JEE Journal of Ecological Engineering

Journal of Ecological Engineering, 2025, 26(10), 87–102
https://doi.org/10.12911/22998993/205542
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Received: 2025.05.11
Accepted: 2025.07.15
Published: 2025.07.22

Sublethal effects of polyvinyl chloride microplastics on growth performance and survival of whiteleg shrimp (*Litopenaeus vannamei*)

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ABSTRACT

This study investigated the sublethal effects of polyvinyl chloride (PVC) microplastics on whiteleg shrimp (*Litopenaeus vannamei*), focusing on behavior, growth, feed efficiency, and survival. Whiteleg shrimp were exposed to three concentrations of PVC microplastics (3, 6, and 9 mg/L) over 45 days. Results showed that higher exposure levels reduced swimming activity and feeding response, indicating physiological stress. Microplastics accumulated significantly in the digestive tract, with the highest average (85.04 particles/individual) found at the highest exposure level. Shrimp growth, measured as changes in body length and weight, declined with increasing microplastic concentration, as did feed conversion efficiency and specific growth rate. Survival also decreased sharply, with the lowest rate (37%) observed in the highest treatment group. These findings suggest that even environmentally relevant concentrations of PVC microplastics can impair shrimp health and aquaculture productivity. The study underscores the need for stricter waste management and recommends further research into long-term effects and mitigation strategies.

Keywords: *Litopenaeus vannamei*, PVC microplastics, shrimp growth, behavior, sustainable aquaculture.

INTRODUCTION

Microplastics (MPs), defined as plastic particles less than 5 mm in size, have emerged as pervasive contaminants in aquatic ecosystems. These particles originate from larger plastic debris fragmentation or primary sources such as microbeads used in personal care products (Delvalle de Borrero et al., 2020; Lang, 2022). Due to their minute size and buoyant properties, MPs are highly persistent and easily dispersed, infiltrating diverse aquatic environments, including marine, estuarine, and aquaculture systems. Their environmental ubiquity is of particular concern, as MPs can be ingested by a wide array of aquatic organisms across trophic levels, leading to bioaccumulation and potential biomagnification along food webs (Hamilton et al., 2021; Li et al., 2023). Numerous studies have identified concentrations of MPs in sediments of aquaculture ponds ranging from 50.67 to 315.2 particles/kg, highlighting a growing environmental challenge for sustainable aquaculture (Hasan et al., 2021; Hasanah et al., 2023; Musa et al., 2023).

In addition to their physical presence, MPs act as vectors for various toxic pollutants, including persistent organic pollutants (POPs), heavy metals, and pathogenic microorganisms, thereby amplifying their ecological risks (Everaert et al., 2020; Gomiero et al., 2018; Le et al., 2024). Polymers such as polyvinyl chloride (PVC) are of particular concern due to their chemical additives and potential for leaching hazardous substances, including plasticizers and stabilizers (Liu et al., 2023). These substances can induce oxidative stress, disrupt immunological responses, and cause cellular damage in aquatic organisms (Del Piano et al., 2023; Yang et al., 2021). Despite increasing evidence of microplastic toxicity, most current research has focused on marine fish species, leaving substantial gaps in our understanding of their effects on aquaculture invertebrates, particularly shrimp.

Whiteleg shrimp (*Litopenaeus vannamei*) is a globally important aquaculture commodity and a dominant crustacean species cultivated in Indonesia. Its intensive production system is highly dependent on environmental quality, making it vulnerable to emerging contaminants like MPs (Emerenciano et al., 2022; Wu et al., 2025). Optimal shrimp growth and survival are strongly influenced by water parameters such as dissolved oxygen, salinity, and pH (Hassan et al., 2022; Pang et al., 2019; Wu et al., 2025), but little is known about how sublethal stressors like microplastics affect shrimp physiology and performance under controlled aquaculture conditions. Furthermore, recent studies have suggested that microplastic ingestion can alter feeding behavior, reduce nutrient absorption efficiency, and compromise growth performance in aquatic species (Apresia et al., 2024; Jaikumar et al., 2019; Zhang et al., 2024).

Behavioral disruptions such as altered locomotion, reduced feeding activity, and avoidance responses have been reported in fish exposed to MPs (Kenan and Teksoy, 2022; Zhang et al., 2023), yet equivalent studies on crustaceans remain limited. Since behavior is an early indicator of physiological stress, its quantitative assessment in shrimp exposed to MPs could offer valuable insights into sublethal toxicity mechanisms. Moreover, recent findings indicate that MPs not only accumulate in the digestive tract and gills of shrimp but may persist for extended periods, potentially affecting long-term survival and productivity in aquaculture (Runwal, 2023; Valencia-Castañeda et al., 2024).

Despite growing concern, the literature still lacks comprehensive data on how PVC microplastics specifically affect the growth, feed efficiency, behavior, and survival of *L. vannamei*, particularly under varying exposure concentrations relevant to realistic aquaculture conditions. The effects of MPs on critical performance metrics such as absolute growth (length and weight), feed conversion ratio (FCR), specific growth rate (SGR), and survival rate (SR) have not been systematically quantified in shrimp. While some studies have indicated potential growth and feed efficiency reductions due to oxidative stress and digestive obstruction (Li et al., 2024a), further empirical validation under standardized experimental conditions is required.

