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An overview of the impact of heavy metal accumulation on marine molluscs

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Abstract
Seafood, particularly bivalves, is an excellent source of balanced food. However, due to the rising concentration of heavy metals in the aquatic environment, it can have a negative effect on public health. Heavy metals are common inorganic pollutants in the environment, and their presence poses a significant threat to human beings due to their toxic effect on the biotic system. Various biological and geochemical factors influence the uptake and bioaccumulation of these heavy metals in marine organisms. As a result of the contamination from industrial wastage and domestic discharges from urbanized areas, marine organisms, including molluscs, reflect the rising level of environmental pollution. This study aimed to gather information on environmental contamination in different aquatic organisms and molluscs. Despite their potential as bioindicators for heavy metal pollution in aquatic organisms, there needs to be more research on nutritional composition and bioaccumulation in molluscs.

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Introduction

The increasing human population and urbanization put enormous pressure on the natural resources. Molluscs are the second most diverse group of aquatic filter-feeder animals in freshwater and marine water. These are soft-bodied animals widely used as supplementary food worldwide. These animals are nutraceutical-rich and contain high proteins; several are potential biomedical compound sources (Ministry of Environment and Forests, 2010) [14]. Soft body tissues of molluscs are protein-rich diet will provide essential amino acids that have a role in different metabolism processes as metabolites. Most of all biological functions are carried out by protein molecules; this need is fulfilled by protein-rich food, which contains all essential amino acids. Vitamins are also important for regulation and metabolism. Those molecules have a role in developing immunity. Enzymes are biocatalysts for their activation; they need some cofactors. Vitamins play a crucial role in the activation of enzymes and have a role as co-enzymes in many biological functions. Species are also known for their response against foreign bodies, which results in pearl formation as a defensive secretary element. Mollusc species can accumulate hazardous metal ions from the surrounding environment, which are the novel properties of organisms. They are the filter feeders that feed opportunistically on any phytoplankton, detritus, or benthic algae available in their habitats.

The heavy metals levels in molluscs and other invertebrates are often considerably higher than the other constituents of the marine environment (Hamed & Emara, 2006; Suryawanshi *et al*., 2011) [7, 22, 23].

Heavy metals discharged into the sea can damage both marine species' diversity and ecosystems (Ponnusamy *et al*., 2014) [17] due to their toxicity and accumulative behaviour (Matta *et al*., 1999) [13]. Significant alterations in industrialization and increased discharge of chemical effluents, such as anthropogenic activities, damage marine habitats, become a serious concern to resource managers and public health officials and harm many marine organisms. It exhibits high filtration rates of suspended particles and a high metal bioaccumulation capability (Lima *et al*., 1986; Rebelo *et al*., 2003; Wallner-Kersanach *et al*., 2000) [10, 19, 27].

Over 60 % of bivalve species exceeded the maximum permitted levels of Cd and Cr; more than 40 % of gastropod species exceeded the maximum levels of Sb and Cr.

Accumulation of metal residues in the tissues of various species of marine organisms and their bio-magnification through the food chain, hazards to human health and leads to severe diseases. Bioaccumula-tion is a biological property and relates directly to the target organism (Beeby, 2001) [1]. Health assessment of the species at the molecular and cellular level is essential in growth, reproduction, developmental abnormalities, or decreased survival. This has resulted in the need to understand ecosystem interrelationships for effectively using and preserving natural and biological resources.

Considerable progress has been made in understanding the heavy metals accumulation in aquatic organisms over the past decades (Mason *et al*., 1996; Suryawanshi G.D. *et al*., 2011) [12, 23] and show the levels of heavy metals (Cu, Zn, Pb, Cr, Ni, Fe, and Mn) in the coastal water, sediments, and soft tissues of the molluscs like gastropods limpet (Patella coerulea), bivalve (Barbatus barbatus) and in the oyster (Crassostrea rhizophorae) in the Gulf of Suez.

