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Research Paper

# Combination of Biochar and Polyurethane Media in a Series-Connected Filtration Column for Microplastic Removal and Effluent Toxicity Testing

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**Abstract**

This study aimed to evaluate the efficiency of microplastic removal using filtration media composed of coconut shell biochar and polyurethane sponge, as well as to assess the potential toxicity of the filtered water on feed consumption efficiency in Nile tilapia (*Oreochromis niloticus*) and microplastic bioaccumulation by fish. The filtration system had a diameter of 10 cm, employed an upward flow configuration, and operated at a flow rate of 30 mL/min. Optimization was conducted using an artificial solution containing microplastics through two series-connected filtration columns with a media thickness of 40 cm. Toxicity tests on the filtered water were performed on Nile tilapia using feed efficiency and the fish's bioaccumulation capacity of microplastics as parameters, with fish sized 4-5 cm. Results showed that the highest microplastic removal efficiency for the first and second filter averaged 79% and 93%, respectively. Toxicity tests based on feed efficiency showed favorable percentages in experiments using the effluent from the second series column filter compared to the first series, even though the fish feed efficiency of both water effluent was decrease in day 14. The highest microplastic accumulation was observed in the digestive tract, followed by the fish gill, and fish muscle subsequently. The bioaccumulation factor (BAF) value of microplastic in fish was less than 1, indicating a low level of bioaccumulation. This study demonstrates that the combination of coconut shell biochar and polyurethane sponge in two series of filtration has strong potential as an effective, economical, and accessible solution for microplastic filtration in water treatment.

**Keywords**

Coconut Shell Biochar, Filter, Microplastics, Nile Tilapia, Polyurethane Sponge

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## 1. INTRODUCTION

An irrigation canal in Padang City is widely used by the local community to irrigate fish ponds, especially for tilapia farming. The numerous daily activities in the irrigation canal, such as tourism, bathing, washing, defecation, and vehicle washing, are the cause of microplastic pollution due to the disposal of plastic, metal, rubber, paper, textile, and other waste into the irrigation water. These microplastics in the water can be ingested by aquatic organisms, including fish. Microplastics can be swallowed or get trapped in fish gills, posing a threat to their survival (Edwin et al., 2023). Microplastics are plastic particles with a diameter of 0.3 to 5 mm and take a long time to degrade. Even the biodegradable plastic needs around 70 days to degrade (Permana et al., 2023). Microplastics can have adverse effects on the environment because they act as a vector for harmful contaminants like polycyclic aromatic hydrocarbons and persistent organic pollutants (Conesa, 2022).

Biochar derives from agricultural wastes is an easily accessible and environmentally friendly material that shows potential for removing pollutants like nutrients and also microplastics from wastewater through filtration mechanisms (Bautista Quispe et al., 2024; Edwin et al., 2025a). Edwin et al. (2024) found that nutrients from irrigation wastewater can be removed using a filter with coconut shells biochar and polyurethane sponge in a 2:1 ratio as a medium. However, the ability of this filter to remove microplastics has not been previously studied. Filtration using a series column arrangement also allows the solution to interact with the filter media in stages, making it more efficient in removing contaminants due to the longer contact time required (Edwin et al., 2025b).

Despite the fact that filters are designed to remove contaminants, they may produce toxic byproducts. Therefore, it is essential to ensure that filters pose no risk to aquatic organisms and humans through toxicity testing. One measurable response in aquatic organisms is a change in feed efficiency. Additionally, due to their extremely small size, microplastics may pass through the filter and still be taken up by test animals, leading to bioaccumulation. Wastewater filtration systems must be ecologically and health-safe. Therefore, toxicity studies are crucial to conduct. Therefore, this study aims to analyze microplastic removal using coconut shell biochar and polyurethane sponge filters in series and to analyze the toxicity of the filtered water to tilapia based on parameters of feed efficiency and microplastic bioaccumulation.

