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Research article

Nutritional evaluation of some economically important marine and freshwater mollusc species of Bangladesh

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ABSTRACT

Molluscs are the most important resources among all the seafood items in South-East Asian countries. However, very little information available on nutritional value of molluscs in these regions. In this study, we evaluated the 7 economically important species of molluscs in terms of proximate composition, amino acids profile, fatty acids profile, cholesterol and heavy metal contents in the bivalves (mussels, oysters, clams and cockles) and univalve (snail) collected from freshwater and marine environments of Bangladesh. The results of the proximate analyses revealed that significantly higher amount of crude protein contents were present in marine water oysters, clams and cockles (59.3 ± 0.3 to 75.4 ± 0.2%) than the freshwater mussels and snail (36.9 ± 0.4 to 49.6 ± 0.6%) on dry matter basis. However, carbohydrate contents were significantly higher in freshwater mussels and snail (30.2 ± 0.9 to 57.3 ± 0.2%) compared to the marine water bivalves (8.1 ± 0.4 to 20.2 ± 0.6%). Crude lipid contents were ranged from 2.5 ± 0.2 to 11.2 ± 0.1% and ash from 11.4 ± 0.1 to 16.8 ± 0.6% among the bivalves and snail species. The amino acid contents were comparatively higher in marine water bivalves than their freshwater counterparts. Saturated fatty acid contents were found to be higher in marine water bivalves than the freshwater mollusc species. The results also show that the omega-3 (eicosapentaenoic acid, EPA and docosahexaenoic acid, DHA) fatty acids were comparatively higher in oysters, clams and cockles in marine water than those in freshwater mussels and snail. However, omega-6 fatty acids like linoleic acid (LA), α- linolenic acid (ALA) and arachidonic acid (ARA) were higher in freshwater mussels and snail than in the marine bivalves. The n-3/n-6 ratio were significantly higher in oysters and cockle species than the other groups of bivalves and snail. The index of atherogenicity and index of thrombogenicity of the mollusc species ranged from 0.74 ± 0.1 to 1.74 ± 0.2 and 0.5 ± 0.1 to 2.6 ± 0.2, respectively. The results show that marine water bivalves contained higher amount of potassium, sodium, iron, chlorine especially oyster species contained significantly higher iodine than the freshwater bivalves and snail. However, freshwater mussels and snail showed significantly higher amount of zinc contents than the marine bivalves. The heavy metal contents such as arsenic, chromium and mercury were absent or present in very tiny amounts among the mollusc species. Significantly higher amount of cholesterol was present in marine bivalves and freshwater snail species than the freshwater mussels. Overall, the results indicate that marine bivalves can be good sources of high quality protein and lipid especially EPA and DHA. On the other hand, freshwater mussels and snails also could be good sources of protein, LA and ARA but scarcity of EPA and DHA.

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1. Introduction

Shellfishes can be enjoyed in a variety of ways because of its nutritious value. It can have a pair of shells (bivalve) or a single shell (univalve). From the different groups of shellfishes, mollusc is considered as one of the most vital shellfishes. Proteins especially essential amino acids are highly present in mollusc. Molluscs are also a good sources of essential trace minerals together with vitamin B complexes. In Bangladesh, there are about 362 species of mollusc, of which, 336 species are marine and 26 species are freshwater sources (Anisuzzaman et al., 2016). There are seven classes of phylum Mollusca, where gastropod and bivalves are the two most important classes. Gastropods are the snails, slugs and limpets, and bivalves are the mussels, clams, oysters and scallops (Mason et al., 2014). It has been reported that mussels and snails may contain high quality nutrients and bioactive compounds which have great influence on human health such as high quality protein and amino acids, and long chain fatty acids like eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), arachidonic acid (ARA) as well as vitamins and minerals especially from marine species (Smoothey, 2013). Mussels contained a large proportion of omega-6 and omega-3 fatty acids, as well as good saturated, monounsaturated and other polyunsaturated fatty acids which can be considered as low fat diet with high bioactive properties (King et al., 1990). Ersoy and Sereflisan (2010) observed that the freshwater mussel (*U. terminalis* and *P. littoralis*) contained crude protein (11.87–11.97%), lipid (2.55–1.05%), ash (1.68–1.61%) and moisture (80.36–81.69%), saturated fatty acids (SFA), monounsaturated fatty acids (MUFA), polyunsaturated fatty acids (PUFA). The n3/n6 ratio of *U. terminalis and P. littoralis* were found to be 1.54 and 1.40, respectively. Both of these species are good sources of EPA and DHA. Saritha et al. (2015) reported that marine bivalve *P. viridis* is a valuable food source for human consumption due to its high quality protein and well-balanced nutritional composition. Bender (1992) postulated that the amino acids in protein of snail meat would balance the cereal sources of protein in terms of their relative shortage of lysine. Snail meat can used as a remedy for different kind of diseases like heart attack, cardiac arrest, hypertension and stroke because of the presence of low fat and low cholesterol. The proportion of mineral content in snail is higher than the other meat like beef, broiler, goat and pigs (Bender, 1992). Therefore, it is important to know the nutritional composition of the mussels and snails from the freshwater and marine sources. Snail meal is reported to have a good lysine (4.35–4.60%) content (Imevbore and Ademosun, 1988). These nutritional properties have made snail an increasingly important dietary protein source for human beings in several regions of the world (Ali and Leeson, 1995). Asha et al. (2014) confirmed that moisture, protein, fat, carbohydrate and ash contents in the oyster (*C. madrasensis*) were 82.64%, 9.41%, 3.25% 3.2% and 1.01%, respectively and it was rich in macro-minerals and trace elements especially selenium. Compared to the poultry and other meat from livestock, snail contained high levels of protein, iron, lysine, leucine, arginine, calcium and phosphorus and relatively low in amount of sodium, fat and cholesterol (Simpson, 1990; Thompson, 1996). Snail meat can be used as a medicine for labor pain, blood loss during delivery and small pox (Wosu, 2003). They also used as the treatment for anemia, hypertension, high blood pressure and other fat-related ailments (Akinnusi, 1998). Day-by-day the necessity of protein rich food is rising particularly in developing countries with the progression of human population. Not only the marine fin fishes provide vital place in human diet but also the crustaceans and molluscs added in human diet (Adegbola, 1998). Therefore, to elucidate the potential of different mussel and snail species for human health and animal nutrition, it is imperative to have the comprehensive information on their nutritional status.

2. Materials and methods

2.1. Sample collection and species identification

Samples of economically important mussels and snails were collected in fresh condition from selected places of Bangladesh based on marine source from the Bay of Bengal (St. Martin Island at 20°36′47″N 92°19′36″E and Maheshkhali Island at 21°33′N 91°57′E) and ponds from freshwater (Mymensingh at 24°38′3″N 90°16′4″E) regions. A total of 7 edible mollusc species were selected for the analysis. Among the 7 species, 2 oyster species (*Saccostrea cucculata* and *Crassostrea virginica*), 1 clam species (*Meretrix meretrix*), 1 cockle species (*Andara granosa*), 1 snail species (*Pila globosa*) and 2 mussel species (*Lamellidens marginalis* and *Lamellidens corrianus*) were used for the nutritional analysis (Figure 1). After collection of the mollusc species, the samples (50 samples per species) were separated according to the species and washed with clean water. The separated species were cleaned and iced instantly in an insulated styrofoamboxes and transported into the Fish nutrition and Feed technology laboratory of Bangladesh Fisheries Research Institute, Mymensingh for further processing. The molluscs were taxonomically identified based on Siddique et al. (2007) and the molluscabase.org. Afterwards, edible parts of the mussel and snail were removed from the shell to prepare the sample for nutritional analyses. The edible parts of the species were homogenized by mincing and proximate composition, amino acid contents, fatty acid contents, minerals, heavy metals and total cholesterol contents were determined.

