Scientific Papers. Series D. Animal Science. Vol. LXIX, No. 1, 2026
ISSN 2285-5750; ISSN CD-ROM 2285-5769; ISSN Online 2393-2260; ISSN-L 2285-5750

GROWTH PERFORMANCE OF JUVENILE CARP (*Cyprinus carpio*) REARED USING SLUG (*Arion vulgaris*) MEAL AS AN ALTERNATIVE PROTEIN SOURCE IN FISH FEED

George-Cătălin MUNTEAN[1], Călin LAȚIU[1], Daniel COCAN[1], Radu CONSTANTINESCU[1], Tudor PĂPUC[1], Raul-Lucian SAVIN[1], Anca BECZE[2], Iulia TOROK[2], Paul UIUIU[1], Aurelia COROIAN[1]

[1]Faculty of Animal Science and Biotechnologies, USAMV Cluj-Napoca, 3-5 Calea Mănăștur, Cluj-Napoca, Romania
[2]National Institute for Research and Development of Optoelectronics INOE 2000, Research Institute for Analytical Instrumentation, 67 Donath Str., 400293, Cluj-Napoca, Romania

Corresponding author email: paul.uiuiu@usamvcluj.ro

Abstract

Alternative protein sources to fish meal in aquaculture feeds are being researched for decades. This continuous race is driven by the problems that surround fish meal: high cost, availability issues, environmental impact. Throughout the world, gastropods (class Gastropoda) are a common occurrence, and have been researched as candidates to substitute fish meal in aquaculture feeds. Among gastropods, research did not focus on slug species for their potential as alternative protein sources to fish meal, although they are widespread and in some regions are manifesting as invasive species. In this research slug meal obtained from the invasive species Arion vulgaris, was tested as an alternative protein source in an experimental feed on the growth of juvenile carp (Cyprinus carpio) in parallel to a feed containing fish meal. The results displayed no statistically significant differences between the experimental feed and the control feed, showing the potential of slug meal as an alternative protein source.

Key words*: aquaculture nutrition, fish meal, Gastropoda, growth dynamics, invasive.*

INTRODUCTION

Aquatic organisms represent an important food source for the world population. Aquaculture products' availability is increasing along with the continuous rise in production driven by the high demand of fish, shellfish or various other aquatic organisms (FAO, 2022). The economic importance of aquaculture became unquestionable when aquaculture productions surpassed for the first time capture fisheries productions in 2020, with 57 percent of the aquatic animals consumed by humans being aquaculture produced (FAO, 2024). Market growth and importance is also demonstrated by the consumers who are looking for better, safer and higher quality products (Freitas et al., 2020; Lațiu et al., 2024).

The increase in aquaculture production triggers and stimulates aquaculture research. Feed costs are the highest expenditure for the majority of aquaculture systems and research for improving feed and feed production is ongoing worldwide, addressing the issue of continuously rising prices of feed ingredients and the shortages of some raw materials (Rana et al., 2022; Baki & Yücel, 2017). Protein requirements of aquaculture feed are strict, and feed must contain the appropriate amount and type of protein for the aquatic animal which it is destined for. Fish meal is the most utilized protein source in aquaculture feed for decades (FAO, 2004), with excellent nutritional properties, but ever-increasing costs are making it harder to obtain (Nagappan et al., 2021). Substitutes to fish meal are heavily researched for years. Alternative protein sources of vegetal and animal origin are the most studied (Nagappan et al., 2021; Serra et al., 2024). Animal protein sources are more desirable, due to their amino acids composition, which makes them more appropriate for consumption by aquatic animals, and alternative sources studied vary from food industry by-products to insects and other invertebrates (Vrabec et al., 2015; Luthada-Raswiswi et al., 2021; Nagappan et al., 2021; Serra et al., 2024).

The use of gastropods (class Gastropoda) as alternative protein sources in animal feeds has been documented in the speciality literature since the 1950's (Mead & Kemmerer, 1953; Mead, 1961). Aquatic and terrestrial snails and slugs have been used as a feed ingredient in poultry growing (Diarra, 2015), swine growing (Kaensombath, 2005) and their potential was also studied for aquatic animal's feed, with at least 36 studies mentioning the use of gastropods in aquaculture (Muntean et al., 2024a). The most utilized species as alternative protein source are generally terrestrial snails, like the golden apple snail *Pomacea canaliculata* (Lamarck, 1822) (Phonekhampheng et al., 2009; Visca et al., 2018), or the African garden snail *Limicolaria aurora* (Jay, 1839) (Adéyèmi et al., 2020; Sogbesan et al, 2006).

Among the gastropod species studied as alternative protein sources, there is a lack of research regarding slugs, the gastropods that do not have hard shells. Terrestrial slug species are found throughout the world and in many cases, they are considered pests for agricultural crops (Das et al., 2020). Tshernyshev et al. (2022) study highlights the potential of rearing *Limacus flavus* (Linnaeus, 1758) and analyses their nutritional value, indicating they could be utilized for human consumption or animal feed. More in-depth research on the topic of slug potential as feed ingredients in animal rearing are necessary.

Central and Eastern Europe faces an invasion of the Spanish slug *Arion vulgaris* Moquin-Tandon, 1855. This species is often confused with *Arion lusitanicus* Mabille, 1868 and it is hard to differentiate between them morphologically, and it is considered that in most cases across Europe *Arion vulgaris* is present (Zając et al., 2017). Research suggests that the species could be native to Central Europe, based on genetic studies, and that it has manifested as an invasive species in the last decades due to various factors such as phenotypic plasticity, climate change or rapid response to natural selection. Regardless of origin, the species clearly acts as invasive in various regions (Pfenninger et al., 2014; Zając et al., 2017). The presence of *Arion vulgaris* was reported in Romania as well for at least ten years, with a very aggressive spread across the country, and it is considered a pest (Păpureanu et al., 2014). This species was considered a suitable candidate for our research, being easily available to collect and to implement an experiment in which Spanish slug meal was utilized as an alternative protein source in aquaculture feed. Prior to this experiment, the Spanish slug meal was tested for its chemical composition and nutritional value (Muntean et al., 2024b) along with other gastropod sourced meals. Slug meal had a protein content of 47.98%, 4.6% fat and around 8% ash content. Based on these results, the Spanish slug meal was chosen to continue the research, because it displayed an agreeable nutritional spectrum, it is considered a pest with no other use and creates environmental damage. An experiment was developed to analyse the fish growth dynamics when using a feed that contains slug meal as an alternative protein of animal origin, and to compare it in laboratory conditions to a feed that contains standard fish meal as an animal protein source.

The purpose of the experiment was to see if statistically significant differences occur in growth dynamics between the fish reared using the slug meal based feed and the fish reared using the fish meal based feed. The present research aim is to assess slugs' potential as an alternative protein source in aquaculture.

