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Depuration of mussels (*Pilsbryoconcha exilis*) from microplastics using banana peel adsorbents in coastal areas of Indonesia

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Abstract: Global contamination of the marine environment by plastics has led to the discovery of microplastics in various marine species, including those for human consumption. Depuration reduces the concentration of microplastics and in turn, reduces human exposure to microplastics that enter the human body. This study looked at the effectiveness of microplastic depuration on *Pilsbryoconcha exilis* using a natural adsorbent from banana peel. An investigation was also conducted on effectiveness by time variation to determine the most viable depuration time. A completely randomised design was employed with two repetitions of mussel treatment for durations of 12, 24, and 36 h. The results showed that the effectiveness of depuration by time variation was fluctuating. The most effective depuration time was 12 h. The highest average concentration of microplastics, 0.555 MPs·ind^{-1}, occurred after 24 h of depuration, while the lowest, 0.370 MPs·ind^{-1}, did after 12 h of depuration. Dry banana peel as a depuration adsorbent was proven to reduce the number of microplastics. More research is needed on depuration and the most effective types of adsorbents. Research like this will help many people reduce the quantity of microplastics that enter the body.

Keywords: adsorbents, banana peel, depuration, microplastics, mussel, *Pilsbryoconcha exilis*

INTRODUCTION

Plastics see applications in a variety of fields, ranging from simple markers to spacecraft. Certain widely used plastics, such as single-use plastic products or packaging materials, tend to accumulate in the environment, despite the undeniable value of plastics to humanity. Approximately 10% of the residential waste collected by city authorities worldwide is plastic (Daud and Birawida, 2022). Globally in 2021, it is estimated that there will be around 6,300 mln Mg of plastic waste and around 23 mln Mg of plastic waste entering the ocean (Tejaswini *et al.*, 2022).

Physical abrasion and photodegradation can result in the transformation of macroplastics into microplastics. These processes occur slowly in coastal regions where macroplastics are more susceptible to sea waves and protracted UV exposure (Sutkar, Gadewar and Dhulap, 2023). Microplastics are complex polymer mixtures containing chemical additives, adsorbed organic/inorganic materials, and living substances that can interact with biotic and abiotic marine environment components (Elgarahy, Akhdhar and Elwakeel, 2021).

Microplastics can infiltrate the bodies of marine organisms, including fish and mussels. This circumstance will establish a supply chain system (Mondal *et al.*, 2024). Multiple investigations have demonstrated that microplastics are present in marine life. Eleven *Nemiptus japonicas* and seven *Rastrelliger sp.* were found to contain microplastics in Daud's research in 2021.

Microplastics were only found in line or fibre forms. These microplastics were believed to originate from degraded fishing nets, tarpaulin boat coverings, and layers of seats along the Beba coastline, Tamasaju village, Takalar (Daud *et al.*, 2021).

Figure 1 displays a visualisation of keyword networks that frequently appear in scientific articles related to microplastics research. The keyword "microplastic" is the most dominant, indicating that this topic is a primary focus in many studies. Other prominent keywords such as "plastic waste", "toxicity", "risk assessment", "ingestion", and "polymer" suggest that the issues of plastic contamination and its toxicity are widely discussed. In addition, it can be seen that there are also keywords such as "biomarker", "ecotoxicology", and "health risks", which indicate that there are studies that also discuss the evaluation of health risks and ecotoxicological impacts of plastic contamination in the marine environment.

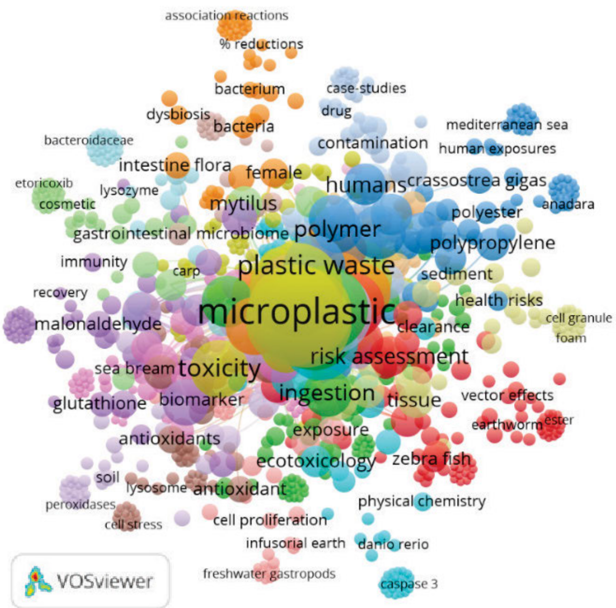

Fig. 1. Keyword network visualisation of microplastic research; source: own elaboration using VOSviewer

The visualisation in Figure 2 highlights countries that are active in microplastics research, with China and Spain emerging as the main hubs, marked by the brightest yellow areas. This indicates that a significant amount of research or publications on microplastics originate from these countries. Other countries such as the United States, Australia, Italy, Brazil, and Singapore also show significant research activity, marked by the bright green areas around them. However, Indonesia is not visible in the visualisation in Figure 2, indicating that microplastic research in Indonesia is lower than in some other countries.