Therefore, this study aims to evaluate and quantify the sublethal effects of PVC microplastics on whiteleg shrimp (*L. vannamei*) through a controlled laboratory experiment. The primary objectives are: (1) to assess changes in shrimp behavior in response to different concentrations of PVC microplastics, (2) to evaluate impacts on growth performance indicators (absolute length and weight), (3) to determine alterations in FCR and SGR, and (4) to estimate SR under sublethal PVC exposure. This study addresses the following research questions: How do varying sublethal doses of PVC microplastics affect the behavior, growth, feed efficiency, and survival of whiteleg shrimp? It is hypothesized that increasing doses of PVC MPs will result in adverse effects on all measured parameters, indicating a dose-dependent relationship.

By filling these knowledge gaps, this research contributes to the growing field of microplastic ecotoxicology in aquaculture species. It provides essential data for environmental risk assessments and sustainable shrimp farming practices. The findings are expected to inform policymakers and aquaculture stakeholders about potential thresholds for microplastic exposure and serve as a scientific foundation for developing mitigation strategies in shrimp aquaculture systems.

RESEARCH METHOD

This study used a complete random design (CRD) consisting of four microplastic concentration treatments and three replicates in each treatment, resulting in 12-unit experiments. The treatment included the PVC microplastic concentration of 0 mg/L (control), 3 mg/L, 6 mg/L, and 9 mg/L. The sketch of the experimental setup can be seen in Table 1. This concentration range was chosen based on ecological and physiological considerations and referred to references to previous studies, primarily research Wang et al. (2021), which examines the acute impact of microplastics on whiteleg shrimp (*Litopenaeus vannamei*). In the study, applications of doses of 0 μg/L, 50 μg/L, 500 μg/L, and 5.000 μg/L for 48 hours showed that exposure to microplastics at the highest doses lowered shrimp survival rates by up to 83%.

Table 1. Sketch of the experimental setup

$P2_1$	$P3_2$	$P4_1$	$P1_2$	$P2_2$	$P4_3$
$P3_3$	$P2_3$	$P1_1$	$P4_2$	$P3_1$	$P1_3$

Note: the boxes show the test unit inside the laboratory. At $P2_1$: Code P2 indicates concentration treatment 2; Subscript number 1 indicates the first iteration.

In contrast to the short-term acute approach, this study was designed to evaluate the effects of chronic exposure to PVC microplastics during a 45-day maintenance period. Long-term exposure has the potential to lead to the accumulation of physiological impacts and more complex behavioral changes. Therefore, the concentration of microplastics used in this study was set at a sublethal level so that changes in physiological parameters (such as length, weight, FCR, SGR, and SR), as well as shrimp behavioral responses, could be observed representatively, without causing high mortality rates that could potentially impair the validity of the results.

The selection of concentrations of 3 mg/L, 6 mg/L, and 9 mg/L is based on three primary considerations. First, the concentration is in the sublethal range based on previous toxicology studies that showed that microplastics in the range of 1–10 mg/L do not directly trigger mass mortality but affect the physiological and metabolic aspects of shrimp (Jaikumar et al., 2019; Xing et al., 2023). Second, this range reflects realistic microplastic exposure scenarios in intensive pond environments, given that the presence of PVC microplastics has been significantly reported in the waters and sediments of aquaculture systems (Gomiero et al., 2018; Liu et al., 2023). Third, this variation of concentration allows for a gradual analysis of dose-response relationships to identify possible threshold effects on the growth and survival of whiteleg shrimp.

In addition, the concentration is also adjusted to the maintenance period and biological adaptation capacity of whiteleg shrimp in a closed system so that extreme environmental stress can be minimized, which can obscure the observation results. With this approach, the research is expected to be able to provide more comprehensive information on the impact of chronic exposure to PVC microplastics on whiteleg shrimp cultivation performance, as well as strengthen the ecological validity of the study results through simulation of microplastic pollution conditions that are close to the reality of the tropical cultivation environment.

Container preparation and maintenance media

The containers used in the study were 45 L. The containers were washed first with soap and rinsed with fresh water until clean, then dried for 8 hours. Furthermore, maintenance media are prepared by depositing seawater for 24 hours. Sterilization was carried out using 10 ppm chlorine. The maintenance container is filled with 20 liters of seawater in each aerated container.

Test animal preparation

The test organism used in this study was whiteleg shrimp (*Litopenaeus vannamei*) at the postlarvae-30 (PL-30) stage, sourced from PT Bibit Unggul (Global Gen), a certified hatchery located in North Lombok Regency, Indonesia. All shrimp were subjected to a standardized acclimatization procedure for seven days before the exposure trials to ensure uniform physiological status and reduce variability due to transport-related stress. This process was crucial to stabilize physiological functions, facilitate environmental adaptation, and enhance experimental reproducibility, particularly when evaluating sublethal effects under controlled conditions.Shrimp were maintained in aerated transport bags upon arrival at the experimental facility. A temperature and salinity equilibration step was conducted by floating the plastic transport bags in acclimatization tanks filled with filtered brackish water for 30 minutes. This procedure was carried out during the early morning (7 am) to minimize thermal stress, leveraging the naturally lower ambient temperatures and reduced solar radiation. After the floating period, small volumes of acclimatization water were incrementally added to the bags every 10 minutes for 1 hour to gradually adjust to new salinity, pH, and dissolved oxygen conditions, thus reducing osmotic shock.

