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Sustainable depuration using environmentally friendly adsorbents as mitigation of microplastics in edible shellfish in Indonesian coastal waters

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ABSTRACT

Marine plastic pollution has led to the accumulation of microplastics in edible mollusks, which may pose a health risk to humans. Depuration offers a sustainable method for reducing microplastic content in seafood. This study investigated the efficiency of microplastic depuration in Meretrix meretrix using natural adsorbents derived from banana peels and corn cobs for 12, 24, and 48 hours. A completely randomized experimental design was applied, and microplastic concentrations were measured and analyzed using analysis of variance (ANOVA). Depuration time significantly affected microplastic removal, with the highest efficiency observed after 48 hours. The average microplastic concentration decreased from 4.27 MPs·ind^{-1} at 24 hours to 2.53 MPs·ind^{-1} at 48 hours. Both adsorbents reduced microplastic content, with corn cobs achieving greater removal than banana peels. These results indicate that agricultural by-products can serve as effective and low-cost depuration agents to reduce microplastic contamination in shellfish, providing a practical approach to improving food safety in aquaculture.

Keywords: adsorbent, depuration, microplastics, *Meretrix meretrix*, banana peels, corn cobs.

INTRODUCTION

Plastic materials are widely used across numerous applications, from everyday consumer products to high-precision technological devices. While plastic provides many functional benefits, certain types, particularly single-use plastics and packaging materials, accumulate in the environment and contribute to ecological pollution. Plastic waste discharged into rivers and oceans originates not only from coastal zones and estuaries but predominantly from urban human activities and industrial sources. Transported by river currents, these wastes reach estuaries and are subsequently carried into marine environments.

Among environmental plastic pollutants, microplastics (<5 mm) represent a critical global concern due to their persistence, widespread distribution, and potential to enter the marine food chain. Microplastics have been detected in water columns, sediments, and diverse marine organisms worldwide, raising concerns regarding ecosystem health and food safety (Moura et al., 2025). Filter-feeding organisms, including clams (*Meretrix meretrix*), are particularly prone to microplastic accumulation. Field studies in tropical and subtropical regions have documented fibers, fragments, and films of microplastics in edible clam tissues (Werorilangi et al., 2025). In Indonesia, Daud et al. (2021) reported fiber-shaped microplastics in *Nemiptus japonicas* and *Rastrelliger* sp., originating from the degradation of fishing nets, boat tarpaulins, and coastal seat covers.

Microplastics serve not only as physical pollutants but also as vectors for chemical contaminants, including heavy metals. Their large surface area and hydrophobic properties facilitate adsorption of metals such as Pb, Cu, Zn, and Cd (Barus et al., 2021). As shellfish are widely consumed as a source of marine protein, the accumulation of microplastics and associated pollutants in their tissues poses potential health risks to humans. Ingested microplastics may interact with gastrointestinal mucus and translocate into the lymphatic and circulatory systems, accumulating in organs and potentially causing adverse health effects (Smith et al., 2018; Yang et al., 2023).

Effective strategies to reduce microplastic content in marine organisms are therefore essential. Depuration, the maintenance of shellfish in clean or controlled aquatic environments, is a common method for facilitating the gradual elimination of contaminants. Previous studies indicate that depuration duration significantly affects microplastic removal, with extended periods generally associated with reduced particle abundance (Saputri et al., 2020). The efficiency of depuration may be further enhanced through integration with adsorption techniques using natural biosorbents. Agricultural by-products such as banana peels (*Musa* spp.) and corn cobs (*Zea mays*) contain high cellulose and lignocellulose content, providing functional groups (–OH, aromatic groups) capable of binding pollutants, including microplastics (Mayangsari, 2021; Vasić et al., 2023). Banana peels contain 7–12% cellulose, 6–9% hemicellulose, 6–12% lignin, and 5–10% pectin (Wani and Dhanya, 2025), whereas corn cobs exhibit higher cellulose (33–43%) and hemicellulose (26–36%) contents (Gandam et al., 2022), suggesting differential adsorption capacities.

Despite preliminary evidence indicating the potential of biomass-based adsorbents to enhance depuration (Daud et al., 2025), systematic studies evaluating the effectiveness of banana peels and corn cobs for microplastic removal in *Meretrix meretrix* are limited. Addressing this knowledge gap is critical for developing sustainable, low-cost mitigation strategies for microplastic contamination in seafood.

This study therefore aims to evaluate the effectiveness of microplastic depuration in *Meretrix meretrix* using banana peel and corn cob adsorbents over 12, 24, and 48 hours. We hypothesize that (i) the addition of natural adsorbents increases microplastic removal compared to conventional depuration, (ii) depuration efficiency is time-dependent, and (iii) corn cobs, due to their higher lignocellulose content, are more effective than banana peels. The results are expected to provide quantitative evidence for optimizing depuration protocols and contribute to the development of sustainable approaches for reducing microplastic exposure in marine food chains.

MATERIALS AND METHODS

Research design

This study used a completely randomized experimental design to evaluate the effectiveness of environmentally friendly adsorbents in improving the removal of microplastics from *Meretrix meretrix*. Two adsorbent treatments (banana peel and corn cob) and one control (no adsorbent) were tested at three cleaning durations: 12, 24, and 48 hours. Each treatment consisted of three independent replications, with 15 individuals per replication.