Histochemical and histopathological levels of metals have been quantified in specific tissues such as digestive glands, gills, kidneys and some target cells, which are involved in metal uptake, storage and detoxification. The different physiochemical properties of the surrounding medium affect the cellular uptake and excretion of metal. So histochemistry and related techniques help detect and know the level of metal concentration in tissue. The population level responds to the metal, leading to a decline in the number of individuals, and is closely related to a histological effect such as gonad abnormalities.

Nutritional importance of bivalves

The seafood consumption rate is increasing due to rapid growth in the world population. The different parts of molluscs that can be eaten, including their motor muscle, mantle, and adductor, have been analysed for their nutritional composition. It was found that molluscs had low fat content, and their main components were protein and carbohydrates. The edible parts of both molluscs contained high content of amino acids such as glycine, glutamate, aspartic acid, alanine, leucine, lysine, and arginine. The significant elements present were sodium, potassium, magnesium, calcium, iron, zinc, and nickel. With their high-quality protein content, these edible molluscs could be excellent sources of nutrition and may have potential applications in nutricosmetics and functional foods after further study (O. V. Tabakaeva *et al*., 2018) [24].

The study analysed the amino acid compositions in the soft tissues of the Far-East bivalve mollusc Anadara broughtonii. A total of 28 free amino acids were identified, with 15 being common in all soft tissues. Proteins in these tissues contained 19 amino acids, 8 of which were considered essential (O. V Tabakaeva & Tabakaev, 2016) [25]. The study evaluated the levels of protein, carbohydrate, lipid, vitamins, minerals (including iron, copper, zinc, calcium, magnesium, and manganese), and carbon, nitrogen, and calorie content. Among the three types of mussels tested, Perna viridis had a better nutritional composition when compared to Donax cuneatus and Meretrix meretrix. The study found that all samples contained appreciable amounts of the dietary elements tested, which could make them suitable partial or complete substitutes for conventional seafood (Gopalakrishnan & Vijayavel, 2009) [6]. The study on commercially important bivalve species showed that meat yield values ranged from 31.4% in F. glaber to 44.5% in M. varia. The results showed that molluscs are excellent food items due to their high protein and mineral content (Ca, K, Na, Fe, Zn, Cu), essential polyunsaturated fatty acids (PUFAs), and low cholesterol levels. M. galloprovincialis had the highest levels of eicosapentaenoic (EPA) and M. varia had the highest levels of docosahexaenoic acids (DHA) (Biandolino *et al*., 2019) [2].

Heavy metals and pollutants bioaccumulation in bivalve

Some of the most popular seafood products in the world are bivalve molluscs such as oysters, mussels, scallops, and clams. Oysters showed the ability to hyperaccumulate copper and zinc, while scallops are hyperaccumulators of cadmium. However, data reviews have raised concerns about the potential safety risks of cadmium in oysters and scallops (Wang *et al*., 2017) [28]. The distribution of heavy metal and metalloids (As, Cd, Cr, Hg, Ni and Pb) in bivalve molluscs from coastal areas of southeast China showed average concentrations of As, Cd, Cr, Hg, Ni and Pb were 1.83, 0.581, 0.111, 0.0117, 0.268 and 0.137 mg kg^{-1} wet weight in bivalves. The average estimated daily intakes for As, Cd, Cr, Hg, Ni and Pb were 1.156, 0.367, 0.07, 0.007, 0.167 and 0.087 μg kg^{-1} body weight/day (Pan & Han, 2023) [16].

Heavy metals such as Zn, As, Hg, Pb, Ni, Cr, Cu, and Ag that are present at concentrations common in ambient marine waters significantly impact the trophic structure of a biological community. Heavy metal uptake is dependent on both geochemical and biological factors. In bivalves, the extent of accumulation is a function of several biotic and abiotic variables. Bivalve molluscs have proven to be useful biomonitors for a host of inorganic contaminants (Boening, 1999) [3]. The study conducted on molluscan shells and surface sediments from sites on the Gulf of Aqaba and Red Sea coasts in Egypt showed that each mollusc species had varying abilities to accumulate heavy metals such as Fe, Mn, Cu, Zn, Pb, Ni, Cd, and Co in their shells. Tridacna squamosa had the highest accumulation ability for Pb, Ni, and Zn, Chama pacifica for Co and Cd, and Periglypta reticulata for Cu. A positive correlation was observed between Cu, Zn, Pb, and Ni concentration and shell size, and a negative correlation with Fe, Mn, Co, and Cd. These findings on the bioaccumulation of molluscan species aligned with the enrichment factors for sediments (Nour, 2020) [15].

