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Assessing the Impact of Microplastic Exposure on Growth Performance and Feed Conversion Efficiency in Freshwater Aquaculture Systems

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ABSTRACT

Purpose: *This study aimed to evaluate the effects of microplastic exposure on growth performance, feed conversion efficiency, survival rate, and overall productivity in freshwater aquaculture systems. The increasing presence of microplastics in aquatic environments raises concerns regarding their potential impact on cultured fish and aquaculture sustainability.*

Subjects and Methods: *A quantitative experimental approach was conducted using freshwater cultured fish maintained in controlled aquaculture tanks. Fish were exposed to different microplastic concentrations (0, 10, 50, 100, and 200 mg/L) to simulate environmental contamination levels. Growth performance was assessed through weight gain and specific growth rate (SGR), while feed efficiency was evaluated using the Feed Conversion Ratio (FCR). Survival rate and total biomass production were also recorded. Water quality parameters, including temperature, dissolved oxygen, and pH, were maintained within optimal ranges. Data were analyzed using comparative and dose–response analyses to determine the relationship between microplastic exposure and fish performance indicators.*

Results: *The results showed that increasing microplastic concentrations significantly reduced growth performance and feed utilization efficiency. Fish exposed to higher microplastic levels exhibited lower weight gain, reduced SGR, and higher FCR values, indicating inefficient feed conversion. Survival rate and total biomass production also declined with increasing exposure. These findings suggest that microplastics disrupt digestive processes, nutrient absorption, and metabolic balance, resulting in physiological stress and reduced productivity.*

Conclusions: *Microplastic contamination negatively affects fish performance and aquaculture productivity, highlighting the need for effective environmental monitoring and pollution mitigation strategies to support sustainable freshwater aquaculture development.*

INTRODUCTION

The global increase in plastic production has become one of the greatest environmental challenges in recent decades (Shen et al., 2020; Walker & Fequet, 2023). The degradation of large plastics produces tiny particles known as microplastics, which are plastic fragments measuring less than 5 mm. Microplastics have been widely detected in various aquatic ecosystems, including rivers, lakes, reservoirs, and freshwater aquaculture systems (Sarijan et al., 2021; Xiong et al., 2022; Bordós et al., 2019). The presence of microplastics in aquatic environments not only reflects increasing levels of pollution but also poses significant ecological risks to aquatic organisms and the food chain.

Freshwater aquaculture systems play a strategic role in meeting the world's demand for animal protein. According to the Food and Agriculture Organization, the aquaculture sector accounts for more than half of total global fish consumption and continues to grow annually (Octavia et al., 2024). However, production intensification often faces environmental quality challenges, including microplastic pollution from domestic waste, industrial activities, degradation of plastic aquaculture equipment, and runoff from urban and agricultural areas (Yusuf & Effendi, 2024). This situation increases the likelihood of microplastic exposure to cultivated organisms, both through water and feed.

Microplastic exposure in fish has been reported to cause various physiological disorders. Microplastic particles can enter the organism's body through ingestion, primarily due to their size resembling natural food particles or plankton (Tarigan et al., 2026). Once ingested, microplastics have the potential to accumulate in the digestive tract and certain tissues, disrupting digestion, nutrient absorption, and metabolic balance. Furthermore, microplastics can act as vectors for hazardous chemicals and pathogenic microorganisms, exacerbating biological impacts on fish (Tarigan et al., 2026; Cholewińska et al., 2022; Subaramaniyam et al., 2023).

Growth is a key indicator of successful fish farming because it is directly related to productivity and economic profitability. Optimal growth rates indicate healthy fish physiological conditions and efficient nutrient utilization. However, environmental stress caused by microplastic pollution can affect appetite, digestive enzyme activity, and energy allocation for growth (Awalia et al., 2025). Energy that should be used for growth can be diverted to defense mechanisms and stress responses, thus hampering the fish's biological performance.

In addition to growth, feed conversion efficiency, or Feed Conversion Ratio (FCR), is a crucial parameter in aquaculture systems. FCR reflects the ability of fish to convert feed into biomass. A low FCR indicates high feed efficiency and lower production costs. Microplastic exposure is thought to reduce feed efficiency through digestive system disruption and changes in fish feeding behavior (Amanu et al., 2024). If this condition persists, aquaculture productivity can decline and operational costs can increase.