2.2. Proximate compositions

Whole body proximate composition of the collected samples such as protein, lipid, ash, moisture were done according to the AOAC method (1995). Briefly, moisture contents (1 g for each sample) of shellfish were determined by drying at 135 °C for 2 h. Crude protein content in the homogenized (0.1g) was determined using the Kjeldahl method (N × 6.25) after acid digestion, distillation and titration of the samples. By constant extraction of lipid, the crude lipid content of the samples was assessed with petroleum ether. According to Folch et al. (1957) chloroform/methanol (2:1) was used to extract the total lipid content. The lipids were measured gravimetrically and aliquots of the chloroforms layer extract were vaporized. In this process, 1g for each sample were used for soxhlet extraction (Soxtec system, Tecator AB, Hoganas, Sweden). Ash content (1 g for each sample) was estimated by a muffle furnace at 550 °C for 4 h. Results were showed as percentage of dry weight. Energy value was determined assuming conversion factors (formulae 6) from the amount of protein, lipids and carbohydrates (formula 1-5) (Moniruzzaman and Mollah, 2010; NRC, 2011).

$$\text{Moisture (\%)} = \text{wet sample weight – dried sample weight / wet sample weight} \times 100 \quad (1)$$

$$\text{Crude protein (\%)} = \text{\% nitrogen (N)} \times 6.25 \quad (2b)$$

$$\text{\% nitrogen} = \text{milliequivalent of nitrogen (0.014)} \times \text{titrant value (ml)} \times \text{strength of HCl / sample weight} \times 100 \quad (2a)$$

$$\text{Crude lipid (\%)} = \text{weight of lipid/ weight of sample} \times 100 \quad (3)$$

$$\text{Ash (\%)} = \text{weight of ash/ weight of sample} \times 100 \quad (4)$$

$$\text{Carbohydrates (\%)} = 100 - (\text{moisture} + \text{lipids} + \text{proteins} + \text{ash}) \quad (5)$$

$$\text{Energy value (kJ/100g)} = \text{proteins (g)} \times 23.6\text{kJ} + \text{lipids (g)} \times 39.5\text{kJ} + \text{carbohydrates (g)} \times 17.2\text{kJ} \quad (6)$$

2.3. Analyses of micronutrients

2.3.1. Amino acids

To determine the amino acid content Ishida et al. (1981) method was followed by applying high performance liquid chromatography (HPLC) (Shimadzu Chromatograph LC-10AT vp) prepared with an ion exchange column, quaternary pump, a 20 micro liter injection valve and a fluorescence indicator. Movable part A, contained sodium citrate and ethanol (pH 3.5) and part B, had sodium citrate and NaOH (pH 9.8). The flow rate

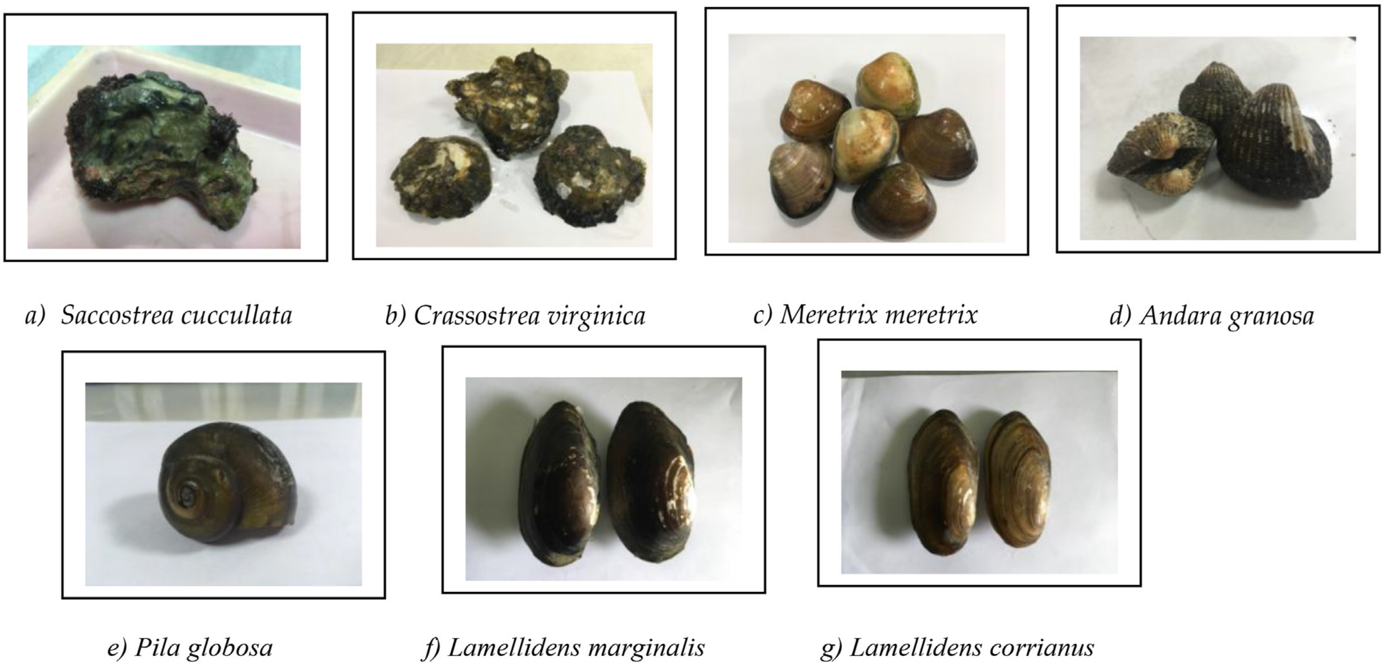

Figure 1. The specimens of the 4 mollusc species of marine water a) *Saccostrea cucullata* b) *Crassostrea virginica* c) *Meretrix meretrix* d) *Andara granosa* and 3 species of freshwater e) *Pila globosa* f) *Lamellidens marginalis* g) *Lamellidens corrianus* in the present study.

was constant at 0.4 ml/min and the column temperature was set at 60 °C. The wavelength of fluorescence excitation and emission were 340 and 450mm respectively. By keeping the temperature at 110 °C the sample were hydrolyzed in 6 N Hydrochloric acid in evacuated sealed tubes for 24h. After derivatization by evaluation of their retention times with those of standard (Sigma).