The study assessed the effectiveness of four types of bivalve molluscs (Sanguinolaria acuminata, Anadara granosa, Meretrix meretrix, and Pelecyora trigona) in detecting heavy metals (Cu, Pb, Cd, Zn, and Hg) in intertidal areas of the Sunderban mangrove wetland in the northeastern part of the Bay of Bengal. The research showed that there were significant variations in both species and time. The bivalves had a high degree of organ specificity, with the gill and mantle showing higher accumulation of metals due to the ion exchange properties of the mucous layers, while shells had poor accumulation. Elevated levels of Zn and Cu indicate a high potential for biomagnification through the marine food chain. The concentrations of metals in different body size groups of the bivalves did not follow a uniform trend. Statistically significant couplings were observed for Pb-Zn, Pb-Cu, Zn-Cu, and Hg-Cu metal pairings. The metal concentrations in specific organs (visceral mass, mantle, and gill) of the bivalves exceeded the safe levels according to international standards for metals from the Food and Agricultural Organization of the United Nations (Health *et al*., 2008). The levels of Cd, Cu, Fe, Ni, Zn, and Pb in various body parts of six different bivalve species were examined. The study found that certain parts of Perna viridis, Scpharca broughtonii, Trisidos kiyonoi, Polymesoda erosa, Donax faba, and Gelonia expansa were highly accumulative of Cu, Cd, Zn, Pb, and Ni. However, it was also discovered that most of the bivalves had metal concentrations that were within safe limits set by five different countries, indicating they should not pose any toxicological risk to consumers. It is important to note that high levels of Fe were found in different parts of the bivalve, but this is considered normal since Fe is an essential metal involved metabolic activities and is abundant in nature (Edward *et al*., 2009) [4].

A study was conducted to explore the accumulation of heavy metals (Cr, Cu, Hg, Zn, As, Cd, and Pb) in three types of benthic bivalves (Scapharca subcrenata, Mactra veneriformis, and Ruditapes philippinarum) collected from Laizhou Bay in the Bohai Sea, with a focus on the tissue and species specificity of accumulation. The findings showed that the bivalves' visceral masses were more efficient in accumulating heavy metals than their muscles. Furthermore, the bivalves' capacities for metal accumulation followed a similar sequence: Cd > Hg > Zn = As > Cu > Cr = Pb. The metal contamination levels were more severe along the eastern coast than in other areas. Overall, the Manila clam was found to be more heavily contaminated by heavy metals than the surf clam and ark shell (Liu *et al*., 2017). An assessment of heavy metal Cd, Cr, Cu, Pb, and Zn accumulation in seven different body parts of two edible bivalve species, Perna viridis and Modiolus metcalfei showed that Zn had the highest concentration, while Cd had the lowest concentration, and these values varied depending on the body part being examined. For P. viridis, the accumulation levels ranged from Cd (0.022-0.091 μg/g), Cr (0.147-0.447 μg/g), Cu (0.126-0.356 μg/g), Pb (0.145-1.57 μg/g), and Zn (0.964–8.607 μg/g). For M. metcalfei, the accumulation levels ranged from Cd (0.013-0.095 μg/g), Cr (0.092-0.495 μg/g), Cu (0.063-0.367 μg/g), Pb (0.528-1.263 μg/g), and Zn (2.172-11.113 μg/g). Cluster analysis (Bray-Curtis Similarity) was carried out to determine the similarity percentage between different body parts of the bivalves and compared this to sediment metal concentration. Overall, all heavy metals were found to be below the permissible levels set by WHO/EPA, except for Cr and Pb in both bivalves (Ponnusamy *et al*., 2014) [17].