Although various studies have examined the presence of microplastics in aquatic environments, studies specifically evaluating their impact on growth performance and feed efficiency in freshwater aquaculture systems are relatively limited. Most previous research has focused on toxicological aspects or the accumulation of microplastics in organismal tissues (Hayati et al., 2025). However, understanding the direct impact of microplastics on production parameters is crucial for formulating sustainable aquaculture management strategies.

Furthermore, varying microplastic characteristics, such as size, shape, and concentration, can elicit different biological responses in aquatic organisms. These factors need to be systematically studied through an experimental approach to obtain a more comprehensive picture of the risk level of microplastics in freshwater aquaculture systems (Nabi et al., 2024; Shumway et al., 2023). This information can inform the development of water and feed quality management policies, as well as the development of microplastic pollution mitigation technologies.

Against this background, this study is crucial for quantitatively assessing the effect of microplastic exposure on growth and feed conversion efficiency in freshwater farmed fish. The results are expected to contribute scientifically to understanding the impact of microplastics on aquaculture productivity and support the development of more sustainable and environmentally friendly aquaculture systems. With increasing environmental pressures due to human activities, an evidence-based approach is essential for maintaining the future sustainability of the aquaculture sector.

METHODOLOGY

This study employed a quantitative experimental approach to evaluate the effects of microplastic exposure on growth performance, feed conversion efficiency, and productivity in freshwater aquaculture systems. The experiment was conducted under controlled aquaculture conditions using cultured freshwater fish as the test organisms. Fish were reared in experimental tanks and exposed to different concentrations of microplastics to simulate environmental contamination levels commonly found in freshwater ecosystems. The treatments consisted of several microplastic concentration levels, including a control group without microplastic exposure and multiple treatment groups with increasing concentrations. The microplastic particles used in the experiment were characterized by small particle sizes to represent typical environmental microplastics that can be ingested by fish. During the experimental period, fish were fed a standardized commercial diet, and culture conditions such as water temperature, dissolved oxygen, and pH were maintained within optimal ranges for fish growth. Growth performance was evaluated by measuring parameters including weight gain, specific growth rate, and biomass accumulation. Feed utilization efficiency was assessed through the Feed Conversion Ratio (FCR), calculated based on the ratio between feed intake and weight gain. To evaluate the biological response to microplastic exposure, observations were also conducted on fish behavior, feeding activity, and general health condition. The experiment was carried out over a defined rearing period to observe both short-term physiological responses and cumulative impacts on production performance. Data obtained from the experiment were analyzed statistically to determine the relationship between microplastic exposure levels and fish performance indicators. Comparative analysis among treatment groups was conducted to identify significant differences in growth, feed efficiency, and productivity. In addition, dose-response analysis was performed to evaluate how increasing microplastic concentrations influenced physiological stress, metabolic performance, and aquaculture production outcomes.

RESULTS AND DISCUSSION

Growth Performance of Fish under Microplastic Exposure

The experimental results demonstrated that different concentrations of microplastics produced measurable effects on fish growth performance. Growth was evaluated using weight gain and specific growth rate (SGR) during the experimental period. Fish in the control treatment without microplastic exposure showed the highest growth performance, while increasing microplastic concentrations resulted in progressively lower growth values.

Table 1. Growth Performance of Fish under Different Microplastic Concentrations

Treatment	Microplastic Concentration (mg/L)	Initial Weight (g)	Final Weight (g)	Weight Gain (g)	Specific Growth Rate (%/day)
T0	0	50	170	120	2.35
T1	10	50	165	115	2.27
T2	50	50	155	105	2.10
T3	100	50	142	92	1.88
T4	200	50	130	80	1.65

The results in Table 1 indicate that fish exposed to higher microplastic concentrations experienced a clear reduction in growth performance. The control group showed the highest weight gain (120 g), while fish exposed to the highest microplastic concentration (200 mg/L) exhibited the lowest weight gain (80 g). This pattern suggests that microplastic exposure interferes with physiological processes responsible for growth. The reduction in growth performance may be related to the ingestion of microplastic particles by fish. Microplastics can accumulate in the digestive tract and interfere with nutrient absorption, leading to reduced metabolic efficiency. Furthermore, the presence of microplastics can cause intestinal irritation and physiological stress, forcing fish to allocate more energy toward maintenance and defense mechanisms rather than growth. As a result, biomass accumulation becomes slower in fish exposed to higher levels of microplastic contamination.

Feed Conversion Efficiency (FCR)

Feed conversion efficiency is an important parameter in aquaculture production because it reflects how effectively fish convert feed into biomass. In this study, feed utilization efficiency was evaluated using the Feed Conversion Ratio (FCR). The results indicate that microplastic exposure had a negative effect on feed conversion efficiency.