Study area and sampling

Meretrix meretrix specimens were collected manually from the estuarine zone at the mouth of the Tallo River, Makassar City, Indonesia (Figure 1), an area affected by dense human settlements, port activities, and small-scale industry, which are potential sources of plastic pollution. Only individuals with a shell length greater than 3 cm were selected to minimize size-related variation.

The collected mussels were immediately transported to the nearest settlement in oxygen-enriched seawater containers on the day of sampling. The depuration experiment was conducted in clay pots measuring 10.5 cm in height, 55.24 cm in circumference, and 17.6 cm in diameter (Figure 2).

Adsorbent preparation

Banana peels (*Musa* spp.) and corn cobs (*Zea mays*) are thoroughly washed with distilled water to remove surface dirt. The materials were cut into relatively uniform pieces (3 × 3 cm; acceptable range: 2–4 cm) as shown in Figure 3. Corn cobs were treated with a controlled combustion procedure to increase adsorption capacity at 500 °C for 15 minutes in an air atmosphere.

After processing, each adsorbent is weighed (400 g per experimental unit) and, if necessary, dried to a specific moisture content (10%) before being placed in the purification system. The adsorbents are then distributed evenly in the purification vessel for the microplastic removal experiment.

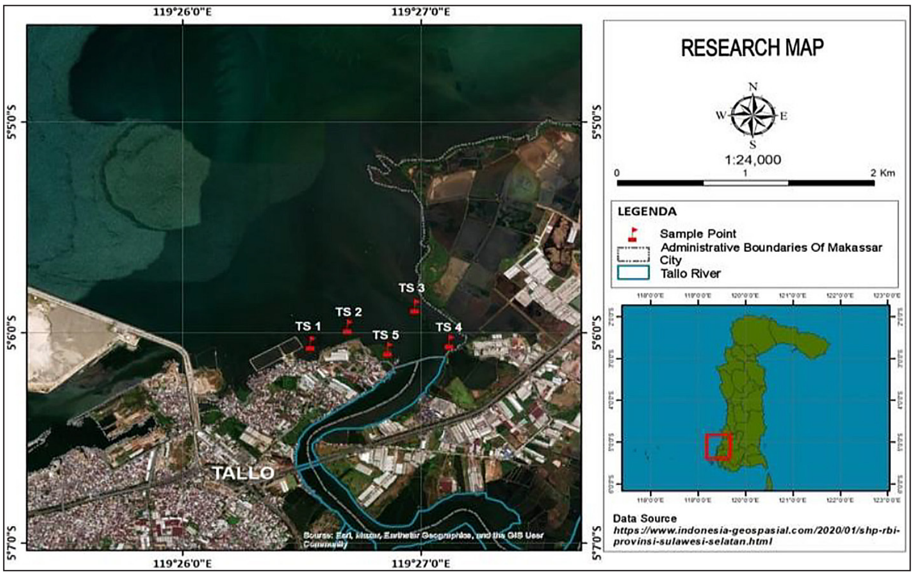

Figure 1. Map of mussel sampling at the mouth of the Tallo River

Depuration process

Depuration was carried out in earthenware containers filled with 5 L of filtered seawater (Figure 4). Fifteen mussels were randomly placed in each container. For the treatment group, 400 g of prepared banana peel or corn cobs were added, while the control group was kept without adsorbents. The pH and salinity of the water were recorded at the beginning of each experiment. Continuous water circulation and mixing were maintained using a mechanical stirrer to maximize interaction between organisms and suspended particles. Shellfish were not fed during the depuration period to prevent the introduction of additional contaminants. The environmental conditions for depuration were maintained at a temperature of 25–30 °C with a 12-hour light-dark cycle throughout the experiment. Depuration process lasted for 12, 24, or 48 hours. At the end of each depuration period, 5 shells were randomly selected for testing, rinsed gently with clean water, placed in labeled, tightly sealed containers, and transferred in a cooler to the laboratory for further analysis.

Figure 2. Depuration container

Morphometric measurements

The length, width, and height of the shells were measured using vernier calipers. Total wet weight was determined before and after shell removal using digital scales (Figure 5). To avoid cross-contamination between samples, all tools and glassware were rinsed three times with ultrapure water.

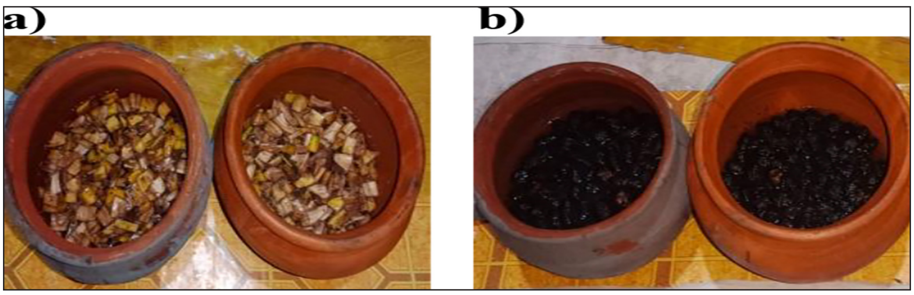

Figure 3. Depuration adsorbent: (a) banana peel adsorbent; (b) corn cob adsorbent