The investigation of the heavy metal concentration of Cu, Cd, Pb, Ni and Cr in the bivalve Mytilus galloprovincialis, seawater, and sediments collected from three locations along the Romanian Black Sea coast (Mila 9, Cazino Mamaia, Costinesti) was carried out. Additionally, the study aimed to evaluate the degree of bioaccumulation of these metals using bioaccumulation factors (Biota Sediment Accumulation Factor - BSAF and Biota Concentration Factor - BCF). The results of this study demonstrate that M. galloprovincialis accumulates heavy metals from the surrounding environment in terms of concentration (μg/g DW) in the order: Cu > Ni > Cr > Cd > Pb. In seawater, the concentration of heavy metals (μg/l) was found to be Cr > Cu > Ni > Pb > Cd, while for sediments, the following concentrations were observed (μg/g DW): Cr > Ni > Pb > Cu > Cd. This study also determined that M. galloprovincialis can function as either a macroconcentrator (BSAF > 2), microconcentrator (1 < BSAF < 2), or deconcentrator (BSAF < 1) for the analyzed heavy metals. The distribution behavior of heavy metals among water, sediments, and M. galloprovincialis, expressed as bioaccumulation factors (BSAF and BCF), provided insights into the toxicity and bioaccumulation of metals in the studied mussels and the marine environment (Rosioru *et al*., 2016) [21]. Heavy metal concentrations were measured in Bivalves (Modiolus auriculatus and Donax trunculus) collected from the Egyptian coasts of the Mediterranean Sea and Brachiodonates sp. from the Egyptian coasts of the Red Sea. The metals analyzed included Cd, Co, Cu, Fe, Mn, Ni, Pb, and Zn. On average, the heavy metal concentrations exhibited the following order of decreasing amounts: Fe > Zn > Cu > Mn > Ni > Co > Pb > Cd for both the Mediterranean Sea and the Red Sea. Samples collected from the Red Sea showed higher average concentrations of Cd, Co, Ni, Pb, and Zn than those collected from the Mediterranean Sea. On the other hand, Fe, Cu, and Mn showed the opposite results (El-Sikaily *et al*., 2004). Tissue and sediment samples were gathered from four stations along Kuala Perlis Coast and analyzed for heavy metals. The soft tissue showed a decreasing order of heavy metal concentrations: Zn > Cu > As > Cd. Meanwhile, the sediment exhibited a mean concentration trend of Zn > Cu > Cd > As. The tissue's mean concentration of Arsenic, Cadmium, and Copper exceeded the permissible limit set by FAO/WHO 2004 and Food Regulation 1985, except for Zinc. Thus, it is unsafe to consume bivalves from the Coastal area of Kuala Perlis due to these heavy metal concentrations, which pose a risk to human health (Lias *et al*., 2013) [9].

Risk Assessment of Heavy Metals in Bivalve

The concentrations of metals in bivalve tissues were analyzed with results showing that Zinc (Zn) had the highest concentration followed by Copper (Cu), Arsenic (As), Chromium (Cr), Cadmium (Cd), Lead (Pb) and Mercury (Hg). The concentrations of these metals varied among the five types of bivalves studied. Most of the samples had heavy metal concentrations in their edible tissues below safety limits set by national and international regulations. Significant correlations were found among metals. Their levels were analyzed and compared to the Provisional Tolerable Daily Intake (PTDI) values. It was found that the Estimated Daily Intake (EDI) values for each metal in each bivalve were significantly lower than the corresponding PTDI values. A health risk assessment was done which revealed that there is no noncarcinogenic health risk for individuals exposed to individual or combined metals from these bivalves. However, there is a carcinogenic risk from Cadmium (Cd) and Chromium (Cr) exposure. It is therefore important to monitor and control bivalve consumption in the long term. Current accumulation levels of bivalves are safe; continued and excessive lifetime consumption over 70 years may pose a target cancer risk for individuals (Qin *et al*., 2021) [18].

