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A review of the nutritional potential of edible snails: A sustainable underutilized food resource

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Despite the use of snails as food in many different communities in the world, the consumption of snail meat is still far from being appreciated. The authors compiled and reviewed the nutrient composition of edible snail meat based on the available scientific literature. The protein, fat, and ash content of snail meat were found to be 14.0, 1.4 and 2.1% on the basis of fresh matter respectively. Comparable protein content with conventional foods of animal origin along with the presence of all essential amino acids and less carbon footprint makes the snail meat a sustainable food source. Moreover, less fat content but higher proportion of polyunsaturated fatty acids, and considerable presence of minerals with nutritional importance especially calcium, zinc, and iron could exhibit human nutritional benefits. However, the establishment of heliciculture facilities is a necessity in order to support this sustainable food resource and also enhance the economic condition of certain local areas.

Keywords: Amino acids, Angiostrongyliasis, Food safety, Food security, Minerals, Protein

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Introduction

According to the recent report of the global hunger index[1], 828 million people are suffering from undernourishment (defined as a lack of sufficient calories in the food) and inadequate nutrition (defined as a lack of nutrients in the diet). Sub-Saharan Africa and South Asia are regions with the highest hunger and undernutrition levels in the world[1]. At least 2 billion people are suffering from micronutrient deficiency which is often termed "the hidden hunger"[2], but at the same time about 2 billion people suffer from overweight or obesity. In the context of a still expanding global population and the unanticipated climate change, we as humans are forced to explore alternative sustainable food sources to feed the people in future.

We need to increase the production of nutrient-rich food without harming the environment or increasing greenhouse gas emissions, or demanding to provide additional water, but with an aim to achieve low feed conversion ratios and to intensify farming systems without laying off farm workers. To understand the linkages between sustainability, productivity or yield of food not only the unit area of land has to be considered but inputs like irrigation needs, fertilizers, insecticides, herbicides, machinery, fuel costs, emission of greenhouse gases (GHG) etc. must not be overlooked either. It was first suggested by Meyer-Rochow to use unconventional (alternative) foods, like for instance edible insects to ease global food shortages and to involve the FAO as well as WHO[3]. The idea slowly gained acceptance and has led to the current interest in entomophagy[4]. Algae as a food source has also received some attention in the last few decades[5], but snails as a candidate to augment the spectrum of available food items has been given a comparatively poor attention in the agriculture sector. This is somewhat surprising because a variety of snail species are even now commonly consumed by members of numerous communities around the world. In fact, the use of snails as food has a long history and in the Mediterranean region has been known from prehistoric times[6] to this day[7].

According to the estimates of FAOSTAT[8], there is an increasing trend to produce food based on snails (marine

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species not included) year by year (Fig. 1). On average, 15% of the snails come from snail-breeding units, while the remaining 85% are harvested from Nature[9]. Snail farming, known as 'Heliciculture', is not at all a new entrant in the agriculture sector, but initiatives to explore this food resource have been limited and the resource clearly remains as under-utilized.

In the era of globalization, we tend to lose traditional foods with the result of nutrient deficiencies and negative health consequences[10]. Most often the interruption of a regular supply plays a critical role in the declination of traditional foods. Halwart, reported that there was no tradition of snail farming and marketing in south-east Asia although rural people of different parts of this region preferred to eat native snails[11]. In Japan, snail farming became popular in the 90s, and many governmental and non-governmental livelihood projects were established to support a backyard cottage industry[11]. Snails have also been used as feed for broiler chickens, ducks, and pigs[11-13]. However, because of an assumed high pest potential, farming systems did not continue to use snails much as animal feed and, to cite an example, Vietnam banned snail farming in mid-1992. In many parts of India, local people do collect edible terrestrial as well aquatic snails from the forest and water bodies and consume them[14] (personal observations of SG). Recently some small scale snail farms have been developed (personal communication of SG).

In a survey on bushmeat in Nigeria, Martin placed snails in a separate category from bushmeat as they were very common (especially the giant African snail *Archachatina marginata*) particularly in the forested areas where people did not consider them as bushmeat[15]. For the last few decades Africa, and in particular western Africa, is experiencing a rapid growth of the number of snail farms with the adequate help of governmental as well as non-governmental agencies[16-18]. Snail farming has also received attention in developed country like Korea. Ghosh *et al.*, described the farming system of *Pomacea canaliculata*, as edible snail, as it is practiced as mini-livestock in Korea[19]. From 1995 to 2010, Italian snail production and consumption increased almost four times and the annual sale in 2013 was worth about 265 million Euros[20]. Allen estimated that the consumption of edible snail *Theba pisana* accounts for approximately 4000 tons per year[7,21]. Snail farming is characterized by not involving labour-intensive work, or requiring high capital investment, or sophisticated technical and professional knowledge, and this makes it suitable for developing and/or underdeveloped areas. However, in order to appreciate the nutritional advantages of the rearing and consumption of snails, it is essential to examine and highlight the nutrient composition of the snails. The primary aim of this review has therefore been to evaluate the nutrient content of the edible species.

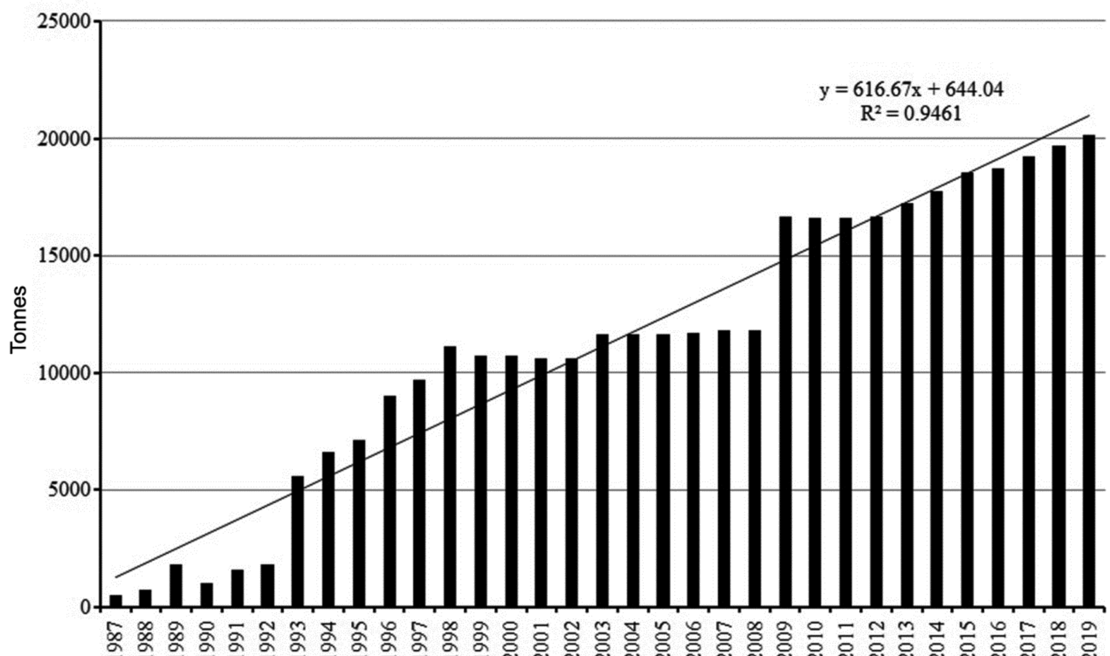

Fig. 1 — Global production of snails (marine species not included) with the year (*Source*: FAOSTAT, 2021).

