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Microplastic Depuration Using A Circulation Pump System With Adsorbent On Brown Mussels (*Modiolus Modulaides*) In Tamarunang Waters

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Abstract

Plastic waste from coastal settlements, fisheries, and marine activities has become a major source of microplastic pollution in the Tamarunang Waters of Jeneponto Regency**,** where filter-feeding brown mussels (*Modiolus modulaides*) readily accumulate microplastics. This study evaluated the effectiveness of microplastic depuration using a pump-circulation system with a natural bioadsorbent. A quantitative experimental approach with a completely randomized design (CRD) was employed, comprising five treatments: a control (no depuration) and depuration periods of 1, 2, 3, and 4 days, each replicated three times. Mussels were collected using purposive sampling from sites with high mussel abundance and potential plastic contamination. Of 810 mussels collected, 405 individuals were analyzed (5 treatments × 3 replications × 27 mussels). Data were analyzed using Analysis of Variance (ANOVA) and linear regression. The novelty of this study lies in the use of mashed kepok banana peels as a natural bioadsorbent. The lowest microplastic content was observed after four days of depuration. Although three- and four-day periods showed no significant difference, both were significantly more effective than shorter depuration periods. Depuration efficiency increased from 47.825% at day 0 to 94.132% after four days. Fragments, fibers, and films were the dominant types of microplastics. These findings demonstrate that a banana peel bioadsorbent, combined with a circulation system, effectively reduces microplastic contamination and provides a sustainable, low-cost depuration method. Future studies should validate this approach under commercial-scale and field conditions while assessing its effects on mussel quality and food safety.

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Introduction

Indonesia is the second-largest contributor of plastic waste to the ocean after China, with an estimated 0.48- 1.29 million metric tons of plastic per year. As Indonesia's population increases, so does the amount of plastic waste generated (Tubagus et al., 2020; International Bank for Reconstruction and Development, 2021). Plastic is a synthetic material produced through the polymerization *(polycondensation)* of various monomers *(styrene, vinyl chloride, butadiene*, and *acrylonitrile).* Plastic polymers are highly stable materials, allowing them to remain in the environment for long periods (OECD, 2022). The increasing production of plastic, combined with its slow degradation rate, which can span decades to centuries, has contributed to the environmental problem of microplastic accumulation in marine habitats. Physical abrasion from mechanically assisted waves and photochemical processes triggered by UV-B radiation can lead to plastic fragmentation (Khan et al., 2020; Revel et al., 2020).

Plastic waste that enters the environment does not decompose quickly. When this waste enters a bay, it will be carried by water currents into the ocean. Bays are the main route for plastic waste to reach the ocean because they are ocean inlets that jut into land and are bordered by land on three sides, where human activities are concentrated. The sources of microplastics include primary and secondary microplastics (Zhu et al., 2019). Primary microplastics are plastics that are released directly into the environment as small particles.

In contrast, secondary microplastics originate from the degradation of larger plastic items into smaller fragments upon exposure to the marine environment (Zhu et al., 2019; Kazour, 2020). This degradation process can occur through several mechanisms, including photodegradation (sunlight exposure), biodegradation (biological activity), and thermal degradation (water temperature). These processes accelerate the mechanical breakdown of plastic into smaller particles, resulting in large quantities of microplastics being found in aquatic environments (Windsor et al., 2019).

Plastic that ends up in ocean waters gradually breaks down into smaller particles, shrinking from its original size to microscopic dimensions. This shrinkage is caused by waves that induce abrasion, leading to the accumulation of plastic particles in both sediments and the water column (Rehse, Kloas, & Zarfl, 2018). Microplastics are made from hazardous base materials. They can absorb toxic hydrophobic compounds from the surrounding environment, such as dichloro-diphenyl-trichloroethane (DDT), polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), nonylphenols, and other nonpolar substances that adsorb onto the plastic surface and can be consumed by organisms. (Rillig, Ingraffia, & de Souza Machado, 2017). Microplastics pose a potential threat to human health and activities. The accumulation of microplastics in organisms causes physical and chemical damage, including damage to internal organs, blockage of the digestive tract, carcinogenic effects, and endocrine disruption (Frydkjær, Iversen, & Roslev, 2017).