2.3.2. Fatty acids and cholesterols

For fatty acids analysis of whole body lipid was extracted according to Folch et al. (1957). Fatty acid methyl esters (FAMEs) of whole body lipid were prepared using acid-catalyzed trans-esterification method. The composition of FAMEs was determined by a gas chromatography mass spectrometry (GC-MS) (Trace GC, Thermo Finnigan, San Jose, CA, USA). The total cholesterol levels in extracted lipid from each species of mollusc were determined by the method of AOAC (2000). The fatty acids data were calculated for the index of atherogenicity (IA) and the index of thrombogenicity (IT) according to Ulbricht and Southgate (1991). The following Eqs. (7) and (8) were applied for IA and IT:

$$IA = (12{:}0 + 4 \times 14{:}0 + 16{:}0) / [\Sigma MUFA + \Sigma\ PUFA] \quad (7)$$

$$IT = [14{:}0 + 16{:}0 + 18{:}0] / [(0.5 \times MUFA) + (0.5 \times n\text{-}6) + (3 \times n\text{-}3) + (n\text{-}3/n\text{-}6)] \quad (8)$$

2.3.3. Minerals and heavy metals

By using AOAC method (2000) minerals were measured by using flame photometry, micro elements were determined with the help of working standard in the range of 10–40ppm for each element such as sodium (Na), potassium (K), calcium (Ca) as well as heavy metals like mercury (Hg), chromium (Cr) and arsenic (As). The trace metal contents in each sample (1 g per sample) were determined by using Inductively Coupled Argon Plasma Mass Spectrometer (ICP-MS) (ICP-MS; Perkin-Elmer 3300, Waltham, MA, USA).

2.4. Statistical analyses

The data obtained were subjected to analysis of variance (ANOVA) to test the nutritional composition of the bivalves and snail. The data were analyzed using the SAS software (SAS 9.1, SAS Institute, Cary, NC, USA). Tukey's HSD (honestly significant difference) post-hoc test was used to compare means amongst treatments with significant effects ($P < 0.05$). Data values are expressed as mean ± standard deviation of three replicates of each specimen groups.

3. Results

This study was conducted to analyze the nutritional properties of 7 marine and freshwater mollusc species of Bangladesh. The data of mollusc species displayed in the table are normally captured from open water indiscriminately for different uses. In the context of Bangladesh, the species are indiscriminately capturing for lime production, poultry feed production, as well as shrimp and prawn feed and dead shell for button and decoration purposes (Siddique et al., 2020; Das et al., 2020). Nutrient values of marine and freshwater molluscs are totally unknown for the people which can replace the demand of fish and meat as protein source. However, in this study, our plan was to explore the nutrient contents and health benefits of the mollusc species to the stakeholders.

3.1. Proximate composition

Table 1 shows that the biochemical composition of molluscs varies among species to species. Protein percentages varied between 36.9 ± 0.4 in *L. marginalis* and 75.4 ± 0.2 in *A. granosa*. Significantly higher amount of crude protein contents were present in marine water oysters, clams and cockles (59.3 ± 0.3 to 75.4 ± 0.2%) than the freshwater mussels and snail (36.9 ± 0.4 to 49.6 ± 0.6%) on dry matter basis. Lipid percentages were ranged from 2.5 ± 0.2 in *C. virginica* to 11.2 ± 0.1 in *S. cucullata*. Both marine and freshwater molluscs with ash percentages found more or less similar while significantly higher value was observed in *P. globosa* (16.8 ± 0.6) and significantly lower value observed in *L. corrianus* (11.4 ± 0.1). The data of moisture percentages also found very close to each species (83.4 ± 0.6 to 89.4 ± 0.6). Marine water cockle, *A. granosa* was contained significantly lower amount of carbohydrate where freshwater mussels *L. corrianus* contained significantly higher amount of carbohydrate. Energy value (kJ/100g) was significantly lower in *P. globosa* and higher in *L. corrianus*.

Table 1. Proximate composition of the 7 economically important marine and freshwater mollusc species (% dry matter basis).

Species	Protein (%)	Lipid (%)	Ash (%)	Moisture (%)	Carbo hydrate (%)	Energy value (kJ/100g)	Energy value (kcal/100g)
Marine water							
Saccostrea cucculata	65.3 ± 1.1^{c}	11.2 ± 0.1^{a}	13.8 ± 0.2^{c}	88.4 ± 0.2^{c}	9.6 ± 0.6^{f}	1672±1^{b}	400±1^{b}
Crassostrea virginica	67.2 ± 0.3^{b}	2.5 ± 0.2^{e}	12.8 ± 0.3^{d}	89.4 ± 0.6^{a}	17.4 ± 0.2^{e}	1508.0 ± 0.8^{f}	360.0 ± 0.7^{f}
Meretrix meretrix	59.3 ± 0.3^{d}	5.8 ± 0.1^{b}	14.8 ± 0.1^{b}	85.4 ± 0.8^{d}	20.2 ± 0.6^{d}	1547.0 ± 1.1^{c}	370.0 ± 0.2^{c}
Andara granosa	75.4 ± 0.2^{a}	3.2 ± 0.1^{d}	13.1 ± 0.4^{cd}	88.8 ± 0.1^{b}	8.1 ± 0.4^{g}	1516.0 ± 0.9^{e}	362.0 ± 0.4^{e}
Freshwater							
Pilaglobosa	49.6 ± 0.6^{e}	3.0 ± 0.2^{d}	16.8 ± 0.6^{a}	83.4 ± 0.6^{f}	30.2 ± 0.9^{c}	1447.0 ± 1.2^{g}	346.0 ± 0.1^{g}
Lamellidensmarginalis	36.9 ± 0.4^{g}	4.4 ± 0.2^{c}	13.1 ± 0.2^{cd}	84.8 ± 0.2^{e}	45.3 ± 0.1^{b}	1540.0 ± 0.8^{d}	368.0 ± 0.2^{d}
Lamellidens corrianus	40.9 ± 0.9^{f}	4.8 ± 0.3^{c}	11.4 ± 0.1^{e}	85.4 ± 0.7^{d}	57.3 ± 0.2^{a}	1822.0 ± 1.3^{a}	436.0 ± 0.1^{a}

Data represent mean ± SD values of three analytical measurements (n = 3) conducted on pooled mussels and snails samples of several individuals per species. Values in each column with different superscripts are significantly different ($P < 0.05$).

3.2. Amino acids profile

The amino acid profile of the analyzed shell fishes is listed in Table 2. All the amino acids composition varied among species to species but higher concentration of all amino acid composition observed in marine species especially in *A. granosa* than the freshwater species. Aspartic acid showed values from 4 ± 0.2 (*M. meretrix*) to 5.1 ± 0.2 (*A. granosa*) in marine species, while 2.6 ± 0.2 (*L. margianlis*) to 3.4 ± 0.1 (*P. globosa*) values showed in freshwater species. Similarly lysine values lies between 3.7 ± 0.1 (*M. meretrix*) to 4.7 ± 0.1 (*A. granosa*) for marine species when 2.4 ± 0.7 (*L. margianlis*) to 3.1 ± 0.2 (*P. globosa*) values were found in freshwater species. Correspondingly, glutamic acid showed values from 6.1 ± 0.1 (*M. meretrix*) to 7.6 ± 0.2 (*A. granosa*) for marine species, while 3.8 ± 0.2 (*L. margianlis*) to 5.1 ± 0.2 (*P. globosa*) values observed in freshwater species (Table 2).

