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Development of Eco-Friendly Microplastic Removal Filter For Sea Salt Farm

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Abstract: *The increasing contamination of microplastics (MPs) in marine environments poses significant risks to aquatic ecosystems and human health, particularly in sea salt production. This study aimed to develop a sustainable coconut coir filter to remove MPs from seawater at sea salt farms. Experiments were conducted using a batch glass column (10 cm × 10 cm × 40 cm) containing cleaned Coconut coir, supported by layers of gravel (10 cm) and sand (4 cm). In order to establish optimum performance, three variables were tested: fiber length (short: 2-5 cm vs. long: 6-29 cm), packing density (37-148 g/dm), and thickness (3-5 cm). The essential performance indicators were MP removal efficiency, salinity stability, and flow rate of effluents. The results showed that salinity did not decrease across all experiments. The optimal length of coconut coir is short fibers (2-5 cm), which performed significantly better than long fibers, achieving 90% removal efficiency versus 45% with long fibers. It was established that the optimal filter setup was a density of 111 g/dm^3 and 3 cm thickness, which had a removal efficiency of over 90 percent and a flow rate of 0.045 dm^3/s. Results demonstrated high removal efficiencies across all tested polymers and concentrations (1-10 mg/L), with performance improving at higher MP concentrations. The efficiency of removal was polymer-dependent (300 μm -1 mm) and was in the following order: PS (92 -98%), PP (90 -97%), and PET (87 -95%), which was attributed to differences in polymer hydrophobicity and surface chemistry. These findings indicate that coconut coir, particularly short fibers, is an effective and eco-friendly solution for mitigating microplastic contamination in sea salt, which provides a promising approach to enhancing environmental sustainability and food safety in marine-based industries.*

Keywords: Coconut coir; Coconut filter; Microplastic; Sea salt farm

1. INTRODUCTION[1]

Microplastics (MPs, <5 mm) are pervasive pollutants in marine ecosystems, originating from the degradation of plastics, synthetic textiles, and industrial waste. Larger plastic items, including textiles and cosmetics, break down into tiny pieces known as microparticles. Various factors, including temperature, physical and chemical interactions, and exposure to UV light, influence this process. Around 51 trillion plastic particles can be found spread across the surface waters of the globe [1], [2]. It has become a pressing global concern, infiltrating various environmental compartments, marine ecosystems, and humans [3]. The occurrence and impact of MPs in commercial sea salts that humans consume have not been well studied so far [4].

Salt is a product from the ocean that humans consume. Depending on its origin, salt is categorized into various types, including sea, lake, rock, river, and well salts. Sea salts are the most common type of salt available and consumed worldwide [5, 6, 7]. Recently, a major issue surrounding the quality of sea salts has been the presence of microplastics (MPs) in salt products, because they are made by evaporating seawater and forming salt crystals [8], and is well known that the marine environment (sea and ocean) is the world's largest receiver of mismanaged plastic waste [9]. Research in various countries indicates that sea salt has been contaminated with MP [10]. Expensive and non-biodegradable, conventional filtration techniques like membrane-based systems call for sustainable substitutes.

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Coconut coir, in particular, is noteworthy due to its porous structure, high surface area, and low cost, making it a sustainable, renewable resource suitable for large-scale use [11]. The coir fiber is the most robust and resistant among all naturally occurring commercial fibers. A low decomposition rate is the key advantage for making durable products [12]. Coconut coir has multiple beneficial characteristics that render it highly effective for eliminating microplastics. Its fibrous nature allows for adsorption over a wide area, enabling effective trapping and retention of microplastics. Additionally, coconut coir is hydrophilic, meaning it has a strong affinity for water, facilitating the capture of microplastics suspended in wastewater. Coir fibers have a rough, multi-layered surface with natural pores that mechanically entangle MPs [13]. Additionally, coconut coir is capable of decomposing naturally and presents low ecological hazards when contrasted with artificial adsorbents typically utilized in the treatment of wastewater. Several research projects have explored the effectiveness of materials derived from coconuts in the field of wastewater management. For instance, Kasmuri et al. and [14] investigated the utilization of a mixture of coconut fiber and rice fiber as activated carbon for the treatment of wastewater.

This study aims to evaluate the efficacy and feasibility of using coconut coir in expediting microplastic removal within sea salt production processes. It meticulously examined the capabilities of coconut coir in removing diverse types of microplastics across various operational scenarios, with a specific focus on comparing the microplastic removal efficiency between short (2–5 cm) and long (6–29 cm) coconut coir fibers.