MATERIALS AND METHODS

Obtaining slug meal

Research took place between July 2024 and February 2025. The gathering and processing of slugs (*Arion vulgaris*) and the fish growing experiment were approved by the Bioethics Commission of the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca through the decision of the Bioethics Commission number 401 from the 21st of September 2023. The research was conducted in compliance with the European Directive 2010/63/EU on the protection of animals used for scientific purposes and Law 43/2014 enforced in Romania.

Slugs (*Arion vulgaris*) were gathered in a 30-day period during July 2024 and August 2024 from the wooded areas of the campus of the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca. Slugs

were captured using specially designed traps made from covered plastic containers with longitudinal 2 cm wide slots cut at the top of the container. The traps were baited with beer, which attracted the slugs to the trap. A number of 10 to 20 traps were set daily around noon and left until the following morning, when the slugs were collected and the traps reset with fresh bait. Collected slugs were then taken to the Animal Physiology Laboratory of the Faculty of Animal Science and Biotechnologies of the University of Agricultural Sciences and Veterinary Medicine of Cluj-Napoca. In the laboratory, the slugs were humanely euthanized using a solution of 50% ethanol and 50% water, then were thoroughly rinsed of any debris and stored in a freezer until the necessary amount of slugs were gathered and further processing could take place.

Slugs were processed and slug meal was obtained in the laboratories of the INCDO-INOE 2000, Research Institute for Analytical Instrumentation of Cluj-Napoca. After defrosting the slugs, they were dried using a drying oven (UFE 400 oven from Memmert, Büchenbach, Germany) at a temperature of 60oC. To determine if the dehydration process was complete, mass monitoring was conducted repeatedly using an analytical balance (WSP4000/C/2, Partner Radwag, Radom, Poland). Dehydrated slugs were then ground to a fine meal using a mill (PM 100, Retsch GmbH, Haan, Germany).

Feed manufacturing process

The experiment required the development of two feeds, an experimental feed that contained slug meal as an animal protein source and a control feed that contained fish meal as an animal protein source. Feeds were developed using complimentary ingredients of vegetal origin and vitamin-mineral premix. Following the modified method of Masithoh et al. (2020), using the Fourier transform near-infrared (FT-NIR) technology with the Tango Brucker spectrometer (Billerica, MA, USA), slug meal, fish meal and various vegetal ingredients were tested. This non-destructive analytical method allows rapid determination of proximate components such as protein, fat, moisture, fibre, and ash based on the absorption of near-infrared light by molecular bonds (mainly C–H, O–H, and N–H). Samples were scanned in reflectance mode, and spectra were analysed using instrument-calibrated models for feed matrices. This technique provided fast and reliable estimates, facilitating the formulation of nutritionally equivalent experimental and control diets. The complimentary ingredients chosen to develop the feeds were: sunflower meal, soybean meal, wheat bran, oat bran, corn germ, tiger nut flour and vitamin-mineral premix Romzeofort (Romvac, Romania). The experimental feed and the control feed recipes were made using the same amount of animal origin meal, slug meal or fish meal (30%) and using the same complimentary ingredients, but with different proportions for each recipe. We used different proportions of the complimentary ingredients because we strived to obtain two similar feeds regarding their protein content. The exact formulation of the experimental feed and the control feed are presented in Table 1. The feeds were produced through a cold pelleting process using an Agrofortel AGF-150M pelleting machine (Romania) equipped with a 2 mm diameter die. All solid raw materials were subjected to a preliminary grinding step using a hammer mill fitted with fine screens (≤1 mm) to reduce particle size. This step enhanced the homogeneity of the mixture, ensuring uniform nutrient distribution and facilitating consistent extrusion during pelleting. Subsequently, the ingredients were accurately weighed according to the formulated composition and thoroughly mixed to obtain a uniform blend. The moisture content of the mixture was adjusted to approximately 15% by adding water, to optimize pellet formation. Pelleting was conducted at a processing capacity of 60-80 kg/h under semi-cold conditions, without applying high temperatures, thereby preserving the nutritional and functional integrity of thermosensitive compounds such as vitamins, polyphenols, and hydrolysed proteins. The resulting cylindrical pellets (2 mm diameter, 3-5 mm average length) were air-dried at ambient temperature for 24 to 48 hours and stored under cool, dry, and dark conditions until use.

Table 1. Experimental feed and control feed formulation

Ingredient (%)	Experimental feed	Control feed
Slug meal (%)	30	0
Fish meal (%)	0	30
Sunflower meal (%)	5	5
Soybean meal (%)	20	10
Wheat bran (%)	5	10
Oat bran (%)	5	15
Corn germ (%)	15	10
Tiger nut flour (%)	19	19

Quality assessment of feed

The pellets from each recipe were tested in triplicate for their proximate content using the same method as for testing the ingredients (Table 2).

Table 2. Experimental and control feeds proximate composition

Nutrient (%)	Experimental feed		Control feed	
	M ± SEM	SD	M ± SEM	SD
Ash (%)	5.8 ± 0.01	0.01	7.91 ± 2.15	3.04
Carbohydrates (%)	7.37 ± 0.28	0.40	18.10 ± 5.50	7.78
Dry matter (%)	95.02 ± 0.04	0.06	95.82 ± 0.07	0.10
Dietary fiber (%)	32.83 ± 0.09	0.12	28.80 ± 0.17	0.24
Fat (%)	6.8 ± 0.10	0.14	7.53 ± 0.07	0.09
Protein (%)	29.76 ± 0.05	0.07	28.53 ± 0.09	0.13
Total sugars (%)	3.47 ± 0.03	0.05	4.9 ± 0	0.00

Legend: M – mean; SD – standard deviation of the mean; SEM – standard error of the mean.

The water dispersibility of the slug-based feed pellets was evaluated gravimetrically by measuring mass loss over time. A quantity of 5 grams of dry pellets (m_0) was weighed and introduced into a 500 mL Berzelius beaker filled with water at room temperature. After 30 minutes of immersion, the pellets were removed, dried in a desiccator until a constant weight was reached, and reweighed (m_1). Water dispersebility was calculated using the following formula:

$$Water\ dispersibility\ (\%\ loss) = \frac{m_0 - m_1}{m_0}\ x\ 100$$

In aquaculture, high-quality pellets should maintain their structural integrity in water for at least one hour without excessive breakdown. Mass losses below 10–15% are generally considered acceptable. This test was conducted to assess the physical stability of the pellets under simulated aquaculture conditions, where feed must remain intact long enough to be consumed by fish, while minimizing organic matter release into the aquatic environment.

The slug meal-based feed showed a mass loss of 7.12%, indicating a good water stability profile within the optimal range for aquaculture feeds (<10-15%).