3.3. Fatty acids profile

Fatty acid concentration of the selected species of shellfishes is presented in Table 3. Twenty one types of fatty acid (%) were identified in 7 species of molluscs with highest value 59.9 ± 0.1% (*M. meretrix*) saturated fatty acids (SFA), 43.8 ± 0.6% (*L. marginalis*) monounsaturated fatty acids (MUFA), and 33.9 ± 0.8% (*L. corrianus*) polyunsaturated fatty acids (PUFA). The MUFA and PUFA were higher in *L. marginalis* and *L. corrianus* compared to the other marine and freshwater species. All the polyunsaturated fatty acids belonged to Σn-3 and Σn-6 series. The content found for Σn-3 PUFA ranged from 0.6 ± 0.1 for *M. meretrix* to 18.8 ± 0.2% for *C. virginica*. The content found for Σn-6 PUFA lies between 0.9 ± 0.1 (*M. meretrix*) and 16.6 ± 0.2 (*P. globosa*). This characterizes the marine species which have high percentages of Σn-3 PUFA and less of Σn-6 PUFA compared to fresh water species which have high percentages of Σn-6 PUFA and less of Σn-3 PUFA [60, 61]. The richest PUFA were eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) with 9.6 ± 2.3% (*S. cuccullata*) and 6.5 ± 0.2% (*L. corrianus*) for EPA, 8.4 ± 0.1% (*C. virginica*) and 5.3 ± 0.7% (*S. cuccullata*) for DHA. The Σn-3/Σn-6 ratio was found 5.4 ± 0.1 and 3.6 ± 0.1 in *C. virginica* and *A. granosa*, respectively.

3.4. Lipid health indices

The lipid health indices (IA and IT) also determined from 7 different mollusc species. From the analysis, maximum IA observed in *A. granosa* (1.74 ± 0.2) and minimum IA observed in *L. corrianus* (0.74 ± 0.1) while highest IT was found in *M. meretrix* (2.6 ± 0.2) and lowest IT was found in *L. corrianus* (0.5 ± 0.1) respectively (Table 3).

3.5. Mineral composition

The results of mineral contents (mg/100g) also varied among different species of molluscs. Macro-minerals such as calcium contents

Table 2. Amino acid profile of the 7 economically important marine and freshwater mollusc species (% of protein).

Amino acids	Species						
	Saccostrea cucculata	*Crassostrea virginica*	*Meretrix meretrix*	*Andara granosa*	*Pila globosa*	*Lamellidens marginalis*	*Lamellidens corrianus*
Aspartic acid (Asp)	4.5 ± 0.1^{ab}	4.5 ± 0.1^{ab}	4.0 ± 0.2^{b}	5.1 ± 0.2^{a}	3.4 ± 0.1^{bc}	2.6 ± 0.2^{c}	2.8 ± 0.1^{c}
Threonine (Thr)*	2.7 ± 0.2^{ab}	2.9 ± 0.2^{ab}	2.5 ± 0.3^{ab}	3.2 ± 0.3^{a}	2.1 ± 0.1^{b}	1.6 ± 0.2^{c}	1.7 ± 0.1^{c}
Methionine (Met)*	1.1 ± 0.1^{a}	1.1 ± 0.1^{a}	0.9 ± 0.2^{ab}	1.2 ± 0.1^{a}	0.8 ± 0.1^{ab}	0.6 ± 0.1^{b}	0.7 ± 0.1^{b}
Valine (Val)*	2.1 ± 0.4^{ab}	2.4 ± 0.1^{a}	2.1 ± 0.1^{ab}	2.7 ± 0.1^{a}	1.6 ± 0.1^{b}	1.2 ± 0.2^{b}	1.4 ± 0.1^{b}
Leucine (Leu)*	3.5 ± 0.2^{a}	3.5 ± 0.1^{a}	3.1 ± 0.2^{ab}	3.9 ± 0.1^{a}	2.6 ± 0.1^{b}	2.0 ± 0.1^{b}	2.2 ± 0.2^{b}
Iso-leucine (Ileu)*	2.4 ± 0.2^{a}	2.3 ± 0.1^{a}	2.1 ± 0.1^{ab}	2.6 ± 0.1^{a}	1.8 ± 0.4^{ab}	1.4 ± 0.3^{b}	1.5 ± 0.4^{b}
Histidine (His)*	2.7 ± 0.2^{a}	2.4 ± 0.1^{ab}	2.2 ± 0.1^{ab}	2.7 ± 0.1^{a}	2.0 ± 0.3^{ab}	0.8 ± 0.1^{b}	0.9 ± 0.2^{b}
Lysine (Lys)*	4.1 ± 0.2^{a}	4.2 ± 0.1^{a}	3.7 ± 0.1^{ab}	4.7 ± 0.1^{a}	3.1 ± 0.2^{b}	2.4 ± 0.7^{c}	2.6 ± 0.3^{c}
Tyrosine (Tyr)	2.5 ± 0.4^{ab}	2.5 ± 0.1^{ab}	2.2 ± 0.1^{ab}	2.8 ± 0.1^{a}	1.9 ± 0.1^{b}	1.5 ± 0.3^{b}	1.7 ± 0.4^{b}
Arginine (Arg)*	2.8 ± 0.4^{ab}	3.0 ± 0.1^{a}	2.7 ± 0.1^{ab}	3.4 ± 0.1^{a}	2.2 ± 0.2^{b}	1.6 ± 0.2^{c}	1.8 ± 0.3^{c}
Serine (Ser)	3.1 ± 0.3^{ab}	3.4 ± 0.1^{a}	2.9 ± 0.1^{ab}	3.8 ± 0.1^{a}	2.4 ± 0.4^{ab}	1.7 ± 0.1^{b}	1.9 ± 0.3^{b}
Glutamic acid (Glu)	6.6 ± 0.3^{ab}	6.8 ± 0.1^{ab}	6.1 ± 0.1^{b}	7.6 ± 0.2^{a}	5.1 ± 0.2^{c}	3.8 ± 0.2^{d}	4.1 ± 0.3^{d}
Glycine (Gly)	3.2 ± 0.2^{ab}	3.3 ± 0.1^{ab}	2.7 ± 0.1^{b}	3.8 ± 0.1^{a}	2.4 ± 0.2^{b}	1.8 ± 0.3^{c}	1.9 ± 0.1^{c}
Alanine (Ala)	2.7 ± 0.3^{ab}	2.9 ± 0.1^{ab}	2.5 ± 0.1^{b}	3.3 ± 0.1^{a}	2.0 ± 0.1^{c}	1.5 ± 0.2^{d}	1.7 ± 0.3^{cd}

Data represent mean ± SD values of three analytical measurements (n = 3) conducted on pooled mussels and snails samples of several individuals per species. Values in each row with different superscripts are significantly different ($P < 0.05$).

* Essential amino acids for human.

Table 3. Fatty acid profile of the 7 economically important marine and freshwater mollusc species (% of fat).