In the work of Hajra El *et al.* (2020), microplastic concentration was defined as the number of plastic particles smaller than 5 mm found in shells. Microplastics in shells found in the Takalar Sea originated from plastic waste pollution. According to this investigation, microplastics in shells were found in an average concentration of 6.7 items per shell (Hajra El *et al.*, 2020). However, the maximum concentration of microplastics in fish varies by habitat, as Arshad *et al.* (2023) has discovered in shallow coastal waters. By habitat, coastal and estuarine fish are notably distinct (Kruskal-Wallis test, $p = 0.0001$) (Arshad *et al.*, 2023).

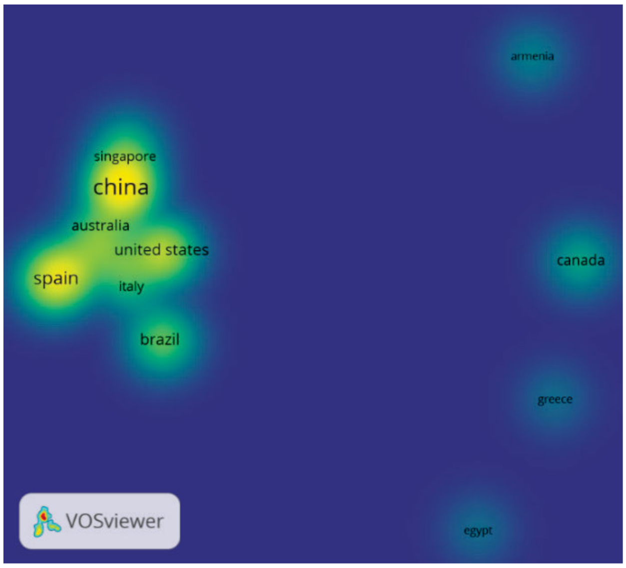

Fig. 2. Visualisation of countries conducting research related to microplastics; source: own elaboration using VOSviewer

Microplastics can accumulate various organic and inorganic contaminants in water (Jinhui *et al.*, 2019). Humans consume seafood such as clams, fish, crabs, squid, and shrimp on a regular basis, which indirectly enables microplastics to infiltrate the human body via marine biota (Jinadasa, Uddin and Fowler, 2023). Microplastics can infiltrate the human body through the oral route by the consumption of seafood. Microplastics will interact with phlegm structures in the gastrointestinal tract before being transmitted to the lymphatic and circulatory systems. Microplastics accumulate in organs via blood circulation and can impair health (Yang *et al.*, 2023).

Previous research has largely discussed the issue of microplastic accumulation in aquatic ecosystems at all levels of food webs, especially in rivers and seas. However, there is no evidence that the accumulation of microplastics in living organisms causes biomagnification (Miller, Hamann and Kroon, 2020), which occurs in food chains in coastal ecosystems far from humans (Amelia *et al.*, 2021). Although research has been conducted on the hazards of microplastics to human health, there have been no conclusive findings.

Seeing the risk of health problems caused by microplastics in marine biota, a method is needed to reduce or even eliminate microplastics in marine biota. An alternative way to reduce the concentration of microplastics is to perform depuration. Depuration is a method to reduce/eliminate contamination, including microplastics, by using a circulating water system. There are several studies regarding the effectiveness of depuration, including the research by Birnstiel, Soares-Gomes and Gama da (2019), which proved that the depuration process was able to reduce microplastics (ANOVA, $p = 0.02$) in wild (46.79%) and cultivated mussels (28.95%) (Birnstiel, Soares-Gomes and Gama da, 2019).

Several methods for purifying hazardous substances such as heavy metal waste and microplastics include precipitation and coagulation, chemical oxidation, sedimentation, filtration, membrane separation, and ion exchange. Among the existing methods, adsorption is used more often because it is cleaner, more efficient, and cheaper (Zustriani, 2019).