Experimental design

The fish growing experiment was conducted on juvenile carp (*Cyprinus carpio* Linnaeus, 1758) obtained from a classic system farm from Cluj County. The experiment took place in a controlled environment at the INCDO-INOE 2000, Research Institute for Analytical Instrumentation of Cluj-Napoca. The carp juveniles were acclimated to laboratory conditions for five weeks prior to the experiment and were fed with pelletized feed used in the farm of their provenance. After the acclimation period, four groups of fish were created with 50 specimens each. The fish were individually weighed and based on their weight were attributed to a group, to obtain groups as uniform as possible. The mean weight of the specimens ranged between 20.43 g to 20.53 g, with a minimum weight of 16.1 g to a maximum weight of 27.9 g across all four groups, thus ensuring a tight similarity between groups. The uniformity of the groups at the initial stage was confirmed by the variance which ranged across groups from 6.52 to 8.78. The groups were labelled as Treatment A, Treatment B, Treatment C and Treatment D. Treatment A, Treatment B and Treatment C, were fed with 2% of their biomass daily using the slug meal experimental feed and were considered as the experimental treatments. Treatment D was fed with 2% of the biomass daily using the fish meal control feed and was considered the control treatment. A feeding plan for the entire experiment period was calculated based on their biomass. A fasting day was set for all groups each week, and the experiment went on for 40 days. The amount of daily feed for each treatment was fed half at the beginning of the light period and half at the end of the light period, which lasted for 8 hours daily. Fish were fed by hand by spreading the pellets in the same area of the tank at each feeding, opposite to where the submersible pump was set in the tank. For each treatment we utilized a 750-litre circular tank, with 600 litres of water and a depth of the water column of 65 cm. Each tank was fitted with an individual pump and external filtration system which facilitated mechanical filtration, biological filtration and UV

sterilization. Supplementary aeration was supplied to each tank trough a 50 mm air stone. Each tank had an underwater digital thermometer, and the temperature ranged during the experiment across treatments between 19.3OC and 21.3OC. pH was sampled in the morning of each feeding day with a portable pH-meter and the values of the pH ranged during the experiment across treatments between 7.18 and 7.37. The dissolved oxygen (O2) content was sampled weekly and tested through laboratory analysis and ranged across treatments between 7.96 mg O2/L and 9.08 mg O2/L.

Evaluation of growth performances

At half of the experiment period, an intermediary measurement of each individual was conducted and also at the end of the experiment period. Each of the measurement phases, at the beginning of the experiment (initial measurement), at half of the experimental period (intermediary measurement) and at the end of the experiment (final measurement), took place in the following manner. Each specimen of juvenile carp body weight (W) (g) was determined individually using a 0.1 g precision balance (Adam Dune DCT 2000, Adam Equipment, UK). Each specimen was photographed on its left side in a small fish tank equipped with a millimetric scale and a black plastic sheet that allows to photograph the fish against the aquarium glass, and a camera was set to be always at the same distance and position against the fish tank. Using the photographs, we determined several somatic measurements using the AmScope ToupView 3.7 software following an established morphometric method (Lațiu, 2025). The somatic measurements determined were: total length (Tl) (cm), standard length (Sl) (cm), commercial length (Cl) (cm), fork length (Fl) (cm), maximum height (H) (cm), minimum height (h) (cm), head length (Hl) (cm), caudal peduncle length (Pl) (cm).

Weight gains and the specific growth rate (SGR) were calculated at the end of the experiment for each treatment. Total gain (TG) (g) was calculated using the following formula:

$$TG = Final\ Biomass - Initial\ Biomass$$

Daily weight gain (DG) (g) was calculated using the following formula:

$$DG = \frac{TG}{number\ of\ experiment\ days}$$

The specific growth rate (SGR) was calculated using the following formula:

$$SGR\ (\%) = \frac{ln_{Final\ Biomass} - ln_{Initial\ Biomass}}{number\ of\ experiment\ days}\ x\ 100$$

Data analysis

Growth dynamics for body weight and each of the somatic measurements was analysed across treatments, to see if statistically significant differences occur between treatments during the intermediary measurement phase or the final measurement phase. Descriptive statistics was conducted for the data and the data were tested for their normality using the Shapiro-Wilk test. For normally distributed data the ANOVA test was applied paired with the post-hoc Tukey test for multiple comparisons and for non-normally distributed data the Kruskal-Wallis test was applied paired with the post-hoc Dunn test for multiple comparisons. The significance threshold was set at $\alpha = 0.05$. Data was centralized using Microsoft Office Excel software and statistical analysis and together with the graphical representation of the results was conducted using GraphPad Prism 8.0 software. During the experiment, no fatalities were recorded, the 200 specimens from all treatments survived the 40 days of experiment.

To better display the results in regard to treatment and phase, body weight and somatic measurements abbreviations were followed by a subscript with the letter of the treatment (A, B, C, D) if it represented determinations from the initial phase; were followed by a subscript beginning with letter "i" followed by treatment letter (iA, iB, iC, iD) if it represented determinations from the intermediary phase; were followed by a subscript beginning with letter "f" followed by treatment letter (fA, fB, fC, fD) if it represented determinations from the final phase.

RESULTS AND DISCUSSIONS

Total weight gain (TG) (g), daily weight gain (DG) (g) and specific growth rate (SGR) (%) for each treatment are presented in Table 3. The biggest weight gain for an experimental treatment was achieved by Treatment B with a

total weight gain of 98.90 g and a daily weight gain of 2.47 g. The control group had a total weight gain of 116.10 g and a daily weight gain of 2.90 g. The mean total weight gain across groups was 86.28 g and the mean daily weight gain was 2.16 g. The biggest SGR for an experimental treatment was achieved by Treatment B, with a SGR of 0.23%, and the biggest SGR across all treatments was achieved by Treatment D with a SGR of 0.27%. The mean SGR across all treatments was 0.20%.

Table 3. Total weight gain (TG), daily weight gain (DG) and specific growth rate (%) for all treatments

	Final Biomass (g)	Initial Biomass (g)	Total Gain (g)	Daily Gain (g)	SGR (%)
Treatment A	1098.10	1026.70	71.40	1.78	0.17
Treatment B	1120.80	1021.90	98.90	2.47	0.23
Treatment C	1083.90	1025.20	58.70	1.47	0.14
Treatment D	1141.80	1025.70	116.10	2.90	0.27
Minimum	1083.90	1021.90	58.70	1.47	0.14
Maximum	1141.80	1026.70	116.10	2.90	0.27
Mean	1111.15	1024.88	86.28	2.16	0.20
SD	25.47	2.08	26.02	0.65	0.06
SEM	12.73	1.04	13.01	0.32	0.03
CV%	2.29%	0.20%	30.16%	30.12%	29.07%

Legend: SD – standard deviation of mean; SEM – standard error of mean; CV% - coefficient of variation; SGR – specific growth rate.

Body weight (W) growth dynamics are represented in Figure 1 and Table 4.

In regard to body weight and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual body weight at the end of the experiment ranged between 21.68 g and 22.84 g, with the biggest mean weight recorded for the control group. In experimental Treatment B, it is noticeable that the biggest specimen from the experiment was recorded at 35 g, meaning that one specimen from Treatment B grew at least 7.9 g, taking into consideration that the biggest specimen at the beginning of the experiment from Treatment B weighed 27.10 g.