Fatty acids	Species						
	S. cuccullata	*C. virginica*	*M. meretrix*	*A. granosa*	*P. globosa*	*L. marginalis*	*L. corrianus*
14:0	2.8 ± 0.3[c]	3.4 ± 0.1[b]	3.5 ± 0.2[b]	11.8 ± 0.3[a]	11.6 ± 1.2[a]	1.8 ± 0.1[d]	2.3 ± 0.1[c]
16:0	37.4 ± 0.2[b]	34.7 ± 0.3[c]	48.4 ± 0.3[a]	33.6 ± 0.3[cd]	28.8 ± 1.5[e]	34.5 ± 2.2[c]	30.4 ± 2.2[d]
18:0	7.1 ± 0.1[ab]	5.9 ± 0.4[bc]	6.3 ± 0.1[b]	5.1 ± 0.3[c]	8.0 ± 0.7[a]	7.1 ± 0.1[ab]	6.2 ± 0.2[b]
22:0	3.9 ± 0.7[a]	2.8 ± 0.3[b]	1.1 ± 0.2[c]	1.3 ± 0.3[c]	LOQ	LOQ	3.5 ± 0.3[ab]
24:0	LOQ	LOQ	0.7 ± 0.1[c]	1.8 ± 0.2[a]	LOQ	1.4 ± 0.2[b]	1.6 ± 0.2[ab]
ΣSFAs	51.2 ± 1.1[c]	47.3 ± 0.1[d]	59.9 ± 0.1[a]	53.7 ± 0.2[b]	48.5 ± 0.3[d]	44.9 ± 3.2[e]	44.1 ± 2.3[e]
14:1	LOQ	1.2 ± 0.2[c]	1.3 ± 0.3[c]	3.1 ± 0.1[a]	2.1 ± 0.0[b]	0.5 ± 0.4[d]	LOQ
16:1	4.1 ± 0.1[e]	9.9 ± 0.4[d]	21.8 ± 0.4[a]	14.4 ± 0.2[c]	LOQ	17.2 ± 0.8[b]	3.5 ± 0.3[f]
18:1	14.9 ± 1.1[d]	14.4 ± 0.2[d]	14.1 ± 0.4[d]	15.1 ± 0.4[c]	17.1 ± 1.1[a]	15.1 ± 1.6[c]	16.1 ± 1.0[b]
20:1	3.2 ± 0.4[b]	0.8 ± 0.1[e]	1.3 ± 0.3[d]	0.9 ± 0.2[e]	10.9 ± 0.7[a]	10.9 ± 1.3[a]	2.4 ± 0.5[c]
ΣMUFAs	22.2 ± 1.2[f]	26.8 ± 0.4[e]	38.6 ± 0.1[b]	33.6 ± 0.4[c]	30.1 ± 1.6[d]	43.8 ± 0.6[a]	22.0 ± 2.0[f]
18:2, LA	2.2 ± 0.5[c]	1.4 ± 0.2[d]	0.8 ± 0.1[e]	2.3 ± 0.3[c]	9.2 ± 0.6[a]	3.3 ± 1.0[b]	8.7 ± 0.7[a]
18:3, ALA	2.9 ± 0.5[c]	4.5 ± 1.9[b]	LOQ	2.6 ± 0.1[cd]	4.6 ± 1.6[b]	3.0 ± 0.5[c]	11.6 ± 0.9[a]
20:4, ARA	6.3 ± 0.6[b]	2.1 ± 0.1[c]	LOQ	LOQ	7.4 ± 1.1[a]	2.6 ± 0.7[c]	7.1 ± 1.3[a]
20:5, EPA	9.6 ± 2.3[a]	5.9 ± 0.3[b]	0.4 ± 0.1[de]	4.1 ± 0.3[c]	LOQ	1.1 ± 0.1[d]	6.5 ± 0.2[b]
22:6, DHA	5.3 ± 0.7[b]	8.4 ± 0.1[a]	LOQ	2.2 ± 0.3[c]	LOQ	0.9 ± 0.3[d]	LOQ
ΣPUFAs	26.6 ± 0.5[b]	26.6 ± 0.4[b]	1.5 ± 0.1[e]	12.7 ± 0.3[d]	21.4 ± 0.4[c]	11.1 ± 0.3[d]	33.9 ± 0.8[a]
ΣUFA	48.8 ± 0.6[c]	53.1 ± 0.8[b]	40.1 ± 0.3[e]	46.3 ± 0.4[d]	51.5 ± 0.7[bc]	55.1 ± 0.6[a]	56.2 ± 0.6[a]
Σn-3	17.8 ± 0.2[b]	18.8 ± 0.2[a]	0.6 ± 0.1[f]	8.9 ± 0.2[c]	4.5 ± 0.1[e]	5.1 ± 0.2[d]	18.1 ± 0.3[ab]
Σn-6	8.5 ± 0.3[b]	3.5 ± 0.4[d]	0.9 ± 0.1[f]	2.5 ± 0.1[e]	16.6 ± 0.2[a]	5.9 ± 0.1[c]	15.8 ± 0.3[a]
n-6/n-3	0.48 ± 0.1[c]	0.2 ± 0.1[d]	1.50 ± 0.1[ab]	0.28 ± 0.1[d]	3.69 ± 0.2[a]	1.15 ± 0.1[b]	0.87 ± 0.1[c]
n-3/n-6	2.1 ± 0.1[c]	5.4 ± 0.1[a]	0.6 ± 0.1[de]	3.6 ± 0.1[b]	0.3 ± 0.1[e]	0.7 ± 0.1[de]	1.2 ± 0.1[d]
IA	0.99 ± 0.2[c]	0.90 ± 0.1[c]	1.55 ± 0.1[ab]	1.74 ± 0.2[a]	1.46 ± 0.2[b]	0.75 ± 0.1[d]	0.74 ± 0.1[d]
IT	0.6 ± 0.1[d]	0.7 ± 0.1[cd]	2.6 ± 0.2[a]	1.1 ± 0.1[b]	1.3 ± 0.2[b]	0.9 ± 0.1[c]	0.5 ± 0.1[d]

Data represent mean ± SD values of three analytical measurements (n = 3) conducted on pooled mussels and snails samples of several individuals per species. Values in each row with different superscripts are significantly different ($P < 0.05$).
SFAs, saturated fatty acids; MUFAs, monounsaturated fatty acids; LA, linoleic acid; ALA, alpha-linolenic acid; ARA, arachidonic acid; EPA, eicosapentaenoic acid; DHA, docosapentaenoic acid; PUFAs, polyunsaturated fatty acids; UFA, unsaturated fatty acid; IA, index of atherogenicity; IT, index of thrombogenicity; LOQ = limit of quantification.