The research conducted by Saputri *et al.* (2020) also discovered that depuration time is significantly affected by microplastic depuration effectiveness in shells. There is a tendency that a longer depuration time will reduce the microplastic content in shells more. The effective time for depuration to reduce the microplastic content in *Asaphis detlorata* is 3 or 4 days (Saputri *et al*., 2020).

The depuration process requires an adsorbent that can adsorb microplastics. Banana peel (*Musa acuminata*) is known to be used as a bio adsorbent that removes the content of particles (substances) in aquatic biota, given that banana peel fibres contain greater lignin and cellulose. Banana peel comprises carbohydrate (60–70%), protein (2–3%), fibre (4–5%), lipid (4–5%), and moisture (20%). In dry form, it contains 7.6–9.6% cellulose, 10–21% pectin, 6.4–9.4% hemicellulose, 6–12% lignin, and some low molecular compounds (Suchaiya *et al*., 2022; Mishra *et al*., 2023). Using banana peel as an adsorbent for microplastic degradation is a potential preventive measure in coastal areas. This study aims to determine the effectiveness of the banana peel adsorbent in reducing the microplastic concentration in the body of *Pilsbryoconcha exilis*. Additionally, the efficacy of depuration by time variation was investigated to determine the most viable depuration time.

MATERIALS AND METHODS

RESEARCH DESIGN

This study used a quantitative approach with a completely randomised experimental design. The treatments tried were varied by depuration time (12, 24, and 36 h), each being repeated twice. An experimental container filled with water and dry banana peel (*Musa acuminata*) was used.

SAMPLE LOCATION

Figure 3 displays a map of the research location, the Tallo River and its two tributaries, namely the Sinassara River and the Pampang River, which extend into various areas of the city. The slope of the channel bed is very steep, causing the water flow rate to be slow which has implications for high sedimentation. The morphology downstream is meandering and winding resulting in a sedimentation process that shallows the river.

In this area, many service activities have developed such as the shipbuilding industry, wood industry and warehousing. Along the riverbank is also densely populated by residential areas which can have implications for the presence of a lot of garbage along the Tallo River and affect the existing aquatic biota.

SAMPLE PREPARATION

Mussel samples were taken from the coastal city of Makassar, South Sulawesi. The mussels used in this study were Kijing mussels (*Pilsbryoconcha exilis*). The mussels were taken directly from the Tallo River estuary while still alive and the mussel samples were taken using a garuk or dredge fishing tool. The mussels taken in this study were >3 cm in length, which is classified as large.

The mussel samples were given a treatment for three different durations (12, 24, and 36 h) with two repetitions. The shells prepared for each repetition total around 360, with 180 shells used in one repetition. The mussels were then separated into two groups (control and desiccated banana peel husk groups) and two stations. Each pottery container held 15 mussels. Upon the completion of each depuration period, five mussels from each treatment were taken randomly for analysis.