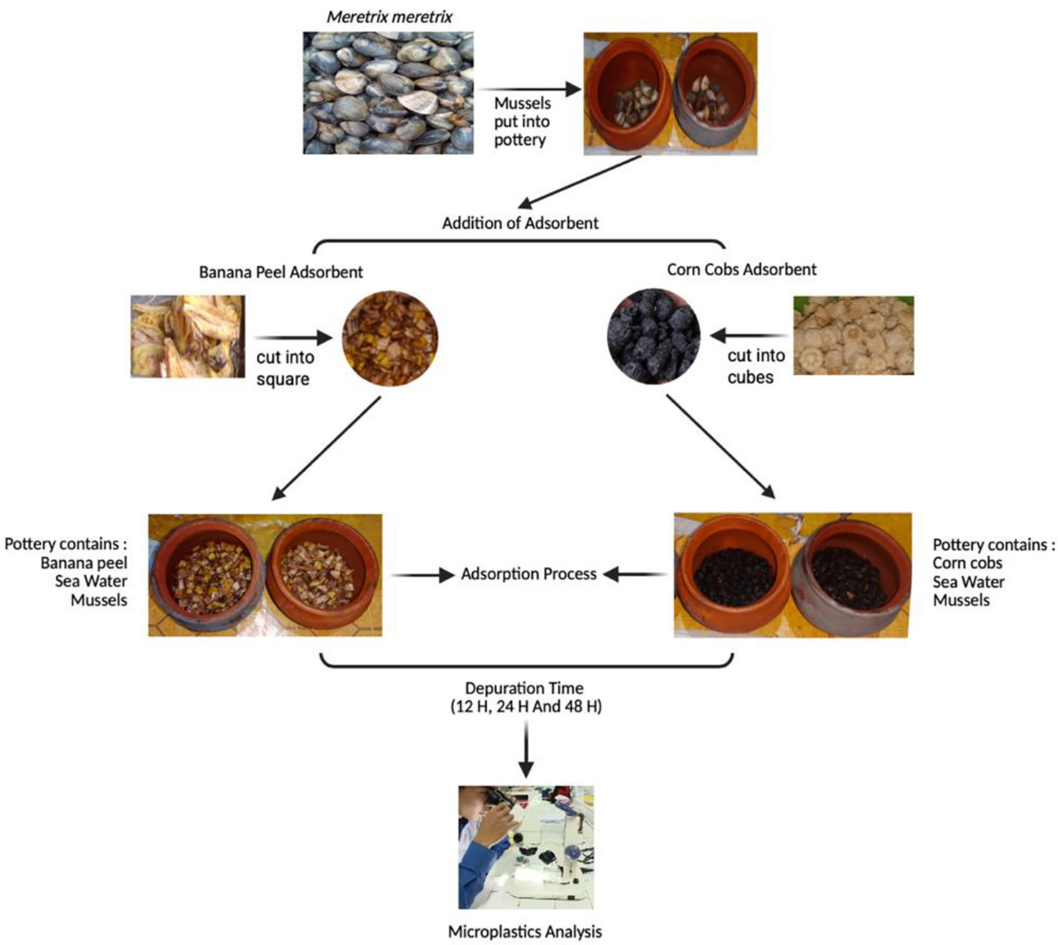

Figure 4. Illustration of the adsorbent production scheme and depuration process

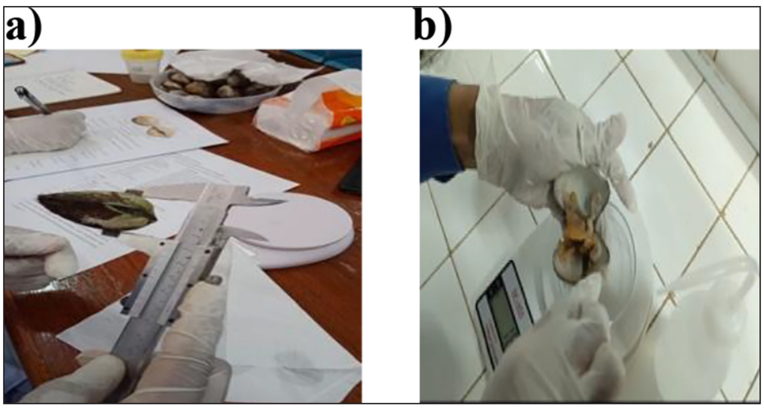

Figure 5. Morphometric tools: (a) vernier caliper; (b) digital scales

Chemical digestion

The soft tissue of the shellfish, which has been separated from its shell, is then placed in a clean, labeled sample bottle and digested using a 20% potassium hydroxide solution with a volume approximately three times greater than the volume of the tissue (Figure 6). The sample is sealed and left at room temperature for approximately two weeks to ensure that the soft tissue degrades completely.

Observation and identification of microplastics

After digestion, the residue was examined under a Carl Zeiss binocular microscope at a

Figure 6. Digestion method

magnification of up to 80×, using glass petri dishes that had been rinsed three times with ultrapure water. The sample is then poured into a glass petri dish (3–5 ml) for observation using a microscope. Particle observation is classified as microplastic based on physical characteristics, including shape, color, and surface texture. The number of particles in each sample is recorded.

Data analysis

Statistical analyses were performed using Microsoft Excel and the Statistical Package for the Social Sciences (SPSS). Descriptive statistics were calculated to summarize the frequency distribution, central tendency (mean, median, mode), and variability (standard deviation, minimum, and maximum) of the collected data. Using sampling coefficients of skewness and kurtosis, as well as the Kolmogorov-Smirnov and Shapiro-Wilk tests, we checked for normality of the sample data.