## 2. EXPRIMENTAL SECTION

### 2.1 Materials

The sample in the filter experiment was artificial irrigation water containing microplastics. The microplastic sample was made from degradable plastic bags that had been shredded. This type of plastic bag was chosen because it is assumed to fragment into microplastics more quickly in the environment than non-biodegradable plastics. The microplastic samples were prepared by cutting the plastic bags with scissors to form small plastic fragments. The ground samples were then sieved using 5 mm and 0.3 mm sieves. The microplastic concentration in the artificial water was the same as in irrigation water, around 400 Particles/L.

The filter installation was carried out at the Environmental Engineering Research Laboratory. The filter installation consisted of a filter column and an influent storage tank. The filter column was made of a 10 cm diameter PVC pipe filled with coconut shell biochar and polyurethane sponge with a ratio of 2:1. Before used, the coconut shells were pyrolyzed at a temperature of 300 °C for approximately 3 hours during the burning process, then the coconut shell biochar was cut into coarse pieces measuring approximately 0.5×0.5×0.3 cm. A polyurethane sponge was used to extend the residence time of the flow and even it out. The sponge size was ± 0.5×0.5×0.5 cm (Edwin et al., 2024). Water samples were pumped upward through the filter using a series configuration consisting of two columns with a media thickness of 40 cm and a biochar-to-sponge. The flow rate was set at 30 mL/minute using a dimmer. The experiment was conducted in duplicate over 14 days. The effluent from the first and second series of filters was also collected for toxicity testing.

### 2.2 Biochar Morphological Analysis

The physical characteristics of each biochar were observed using a Hitachi S-3400N Scanning Electron Microscope-Energy Dispersive X-ray (SEM-EDX) equipped with a Hitachi E-1045 ion sputter to obtain an overview of its surface morphology.

### 2.3 Microplastic Concentration Analysis

Microplastic analysis of water samples using the gravimetric method (Masura et al., 2015). This method is common for analyzing microplastic concentrations in water samples. The materials required include Fe(II), 30% $H_2O_2$, and NaCl. The sample destruction process can be summarized as follows: 200 mL of the sample is placed in a 500 mL beaker. Filter the sample using a 5 mm and a 0.3 mm sieve. Add 20 mL of 30% $H_2O_2$ and $FeSO_4$. Heat to 75 °C. Add 200 mL of saturated salt solution and homogenize. Allow to settle until a supernatant and precipitate form. The supernatant is filtered using Whatman filter paper with the aid of a vacuum pump. Microplastic concentration analysis is performed using a microscope. Microplastic concentration analyzed on days 3, 5, 7, 9, 11, and 14 over a 2-week period. Microplastic concentration was calculated using Equation 2, and separation efficiency was calculated using Equation 1.

$$\mathrm{MP} = \frac{\text{Number of Microplastic Particles (particles)}}{\text{Volume of Filtered Water (L)}} \tag{1}$$

$$\mathrm{Eff}\,\% = \frac{C_{\mathrm{in}} - C_{\mathrm{out}}}{C_{\mathrm{in}}} \times 100\% \tag{2}$$

Where: $C$ is the concentration of microplastics (Particles/L), $C_{\mathrm{in}}$ is the concentration of microplastics in the influent, and $C_{\mathrm{out}}$ is the concentration of microplastics in the filter effluent (Particles/L).

### 2.4 Filter Effluent Toxicity Test

The toxicity test used fish tanks measuring 35×30×30 cm, each consisting of an aquarium containing tap water as a control experiment and two aquariums containing effluent from series 1 column filters and water from series 2 column filters. The number of Tilapia to be tested for toxicity is 15, with 5 fish in each tank, with the size of 4-5 cm in size. Tilapia were fed daily with pellet fish food. The feed amount was 5% of the fish's body weight, totaling 1.25 g per day, divided into two meals of 0.625 g each in the morning and evening. The fish tanks were continuously aerated to ensure the fish's survival.