Edible snail species in the world

Based on the available scientific literature, the authors compiled an inventory of edible snails around the globe and presented it in Table 1. Although there are undoubtedly many more, we focused on those species that are widely popular and have, to some extent, been scientifically studied with regard to chemical composition, biology, and breeding. Such

Table 1 — Inventory of edible snail and bivalve species around the world

Scientific name	Geographical location	Purpose	Reference
Africa			
Helix aspersa	Morocco	Food	50
Limicolaria aurora	Uyo main market, Akwa Ibom state, Nigeria	Food	51
Archachatina marginata *Archatina* *Limicolaria*	Ikere-Ekiti market, Ondo state, Nigeria	Food	52
Achatina achatina	Ghana	Food	53
Limicolaria sp. *Archatina archatina* *Archachatin amarginata*	Oba market (Ado-Ekiti), Ekiti state, Nigeria	Food	54
Lymnaea stagnalis	Kuto market in Abeokuta, Ogun state, Nigeria	Food	55
Archachatina marginata ovum *Archachatina marginatasaturalis* *Achatina achatina* *Limicolaria* sp.	King's market, Ado Ekiti, Ekiti state, Nigeria	Food	56
Archachatina marginata ovum *Archachatina marginatasaturalis* *Limicolaria* sp. *Lanistes varicus* *Nucella lapillus*	Wild collection from Calabar, Odukpani and Ugep; Nigeria	Food	57
Archachatina marginata *Achatina achatina* *Achatina fulica*	Markets in Ibadan metropolis, Oyo state, Nigeria	Food	58
Achatina fulica *Limicolaria* sp. *Helix pomatia*	Uyo, Akwa Ibom state, Nigeria	Food	59
Helix trunculus	Sfax city fish market, Tunisia	Food	60
Archachatina marginata	Minna, Niger state, Nigeria	Food	61
Archachatina marginata	Farm at Rivers State University of Education, Ndele campus, Nigeria	Food	62
Achatina achatina	Farm in Kumasi, Ghana	Food	63
Limicolari flammea	Agboville, Côte d'Ivoire	Food	64
Archachatina marginata	Itoku market, Abeokuta, Ogun state, Nigeria Oje market, Oyo state, Nigeria Oyingbo market, Lagos state, Nigeria Oja Oba market, Osogbo, Osun state, Nigeria Oja Oba market, Akure, Ondo state, Nigeria	Food	65
Archachatina marginata	Oyo state, Nigeria	Food	66
Achatina fulica *Archachatina marginata*	Littoral (Wouri), Center (Lekie) and West (Santchou), Cameroon	Food	67
	Asia		
Pila scutata *Bellamyiaingallsiana*	Malaysia	Food	68
Ampullarius insularus *Achatina fulica*	Jepllabuk-do, Korea	Food	69
Pomacea canaliculata	Thailand Vietnam Taiwan Philippines	Food	11
Achatina fulica	Junchun Food Co., Kimhae, Korea	Food	70
Pila globosa	29 tribal groups in Bangladesh	Food	71,72
Apple snail	Japan	Food	73
Helix pomatia	Local processing company in Cukurova, Turkey	Food	74

(*Contd.*)

Table 1 — Inventory of edible snail and bivalve species around the world (*Contd.*)

Scientific name	Geographical location	Purpose	Reference
Semisulcospira gottschei	Korea	Food	75
Achatina fulica *Pomacea canaliculata*	China	Food	76
Bellamya bengalensis *Bellamya bengalensis f. typica* *Bellamya bengalensis f. balteata* *Bellamya dissimilis* *Pila globosa* *Pila scutata* *Pila theobaldi* *Pila virens* *Brotia costula*	North East India	Food	77
Bellamya sp. *Bellamya bengalensis* *Pila scutata* *Lamellidens* sp. *Parreysia* sp. *Lamellidens* sp.	Northern part of Bihar (Khagaria, Saharsa, Medhepura, Purnea), India	Ethnomedicinal uses	23
Semisulcospira coreana *Semisulcospira gottschei* *Semisulcospira forticosta* *Semisulcospira libertina* *Semisulcospira tegulata*	Korea	Food	78
Helix aspersa	Asian Istanbul, Turkey	Food	79
Viviparid snail	Vietnam	Food	80,27
Chamberlainiahainesiana	Thailand, Vietnam	Food	
Brotiacostula *Bellamya bengalensis* *Bellamya dissimilis* *Pila globosa*	Wild (pond, paddy field, wetland) and market, Lembucherra, Tripura, India	Food	81
Helix aspersa	Tribal people of Chhindwara (Gond, Bharia, Mawasi, Ahir), Madhya Pradesh, India	Ethnomedicinal uses	24
Pila sp.	Tribal belt of Gondwanavindhyan region, Madhya Pradesh, India	Ethnomedicinal uses	25
Pomacea canaliculata	Farm in Andong, Korea	Food	82
Pila globosa	Consumed by Muda tribe, Jharkhand, India	Food	83
Unidentified snails species	Local markets (collected from wild areas like water bodies) in northern part of West Bengal, India	Food	Personal experience of SG
Unidentified snails species	Consumed by Baiga tribe, Madhya Pradesh, India	Food	14
	Australia		
Cookia sulcata	Te Oka Bay, Canterbury, New Zealand (consumed by Maori people)	Food	84
Turbo militaris *Lunella undulata* *Lunella torquata*	Woolgoolga, Coffs harbour, Australia	Food	85
	Europe		
Helix adspersa *Helix pomatia* *Helix lucorum* *Helix aperta* *Helix cincta* *Otala* sp. *Eobania vermiculata*	Europe	Food and Therapeutic uses	22,86
Helix pomatia	Farm and wild, Latavia	Food	87
Lymnaea sp.	Europe	Therapeutic uses	22
Thebapisana	Portugal	Food	7
Otalalactaea	Portugal	Food	
	South America		
Helix aspersa maxima	Brazil	Food	88,89

species include the snails *Achatina* sp., *Archachatina marginata*, *Limicolaria* sp., *Lanistes varicus*, *Nucella lapillus*, *Lymnaea stagnalis*, *Helix* sp., *Pila* sp., *Semisulcospira* sp., *Pomacea canaliculata*, *Bellamya* sp., *Theba pisana* and *Otala lactea. Escargots* (mainly *Helix pomatia* but some other species as well) are considered a delicacy in France and some other European countries. A systematic review of the literature reveals that the consumption of snails as a planned part of the diet is more common in Africa and Asia, although the acceptance varies to a great extent from region to region.