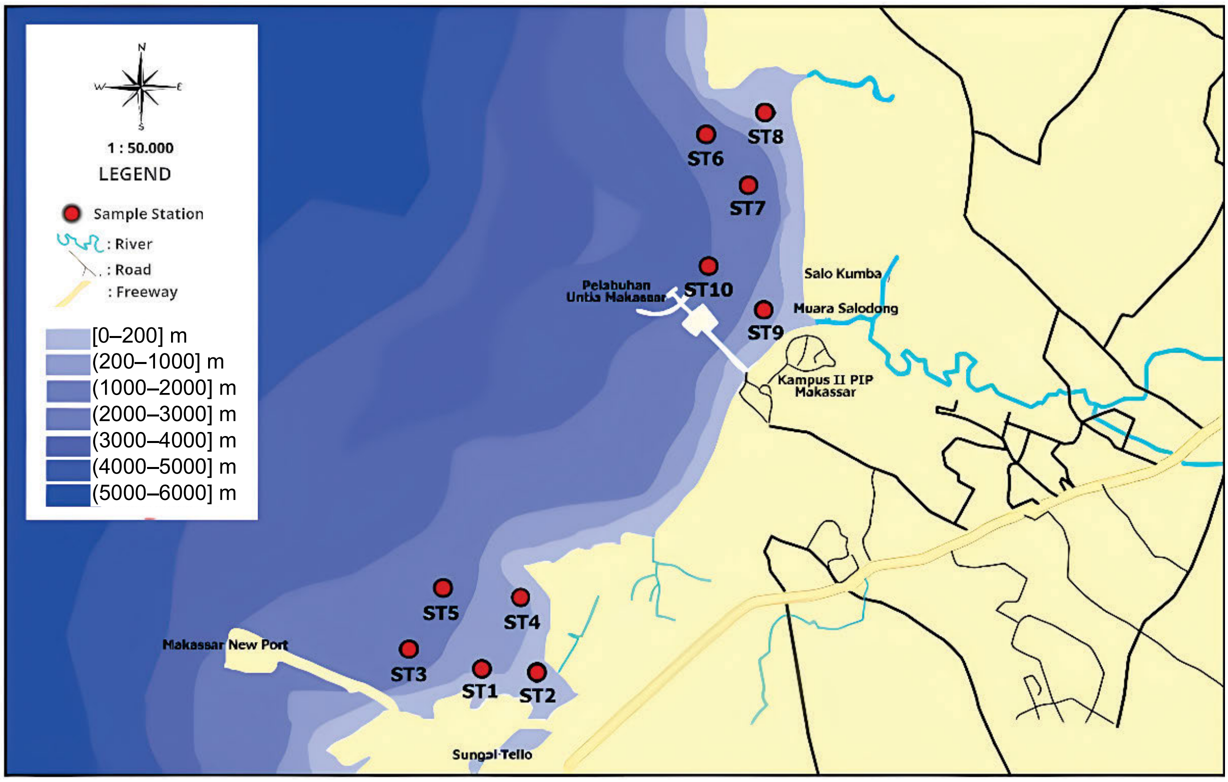

Fig. 3. The map of mussel sampling in Tallo River estuary; source: own study

DEPURATION PROCESS

Based on Figure 4, there is a total of 15 randomly selected mussels from all of the mussels that were prepared. Each pottery container was filled with 5 dm^3 of water and 400 g of banana fibre, and the temperature and pH of the water were measured. Based on the range of quality standards for marine biota according to Decree of the Minister of Environment No. 51 of 2004 (Ind.: Keputusan Menteri Lingkungan Hidup Nomor 51 Tahun 2004), the normal temperature for maintaining the survival of marine biota is in the range of 28–30°C (Keputusan, 2004).

The treatment was administered for depuration durations of 12, 24, and 36 h, each with two repetitions. After the end of each depuration time, all test mussels at each experimental station (unit) were placed in a container labelled according to the treatment duration and then in a cold box for transportation to the laboratory. The depuration process of *Pilsbryoconcha exilis* mussels was conducted under controlled laboratory conditions, maintaining room temperature at approximately 25–30°C and normal ambient lighting (12-h light–dark cycle) to simulate natural environmental conditions. These parameters were kept constant throughout the depuration process to ensure consistency in microplastic reduction measurements.

The mussels were identified by measuring their length, width, and height. The mussels that had been measured were then weighed with and without shells. All glass tools and equipment were rinsed with ultrapure water three times to avoid cross-hazards between samples. The sucked mussels, or the mussels whose shells had been removed, were then put into a sample bottle and immersed in a 20% KOH solution (20–30 cm^3) up to three times the volume of the mussel meat to extract microplastics debris from the mussel body. The extracted samples were then stored for two weeks for later analysis. The adsorption process was carried out using a stirring system, in which a dry banana peel adsorbent was added in the form of powder, then mixed and stirred in a container so that a rejection between the absorbent particles and the fluid occurred.

RESULTS AND DISCUSSION

MICROPLASTIC CONTAMINATION IN MUSSELS

The data in the Table S1 shows the presence of microplastics in various species of shellfish throughout the world along with the depuration times and reference sources. It is important to note that analytical methods varied across studies, including shell macrometrics, depuration time, and depuration effectiveness. Refer to the source reference for further details.

MUSSEL MORPHOMETRICS AND MICROPLASTIC CONCENTRATION IN *Pilsbryoconcha exilis*

The mussels (*Pilsbryoconcha exilis*) from the coast of Makassar City (Photo 1) were found to contain microplastics. After depuration, *Pilsbryoconcha exilis* had an average weight of 5.33 g, with a standard deviation of 0.45 g. This average figure indicates that the microplastic concentration in *Pilsbryoconcha exilis* in this study was higher than the concentrations found by Saha *et al*. (2021) in Goa, India. The *Pilsbryoconcha exilis* originating from the Chapora River, Goa, India, had an average weight of 3.2 g, with a standard deviation of 0.21 g, and the *Pilsbryoconcha exilis* originating from the Mandovi River, Goa, India, had an average weight of 5.02 g, with a standard deviation of 0.38 g (Saha *et al*., 2021). It indicates that the microplastics pollution on the coast of Makassar City was relatively high, even after depuration.