Microplastic pollution in aquatic environments can have adverse effects, particularly on marine organisms. The physical effects of microplastics are evident at high concentrations (Guzzetti et al., 2018). The type of basic substrate is a very important factor in the lives of benthic organisms because the substrate influences community structure and provides places to live, eat, and be protected (Yokota et al., 2017). The presence and characteristics of substrates determine the abundance and types of benthic organisms that can thrive in waters. However, the stability of this substrate can be disrupted by human activities, such as intensive mussel fishing with trawl-type gear. This activity stirs up the bottom substrate, leading to habitat degradation, indicating that trawling can seriously damage benthic habitats (Crawford & Quinn, 2017; de Souza Machado et al., 2018).

Mussels are among marine biota that can be contaminated by microplastics (Prata, 2018). As shellfish are widely consumed seafood, ensuring their safety and quality is crucial. One method to reduce microplastic content in shellfish is depuration, a treatment process designed to remove contaminants from the bodies of aquatic organisms collected from polluted waters (Lees et al., 2019). In addition to removing heavy metals, depuration can also remove microplastics. This can be carried out in various ways, including through recycling systems (Lees et al., 2019).

Tamarunang waters, located in Binamu District, Jeneponto Regency, are a coastal area with mangrove forests that support a variety of aquatic organisms, including mussels. However, community activities around the Tamarunang waters can generate large amounts of plastic waste that harm aquatic organisms. Microplastics in this area originate from domestic waste, tourism, the fishing industry, agriculture, and other human activities. Based on this description, the purpose of this study is to analyze Microplastic depuration using a pump circulation system with adsorbents in Brown Mussels (Modiolus modulaides) from Tamarunang Waters, Jeneponto Regency.

Methods

Study Design

This study employed a quantitative experimental research approach to evaluate the effect of different depuration durations on microplastic reduction in brown mussels. The experiment was designed to establish a cause-and-effect relationship by manipulating the depuration time while controlling other environmental variables. A Completely Randomized Design (CRD) was used, in which experimental units were randomly assigned to treatments to minimize bias and ensure that observed differences resulted from the treatments rather than external factors (Ibrahim et al., 2018). The treatments consisted of a control (no depuration) and depuration periods of 1, 2, 3, and 4 days, with each treatment replicated three times.

Place and Time of Research

This research was conducted in the waters of Tamarunang, Jeneponto Regency. Data collection was conducted from February to August 2025.

Population and Sample

A total of 810 Brown Mussel samples (Modiolus modiolus) were collected and brought to the laboratory for depuration. The number of mussel samples was calculated as 5 treatments × 3 replications × 27 mussels = 405 mussels. Brown Mussel *(Modiolus modiolus)* was then separated into 2 groups: the depuration group (324 shells) and the control group (81 shells). For the control group, 81 mussels (27 mussels × 3 repetitions) were randomly selected for microplastic content analysis. In the depuration group, 324 mussels were further divided into groups of 36 shells for placement in nine aquariums (4 treatments × 3 repetitions) using a pump circulation system with mashed banana peel as an absorbent. After the depuration process, 10 mussels (3 replicates) from each treatment were taken to the Ecotoxicology Laboratory at the Faculty of Fisheries and Marine Sciences (FPIK), University Hasanuddin, for microplastic identification. Furthermore, representative microplastic samples (based on shape and color, n = 8) were further analyzed using Fourier Transform Infrared (FT-IR) Spectroscopy (Birnstiel, Soares-Gomes, & da Gama, 2019; Hendrickson, Minor, & Schreiner, 2018).

Data collection

a) Direct observation. Sampling of Brown Mussels *(Modiolus modiolus)* was conducted directly at the study site.
b) Measurement and Examination. Measurements and examinations were carried out on mussel samples, including mussel morphometrics, the number of microplastics in mussels, microplastic

size and color, depuration duration, depuration water quality, and the effectiveness of the circulation pump system using dry coconut fiber absorbent. The data were analyzed using SPSS version 16 and were supported by the literature.

c) Microplastic Content Examination. Microplastic content was carried out at the Ecotoxicology Laboratory of the Faculty of Marine Sciences, Hasanuddin University.

