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IMPACT OF HEAVY METAL CONTAMINATION ON PHYTOCHEMICAL PROFILES IN MARINE CRUSTACEANS: A COMPARATIVE STUDY OF *Farfantepenaeus notialis* AND *Macrobrachium vollenhovenii*

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ABSTRACT

Heavy metal contamination poses significant risks to marine ecosystems and human health. This study investigates the impact of heavy metal contamination on the phytochemical profiles of two marine crustacean species, *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii*. Samples of these crustaceans were collected from Bodija Market, Ibadan, Nigeria, and analyzed for heavy metal content (Cu, Cd, Pb, Hg, As) and phytochemical constituents including alkaloids, flavonoids, saponins, tannins, anthraquinones, terpenoids, cardiac glycosides, steroids, and phenols. The heavy metal analysis revealed that *Farfantepenaeus notialis* had concentrations of Cu at 0.592 ± 0.03 mg/g and Pb at 0.080 ± 0.06 mg/g, while *Macrobrachium vollenhovenii* had lower concentrations of Cu (0.331 ± 0.07 mg/g) and Pb (0.061 ± 0.02 mg/g). Phytochemical screening showed that *Farfantepenaeus notialis* had higher levels of alkaloids (1.65 ± 0.004% w/w), flavonoids (0.35 ± 0.17% w/w), and saponins (0.80 ± 0.002% w/w) compared to *Macrobrachium vollenhovenii*, which had lower concentrations of these compounds (alkaloids: 0.75 ± 0.002% w/w, flavonoids: 0.12 ± 0.10% w/w, saponins: 0.75 ± 0.001% w/w). Both species were positive for steroids and cardiac glycosides but lacked detectable levels of tannins and phenols. These results indicate that heavy metal contamination significantly influences the phytochemical composition of marine crustaceans. The higher heavy metal levels in *Farfantepenaeus notialis* correlated with higher phytochemical concentrations, whereas *Macrobrachium vollenhovenii* showed lower phytochemical levels, possibly due to its lower heavy metal accumulation. This comparative analysis underscores the need for ongoing monitoring of heavy metal pollution in marine environments and its effects on aquatic organisms' biochemical profiles.

Keywords: Heavy metals, Contamination, Marine crustaceans, *Farfantepenaeus notialis*, *Macrobrachium vollenhovenii*, Phytochemical profiles, Ecological impact

INTRODUCTION

Marine ecosystems are vital to global biodiversity and human nutrition, with marine crustaceans such as *Farfantepenaeus notialis* (prawn) and *Macrobrachium vollenhovenii* (freshwater shrimp) playing significant roles. These crustaceans are not only a critical component of aquatic food webs but also an important source of dietary proteins and bioactive compounds for humans (López-Pedrouso et al.2020). Their biochemical profiles, particularly phytochemicals like alkaloids, flavonoids, and saponins, contribute to their ecological roles and potential health benefits (Kaushik et al. 2021). However, environmental pollution, particularly from heavy metals, poses a serious threat to these aquatic organisms and can alter their biochemical compositions (Ali et al. 2019).

Heavy metals such as copper (Cu), cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) are prevalent contaminants in marine environments, resulting from industrial activities, agricultural runoff, and improper waste disposal (Sonone et al. 2020). These metals can accumulate in aquatic organisms, leading to potential health risks for both wildlife and humans (Uddin et al. 2021). The contamination of marine environments with heavy metals has been well-documented, and their adverse effects on marine life, including crustaceans, are a growing concern (Shah, 2021). Heavy metal toxicity can disrupt physiological processes, impair growth, and alter the biochemical profiles of marine organisms (Arambourou et al. 2020).

Phytochemicals, including alkaloids, flavonoids, saponins, and terpenoids, are secondary metabolites produced by plants and some marine organisms (Saudagar and Saokar, 2019). These compounds have been recognized for their antioxidant, anti-inflammatory, and antimicrobial properties (Ojha et al. 2019). In crustaceans, phytochemicals contribute to their ability to cope with environmental stressors and pathogens (Rahman et al. 2019). Understanding how heavy metal contamination affects these phytochemicals is crucial for assessing the health and ecological roles of marine crustaceans (Derrick et al. 2024).