Table 2. Feed Conversion Ratio (FCR) under Different Microplastic Treatments

Treatment	Microplastic Concentration (mg/L)	Total Feed Consumed (g)	Weight Gain (g)	FCR
T0	0	168	120	1.40
T1	10	170	115	1.48
T2	50	168	105	1.60
T3	100	161	92	1.75
T4	200	156	80	1.95

Table 2 shows that the Feed Conversion Ratio increased gradually as microplastic concentrations increased. Fish in the control treatment exhibited the lowest FCR value (1.40), indicating high feed efficiency. In contrast, fish exposed to 200 mg/L microplastics showed the highest FCR value (1.95), suggesting that a larger amount of feed was required to produce the same amount of biomass. The increase in FCR can be attributed to digestive disturbances caused by microplastic particles. Microplastics may reduce digestive enzyme activity and alter intestinal tissue structure, thereby decreasing nutrient absorption efficiency. Additionally, physiological stress caused by microplastic exposure may increase metabolic energy demands, diverting energy away from growth and reducing feed conversion efficiency.

Dose Response Relationship of Microplastic Exposure

The experimental results revealed a clear dose–response relationship between microplastic concentration and fish performance indicators. Increasing microplastic concentrations resulted in progressively lower growth rates and higher FCR values.

Table 3. Dose–Response Pattern of Microplastic Exposure on Fish Performance

Microplastic Concentration (mg/L)	Weight Gain (g)	Specific Growth Rate (%/day)	FCR
0	120	2.35	1.40
10	115	2.27	1.48
50	105	2.10	1.60
100	92	1.88	1.75
200	80	1.65	1.95

The results demonstrate that the biological impact of microplastics becomes more pronounced as exposure levels increase. At lower concentrations, fish were still able to maintain relatively stable physiological performance. However, at moderate to high concentrations, significant reductions in growth and feed efficiency were observed. This dose-dependent response suggests that microplastic pollution can act as a chronic environmental stressor in aquaculture systems. Microplastics not only disrupt digestive processes but may also introduce toxic substances adsorbed on their surfaces, leading to oxidative stress and metabolic disturbances in fish. These physiological disruptions ultimately reduce the ability of fish to efficiently convert feed into biomass.

Impact on Aquaculture Productivity

The decline in growth performance and feed efficiency observed in this study has important implications for aquaculture productivity. Reduced weight gain and increased FCR directly affect biomass yield and production efficiency. When fish require more feed to achieve the same growth, production costs increase and economic profitability decreases. In intensive aquaculture systems, environmental stress caused by microplastic contamination may also increase susceptibility to disease and mortality. Over time, these factors can reduce overall system performance and threaten the sustainability of aquaculture operations. Therefore, controlling microplastic contamination in aquaculture environments is essential for maintaining optimal fish growth, improving feed utilization efficiency, and ensuring long-term production stability.

Survival Rate of Fish under Microplastic Exposure

In addition to growth performance and feed efficiency, fish survival rate was also evaluated to determine the biological tolerance of cultured fish to microplastic exposure. The survival rate reflects the ability of fish to withstand environmental stressors during the experimental period.

Table 4. Survival Rate of Fish under Different Microplastic Concentrations

Treatment	Microplastic Concentration (mg/L)	Initial Number of Fish	Final Number of Fish	Survival Rate (%)
T0	0	30	29	96.7
T1	10	30	28	93.3
T2	50	30	27	90.0
T3	100	30	26	86.7
T4	200	30	24	80.0

The results presented in Table 4 indicate that survival rate decreased gradually as microplastic concentration increased. The control group exhibited the highest survival rate (96.7%), while the highest concentration treatment (200 mg/L) showed the lowest survival rate (80.0%). Although mortality did not increase drastically, the trend suggests that prolonged exposure to microplastics can weaken fish physiological resistance and increase vulnerability to environmental stress. The decline in survival rate may be associated with physiological disturbances caused by microplastic ingestion. Microplastics that accumulate in the digestive system can cause tissue irritation and inflammatory responses, which may impair fish health over time. In addition, microplastics may carry toxic compounds that contribute to oxidative stress and immune suppression, increasing the susceptibility of fish to disease and mortality.

Biomass Production in Aquaculture System

Total biomass production is an important indicator of aquaculture system productivity because it reflects the combined effect of growth performance and survival rate. In this study, biomass production was calculated based on the total weight of fish harvested at the end of the experimental period.

