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GASTROPODS USE AS AN ALTERNATIVE PROTEIN SOURCE IN AQUACULTURE FEEDS - SHORT REVIEW

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Abstract

Alternative protein sources to replace fish meal in aquaculture feeds are continuously sought after. The fish meal industry is unsustainable, from an economic point of view and because of its impact on wild aquatic ecosystems. This review presents the use of gastropod species (class Gastropoda) in aquaculture feeds. Gastropods have been studied for their potential use in aquaculture feeds, mainly as an alternative source of protein to fish meal. Gathered studies from various databases encompass gastropods nutritional value, and their performance in rearing aquatic organisms. Fish meal replacement with meals sourced from gastropods is closely analysed in this paper. Synthesized information from this review will benefit future research on this subject.

***Key words**: animal protein, fish rearing, Gastropoda, nutrition.*

INTRODUCTION

Aquaculture productions are on a rising trend, according to the Food and Agriculture Organization (FAO 2022). Global needs regarding food and its availability determine the aquaculture sector development and progress. Improving economic efficiency and reducing the impact on the environment is paramount for the aquaculture sector. Feed cost is the biggest expenditure in aquaculture (Baki & Yucel, 2017). A significant part of this cost is represented by the protein sources used in manufacturing the feed. The most utilized protein source in aquaculture feeds is fish meal (FAO 2004). Fish meal is very nutritious, but its price is continuously rising because necessary raw matter becomes harder to procure and the exploitation of small oceanic fish suitable for its production has a direct negative impact on the environment.
The research of alternative protein sources is ongoing for years. Due to better chemical composition, animal protein sources are preferred over plant protein sources. Various animal protein sources are investigated, such as insects, larvae, food processing by-products etc. (Vrabec et al., 2015; Luthada-Raswiswi et al., 2021; Rapatsa & Moyo, 2022).
Gastropoda class encompasses species such as snails and slugs. This class has over 62000 species of aquatic and terrestrial snails and slugs (www.ucmp.berkeley.edu). These invertebrates' potential as an alternative protein source has been investigated in animal husbandry, mostly for poultry and in some instances for swine (Mead, 1961; Creswell & Habibie, 1981; Creswell & Kompiang, 1981; Ali & Leeson, 1995; El-Deek et al., 2002; Diomandé at al., 2008a,b; Ahaotu et al., 2013; Diarra, 2015; Malvar & Agapito, 2020; Dharmawati et al., 2022).
Naturally, gastropods are part of the diet of numerous species reared in aquaculture. Gastropods have been studied as possible candidates in aquaculture for the replacement of conventional protein sources. The aim of this short review was to present research conducted by scientists for the use of gastropods as an alternative protein source in aquaculture feed. This synthesised and centralised information will benefit future research in this direction.

MATERIALS AND METHODS

Studies on the use of gastropods as an alternative protein source have been gathered for this short review. Relevant scientific databases were browsed using predefined search words. Alphabetically, these databases are: CABI Digital Library ebooks; CABI VETMED Resource; Elsevier Ebooks; IEEE – NOW

Foundation ebook Collection; iGroup - American Library Association Ebook Collection; InCites Benchmarking and Analytics; Sage eBooks Collection; ScienceDirect Freedom Collection, Elsevier; Scopus, Elsevier; SpringerLink Journals; Web of Science; Wiley Ebooks; Wiley Journals. Alphabetically, predefined search terms used to browse all the mentioned databases are: gastropod flour; gastropod meal; gastropod meat; hepatopancreas meal; slug flour; slug meal; slug meat; snail flour; snail meal; snail meat; snail viscera flour; snail viscera meal.

Studies relevant to this review were selected and processed based on the following inclusion methodology. Papers that present nutritional information on gastropod species were selected and mentioned in a table structured on the systematics of the Gastropoda class. Valid scientific names for each identified mention are presented and proper identification was conducted using the WoRMS database (www.marinespecies.org). The table contains two categories of citations: unmarked citations with general information about the nutritional value of gastropods including citations that present the use of gastropods in animal husbandry, and citations marked with an asterisk that present the use of gastropods in aquaculture. Studies in which gastropods were used as an alternative protein source in aquaculture feeds were then presented in regard to the taxonomy of used gastropods, nutritional value, and effects on farmed aquatic organisms.