Microplastic concentration analysis in fish is performed by dissecting the fish and separating each part of the fish as a sample. In this study, microplastic concentration was analyzed to muscle, gill, and digestive tract of fish. The bioaccumulation factor (BAF) value was calculated to determine the amount of microplastics accumulated in fish organs compared to their environment. A BAF value greater than 1 indicates the potential for bioaccumulation under steady-state conditions (Elawady et al., 2026). To calculate the bioconcentration factor of microplastics using Equations 3 and 4.

$$C_{fish} = \frac{N_{MP}}{W_{organ}} \tag{3}$$

$$\mathrm{BAF} = \frac{C_{fish}}{C_{water}} \tag{4}$$

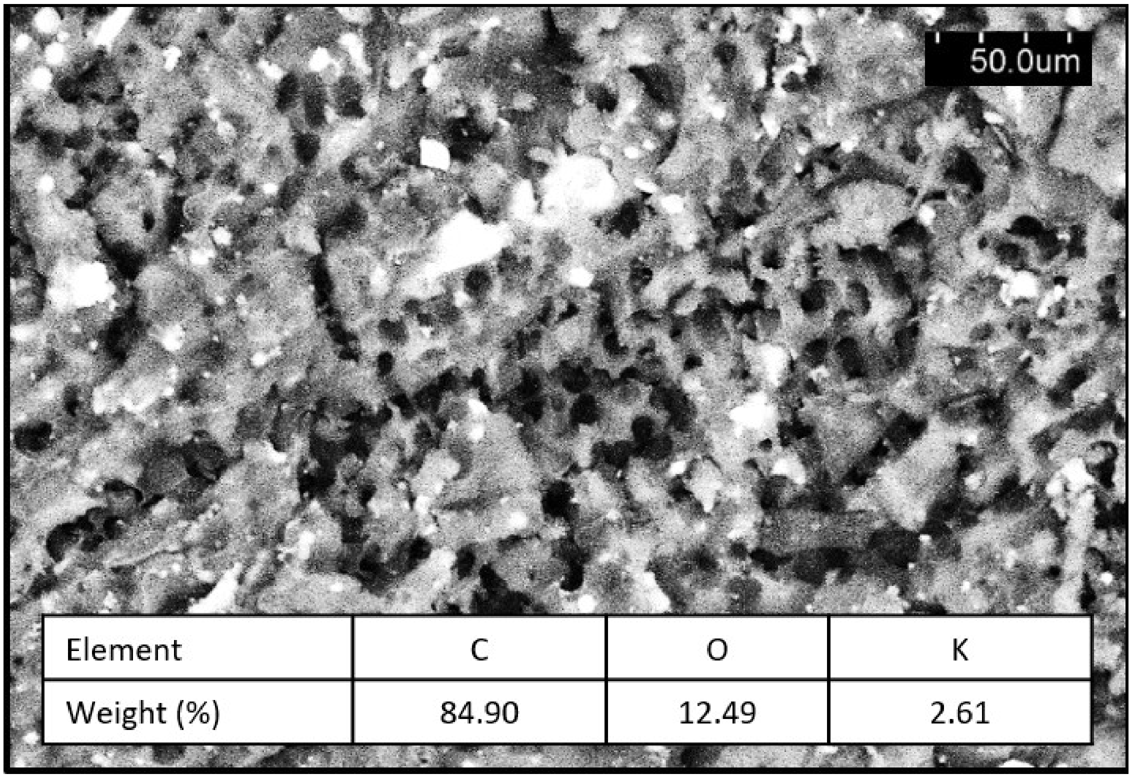


**Figure 1.** Morphology of Coconut Shell Biochar

**Table 1.** Significance Test of the Measured Variables among Treatment Groups

| Variables | Method | $p$-value |
|---|---|---|
| Microplastic in Water Filter Effluent | t-test | 0.318 |
| Microplastic in Fish | ANOVA | 0.418 |
| Fish Feed Efficiency | ANOVA | 0.125 |