2. METHODOLOGY

2.1 Method framework

This study was conducted by a selected sea salt field in Kampot Province, Cambodia's largest sea salt production site. To conclude this research, we limited the scope of our study to initial fieldwork encompassing macroplastic monitoring and seawater and sea salt sampling for microplastic analysis at the designated study site (the sea salt farm in Kampot Province). The subsequent analysis verified the presence of microplastics in both the seawater and the sea salt. Following this confirmation, the development of the EMRF was executed, as illustrated in **Fig. 1**.

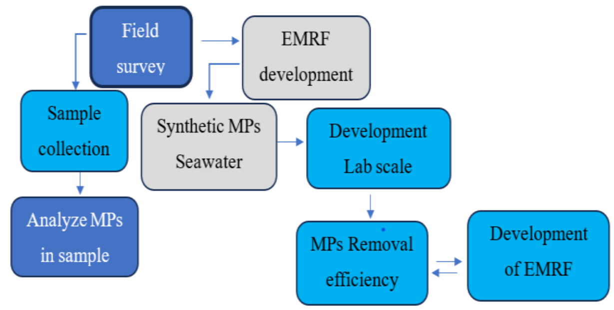

Fig. 1. Method Framework

2.2 Material Preparation

To ensure the reliability and reproducibility of experimental outcomes, a protocol was adopted a set of procedures was established for preparing coconut coir, incorporating treatment methods to reduce variations in material characteristics across different batches. The pre-treatment process began with washing the coconut coir thoroughly to remove any dirt and debris. This was done using tap water. The washed coconut coir, both short and long length ranges from (2–5 cm) and (6–29 cm) respectively, was then dried in an oven at 60 ◦C for 24 hours to reduce moisture content and prevent mold growth. Once dried, the coconut coir is weighed, then put into the column and compressed with pressure to obtain coconut coir fibers of uniform size and thickness. Lastly, the width, length, and height of the coconut coir are noted to calculate its density.

2.3 Experimental set-up

In the experimental setup, batch systems were employed to investigate the efficacy of microplastic removal using coconut coir fibers within a glass column (10 cm in diameter and 40 cm in height). Synthetic materials contaminated with microplastics were treated under natural gravity conditions. The filter was constructed sequentially with distinct layers, starting with supporting layers at the base consisting of 10 cm of gravel and 4 cm of coarse sand to prevent coconut coir debris from entering the treated water. The coconut coir fibers were positioned on top of the sand, serving as the main filtration medium, and covered by a 1 cm layer of gravel to ensure the stability of the core filtration bed during filtration (Fig. 2).

The columns were then filled with 1 L of synthetic MP seawater (31 g NaCl dissolved in 1 L of DI water) containing microplastics ranging from 300 µm to 1 mm. In this study, MPs of polypropylene (PP) were selected as adsorbents due to their high detection frequency and potential toxicological effects in aquatic environments [15].

The coir fibers were incorporated into the experimental setup, and the effluent rate will be measured. Coconut coir removes MPs through physical filtration (trapping in fibrous matrix) and adsorption (hydrophobic interactions, electrostatic forces) [16]. While proceeding with the experiment, the effluent concentration of MPs and salinity were monitored continuously. Experiments were replicated twice, and statistical analysis techniques were employed to quantify variability and assess the importance of noted differences, guaranteeing thorough data evaluation. These efforts collectively aimed to control potential variable sources and enhance the reliability of results.

Fig.2 below shows an experimental setup. For the lab-scale experiment, glass has been chosen as a container to avoid using plastic material.

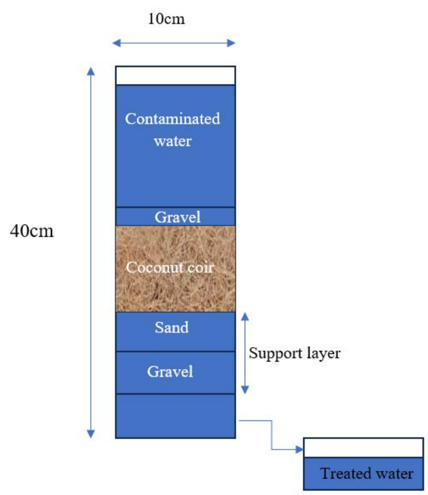

Fig. 2. Experimental set-up

2.4 Analytical method

The density of coconut coir is studied to determine microplastic capture efficiency, where different packing densities can create varying filtration efficiencies [17]. Researchers aim to find the optimal density that maximizes the removal of microplastics while maintaining an acceptable flow rate for the sea salt production process by using Eq.1.