Although these species are used primarily as food, ethnomedicinal uses as reviewed by Meyer-Rochoware are also common and involve a wide variety of slugs and snails in connection with dermatoses, gastro-enteric troubles, coughs, colds, heart ailments and even bone fractures[22]. Consumption of snail soup or curry containing, for example, *Bellamya* sp., *Pila* sp., *Lamellidens* sp., or *Parreysia* sp. is common among the people of the Kosi River basin of Bihar (India) for treating asthma, arthritis, rickets, cardiac disorders, giddiness, night blindness, etc.[23]. An ethnozoological use of the garden snail (*Helix aspersa*) for the treatment of tuberculosis by the indigenous people of the Chindwara District of Madhya Pradesh (India)[24], the use of *Pila* sp. snails for treating weakness and paralysis by the tribal people and communities of the Gondwana Vindhyan region of Madhya Pradesh (India)[25] and the use of snails for bone strength, for treatment of body ache, joint pain, etc. by the Baiga people of Baihar tehsil of Balaghat district of Madhya Pradesh (India)[14] are examples of therapeutic uses of snails in India.

Edible snails belong to the molluscan class Gastropoda and families like Achatinidae, Helicidae, Ampullariidae, Viviparidae, Thiaridae, Planorbidae, Pachychitidae, Turbinidae are represented. In general, a generic freshwater snail is dioecious, while those belonging to the subclass Pulmonata are hermaphrodites[26]. Even in the case of the hermaphroditic species mating between two individuals occur followed by the deposition of eggs often covered with a protective gelatinous coat. Although developmental duration and life cycles are species-specific, under favourable conditions eggs usually hatch after about 2 weeks to one month. Thiarid (family Thiaridae) females are parthenogenic[26] and Ampullarids (family Ampullariidae), commonly known as ‘apple snails’, are mostly amphibious with a mantle cavity containing organs that function as gills and lungs. *Pila* is a common and widely distributed genus in tropical Asia, but *Pomacea canaliculata* is an example that was introduced to many Asian countries from the USA and South America and became established[11,27]. The Achatinidae is a family containing terrestrial pulmonate gastropods from Africa, such as the genera *Achatina*, *Limicolaria*, and *Archachatina*. Viviparidae are often known as river snails and contain live-bearing species in which the females do not lay eggs, but retain them in their body.

Nutrient composition of edible snails

Moisture content

The moisture content of edible snail species varies within a range of 65.8 to 89.2% (Fig. 2 and Table 2). Fresh snails are generally used in preparations that include boiling, smoking, and using them for curries. In France, *Escargots-in-garlic-and-parsley-butter* is a famous snail dish; other worthwhile snail cuisines are the *Gaeng-Kui-Hoi-Khom* fresh water snail in red curry in Thailand, the *Tharoi Thongba* river snail curry in Manipur (India), the *Ốchương* stir-fried snail and *BúnỐc* in Vietnam, the *Lumacheâlla Romana* in Rome (Italy), *Cargols* in Spain, *Caracóis* stewed snail in Portugal, and *Kohlibourbouristi* pan-fried snail in Greece. In general, the high moisture content of snails makes their meat more susceptible to microbial contamination[28]. Therefore in order to increase the

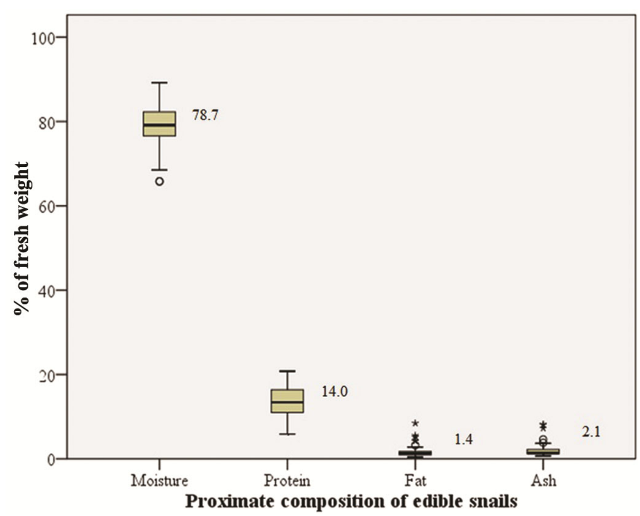

Fig. 2 — Proximate composition (% of fresh weight basis) of edible snail species. Number indicates the mean value of corresponding proximate composition i.e., moisture, protein, fat, ash [Graphical representation was plotted based on Table 2].