varied from 785.0 ± 4.1 (*S. cuccullata*) to 2971.0 ± 5.5 (*M. meretrix*), magnesium values observed more or less similar in each species, while lowest in *L. corrianus* (25.5 ± 0.2) and highest in *C. virginica* (28.2 ± 0.2), sodium content ranged from 272.0 ± 15.2 (*L. corrianus*) to 993.0 ± 5.0 (*S. cuccullata*), phosphorus content found between 220.0 ± 2.1 (*L. corrianus*) to 346.0 ± 0.5 (*S. cuccullata*), chlorine content in between 316.0 ± 3.5 (*L. corrianus*) to 903.0 ± 5.0 (*S. cuccullata*) and potassium values lies between 98.0 ± 4.0 (*L. marginalis*) to 326.0 ± 2.0 (*M. meretrix*). Micro-minerals or essential trace elements like zinc contents found at 121.0 ± 0.9 (*S. cuccullata*) to 166.0 ± 0.7 (*P. globosa*), copper content from 4.2 ± 0.3 (*M. meretrix*) to 8.3 ± 0.3 (*L. marginalis*), iron content observed between 33.0 ± 1.3 (*L. corrianus*) to 123.0 ± 2.3 (*A. granosa*) and iodine found 50.0 ± 0.9 (*P. globosa*) to 66.0 ± 3.1 (*C. virginica*) (Table 4). The results showed that the marine water bivalves contained higher amount of potassium, sodium, iron, chlorine than the freshwater mussels and snail. Significantly higher amount of iodine was found in oyster species than the freshwater bivalves and snail. Furthermore, freshwater mussels and snail contained significantly higher amount of zinc than the marine bivalves.

3.6. Heavy metals and total cholesterol contents

Heavy metal contamination differs from place to place. In this study, presence of heavy metal (mg/kg) also determined during nutritional analysis. Arsenic and mercury contents were absent in all mollusc species while little amount of chromium found in *S. cucculata* (0.036 ± 0), *P. globosa* (0.020 ± 0), *L. marginalis* (0.020 ± 0) and *L. corrianus* (0.024 ± 0). Cholesterol (mg/100g) values lies between 72 ± 0.1 (*L. marginalis*) to 112 ± 0.2 (*A. granosa*) (Table 5). Significantly higher amount of total cholesterol (>100) was found in two oyster (*S. cuccullata* and

Table 4. Macro- and micro-mineral contents of the 7 economically important marine and freshwater molluscs (mg/100g).

Species	Ca	K	Mg	Na	Zn	Cu	P	Cl	Fe	I
S. cuccullata	785.0 ± 4.1[g]	312.0 ± 2.5[b]	25.6 ± 0.3[cd]	993±5[a]	121.0 ± 0.9[f]	4.5 ± 0.5[de]	346.0 ± 0.5[a]	903±5[a]	78.0 ± 0.2[b]	64.0 ± 3.3[a]
C. virginica	1270.0 ± 2.5[f]	258.0 ± 4.0[c]	28.2 ± 0.2[ab]	872±4[b]	136±2[e]	6.3 ± 0.3[b]	322.0 ± 1.5[b]	886.0 ± 3.1[b]	76.0 ± 1.1[b]	66.0 ± 3.1[a]
M. meretrix	2971.0 ± 5.5[a]	326.0 ± 2.0[a]	28.0 ± 0.4[a]	532±4[c]	122±2[f]	4.2 ± 0.3[e]	288±2[c]	653.0 ± 3.2[c]	64.0 ± 0.9[c]	56.0 ± 2.1[b]
A. granosa	1358.0 ± 6.1[e]	239.0 ± 3.1[d]	27.5 ± 0.3[b]	453.0 ± 2.6[d]	148.0 ± 3.1[d]	5.4 ± 0.3[cd]	256.0 ± 2.6[e]	623.0 ± 3.2[d]	123.0 ± 2.3[a]	58.0 ± 2.1[b]
P. globosa	1739.0 ± 8.3[b]	202.0 ± 3.0[e]	25.7 ± 0.2	300 ± 11[e]	166.0 ± 0.7[b]	4.6 ± 0.2[de]	245.0 ± 1.9[f]	402.0 ± 1.5[f]	54.0 ± 0.5[d]	50.0 ± 0.9[b]
L. marginalis	1709.0 ± 2.4[c]	98.0 ± 4.0[g]	26.3 ± 0.2[c]	330 ± 11[e]	173.0 ± 0.5[a]	8.3 ± 0.3[a]	267.0 ± 1.8[d]	458.0 ± 6.1[e]	48.0 ± 0.8[e]	51.0 ± 0.1[b]
L. corrianus	1663.0 ± 10.7[d]	103.0 ± 4.7[f]	25.5 ± 0.2[d]	272.0 ± 15.2[f]	153±1[c]	5.5 ± 0.3[c]	220.0 ± 2.1[g]	316.0 ± 3.5[g]	33.0 ± 1.3[f]	53.0 ± 2.3[b]

Data represent mean ± SD values of three analytical measurements (n = 3) conducted on pooled mussels and snails samples of several individuals per species. Values in each column with different superscripts are significantly different ($P < 0.05$).

C. virginica), cockle (*A. granosa*) and snail (*P. globosa*) species than the other molluscs.

4. Discussion

Different types of nutrient such as minerals, Omega-3, -6 fatty acids, essential amino acids and protein are contained in 7 different shellfishes which may have beneficial effect on human health; however they also contained unwanted materials like chromium and high cholesterol. The health benefits and potential restriction of nutrition is discussed in this section.

Molluscs constitute the major and cheapest sources of protein in Nigeria (Ademolu et al., 2004). In this study, proximate composition data of the whole flesh of 7 different molluscs revealed that protein content was found to be higher in *A. granosa* (75.4 ± .02%), while the lipid content was higher in *S. cucculata* (11.2 ± 0.1%), ash content was higher in *P. globosa* (16.8 ± 0.6%), moisture content was higher in *C. virginica* (89.4 ± 0.6%) and carbohydrate observed to be higher in *L. corrianus* (57.3 ± 0.2%). Significantly higher amount of protein was found in *A. granosa* while the least value was obtained from *L. marginalis* (36.9 ± 0.4%). Mason et al. (2014) reported that *Cookia sulcata* contained 78.8% protein, 4.0% lipid, 2.1% ash on dry matter basis which supported the results of the present study for *A. granosa*. Furthermore, in consistent of our study, Tabakaeva et al. (2018) found that 68% protein may present in *Andara broughtonii* from the Sea of Japan coast. In case of oyster species, *S. cucculata* showed significantly higher amount of lipid but lower in *C. virginica* among the mollusc species in the present study. Chakraborty et al. (2016) postulated that lipid contents in *C. madrasensis* ranged between 5-7% that is close to the lipid contents in *S. cucculata* and *C. virginica*. In a recent study, Zhu et al. (2018) reported that Pacific oyster, *C. gigas* contained about 50.76–56.57% protein which is very near to our present findings for oyster species. However, composition of protein, moisture, ash and crude fat vary according to sample species and seasonal variations (Chakraborty et al., 2016; Zhu et al., 2018). Moisture (77.04%), protein (42.05%), lipid (9.75%), carbohydrate (14.73%) was found in Beach Clam (*D. cuneatus*) on dry matter basis (Abirami et al., 2015) which are very lower except for lipid than the present study for the clam species *Meretrix meretrix*. Karnjanapratum et al. (2013) found 49–55% protein and 6–7% lipid in Asian hard clam (*M. lusoria*) which support the data for *M. meretrix* of this study. Sohail et al. (2016) reported protein and fat contents of freshwater mussels in *Anodonta anatina* were found to be 33.12 ± 1.44 and 1.99 ± 0.16%, respectively. In addition, Babar et al. (2017) found that *Lamellidens corrianus* from Bhatsa River of India contained 30–40% protein, 1–3% lipid and 9–11% carbohydrate based on different locations which supported the results of the present findings except for the carbohydrate that is very high in our study for *L. marginalis* and *L. corrianus*. For the freshwater golden apple snail, Ghosh et al. (2017) reported that the species contained 48.5% protein which is in agreement of the present study for apple snail *P. globosa* that could be a good source of protein for human consumption. Comparing to the previous study proximate composition of 7 mollusc species in Bangladesh is much higher in which protein, lipid and ash source can fulfill the requirement for human with health benefits.