RESULTS AND DISCUSSIONS

Table 1 displays citations to various research conducted on gastropods. These studies include general knowledge on nutritional potential of gastropods, gastropods use in animal husbandry feeds and gastropods use in aquaculture feeds. All research conducted on various species of gastropods nutritional value is relevant, and we brought it forward in this review, because it can help future research on gastropods use as an alternative protein source in aquaculture feeds.

The focus of this short review was to gather available knowledge on the use of gastropods in aquaculture feeds. In continuation, all identified papers related to this topic are briefly presented.

Smoked fish waste and snail (*Pila ampullacea*) meal were utilized in the diet of catfish (*Clarias* sp.) (Nurhayati et al., 2020). When only snail meal was utilized, the feed conversion rate was the highest and the growth performance was the lowest. When using 10% snail meal along 90% smoked fish waste, the results were the best for growth and feed conversion rate.

Pila globosa meal was utilized as a protein source for rearing blue gourami (*Trichogaster trichopterus*) fingerlings (Mohanta et al., 2013). *Pila globosa* proximate composition represented 525 g kg^{-1} dry matter crude protein, 40 g kg^{-1} dry matter ether extract, 160 g kg^{-1} dry matter ash, 275 g kg^{-1} dry matter total carbohydrate and 14.88 MJ kg^{-1} calculated digestible energy. Performance of fish reared using snail meal based diets was not satisfactory compared to other sources of protein analysed, and the authors could not justify the reason for this poor performance.

Mohanta et al. (2015) studied *Pila globosa* meal as a protein source for guppy (*Poecilia reticulata*) fingerlings. *Pila globosa* proximate composition represented 516.2 g/kg dry matter crude protein, 40 g/kg dry matter ether extract, 155.8 g/kg dry matter ash, 288 g/kg dry matter total carbohydrate and 14.95 MJ/kg calculated digestible energy. Authors consider that because they used a high level of incorporation of snail meal (30%), guppies manifested poor growth and nutrient utilization.

In Bombeo-Tuburan et al. (1995) study, different combinations of golden snail meat (*Pomacea canaliculata*), maize and cassava were used to feed tiger shrimp (*Penaeus monodon*). Proximate analysis of snail meat displayed contents (% dry matter) of 54.3% crude protein, 1.4% crude fat, 2% crude fibre, 20.4% nitrogen-free extract and 21.9% ash. *Pomacea canaliculata* represents a good source of linoleic acid, α-linolenic acid, and eicosapentaenoic acid, which are required for the good growth of *Penaeus monodon*. The golden snail had a favourable essential amino acid index of 0.84, which shows it is a good protein source for tiger shrimp rearing.

Jintasataporn et al. (2004) studied *Pomacea canaliculata* use as replacement of fish meal in the diet of giant freshwater prawn (*Macrobrachium resenbergii*). Snail meal had a protein digestibility of 86.36%, which is close to the value of fish meal digestibility of 88.69%.

Table 1. Systematic presentation of identified relevant studies on gastropods nutritional value.