Previous studies have highlighted the impact of heavy metal exposure on various biological systems (Parida and Patel, 2023), but comprehensive research on its effects on the phytochemical profiles of marine crustaceans is limited. This gap in knowledge underscores the importance of investigating how heavy metal contamination influences the concentration and composition of phytochemicals in species like *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii*. Such studies are essential for evaluating the ecological consequences of pollution and the potential health risks to humans who consume contaminated seafood (Baki et al. 2018).

In this study, we focus on *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii* to explore the relationship between heavy metal contamination and phytochemical profiles. Samples collected from Bodija Market in Ibadan, Nigeria, were analyzed for heavy metal content and phytochemical constituents. This comparative analysis aims to provide insights into how different levels of heavy metal contamination affect the biochemical composition of these crustaceans and to highlight the potential implications for marine ecosystem health and human safety.

Understanding the impact of heavy metal contamination on the phytochemical profiles of marine crustaceans can inform strategies for environmental monitoring and pollution control. It can also contribute to public health initiatives by identifying potential risks associated with the consumption of contaminated seafood. This research adds valuable knowledge to the field of marine ecology and environmental science, emphasizing the need for continued vigilance and intervention to protect aquatic environments and their inhabitants.

MATERIALS AND METHODS

Sample Collection

Marine crustaceans *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii* were collected from Bodija Market, Ibadan, Nigeria. Samples were transported to the laboratory in sterile containers and stored at -20°C until further processing.

Heavy Metal Analysis

Sample Preparation

The samples were thawed, washed with distilled water, and dried to a constant weight at 60°C. The dried samples were then ground into a fine powder using a mortar and pestle.

Digestion

Approximately 0.5 g of each powdered sample was digested using a mixture of concentrated nitric acid (HNO_3) and hydrogen peroxide (H_2O_2) in a digestion chamber. The digestion followed standard protocols to ensure complete dissolution of the samples.

Heavy Metal Determination

The digested samples were analyzed for copper (Cu), cadmium (Cd), lead (Pb), mercury (Hg), and arsenic (As) using Atomic Absorption Spectroscopy (AAS). Calibration curves for each metal were prepared, and the concentrations in the samples were quantified based on these curves.

Phytochemical Screening

Qualitative Analysis

Phytochemical screening was performed to detect the presence of various compounds using standard qualitative tests:

Alkaloids

Dragendoff's reagent, Mayer's reagent, and Wagner's reagent.

Flavonoids: Ammonia/H_2SO_4, aluminum solution, and ethyl acetate/ammonia.
Saponins: Frothing test.
Tannins: Ferric chloride test.
Anthraquinones: Borntrager's test.
Terpenoids: Salkowski test.
Cardiac Glycosides: Keller-Killiani test.
Steroids: Liebermann-Burchard test.
Phenols: Ferric chloride test.

Quantitative Analysis

Alkaloids

Alkaloid content was determined gravimetrically following extraction with hydrochloric acid.

Terpenoids

Extracts were prepared with organic solvents, and the concentration of terpenoids was determined using the Salkowski test.

Saponins

Saponins were quantified gravimetrically after extraction with boiling water.

Flavonoids

The flavonoid content was quantified using a colorimetric method with quercetin as the standard. Absorbance was measured at 420 nm using a spectrophotometer.

Data Analysis

Data from the heavy metal analysis and phytochemical assays were expressed as means ± standard deviation. Statistical comparisons between *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii* were conducted using appropriate statistical tests. All measurements were performed in triplicate to ensure accuracy and reliability.

RESULTS AND DISCUSSION

The concentration of copper in *Farfantepenaeus notialis* was significantly higher than in *Macrobrachium vollenhovenii in* Table 1. Lead was also higher in *F. notialis*, while cadmium levels were near detection limits for both samples, with *M. vollenhovenii* showing even lower levels. Mercury concentrations were slightly elevated in *M. vollenhovenii* compared to *F. notialis*. Arsenic was detected only in *M. vollenhovenii* with negligible levels in *F. notialis*. These variations indicate differential exposure to heavy metals between the two species.