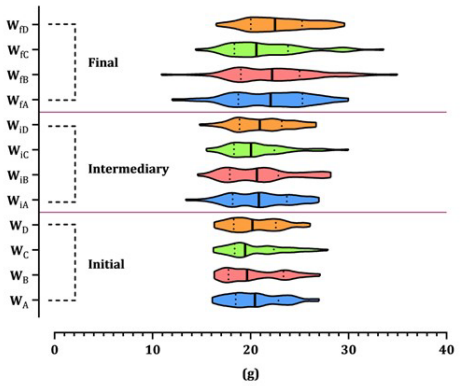


Figure 1. Growth dynamics regarding body weight (W) across treatments and experiment phases

Table 4. Descriptive statistics of growth dynamics regarding body weight (W)

	W_A (g)	W_B (g)	W_C (g)	W_D (g)	W_{iA} (g)	W_{iB} (g)	W_{iC} (g)	W_{iD} (g)	W_{fA} (g)	W_{fB} (g)	W_{fC} (g)	W_{fD} (g)
Minimum	16.10	16.30	16.20	16.30	13.40	14.60	15.50	14.80	12.00	10.90	14.40	16.50
Median	20.45	19.65	19.45	20.20	20.85	20.65	20.05	20.95	22.05	22.20	20.60	22.50
Maximum	27.00	27.10	27.90	26.10	27.00	28.20	30.00	26.70	30.00	35.00	33.60	29.60
Mean	20.53	20.44	20.50	20.51	20.96	21.01	20.55	21.17	21.96	22.42	21.68	22.84
SD	2.76	2.99	2.92	2.58	3.24	3.60	3.04	2.91	4.06	4.60	4.04	3.33
SEM	0.39	0.42	0.41	0.36	0.46	0.51	0.43	0.41	0.57	0.65	0.57	0.47

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Total length (Tl) growth dynamics are represented in Figure 2 and Table 5. In regard to total length and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual total length at the end of the experiment ranged between 11.32 cm and 11.52 cm, with the biggest mean total length recorded for the control group. In experimental Treatment C, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 13.38 cm, meaning that one specimen from Treatment C grew at least 1.95 cm, taking into consideration that the biggest value for total length at the beginning of the experiment from Treatment C was 11.43 cm.

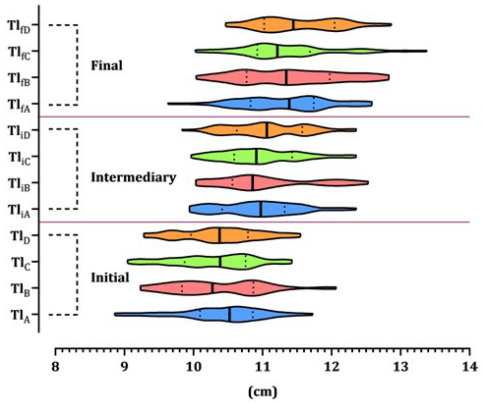


Figure 2. Growth dynamics regarding total length (Tl) across treatments and experiment phases

Table 5. Descriptive statistics of growth dynamics regarding total length (Tl)

	TlA (cm)	TlB (cm)	TlC (cm)	TlD (cm)	TliA (cm)	TliB (cm)	TliC (cm)	TliD (cm)	TlfA (cm)	TlfB (cm)	TlfC (cm)	TlfD (cm)
Minimum	8.86	9.23	9.05	9.28	9.94	10.03	9.97	9.84	9.63	10.04	10.03	10.47
Median	10.52	10.27	10.39	10.38	10.98	10.86	10.91	11.06	11.39	11.34	11.22	11.45
Maximum	11.73	12.07	11.43	11.55	12.36	12.53	12.36	12.36	12.59	12.83	13.38	12.87
Mean	10.41	10.37	10.30	10.39	10.93	11.05	10.98	11.07	11.32	11.41	11.37	11.52
SD	0.63	0.66	0.61	0.58	0.58	0.70	0.57	0.57	0.67	0.74	0.72	0.59
SEM	0.09	0.09	0.09	0.08	0.08	0.10	0.08	0.08	0.09	0.10	0.10	0.08

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Standard length (Sl) growth dynamics are represented in Figure 3 and Table 6. In regard to standard length and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual standard length at the end of the experiment ranged between 9.08 cm and 9.31 cm, with the biggest mean standard length recorded for the control group. In control Treatment D, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 10.75 cm, meaning that one specimen from Treatment D grew at least 1.35 cm in standard length, taking into consideration that the biggest standard length for a specimen at the beginning of the experiment from Treatment D was 9.40 cm.

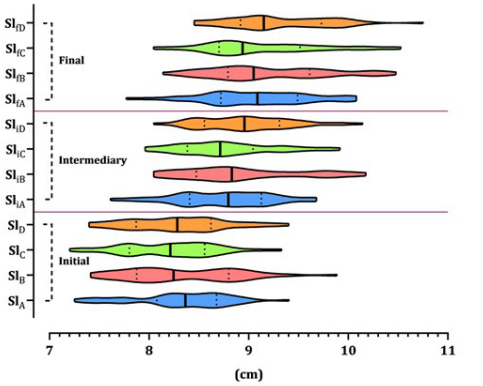


Figure 3. Growth dynamics regarding standard length (Sl) across treatments and experiment phases

Table 6. Descriptive statistics of growth dynamics regarding standard length (Sl)

	SlA (cm)	SlB (cm)	SlC (cm)	SlD (cm)	SliA (cm)	SliB (cm)	SliC (cm)	SliD (cm)	SlfA (cm)	SlfB (cm)	SlfC (cm)	SlfD (cm)
Minimum	7.25	7.41	7.20	7.40	7.61	8.05	7.96	8.05	7.77	8.14	8.05	8.45
Median	8.37	8.25	8.21	8.28	8.80	8.83	8.71	8.96	9.09	9.05	8.94	9.15
Maximum	9.41	9.89	9.33	9.40	9.68	10.18	9.92	10.15	10.08	10.48	10.53	10.75
Mean	8.32	8.35	8.20	8.29	8.75	8.94	8.78	8.97	9.08	9.21	9.13	9.31
SD	0.49	0.57	0.47	0.49	0.48	0.60	0.48	0.45	0.54	0.59	0.60	0.52
SEM	0.07	0.08	0.07	0.07	0.07	0.08	0.07	0.06	0.08	0.08	0.08	0.07

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Commercial length (Cl) growth dynamics are represented in Figure 4 and Table 7. In regard to commercial length and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual commercial length at the end of the experiment ranged between 6.18 cm and 6.45 cm, with the biggest mean commercial length recorded for the control group. In experimental Treatment C, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 7.59 cm, meaning that one specimen from Treatment C grew at least 1.10 cm in commercial length, taking into consideration that the biggest commercial length for a specimen at the beginning of the experiment from Treatment C was 6.49 cm.