Spearman's rank correlation test was applied to evaluate the relationship between mollusk morphometric parameters and microplastic concentrations. The effect of depuration treatment on microplastic concentrations was assessed using one-way analysis of variance (ANOVA). If significant differences were found ($p < 0.05$), a post hoc Tukey's honest significant difference (HSD) test was performed to identify pairwise differences between treatment groups. All analyses were conducted at the 95% confidence level, and results are presented as mean ± standard deviation unless otherwise stated.

RESULTS AND DISCUSSION

Microplastic contamination in shellfish

The results of microscopic analysis in this study showed that 100% of clams (*Meretrix meretrix*) were found to contain microplastics. *Meretrix meretrix* contained 1–8 Mps.Ind^{-1} with a total of 152 microplastics found. There were two types of microplastics in this study, namely fiber (98.02%) and film (1.98%). Meanwhile, based on the observation results, there were six types of microplastic colors in *Meretrix meretrix* in Figure 7, ranging from the dominant color, which was blue, then black, red, transparent, green, and brown.

The quantity and type of microplastics are related to the source of pollution. At the research site (Tallo sub-district, Makassar city), microplastic pollution originated from anthropogenic

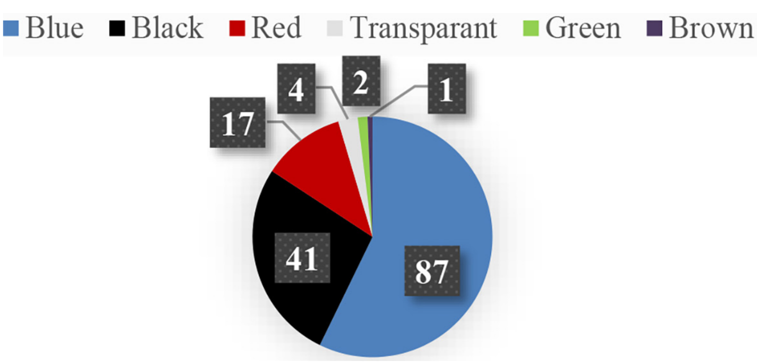

Figure 7. Color of microplastics in clams (*Meretrix meretrix*)

activities such as household waste, industrial activities, and agricultural activities. Microplastics can also originate from river flow into the sea. In addition to plastic waste from land, the high amount of microplastics is caused by industrial vessels and fishing waste, such as used nets, seaweed farming bottles, and ropes. Table 1 summarizes the reported occurrence of microplastics in various clam species worldwide, including the applied depuration durations and their respective references. It is essential to consider that methodological approaches differ among the cited studies, particularly regarding shell morphometric measurements, depuration intervals, and the evaluation of depuration efficiency. Therefore, readers are advised to refer to the original publications for comprehensive methodological details.

Morphometric characteristics of shellfish and microplastic concentration in *Meretrix meretrix*

Shell morphometric variation is influenced by various environmental factors, including water quality and food availability. Weinstein et al. (2022) highlight that body size can affect plastic particle accumulation and elimination, as larger individuals generally filter greater volumes of water and therefore experience different exposure dynamics. The relatively smaller size of *Meretrix meretrix* observed along the Makassar coast may be related to intensive harvesting pressure by local communities. In addition, domestic, industrial, and aquaculture activities around coastal zones potentially contribute to environmental degradation that may inhibit growth.Field observations indicate that marketable individuals are generally 4 to 7 cm in size, while historical records show that shell length previously reached 10–12 cm before rapid coastal development occurred. Decreased growth in bivalve mollusks is widely associated with ecological stress, including pollution, changes in nutritional regimens, and habitat modification. Food supplies such as phytoplankton, zooplankton, and dissolved organic matter, along with habitat narrowing driven by industrial and agricultural expansion near river systems, may play an important role in limiting size structure.

In this study (Table 2), morphometric measurements showed that the sampled individuals weighed between 24 and 68 g (average 45.84 ± 10.74 g). Compared to specimens reported from southern China by Zhang et al. (2023), which averaged 31.32 ± 5.37 g, the Makassar population appears to consist of heavier individuals. This difference does not directly indicate higher microplastic loads, but rather indicates differences in environmental conditions, exposure history, and filtration dynamics between regions. Therefore, susceptibility to microplastic contamination should be interpreted as the result of complex interactions between habitat quality, anthropogenic pressures, and species physiology, rather than based on body size alone.

Descriptive statistics for microplastics from three treatments (12, 24, and 48 hours) have been obtained and are shown in Table 3. Using the skewness and kurtosis coefficients, we propose the following hypotheses regarding the normality of the sample data:

Table 1. Synthesis table of microplastic depuration processes in clams worldwide

No	Country	Sample/ Population	Depuration method	Results	Ref.
1.	Brazil	*Perna perna*	Natural depuration for 93 hours in clean seawater	Microplastic content decreased by 46.8% in wild mussels and 28.9% in farmed mussels.	Birnstiel et al., 2019
2.	Italia	Mytilus galloprovincialis	Depuration for 7 days in a controlled filtration system; MP particles of 1 µm and 10 µm naturally occurring for 93 hours in clean seawater	The depuration rate is higher for small particles; depuration efficiency increases after the 7th day.	Blasco et al., 2024
3	Portugal	*Crassostrea gigas (tiram Pasifik)*	48–96 hours of depuration with clean seawater circulation	Microplastics decreased by 78% after 48 hours and 59% after 96 hours under commercial conditions.	Moura et al., 2025
4.	Indonesia	*Pilsbryoconcha exilis* (kerang kijing)	Depuration for 12–36 hours using banana peel adsorbent	Twelve hours of depuration with banana peel produced the lowest MP concentration (0.370 MPs/individual).	Daud et al., 2025