Following this, shrimp were gently released into the acclimatization tanks (volume: 60 L) and held for 7 days under consistent water quality parameters (salinity: 25–28 ppt, temperature:

28–30 °C, pH: 7.8–8.3, dissolved oxygen: > 5 mg/L), with continuous aeration provided by air stones connected to a central blower system. Tanks were cleaned daily by siphoning feces and uneaten feed to prevent ammonia buildup and maintain a hygienic environment. During acclimatization, shrimp were fed ad libitum twice daily (8 am and 5 pm) with a commercial shrimp feed (CP Prima 781, protein content 38%), and feeding behavior was monitored to ensure normal activity levels and appetite.

During the experimental phase, stocking density was set at one individual per liter, with 20 shrimp housed in each 20-liter container. Shrimp that exhibited abnormal behavior (lethargy, erratic swimming, or surface floating) or physical deformities during the acclimation period were excluded from subsequent trials to ensure data validity. This systematic acclimatization protocol was designed to minimize pre-experimental stress and establish baseline health status, ensuring that observed treatment effects could be attributed primarily to microplastic exposure rather than environmental or procedural artifacts.

Microplastics polyvinyl chloride preparation

The type of microplastic used is PVC, which comes from PVC pipes. The first step is to crush the pipe using a grinder until it is smooth or micro (< 5 mm). Next, the microplastics were sifted using a tea sieve measuring 200 mesh. The sifted microplastics are weighed using an analytical scale according to the dose. Next, the microplastics that have been weighed are put into plastic clips.

Animal husbandry test and microplastic exposure

The maintenance of test animals is carried out for 45 days. Before being treated, whiteleg shrimp are acclimatized for more than 24 hours to adapt to the new environment and minimize stress and death. During the maintenance period, feeding is carried out with a dose of 5% of the total weight of shrimp, as many as 4 times a day, namely at 7 am, 11 am, 3 pm, and 7 pm. During maintenance activities, water is pumped and changed every 3 days, and water quality is checked every 1 week. Microplastic exposure is carried out by dissolving microplastics in water and adding them to the maintenance medium according to the treatment dose.

Identification of microplastic abundance in the gastrointestinal tract

The abundance of microplastics in the gastrointestinal tract of whiteleg shrimp was identified before being treated with microplastic exposure and at the end of rearing. Microplastic preparation before exposure treatment is done to determine if microplastics are in the shrimp's digestive tract. Before sampling the whiteleg shrimp digestive tract, the length and weight of the shrimp sample were first measured. Furthermore, the shrimp is carefully dissected to remove the digestive tract in the form of a stomach and intestines, then weighed to determine the weight of the shrimp's digestive tract. The next step is to insert the digestive tract into the Erlenmeyer, then add a 50% H_2O_2 solution 3 times the weight of the digestive tract sample, covered with aluminum foil, and heated at 60 °C for 24 hours until the digestive tract dissolves with H_2O_2 and separates microplastic particles. After being ovened for 24 hours, the sample is filtered using filter paper. The filtering results are placed in a petri dish and then baked for 1 hour at a temperature of 105 °C. The last step is to identify the type and abundance of microplastics using a microscope.

RESEARCH PARAMETERS

The parameters measured in this study include two parameters, namely the primary parameter and the supporting parameters. Some of the main parameters consist of checking the physiological condition of the test animals, such as behavior, and checking biological conditions, such as identification of the abundance of microplastics in the digestive tract of whiteleg shrimp, absolute length, absolute weight, SGR, FCR and SR. Meanwhile, the supporting parameters in this study consist of water quality parameters (physics and chemistry) such as temperature, DO, pH, salinity, and ammonia.

Physiological changes

Identifying physiological changes in shrimp is one of the main parameters in this study, where physiological changes in shrimp are characterized by intestinal distension and abnormal swimming behavior (Choi et al., 2018). In addition, shrimp exposed to microplastics can also experience metabolic disorders, endocrine disorders, inflammation, tissue damage, decreased growth, and even decreased survival (Wicaksono, 2022). Checking for physiological changes in shrimp is carried out once every 1 week. Physiological checks were carried out for 1–2 hours by paying attention to the swimming behavior and the response of whiteleg shrimp to feed.

Identification of microplastic abundance

The identification of microplastic abundance in this study was carried out to determine the abundance of microplastics of the PVC type contained in the digestive tract of whiteleg shrimp raised during the study. According to Arisanti et al. (2023), the calculation of microplastic abundance is calculated using the equation:

$$Abundance\ of\ microplastics = \frac{Number\ of\ microplastic\ (particles)}{Dry\ weight\ of\ the\ sample\ (grams)} \quad (1)$$

Absolute length

Absolute length measurements in whiteleg shrimp were taken weekly during the study and expressed in mm. The measurement of absolute length can be calculated using the formula according to Lucas et al. (2015), that is:

$$L\ (\text{cm}) = Lt - L0 \quad (2)$$

where: L – absolute length of preserved shrimp (cm), Lt – length of shrimp at end of rearing (cm), $L0$ – shrimp length at the beginning of rearing (cm).