Several factors, including water conditions and food availability, influenced differences in mussel morphometrics. The accumulation and elimination of plastic waste that entered the bodies of mussels were influenced by the mussels' sizes and bodies (Weinstein, Ertel and Gray, 2022). The *Pilsbryoconcha exilis* obtained from the coast of Makassar City were relatively small due to the continuous harvesting of mussels by the community. Household, industrial, and agricultural activities around the research location could also harm aquatic ecosystems.

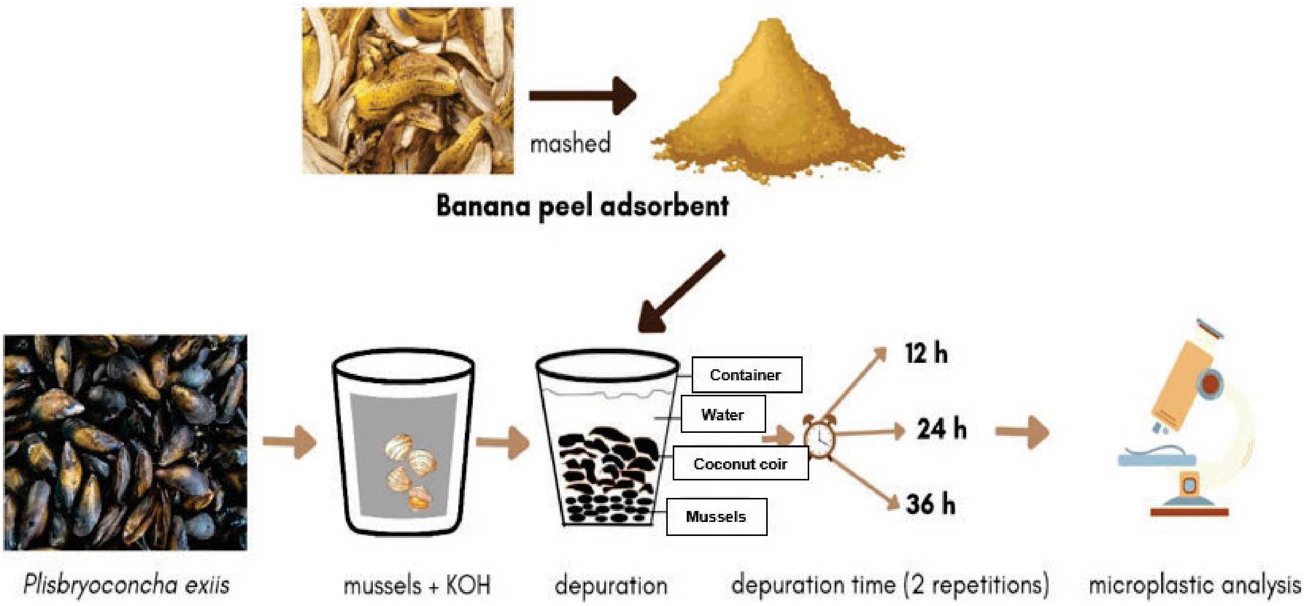

Fig. 4. Schematic illustration of the manufacture of adsorbents and depuration processes; source: own elaboration; photo of banana peel by *A. Daud*; photo of *Pilsbryoconcha exilis* by *A.B. Birawida*

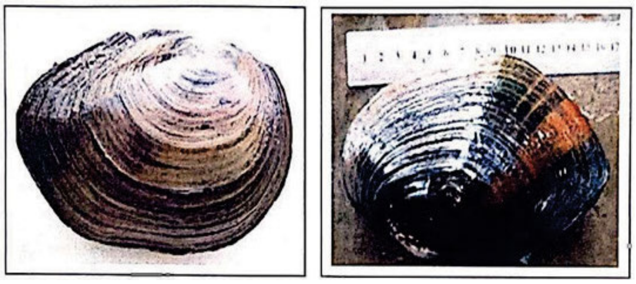

Photo 1. Mussel (*Pilsbryoconcha exilis*) and macrometric measurements of the body of the mussel (phot. *A. Ambeng*)

Based on field observations, the *Pilsbryoconcha exilis* sold in the market also had small sizes ranging from 4 cm to 7 cm. Before the proliferation of development activities around the river, *Pilsbryoconcha exilis* could reach a size of 10–12 cm. The size of the mussels was also affected by the polluted environment. The life of *Pilsbryoconcha exilis* could be influenced by biological factors, such as the availability of food, phytoplankton, zooplankton, suspended organic matter, and other living things around them, as well as land narrowing due to development, as in industrial and agricultural sectors, around rivers.

