*, is capable of causing lethal infections in native species, whereas introduced species such as *A. hortensis*, *A. subfuscus*, and *L. maximus* avoid infection through specific feeding strategies that reduce contact with the pathogen [40]. Behavioral analysis of *P. hermaphrodita* further demonstrated that in the presence of mucus, it reduces its direct sliding activity [41].

In contemporary scientific research, increasing attention is being paid to alternative protein sources, driven by global trends toward ensuring food security and minimizing the negative environmental impact of the food industry [42]. In particular, studies on the utilization of unconventional protein resources, such as

terrestrial gastropod mollusks, play a significant role in this context [43].

Researchers from Ukraine have made substantial contributions to the study of the nutritional properties of alternative protein sources, particularly in the field of production and application of selenium-protein supplements in food technology. Their research demonstrates that the enrichment of dietary products with biologically active compounds enhances the nutritional value and functional properties of the final products [44; 45]. Selenium-protein supplements are successfully employed in the technology of functional foods, including the production of frozen semi-finished products made from yeast dough [46], meat [47], and dairy semi-finished products [48], as well as in formulations of foods intended for special dietary consumption [49]. Moreover, several studies indicate the promising potential of emulsion systems based on unconventional protein sources in novel food products, addressing technological aspects of obtaining such emulsions [50].

A number of studies have indicated that the enrichment of food matrices with such additives enhances their nutrient profile, antioxidant activity, and technological properties, including structural and mechanical characteristics [51; 52]. The investigation of morphometric traits and chemical composition of terrestrial mollusks as a protein source is critically important for assessing the safety of their consumption by living organisms, particularly humans [53].

Currently, numerous studies on the chemical composition of mollusks from the class *Gastropoda* are known, and comparative analysis of their results reveals significant differences in the chemical makeup of the meat and mucus of the studied specimens. Moreover, attention is increasingly focused on the potential dependence of chemical composition on dietary intake. A notable study involved rearing slugs on a compound feed supplemented with alunite flour. Analysis of the nutrient composition of the experimental group demonstrated, compared to the control, an increase in dry matter by 11.2 %, protein by 17.1 %, and fat by 31.7 % [54; 55]. This evidence highlights the considerable variability in the chemical composition of slug meat not only between different species but also within the same species under varying rearing conditions.

The meat of marine gastropods is a rich source of proteins, amino acids, fatty acids, and bioactive compounds, making it a promising candidate for applications in the food industry and medicine. The chemical composition of marine gastropod meat is abundant in nutrients and bioactive substances.

In light of the above, the relevance of further research on terrestrial gastropods as a prospective protein source is justified both from the standpoint of their chemical composition and considering their technological and microbiological characteristics. Determining the morphofunctional features of these organisms, particularly species such as *Limax flavus*, *Arion subfuscus*, and *Malacolimax tenellus*, will help delineate their potential for the food industry and develop approaches for their utilization in the production of functional products.

Experimental

Limax flavus and *Arion subfuscus* are widespread both in Europe and Ukraine. *L. flavus* is adapted to anthropogenic landscapes such as homesteads, parks, and fences. It is commonly found in the areas of Dnipro, Kryvyi Rih, and Kamianske, as well as their surroundings. Outside urban development, it predominantly inhabits moist locations along the Samara and Orel rivers. *A. subfuscus* is mostly found in forested and agricultural regions in the northern and eastern parts of the oblast. It predominates in forest and meadow ecosystems. For this study, sample collection was conducted, among other locations, near the Dnipro-Donetsky watershed.

Malacolimax tenellus is less widespread than the aforementioned species. It prefers moist forest litter and shady habitats. In the Dnipropetrovsk region, it can be found in forests, especially in areas with high humidity located in the southern and eastern parts of the region, closer to steppe zones. Samples were mostly collected from protected natural areas within the region.

During sample collection, we relied on occurrence data based on observations of the studied species from the iNaturalist platform, which provides evidence of the distribution of these species in the Dnipropetrovsk region and Ukraine as a whole (fig. 1).

We confirmed the locations of the specified ranges and collected samples for analysis in the following quantities (see table below).