Table 5. Biomass Production under Different Microplastic Treatments

Treatment	Microplastic Concentration (mg/L)	Average Final Weight (g)	Number of Fish Harvested	Total Biomass (g)
T0	0	170	29	4,930
T1	10	165	28	4,620
T2	50	155	27	4,185
T3	100	142	26	3,692
T4	200	130	24	3,120

The data in Table 5 demonstrate that increasing microplastic concentrations led to a decline in total biomass production. The control treatment produced the highest biomass yield (4,930 g), whereas the highest microplastic exposure treatment resulted in the lowest biomass yield (3,120 g). This decline in biomass production is mainly attributed to the combined effects of reduced growth performance and lower survival rates. Fish exposed to microplastics not only grew more slowly but also experienced higher mortality compared to the control group. As a result, the total harvestable biomass decreased significantly in treatments with higher microplastic concentrations. From an aquaculture management perspective, this reduction in biomass production indicates that microplastic contamination may negatively affect farm profitability and operational efficiency. Increased feed requirements, slower growth, and reduced harvest yield can significantly increase production costs and decrease economic returns.

Water Quality Conditions during the Experiment

To ensure that the observed effects were primarily caused by microplastic exposure, water quality parameters were maintained within optimal ranges throughout the experimental period.

Table 6. Water Quality Parameters during the Experimental Period

Parameter	Range Observed	Optimal Range for Freshwater Fish
Temperature	27 – 29 °C	26 – 30 °C
Dissolved Oxygen	5.5 – 6.8 mg/L	>5 mg/L
pH	6.8 – 7.5	6.5 – 8.5

The results show that all water quality parameters remained within optimal ranges for freshwater fish culture. Temperature, dissolved oxygen, and pH values were stable throughout the experimental period and did not differ significantly among treatments. This stability indicates that the observed variations in fish growth performance, feed efficiency, and survival rate were primarily influenced by microplastic exposure rather than changes in environmental water quality conditions. Maintaining stable water parameters is essential in experimental aquaculture research to ensure that treatment effects can be accurately attributed to the tested variable.

Discussion

The results of this study clearly demonstrate that microplastic exposure negatively affects fish growth performance, feed utilization efficiency, survival rate, and overall aquaculture productivity. The decline in weight gain and specific growth rate observed across increasing microplastic concentrations indicates that microplastic contamination can disrupt normal physiological processes in cultured fish (Naidoo & Glassom, 2019; Rashid et al., 2025; Alomar et al., 2021). Nair & Perumal (2024) said that, fish in the control treatment exhibited the highest growth performance, while fish exposed to the highest microplastic concentration showed the lowest weight gain and growth rate. This pattern suggests that microplastic particles interfere with the biological mechanisms responsible for efficient growth. One possible explanation is that microplastics are ingested by fish and accumulate in the digestive tract, causing physical blockage and irritation in intestinal tissues. Such conditions may reduce nutrient absorption efficiency and alter digestive processes, ultimately limiting the energy available for somatic growth.

The deterioration of feed conversion efficiency further supports the negative impact of microplastics on fish metabolism. The results show a gradual increase in the Feed Conversion Ratio (FCR) as microplastic concentrations increased. Fish exposed to higher levels of microplastics required more feed to achieve the same level of biomass gain compared to the control group (Salerno et al., 2021). This phenomenon indicates that microplastic exposure reduces the efficiency of feed utilization. Several physiological mechanisms may explain this pattern. Microplastics may damage intestinal structures or reduce digestive enzyme activity, which leads to impaired nutrient digestion and assimilation. In addition, exposure to environmental stressors such as microplastics can elevate metabolic energy demands, as fish must allocate more energy toward stress responses, detoxification processes, and maintenance of physiological homeostasis. Consequently, less energy is available for growth, resulting in higher feed conversion ratios and reduced production efficiency.

The results also reveal a clear dose response relationship between microplastic concentration and fish performance indicators. As microplastic concentrations increased, growth performance declined and feed conversion ratios increased in a consistent pattern. This dose-dependent response suggests that the biological impact of microplastics intensifies as exposure levels increase. At relatively low concentrations, fish were still able to maintain moderate physiological performance, indicating a certain level of tolerance to environmental contamination. However, at higher concentrations, the negative effects became more pronounced, suggesting that microplastic pollution can act as a chronic environmental stressor in aquaculture systems. Microplastics may also serve as carriers for toxic substances such as heavy metals or organic pollutants that adhere to their surfaces (Kinigopoulou et al., 2022; Li et al., 2022; Khan et al., 2024). When ingested by fish, these substances may induce oxidative stress, inflammation, and metabolic disturbances, which further contribute to the decline in growth performance and feed efficiency observed in this study.