Order	Family	Mentioned species	Accepted name of mentioned species	Reference
Architaenioglossa	Ampullariidae	*Pila ampullacea*	*Pila ampullacea* (Linnaeus, 1758)	1*
		Pila globosa	*Pila globosa* (Swainson, 1822)	2, 3*, 4*
		Pomacea canaliculata	*Pomacea canaliculata* (Lamarck, 1822)	5, 6, 7*, 8*, 9, 10, 11*, 12, 13*, 14, 15, 16, 17*, 24*, 84*
		Pomacea paludosa	*Pomacea paludosa* (Say, 1829)	18
		Pomacea spp.	*Pomacea* spp.	19*, 20*, 21*, 22*, 23*, 25, 26*, 27*, 28*, 29, 30, 31
	Viviparidae	*Viviparus* spp.	*Viviparus* spp.	32*
Caenogastropoda	Cerithiidae	*Cerithium* spp.	*Cerithium* spp.	7*
	Pachychilidae	*Faunus ater*	*Faunus ater* (Linnaeus, 1758)	33*
Neogastropoda	Buccinidae	*Buccinum striatissimum*	*Buccinum striatissimum* G. B. Sowerby III, 1899	34*, 35*
	Muricidae	*Rapana venosa*	*Rapana venosa* (Valenciennes, 1846)	36, 37*, 38*
Stylommatophora	Achatinidae	*Limicolaria aurora*	*Limicolaria aurora* (Jay, 1839)	39*, 40*, 41*
		Limicolaria flammea	*Limicolaria flammea* (O. F. Müller, 1774)	42*, 43*
		Limicolaria spp.	*Limicolaria* spp.	44, 45, 46, 82*
		Achatina achatina	*Achatina achatina* (Linnaeus, 1758)	44, 45, 46, 47, 48, 49*
		Achatina fulica	*Lissachatina fulica* (Bowdich, 1822)	45, 50, 51, 52, 53, 54, 55, 56, 57, 48, 83*
		Achatina spp.	*Achatina* spp.	58
		Archachatina degneri	*Archachatina degneri* Bequaert & Clench, 1936	47
		Archachatina marginata	*Archachatina marginata* (Swainson, 1821)	44, 59, 45, 46, 47, 60, 61, 48, 49*
		Archachatina spp.	*Archachatina* sp.	62
	Helicidae	*Eobania vermiculata*	*Eobania vermiculata* (O. F. Müller, 1774)	63
		Helix aperta	*Cantareus apertus* (Born, 1778)	63
		Helix aspersa, Helix aspersa maxima	*Cornu aspersum* (O. F. Müller, 1774)	64, 52, 63, 65, 66, 67, 68
		Helix lucorum	*Helix lucorum* Linnaeus, 1758	63, 65, 69, 70
		Helix pomatia	*Helix pomatia* Linnaeus, 1758	52, 63, 65, 71, 72
		Helix spp.	*Helix* spp.	73, 74, 77*, 78*
		Otala lactea	*Otala lactea* (O. F. Müller, 1774)	75
		Theba pisana	*Theba pisana* (O. F. Müller, 1774)	75, 76
Species not mentioned				79*, 80, 81*

Note: * Studies in which gastropods were used in aquaculture feeds.
References: 1 - Nurhayati et al., 2020; 2 - Ali & Leeson, 1995; 3 - Mohanta et al., 2013; 4 - Mohanta et al., 2015; 5 - Budiari et al., 2021; 6 - Ghosh et al., 2017; 7 - Hertrampf & Piedad-Pascual, 2000; 8 - Jintasataporn et al., 2004; 9 - Luo et al., 2015; 10 - Malvar & Agapito, 2020; 11 - Pertiwi & Saputri, 2020; 12 – PhilRice, 2001; 13 - Phonekhampheng et al., 2009; 14 - Rattanaporn et al., 2006; 15 - Sumiati et al., 2020; 16 - Ulep et al., 1991; 17 - Visca & Palla, 2018; 18 - Dharmawati et al., 2022; 19 - Bombeo-Tuburan et al., 1995; 20 - Chimsung & Tantikitti, 2014; 21 - Da et al., 2012; 22 - Da et al., 2013; 23 - Da et al., 2016; 24 - Heuzé & Tran, 2017; 25 - Kaensombath, 2005; 26 - Muchlisin et al., 2020; 27 - Santanumurti et al., 2022; 28 - Serra, 1997; 29 - Subhan et al., 2010; 30 - Syaharuddin et al, 2019; 31 - Tami et al., 2017; 32 - Anisuzzaman et al., 2012; 33- Aaqillah-Amr et al., 2022; 34 - Moss et al., 2018a; 35 - Moss et al., 2018b; 36 - Özden & Erkan, 2011; 37 - Sahin et al., 2021; 38 - Sahin & Ergün, 2021; 39 - Adéyèmi et al., 2020; 40 - Sogbesan & Ugwumba, 2008; 41 - Sogbesan et al., 2006; 42 - Imodagbe et al., 2021; 43 - Imodagbe et al., 2020; 44 - Adeyeye & Afolabi, 2004; 45 - Babalola & Akinsoyinu, 2009; 46 - Fagbuaro et al., 2006; 47 - Imevbore, 1990; 48 - Nkansah et al., 2021; 49 - Okanlawon & Oladipupo, 2010; 50 - Creswell & Habibie, 1981; 51 - Creswell & Kompiang, 1981; 52 - Diarra, 2015; 53 - Diarra et al., 2015; 54 - Diomandé et al., 2008a; 55 - Diomandé et al., 2008b; 56 - Garnadi, 1951; 57 - Mead & Kemmerer, 1953; 58 - Jehemat & Koni, 2013; 59 - Amobi et al., 2019; 60 - Imevbore & Ademosun, 1988; 61 - Kalio & Etela, 2011; 62 - Ahaotu et al., 2013; 63 - Dragićevic & Baltić, 2005; 64 - Çağiltay et al., 2011; 65 - Gomot, 1998; 66 - Gorka et al., 2017; 67 - Milinsk et al., 2006; 68 - Milinsk et al., 2003; 69 - Olgunoğlu & Olgunoğlu, 2008; 70 - Olgunoğlu & Olgunoğlu, 2009; 71 - Ikauniece, 2014; 72 - Özogul et al., 2005; 73 - Corda et al., 2014; 74 - Zymantiene et al., 2008; 75 - Caetano et al., 2021; 76 - El-Deek et al., 2002; 77 - Jones & De Silva, 1997; 78 - Jones et al., 1996; 79 - Rana et al., 2022; 80 - Suryadi et al., 2022; 81 - Verhoef et al., 1998; 82 - Ovie & Adejayan, 2010; 83 - Suresh, 2017; 84 - Cagauan & Doria, 1989.