THE RELATIONSHIP BETWEEN DEPURATION TIME AND MICROPLASTIC CONCENTRATION IN *Pilsbryoconcha exilis*

The data below (Fig. 5) illustrates the relationship between depuration time and microplastic concentration in *Pilsbryoconcha exilis*. As microplastic pollution becomes more common in aquatic environments, understanding how long it takes for these organisms to clear microplastics from their systems is critical. This diagram shows how the duration of the depuration process can affect the concentration of microplastics present in the mussel.

The highest concentration of microplastics, as shown in Figure 5, of 0.555 MPs·ind^{-1}, occurred after 24 h of depuration, while the lowest, 0.370 MPs·ind^{-1} did after 12 h. The figures fluctuated because they were influenced by the quantity of microplastics, the use of adsorbents, and the duration of depuration. This research proved that depuration could reduce the abundance of microplastics, which is related to the sources of pollutants. These results indicate that microplastic contamination in mussels generally fluctuated in each treatment (time) due to the influence of the microplastics in each depuration. The number of microplastics did not consistently decrease during the 24-h depuration throughout repetitions. This was due to the time of only 6 h. Even at 36 h of depuration, the concentration of microplastics decreased. In addition, the average concentration of microplastics during the 24-h depuration being higher than that during the 12-h depuration was due to the adaptation process of the mussels (lag phase). However, after 36 h of depuration, there was an average decrease of 0.09 MPs·ind^{-1} from 0.55 MPs·ind^{-1} to 0.46 MPs·ind^{-1}. Differences in the effectiveness of depuration time began to appear, with significance in differences compared to no treatment (control).

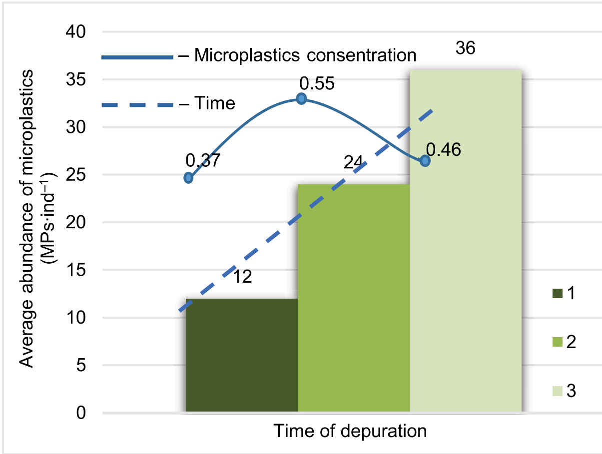

Fig. 5. The relationship between depuration time and microplastic concentration in *Pilsbryoconcha exilis* (MPs·ind^{-1}); *1* = 12 h, *2* = 24 h, *3* = 36 h; source: own study

Figure 6 shows that depuration could reduce the amount of microplastics in *Pilsbryoconcha exilis* to a greater extent than non-

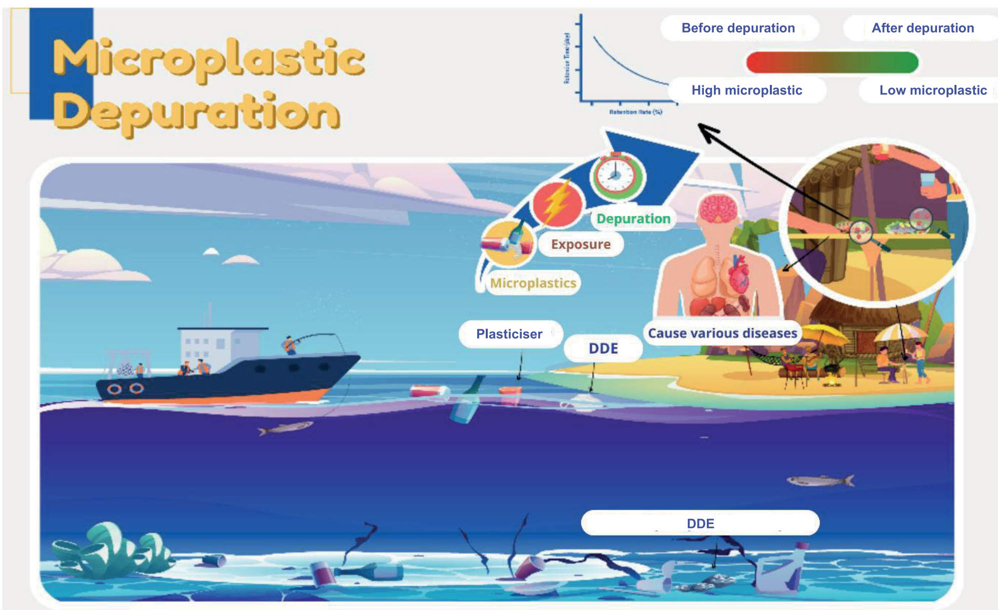

Fig. 6. Microplastics exposure in the environment and solutions through depuration; DDE = dichlorodiphenyl dichloroethylene; source: own study