Data Analysis and Processing

Data processing involved comparing the concentration values obtained from laboratory identification with differences in depuration outcomes for each treatment on microplastic concentrations in shells. This study is classified as quantitative research, employing descriptive and regression analyses. The descriptive analysis method was used to provide explanations, interpretations, and information through data tabulations. To determine the relationship between different depuration times and microplastic concentrations in shells, the data were analyzed using one-way ANOVA and linear regression analysis (Saat & Mania, 2020).

Ethical Considerations

This research has undergone a research protocol examination by the Health Research Ethics Commission under No. RK.197/KEPK/STIK/VII/2025 at the Maluku Husada College of Health Sciences.

Results and Disussion

Table 1. Number and Size of Microplastics in Brown Mussel *(Modiolus modulaides)* Meat at Different Depuration Periods

Description	Control (Min-Max, Mean±SD	Depuration Period 1 (Min-Max, Mean±SD)	2 (Min-Max, Mean±SD)	3 (Min-Max, Mean±SD)	4 (Min-Max, Mean±SD)
Microplastic Content (MPs/shellfish)	7.5-9.7 8.7 ±1.6	2.3-8.8 4.8 5.1	2.1-8.7 6.5 ±4.5	0.5-1.6 0.9 ±0.5	0.3-1.5 0.9 ± 0.4
Microplastic size (mm)	0.7-1.1 1.01 ±0.3	1.6-2.4 1.9 ±0.7	1.4-1.8 1.9 ±0.4	0.8-1.9 0.9 ±0.8	0.2-1.7 1.2 ±0.9

Note: SD (±) shows the standard deviation; A lower standard deviation value shows data points closer to the mean, while a higher value indicates greater variability

Table 1 shows that mussels without depuration (control) contained microplastics with an average of 8.7 MPs/shell. In the depuration group, the highest average microplastic content was observed on day 2 (6.5 MPs/shell), while the lowest was on days 3 and 4 (0.9 MPs/shell each). For microplastic size, mussels in the control group had an average length of 1.01 mm. In the depuration groups, the largest microplastic size was recorded on days 1 and 2 (average = 1.9 mm), while the smallest average size was observed on day 3 (0.9 mm).