Table 2. Results of morphometric and microplastic concentrations of the Tahu Clam (*Meretrix meretrix*)

Para-meter (unit)	Sample code														
	KK 1	KK 2	KK 3	KK 4	KK 5	KP 1	KP 2	KP 3	KP 4	KP 5	KT 1	KT 2	KT 3	KT 4	KT 5
12 Hours															
Bb (g)	6	5	8	7	6	6	7	6	8	6	7	6	9	7	7
Bk (g)	46	39	58	47	44	49	48	49	62	43	65	48	55	68	42
P (cm)	4.4	4.1	4.8	4.4	4.1	4.8	5.4	5.8	6	5.5	5	4.4	4.5	4.9	4.5
L (cm)	5.4	5.2	6	5.2	5.4	5.3	4.5	4.7	5	4.6	6	5.7	5.8	6	5.7
T (cm)	3	3.1	3.4	3.2	3.1	2.3	3.3	3.3	3.6	3.5	3.5	3.2	3.3	3.4	3.1
Mp	3	6	6	4	6	2	6	3	1	4	2	1	2	2	2
24 Hours															
Bb (g)	14	12	12	12	14	14	14	16	12	9	6	15	8	10	11
Bk (g)	52	42	46	42	46	49	49	62	38	33	43	47	31	47	31
P (cm)	5.4	5.3	5.1	4.2	5.9	4.8	4.2	5	4.8	4.2	4.9	5	4.7	5	4.1
L (cm)	5.5	6	6.2	5.1	6.3	5.3	5.7	6.6	5.9	5.4	5.1	5.6	5.4	5.1	4.4
T (cm)	5.8	3	3.2	3.2	3.2	2.9	2.4	3	3	3.1	3.7	3.4	3.3	3.1	2.2
Mp	6	5	5	5	4	7	8	5	5	4	3	1	4	1	1
48 Hours															
Bb (g)	4	10	11	15	10	4	4	8	10	10	6	10	13	11	17
Bk (g)	24	33	46	62	36	28	28	40	68	41	36	38	57	48	57
P (cm)	4.5	4.2	5	6.2	4.8	4.3	5	4.2	5.1	4.5	5.4	5.2	5.6	5.4	5.1
L (cm)	5.9	5.2	6	7.3	6.3	5	5.5	5.8	7.2	5.8	6.8	6.3	7	6	7.2
T (cm)	2.3	2.2	2.8	3.3	2.5	2.1	2.2	2.2	3.3	2.1	2.7	2.3	2.2	3	3
Mp	4	4	6	3	4	2	1	2	3	2	3	1	1	1	1

Note: Bb - net weight, Bk - weight with shell, P - length, L - width, T - tall, Mp - microplastic concentration.

- Null hypothesis H0: The sample comes from a normally distributed population (skewness and kurtosis coefficients are equal to zero).
- Alternative hypothesis H1: The sample does not come from a normally distributed population (skewness and kurtosis coefficients are different from zero).

The results of the analysis are presented in Table 3. The standard errors of skewness and kurtosis indicate that for all three treatments, the value of |Z| is significantly within the range of ±1.96, so there is no reason to reject the null hypothesis for the three samples. Therefore, we conclude that the skewness and kurtosis coefficients for the three treatments are statistically insignificant, and the three treatments are most likely normally distributed. For the Kolmogorov-Smirnov and Shapiro-Wilk tests, two hypotheses are formulated as follows:

- Null hypothesis H_0: The sample data is taken from a normally distributed population.
- Alternative hypothesis H_1: The sample data is not taken from a normally distributed population.

For all experiments, there is no reason to reject the null hypothesis of normal distribution. All purification time groups (12, 24, and 48 hours) show significant values ($p > 0.05$) as shown in the Table 4. All values are above the significance level of 0.05, so H_0, which states that the data is normally distributed, is accepted and H_1 is rejected.

Based on the results of the Spearman correlation test in Table 5, morphometric parameters did not show a significant relationship with microplastic concentration ($p > 0.05$). Tissue weight, total weight including shell, length, width, and height did not show a significant correlation with the number of particles detected. The pattern is consistent with the general trend that morphometric factors are not always the main determinants of microplastic load in bivalve mollusks. Similar findings were reported by Baechler et al. (2020) in Crassostrea gigas, where body size showed no significant relationship with particle abundance ($p = 0.514$). Therefore, variations in accumulation likely reflect differences in environmental exposure, filtration activity, and individual physiological conditions rather than morphological dimensions.

Table 3. Descriptive statistics

Indicator	12 hours	24 hours	48 hours
Mean	3.33	4.27	2.53
Lower bound	2.29	3.11	1.70
Upper bound	4.37	5.42	3.37
Median	3.00	5.00	2.00
Variance	3.52	4.35	2.27
Std. Deviation	1.88	2.09	1.51
Minimum	1	1	1
Maximum	6	8	6
Range	5	7	5
Skewness	.487	-.245	.796
Std. eror skewness	.580	.580	.580
$\lvert z_{skewness}\rvert$ = Skewnes/Std. eror	0,839	-0.422	1.372
Kurtosis	-1.311	-.261	.216
Std. eror kurtosis	1.121	1.121	1.121
$\lvert Z_{kurtosis}\rvert$= Kurtosis/Std. eror	-1.169	-0.232	0.193