The levels of heavy metals in bivalves and seawater were analyzed, showed the average concentrations of Zn, Cu, Cr, Pb, As, Cd, and Hg in bivalves decreased in that order. The bioconcentration factor values of bivalves were all greater than 100, indicating that bivalves have a strong ability to accumulate these metals. A nonmetric multidimensional scaling analysis revealed that all bivalves have a high capacity to accumulate Cu and Zn. However, it was also discovered that consuming bivalves can pose health risks, especially for children who are more vulnerable than adults (Yuan *et al*., 2020) [29].

Study examined the levels of Cd, and Pb in four different bivalve species (Meretrix lyrate, Perna viridis, Anadara subcrenata, and Anadara granosa) and used the target hazard quotient (THQ) and target cancer risk (TR) to estimate the non-carcinogenic and carcinogenic health risks associated with consuming bivalve showed that bivalves had lower levels of Cd and, but higher levels of Pb. The THQ for Cd, and Pb was below the threshold of 1, indicating no potential health risks. The results suggest that continuous and excessive consumption of these foods for more than 70 years may increase the probability of target cancer risk (Thang *et al*., 2021) [29]. After conducting a health risk assessment, it was determined that consuming bivalves did not pose a non-carcinogenic health risk to the general population in regards to these metals. However, there is a potential cancer risk from consuming molluscs that contain Cd. Therefore, it is recommended that marine ecosystems undergo regular monitoring for heavy metals, specifically Cd, to prevent potential contamination (Pan & Han, 2023) [16].

Metal concentrations were measured in two bivalve species, Anadara tuberculosa and Anadara similis ranged from 0.211 to 0.948 mg per kg for cadmium, 0.038 to 0.730 mg per kg for chromium, and 0.067 to 0.923 mg per kg for lead. Each metal's potential health risk was calculated based on measured concentrations and bivalve weight. The results showed a high health risk for consumers from cadmium, but only in bivalves of a certain weight. For lead, there was a high health risk for children. Chromium did not pose a risk to health (Romero-Estévez *et al*., 2020) [20].

Conclusion

According to study, marine bivalves contain high levels of heavy metals. The amount of heavy metals that accumulate in the bivalve mollusc depends on various environmental factors and the specific body part. When compared to sediment and water, bivalves are more efficient at accumulating heavy metals. As a result, they are a valuable biomonitoring organism for assessing heavy metal pollution levels. Unfortunately, pollution and toxic accumulation in edible marine species are becoming increasingly common throughout the world. Typically, the highest concentration of heavy metals accumulates in the estuarine zone and continental shelf, as these areas are prone to suspended marine and land-derived contaminants.