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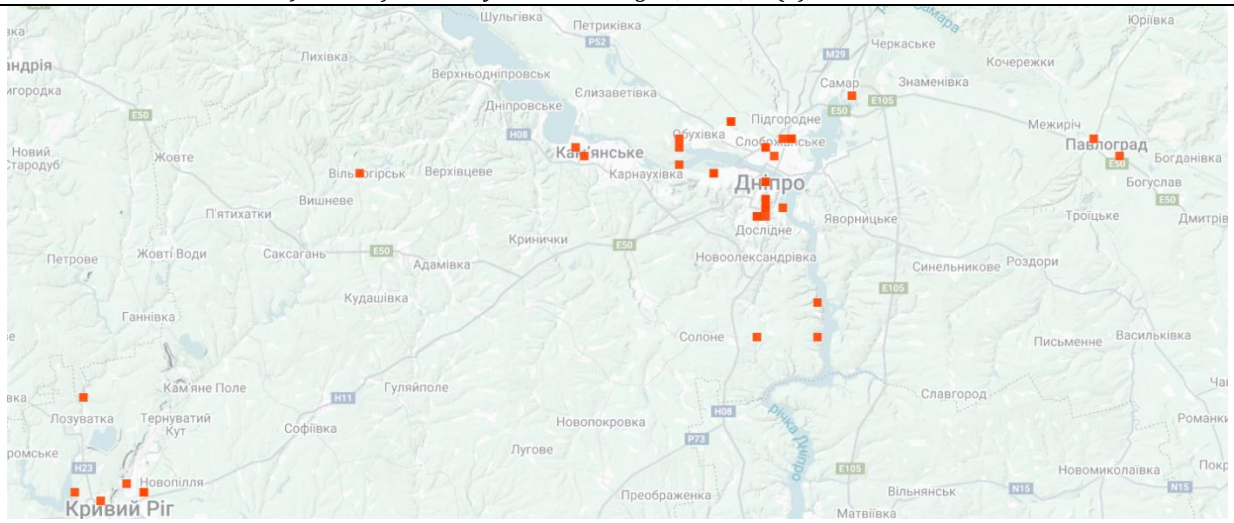

Fig. 1. Mapping of the distribution ranges of the studied gastropod species across Dnipropetrovsk region based on data from the iNaturalist platform [56]

Table 1

The number of specimens collected for the study from the investigated distribution range

Species	Administrative center and nearby settlements			
	Dnipro city	Kryvyi Rih city	Pavlohrad city	Total samples
Limax flavus	245	339	151	735
Arion subfuscus	206	120	105	431
Malacolimax tenellus	94	12	60	166
Total samples in the center	545	471	316	1332

A total of 1,332 slug samples from the three studied species were collected: *L. flavus* – 735 (55.2 % of the total), *A. subfuscus* – 431 (32.4 %), and *M. tenellus* – 166 (12.5 %). The largest number of samples was obtained in the city of Dnipro – 545 (40.9 % of the total), while the smallest number, 316 (23.7 %), was collected in Pavlohrad.

L. flavus was the dominant species across all three locations, indicating its wide distribution and adaptability to various environmental conditions. *A. subfuscus* was sufficiently represented in Dnipro (206 specimens) and Kryvyi Rih (120 specimens). *M. tenellus* proved to be the least widespread species, especially in Kryvyi Rih, where only 12 samples were collected, which may indicate specific habitat requirements or a limited distribution range.

The proportions of different body parts and parameters of the studied slugs are presented in tabl. 2, from which it is evident that live weight, body length and width, and the quantitative parts of the muscular sac, mucus, and internal organs vary differently across species.

Table 2

Proportions of the main body components and parameters of the studied slugs depending on their species (n = 6, p ≤ 0,05)

Parameter	*Limax flavus*	*Arion subfuscus*	*Malacolimax tenellus*
Average weight, g	12.34 ± 0.62	8.76 ± 0.44	5.43 ± 0.27
Length, mm	120.72 ± 5.3	78.62 ± 3.9	52.31 ± 3.1
Width, mm	12.41 ± 0.9	5.84 ± 0.8	7.89 ± 0.6
Mass fraction of meat, %	50.23 ± 2.51	45.67 ± 2.28	55.89 ± 2.79
Mass fraction of mucus, %	15.45 ± 1.27	10.12 ± 1.51	10.34 ± 1.02
Mass fraction of viscera, %	34.32 ± 1.22	44.21 ± 1.21	33.77 ± 1.19

To assess the presence of correlations between various body components and parameters of the studied slugs, Pearson's correlation coefficient (r) was calculated, which indicates the degree of linear association between two variables. The results are presented in tabl. 3-5, categorized by slug species.