depuration. These results align with the research conducted by Saputri *et al.* (2020), which found that with longer depuration time, the microplastics content in mussel meat tends to decrease (Saputri *et al*., 2020). However, the research by Saputri *et al.* (2020) used depuration durations of 1, 2, 3, and 4 days. There were no significant differences in the results obtained on days 1 and 2, but on days 3 and 4, the concentration of microplastics decreased. Even in the paper by Rist *et al.* (2019), it has been shown that there was no significant difference between the number of beads in shell exposure and depuration, suggesting that there was very little or no egestion.

THE EFFECTIVENESS OF USING BANANA PEEL ADSORBENTS IN REDUCING MICROPLASTIC CONCENTRATIONS IN *Pilsbryoconcha exilis*

The diagram (Fig. 7) presents findings on the effectiveness of using banana peel adsorbents to reduce microplastic concentrations in *Pilsbryoconcha exilis*. The data below shows the results of microplastic reduction tests, without treatment (control) and using banana peel adsorbents with each being repeated two times. As microplastic pollution increasingly threatens aquatic ecosystems, innovative and sustainable recovery strategies are needed.

Based on the diagram (Fig. 7), a depuration process can reduce the concentration of microplastics in mussels. The principle of the depuration process is to maintain mussels in aqueous media (Birnstiel, Soares-Gomes and Gama da, 2019). The resulting figures experienced fluctuations because they were influenced by the quantity of microplastics, the use of an adsorbent, and depuration duration. Based on the study's results, the decrease in microplastic concentration was more significant in the second repetition than in the first. Using banana peel as an adsorbent is effective in reducing the concentration of microplastics in mussels.

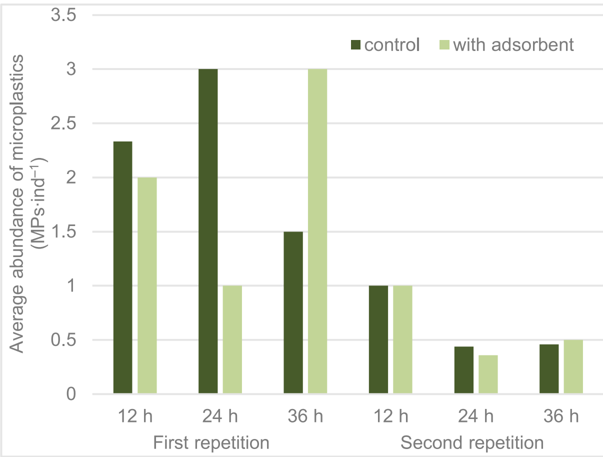

Fig. 7. Effectiveness of using banana peel adsorbents in depuration; source: own study

The increase in microplastic concentration after 36 h of depuration in the first repetition may be due to the saturation of the adsorbent, where the binding sites on the banana peel become fully occupied by microplastic particles, reducing its adsorption capacity. Saturation can induce the desorption or release of previously adsorbed microplastics back into the depuration water, thereby increasing the microplastic concentration in mussels. Physical and chemical degradation of the banana peel adsorbent during extended exposure may alter its structural integrity, diminishing its effectiveness in capturing microplastics. The breakdown of the adsorbent structure can lead to the re-release of microplastics, impacting its overall performance. Variations in the quality of the banana peel and experimental inconsistencies may also affect microplastic adsorption capacity, contributing to the observed fluctuations in microplastic levels (Suryadi *et al*., 2019; Mishra *et al*., 2023).

Banana peel has a different component composition depending on where the banana is grown. Graham (2019) obtained an average uptake of microplastic particles of 19.4 ±1.1% after 24 h of depuration and 19.4 ±2% after 48 h of depuration. After 72 h, the average uptake was 12.9 ±2% (Graham *et al*., 2019). These values also indicate variations in depuration results based on time.

In its molecular structure, banana peel contains cellulose, which is composed of several hydroxyl groups, and lignin, which is composed of phenolic acids that bind substances (particles) (Stanisz *et al*., 2022). Cellulose and lignin function as biopolymers related to binding substances (particles). Lignin has functional groups such as aldehydes, ketones, acids, phenols, and ethers, which allow chemical adsorption to occur (Suchaiya *et al*., 2022; Mishra *et al*., 2023).