Absolute weight

Absolute weight measurements in whiteleg shrimp were performed weekly during the study and expressed in grams. According to Setyono et al. (2023). To determine the absolute weight, the formula can be calculated using the following formula:

$$W\ (\text{grams}) = Wt - W0 \quad (3)$$

where: Wm – absolute weight (grams), Wt – weight of end-prying shrimp (grams), Wo – weight of shrimp at the beginning of the rearing (grams).

Feed conversion ratio (FCR)

FCR is a measure that expresses the ratio of the amount of feed used during maintenance. The FCR value can be calculated using the formula according to Amoah et al. (2019), that is:

$$FCR = \frac{F}{W} \quad (4)$$

where: FCR – feed conversion ratio, F – total feed (kg), W – total harvest (kg).

Specific growth rate (SGR)

SGR is a parameter used to determine the growth rate in shrimp during rearing. The specific growth rate can be calculated using the formula according to Muchlisin et al. (2017), that is:

$$SGR\ (\%) = \frac{(Ln\, Wt - Ln\, W0)}{t} \times 100 \quad (5)$$

where: SGR – specific growth rate (%/day), Wo – average body weight at the beginning of maintenance (grams), Wt – end-of-maintenance average body weight (grams), t – maintenance time (days).

Survival rate (SR)

Survival rate is the percentage of life from the beginning to the end of maintenance. According to Permatasari et al. (2023), Shrimp survival can be calculated using the formula:

$$SR\ (\%) = \frac{Nt}{No} \times 100 \quad (6)$$

where: SR – survival rate (%), Nt – final amount of whiteleg shrimp (individual), $N0$ – initial amount of whiteleg shrimp (individual).

Water quality

Water quality parameters are the supporting parameters in this study. The measurement of quality parameters includes water quality, physics, and chemistry in the maintenance media of whiteleg shrimp (*Litopeneaus vannamei*). The quality of the water includes temperature, acidity (pH), dissolved oxygen (DO), salinity, and ammonia (NH_3). Water quality measurement is carried out weekly at 8 am and 4 pm.

Data analysis

The data obtained from the results of the study, in the form of the abundance of PVC microplastics in the digestive tract, absolute length, absolute weight, FCR, SGR, and SR were tested using

Analysis of variance (ANOVA) at a confidence level of 95% using the SPSS 16 program. This analysis of variance test aims to determine the effect of each treatment given. Different final results will be tested further with the Duncan test. Meanwhile, data on physiological changes in whiteleg shrimp exposed to microplastics and water quality are presented in a table and described descriptively.

RESULTS AND DISCUSSION

Physiological changes in *Litopenaeus vannamei* exposed to microplastics

Exposure to MPs in aquatic environments has induced various physiological and behavioral changes in crustaceans, including *Litopenaeus vannamei*. These alterations are often sublethal but can significantly affect shrimp performance and survival in aquaculture systems. The present study observed progressive behavioral and physiological disruptions in shrimp exposed to polyethylene-based microplastics, consistent with previous findings (Lv et al., 2024; Niemcharoen et al., 2022; Xing et al., 2024) (Table 2 and 3).

During the initial week of exposure, most shrimp displayed regular swimming activity (NS). However, as exposure continued, distinct changes emerged in certain treatment groups, particularly in P3 and P4. These groups exhibited weak swimming (WS) and, in some cases, a tendency to remain motionless at the bottom (SB) by the third and fourth weeks. Such reductions in locomotor activity are indicative of physiological stress, possibly caused by internal damage or energy depletion (Lv et al., 2024). Behavioral impairments like these have been linked to microplastic-induced neurotoxicity and muscular fatigue due to oxidative damage (Xing et al., 2024), which interferes with normal neuromuscular function and metabolic processes essential for sustained swimming activity.

Shrimp feeding behavior also declined over time in higher MP concentrations. While individuals in lower exposure groups (P1 and P2) continued to show positive feeding responses (WE – Want to Eat), shrimp in P3 and P4 treatments began to show partial appetite suppression (SE – Some do not want to eat), especially during weeks 3 and 4. Reduced feeding behavior is a typical physiological response to sublethal stress and gastrointestinal dysfunction. It has been hypothesized that MPs disrupt the digestive tract through abrasion, blockage, or inflammation, thus reducing appetite and digestion efficiency (Niemcharoen et al., 2022; Vitheepradit and Prommi, 2023). Moreover, MPs can adsorb and carry toxic substances, which may further impair the gut lining, leading to reduced food absorption and nutrient uptake.

Chronic MP exposure has also been associated with metabolic stress and oxidative imbalance. Studies have reported increased malondialdehyde (MDA) content—a biomarker of lipid peroxidation—and alterations in the activity of antioxidant

Table 2. Swimming activity response of whiteleg shrimp exposed to microplastics

Treatment	Week 1			
	1	2	3	4
P1	NS	NS	NS	NS
P2	NS	NS	NS	NS
P3	NS	NS	WS	WS
P4	NS	SB	WS	WS:SB

Note: SB – silent at the bottom, WS – weak swim, NS – nornal swim.