Table 4. Testing of normal distribution

Depuration_time	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
12	.218	15	.053	.884	15	.061
24	.182	15	.192	.918	15	.178
48	.179	15	.200*	.881	15	.054

Table 5. Spearman’s rho test result

Spearman’s rho		Bb (gram)	Bk (gram)	P (cm)	L (cm)	T (cm)	Mp
Bb (gram)	Correlation coefficient	1.000	.331*	.273	.435**	-.004	.000
	Sig. (2-tailed)	.	.026	.069	.003	.977	1.000
	N	45	45	45	45	45	45
Bk (gram)	Correlation coefficient	.331*	1.000	.441**	.279	.523**	-.038
	Sig. (2-tailed)	.026	.	.002	.064	.000	.805
	N	45	45	45	45	45	45
P (cm)	Correlation coefficient	.273	.441**	1.000	.355*	.353*	-.172
	Sig. (2-tailed)	.069	.002	.	.017	.017	.260
	N	45	45	45	45	45	45
L (cm)	Correlation coefficient	.435**	.279	.355*	1.000	-.116	-.065
	Sig. (2-tailed)	.003	.064	.017	.	.446	.671
	N	45	45	45	45	45	45
T (cm)	Correlation coefficient	-.004	.523**	.353*	-.116	1.000	.143
	Sig. (2-tailed)	.977	.000	.017	.446	.	.349
	N	45	45	45	45	45	45
Mp	Correlation coefficient	.000	-.038	-.172	-.065	.143	1.000
	Sig. (2-tailed)	1.000	.805	.260	.671	.349	.
	N	45	45	45	45	45	45

Note: Bb - net weight, Bk - weight with shell, P - length, L - width, T - tall, Mp - microplastic concentration.

Relationship between depuration time and microplastic concentration in *Meretrix meretrix*

The results of the study show that the duration of depuration affects the dynamics of the size and number of microplastics found in oysters. Table 6 shows that in the early stages of depuration, namely 12 hours, the size of the microplastics detected was relatively small, with an average of 0.44, while at 24 hours and 48 hours, the average size increased to 1.23 and 1.32, respectively. This increase in average size indicates that smaller microplastics are eliminated from the shellfish's body more quickly, so that over time, the remaining particles are dominated by larger microplastics that are more difficult to expel. This pattern is consistent with the physiological mechanism of shellfish as filter-feeding organisms that more easily expel light and small particles through the filtration process.

Meanwhile, the amount of microplastics showed a fluctuating pattern (Figure 8). At 12 hours, the average amount of microplastics was 3.33 particles and increased slightly at 24 hours to 4.27 particles before finally decreasing to 2.53 particles at 48 hours. The increase in quantity at 24 hours may be due to the redistribution of particles within the mussels' bodies, whereby microplastics that were previously located in certain parts moved to areas that were more easily detected during the analysis process. In addition, physiological variability between individual mussels and differences in particle characteristics may also influence this pattern. The decline at 48 hours indicates that the depuration process began to work more stably after the redistribution phase, allowing the mussels to expel most of the remaining microplastics.

The results of the analysis of Table 7 show that there is a relationship between the depuration time group and the concentration of microplastics (P-value = 0.045 < 0.05). This indicates that the duration of depuration significantly affects the amount of microplastics in the mussels' bodies. These results are in line with research conducted by Saputri et al. (2020), who found that the longer the depuration time (days), the fewer microplastic contaminants in Asaphis detlorata. Depuration time significantly affects the MP content in shellfish meat. In the control, 1-day, and 2-day treatments, there were no significant differences

Table 6. Average size of microplastics in mussels at each depuration time treatment

Depuration Time	Maximum	Average	Minimum	SD
	Size			
12 h	1.50	0.44	0.05	0.28
24 h	6.50	1.23	0.28	1.09
48 h	3.93	1.32	0.15	1.02

Note: SD-standar deviation.

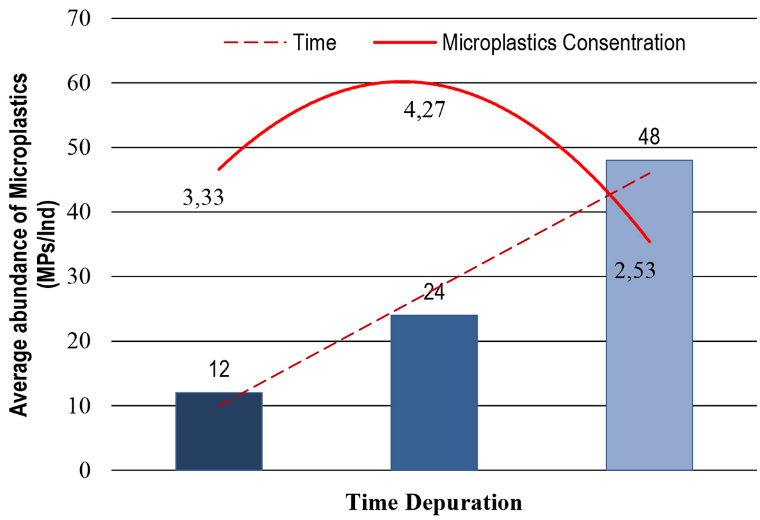

Figure 8. Average microplastics in *Meretrix meretrix*; 1 = 12 hours, 2 = 24 hours, 3 = 48 hours; source: own study

Table 7. ANOVA test result

Source of variance	Sum of squares	df	Mean square	F	Sig.
Between groups	22,578	2	11,289	3.339	0.045
Within groups	142,000	42	3.381		
Total	164,578	44			

Note: primary data 2025.

between the three, but there were significant differences between the 3-day and 4-day treatments.