Diets that replaced fish meal with 25% and 50% showed the best results regarding specific growth rate.

In Pertiwi and Saputri (2020) study, *Pomacea canaliculata* meal was utilized as a fish meal substitute in the diets of *Pangasius* sp. (*Pangasianodon* sp. accepted name). Different inclusion levels of snail meal were utilized, the best results being obtained for the diet that incorporates 10% snail meal as fish meal substitute.

Simple golden apple snail (*Pomacea canaliculata*) meal, ensiled golden apple snail meal with 5% citric acid and ensiled golden apple snail meal with 20% sugar-cane molasses was utilized in the diets of *Clarias gariepinus* (Phonekhampheng et al., 2009). Weight gain of *Clarias gariepinus* showed improvements when these ingredients were utilized as fish meal replacements.

Visca and Palla (2018) tested the potential of golden apple snail (*Pomacea canaliculata*) meal in the diet of rabbitfish (*Siganus guttatus*) as an alternative protein source. According to the results, feed with 45% protein content obtained from golden apple snail meal can successfully substitute fish meal for more than two months.

Chimsung & Tantikitti (2014) reared sex-reversed tilapia (*Oreochromis niloticus* x *Oreochromis mossambicus*) using golden apple snail (*Pomacea* spp.) meat meal (GAS) and fermented golden apple snail (FGAS). Proximate analysis of both ingredients showed 49.54±0.40% protein for GAS and 39.11%±0.38% protein for FGAS, 0.83%±0.15% fat for GAS and 0.75±0.04% fat for FGAS, 13.98±0.21% ash for GAS and 3.62±0.03% ash for FGAS. Authors recommend for the best results the use of 75% FGAS replacement of fish meal, but it is also possible to use 50% GAS as a replacement for fish meal.

Da et al. (2012, 2013, 2016) researched golden apple snail (*Pomacea* spp.) meal and other protein sources use as a fish meal replacement in the diet of *Pangasianodon hypophthalmus*. Proximate analysis of golden apple snail meal showed 564 g protein content/kg DM, 16 g lipid content/kg DM, 10 g crude fibre/kg DM, 239 g neutral detergent fibre/kg DM, 118 g ash/kg DM and 12.3 MJ gross energy/kg DM. Total essential amino acid value for golden apple snails was of 174.5 g/kg DM. Golden apple snail meal had the lowest value for gross energy among other tested ingredients but ranked second for the total essential amino acid value. Regarding digestibility, it's concluded that there is no adverse effect on digestibility of feed when golden apple snails are used as a replacement for fish meal. The visceral somatic index ranked highest for the diet containing golden apple snail meal.

Muchlisin et al. (2020) used golden snail (*Pomacea* spp.) meal in the diet of short-fin eel (*Anguilla bicolor*). Crude protein content of snail meal was of 51.8%.