Table 3. Feeding response of whiteleg shrimp exposed to microplastics

Treatment	Week 1			
	1	2	3	4
P1	WE	WE	WE	WE
P2	WE	WE	WE	SE
P3	WE	SE	SE	SE
P4	WE	SE	SE	WE

Note: NE – not want to eat, SE – some do not want to eat, WE – want to eat.

enzymes such as superoxide dismutase (SOD) and catalase (CAT), suggesting the induction of oxidative stress in *L. vannamei* (Lv et al., 2024). In addition to oxidative disturbances, microplastics have been linked to immunosuppression by interfering with hemocyte function, reducing phenoloxidase activity, and altering the expression of immune-related genes such as those regulating apoptosis and detoxification pathways (Niemcharoen et al., 2022; Xing et al., 2024).

Microplastics have been shown to accumulate in key tissues, including the digestive tract and hepatopancreas, where they can cause structural and functional damage. Histopathological studies revealed epithelial detachment, vacuolation, and lipid degeneration in the hepatopancreas of exposed shrimp (Li et al., 2024b), indicating disruption of lipid metabolism. The altered fatty acid composition observed in hepatopancreatic tissues of MP-exposed shrimp suggests compromised lipid homeostasis, which can affect energy storage, molting, and immune competence.

Beyond individual physiological responses, microplastic accumulation in shrimp tissues may threaten food safety and public health. Residual MPs in edible parts of aquaculture species can enter the human food chain, raising concerns over bioaccumulation and potential toxicity (Vitheepradit and Prommi, 2023). Furthermore, environmental microplastics may act synergistically with pathogens. For example, damage to immune barriers in shrimp has been reported to increase vulnerability to opportunistic infections such as White Spot Syndrome Virus (WSSV), especially in environments with high microplastic loadings (Priyanka Runwal, 2023).

The findings of this study reinforce growing evidence that microplastic exposure adversely affects shrimp physiology through multiple interrelated mechanisms, including oxidative stress, behavioral disruption, immunosuppression, and impaired metabolism. These alterations may compromise aquaculture productivity and pose risks to food security, underscoring the urgent need for improved plastic waste management in coastal and aquaculture ecosystems (Mohan and Raja, 2024).

Abundance of microplastics in the digestive tract of whiteleg shrimp

The quantitative results of microplastic abundance in the digestive tract of *Litopenaeus vannamei* show significant variation across treatments. The average microplastic abundance ranged from 10.98 ± 1.40 particles in the control group (P1) to 85.04 ± 16.90 particles in the highest exposure treatment (P4) (Figure 1). P2 and P3 showed intermediate values of 45.30 ± 6.36 and 57.26 ± 2.02 particles, respectively. ANOVA analysis ($\alpha = 0.05$) confirmed that microplastic exposure had a significant effect on microplastic abundance in shrimp digestive tracts ($p < 0.05$), with Duncan's post-hoc test indicating significant differences, particularly between P1 and all other treatments, and between P4 and P2/P3.

These results support the hypothesis that increased concentrations of microplastic exposure lead to increased ingestion and accumulation of microplastics in shrimp. Interestingly, even the control group (P1), not intentionally exposed to MPs, exhibited detectable microplastic presence, likely due to ambient environmental contamination, as also reported by Welden and Cowie (2016) and Chairrany et al. (2021). This finding is ecologically relevant because it reflects the ubiquitous nature of microplastics, even in controlled environments.

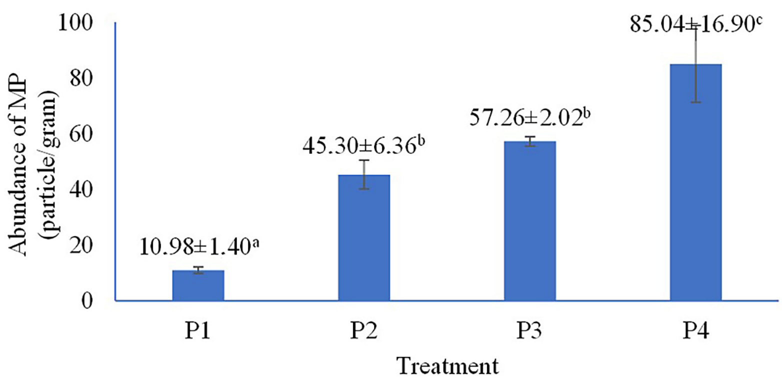

Figure 1. Abundance of microplastics in the digestive tract of shrimp

The PVC fragments used in this experiment—representing a standard aquaculture material—are known to degrade over time due to mechanical wear and UV exposure (Świetlik and Magnucka, 2024). These fragments, characterized by their irregular shape, were visually confirmed under 10× magnification and are consistent with previous findings by Seftianingrum et al. (2023), who reported that fragment-type microplastics dominate in aquaculture environments due to the structural degradation of PVC and other polymeric equipment.