Table 1: Heavy Metal Concentrations in Marine Crustaceans

Metal	Sample A (*Farfantepenaeus notialis*)	Sample C (*Macrobrachium vollenhovenii*)
Copper (Cu) (mg/g)	0.592 ± 0.03	0.331 ± 0.07
Cadmium (Cd) (mg/g)	0.002 ± 0.05	0.000 ± 0.00
Lead (Pb) (mg/g)	0.080 ± 0.06	0.061 ± 0.02
Mercury (Hg) (mg/g)	0.004 ± 0.04	0.008 ± 0.03
Arsenic (As) (mg/g)	0.000 ± 0.00	0.002 ± 0.04

Both *F, notialis* and *M, vollenhovenii* exhibited a variety of phytochemicals in Table 2. Both species tested positive for alkaloids, flavonoids, saponins, anthraquinones, terpenoids, cardiac glycosides, and steroids, though the intensity varied. Specifically, *F. notialis* showed more pronounced reactions in alkaloids and flavonoids compared to *M. vollenhovenii*. Neither species contained detectable levels of tannins or phenols. The presence of these phytochemicals suggests their potential for various biological activities.

Table 2: Qualitative Phytochemical Screening of Marine Crustaceans

Phytochemical	*Farfantepenaeus notialis*	*Macrobrachium vollenhovenii*
Alkaloids	+ve	+ve
Flavonoids	+ve	+ve
Saponins	+ve	+ve
Tannins	-ve	-ve
Anthraquinones	+ve	+ve
Terpenoids	+ve	+ve
Cardiac Glycosides	+ve	+ve
Steroids	++ve	++ve
Phenols	-ve	-ve

In Table 3, the Quantitative analysis indicated that *Farfantepenaeus notialis* exhibited higher concentrations of alkaloids (1.65% w/w) and a broader range of flavonoid content compared to *Macrobrachium vollenhovenii*, which had 0.75% w/w alkaloids and a narrower flavonoid range. Terpenoids were more concentrated in *Farfantepenaeus notialis* (1.55% w/w) than in *Macrobrachium vollenhovenii* (1.35% w/w). Saponins were slightly higher in *Farfantepenaeus notialis* compared to *Macrobrachium vollenhovenii*. The results suggest that *Farfantepenaeus notialis* has a potentially richer phytochemical profile compared to *Macrobrachium vollenhovenii*.

Table 3: Quantitative Phytochemical Screening of Marine Crustaceans

Phytochemical	*Farfantepenaeus notialis* (% w/w)	*Macrobrachium vollenhovenii* (% w/w)
Alkaloids	1.65 ± 0.004	0.75 ± 0.002
Terpenoids	1.55 ± 0.002	1.35 ± 0.004
Saponins	0.80 ± 0.002	0.75 ± 0.001
Flavonoids	0.35 ± 0.17 to 5.64 ± 0.17	0.12 ± 0.10 to 4.32 ± 0.06

Discussion

Heavy metal contamination represents a significant environmental challenge, particularly for marine and freshwater ecosystems. These contaminants induce oxidative stress, disrupt metabolic pathways, and alter phytochemical profiles in aquatic organisms, affecting both their ecological fitness and nutritional quality (Eskander and Saleh, 2020). In this study, *Farfantepenaeus notialis* exhibited higher concentrations of copper and lead compared to *Macrobrachium vollenhovenii*, suggesting differential exposure patterns likely shaped by their distinct habitats. The near-detection levels of cadmium in both species and the presence of arsenic only in *M. vollenhovenii* reflect unique pollutant sources and environmental conditions. The slightly elevated mercury levels in *M. vollenhovenii* further underscore the need to assess localized contamination sources in freshwater systems.

These findings raise critical food safety concerns, as copper and lead are known to disrupt cellular metabolism and cause neurotoxicity at elevated levels. The variation in heavy metal concentrations appears to have influenced the phytochemical profiles of the studied species. The significantly higher levels of alkaloids (1.65% w/w) and flavonoids (up to 5.64% w/w) in *F. notialis* compared to *M. vollenhovenii* indicate a stronger adaptive response to oxidative stress induced by heavy metal exposure. Phytochemicals such as flavonoids, terpenoids, and alkaloids play pivotal roles in scavenging reactive oxygen species (ROS), thus mitigating cellular damage (Cilwyn et al. 2021). The elevated flavonoid levels observed in *F. notialis* align with the findings of Vanhees et al. (2013), which reported enhanced antioxidant capacity in organisms exposed to environmental stressors.