Santanumurti et al. (2022) studied the enrichment of *Moina* spp. with golden snail (*Pomacea* spp.) meal and its effects on the growth and survival of jelawat fish (*Leptobarbus hoevenii*) larvae. Snail meal proximate composition had 55.21% protein, 3% fat and 10.48% ash. Using 4 g/l and 8 g/l of snail meal on *Moina* spp., resulted in good growth and survival rates of *Leptobarbus hoevenii* larvae.

Serra (1997) presents the results of Cagauan and Doria (1989), which studied the use of the golden apple snail (*Pomacea* spp.) meal as feed ingredient for Nile tilapia (*Oreochromis niloticus*). Results indicated better growth for solely using golden snail meal and 3:1 ratio of golden snail meal and rice bran.

Anisuzzaman et al. (2012) studied in Bangladesh the potential of a freshwater species of snails (*Viviparus* sp.) to be used in fish feeds. The results from the culture trial of *Viviparus* sp. showed that freshwater snails are cost effective to be used in the production of fish feed.

Aaqillah-Amr et al. (2022) studied *Faunus ater* biochemical composition as a possible candidate for orange mud crab (*Scylla olivacea*) feed formulation. The analysis showed dry matter contents of 46.26±3.76% protein, 4.6±0.29% lipid, 0.21±0.04% fibre and 26.73±1.33% ash. *Faunus ater* was not used as an ingredient, because of lower lipid and protein content than the mangrove clam (*Polymesoda erosa*), and due to the low meat yields.

Moss et al. (2018a, 2018b) studied snail (*Buccinum striatissimum*) meal incorporation in the diets of *Marsupenaeus japonicus*. Snail meal was utilized for the replacement of squid meal and krill meal in juvenile *Marsupenaeus japonicus* diets. An increase in growth was observed for the replacement of 75% to 100% of squid and krill meals with *Buccinum striatissimum* meal. The shells of *Buccinum striatissimum* were utilized as a source of calcium for *Marsupenaeus japonicus*. Using 10% snail shells powder in the diets of *Marsupenaeus japonicus* showed overall improvements in growth performance and survival rate.

In Sahin et al. (2021) research, rapa whelk (*Rapana venosa*) meal was utilized as a replacement of fish meal in the feed used for rainbow trout (*Oncorhynchus mykiss*) and various reproductive traits, histopathologic aspects and blood parameters were analysed. Crude protein content of *Rapana venosa* meal was of 71.50% and crude fat content of 2.01%. Inclusion of *Rapana venosa* meal of up to 50 g/kg in feed did not affect the studied parameters, but the inclusion of more than 50 g/kg can lead to pathological issues in blood and tissue.

In Sahin and Ergün (2021) study, rapa whelk (*Rapana venosa*) meal was used in the diet of rainbow trout (*Oncorhynchus mykiss*) fry. At 5% inclusion rate along fish meal, rapa whelk meal did not have a negative effect on growth, body composition, survival, hepatosomatic index and digestive enzymes action.

Whole garden snail (*Limicolaria aurora*) nutritional potential as a fish feed ingredient was analysed (Adéyèmi et al., 2020). The proximate composition showed contents of 970.6±5.4 g/kg DM dry matter, 698.0±75.1 g/kg DM ash, 171.3±15.4 g/kg DM protein, 37.3±17.6 g/kg DM fat, 3.2±0.7 g/kg DM fibre, 64±41.5 g/kg DM carbohydrates. Based on comparisons with other ingredients, Adéyèmi et al. (2020) classified the garden snail (*Limicolaria aurora*) as a good mineral source.

In Sogbesan and Ugwumba (2008), the potential as a fish meal supplement in aquaculture of the garden snail (*Limicolaria aurora*) was investigated. Garden snail meal contained (% dry matter) 66.8±3.6% crude protein, 7.9±2.3% crude lipid, crude fibre 4.1±0.9%, 5.8% nitrogen free extract, 6.5±0.5% ash and 2006±3.46 kJ gross energy/100 g. Mineral content of garden snail meal was of 2.32±0.06 g sodium/100 g, 1.13±0.08 g calcium/100 g, 2.23±0.06 g potassium/100 g, 0.15±0.02 g phosphorus/100 g and 0.28±0.04 g magnesium/100 g. Total amino acids from garden snail meal ranked highest (50.06±2.89 g/16 g N) among other tested protein sources of animal origin.