The accumulation trend observed in P2–P4 aligns with Valencia-Castañeda et al. (2022), who found that microplastics are most likely to accumulate in digestive tissues due to ingestion during feeding. This phenomenon is critical from a food safety standpoint, especially as shrimp consumption is usually whole or semi-whole in some cultures. These results answer the central research question: Does increased exposure to microplastics affect the physiological and behavioral response of whiteleg shrimp, including accumulation in their digestive tract? The significant dose-response relationship demonstrated here confirms that increased microplastic exposure directly correlates with microplastic accumulation in the gastrointestinal tract of shrimp. This also validates the concern regarding microplastics' bioavailability and ingestion risk in intensive and semi-intensive aquaculture settings.

Moreover, as discussed earlier, physiological disturbances, such as reduced feeding and altered swimming behavior, are closely associated with this accumulation. The physical presence of microplastics in the digestive system could contribute to intestinal blockage or reduced nutrient absorption, further explaining the sublethal behavioral impairments observed (Lv et al., 2024; Niemcharoen et al., 2022). As the digestive tract becomes a site for microplastic retention, the shrimp's overall health and productivity are likely compromised, reducing aquaculture efficiency and posing potential food chain risks.

Absolute length of whiteleg shrimp

The absolute length measurement in *Litopenaeus vannamei* after 45 days of rearing revealed that shrimp length ranged from 1.9 to 3.0 cm across treatments (Figure 2). The control group (P1) recorded the highest growth, averaging 3.0 cm, while the lowest average growth was found in P3 (1.9 cm). Treatment P2 and P4 resulted in 2.3 cm and 2.2 cm, respectively. The one-way ANOVA test at a 95% confidence level indicated that the treatment significantly affected absolute length ($p < 0.05$). Duncan's post hoc test confirmed that P1 significantly differed from P2, P3, and P4, whereas P2 did not differ significantly from P3 and P4.

These findings demonstrate a clear negative impact of microplastic exposure on shrimp growth, thus directly answering the research question of whether microplastics affect shrimp physiological parameters. The highest growth observed in the control group (P1) emphasizes that the absence of microplastics enables optimal growth, while the decreasing trend from P2 to P4 supports the hypothesis that increasing microplastic concentrations impair somatic development in shrimp.

The inhibited length growth in microplastic-exposed treatments (P2–P4) may be attributed to physiological stress or digestive interference, reducing nutrient uptake efficiency from the feed. Hidayat et al. (2017) reported that inadequate feed

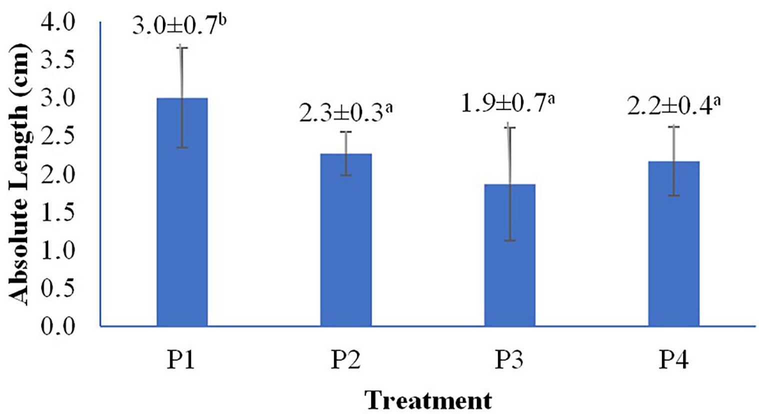

Figure 2. Absolute length of whiteleg shrimp

utilization in shrimp leads to protein and fat deficiencies, ultimately hindering growth. This mechanism is consistent with our observation, suggesting that microplastics interfere with the digestive system, possibly causing intestinal abrasion or blockage, thus limiting nutrient assimilation.

Moreover, studies such as Saha and Chandrasekaran (2024) provide corroborative evidence that microplastic exposure significantly decreases the growth rate in aquatic invertebrates. They observed that Artemia salina exposed to microplastics showed a 14.95% reduction in growth, highlighting the universal nature of this physiological disruption across taxa.

In summary, the significant reduction in absolute length in shrimp exposed to PVC-derived microplastics confirms that microplastics are a growth-inhibiting stressor. These findings underline the ecological risk of microplastic contamination in aquaculture systems and reinforce the need to reduce plastic use or enhance waste management in shrimp farming practices.

Absolute weight of whiteleg shrimp

The absolute weight of *Litopenaeus vannamei* after 45 days of cultivation showed a considerable variation across treatments, ranging from 3.6 to 35.3 grams (Figure 3). The highest weight gain was recorded in the control group (P1), with an average of 35.3 grams, followed by P2 (7.4 g), P3 (6.1 g), and the lowest value in P4 (3.6 g). One-way ANOVA analysis confirmed that microplastic treatment significantly affected shrimp weight gain ($p < 0.05$). Further, Duncan's test revealed that P1 significantly differed from all other treatments (P2, P3, P4), indicating the detrimental effect of microplastics on shrimp biomass accumulation.