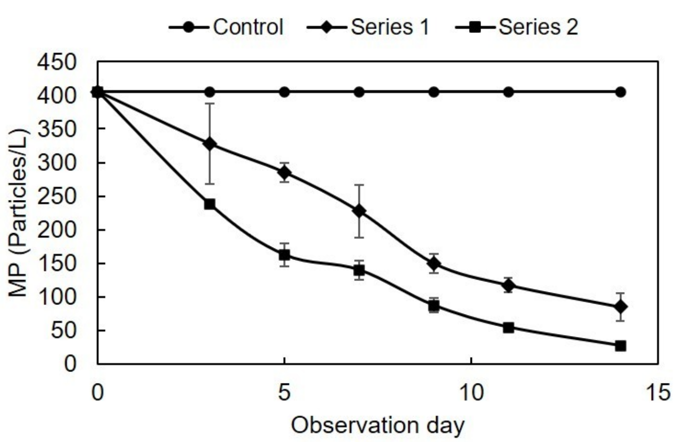


**Figure 2.** Microplastic Concentration in Influent and Effluent of the Filter

Where: BAF is the bioconcentration factor, $C_{fish}$ is the concentration of microplastics in the test animal (particles/g), and $C_{water}$ is the concentration of microplastics in the water (particles/L), $N_{MP}$ is the microplastic concentration in organs (microplastic/fish), and $W_{organ}$ is organ weight (g).

Filter toxicity on feed efficiency was conducted in three fish tanks, each containing tap water as a control, and water from filter effluent series 1 and series 2. Each aquarium contained five tilapias. Feeding was carried out twice a day, in the morning and afternoon. Feed efficiency was calculated weekly on the first day, the seventh day, and the fourteenth day. Feed was provided at 5% of the fish's body weight. The data required to calculate feed efficiency included the fish's body weight at the start of the study, the fish's body weight at the observation day, and the amount of feed provided during the study period. Feed efficiency levels calculated using Equation 5.

$$EP = \frac{(W_t + W_d) - W_0}{F} \times 100\% \tag{5}$$

Where: $EP$ is feed efficiency (%), $W_t$ is fish weight at the observation day (g), $W_0$ is initial fish weight (g), $W_d$ is the total weight of dead fish during observation (g), and $F$ is the amount of feed given (g).

### 2.5 Statistical Analysis

In this study, the normality and homogeneity of variance of each dataset were tested using the Shapiro-Wilk test. The t-test method was used to determine the differences in microplastic abundance in filter water effluent. While a one-way ANOVA statistical analysis was performed to see a significant difference in microplastics in fish as well as fish feed efficiency between the control, series 1, and series 2 treatments. If a significant difference ($p < 0.05$) was obtained in the ANOVA test.

## 3. RESULTS AND DISCUSSION

### 3.1 Surface Morphology of Coconut Shell Biochar

The surface morphology of coconut shell biochar shows the numerous pores with a size of less than 50 nm. The number of pores on the surface of biochar is related to the larger area available for the adsorption of microplastics (Ji et al., 2024). The surface pores of biochar play an important role in microplastic filtration because they enable physical trapping and increase the surface area for chemical interactions (Wang et al., 2020).

Macropores (>50 nm) mechanically capture large microplastics (Suárez-Hernández et al., 2017). A pore size of 10 $\mu$m is more effective for capturing microplastics with an efficiency of 95% (Wang and Guo, 2020). A well-structured pore system also slows down water flow, providing more time for interaction between microplastics and functional groups on the biochar, thereby enhancing filtration efficiency (Leng et al., 2021).

The structural properties of coconut shell biochar enable the removal of microplastics through physical entrapment, hydrophobic interactions, and electrostatic interactions (Olubusoye et al., 2024). This study did not analyze the biochar using FTIR. However, results from other studies showed that coconut shell biochar contains oxygen-rich functional groups (−OH, CO, C−O) and aromatic structures (Badiger and Nidheesh, 2024; Edwin et al., 2025b). While study on coconut shell biochar, XRD indicated the presence of an amorphous carbon phase with graphite content (Sujiono et al., 2022). It can contribute to the potential of physical adsorption of microplastics by biochar, as well as enhance the interaction between microplastics and biochar, which can lead to the removal of microplastics using this filter.