Table 2 — Proximate composition of edible snail species

Scientific name	Proximate composition (% Fresh weight basis)						Reference
	Moisture	Protein	Lipid	Fibre	Ash	NFE/Carbohydrate	
		Land					
Achatina sp.	89.20	9.90	1.40	--	2.10	4.40	90
Helix aspersa (small, 2.5 g)	83.30	12.00	0.70	--	2.70	0.50	91
Helix aspersa (large, 3.5 g)	87.60	9.90	0.50	--	1.20	0.40	
Achatina fulica (Gray)	82.18	11.53	0.91	--	1.39	--	70
Achatina fulica (Yellow)	82.36	13.42	1.28	--	1.29	--	
Achatina fulica (White)	81.20	13.69	0.97	--	1.25	--	
*Limicolaria aurora**	71.24	14.78	2.79	--	3.38	7.79	51
Archachatina marginata	76.63	20.76	1.20	ND	1.42	--	52
Archatina sp.	79.89	14.52	4.24	ND	1.34	--	
Limicolaria sp.	77.90	17.51	4.30	ND	1.12	--	
Helix aspersa aspersa	83.70	10.50	1.60	--	1.50	--	92
Helix aspersa maxima	85.80	8.10	1.50	--	1.20	1.70	
Helix lucorum	84.00	10.80	1.50	--	1.40	--	
Helix pomatia	84.20	10.70	1.10	--	1.80	--	
*Helix aspersa maxima****	79.85	9.50	2.66	--	0.92	--	89
	79.05	10.47	1.51	--	0.65	--	
	77.47	11.31	0.45	--	0.76	--	
	78.41	12.56	0.63	--	0.65	--	
Helix aspersa	80.80	16.35	0.41	--	1.89	--	74
Archachatina marginata (ovum) Pfeiffer	76.56	20.56	1.38	ND	1.44	0.01	56
Archachatina marginata (saturalis) Philippi	76.67	20.34	1.23	ND	1.40	0.37	
Achatina achatina	77.54	19.27	1.43	ND	1.34	0.42	
Limicolaria sp.	78.68	18.66	1.17	ND	1.35	0.15	
*Archachatina marginata ovum**	80.78	16.23	0.86	0.10	0.77	1.26	57
*Archachatina marginata saturalis**	80.30	15.95	0.79	0.20	0.89	1.89	
Limicolaria sp.*	78.64	15.33	0.80	0.21	1.50	3.31	
Archachatina marginata	73.67	19.53	2.44	--	2.56	1.80	58
Achatina achatina	75.28	17.20	2.21	--	2.33	2.98	
Achatina fulica	79.28	10.08	1.61	--	1.78	7.25	
Limicolaria sp.	84.91	5.86	1.05	--	1.27	6.91	
Helix pomatia	79.57	15.44	1.18	0.00	1.26	--	59
Helix sp.	83.20	8.64	0.57	0.004	1.04	6.55	93
Helix aspersa	82.50	12.87	0.58	--	1.07	4.99	79
*Archachatina marginata***	73.95	20.22	2.09	1.01	1.73	1.09	65
	79.67	15.77	1.46	0.79	1.35	0.86	
	78.85	16.42	1.60	0.82	1.40	0.92	
	77.41	12.54	1.73	0.88	1.51	0.95	
	77.00	17.88	1.77	0.89	1.53	0.94	
Archachatina marginata (Adult)	79.25	17.22	1.46	--	1.34	--	94
Archachatina marginata (Grower)	79.93	16.30	1.35	--	1.24	--	
Archachatina marginata (Snailet)	80.39	15.83	1.24	--	1.18	--	
Otala lactea (boiled)	83.50	9.60	1.26	--	1.38	0.28	7
Otala lactea (cooked)	78.60	12.90	1.54	--	3.45	0.32	
Theba pisana (boiled)	83.20	11.40	2.33	--	1.11	0.21	
Theba pisana (cooked)	77.50	13.40	3.23	--	3.05	0.35	
		Freshwater					
Pila globosa	85.50	8.27	0.73	0.03	2.60	2.90	93
Bellamya bengalensis	82.10	8.97	0.98	0.04	3.64	4.31	
Melaniatu berculata	74.60	12.36	1.79	0.05	3.68	7.57	
Anisus convexiusculus	75.70	12.93	0.97	0.04	4.61	5.79	
Brotia costula	69.86	12.91	0.82	ND	7.28	9.12	81
Bellamya bengalensis	65.80	13.14	0.96	ND	8.11	11.97	
Bellamya dissimilis	65.80	11.18	0.96	ND	8.15	11.46	
Pila globosa	73.80	15.59	1.15	ND	3.82	5.62	

(*Contd.*)

Table 2 — Proximate composition of edible snail species (*Contd.*)

Scientific name	Proximate composition (% Fresh weight basis)						Reference
	Moisture	Protein	Lipid	Fibre	Ash	NFE/Carbohydrate	
		Marine					
Turbo militaris	73.08	16.19	5.57	--	2.14	3.02	85
Lunella undulata	70.83	18.49	5.20	--	1.97	3.51	
Lunella torquata	68.50	18.03	8.46	--	2.10	2.92	

*Calculated form obtained data on the dry weight basis to fresh weight basis
**Five values were obtained for the samples collected from five regions
**Four values were obtained for each component because of four different feed treatments
ND= Not determined

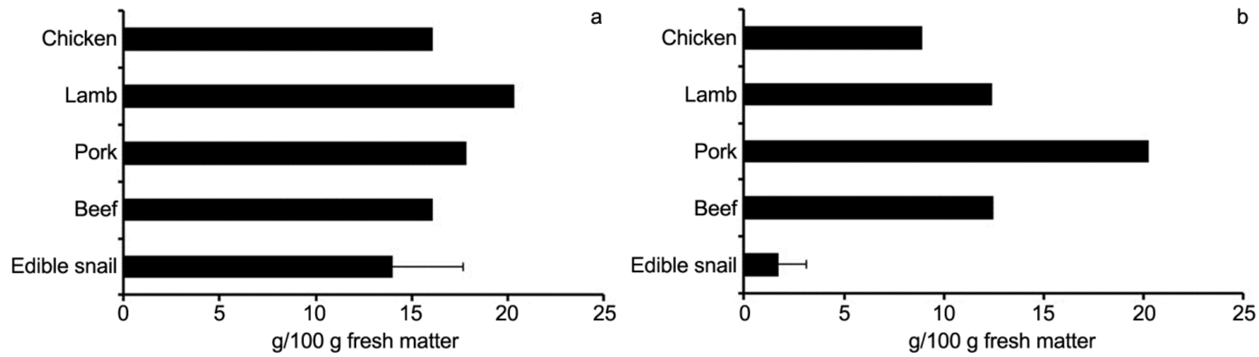

Fig. 3 — Comparative account of a) protein content (g/100 g fresh weight basis) of edible snails and conventional foods of animal origin; and b) fat content (g/100 g fresh weight basis) of edible snails and conventional foods of animal origin. [Data other than edible snails were obtained from USDA database https://fdc.nal.usda.gov accessed 10th February 2021].

shelf life of snails, drying prior to processing them further can be useful.