These results strongly support the hypothesis that exposure to microplastics negatively affects shrimp growth performance, particularly in terms of biomass. Even at the lowest dose of 3 mg/L (P2), the significant drop in weight gain implies that microplastics begin exerting inhibitory effects at minimal concentrations, highlighting their toxicological relevance in aquaculture environments.

The mechanism behind weight reduction is likely due to the accumulation of microplastics in the digestive tract, which interferes with nutrient absorption and metabolic processes. As Hanif et al. (2021) explained, microplastic ingestion can disrupt energy absorption, hormonal balance, and growth metabolism, all contributing to reduced weight gain. In the current study, shrimp in treatments P2, P3, and P4 likely ingested significant amounts of microplastics due to their resemblance to feed particles, a phenomenon also observed in fish, bivalves, and invertebrates (Saha and Chandrasekaran, 2024).

In contrast, the control group (P1) exhibited optimal growth conditions, with shrimp reaching 3.4–4 g/head, in alignment with previous findings by Akbarurrasyid et al. (2023), who reported weight ranges of 1.61–2.11 g/head under similar rearing conditions. This confirms that shrimp can digest and utilize nutrients effectively without microplastic stressors, enhancing somatic growth.

Overall, the statistically significant weight decline across microplastic-exposed treatments demonstrates that microplastics act as an inhibitory agent for weight gain, posing a serious threat to shrimp farming productivity. These findings

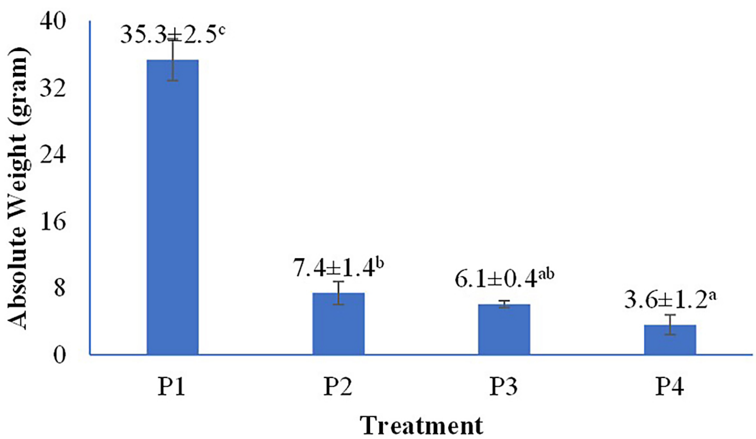

Figure 3. Absolute weight of whiteleg shrimp

provide crucial evidence that microplastic pollution in aquaculture waters can compromise feed efficiency and thus diminish economic yields, directly answering the study's core question on the physiological effects of microplastics on whiteleg shrimp.

Feed conversion ratio (FCR)

The FCR, which indicates the efficiency of feed utilization to gain 1 kg of biomass, varied significantly among treatments, ranging from 1.49 to 2.14 (Figure 4). The lowest FCR was recorded in the control group (P1) with a mean value of 1.49 ± 0.07, while the highest values were observed in P2 (2.14 ± 0.10), P3 (2.13 ± 0.05), and P4 (1.97 ± 0.08). Statistical analysis using ANOVA ($p < 0.05$) confirmed that the microplastic exposure significantly affected FCR values. Duncan's post hoc test further showed that P1 differed significantly from all other treatments, whereas no significant difference was found among P2, P3, and P4.

These results support the hypothesis that microplastic exposure reduces feed utilization efficiency, as reflected in the elevated FCR values. In the control treatment (P1), an FCR value of 1.49 indicates that shrimp converted feed into biomass more efficiently compared to other groups, which aligns with the ideal FCR for whiteleg shrimp culture as proposed by (Arsad et al., 2017), stated that an FCR ≤ 1.5 reflects optimal performance.

Conversely, the significantly higher FCR values in P2–P4 suggest a decline in feed digestibility and assimilation in microplastic-exposed shrimp. This inefficiency may result from microplastic ingestion, which disrupts digestive tract functions and nutrient uptake. However, it differs from research by Hidayatullah et al. (2025), i.e., the FCR value did not differ significantly even though catfish were exposed to PVC microplastics for 45 days. This indicates that the dose is still within the sublethal threshold, which does not directly interfere with metabolic efficiency. The effective catfish excretion mechanism allows the elimination of microplastics without inhibiting the absorption of nutrients. In addition, a stable appetite during treatment reflects physiological tolerance to environmental stressors.

The data also emphasize the interconnectedness between FCR, growth performance, and environmental conditions. According to Seftianingrum et al. (2023), a low FCR reflects efficient feed use, contributing to faster growth and higher profitability in aquaculture systems. In this context, the control group's superior FCR correlates well with its higher absolute weight, reinforcing the conclusion that microplastic exposure negatively affects feed efficiency and growth. These findings directly address the core question of the study—how microplastics influence the physiological and production parameters of whiteleg shrimp—by demonstrating an apparent degradation in performance metrics under microplastic stress.