### 3.2 Filter Performance in Removing Microplastics

The concentration of microplastics in the effluent water of filter series 1 and series 2 is presented in Figure 2 and Figure 3. Coconut shell biochar and polyurethane sponge have good contaminant adsorption and filtration capabilities. Therefore, microplastics decrease as they are filtered and adsorbed by the coconut shell biochar and polyurethane sponge filter media. The distribution of microplastic concentrations is shown in Figure 3. The range of microplastic concentration in the effluent of the series 1 filter is 85-328 particles/L, while in the effluent of the series 2 filter in the range of 28-238 particles/L. The efficiency of microplastic removal with the series 1 filter is in the range of 19-79%, while with the series 2 filter it is in the range of 41-93%. This study highlights that a two-series biochar filter results in higher microplastic removal efficiency.

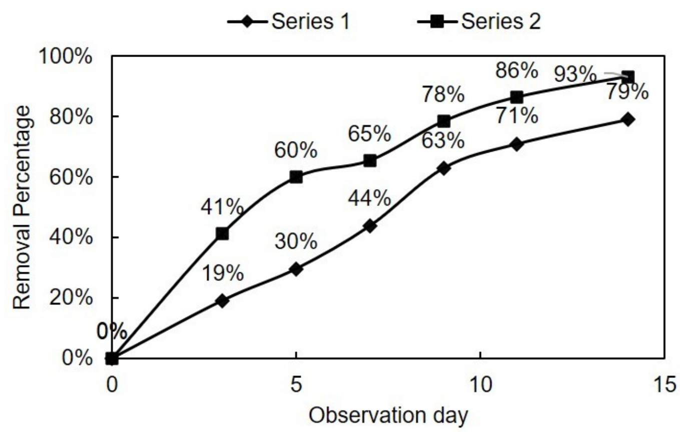


**Figure 3.** Percentage of Microplastic Removal Using Filter Series 1 and 2

The filtration process was performed using the media of coconut shell biochar and polyurethane sponge. According to Wang et al. (2020), treating river water containing microplastic contaminants using biochar can remove microplastics to more than 95%. Similarly, a study by Changlor et al. (2025) demonstrated that biochar filters can remove up to 96% of small microplastics, with removal efficiency increasing as flow rates rise. When compared to this study, the use of coconut shell biochar and polyurethane sponge filters is effective but still less efficient than previous studies.

According to previous studies, the thicker the filter media used in the filtration process for the experiment, the greater the increase in the amounts of contaminants trapped in the filter media (Adriati et al., 2020; Manga et al., 2016). When the influent only flows through certain parts rather than being evenly distributed across the entire filter surface, this can reduce the channel effect and result in a significant decrease in contaminant concentration. Additionally, this can also increase the penetration rate between liquid and solid phases within the filter column. As a result of these conditions, contaminants will only occur in the filter column without sufficient adsorption.

### 3.3 Filter Toxicity

Toxicity tests were conducted for two weeks to observe the feed efficiency of tilapia in filtered effluent water. During the study period, water quality measurements were taken in the