Figure 1. Brown Mussel Figure

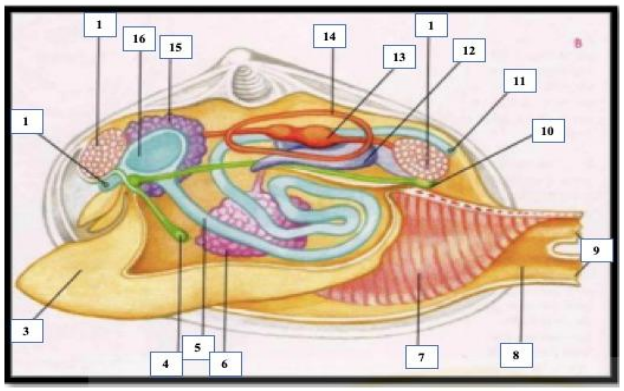

Figure 2. Anatomy of Brown Mussels

Figure 3. Microplastic in the Control

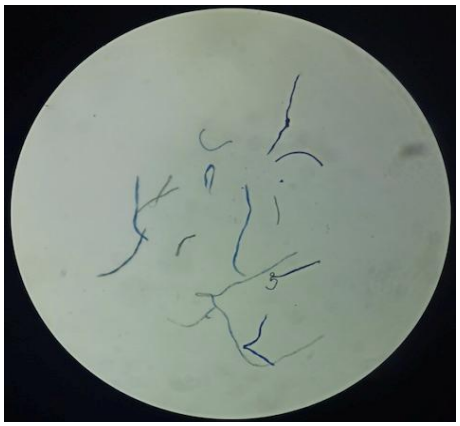

Figure 4. Microplastic Depuration in Brown Mussels

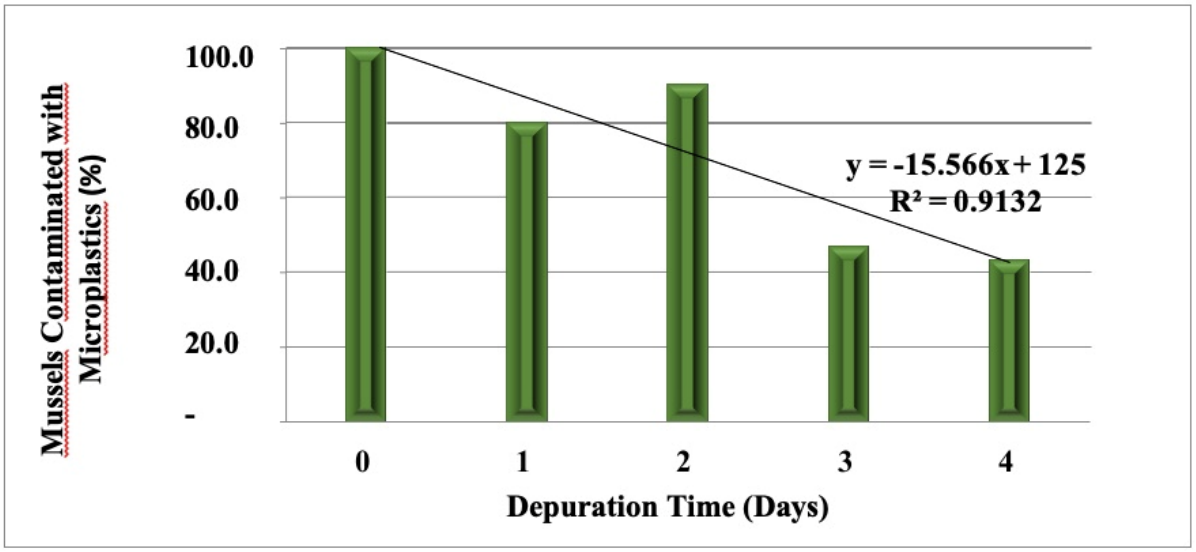

Figure 5. Percentage of Microplastic Contamination in Brown Mussels *(Modiolus modulaides)*

Microplastic contamination showed a gradual decrease across all treatments. This shows that the longer the depuration period (in days), the fewer microplastic contaminants remain in Brown Mussels *(Modiolus modulaides)*.

Table 2. Average Microplastics (MPs/Individual) Based on Form and Color

Types of Microplastics	Microplastic Color				
	Yellow	Transparent	Red	Blue	Black
Fragment	0.83	0.41	0.21	0.33	0.51
Fiber	0.11	1.67	0.09	0.46	0.21
Film	0.34	0.68	1.37	1.83	0.19

Table 2 shows that microplastics found in Brown Mussel *(Modiolus modulaides)* were dominated by blue film particles, with an average of 1.83 MPs/individual. In contrast, the lowest average was observed for black fragments (0.11 MPs/individual).

Table 3. Depuration Water Quality

Parameter	Treatment/Depuration (Days)				Mark Optimal
	1 (Min-Max Average ±SD	2 (Min-Max Average ±SD	3 (Min-Max Average ±SD	4 (Min-Max Average ±SD	
pH	7.20-8.13	8.38-9.14	6.68-7.15	6.84-8.11	7-8.6
	8.12 ±0.29	8.53 ±0.35	7.64 ±0.71	7.51 ±0.59	
Temperatur	23.3-24.75	24.7-26.12	25.04-26.71	25.79-27.35	28-32
e (^{0} C)	24.65 ±0.38	26.13 ±0.57	26.85 ±0.77	26.82 ±0.63	
Salinity	34.27-35.28	34.76-35.45	35.71-36.01	34.29-36.07	<30
(ppt)	35.47 ±0.39	35.51 ±0.27	36.15 ±1.12	35.07 ±0.54	

Note: SD (±) shows the standard deviation; Lower SD values indicate data close to the average; higher SD values indicate wider variability.

During the depuration process, water quality was measured twice daily, in the morning and evening. Table 3 shows that the pH values ranged from 6.84 to 9.14, with the highest value recorded during 2-day depuration. Water temperature ranged from 23.3 °C to 27.35 °C, which is slightly below the quality standards stated in the Decree of the Minister of State for the Environment No. 51 of 2004

(28–32 °C for marine biota). Salinity values during depuration ranged from 34.27 to 36.07 ppt.