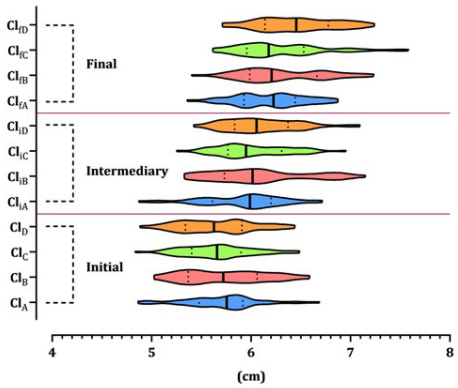


Figure 4. Growth dynamics regarding commercial length (Cl) across treatments and experiment phases

Table 7. Descriptive statistics of growth dynamics regarding commercial length (Cl)

	ClA (cm)	ClB (cm)	ClC (cm)	ClD (cm)	CliA (cm)	CliB (cm)	CliC (cm)	CliD (cm)	ClfA (cm)	ClfB (cm)	ClfC (cm)	ClfD (cm)
Minimum	4.87	5.03	4.84	4.88	4.87	5.33	5.25	5.42	5.36	5.40	5.62	5.71
Median	5.76	5.72	5.66	5.63	5.99	6.02	5.95	6.06	6.23	6.21	6.18	6.45
Maximum	6.69	6.59	6.49	6.44	6.72	7.15	6.96	7.10	6.88	7.24	7.59	7.24
Mean	5.71	5.74	5.66	5.66	5.92	6.09	6.01	6.11	6.18	6.31	6.30	6.45
SD	0.38	0.42	0.35	0.38	0.40	0.48	0.36	0.37	0.35	0.43	0.45	0.39
SEM	0.05	0.06	0.05	0.05	0.06	0.07	0.05	0.05	0.05	0.06	0.06	0.06

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Fork length (Fl) growth dynamics are represented in Figure 5 and Table 8. In regard to commercial length and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual commercial length at the end of the experiment ranged between 10.08 cm and 10.34 cm, with the biggest mean fork length recorded for the control group. In experimental Treatment C and the control Treatment D, it is noticeable that the biggest measurements for specimens from the experiment were recorded at 11.72 cm, meaning that one specimen from Treatment C grew at least 1.41 cm in fork length, taking into consideration that the biggest fork length for a specimen at the beginning of the experiment from Treatment C was 10.31 cm, and one specimen from Treatment D grew at least 1.51 cm in fork length, taking into consideration that the biggest fork length for a specimen at the beginning of the experiment from Treatment D was 10.21 cm.

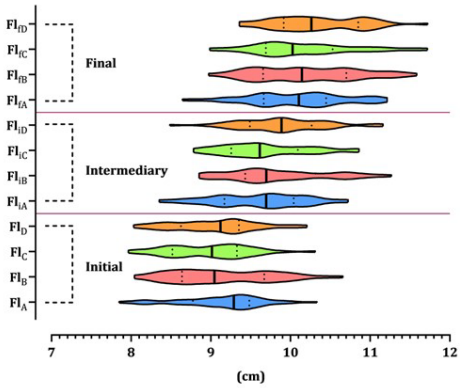


Figure 5. Growth dynamics regarding fork length (Fl) across treatments and experiment phases

Table 8. Descriptive statistics of growth dynamics regarding fork length (Fl)

	FlA (cm)	FlB (cm)	FlC (cm)	FlD (cm)	FliA (cm)	FliB (cm)	FliC (cm)	FliD (cm)	FlfA (cm)	FlfB (cm)	FlfC (cm)	FlfD (cm)
Minimum	7.85	8.04	7.97	8.03	8.35	8.85	8.78	8.49	8.64	8.97	8.99	9.36
Median	9.29	9.05	9.02	9.12	9.69	9.70	9.61	9.89	10.11	10.14	10.03	10.26
Maximum	10.34	10.66	10.31	10.21	10.72	11.27	10.86	11.16	11.21	11.59	11.72	11.72
Mean	9.13	9.14	8.97	9.05	9.60	9.84	9.68	9.89	10.08	10.21	10.15	10.34
SD	0.54	0.64	0.51	0.53	0.58	0.63	0.54	0.55	0.61	0.65	0.64	0.55
SEM	0.08	0.09	0.07	0.07	0.08	0.09	0.08	0.08	0.09	0.09	0.09	0.08

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Maximum height (H) growth dynamics are represented in Figure 6 and Table 9. In regard to the maximum height and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual maximum height at the end of the experiment ranged between 3.34 cm and 3.48 cm, with the biggest mean maximum height recorded for the control group. In experimental Treatment C, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 4.01 cm, meaning that one specimen from Treatment C grew at least 0.39 cm in maximum height, taking into consideration that the biggest maximum height for a specimen at the beginning of the experiment from Treatment C was 3.62 cm.

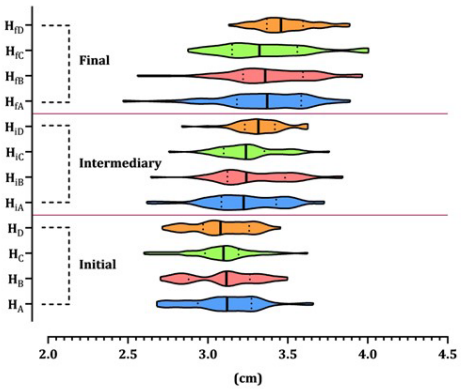


Figure 6. Growth dynamics regarding maximum height (H) across treatments and experiment phases

Table 9. Descriptive statistics of growth dynamics regarding maximum height (H)

	HA (cm)	HB (cm)	HC (cm)	HD (cm)	HiA (cm)	HiB (cm)	HiC (cm)	HiD (cm)	HfA (cm)	HfB (cm)	HfC (cm)	HfD (cm)
Minimum	2.68	2.70	2.60	2.72	2.62	2.64	2.76	2.84	2.47	2.56	2.88	3.13
Median	3.12	3.12	3.10	3.08	3.22	3.24	3.24	3.32	3.37	3.36	3.32	3.46
Maximum	3.66	3.50	3.62	3.46	3.73	3.84	3.76	3.63	3.89	3.97	4.01	3.89
Mean	3.10	3.10	3.08	3.09	3.23	3.29	3.25	3.33	3.34	3.38	3.36	3.48
SD	0.22	0.22	0.20	0.19	0.24	0.23	0.19	0.16	0.28	0.29	0.28	0.17
SEM	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.02	0.04	0.04	0.04	0.02

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Minimum height (h) growth dynamics are represented in Figure 7 and Table 10. In regard to the minimum height and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual minimum height at the end of the experiment ranged between 1.29 cm and 1.34 cm, with the biggest mean maximum height recorded for the control group. In experimental Treatment C, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 1.54 cm, meaning that one specimen from Treatment C grew at least 0.24 cm in minimum height, taking into consideration that the biggest minimum height for a specimen at the beginning of the experiment from Treatment C was 1.30 cm.