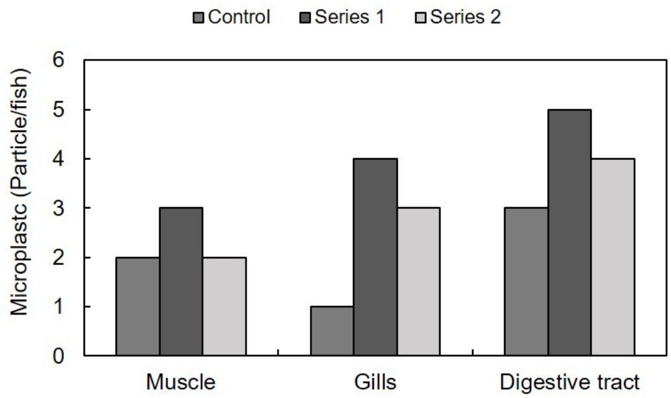


**Figure 4.** Microplastics in Fish Organs

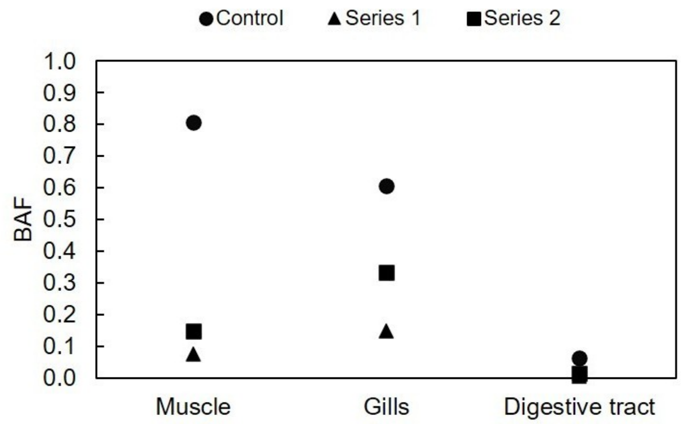


**Figure 5.** Bioaccumulation Factor of Microplastic in Fish Organs

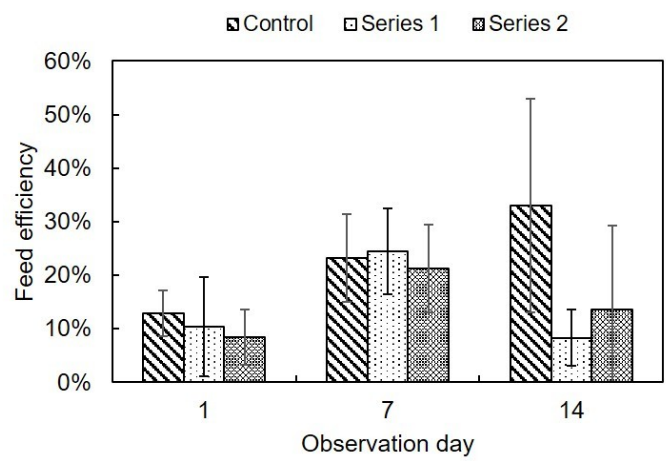


**Figure 6.** Feed Efficiency of Fish

aquarium. Water quality refers to environmental conditions such as temperature, pH, and DO.

The water temperature in the aquarium for the control test ranges from 24.1 to 25.6 °C. For the effluent water from filter series 1, the water temperature ranges from 24.0 to 24.7 °C, while for the effluent water from filter series 2, the water temperature ranges from 24.2 to 24.9 °C. According to the USEPA (2002), the temperature range for freshwater fish to survive is 25-30 °C, but another study found that a temperature range of 22-30 °C is still suitable for freshwater fish to survive (El-Sherif and El-Feky, 2009). The pH parameter of tap water is within the range of 6.28-6.73, the pH of the effluent from the Series 1 filter is within the range of 6.41-6.72, and the pH of the effluent from the Series 2 filter is within the range of 6.43-6.46. This indicates that the pH values still fall within the range of 6-8 (USEPA, 2002). Meanwhile, for the environmental parameter of dissolved oxygen (DO), tap water has a DO value ranging from 6 to 7.25 mg/L, the effluent from filter series 1 has a DO value ranging from 4.7 to 5 mg/L, while the effluent from filter series 2 has a DO value between mg/L. This indicates that the DO value still meets the USEPA regulation of 4 mg/L.

### 3.3.1 Bioaccumulation of Microplastic

In this study, we analyzed microplastics in the muscle, gills, and digestive tract of fish. Microplastics consumed by fish will enter the gastrointestinal tract and spread to body tissues through blood vessels. Muscle tissue or meat will be one of the tissues that can be a place for microplastic accumulation, even though detected in smaller amounts compared to the fish gill and gastrointestinal tract (Atamanalp et al., 2021; Hossain et al., 2024). Microplastics in fish and the bioaccumulation factors of microplastics in fish is presented in Figure 4 and Figure 5. This study shows that fish that were reared in filter effluent series 1 have more microplastic in all observed organs, followed by filter effluent series 2 and control treatment. Digestive tracts contained the highest microplastic numbers, followed by gills and muscles in all treatments.

The presence of microplastics in fish tank water can cause accumulation in the fish. In addition, this process can also occur through the fish's food chain. Microplastics dissolved in water are also directly absorbed by fish body tissue through the process of diffusion or translocation through cell membranes, especially the digestive tracts (Ma et al., 2021).