The test results obtained an F value of 3.339, indicating a difference in the mean between treatment groups. Thus, depuration time significantly affects the number of microplastic particles in shellfish. The analysis was then continued with a further test to determine which groups were significantly different. Post hoc pairwise comparisons Table 8 indicated that depuration time influenced the reduction of microplastic abundance. A significant difference was observed between 24 and 48 hours of depuration ($p = 0.035$), with higher microplastic concentrations recorded at 24 hours. In contrast, no significant differences were detected between 12 and 24 hours ($p = 0.355$) or between 12 and 48 hours ($p = 0.465$). These results suggest that extending the depuration period to 48 hours provides a more pronounced decrease in microplastic loads compared with shorter treatment durations. The absence of significant differences among some intervals may indicate that contaminant elimination requires sufficient exposure time before measurable reductions become evident.

Effectiveness of banana peel adsorbent in reducing microplastic concentration in *Meretrix meretrix*

The results of this study demonstrate the effectiveness of banana peel and corn cob-based adsorbents in reducing microplastic concentrations in Meretrix meretrix. Given the increasing threat posed by microplastic contamination to aquatic ecosystems, the development of innovative and sustainable remediation strategies is becoming increasingly urgent.

Based on the diagram shown in Figure 9, it was found that mussels treated with natural adsorbents experienced a significant reduction in microplastics, while mussels without treatment did not experience a reduction in the amount of microplastics. Depuration works by keeping organisms in a controlled aquatic medium (Birnstiel, 2019). The variation in results observed in this study was influenced by the amount of microplastics accumulated, the type of adsorbent used, and the duration of depuration. Overall, the use of corn cobs showed higher effectiveness than banana peels in reducing microplastics in *Meretrix meretrix*. The efficiency of microplastic removal using corn cobs reached 66.60%, while banana peels only reached 52.38% after 48 hours of depuration. This difference indicates that the lignocellulosic structure of corn cobs has superior stability and better availability of functional groups in the adsorption process. Corn cobs are known to have high lignin and cellulose content and greater porosity, which contribute to an increase in specific surface area and enable more effective interaction with negatively charged microplastic particles (Radenković et al., 2025). The lignin content also provides thermal resistance and structural rigidity that minimizes

Table 8. Tukey HSD test result

(I) Depuration time	(J) Depuration time	Mean difference (I-J)	Std. error	Sig.	95% Confidence Interval	
					Lower bound	Upper bound
12 hours	24 hours	-.933	.671	.355	-2.56	.70
	48 hours	.800	.671	.465	-.83	2.43
24 hours	12 hours	.933	.671	.355	-.70	2.56
	48 hours	1.733*	.671	.035	.10	3.36
48 hours	12 hours	-.800	.671	.465	-2.43	.83
	24 hours	-1.733*	.671	.035	-3.36	-.10

Note: primary data 2025.

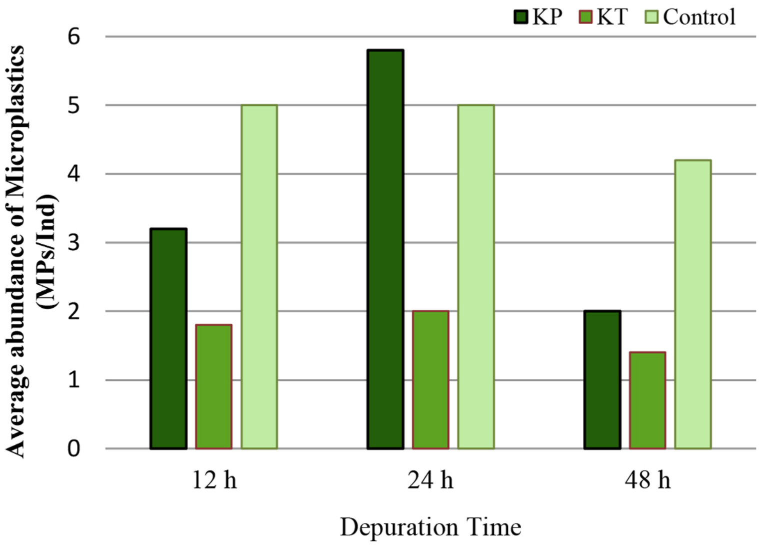

Figure 9. Effectiveness of banana peel (KP) and corn cob (KT) adsorbents in depuration

degradation during the depuration process (Vasić et al., 2023). In contrast, the adsorption effectiveness of banana peel decreases with increasing depuration time. This is related to the degradation of pectin and hemicellulose components, which causes surface instability of the material during repeated exposure to seawater (Ong et al., 2021). Physical damage to the surface also reduces the number of active sites for absorption, thereby decreasing depuration efficiency in *Meretrix meretrix* (Jahin et al., 2024). The decrease in the ability of banana peels to bind microplastics can also be caused by adsorbent saturation, when all active sites are filled, thereby reducing adsorption capacity. This condition can trigger desorption, namely the release of microplastic particles back into the depuration medium, which ultimately increases the amount of microplastics that could potentially re-enter the shellfish's body. The degradation of the adsorbent structure and the variability of material quality and experimental conditions also contribute to the observed fluctuations in microplastic concentration.