In foods, the quantity of amino acids is related to the nutritional quality of protein (Acton and Rudd, 1987). In this study, amino acid composition of 7 economically important shellfishes of different location of Bangladesh is shown in Table 2. In the present study, 8 essential amino acids for human such as threonine (Thr), methionine (Met), valine (Val), leucine (Leu), iso-leucine (Ileu), histidine (His), lysine (Lys), and arginine (Arg) including non-essential amino acids like aspartic acid (Asp), tyrosine (Tyr), serine (Ser), glutamic acid (Glu), glycine (Gly) and alanine (Ala) were available in 7 economically important molluscs (Table 2) and their contents are in accordance with the results reported previously in mollusc species (Karnjanapratum et al., 2013; Asha et al., 2014; Mason et al., 2014; Chakraborty et al., 2016 Ghosh et al., 2017). According to the Table 2, among the 14 different amino acids glutamic acid was highly available in all the mollusc species which is in agreement with Mason et al. (2014) and Karnjanapratum et al. (2013) reported for univalve snail and bivalve clam species, respectively. In contrast to our study, Asha et al. (2014) reported 18 amino acids in oyster *C. madrasensis* where Lys (14.3%) content was the highest followed by Thr (12.3%); Asp (11.8%), Ser (10.6%) and His (7.7 %) were present in high concentrations. In another report, Chakraborty et al. (2016) found higher amount of Arg and lower amount of cysteine in the same species. However, in the present study, we found that Glu was highly present in the mollusc species followed by correspondingly, in decreasing order, Asp > Lys > Leu > Gly, Ser > Arg > Ala > Thr > Tyr > His > Ileu > Met, albeit, Ileu was found to be higher than His in freshwater mussels species. Karnjanapratum et al. (2013) reported higher amount of amino acids but similar amount of His and Ser in Asian hard clam (*M. lusoria*) compared to the *M. meretrix* in the present study. Abirami et al. (2015) found 15 amino acids with high amount of serine, arginine, glutamic acid, lysine, alanine, glycine, leucine, valine, methionine, aspartic acid, phenylalanine, tyrosine, isoleucine, histidine and threonine in decreasing order respectively, in Beach clam. Furthermore, Tabakaeva et al. (2018) postulated that cockle species like *Andara broughtonii* and clam species like *Mactra chinensis* which were collected from the Sea of Japan coast contained high levels of amino acids such as Gly, Glu, Asp, Ala, Leu, Lys and Arg which is in agreement with the results of the present study for clam and cockle species. Likewise, Babu et al. (2012) observed methionine (14.54%), threonine (1.21%) and leucine (10.78%) as major essential amino acids while glutamine 10.87%, glutamic acid 10.85% and arginine 10.66% were the major non-essential amino acids in *Gafrarium tumidum* collected from South-East coast of India. In case of freshwater mussels like *L. marginalis* and *L. corrianus*, the present study showed that the amino acids such as Asp, Thr, Leu, Ileu, Lys, Glu, Gly and Ala contents were significantly lower than the marine water bivalves like oysters and cockles which suggested that marine bivalves are rich source of essential amino acids. Interestingly, the present study also showed that freshwater snail (*P. globosa*) contained significantly higher amount of essential

Table 5. Heavy metal and cholesterol contents of the 7 economically important marine and freshwater molluscs (mg/kg).

Species	As (mg/kg)	Cr (mg/kg)	Hg (mg/kg)	Cholesterol (mg/100g)
S. cucculata	LOQ	0.036 ± 0	LOQ	104 ± 0.5^{d}
C. virginica	LOQ	LOQ	LOQ	106 ± 0.4^{c}
M. meretrix	LOQ	LOQ	LOQ	96 ± 0.1^{e}
A. granosa	LOQ	LOQ	LOQ	112 ± 0.2^{a}
P. globosa	LOQ	0.020 ± 0	LOQ	110 ± 0.4^{b}
L. marginalis	LOQ	0.020 ± 0	LOQ	72 ± 0.1^{g}
L. corrianus	LOQ	0.024 ± 0	LOQ	92 ± 0.1^{f}

Data represent mean ± SD values of three analytical measurements (n = 3) conducted on pooled mussels and snails samples of several individuals per species. Values in each column with different superscripts are significantly different ($P < 0.05$).
LOQ = limit of quantification.

amino acids like Thr, Lys and Arg than the freshwater mussels and most of the amino acid contents in snail were similar to the marine bivalves. The results may attributed to the better food value of snail over freshwater mussels. Şereflişan and Altun (2018) reported *Unio tigridis* had trend of amino acids like Glu > Asp > Lys > Gly > Thr > Ala which supported the data for the freshwater mussels in the present study. Millward (1997) identified the needs of amino acid (g/100 g protein) for adult human as follows; histidine: 1.4; isoleucine: 3.1; leucine: 3.5; lysine: 2.1; threonine: 3.0; tryptophan: 7.0 and valine: 3.1 which are in similar concentrations in relation to our current findings on amino acids profile of 7 important mollusc species. From the current study it can be said that the mollusc species of the present study could fulfill the amino acid requirements for human.