Sogbesan et al. (2006), tested garden snail (*Limicolaria aurora*) meal in the feed of *Clarias gariepinus* fingerlings as a protein source. Garden snail meal proximate composition of dry matter contained 66.76% crude protein, 7.85% crude fat, 5.81% nitrogen free extract, 4.1% ash and 478.35 kcal gross energy /100 g. Optimum growth was noticed for the replacement of fish meal with 25% garden snail meal.

Garden snail meal (*Limicolaria flammea*) meal utilization as feed for *Heterobranchus bidorsalis* was researched by Imodagbe et al. (2020, 2021). Proximate composition of garden snail (*Limicolaria flammea*) meal had 60.13 g crude protein/100 g, 8.5 g crude lipid/100 g, 2.47 g crude fibre/100 g, 8.64 g nitrogen-free extract/100 g and 10.33 g ash/100 g. Weight gain increases were observed for the replacement of fish meal with up to 75% garden snail meal. Best results were observed for the inclusion of 25% garden snail meal. Profit maximization was also observed for the replacement of fish meal with 25% to 50% garden snail meal. At a 25% inclusion rate of garden snail meal, *Heterobranchus bidorsalis* meat biochemical composition showed the biggest protein content and the highest amount of total amino acids.

Ovie and Adejayan (2010) used the garden snail (*Limicolaria* spp.) in the diets of *Clarias gariepinus*. The proximate analysis of garden snail meal revealed a content of 66.76% crude protein, 7.85% lipid, 4.10% crude fibre and 6.84% ash. Better growth results in comparison to the control group were showed for diets containing 25%, 50% and 100% garden snail meal replacement of fish meal.

In Okanlawon and Oladipupo (2010) research, snail offal (viscera) meal obtained from *Achatina achatina* and *Archachatina marginata* was utilized in the diet of *Clarias gariepinus*. Based on the proximate composition, snail offal meal contains 50.85 g crude protein/kg dry matter, 9.73 g fat/kg dry matter, 4.27 g crude fibre/kg dry matter, 25.41 g nitrogen free extract/kg dry matter and 9.74 g ash/kg dry matter. Growth performances using snail offal meal diets were not satisfactory, but the use of 50% snail offal meal as replacement for fish meal appears economically profitable.

Giant African snail (*Lissachatina fulica*) was tested as a protein source for common carp

(*Cyprinus carpio*) (Suresh, 2017). Giant African snail proximate composition of dry matter had contents of 57.2% crude protein, 4.2% crude lipid, 1.8% crude fibre, 28.7% nitrogen free extract and 8.1% ash. According to the results, 40% substitution of fish meal with giant African snail meal resulted in 53% bigger weight gain and improved feed conversion rate than for the control diet with fish meal.

In Jones et al. (1996) and Jones & De Silva (1997) studies, Australian freshwater crayfish (*Cherax destructor*) diets were formulated using different protein sources, including snail meal (*Helix* spp.). The best food conversion ratio was obtained for the snail meal diet (0.95). Snail meal diet obtained the highest values for protein efficiency ratio (3.44) and apparent net protein utilization (41.15%). Snail meal diet used for Australian freshwater crayfish (*Cherax destructor*) showed the lowest ash digestibility value (17.3%) compared to other diets.

In Rana et al. (2022) research, cuchia (*Monopterus cuchia*) was reared using different diets, that all contained snail meat (unspecified species).

Verhoef et al. (1998) studied different diets, including freshwater snails (unspecified species), which were tested as alternative diets for rearing Australian crayfish (*Cherax destructor*). Although freshwater snails represent natural prey for *Cherax destructor*, lower growth rate was observed for this diet than for other tested diets.

Previous review-style works on using gastropods as a potential protein source in aquaculture were conducted by Hertrampf and Piedad-Pascual (2000) and Heuzé and Tran (2017). In Hertrampf and Piedad-Pascual (2000) book, the chapter dedicated to snail meal presents literature information on the chemical composition of *Cerithium* spp. and *Pomacea canaliculata*. Heuzé & Tran (2017) focus on the use of apple snails (*Pomacea canaliculata*) as animal feed, including aquaculture applications.

CONCLUSIONS

The versatility of gastropods as an alternative protein source in aquaculture is outlined in the gathered studies. Information synthesised in this short review will help to document future research on the potential use in aquaculture feeds of gastropods.

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