Protein and amino acids

The protein content of snail meat was found to be within the range of 5.9 to 20.8% with an average value of 14.0% on the basis of fresh matter (Fig. 2 and Table 2). The protein content of edible snails was therefore comparable to that of conventional animal meats (Fig. 3a). However, if converted on the dry weight basis using an average moisture content of 78.7%, the protein content reaches approximately 65.7%, which is higher than the protein contents of conventional protein sources. The nutritive quality of a protein depends on its amino acid composition. Fig. 4 represents the amino acid compositions of edible snails (Table 3). For several species, tryptophan was not determined presumably due to the acid hydrolysis process. Cysteine and methionine amounts are also generally not unambiguously identifiable due to the acid hydrolysis process in the analysis. Apart from the methodological concerns, the average proportion of essential amino acids was found to be about 36.5% while the nonessential amino acids accounted for 51.5%. Of course, the proportion will

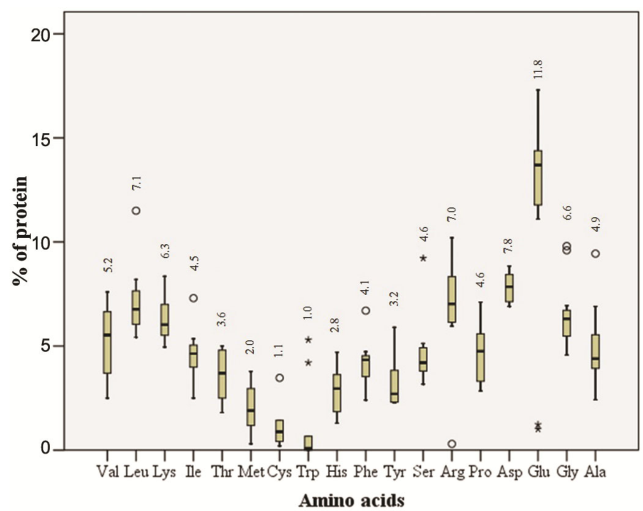

Fig. 4 — Compositional distribution of amino acids on the basis of % of protein of edible snails. Number indicates the mean value of corresponding individual amino acid [Graphical representation was plotted based on Table 3].

be enhanced if cysteine and tyrosine are included as conditionally essential amino acids and arginine as essential for children. Among the essential amino acids, leucine (5.4-11.5%) and lysine (5.0-8.4%) are found predominant while glutamic acid (1-17.3%)

Table 3 — Amino acid composition of edible snails

Scientific name	Amino acid composition (g/100 g protein)																		Reference
	Val	Leu	Lys	Ile	Thr	Met	Cys	Trp	His	Phe	Tyr	Ser	Arg	Pro	Asp	Glu	Gly	Ala	
Achatina fulica (Gray)	6.40	7.19	5.33	5.35	4.91	2.46	1.43	0.68	2.09	4.61	2.82	4.37	7.57	7.11	8.37	13.59	6.38	3.88	70
Achatina fulica (Yellow)	6.46	6.64	4.95	4.83	4.93	3.63	1.44	0.53	3.08	4.45	2.31	5.13	7.00	5.57	8.73	14.37	6.27	4.39	
Achatina fulica (White)	6.84	6.64	5.00	4.85	5.00	3.45	1.44	0.65	2.95	4.46	2.28	4.94	7.05	5.69	8.09	14.61	6.23	4.38	
Limicolaria aurora	7.60	11.50	7.20	7.30	3.90	1.40	0.90	ND	3.70	6.70	5.90	4.00	0.30	5.60	7.80	13.50	6.50	6.90	51
Limicolaria sp.	4.12	6.90	8.28	5.24	1.80	1.81	0.48	ND	3.56	4.37	2.58	4.05	6.74	3.99	7.61	1.01	5.06	3.98	54
Archatina archatina	3.28	5.58	6.06	4.46	2.24	1.37	0.87	ND	2.96	3.84	2.48	3.17	6.31	3.01	6.94	11.10	5.16	2.42	
Archachatina marginata	7.11	8.11	5.74	3.87	2.76	2.00	1.09	ND	4.70	4.73	2.93	3.33	5.96	3.61	7.27	14.4	4.57	5.19	
Hexaplex trunculus	4.72	6.96	8.35	4.81	1.93	1.99	0.36	ND	3.92	4.19	3.17	4.36	7.48	3.01	7.90	1.23	6.35	3.56	60
*Helix aspersa**	6.34	5.42	6.39	4.12	4.00	3.78	3.47	ND	2.25	3.22	5.29	9.22	5.98	2.84	8.84	12.46	6.94	9.44	79
Cookia sulcata (small)	2.50	5.60	6.00	2.60	3.40	0.30	0.20	4.20	1.30	2.40	2.30	3.80	10.10	5.10	7.00	13.80	9.80	4.50	84
Cookia sulcata (big)	2.50	6.50	5.70	2.50	3.50	0.30	0.30	5.30	1.40	2.40	2.30	3.80	10.20	4.80	6.90	14.10	9.60	4.40	
Pomacea canaliculata	4.30	8.20	6.80	4.10	4.70	1.00	0.80	0.20	1.60	4.30	4.50	4.90	9.10	4.70	8.50	17.30	5.80	5.90	82

*Calculated based on obtained values on the basis of total amino acids as protein
ND = Not determined

followed by aspartic acid (6.9-8.8%) was most abundant among the nonessential amino acids.

Currently, on average animal proteins contribute 25% of the protein intake worldwide, providing 18% of the calories[29]. From the nutritional point of view, animal meat contains high-quality protein and highly bioavailable micronutrients like vitamin A, vitamin B12, riboflavin, iron, zinc, calcium, etc.[30]. The consumption of meat in developed countries is much higher than its consumption in underdeveloped as well as developing regions of the world[29]. However, the socio-economic changes like economic development, increased urbanization and globalization are leading to a transition in dietary patterns particularly in low and medium-income countries and increasing demand for animal protein is being observed[31]. At present, ruminants, chickens and pigs are contributing 96% to the global supply of animal protein, while aquaculture is growing fast[32]. However, not only the amount of protein available to the underprivileged societies is of concern, but to improve the production system and the distribution of food and at the same time guarantee sustainability is the challenge of the day. Forte *et al.*, demonstrated that the snail carbon footprint amounted to 0.7 kg CO_2 eq. per kg of edible meat[20], which is far less than the amount generated by the conventional food sources of animal origin like chicken (1.8-5.2), pork (3.6-8.9), beef (11-51)[33], and even the newly advocated mealworm food source with its 2.7 kg CO_2 eq. per kg[34]. Unlike cattle, the carbon footprint of snails is not affected by biogenic enteric methane emission but mainly derived from the feed crop cultivation and processing stages[20].