Density $$\rho = \frac{m}{V} \quad \text{(Eq. 1)}$$

where ρ is the packing density of coconut coir (g/dm^3), m is the mass of coconut coir used(g), and V is the volume of the compressed coconut coir layer in the column (dm^3).

In addition to density, the flow rate analysis is conducted to determine the filter's performance and practical application, such as filter efficiency capacity, to assess how much seawater can pass through the filter per unit of time while effectively removing microplastics. This determines the filter's throughput and overall processing capacity, with ease of optimization for filter improvements without significantly slowing down the process. This helps in achieving maximum microplastic removal efficiency with a balance between effective filtration (small enough pores to catch microplastics) and maintaining an acceptable flow rate for field application.

Flow rate: $$Q = \frac{V}{t} \quad \text{(Eq. 2)}$$

where Q is the flow rate of discharged effluent (l/s). V is the volume of discharge water (l). t is the discharge duration (s).

The microplastic removal efficiency of the filter was determined by comparing the concentrations of microplastics in the effluent with the initial concentrations. Moreover, the percentage of removing MPs concentration using the formula by equation with

Removal efficiency: $$Re\ \% = \frac{C_i - C_f}{C_i} \times 100 \quad \text{(Eq. 3)}$$

where, Re is the removal efficiency of microplastics by coconut coir $(\%)$. C_i is the initial concentration of microplastics in contaminated water or synthetic seawater (mg/l). C_f is the final concentration of microplastic after passing through the coconut coir (mg/l).

2.5 Microplastic Analysis

There is a multi-step process of microplastic analysis involved. Begin with sieving of the treated effluent through a 146 µm pore size sieve to isolate particulate matter. The filtered residues were then rinsed using DI water before oxidation with hydrogen peroxide (H_2O_2) solution. If the residues are rich in organic matter from coconut coir, then the density separation is carried out. Finally, the supernatant is filtered through a 0.45 µm pore size cellulose nitrate filter paper before calculating the removal efficiency by using Eq. 3.

3. RESULTS AND DISCUSSION

3.1 Effect of coconut coir length on MP removal

Table 1. shows the study compared short (2–5 cm) and long (6–29 cm) coconut coir fibers, revealing a significant difference in MP removal efficiency; short fibers achieved 90% removal, while long fibers only reached 45%. This disparity can be attributed to the higher surface area per unit mass, enhancing interactions with MPs, and increasing adsorption capacity for fine particles [13], where long coir had faster flow but lower retention, indicating larger pore spaces. Long coir has faster flow but lower retention aligns with hydraulic studies on natural fiber filters [18]. Short

fibers have a higher chance of being trapped within the coir's irregular pore structure. Long coir may bridge gaps between coir fibers, allowing them to pass through more easily, and Short coir has more exposed surface area per unit mass, increasing interactions with coir fibers [19]. The short coir was chosen to perform an optimal density test.

Fig.2. shows the removal efficiency of coconut coir at different lengths (short and long coconut coir)

Table 1. Effect of Coconut Coir Length on MPs Removal Efficiency

Coconut Coir	Mass of Coconut coir(g)	Height (cm)	Density (g/dm^3)	Re(%)
Short	10	1	111	54
	30	3	111	90
Long	10	1	111	23
	30	3	111	45