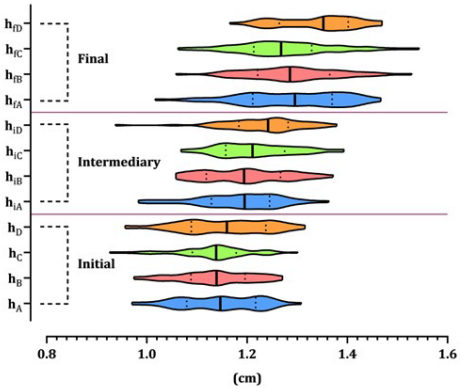


Figure 7. Growth dynamics regarding minimum height (h) across treatments and experiment phases.

Table 10. Descriptive statistics of growth dynamics regarding minimum height (h)

	hA (cm)	hB (cm)	hC (cm)	hD (cm)	hiA (cm)	hiB (cm)	hiC (cm)	hiD (cm)	hfA (cm)	hfB (cm)	hfC (cm)	hfD (cm)
Minimum	0.97	0.97	0.93	0.96	0.98	1.06	1.07	0.94	1.02	1.06	1.06	1.17
Median	1.15	1.14	1.14	1.16	1.20	1.19	1.21	1.24	1.30	1.29	1.27	1.35
Maximum	1.31	1.27	1.30	1.32	1.36	1.37	1.39	1.38	1.47	1.53	1.54	1.47
Mean	1.15	1.14	1.13	1.15	1.18	1.20	1.22	1.23	1.29	1.29	1.28	1.34
SD	0.08	0.07	0.08	0.09	0.08	0.08	0.08	0.08	0.10	0.09	0.10	0.08
SEM	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Head length (Hl) growth dynamics are represented in Figure 8 and Table 11. In regard to the head length and based on the statistical analysis, no statistically significant differences were recorded between treatments during any of the phases of the experiment. Mean individual head length at the end of the experiment ranged between 3.03 cm and 3.18 cm, with the biggest mean head length recorded for the Treatment C. In experimental Treatment C, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 3.87 cm, meaning that one specimen from Treatment C grew at least 0.65 cm in head length, taking into consideration that the biggest head length for a specimen at the beginning of the experiment from Treatment C was 3.22 cm.

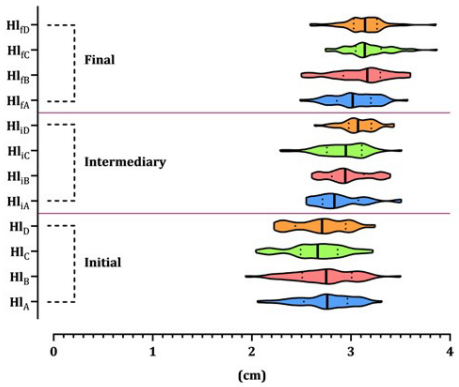


Figure 8. Growth dynamics regarding head length (Hl) across treatments and experiment phases.

Table 11. Descriptive statistics of growth dynamics regarding head length (Hl)

	HlA (cm)	HlB (cm)	HlC (cm)	HlD (cm)	HliA (cm)	HliB (cm)	HliC (cm)	HliD (cm)	HlfA (cm)	HlfB (cm)	HlfC (cm)	HlfD (cm)
Minimum	2.06	1.94	2.04	2.22	2.55	2.61	2.29	2.63	2.49	2.50	2.74	2.59
Median	2.76	2.75	2.67	2.71	2.83	2.94	2.95	3.07	3.02	3.17	3.14	3.14
Maximum	3.31	3.51	3.22	3.24	3.51	3.40	3.51	3.44	3.57	3.60	3.87	3.86
Mean	2.75	2.73	2.65	2.68	2.89	2.97	2.92	3.08	3.03	3.10	3.18	3.13
SD	0.28	0.32	0.28	0.27	0.24	0.22	0.24	0.17	0.23	0.29	0.23	0.21
SEM	0.04	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.03	0.04	0.03	0.03

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Caudal peduncle length (Pl) growth dynamics are represented in Figure 9 and Table 12. In regard to the caudal peduncle length and based on the statistical analysis, statistically significant differences were identified during the final measurements, between Treatment A and Treatment C (**, $p < 0.0001$) and between Treatment B and Treatment C (*, $p = 0.0309$). For the purpose of analyzing the performances of slug meal as an alternative protein source to fish meal, these statistically significant differrences are not relevant, because the differrences are between two experimental groups which were fed the same diet containing slug meal, and not between an experimental group and the control group. Also, the measurement of the caudal peduncle length is susceptible to human error, due to the fact that you must rely on an imaginary line described from the end point of the base of the anal fin towards the top of the caudal peduncle, which stands as the anterior point of measurement from where you measure towards the middle of the base of the caudal fin. Mean individual caudal peduncle length at the end of the experiment ranged between 1.63 cm and 1.80 cm, with the biggest mean caudal peduncle length recorded for the Treatment A. In experimental Treatment A, it is noticeable that the biggest measurement for a specimen from the experiment was recorded at 2.24 cm, meaning that one specimen from Treatment A grew at least 0.22 cm in caudal peduncle length, taking into consideration that the biggest caudal peduncle length for a specimen at the beginning of the experiment from Treatment A was 2.02 cm.

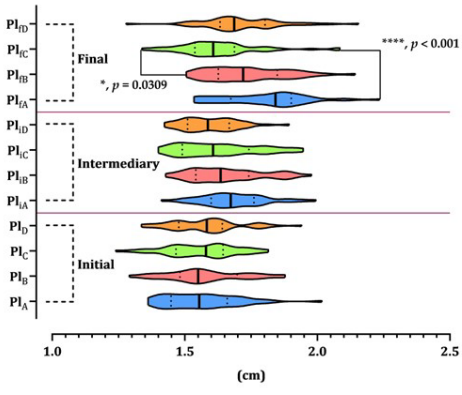


Figure 9. Growth dynamics regarding caudal peduncle length (Pl) across treatments and experiment phases

Table 12. Descriptive statistics of growth dynamics regarding caudal peduncle length (Pl)

	PlA (cm)	PlB (cm)	PlC (cm)	PlD (cm)	PliA (cm)	PliB (cm)	PliC (cm)	PliD (cm)	PlfA (cm)	PlfB (cm)	PlfC (cm)	PlfD (cm)
Minimum	1.36	1.29	1.24	1.34	1.41	1.43	1.40	1.42	1.54	1.51	1.34	1.28
Median	1.55	1.55	1.58	1.58	1.67	1.64	1.61	1.59	1.84	1.72	1.61	1.69
Maximum	2.02	1.88	1.82	1.94	2.00	1.98	1.95	1.89	2.24	2.14	2.09	2.16
Mean	1.57	1.58	1.56	1.58	1.68	1.66	1.63	1.60	1.80	1.74	1.63	1.71
SD	0.14	0.14	0.13	0.13	0.12	0.14	0.15	0.10	0.16	0.15	0.16	0.15
SEM	0.02	0.02	0.02	0.02	0.02	0.02	0.02	0.01	0.02	0.02	0.02	0.02

Legend: SD – standard deviation of mean; SEM – standard error of mean.