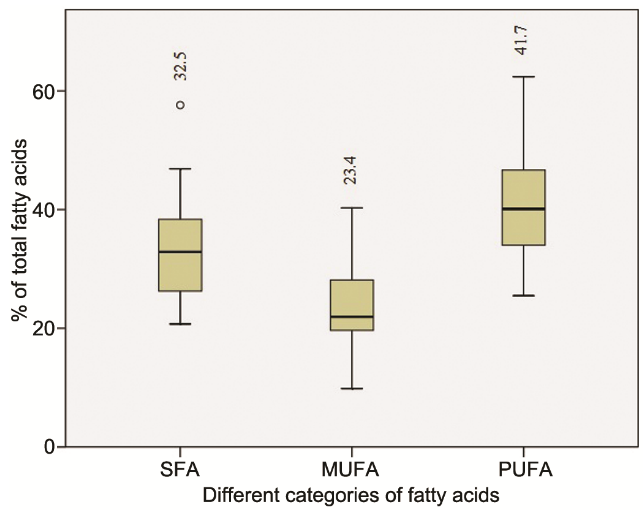

Fig. 5 — Distribution of different categories of fatty acids, i.e. Saturated fatty acids (SFA), Monounsaturated fatty acids (MUFA) and Polyunsaturated fatty acids (PUFA) on the basis of % of total fatty acids of edible snails. Number indicates the mean value of corresponding category of fatty acid [Graphical representation was plotted based on Table 4].

Fat and fatty acid composition

Fat content of snail meat was found to be within the range of 0.4 to 8.5% with an average value of 1.4% on the basis of fresh matter (Table 2). Fat content of edible snails was found lower than that of conventional foods of animal origin (Fig. 3b). Data on snail meat fatty acid profiles available from the literature have been compiled in Fig. 5 and Table 4. Based on their degree of saturation, fatty acids are categorized into three groups, i.e. saturated fatty acids (SFA), mono-unsaturated fatty acids (MUFA) and poly-unsaturated fatty acids (PUFA). With the exception of a few cases, the PUFA content of edible

Table 4 — Fatty acid composition mentioning selective predominant fatty acids and three categories of fatty acids i.e. SFA, MUFA, PUFA (% of total fatty acids) of edible snails

Scientific name	Fatty acid composition (%)									Reference
	Myristic	Palmitic	Stearic	Total SFA	Oleic	Total MUFA	Linoleic (n-6)	Linolenic (n-3)	Total PUFA	
Helix pomatia	0.42	10.29	16.38	37.87	14.70	19.65	13.56	1.87	25.83	74
Helix aspersa maxima	0.57	10.11	13.47	26.26	20.42	23.82	19.37	1.04	49.92	89
	0.42	7.68	14.51	24.86	18.61	22.68	19.74	1.10	52.46	
	0.52	8.11	12.32	23.06	18.32	21.63	24.53	1.34	55.31	
	0.65	6.72	12.59	22.20	16.73	20.74	22.70	1.32	57.06	
Helix aspersa	ND	7.28	17.37	28.76	13.57	20.66	17.53	5.63	34.38	79
Hexaplex trunculus	1.23	6.21	6.01	33.44	3.08	9.84	0.83	3.07	58.37	60
Melanopsis praemorsa[*]	5.66	20.04	8.37	39.00	10.36	21.30	16.33	8.87	39.98	95
	2.35	16.43	8.65	31.12	24.20	40.28	9.37	11.00	28.15	
	5.86	26.48	10.70	46.87	12.60	21.92	12.11	10.72	31.68	
	10.58	33.01	7.27	57.61	10.26	17.33	7.02	5.07	25.50	
Cookia sulcate (Small)	2.30	27.30	8.10	46.60	8.80	14.90	2.30	0.50	32.30	84
Cookia sulcate (Large)	2.30	2.40	9.60	42.20	8.00	10.80	2.10	1.00	36.30	
Assyriellaescheriana[†]	0.58	10.16	10.30	23.05	12.68	14.97	20.45	8.42	62.38	96
Assyriellaguttata[†]	1.85	9.61	12.33	26.95	15.06	16.14	18.54	6.24	56.80	
Lunellatorquata	0.55	23.01	5.68	39.95	8.21	14.45	1.60	0.84	45.59	85
Lunellaundulata	0.96	21.62	6.59	38.61	8.41	14.83	2.82	2.33	46.58	
Turbo militaris	0.13	22.12	5.45	39.83	7.89	14.05	2.92	1.87	45.13	
Pomacea canaliculata	3.10	20.50	9.00	39.50	9.10	17.70	20.60	0.90	42.70	82
Helix lucorum	0.53	9.66	6.75	21.70	22.02	26.53	21.76	10.08	51.77	97
Eobania vermiculata	0.30	10.49	7.76	22.68	19.07	21.77	37.67	7.31	55.56	
Helix pomatia (Farm A)[††]	0.47	10.16	14.31	34.84	13.83	19.55	17.95	2.47	39.68	98
	0.52	11.24	15.51	37.98	15.57	19.91	16.95	1.57	34.14	
	0.54	11.32	15.87	39.26	15.69	20.06	16.69	1.42	32.11	
Helix pomatia (Farm B)[††]	0.47	10.28	14.37	35.21	13.65	19.83	17.87	2.54	38.78	
	0.54	11.39	15.64	38.38	15.63	20.00	16.59	1.40	32.63	
	0.56	11.45	15.84	38.40	15.70	20.16	16.47	1.41	30.89	
Cornuaspersum maxima (Farm A)[††]	0.34	8.36	12.18	28.72	20.36	24.22	32.42	3.50	44.58	
	0.38	10.13	13.74	32.69	23.47	24.78	30.42	1.82	38.58	
	0.38	10.31	13.66	33.49	23.50	27.88	30.43	1.45	38.00	
Cornuaspersum maxima (Farm B)[††]	0.35	8.27	12.23	28.32	26.64	30.91	27.42	3.70	39.81	
	0.40	10.26	13.83	32.88	30.79	31.48	24.55	2.80	31.54	
	0.43	10.34	13.91	33.80	30.80	35.59	25.51	2.70	31.57	
Cornuaspersumaspersum (Farm A)[††]	0.33	8.93	12.28	29.35	19.56	23.89	34.34	3.70	46.65	
	0.37	10.17	13.87	32.87	23.18	24.25	31.84	2.22	40.11	
	0.38	10.5	13.96	33.92	23.40	28.13	31.71	2.21	39.34	
Cornuaspersumaspersum (Farm B)[††]	0.35	8.66	12.89	29.54	25.81	29.85	27.40	3.85	41.30	
	0.41	10.22	13.77	32.90	28.74	33.55	25.12	2.86	33.99	
	0.44	10.51	13.94	33.93	29.02	33.72	25.02	2.44	33.09	
Thebapisana[**]	0.73	12.63	5.41	20.72	28.83	31.27	18.78	7.64	48.10	99
	1.06	15.75	6.31	25.32	28.83	30.49	21.35	8.87	44.19	
Cornuaspersum[**]	0.76	16.02	7.72	26.97	23.79	25.81	22.15	15.78	47.22	
	0.59	13.24	7.24	23.01	29.95	33.53	19.07	15.14	43.56	
*Eobania vermiculata***	0.81	14.63	7.66	25.58	26.03	27.86	21.94	12.40	46.56	
	0.63	13.31	7.59	23.35	29.71	32.24	19.20	15.53	44.41	