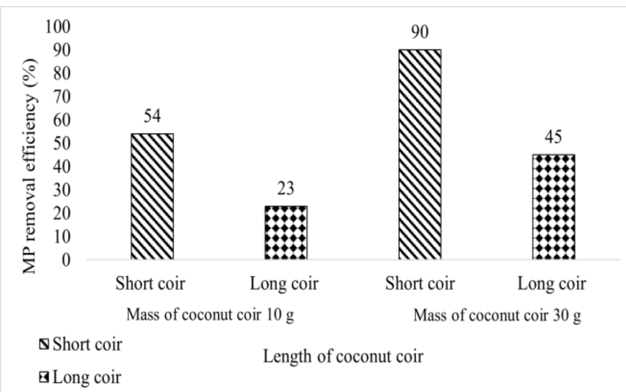

Fig. 3. Removal efficiency of coconut coir at different lengths

3.2 Optimal density

After obtaining the optimal result of coconut coir, Table 2 shows the optimal density that provides the best performance in removing MPs. At 111 g/dm^3, up to 90% of MP removal was achieved with 30 g of coconut core used. At 111 g/dm^3, the flow rate is 0.045 L/s, which was an optimal flow rate among all density operation conditions. There remains a limited body of literature examining the removal efficiency of coconut-based filter media, particularly concerning density variations and their impact on filtration performance [20], [21]. Current research on the density-dependent removal efficiency of coconut-based filters appeared to be insufficient, highlighting a gap in the literature that warrants further investigation. Additional studies are needed to explore how variations in filter density influence contaminant removal effectiveness. In this study, at a density of 148 g/dm^3, a removal efficiency of more than 90% was achieved, but the flow rate decreased. Moreover, the process of manually compacting the coconut coir in the column is rather difficult.

Table 2. Effect of Coconut Coir Density on MPs Removal Efficiency

Mass of coconut coir (g)	Height of coconut coir (cm)	Density(g/dm^3)	Q (L/s)	Re(%)
10	3	37	0.07	30
20	3	74	0.059	40
30	3	111	0.045	90
40	3	148	0.032	>90

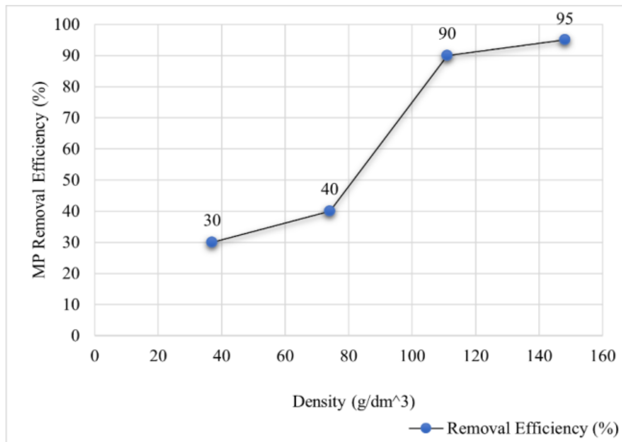

Fig. 4. Removal efficiency with the density of coconut coir

3.3 Optimal thickness

Table 3 shows the effect of coconut coir thickness on removal efficiency, which varied from 1cm, 3cm, and 5 cm, with removal efficiency ranging from 30 %, 90 %, and higher than 90 % respectively. Higher than 90% removal efficiency was achieved, similar to Ganesan et al.'s 2023 study, which focused on optimizing column height for microplastic filtration using coconut coir, found that a 5 cm thickness (at 100 g/dm^3 density) removed 92% of microplastics (MPs), compared to 75% removal at a 2 cm thickness. This indicates that increasing the depth of the coir filter significantly enhances microplastic removal efficiency. Increasing coir weight (e.g., 30g to 50g) likely improves removal efficiency due to higher density and with more contact opportunities with MPs. However, the 3 cm thickness provided sufficient time and removal capacity for MPs to be captured effectively, which is 90%, considering the flow rate. Moreover, the salinity did not decrease in all experiments.

Table 3. Effect of Coconut Coir Thickness on MPs Removal Efficiency

Mass of coconut coir (g)	Height of coconut coir (cm)	Q (L/s)	Re(%)
10	1	0.06	30
30	3	0.045	90
50	5	0.04	>90