Table 3

Correlation between the constituent elements and growth parameters of the *Limax flavus* species

Parameter	Average weight	Length	Width	Mass fraction of meat	Mass fraction of mucus	Mass fraction of viscera
Average weight	1.00	0.93	0.85	0.80	−0.65	−0.15
Length	-	1.00	0.88	0.75	−0.60	−0.10

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Continuation of table 3

Width	-	-	1.00	0.70	–0.55	–0.05
Mass fraction of meat	-	-	-	1.00	–0.45	–0.30
Mass fraction of mucus	-	-	-	-	1.00	0.20
Mass fraction of viscera	-	-	-	-	-	1.00

Table 3 indicates a strong positive correlation (r > 0,90) between the average weight, length, and width parameters of *L. flavus*. This suggests that as the length or width of the slug increases, its weight also increases. The mass fraction of the meat shows a positive correlation with weight, length, and width (r = 0.70…0.80), indicating that larger slugs have a higher proportion of meat. Conversely, the mass fraction of mucus exhibits a negative correlation with weight, length, and width (r = –0.55 to –0.65), revealing that larger individuals of *L. flavus* have a relatively smaller proportion of mucus compared to smaller ones. The mass fraction of the viscera shows a weak correlation with other parameters (r → 0), suggesting that this parameter is independent of slug size. The mass fractions of mucus and viscera display a moderate positive correlation (r = 0.20), which may indicate a slight association between these components.

Thus, the strongest correlations are observed between the weight, length, and width of the slug, which is expected as these parameters are closely related to body size. The mass fraction of meat increases with the slug's size, whereas the mass fraction of mucus decreases. The mass fraction of viscera shows virtually no dependence on other parameters, suggesting a relatively constant proportion within the organisms of this species.

Table 4

Correlation between the constituent elements and growth parameters of the *Arion subfuscus* species

Parameter	Average weight	Length	Width	Mass fraction of meat	Mass fraction of mucus	Mass fraction of viscera
Average weight	1.00	0.92	0.88	0.82	–0.55	–0.28
Length	-	1.00	0.90	0.78	–0.50	–0.25
Width	-	-	1.00	0.75	–0.45	–0.20
Mass fraction of meat	-	-	-	1.00	–0.35	–0.15
Mass fraction of mucus	-	-	-	-	1.00	0.18
Mass fraction of viscera	-	-	-	-	-	1.00

Therefore, the parameters of average weight, length, and width of the *A. subfuscus* species exhibit a strong positive correlation (r > 0.88). This means that as the length or width of the slug increases, its weight also increases. The mass fraction of meat shows a positive correlation with weight, length, and width (r = 0.75…0.82), indicating that larger slugs have a greater proportion of meat. The mass fraction of mucus is inversely correlated with weight, length, and width (r = –0.55 to –0.45): the larger the slug, the relatively smaller the proportion of its mucus. The mass fraction of viscera exhibits a weak correlation with other parameters (again, r ≈ 0). A weak positive correlation was observed between the mass fractions of mucus and viscera (r = 0.18), which may indicate a minor relationship between these components.

Hence, the expected strong correlation is observed between the slug's weight, length, and width. The mass fraction of meat increases with the slug's size, in contrast to the decreasing mass fraction of mucus. The mass fraction of viscera in *A. subfuscus* remains stable and does not show significant correlation with other parameters.

Table 5

Correlation between the constituent elements and growth parameters of the species *Malacolimax tenellus*

Parameter	Average weight	Length	Width	Mass fraction of meat	Mass fraction of mucus	Mass fraction of viscera
Average weight	1.00	0.89	0.85	0.80	-0.50	-0.25
Length	-	1.00	0.88	0.75	-0.45	-0.20
Width	-	-	1.00	0.70	-0.40	-0.15
Mass fraction of meat	-	-	-	1.00	-0.30	-0.10

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Continuation of table 5

Mass fraction of mucus	-	-	-	-	1.00	0.15
Mass fraction of viscera	-	-	-	-	-	1.00

The average weight of *M. tenellus* specimens is positively correlated with their length and width ($r > 0.85$). Thus, as the length or width of the slug increases, so does its weight. A similar trend is observed when assessing the correlation between the meat fraction and weight, length, and width ($r = 0.70…0.80$): larger slugs tend to have a higher proportion of meat. The mass fraction of mucus is inversely correlated with weight, length, and width ($r = -0.50$ to -0.40). The mass fraction of viscera exhibits a weak correlation with other parameters, which is to be expected. A weak positive correlation ($r = 0.15$) was observed between the mass fractions of mucus and viscera, which may indicate a minor association between these components.