[*]fatty acid content of the species was investigated in different seasons like autumn, winter, spring and summer (from the upper row downwards respectively)

[†]these species are not eaten

[††]fatty acid profile was investigated in three forms i.e. raw, cooked and frozen (from upper row downwards respectively)

[**]the species was examined on the raw (upper row) and boiled (lower row) condition

snails is predominating and followed by SFA and MUFA contents. SFA content varied within the range of 20.7 to 57.6%, while MUFA and PUFA accounted for 9.8-40.3 and 25.5-62.4%, respectively. Statistical analysis (one-way ANOVA) with the available values for different categories of fatty acids reveals a significant difference among the three categories of fatty acids (df = 2, 132; F = 57.435, p = 0.000). Fatty acids play many different critical roles in the human body, being structural components of membrane lipids, precursors of molecules like eicosanoids, prostaglandins, and essential components of the metabolism. Saturated fatty acids, in general, are not desirable, because of their linkage with an elevation of cholesterols and thus cardiovascular disease. Lauric, myristic, and palmitic acids contribute comparatively more to a higher level of cholesterol[35], but stearic acid has been reported to lower the cholesterol level[36-38]. Among the SFAs, palmitic and stearic acid were the most abundant in the snail's fat, but oleic acid was the dominant component of the MUFAs. However, the distribution of the fatty acids belonging to PUFA category varied so widely that generalizations at this stage are not possible.

Mineral contents

Minerals contents of edible snails are shown in Fig. 6(a-b) and Table 5. Calcium, an essential macro-mineral, is found to be one of the most abundant minerals in edible snails. In humans, the majority of calcium by virtue of its phosphate salt is present in bones and teeth. It plays vital roles in several enzyme-mediated processes, excretion, blood clotting, and neuromuscular functions. Suboptimal intakes of calcium may hinder normal growth and can lead to manifestations of osteoporosis in older people, especially postmenopausal women[39]. The high potassium and low sodium content of edible snails should be expected to exhibit physiological benefits. Low potassium consumption is often associated with a variety of physiological disorders including respiratory, renal problems and hypertension. Further, edible snails are found to be rich in micro-minerals like iron and zinc. The most vulnerable sections of the population suffering from iron deficiency are infants of the weaning stage, young children, and women of childbearing age. More than 1.2 billion people are suffering from iron deficiency anaemia and iron deficiency in the absence of anaemia is even more frequent[38]. Iron deficiency anaemia is often caused by the low dietary intake of iron and reduced intake of bio-available iron, particularly in developing countries[40]. Zinc is an essential component of a large number of enzymes (more than 300). Moreover, it has anti-oxidative stress and anti-inflammatory functions[41]. Copper, together with zinc, are additional structural components of the antioxidant enzyme superoxide dismutase. Considerable amounts of magnesium, phosphorus, and manganese are also present in edible snails. However, to study the bioavailability of the individual minerals from the snail meat remains a task of the future.

Safety issues

Although edible snails are nutritionally comparable, if not superior to conventional foods of animal origin, proper care has to be taken in relation to safety issues of using snails as food. Accumulation of heavy metals in freshwater snails is one important issue. Lau *et al.*, reported that two aquatic snail *Brotia costula* and *Clithon* sp. tissues contained arsenic contents that were higher than the permissible limit for human consumption[42]. In another experiment on *Pomacea canaliculata* exposed to contaminate

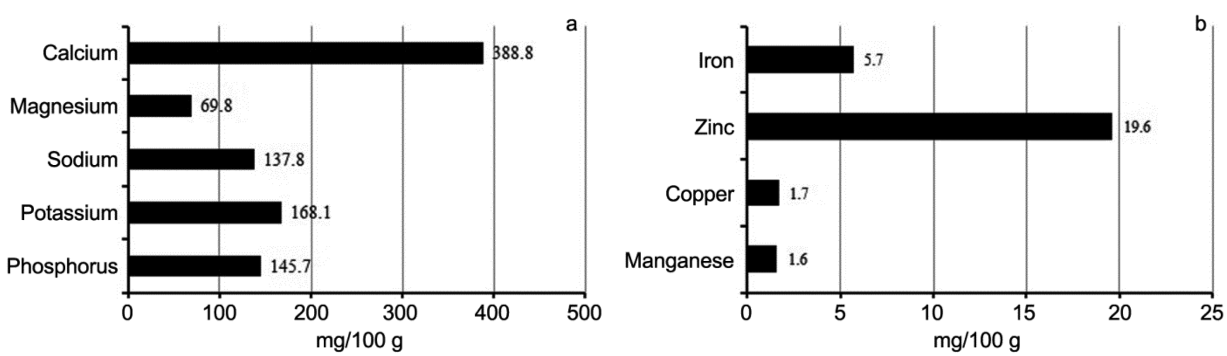

Fig. 6 — Content of macro-minerals a) calcium, magnesium, sodium, potassium, and phosphorus (mg/100 g) and content of micro-minerals; and b) iron, zinc, copper and manganese content (mg/100 g) of edible snail species. [Graphical representation was plotted based on Table 5].