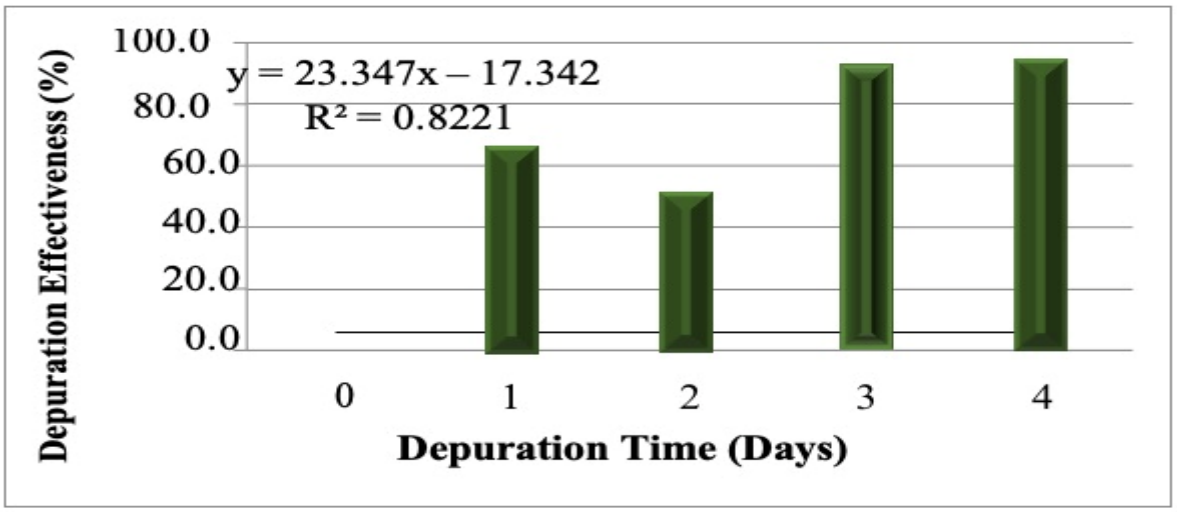

Figure 6. Effectiveness of Microplastics Depuration in Brown Shellfish *(Modiolus modulaides)*

Figure 6 shows that depuration periods of 0 (control), 1, and 2 days did not differ significantly in depuration effectiveness. Similarly, depuration periods of 3 and 4 days showed no significant difference. However, a significant overall effect is evident between the 0-day treatment (47.825%) and the 4-day depuration (94.132%), indicating a substantial reduction in microplastic contamination over time.

Discussion

Brown mussels (Modiolus modulaides) obtained from Tamanung Waters were detected to be 100% contaminated with microplastics. In the control group, microplastic contamination averaged 8.7 MPs/shell, whereas in the depuration group, the lowest average microplastic content was observed on days 3 and 4 at 0.9 MPs/shell. For the non-depurated (control) microplastics, the average microplastic size was 1.01 mm, while the shortest size in the depurated mussels was 0.9 mm on day 3. These findings suggest that the microplastics at the research site have undergone prolonged degradation due to their extremely small size. The fragmentation of macroplastics into microplastics is caused by ultraviolet radiation, the mechanical forces of ocean waves, oxidative reactions in plastic materials, and the hydrolytic properties of seawater. This is in line with the study by Basri et al. (2024), which found no detectable correlation between shell size and microplastic concentration. Feather clams, for instance, were found to contain the highest amount of microplastics—up to 58 MPs/clam, with sizes ranging from 0.027 to 4.587 millimeters (Basri et al., 2024).

High levels of household activity in Tamarunang Waters and inadequate waste management systems can increase microplastic concentrations in aquatic biota, such as mussels. Microplastic contamination in shellfish can also come from fishing nets, textile fibers, and fishing equipment. Beyond domestic waste, tourism and industrial waste are also significant sources of microplastic pollution. This is in line with research conducted by Saleh et al. (2023) in Jeneponto Regency, which showed that microplastic contamination was highest in mangrove ecosystems and residential waters, and lowest in river areas. Blood cockles (Anadara granosa) exhibit high levels of microplastic contamination because plastic pollution originates from waste disposal. The plastic gets caught in fisheries and mangrove ecosystems along the coast (Saleh et al., 2023)