The cause of high concentrations of microplastics in the digestive tract is due to large microplastics being swallowed by fish and entering the digestive tract system. Large microplastics can be trapped and accumulated in the digestive tract and cannot be digested, so they cannot be excreted through fish feces. This allows microplastics to enter the muscle and organs of fish. Microplastics trapped in low organisms in the food chain, such as plankton, can accumulate in the bodies of fish that eat these organisms. This can cause an increase in the concentration of microplastics in fish tissue over time.

Based on Figure 5, the BAF value in fish muscle ranges from 0.15 to 0.81, the BAF value in gills ranges from 0.15 to 0.61, and the BAF value in the digestive tract ranges from 0.01 to 0.06. BAF for muscle, gill, and digestive tract was less than 1, which indicates low accumulative. This also means that the filtered water is relatively safe for tilapia, although there are still residual microplastics that need to be further minimized.

### 3.3.2 Feed Efficiency

Feed efficiency data is presented in Figure 6. In the control experiment, an increase was observed from the first day (13%) to the $7^{th}$ day (23%) and on the $14^{th}$ day (33%). Tilapia in this experiment experienced rapid adaptation to the feed. In the experiment with filter effluent series 1, feed efficiency decreased from day 1 (10%) to day 7 (21%), although it decreased on day 14 (8%). The pollutant in this water likely has a toxic effect that inhibits metabolic efficiency and feed absorption. The decrease in efficiency from day 7 to day 14 strengthens the suspicion of stress or toxic accumulation. The same trend with the toxicity experiment using filter effluent series 2, there was an increase from day 1 (8%) to day 7 (21%), and a decrease on day 14 (14%).

In this study, the toxicity test showed filter effluent 1 was more toxic compared to filter effluent 2. Effluent water from filter series 1 might still potentially toxic for fish because it contained a higher concentration of microplastics compared to series 2 effluent. The higher the feed efficiency, the greater the ability of fish to digest food; conversely, if the feed efficiency is smaller, the ability of fish to digest food is smaller. The higher the feed efficiency value, the better the growth rate. A lot of food enters the fish's digestive system for the body's metabolism to take place, some of which is used for growth. Protein is the main source of energy for fish, followed by fat and carbohydrates. Protein is a very important feed for fish growth (Masura et al., 2015).

### 3.4 Statistical Analysis Result

The results of the Shapiro-Wilk test indicate that the microplastic abundance data in the filter effluent are normally distributed ($p > 0.05$). The results of the study confirmed that the data were normally distributed, thereby supporting the validity of parametric analysis. The results of the t-test showed no significance difference between microplastics in the filter effluent of both series. Although higher removal efficiency was observed in the two-stage filtration system, the t-test showed no significant difference in microplastic concentration between the effluents from the two filtration systems. One-way ANOVA in Table 1 showed no significant difference in microplastic abundance in fish among the treatment groups (control, series 1 and series 2) with $p > 0.05$. These findings suggest that while filtration improves removal efficiency, it does not always lead to a measurable reduction in bioaccumulation under experimental conditions. Overall, these results highlight the complexity of microplastic transfer processes and the need for further research under conditions of prolonged exposure.

## 4. CONCLUSIONS

The best microplastic removal efficiency was in the series 1 in the range of 19-79%, while with the series 2, filter it is in the range of 41-93%. The use of two series of filter columns is more effective in removing microplastics than using only one filter. Toxicity test showed that better condition in terms of feed efficiency occurred in the series 2 column filter effluent compared to series 1, due to a large number of contaminants that had been removed using the two-level filter, which caused less stress in the fish. The highest concentration of microplastics in fish was in the digestive tracts, followed by the gills and the muscle. The bioaccumulation ability of microplastics by fish was low in all treatment variations. Overall, this study shows that two series of biochar and polyurethane filters are potential for microplastic removal in wastewater. As a further study, a long-term evaluation of the performance of this two-stage filtration process under real-world conditions is recommended to support its broader application in wastewater treatment.

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