References

1. Beeby A. What do sentinels stand for? Environmental Pollution. 2001; 112(2):285-298.
2. Biandolino F, Leo A Di, Parlapiano I, Papa L, Giandomenico S, Spada L, Prato E. Nutritional quality of edible marine bivalves from the southern coast of Italy, Mediterranean Sea. Polish Journal of Food and Nutrition Sciences. 2019; 69(1):71-81. https://doi.org/10.31883/pjfns-2019-0001
3. Boening DW. An evaluation of bivalves as biomonitors of heavy metals pollution in marine waters. Environmental Monitoring and Assessment. 1999; 55(3):459-470. https://doi.org/10.1023/A:1005995217901/METRICS
4. Edward FB, Yap CK, Ismail A, Tan SG. Interspecific variation of heavy metal concentrations in the different parts of tropical intertidal bivalves. Water, Air, and Soil Pollution. 2009; 196(1-4):297-309. https://doi.org/10.1007/S11270-008-9777-X
5. El-Sikaily A, Khaled A, ANEM. undefined. (2004). Heavy metals monitoring using bivalves from Mediterranean Sea and Red Sea. Springer, 2004. https://link.springer.com/article/10.1023/B:EMAS.0000038178.98985.5d
6. Gopalakrishnan S, Vijayavel K. Nutritional composition of three estuarine bivalve mussels, Perna viridis, Donax cuneatus and Meretrix meretrix. International Journal of Food Sciences and Nutrition. 2009; 60(6):458-463. https://doi.org/10.1080/09637480701830412
7. Hamed MA, Emara AM. Marine molluscs as biomonitors for heavy metal levels in the Gulf of Suez, Red Sea. Journal of Marine Systems. 2006; 60(3-4):220-234. https://doi.org/10.1016/j.jmarsys.2005.09.007
8. Health H, Kumar Sarkar S, Sarkar SK, Cabral H, Chatterjee M, Cardoso I, *et al*. Biomonitoring of heavy metals using the bivalve molluscs in Sunderban mangrove wetland, northeast coast of Bay of Bengal (India): possible risks to human health. Wiley Online Library. 2008; 36(2):187-194. https://doi.org/10.1002/clen.200700027
9. Lias K, Jamil T, chemistry SAI. Journal of applied, & 2013, undefined. (2013). A preliminary study on heavy metal concentration in the marine bivalves Marcia marmorata species and sediments collected from the coastal area of Kuala, 2008. Academia.Edu. https://www.academia.edu/download/73541433/46270e68e173a22afffb0cebd2de6895756e.pdf
10. Lima NRW, De Lacerda LD, Pfeiffer WC, Fiszman M. Temporal and spatial variability in Zn, Cr, Cd and Fe concentrations in oyster tissues (Crassostrea brasiliana Lamarck, 1819) from Sepetiba Bay, Brazil. Environmental Technology. 1986; 7(1-12):453-460.
11. Liu J, Cao L, bulletin SDM. Pollution, undefined. (2017). Bioaccumulation of heavy metals and health risk assessment in three benthic bivalves along the coast of Laizhou Bay, China, 2017. Elsevier. https://www.sciencedirect.com/science/article/pii/S0025326X17300917
12. Mason R, JRES. Undefined. (1996). Uptake, toxicity, and trophic transfer of mercury in a coastal diatom, 1996. ACS Publications. https://pubs.acs.org/doi/abs/10.1021/es950373d
13. Matta J, Milad M, Manger R, Tosteson T. Heavy metals, lipid peroxidation, and ciguatera toxicity in the liver of the Caribbean barracuda (Sphyraena barracuda). Biological Trace Element Research. 1999; 70:69-79.
14. Ministry of Environment and Forests. Ministry of Environment and Forests. Government of India, 2010.
15. Nour HES. Distribution and accumulation ability of heavy metals in bivalve shells and associated sediment from Red Sea coast, Egypt. Environmental Monitoring and Assessment. 2020; 192(6):1-12. https://doi.org/10.1007/S10661-020-08285-3/METRICS
16. Pan XD, Han JL. Heavy metals accumulation in bivalve mollusks collected from coastal areas of southeast China. Marine Pollution Bulletin. 2023; 189:114808. https://doi.org/10.1016/J.MARPOLBUL.2023.114808
17. Ponnusamy K, Sivaperumal P, MSJ. Of, undefined. (2014). Heavy metal concentration from biologically important edible species of bivalves (Perna viridis and Modiolus metcalfei) from vellar estuary, south east coast of. Researchgate. NetK Ponnusamy, P Sivaperumal, M Suresh, S Arularasan, S Munilkumar, AK PalJournal of

Aquaculture Research & Development, 2014, researchgate.Net, 5, 5. https://doi.org/10.4172/2155-9546.1000258