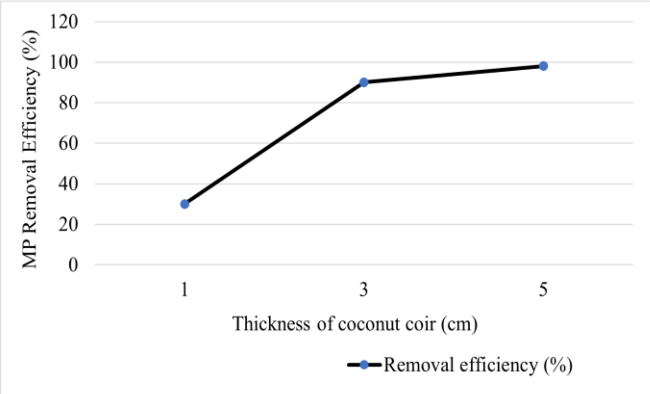

Fig 5. Removal efficiency with different thicknesses of coconut coir

3.4 Variation of the removal efficiency of coconut coir in different types of MP

After obtaining the optimal condition of coconut coir in Tables 1, 2, and 3, coconut coir with mass 30 g at a density of 111 g/dm^3, and a thickness of 3 cm is chosen as the optimal condition while considering the flow rate. Table 4 presents data on the variation of the removal efficiency of coconut coir in removing two types of MP, polypropylene (PP), polyethylene terephthalate (PET), and Polystyrene (PS). Three different concentrations of MP were studied, using 1, 5, and 10 mg/l. The data demonstrated a clear positive correlation between initial MP concentration and removal efficiency (Re%) for all polymers tested. The removal efficiency for PP increased from 90% at 1 mg/L to 97% at 10 mg/L. A similar trend was observed for PET, with efficiency rising from 87% to 95%, and for PS, which showed the highest efficiencies, increasing from 92% to 98% across the same concentration range. This enhancement in performance at higher particle loads suggests that filtration and adsorption mechanisms become more effective as the availability of MPs increases, potentially due to a higher probability of particle-fiber interactions and the formation of a particle layer that aids in trapping additional MPs[22]. PP was removed more efficiently (90–97%) compared to PET (87–95%) across all tested concentrations. The difference may be attributed to surface chemistry, hydrophobicity, and particle size, while the variation in trapped MP concentrations depends on polymer type, size, shape, and environmental conditions [23]. PP is more hydrophobic, allowing stronger interactions with coconut coir fibers [24]. PET, being slightly more polar, may have weaker adsorption. Therefore, this result highlighted the potential of coconut coir as a green filtration material for MP removal, with PP showing slightly better removal rates than PET. Compared to the study of Zharkeno et al., there was a significant enhancement in the effectiveness of removal. This is related to the difference in size of MP used in the experiment, which ranges from 100 µm to 500 µm, smaller than that of this study, where the pristine MP used ranges from 300µm to 1mm [19, 22]. Further optimization (e.g., chemical modification of coir) could enhance PET removal efficiency. Compared to polyethylene terephthalate (PET) and polypropylene (PP), PS is generally less dense (1.05 g/cm³), which may facilitate its retention within the coir fibers [23]. The consistently high efficiency observed in this study strengthens the case for coconut coir as a practical material for large-scale microplastic remediation in aquatic systems and salt production processes.

Table 4. Variation of the removal efficiency of coconut coir in removing MPs

MP type	Mass MP (mg)	Re(%)
PP	1	90
	5	92
	10	97
PET	1	87
	5	91
	10	95
PS	1	92
	5	96
	10	98

4. CONCLUSION

The study has illuminated the significant role of coconut coir in addressing the pervasive challenge of microplastic pollution in seawater. Through meticulous experimentation and analysis, we have uncovered the microplastic removal ability of coconut coir under various conditions. Notably, the use of short coconut coir (2cm to 5cm), as an optimal parameter led to a substantial increase in both specific surface area and pore volume, with typical values rising from 54 % to 90 % better than the long coir's removal efficiency. The optimal density of coconut coir was obtained at 111 g/dm^3, with a thickness of 3cm, a removal efficiency is up to 90 %, and an effluent flow rate of 0.045 dm^3/s. The efficacy of this optimized filter was demonstrated across three prevalent MP types. For polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS), removal efficiencies were consistently high across tested concentrations (1, 5, and 10 mg/L), ranging from 87% to 98%. Notably, PS exhibited the highest removal rates (92% to 98%), followed by PP (90% to 97%) and PET (87% to 95%). This hierarchy underscores the influence of polymer-specific properties, such as hydrophobicity, on the filtration mechanism. Remarkably, the coconut coir filter achieves these notable results in removing microplastics from synthetic seawater, a controlled and ideal setting without decreasing salinity content. This key finding points to a bright direction for implementing coconut coir filters in sea salt farms, where preserving salinity is critical. Therefore, these findings highlight the potential of coconut coir, particularly short fibers, as an effective and eco-friendly solution for mitigating microplastic contamination in sea salt production. This research ultimately provided a promising, sustainable approach to enhancing environmental health and food safety in marine-based industries.

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