Thus, as expected, the parameters of weight, length, and width are closely associated with overall body size, as is the proportion of meat, which is confirmed by the calculated Pearson correlation coefficients. At the same time, the mass fraction of mucus is inversely correlated with dimensional parameters. The mass fraction of viscera shows virtually no dependence on other parameters, indicating its stable proportion within the slug's body.

The next step toward achieving the stated research objectives involved determining the chemical composition of the meat of the studied specimens, the results of which are presented in tabl. 6.

Table 6

Chemical composition of the tissue of the studied specimens

Indicator	Actual value, $P \geq 0.95$, $n = 3$			Standard document on the test method
	L. flavus	*A. subfuscus*	*M. tenellus*	
Mass fraction of moisture, %	84.8±4.24	79.83±3.99	82.5±4.13	DSTU 8029:2015
Mass fraction of ash, %	1.54±0.08	2.1±0.11	1.6±0.08	DSTU 8718:2017
Mass fraction of fat, %	0.4±0.02	1.2±0.06	2.3±0.12	DSTU 8718:2017
Mass fraction of protein, %	10.35±0.52	15.07±0.75	12.8±0.64	DSTU 8030:2015
Mass fraction of carbohydrates, %	2.91±0.15	1.8±0.09	0.8±0.04	Calculation method
Energy value, kcal/100 g	56.9±2.85	79.3±3.97	76.2±3.81	Calculation method
Nutritional value, kJ/ 100 g	238.3±11.91	331.9±16.60	318.7±15.94	Calculation method

The available data on the chemical composition of *L. flavus* meat show a typical distribution of nutrients for representatives of this group of invertebrates. However, the chemical composition varies significantly among the studied slug species. For instance, *A. subfuscus* is characterized by the lowest moisture content (79.2 %) and the highest protein content (15.7 %) among the three species, which may reflect its adaptation to environments with limited water availability and a need to sustain muscular activity. This species also exhibits the highest ash content (2.1 %), indicating a potentially greater concentration of mineral substances.

M. tenellus, on the other hand, stands out for having the highest fat content (2.3 %), which may be related to the need for energy reserves necessary for survival in cooler forest habitats. Meanwhile, its carbohydrate content is the lowest (0.8 %) among the studied species, possibly reflecting metabolic characteristics and dietary specificity.

Results and discussion

To assess the strength and direction of relationships between morphometric parameters and tissue mass fractions in slugs, the Pearson correlation coefficient (r) was used. The statistical significance of the correlation coefficients was tested using the t-test for r at $n = 6$. All obtained values were statistically significant at the $p < 0.05$ level, confirming the reliability of the identified correlations. Since r is a point estimate, Tables 3–5 present only the correlation coefficients without error margins or confidence intervals.

Overall, the correlation patterns observed in *A. subfuscus* are similar to those found in *L. flavus*, although they appear to be somewhat weaker. For instance, the correlation between weight and length in *A. subfuscus* is 0.92, while in *L. flavus* it is 0.95. This may indicate that *A. subfuscus* exhibits a

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less pronounced dependence between body size and weight compared to *L. flavus*.

In the case of *M. tenellus*, correlations between parameters are generally weaker than in *A. subfuscus* and *L. flavus*. Specifically, the correlation between weight and length in this species is 0.89. This may suggest a less pronounced relationship between body size and weight in *M. tenellus* compared to the other species. Furthermore, the parameters of *M. tenellus* show a less distinct inverse correlation between body size and the proportion of mucus, which may indicate the presence of alternative adaptive mechanisms in this species.

In turn, the distribution of nutrient mass fractions in the bodies of the studied specimens was influenced by their size, the physiological mechanisms regulating their vital activity, and their ecological position within the sampling habitat. Research shows that larger slugs exhibit a different chemical composition of meat compared to smaller individuals of the same species or related taxa. Larger specimens are characterized by a lower surface area-to-volume ratio, which affects their water balance and metabolism. In part, this may result from differences in moisture and nutrient content within tissues. In addition, larger individuals generally possess more developed reproductive organs, which may influence the overall chemical composition of the body due to the accumulation of specific substances required for reproduction.