Conversely, the lower phytochemical concentrations in *M. vollenhovenii* could be attributed to its reduced exposure to certain pollutants or potential inhibition of biosynthetic pathways under metal stress (Li et al., 2022). However, the presence of arsenic in *M. vollenhovenii* warrants further investigation into its specific impacts on freshwater organisms and their physiological responses. Saponins and terpenoids, which are critical for detoxification, also showed variability between the two species. The slightly higher saponin content in *F. notialis* (0.80% w/w) compared to *M. vollenhovenii* (0.75% w/w) suggests more effective heavy metal sequestration in the marine shrimp. Saponins and related compounds are known to bind heavy metals, reducing their bioavailability and toxicity (Mirkov et al., 2020). This observation aligns with Wang et al. (2024), who demonstrated that saponins can mitigate heavy metal toxicity through chelation and sequestration. These findings underline the potential of *F. notialis* as a model for studying adaptive responses to metal contamination in marine ecosystems. Nevertheless, the nutritional and therapeutic value of these crustaceans may be compromised by heavy metal accumulation. While flavonoids, alkaloids, and terpenoids are valued for their antioxidant properties, the bioaccumulation of toxic metals could offset these benefits. This emphasizes the critical need for stringent monitoring and regulation of aquatic environments to ensure seafood safety (Meshkati et al. 2016).

Environmental factors, including habitat type, pollution sources, and exposure duration, are critical determinants of heavy metal accumulation and phytochemical responses in aquatic organisms. Marine environments, as observed by Meng et al. (2020), typically exhibit higher pollutant loads due to industrial discharge and urban runoff, potentially explaining the elevated phytochemical levels in *F. notialis*. These findings highlight the intricate interplay between environmental stressors and the adaptive responses of aquatic species, necessitating a holistic approach to pollution assessment. Long-term monitoring of contamination levels and the implementation of advanced remediation strategies, such as phytoremediation and biofilters, could help mitigate heavy metal pollution in aquatic ecosystems (Demarco et al. 2023).

This study not only provides critical insights into the phytochemical and heavy metal profiles of *F. notialis* and *M. vollenhovenii* but also underscores the broader implications for food safety, environmental health, and conservation. Further studies should explore the cumulative effects of multimetal exposure on the physiology and reproduction of aquatic organisms. Moreover, innovative techniques for detecting and remediating heavy metal contamination, including the use of biotechnological tools, should be prioritized to safeguard aquatic biodiversity and public health.

CONCLUSION

This study highlights the significant effects of heavy metal contamination on the physiological and biochemical responses of *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii*, with differential exposure to copper, lead, and arsenic observed between the species. *F. notialis* exhibited higher levels of these metals, which correlated with increased production of antioxidant phytochemicals such as flavonoids, alkaloids, and saponins, suggesting a robust adaptive response to oxidative stress. The higher concentration of these phytochemicals in *F. notialis* implies a more effective detoxification mechanism, potentially enhancing its nutritional and therapeutic value. However, the presence of heavy metals raises concerns about the safety of consuming these species, as contamination could offset the health benefits provided by the antioxidants. These findings stress the need for regular monitoring of aquatic environments to ensure the safety and quality of seafood, particularly in regions with high pollution levels. The study also underscores the necessity of further research into the long-term impacts of heavy metal exposure on aquatic organisms, as well as the development of mitigation strategies to reduce pollution and protect both marine and freshwater ecosystems.

Future Trends

Future research should focus on the long-term effects of heavy metal contamination on the health, reproduction, and biodiversity of aquatic organisms, particularly in ecosystems with elevated pollutant levels. Investigating the mechanisms underlying the differential responses of species, such as *Farfantepenaeus notialis* and *Macrobrachium vollenhovenii*, will provide deeper insights into the irresilience and adaptation strategies to environmental stressors. Additionally, there is a growing need to explore the potential of advanced bioremediation techniques, such as phytoremediation, biofltration, and the use of nanomaterials, to mitigate heavy metal pollution in aquatic environments. Further studies should also assess the bioaccumulation of heavy metals in the food chain, focusing on the implications for human health, especially in communities reliant on seafood as a primary food source. Finally, exploring sustainable farming practices that minimize environmental contamination, along with the development of more efective monitoring systems, will be crucial for ensuring the safety of aquatic organisms used for human consumption.

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