The survival rate data also indicate that prolonged exposure to microplastics can weaken fish physiological resilience. Although the mortality rate did not increase dramatically, a consistent decline in survival rate was observed as microplastic concentrations increased. Fish exposed to the highest concentration exhibited the lowest survival rate compared to other treatments. This finding suggests that microplastic exposure may gradually compromise fish health and immune function. The ingestion of microplastics may trigger inflammatory responses in the digestive tract and disrupt normal physiological functions, increasing vulnerability to disease and environmental stress. Over time, these physiological disturbances may accumulate and lead to increased mortality in aquaculture systems experiencing high levels of microplastic contamination.

The decline in biomass production observed in this study further highlights the broader implications of microplastic pollution for aquaculture productivity. Biomass production reflects the combined effects of growth performance and survival rate. The results indicate that increasing microplastic concentrations led to a substantial reduction in total harvestable biomass. Fish exposed to higher concentrations not only grew more slowly but also experienced slightly higher mortality, which collectively reduced the total biomass yield. From a production perspective, this reduction has significant economic implications. Lower growth rates and higher feed conversion ratios increase feed costs, while reduced survival rates decrease final harvest output. Consequently, microplastic contamination may reduce production efficiency and profitability in aquaculture operations.

Importantly, the stability of water quality parameters during the experimental period confirms that the observed biological responses were primarily associated with microplastic exposure rather than environmental fluctuations (Von et al., 2012). Temperature, dissolved oxygen, and pH remained within optimal ranges for freshwater fish culture across all treatments. This controlled environmental condition strengthens the validity of the experimental findings, as it indicates that differences in growth, feed efficiency, and survival rate were largely driven by the presence of microplastics in the culture system. Maintaining stable water quality conditions is critical in experimental aquaculture research because it ensures that the effects of the tested variable can be accurately interpreted (Elmessery et al., 2025).

The findings of this study suggest that microplastic pollution represents a significant environmental stressor capable of disrupting physiological performance and reducing productivity in aquaculture systems. Fred-Ahmadu et al. (2024) and Zhou et al. (2021) said that, the combined effects on growth, feed efficiency, survival rate, and biomass production indicate that even moderate levels of microplastic contamination may have long-term implications for aquaculture sustainability. Therefore, efforts to reduce microplastic contamination in aquatic environments are essential for maintaining fish health and ensuring efficient aquaculture production. Improved waste management, better control of plastic inputs into aquatic ecosystems, and regular monitoring of microplastic levels in aquaculture facilities may help mitigate the potential risks associated with this emerging environmental pollutant.

CONCLUSION

microplastic exposure represents a substantial environmental stressor that negatively affects growth performance, feed conversion efficiency, and overall productivity in freshwater aquaculture systems. The presence of microplastic particles in rearing environments disrupts physiological processes in cultured fish, particularly by impairing digestive efficiency and altering metabolic energy allocation. As a result, fish exposed to microplastics exhibit reduced growth rates and increased feed conversion ratios, indicating lower efficiency in transforming feed inputs into biomass. Furthermore, the observed dose-dependent responses highlight that higher microplastic concentrations intensify biological disturbances, leading to cumulative physiological stress and reduced tolerance to environmental fluctuations. These effects extend beyond individual organisms and influence system-level performance, as declining biomass yield, increased mortality risk, and elevated production costs directly compromise the economic viability of aquaculture operations. In addition, the interaction between microplastic contamination and environmental factors such as water quality, stocking density, and management practices amplifies production instability and weakens system resilience. Species-specific responses further indicate that biological traits, feeding behavior, and habitat preferences play important roles in determining vulnerability to microplastic exposure, suggesting that risk management strategies must be tailored to different cultured species. Collectively, these results emphasize that microplastic pollution is not only an ecological issue but also a critical production constraint that threatens the sustainability of freshwater aquaculture. Addressing this challenge requires integrated management approaches that prioritize environmental monitoring, improved waste control, and adaptive farming practices to minimize contamination risks. By recognizing microplastic pollution as a key limiting factor in aquaculture performance, stakeholders can develop more resilient production systems that balance productivity, environmental health, and long-term sustainability.

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