Brown Mussel (Modiolus modiolus) contamination levels after 1 and 2 days of depuration were not significantly different from those in the treatment without depuration (control). Based on the data collected during the depuration process, the contamination level on day 2 was actually higher than on day 1. This increase is presumably due to the mussels' adaptation or lag phase during the early depuration period. DifferencesDifferences in depuration effectiveness began to appear on days 3 and 4 and were significant compared to the control, 1-day, and 2-day depuration treatments. These results are consistent with the findings of Saputri et al. (2020) in Mangarabombang District, Takalar Regency, which demonstrated that the longer the depuration time, the lower the microplastic content in mussels (Saputri et al., 2020). Effectiveness began to appear on days 3 and 4, which showed significant differences compared to the control, 1-day, and 2-day depuration treatments. These results are consistent with the findings of Saputri et al. (2020) in Mangarabombang District, Takalar Regency, which demonstrated that the longer the depuration time, the lower the microplastic content in mussels. This depuration can reduce microplastic concentrations in Brown Mussels (Modiolus modulaides) more effectively. This result is in line with research by Birnstiel et al. (2019), which showed that longer depuration times lead to lower microplastic content in mussel tissue (Birnstiel, Soares-Gomes, & da Gama, 2019).

To avoid contamination during this depuration process, the mussels were not fed. Mussels filter food when their shells open, and when threatened, the shells close tightly. Pollutants are absorbed simultaneously with feeding. The adductor muscles control the opening and closing of the shell during filtration (Wolinski, 2025; Moura et al., 2025). The ligaments, which act as connecting structures between the two shell valves, respond to pressure differences by opening or closing the shell valves accordingly (Wolinski, 2025).

The feeding mechanism of shellfish must be carefully considered during depuration. Mechanism: This mechanism is one of the key factors determining the proper functioning of mussel metabolism to achieve effective depuration. Depuration can reduce contaminant levels in shellfish compared to untreated individuals. Live shellfish continue to excrete contaminants, which are subsequently removed through depuration using continuous water purification with a circulation pump system.

Visual observations of microplastics with a binocular microscope can identify them by shape. The microplastics found in this study consisted of fragments, fibers, and films. High rainfall can increase the volume of water in rivers and streams, thereby transporting microplastic particles to the sea. High waves in a body of water can agitate the water, causing microplastics on the bottom to rise to the surface, forming accumulations that are distributed within a particular area. According to Reed et al. (2018), plastic waste can sink to the seabed due to an increase in particle weight, such as biofouling or organism colonization, in addition to turbulent mixing, horizontal dispersion, and biota feces containing microplastics, all of which can accelerate plastic on the seabed (Reed et al., 2018).

A type of hard, flat fragment that comes from waste such as bottles, jars, PVC pipes, broken buckets, and basins. Film-type microplastics are irregularly shaped, wide, and thin (Lenz & Labrenz, 2018). Fiber-type microplastics come from synthetic fabrics, which can be released during washing; from fishing nets; from industrial raw materials; from household appliances; from plastic bags designed to degrade in the environment; or from the weathering of plastic products. Film-type microplastics are generally secondary microplastics derived from the degradation of domestic waste, such as food packaging, beverage packaging, detergent packaging, tarpaulins, and various plastic bags (Ahmad & Almalki, 2025).

The study identified yellow, transparent, red, blue, and black microplastics by color. This research aligns with Nurika et al.'s research in Jember. The results showed that the microplastics found in mussels were predominantly dark-colored (black) (Nurika et al., 2023). The variation in microplastic colors depends on the composition of the plastic's constituent materials. Dark-colored microplastics indicate they have not undergone significant color changes and have experienced

minimal discoloration due to ultraviolet exposure. The black color of microplastics also indicates the absorption of contaminants from external pollutants (Moin et al., 2025). When black microplastics absorb other pollutants, this can contaminate them and alter their texture (Cherdsukjai, Vongpanich, and Akkajit, 2022; Moin et al., 2025).