Discussions

Palatability is a crucial characteristic of any animal feed. Aquaculture feeds with palatability issues are easily refused or not consumed in sufficient amounts, directly affecting the growth process (Dworjanyn et al., 2007). Without prior knowledge, if fish accept feed containing slug meals, the palatability of the experimental feed was not demonstrated until we tested it. From how the experiment went on, we can state that feed containing slug meal as an alternative protein source is readily accepted by carp (*Cyprinus carpio*). The fish from the experiment consumed the feed throughout the experiment and were observed to come to the feed every time with the same drive as the fish from the control treatment. Previous studies that utilized other gastropods as alternative protein sources for aquaculture feeds highlight success in having the alternative feed accepted by the reared organisms (Bombeo-Tuburan et al., 1995; Santanumurti et al., 2022).

Evaluating body weight gain and morphometric developments represents valuable insight on how feed influences growth. The results of the growth dynamics analysis for body weight gain and body measurements development when comparing feed containing slug meal as an alternative protein source to feed containing fish meal as a protein source shows no relevant statistically significant differences. This shows that the potential of slug meal is real and can successfully be used as an alternative protein source in aquaculture feeds. Previous studies show the potential of other gastropods to be utilized as alternative protein sources to conventional ingredients in rearing various aquaculture species (Jintasataporn et al., 2004; Suresh, 2007; Ovie & Adejayan, 2010; Muntean et al., 2024a), and this opens the way for slug meal to be tested on the growth of more aquatic animals, and to enrich the knowledge on this protein source.

Optimization of animal feeds is a key aspect in delivering the best results in growth (Sirdeshmukh & Shembekar, 2019). After seizing the potential of a new protein source, in depth research on it needs to be conducted to see how it can be properly processed and incorporated in feed. The feeds utilized in this research were not optimized for the growth of juvenile carp. The research purpose was to have an experimental feed and a control feed that are as similar as possible, except their animal protein ingredient, for the best initial comparison of consecrated fish meal with slug meal as an alternative protein source. Further research on slug meal must be conducted, to completely understand what makes it a good protein source and enhance its results and what can inhibit growth and how to mitigate negative effects.

Terrestrial slug species are found throughout the world, in various climates, and this enhances their potential to be utilized as alternative protein sources. Some species, like in the case of the Spanish slug (*Arion vulgaris*) are considered invasive and pests in many regions (Zemanova et al., 2016), causing environmental and agricultural damage. Practical use for them can help the fight against their spread by collecting them and not utilizing environmentally unfriendly methods (Schüder et al., 2003), which put at risk native lifeforms.

Finding truly successful alternatives to fish meal, cost and economic aspects are paramount. The nature and scale of the present study is not shedding enough light on these aspects. The high availability of invasive slugs is a favourable economic aspect, but economic research and insight must advance further regarding this topic. Technological research is required as well for the improvement of slug collection and processing to slug meal.

CONCLUSIONS

Utilization of slug (*Arion vulgaris*) meal as an alternative protein source in an aquaculture feed tested on juvenile carp (*Cyprinus carpio*) showed no statistically significant differences when compared to a similar feed that contained fish meal as a conventional protein source. The experimental feed was accepted in the same manner as the control feed, thus highlighting the palatability potential of slug meal. All specimens of carp survived the experiment in its entirety. These results and the lack of knowledge for the topic, motivate the need for further research, but the potential of slug meal as an alternative protein source for aquaculture feeds is there to be explored.

ACKNOWLEDGEMENTS

This work was carried out through the Core Program within the National Research Development and Innovation Plan 2022–2027, with the support of MCID, project no. PN 23 05.

REFERENCES

Adéyèmi, A. D., Kayodé, A. P. P., Chabi, I. B., Odouaro, O. B. O., Nout, M. J. R., & Linnemann, A. R. (2020). Screening local feed ingredients of Benin, West Africa, for fish feed formulation. *Aquaculture Reports*, 17, 100386. https://doi.org/10.1016/j.aqrep.2020.100386

Baki, B., & Yücel, Ş. (2017). Feed cost/production income analysis of seabass (*Dicentrarchus labrax*) aquaculture. *International Journal of Ecosystems and Ecology Sciences IJE*, 7(4), 859–864.

Bombeo-Tuburan, I., Fukumoto, S., & Rodriguez, E. M. (1995). Use of the golden apple snail, cassava, and maize as feeds for the tiger shrimp, Penaeus monodon, in ponds. *Aquaculture*, 131(1–2), 91–100.

Das, P. P. G., Bhattacharyya, B., Bhagawati, S., Devi, E. B., Manpoong, N. S., & Bhairavi, K. S. (2020). Slug: An emerging menace in agriculture: A review. *Journal of Entomology and Zoology Studies*, 8(4), 01–06.

Diarra, S. S. (2015). Utilisation of snail meal as a protein supplement in poultry diets. *World's Poultry Science Journal*, 71(3), 547–554.

Dworjanyn, S. A., Pirozzi, I., & Liu, W. (2007). The effect of the addition of algae feeding stimulants to artificial diets for the sea urchin *Tripneustes gratilla*. *Aquaculture*, 273(4), 624–633.

Food and Agriculture Organization (FAO) (2022). *The state of world fisheries and aquaculture – Towards blue transformation.* Food and Agriculture Organization of the United Nations, Rome, 266 pp.

Food and Agriculture Organization (FAO) (2004). *Protein sources for the animal feed industry*. Expert Consultation and Workshop Bangkok, 29 April - 3 May 2002, 390 pp.

Food and Agriculture Organization (FAO) (2024). *The state of world fisheries and aquaculture 2024 – Blue transformation in action*. Food and Agriculture Organization of the United Nations, Rome, 264 pp.

Freitas, J., Vaz-Pires, P., & Câmara, J. S. (2020). From aquaculture production to consumption: Freshness, safety, traceability and authentication, the four pillars of quality. *Aquaculture*, 518, 734857. https://doi.org/10.1016/ j.aquaculture.2019.734857

Jintasataporn, O., Tabthipwon, P., & Yenmark, S. (2004). Substitution of golden apple snail meal for fishmeal in giant freshwater prawn, *Macrobrachium rosenbergii* (de Man) Diets. *Kasetsart J. (Nat. Sci.)*, 38, 66–71.

Kaensombath, L. (2005). Evaluation of the nutritive value of ensiled and fresh golden apple snails (*Pomacea* spp.) for growing pigs. *MSc. Thesis, Swedish University of Agricultural Sciences.*, 10 p.