18. Qin L, Yan Zhang, R Cang, Liang Y, dan Wu, L chuan, *et al*. Concentrations and health risks of heavy metals in five major marketed marine bivalves from three coastal cities in Guangxi, China. Ecotoxicology and Environmental Safety. 2021; 223:112562. https://doi.org/10.1016/J.ECOENV.2021.112562
19. Rebelo M. de F, M. do A.-M. P. Undefined. (2003). High Zn and Cd accumulation in the oyster Crassostrea rhizophorae, and its relevance as a sentinel species, 2003. Researchgate.Net. https://www.researchgate.net/profile/Mauro-Rebelo-2/publication/9056951_High_Zn_and_Cd_accumulation_in_the_oyster_Crassostrea_rhizophorae_and_its_relevance_as_a_sentinel_species/links/5b91bcda92851c78c4f3d626/High-Zn-and-Cd-accumulation-in-the-oyster-Crassostrea-rhizophorae-and-its-relevance-as-a-sentinel-species.pdf?_sg%5B0%5D=started_experiment_milestone&origin=journalDetail
20. Romero-Estévez D, Yánez-Jácome GS, Dazzini Langdon M, Simbaña-Farinango K, Rebolledo Monsalve E, Durán Cobo G, Navarrete H. An Overview of Cadmium, Chromium, and Lead Content in Bivalves Consumed by the Community of Santa Rosa Island (Ecuador) and Its Health Risk Assessment. Frontiers in Environmental Science. 2020; 8:564904. https://doi.org/10.3389/FENVS.2020.00134/BIBTEX
21. Rosioru D, Oros A, Protection LLJ, of E. Undefined. (2016). Assessment of the heavy metals contamination in bivalve Mytilus galloprovincialis using accumulation factors, 2016. Academia.Edu. https://www.academia.edu/download/51897886/JEPE_book3_2016_874-884.pdf
22. Suryawanshi GD, Shaikh AM, Ragade VR. Heavy metals load in clam Meretrix meretrix from Ratnagiri coast. Journal of Experimental Zoology, India. 2011; 14(2):507-511.
23. Suryawanshi GD, Shaikh AM, Mane UH. Heavy metals concentration in rock oyster Crassostrea cattuckensis from Ratnagiri coast. Journal of Ecophysiology and Occupational Health. 2011; 11(3/4):175-175.
24. Tabakaeva OV, Tabakaev AV, Piekoszewski W. Nutritional composition and total collagen content of two commercially important edible bivalve molluscs from the Sea of Japan coast. Journal of Food Science and Technology. 2018; 55(12):4877-4886. https://doi.org/10.1007/s13197-018-3422-5
25. Tabakaeva OV, Tabakaev AV. Amino-Acid Composition of Soft Tissues of the Far-East Bivalve Mollusk Anadara broughtonii. Chemistry of Natural Compounds. 2016; 52(3):468-471. https://doi.org/10.1007/s10600-016-1674-8
26. Thang NQ, Huy BT, Khanh DNN, Vy NTT, Phuong TH, Sy DT, *et al*. Potential health risks of toxic heavy metals and nitrate via commonly consumed bivalve and vegetable species in Ho Chi Minh City, Vietnam. Environmental Science and Pollution Research. 2021; 28(39):54960-54971. https://doi.org/10.1007/S11356-021-14808-3/METRICS
27. Wallner-Kersanach M, Theede H, UEA. of, & undefined. Accumulation and Elimination of Trace Metals in a Transplantation Experiment with Crassostrea rhizophorae. SpringerM Wallner-Kersanach, H Theede, U Eversberg, S LoboArchives of Environmental Contamination and Toxicology, 2000•Springer. 2000; 38(1):40-45. https://doi.org/10.1007/s002449910005
28. Wang W, Food GLC. Contaminants and residues in, & 2017, undefined. Heavy metals in bivalve mollusks, 2017. Elsevier. https://doi.org/10.1016/B978-0-08-100674-0.00021-7
29. Yuan Y, Sun T, Wang H, Liu Y, Pan Y, Xie Y, Huang H, Fan Z. Bioaccumulation and health risk assessment of heavy metals to bivalve species in Daya Bay (South China Sea): Consumption advisory. Marine Pollution Bulletin. 2020; 150:110717. https://doi.org/10.1016/J.MARPOLBUL.2019.110717