Table 5 — Mineral content of edible snails

Scientific name	Mineral content (mg/100 g)									Reference
	Ca	Mg	Na	K	P	Fe	Zn	Cu	Mn	
Limicolaria aurora	401(DM)	771	178	533	636	ND	259	--	--	51
Archachatina marginata	212.38 (FM)	46.33	196.24	44.18	0.64	9.31	1.44	0.64	0.41	52
Archatina sp.	188.96	37.79	181.87	49.88	215.48	4.95	1.87	0.62	0.38	
Limicolaria sp.	22.24	18.91	53.83	72.82	183.35	4.66	1.23	0.16	0.59	
Helix aspersa (Foot)	200 (FM)	52.7	--	--	73	1	1	3.1	--	92
	1620 (DM)	425			590	8.4	8	25.2		
Helix aspersa (Viscera)	328	183	--	--	536	6.4	46.3	1.7	--	
	1120	625			1830	22	158	6		
Helix aspersa maxima (Foot)	183	76	--	--	83	1.4	0.8	2.1	--	
	1390	575			630	11.2	6.4	16.4		
Helix aspersa maxima (Viscera)	356	182	--	--	473	10.2	43.1	1.2	--	
	1370	700			1820	39.2	166	4.8		
Helix lucorum (Foot)	279	60.8	--	--	66.8	0.9	1.3	3.4	--	
	1840	400			440	6.0	8.8	22.8		
Helixlucorum (Viscera)	260	93.7	--	--	340	18	35.5	1.7	--	
	1040	375			1360	72	142	6.8		
Helix pomatia (Foot)	613	50.2	--	--	140	1.9	1.1	4	--	
	4580	375			1049	14.4	8.8	30		
Helix pomatia (Viscera)	328	134	--	--	487	7.6	60	1	--	
	1340	550			1990	31.2	248	4.4		
Lymnaea stagnalis (Meat)	118.8 (DM)	56.7	82.8	399	--	0.54	--	0.26	--	55
Archachatina marginata (*ovum*) Pfeiffer	201.08(FM)	45.59	50.80	192.78	123.43	8.69	1.54	ND	0.39	56
Archachatina marginata (*saturalis*) Philippi	207.53	45.34	52.93	209.95	123.23	9.41	1.69	ND	0.38	
Achatina achatina	204.63	46.15	60.94	193.74	131.38	9.43	1.76	ND	0.39	
Limicolaria sp.	208.75	45.99	65.10	197.57	153.89	9.46	1.51	ND	0.38	
Archachatina marginata (*ovum*)	180.71(DM)	29.2	--	60.79	59.16	6.79	1.19	--	--	57
Archachatina marginata (*saturalis*)	179.09	28.52	--	70	51.49	8.25	1.18	--	--	
Limicolaria sp.	172.79	27.33	--	64.52	59.79	9	1.14	--	--	
Lanistes varicus	152.7	30.56	--	69.39	62.52	10.1	1.3	--	--	
Nucella lapillus	181.49	31.73	--	72.4	60.19	11.09	1.32	--	--	
Limicolaria sp.	36.2 (FM)	5.28	--	--	8.98	0.72	--	0.29	--	58
Achatina fulica	66.3	15.13	--	--	14.79	1.3	--	0.58	--	
Achatina achatina	106.3	19.28	--	--	19.01	1.88	--	0.77	--	
Archachatina marginata	126.4	25.01	--	--	22.91	2.29	--	1.03	--	
Achatina fulica	186.35	--	28.97	64.15	62.73	1.51	--	--	--	59
	186.32	--	28.94	64.15	62.76	1.49	--	--	--	
Limicolaria sp.	179.65	--	24.78	56.72	58.34	1.36	--	--	--	
	179.64	--	24.83	56.76	58.32	1.36	--	--	--	
Helix pomatia	13.51	--	13.63	31.59	31.17	1.17	--	--	--	
	132.48	--	13.65	31.57	31.14	1.14	--	--	--	
Hexaplex trunculus	674.4 (FM)	178.7	196.1	224.8	95.2	8.1	112.8	3.1	0.68	60
Helix aspersa	135.70 (FM)	17.05	91.95	105.40	96.72	0.52	--	--	--	79
Achatina achatina	585.5 (DM)	--	--	331.8	269.2	9.8	39	3.3	--	63
Cookia sulcata (Small)	140 (DM)	330	400	300	110	5.81	3.22	0.64	--	84
Cookia sulcata (Large)	70	310	410	280	90	7.41	3.82	0.78	--	
Pomacea canaliculata	5161.2 (DM)	56.9	93.4	364.4	550.5	45.5	10.1	7.1	2	82
Lunella torquata	239 (FM)	69	301	305	153	3.24	1.4	0.11	0.05	85
Lunella undulata	44	65	270	333	164	4.11	1.52	0.06	0.05	
Turbo militaris	61	77	400	273	122	1.93	1.22	0.22	0.05	

(*Contd.*)

Table 5 — Mineral content of edible snails (*Contd.*)

Scientific name	Mineral content (mg/100 g)									Reference
	Ca	Mg	Na	K	P	Fe	Zn	Cu	Mn	
Limicolaria flammea	165.45	13.57	66.87	132.45	336.53	4.24	2.92	2.53	6.47	64
Archachatina marginata (Adult)	42.19	59.23	44.75	92.34	295.64	9.53	--	--	--	94
Archachatina marginata (Grower)	31.64	60.04	39.57	77.55	286.65	7.37	--	--	--	
Archachatina marginata (Snailet)	26.46	238.8	31.26	69.24	274.5	5.25	--	--	--	

ND = Not detected
DM= Dry matter basis
FM= Fresh weight basis

sediment for two months it was revealed that higher than desired amounts of metals like iron, manganese, copper, and zinc had accumulated in the digestive tracts and glands[43]. A similar trend was reported for *Bellamya* sp.[44]. Onuoha *et al.*, stated that snails of the species *Archachatina marginata* collected from the crude oil-producing regions in Rivers State, Nigeria were not safe for human consumption, because of the carcinogenic risk posed by the high amounts of nickel in them[45]. Besides, edible snails can host a number of parasites[28,46]. In a study by Tesana *et al.*, from Northeast Thailand, the edible snail species *Pila polita*, *P. pesmei*, and *Hemiplecta distincta* all contained the nematode worm *Angiostrongylu scantonensis,* which can be transmitted to human hosts and cause Angiostrongyliasis[47]. *Pomacea canaliculata* and *Achatina fulica* were found to be the most likely intermediate hosts of *Angiostrongylus cantonensis* in China[48]. Among some other occasionally eaten snails, the species, *Limicolaria aurora*, *L. flammea*, and *Limicolariopsis* sp. were found to be contaminated with mesocercariae of the trematode *Alaria*, while *L. flammea* was furthermore found to contain cercariae of the liver fluke *Dicrocoelium dendriticum*[46]. Therefore, in order to avoid these hazards, maintaining sanitation of the snail farm is necessary and proper processing of edible snails is also important[49].

Conclusion

Although snail farming is not a novel entrant in agriculture, it is far from receiving proper appreciation. Various species of snails are used for food and/or medicinal purposes, but their roles are primarily confined to within the limitation of a few users in a small number of countries. Often dietary transitions due to urbanization, availability of western foods, climate change, etc. are the major factors for the decline in the interest and the use of traditional foods including snails. To halt the erosion of the traditional food wisdom and to support the safe supply of snail meat, the establishment of helicicultural facilities is therefore, a necessity. An increase in snail meat consumption can mitigate nutrient deficiency and also enhance the economic condition of certain local areas in which suitable snails can be farmed and traded.

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Conflict of interest

The authors declare no conflict of interest.

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