The sources of dark-coloured microplastics (black and brown) are thought to be primarily household waste. Coastal tourism and industrial activities are directly adjacent to aquatic habitats. The color diversity of microplastic particles is influenced by UV exposure duration, which induces colorcolor changes through oxidation. Color changes in microplastics indicate the length of time the microplastic particles have been in water and within an object. Gradual fading toward transparent colors suggests that the microplastics have undergone long-term degradation (Nurika et al., 2023). The color of microplastics can indicate the types of polymers that make up an object. The black color of microplastics is often associated with the polymers Polyethylene (PE), Polystyrene (PS), and Polypropylene (PP). Transparent microplastics are also an initial clue for identifying the type of Polypropylene polymer, and red microplastics are suspected to be types of Polypropylene (PP) and Polyester (PES) polymers; brown and blue microplastics indicate the type of Low Density Polyethylene (LDPE), and yellow microplastics indicate the type of Polystyrene (Rahman, Samawi, and Werorilangi 2024).

Marine biota, such as mussels, can experience adverse effects when contaminated by microplastics. Microplastics that have accumulated in the body can disrupt the lives of marine organisms, causing abnormalities or damage to the digestive system, gill damage, stunted growth, and even death (Covernton et al., 2019). In addition to marine organisms being affected by microplastic accumulation, humans who consume them will also be affected by microplastics accumulated in marine organisms (Naji, Nuri, and Vethaak, 2018).

Microplastics can pollute the environment because waste processing cannot eliminate them. Microplastics can negatively impact human health, causing cell damage, inflammation, and triggering chronic diseases such as cancer. These particles can also disrupt the hormonal, metabolic, and nervous systems, and potentially cause fertility problems (Prata, 2018). These impacts occur because microplastics and the harmful chemicals they contain can enter the body through food, accumulate, and cause various health problems (Miskon et al., 2024). One way to reduce microplastic content in shellfish before consumption is through depuration.

The depuration process can reduce microplastics in shellfish, thereby reducing human exposure to microplastics consumed by humans. Depuration can be performed using a seawater recirculation system by immersing shellfish samples in seawater recirculating through a 15-watt UV lamp. Depuration is an effective method for cleaning microplastics. In this study, the remaining depuration media was collected and analyzed for microplastic content. The results indicated that the longer the depuration time, the higher the microplastic content in the media. This increase reflects the release of microplastics from within the mussel body into the depuration media. The marked decrease in microplastic content in the mussels and the increase in microplastic content in the depuration media demonstrate that the depuration treatment applied to Brown Mussels (Modiolus modulaides) effectively reduced microplastic contaminants in the mussels, thereby enhancing the food safety of mussels for consumers. However, this depuration technique still needs further improvement to eliminate microplastic contamination, as microplastics were detected even after 4 days of depuration. The results of research by Birnstiel et al. (2019) showed that the depuration process can significantly reduce the number of microplastics by 28.95% (Birnstiel, Soares-Gomes, and da Gama 2019).

Water quality is an important factor influencing mussel survival and determining the success rate of the depuration process (Md Latip and Clement 2021). During the depuration process, three

mussels were found dead before the depuration process, meaning that water quality during depuration was not the cause of their mortality.

Conclusion

Brown mussels (*Modiolus modulaides*) from Tamarunang Waters, Jeneponto Regency, were contaminated with microplastics, predominantly fragments, fibers, and films. This study demonstrated that a pump-circulation depuration system combined with mashed kepok banana peel as a natural bioadsorbent effectively reduced microplastic contamination, achieving a maximum reduction of 94.132% after four days of depuration. These findings indicate that extended depuration with an inexpensive, environmentally friendly bioadsorbent can significantly improve the safety of shellfish for human consumption. The study contributes to the development of sustainable depuration technology by introducing banana peel waste as a novel natural bioadsorbent for microplastic removal. However, the experiment was conducted under controlled laboratory conditions using mussels from a single sampling location, which may limit the broader applicability of the findings. Therefore, further studies should evaluate this method under commercial-scale and field conditions, investigate its effectiveness across different shellfish species and microplastic polymers, and assess its long-term effects on shellfish quality and consumer safety. The findings are expected to support fisheries managers, aquaculture practitioners, and local governments in developing environmentally sustainable depuration practices and strategies to reduce microplastic contamination in seafood.

Declaration of conflicting interests

The authors declare no conflict of interest for the study.

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Author Contributions

Yuliati initiated and coordinated the research. Yuliati, Alfina Baharuddin, Hasriwiani Habbo Abbas, Arni Rizqiani Rusydi, and Ikhram Hardi conducted the sampling and laboratory examinations. All authors provided critical feedback and assistance in completing the research report.

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