In general, the findings of this study are consistent with the reports by Supanchaiyamat et al. (2019) and Agustin et al. (2022), which state that lignocellulose-based adsorbents with high lignin content have better thermal stability and structural rigidity, thus offering greater and more stable adsorption capacity for both organic and inorganic pollutants. Thus, corn cobs are recommended as an effective natural adsorbent for microplastic depuration applications in aquatic organisms. Based on the comparison results in Figure 10, the use of banana peel and corn cob adsorbents in the Meretrix meretrix depuration process has been proven to reduce microplastic concentrations and directly improve food safety for consumers. However, the depuration technique used still requires further development because microplastics are still detected even after 48 hours of depuration.

Shellfish are organisms that are highly susceptible to microplastic (MP) contamination, as these particles can accumulate in the digestive tract, disrupting filtration and nutrition processes, and potentially being internalized into body tissues. Microplastics, which are <5 mm in size, are persistent pollutants that can survive for long periods in aquatic environments and interact with various biotic and abiotic components. In addition to being physical contaminants, microplastics also serve as vectors for toxic pollutants such as heavy metals and persistent organic compounds, thereby increasing the risk of toxicity to aquatic organisms (Ma et al., 2023). Phytoplankton, zooplankton, and bivalves can accidentally consume microplastics through filtration mechanisms, and such exposure has been linked to physiological disturbances, oxidative stress, decreased enzyme activity, and tissue damage in vital organs such as the gills and digestive system (Pal et al., 2025).

Over time, microplastics ingested by lower trophic level organisms can be transferred to higher trophic level organisms through predation. This mechanism, known as trophic transfer or biomagnification, leads to increased microplastic accumulation in top predators. Field studies in coastal areas of Asia show that commercial fish

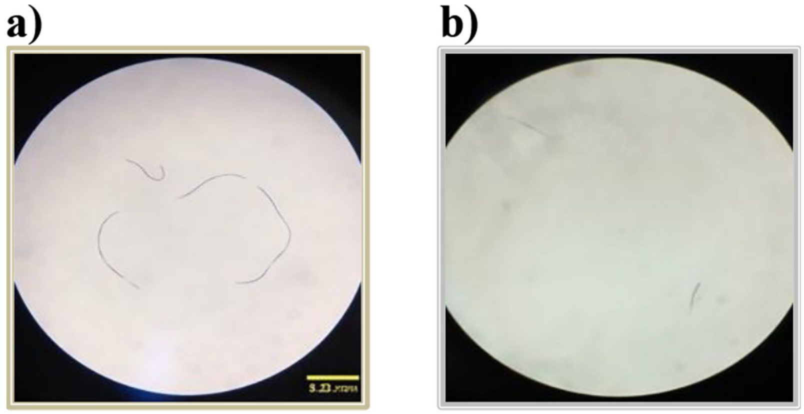

Figure 10. Sources of microplastics: (a) without depuration, (b) with depuration

that feed on zooplankton and bivalves have higher concentrations of microplastics than their prey, indicating cross-trophic accumulation (Cañón et al., 2025). In addition to physical impacts, microplastics also carry adsorbed toxic substances such as bisphenol-A and phthalates, which can cause immune, endocrine, and metabolic disorders in aquatic organisms (Gao et al., 2024).

In humans, exposure to microplastics occurs mainly through the consumption of seafood, drinking water, and inhalation of airborne particles. Microplastics have been detected in blood, lung tissue, and even the placenta, demonstrating their ability to penetrate biological barriers (Morgan et al., 2024). This evidence reinforces the suspicion that microplastics can bioaccumulate in the human body, especially nano-sized particles that are able to enter the blood and lymphatic systems. Toxicology and epidemiology studies also indicate that chronic exposure to microplastics can trigger oxidative stress, systemic inflammation, and hormonal disorders that can potentially affect cardiovascular, respiratory, and reproductive functions. These effects are thought to be related to the physicochemical properties of microplastics, which allow them to bind heavy metals and harmful additives, which then interact directly with human cells and tissues (Zuri et al., 2024).

Although research on the implications of microplastics on human health is still developing and has not yet produced definitive conclusions, various findings have shown that microplastics are toxic to cells and can act as carriers of pathogenic microorganisms and chemical pollutants, including heavy metals. The main routes of microplastic entry into the human body include food consumption, inhalation, and dermal contact.

CONCLUSIONS

This study revealed that shellfish collected from the coastal waters of Makassar were contaminated by microplastics, predominantly in the form of fibers and films. The application of banana peel and corn cob–based adsorbents was shown to effectively decrease microplastic burdens in edible bivalves, achieving a reduction efficiency of 66.60%. The most favorable depuration duration was identified as 48 hours. The highest mean microplastic abundance was observed after 24 hours of depuration (4.27 $MPs \cdot ind^{-1}$), whereas the lowest value was recorded at 48 hours (2.53 $MPs \cdot ind^{-1}$). Correlation analysis indicated that morphometric characteristics were not significantly associated with microplastic concentrations in *Meretrix meretrix*. In contrast, depuration time exhibited a significant relationship with particle abundance. The utilization of banana peels and corn cobs as biosorbents during depuration therefore represents an effective and environmentally sound approach for mitigating microplastic contamination in shellfish intended for human consumption. Such investigations are expected to contribute to efforts aimed at limiting dietary exposure to microplastics. Nevertheless, further studies are required to optimize depuration conditions and to identify the most efficient types of adsorbents.

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