According to the study [57], slugs in the experimental group with a live weight of 43.9 g (compared to 33.8 g in the control group) had higher contents of dry matter, protein, and fat in their meat. However, these differences may primarily be attributed to dietary specifics, which correlate with body size and the chemical composition of tissues.

The body size of slugs is often correlated with their ecological niche and shaped by survival strategies, which manifest in the following adaptive metabolic characteristics: a decrease in mucus proportion and an increase in muscle mass in larger individuals, likely reflecting a shift in energy expenditure from active locomotion to resource storage. Additionally, larger specimens exhibit higher tissue mineralization and protein content, indicating more developed homeostatic regulation and metabolic stability typically associated with reproductively mature forms. For instance, large slugs may accumulate more fat as an energy reserve for periods of food scarcity or adverse environmental conditions, while smaller species may rely on faster metabolism and higher protein content to ensure mobility and adaptive responsiveness to environmental changes.

Differences in mineral content may also be associated with body size. Larger slugs have greater needs for calcium and other minerals for shell formation and maintenance (if present) or for ensuring tissue strength. For example, a study [58] found higher concentrations of macroelements such as Calcium and Phosphorus in larger slugs – by 25.2 % and 39.1 %, respectively – as well as higher levels of trace elements such as iron and cobalt – by 7.1 % and 19.0 %, respectively.

Thus, understanding the aforementioned differences in the chemical composition of slug meat holds significant practical importance, especially in the context of the potential use of these mollusks as a food source or for biotechnological applications.

The varying chemical composition of the studied species encourages the investigation of their functional and technological properties, organoleptic characteristics, and suitability for culinary and nutritional purposes. Notably, it is well known that differences in meat composition can affect the texture of traditional meat products after thermal processing, their ability to absorb flavors, and compatibility with various culinary ingredients.

Additionally, slugs with differing chemical profiles may possess distinct potentials for use in biotechnological processes. For example, species with higher protein content may serve as promising sources of biologically active peptides, while those with a unique mineral profile may be utilized for the extraction of specific nutrients.

It is worth noting that the supplementation of slugs' diet with alunite meal not only improved the chemical composition of their meat but also significantly reduced the content of toxic heavy metals: lead by 50.0 %, cadmium by 44.4 %, arsenic by 35.5 %, and mercury by 63.6 % [59]. The nutritional profiles obtained for the studied species are consistent with data reported for slugs reared on compound feed supplemented with alunite meal [54; 55; 57–59], indicating universal mechanisms influencing the protein, fat, and dry matter content in gastropod meat.This opens up prospects for developing methods to enhance the quality of slug meat through dietary modifications.

Conclusions

The chemical composition of terrestrial slug meat demonstrates significant interspecies

differences, reflecting their evolutionary adaptations, ecological niches, and physiological characteristics. It was found that a high moisture content of 84.8 % and relatively low levels of protein (10.4 %) and fat (0.4 %) characterize *L. flavus*. In contrast, *A. subfuscus* shows a lower moisture content of 79.2 % and a higher protein content of 15.7 %, while *M. tenellus* exhibits the highest fat content among the three species at 2.3 %.

Slug body size significantly correlates with the chemical composition of their meat due to physiological mechanisms such as the surface-area-to-volume ratio, development of the reproductive system, accumulation of energy reserves, and adaptation to available food sources. Experimental data confirm that larger individuals tend to have higher contents of dry matter, protein, fat, and minerals.

Understanding these differences substantiates the significance of slugs in the food industry as a potential source of non-traditional protein raw material. It also highlights their prospects in culinary and biotechnological applications, as well as the importance of developing strategies to optimize the composition of their meat by adjusting husbandry and feeding conditions. Future research will focus on a more detailed analysis of the factors influencing the chemical composition of slug meat and the exploration of methods for its targeted modification to enhance its nutritional and biological value.

Considering the comprehensive evaluation of Gastropoda as a potential food resource, future publications will address age-, sex-, and season-related variability in the chemical composition of the studied species' tissues based on the collected biomaterial, along with assessments of microbiological safety, parasitological control, and optimization of cultivation and purification conditions for the raw material.

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