Different types of fatty acids were found from collected sample of 7 economically important mollusc species of Bangladesh. Identified number of saturated fatty acids (SFAs) were 5 and highest amount of these fatty acids were found in *M. meretrix* (59.9 ± 0.1)*, A. granosa* (53.7 ± 0.2) and *S. cuccullata* (51.2 ± 1.1) as the marine water bivalves which is in agreement with the studies reported by Dridi et al. (2007) and Chakraborty et al. (2016). In the same way, MUFAs number were 4 and highest amount of MUFAs observed in freshwater *L. marginalis* and marine water *M. meretrix* that are similar to the results reported by Babar et al. (2017) and Karnjanapratum et al. (2013). PUFAs number were 5 and highest amount of PUFAs found in *L. corrianus, S. cucculata* and *C. virginica.* Freites et al. (2002) and Vernocchi et al. (2007) observed saturated fatty acids (SFAs) representing 29.05% and 28.01% of total FAs, respectively and 70% of the fatty acids together with unidentified fatty acids combined with both MUFA and PUFA in the mussel, *Mytilus galloprovincialis*. Şereflişan and Altun (2018) observed 70% of mono and polyunsaturated fatty acids (MUFA + PUFA) in *A. pseudodopsis* and *U. tigridis.* In case of highly unsaturated fatty acids (HUFA) like EPA and DHA, the amounts were found to be higher in marine mollusc species compared to the freshwater counterparts (NRC, 2011). In addition, among the marine mollusc species oysters species had significantly higher amount of essential fatty acids like EPA and DHA compared to the other marine or freshwater mollusc species. However, the freshwater mollusc contained comparatively high amount of LA, ALA and ARA than the EPA and DHA that are found in marine molluscs. In agreement of the present study, previous studies reported that marine oysters like *Crassostrea gigas*, *C. madrasensis* and *Ostrea edulis*, contained high amount of EPA and DHA (Abad et al., 1995; Dridi et al., 2007; Chakraborty et al., 2016) than the freshwater snail, *Pomacea canaliculata* (Ghosh et al., 2017) which showed high concentrations of LA than the EPA or DHA. Overall, in the present study, n-3 was found to be higher in *L. corrianus, S. cucculata* and *C. virginica* than the other mollusc species*.* Furthermore, n-6/n-3 was ranged from 0.2 (*C. virginica*) to 3.69 (*P. globosa*) while n-3/n-6 ratio ranged between 0.3 (*P. globosa*) and 5.4 (*C. virginica*). The n-3/n-6 index was found high in *C. madrasensis* indicating a predominance of n-3 fatty acids (Asha et al., 2014). In addition, the n6/n3 ratio was found in *A. pseudodopsis* was 0.90% and in *U. tigridis* was 0.99% (Şereflişan and Altun, 2018). In human or animal body, inflammation may happen if any inequity occurred between n-6 and n-3 FAs in biological tissues. The ratio of n-6:n-3 FAs is reflected an index for human and animal health development on coronary heart disease, cancer and autoimmune diseases by evaluating the nutritional value of a dietary lipid source (Simopoulos, 2002; Calder, 2006). According to WHO (2013) the ratio between n-6 and n-3 should not exceed <5:1. In the present study, our results revealed that the mollusc species are enriched with fatty acids that are required for human health. Furthermore, in this study, IA and IT of the mollusc species are in agreement with results reported by Chakraborty et al. (2016) and Ghosh et al. (2017) for marine oyster and freshwater snail species. The researchers found higher IA and IT in oyster but comparatively lower IA and IT in snail which supported the data of the present study. High levels of IA and IT can occur cardiovascular disease in human. However, our results for IA and IT were in the range for animal meat (0.5–1.0) (Bobe et al., 2004) especially lower than the values for lamb meat (1.87) (Morbidini et al., 2001). Based on the IA and IT values, the results of the present study suggested that marine oysters and freshwater mussels are healthier than the other mollusc species.

Nonetheless, molluscs are good sources of different minerals (WHO, 2013). Minerals added significant elements of hormones, enzymes and enzyme activators in human nutrition. Sodium, potassium, magnesium, calcium, iron, phosphorus and sulfur have significant role in human nutrition (USDA, 2003). Deficiency of minerals can cause biochemical, structural and functional pathological changes (WHO, 2013). According to Table 4, we found that high amount of Ca, K, Na, P, Zn and Cl present (>100 mg/100g) in 7 different mollusc species which is in agreement with Chakraborty et al. (2016), Karnjanapratum et al. (2013), Tabakaeva et al. (2018), Debnath et al. (2016) and Ghosh et al. (2017) reported the results for oyster, clam, cockle and snail species. Sohail et al. (2016) found the macro minerals for freshwater mussels (*Anodonta anatina)* which had high concentration of Ca (46838 ± 984 mg/kg), Na (2706 ± 343 mg/kg), P (6921 ± 1063 mg/kg) and Mn (7207 ± 1046 mg/kg) compared to the results of the present study.

In this study, the heavy metal accumulation tendency in oyster, snail, clam, cockle and mussels were different. It might be because of different species of oyster and mussel have different capacities to filter or accumulate heavy metals (Reinfelder et al., 1997). According to Table 5, very little amount of heavy metal were observed in the mollusc species. Mercury (Hg) is a ubiquitous and persistent heavy metal that can be present in organic or inorganic form in aquatic environment through the food chain (Moniruzzaman et al., 2021). Yesudhason et al. (2013) found total Hg content in oyster tissue (*Saccostrea cuccullata*) with 0.01–0.02 mg/kg whereas, mercury and arsenic (As) were non-detectable for all mollusc species in the present study. The legal standards for mercury is 1.5 mg/kg wet weight (EC, 2001). In case of marine molluscs, chromium (Cr) bioaccumulation is usually lower than the freshwater (Boening, 1999) which also reflected in the present study. Benard et al. (2020) reported Cr concentration at 0.008–0.010 mg/kg in *Crassostrea virginica* which is non-detectable in the same species of present study and slightly higher for *S. cuccullata*. In accordance of our study, Asha et al. (2014) also could not detect Cr in *C. madrasensis* from Indian coast. However, higher concentrations of Cr was recorded 23.9–138.1 μg/g in *Saccostrea cuccullata* on rainy season from the three different habitats of Tanzania (Mtanga and Machiwa, 2010). In this study, freshwater snail and mussel species contained a little amount of Cr which is in agreement with Suryawanshi (2017). Overall, non-detection of mercury and arsenic as well as presence of tiny amounts of chromium confirmed that none of the snail species could be hazardous in terms of pollution (Venugopal and Gopakumar, 2017). Cholesterol present in the blood is associated with atherosclerosis in organisms where significant amount of total cholesterol may present in the mollusc species (Venugopal and Gopakumar, 2017). In the present study, significantly higher concentration of total cholesterol (>100 mg/100 g) was observed in marine cockle, *A. granosa* followed by snail and oyster species, whereas significantly lower concentration of cholesterol (<100 mg/100 g) was found in the marine clam (*M. meretrix*) and freshwater mussel species. In agreement of our study, Asha et al. (2014) reported high amount of cholesterol in oyster*, C. madrasensis* (>100 mg/100 g).

5. Conclusions

In inclusion, taken together, the results of the present study revealed the useful biochemical compounds of marine and freshwater mussels and snails in terms of macro- and micro-nutrients as well as heavy metal contents. In particular, the oysters, clams and cockles of marine water could serve as a source of omega-3 fatty acids, whereas, snails and mussels of freshwater could serve as a source of omega-6 fatty acids. In addition, the results also demonstrate that both of the marine and freshwater mussels and snails are good sources of minerals and free from toxic heavy metals that may benefits the human health. Based on the index of atherogenicity and index of thrombogenicity, the mussels and snails species from seawater and freshwater sources could have beneficial effects on human health. However, further research is warranted to elucidate the seasonal variations of nutrient contents in the above species.

Declarations

Author contribution statement

Mohammad Moniruzzaman, Sonia Sku: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Parvez Chowdhury, Selina Yeasmine, Nazmul Hossen: Performed the experiments; Analyzed and interpreted the data; Wrote the paper.

Mohosena Begum Tanu: Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Taesun Min, Sungchul C. Bai: Analyzed and interpreted the data; Wrote the paper.

Yahia Mahmud: Conceived and designed the experiments; Contributed reagents, materials, analysis tools or data; Wrote the paper.

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Declaration of interests statement

The authors declare no conflict of interest.

Additional information

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