Based on the comparison of the results from Figure 8, the decrease in the concentration of microplastics in mussels proved

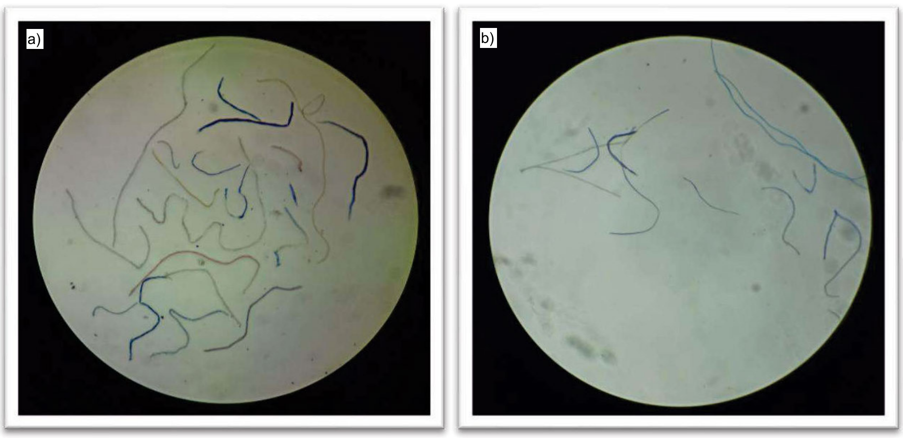

Fig. 8. Results of microplastic analysis using a microscope: a) before depuration, b) after depuration; source: own study

that depuration treatments of *Pilsbryoconcha exilis* using banana peel adsorbents can reduce the concentration of microplastics in mussels and thus increase food safety for mussel consumers. Even so, this depuration technique must be improved if one is to remove microplastic contaminants completely because microplastics were still detected even after 36 h of depuration.

Mussels are a target species for microplastic (MP) pollution as particles can accumulate in the digestive system, disturbing feeding processes and becoming internalised in tissues. MPs may also carry pathogens or pollutants present in the environment (Hellfeld von *et al*., 2022). Several studies have proven that microplastics can harm organisms in water. The impact of microplastic contamination is influenced by physical conditions (shape and size of particles) and chemical components (additives or chemical contaminants) that bind to microplastics (Prajapati, Narayan Vaidya and Kumar, 2022). Other research states that the entry of microplastics into the bodies of vertebrate and invertebrate animals can cause injuries to internal organs, block the digestive tract, inhibit growth and enzyme production, reduce steroid hormones, accumulate lipids in the liver, cause inflammation, and infect the intestines (Huang *et al*., 2021).

Contamination of the marine environment with microplastics (plastic items from 1 μm to 5 mm in length) is prevalent, with up to 51 tn floating microplastics estimated to occur in this environment globally (Santana *et al*., 2021). Microplastics can enter the food chain, accumulate, and be consumed by humans, as in the case of the biomagnification of xenobiotic substances (foreign compounds not needed by the body) (Pironti *et al*., 2021). Based on the research by Miller, Hamann and Kroon (2020), microplastics have accumulated and existed at all levels in food webs in aquatic ecosystems, especially in rivers and seas. However, there is no indication that the accumulation of microplastics that occur in living bodies causes biomagnification. It is undeniable that microplastics already exist in freshwater and marine animals consumed by humans, even in land animals (Miller, Hamann and Kroon, 2020).

Research on the dangers of microplastics to human health has been carried out, although there have yet to be conclusive results from it. There are indications that microplastics are harmful to the human body because they are toxic to the body's cells and can carry microorganisms or other compounds, such as heavy metals, harming human health. Microplastics can enter the human body through ingestion, inhalation, and contact with the skin.

CONCLUSIONS

This study showed that mussel morphometrics did not have a significant relationship with the concentration of microplastics in mussels (*Pilsbryoconcha exilis*). The effectiveness of depuration time was fluctuating. The most effective depuration time was 12 h. The highest average concentration of microplastics occurred after 24 h of depuration (0.555 MPs·ind^{-1}), and the lowest did after 12 h of depuration (0.370 MPs·ind^{-1}). Dry banana peel as an adsorbent in depuration has been proven to reduce microplastic concentration. More research is needed on depuration and the most effective types of adsorbents. Research like this will help many people reduce the quantity of microplastics that enter the body.

SUPPLEMENTARY MATERIAL

Supplementary material to this article can be found online at https://www.jwld.pl/files/Supplementary_material_Daud.pdf

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CONFLICT OF INTERESTS

All authors declare that they have no conflict of interests.

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