Lațiu, C. (2025). A digital approach to fish morphometry: Advancing animal welfare and biodiversity conservation. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Animal Science and Biotechnologies*, 82(1), 51–57.

Lațiu, C., Ujică, P.L., Constantinescu, R., Păpuc, T., Muntean, G.C., Uiuiu, P., Cocan, D., Matei-Lațiu, M. C., & Martonos, C. (2024). Consumer perception on aquaculture goods and services in Romania. *Scientific Papers. Series D. Animal Science.*, LXVII(1), 697–706.

Luthada-Raswiswi, R., Mukaratirwa, S., & O'Brien, G. (2021). Animal protein sources as a substitute for fishmeal in aquaculture diets: A systematic review and meta-analysis. *Applied Sciences*, 11(9), 3854. https://doi.org/10.3390/ app11093854

Masithoh, R. E., Amanah, H. Z., & Cho, B. K. (2020). Application of Fourier Transform Near-Infrared (FT-NIR) and Fourier Transform Infrared (FT-IR) spectroscopy coupled with wavelength selection for fast discrimination of similar color of tuber flours. *Indonesian Journal of Chemistry*, 20(3), 680. https://doi.org/ 10.22146/ijc.48092

Mead, A. R. (1961). The giant African snail: A problem in economic malacology. *The University of Chicago Press, Chicago & London*, 160-171 pp.

Mead, A. R., & Kemmerer, R. (1953). Amino acid content of dehydrated African snails (*Achatina fulica* Bowdich). *Science*, 117, 138-139.

Muntean, G.C., Lațiu, C., Uiuiu, P., Constantinescu, R., Mireșan, V., Păpuc, T., Becze, A., Cocan, D., & Coroian, A. (2024a). Gastropods use as an alternative protein source in aquaculture feeds - Short review. *Scientific Papers. Series D. Animal Science.*, LXVII(1), 736–744.

Muntean, G.C., Simedru, D., Uiuiu, P., Tanaselia, C., Cadar, O., Becze, A., & Coroian, A. (2024b). Evaluation of alternative sources of proteins and other nutrients with potential applications in fish nutrition. *Molecules*, 29(10), 2332. https://doi.org/10.3390/molecules29102332

Nagappan, S., Das, P., AbdulQuadir, M., Thaher, M., Khan, S., Mahata, C., Al-Jabri, H., Vatland, A. K., Kumar, G. (2021). Potential of microalgae as a

sustainable feed ingredient for aquaculture. *Journal of Biotechnology*, 341, 1–20.

Ovie, S. O., & Adejayan, A. B. (2010). Effects of supplementing fish meal with garden snail (*Limicolaria* spp.) in *Clarias gariepinus* diets. *Report and Opinion*, 2(1), 58–62.

Păpureanu, A.M., Reise, H., & Varga, A. (2014). First records of the invasive slug *Arion lusitanicus* auct. non Mabille (Gastropoda: Pulmonata: Arionidae) in Romania. *Malacologica Bohemoslovaca*, 13, 6–11.

Pfenninger, M., Weigand, A., Bálint, M., & Klussmann-Kolb, A. (2014). Misperceived invasion: The Lusitanian slug (*Arion lusitanicus* auct. non-Mabille or *Arion vulgaris* Moquin-Tandon 1855) is native to Central Europe. *Evolutionary Applications*, 7(6), 702–713.

Phonekhampheng, O., Hung, L. T., & Lindberg, J. E. (2009). Ensiling of golden apple snails (*Pomacea canaliculata*) and growth performances of African catfish (*Clarias gariepinus*) fingerlings fed diets with raw and ensiled golden apple snails as protein source. *Livestock Research for Rural Development*, 21(2), 1–9.

Rana, M., Haq, I., Hossain, I., Talha, A., Zafar, A., & Methun, I. H. (2022). Growth performance and economic analysis of swamp eel (*Monopterus cuchia*): An application of Cobb-Douglas production function. *Aquaculture Studies*, 23(4), https://doi.org/10.4194/AQUAST990.

Santanumurti, M. B., Sidik, J., Putri, B., & Hudaidah, S. (2022). Effects of *Moina* sp. [Straus, 1820] adding of snail flour to increase the larvae performance of jelawat fish (*Leptobarbus hoevenii* [Bleeker, 1851]). *IOP Conference Series: Earth and Environmental Science*, 1036(1), 012116. https://doi.org/10.1088/1755-1315/1036/1/012116

Schüder, I., Port, G., & Bennison, J. (2003). Barriers, repellents and antifeedants for slug and snail control. *Crop Protection*, 22(8), 1033–1038.

Serra, V., Pastorelli, G., Tedesco, D. E. A., Turin, L., Guerrini, A. (2024). Alternative protein sources in aquafeed: Current scenario and future perspectives. *Veterinary and Animal Science*, 25, 100381. https://doi.org/10.1016/j.vas.2024.100381

Sirdeshmukh, U. P., & Shembekar, D. V. S. (2019). Feed formulation and optimization of fish feed for different developmental stages of Indian major carps from spawn to marketable size fish stage. *JETIR*, 6(6), 654–659.

Sogbesan, A. O., Ugwumba, A. A. A. (2006). Nutritive potentials and utilization of garden snail (*Limicolaria aurora*) meat meal in the diet of *Clarias gariepinus* fingerlings. *African Journal of Biotechnology*, 5(20), 1999–2003.

Suresh, V. R. (2007). Giant African snail meat as dietary animal protein source for common carp (*Cyprinus carpio* var. Communis Linn.). *Indian J. Fish.*, 54(2), 203–210.

Tshernyshev, S. E., Babkina, I. B., Modyaeva, V. P., Morozova, M. D., Subbotina, E. Y., Shcherbakov, M. V., & Simakova, A. V. (2022). Invertebrates of Siberia, a potential source of animal protein for innovative food production. 1. The keelback slugs (Gastropoda: Limacidae). *Acta Biologica Sibirica*, 8, 749–762.

Visca, M. D. J., & Palla, S. Q. (2018). Golden apple snail, *Pomacea canaliculata* meal as protein source for rabbitfish, *Siganus guttatus* culture. *AACL Bioflux*, 11(2), 533–542.

Vrabec, V., Kulma, M., & Cocan, D. (2015). Insects as an alternative protein source for animal feeding: A short review about chemical composition. *Bulletin of University of Agricultural Sciences and Veterinary Medicine Cluj-Napoca. Animal Science and Biotechnologies*, 72(2), 116–126.

Zając, K. S., Gaweł, M., Filipiak, A., & Kramarz, P. (2017). *Arion vulgaris* Moquin-Tandon, 1855 – the aetiology of an invasive species. *Folia Malacologica*, 25(2), 81–93.

Zemanova, M. A., Knop, E., & Heckel, G. (2016). Phylogeographic past and invasive presence of *Arion* pest slugs in Europe. *Molecular Ecology*, 25(22), 5747–5764.