Specific growth rate (SGR)

The SGR analysis revealed a clear trend influenced by microplastic exposure levels (Figure 5). The highest SGR was recorded in the control group (P1) at 2.60 ± 0.23%/day, while P2, P3, and P4 exhibited significantly lower values of 0.74 ± 0.17, 0.69 ± 0.06, and 0.40 ± 0.15%/day, respectively. Statistical analysis using ANOVA ($p < 0.05$) confirmed that microplastic exposure significantly affected SGR. Furthermore, Duncan's post hoc test showed that the SGR in P1 differed significantly from the exposed groups (P2–P4),

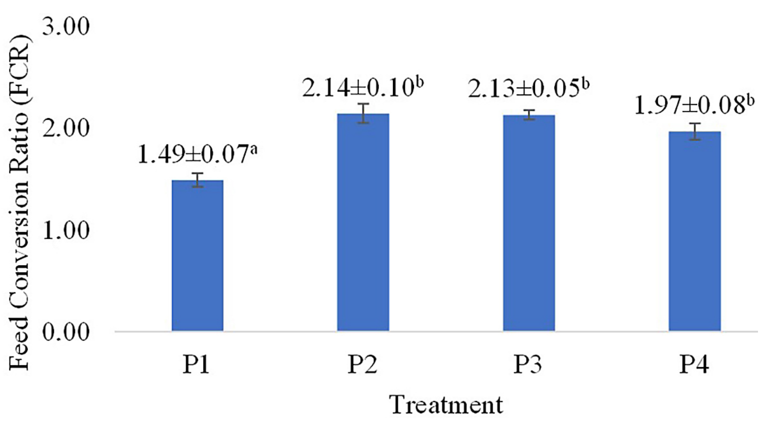

Figure 4. Feed conversion ratio of whiteleg shrimp

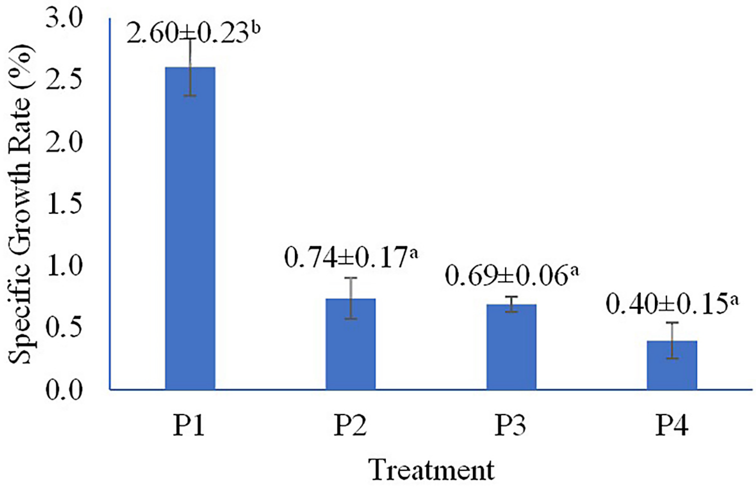

Figure 5. Specific growth rate of whiteleg shrimp

whereas no significant differences were found among P2, P3, and P4 despite their differing exposure concentrations.

These results directly demonstrate that microplastic exposure, even at low concentrations, severely impairs the growth performance of whiteleg shrimp. The sharp decline in SGR from 2.60%/day in P1 to only 0.74%/day in P2, despite the latter receiving only 3 mg/L of microplastic, suggests a strong physiological stress response initiated early during exposure. This finding aligns with the core hypothesis of this study: that microplastics disrupt shrimp growth by altering physiological functions essential for nutrient assimilation and energy allocation. No significant difference was observed between P2, P3, and P4, even though they received increasing doses of microplastics, indicating a threshold effect, wherein minimal exposure is already sufficient to induce maximal physiological disturbance. According to Baalkhuyur et al. (2018), ingested microplastics accumulate in the digestive tract, causing intestinal blockages, physical injury, and false satiety, reducing feeding activity and impairing nutrient absorption. This explains the reduced growth rates across all exposed groups.

Furthermore, Muhib and Rahman (2023) reported that microplastics may cause organ and tissue damage, while Saha and Chandrasekaran (2024) highlighted that exposure can result in malnutrition, energy depletion, and structural damage to the gastrointestinal tract. These pathological effects correspond with the observed stagnation in SGR under increasing microplastic concentrations in this study.

Overall, these findings establish a direct causal link between microplastic exposure and reduced growth efficiency and support the conclusion that even environmentally relevant concentrations of microplastics can significantly compromise aquaculture productivity. The significant drop in SGR under all exposure treatments addresses the research question by providing strong evidence that microplastics adversely affect shrimp growth performance through physiological and digestive disruption.

Survival rate

The survival rate (SR) of whiteleg shrimp (*Litopenaeus vannamei*) over the 45-day rearing period exhibited a marked decline across increasing levels of microplastic exposure (Figure 6). The control group (P1) showed the highest SR at 87%, whereas treatments with microplastic exposure resulted in lower survival: 52% in P2, 48% in P3, and the lowest value of 37% in P4. Statistical analysis using ANOVA ($p < 0.05$) confirmed that microplastic exposure significantly affected shrimp survival. Subsequently, Duncan's multiple range test indicated that P1 differed significantly from all treatments (P2–P4). However, the relationships between P2, P3, and P4 were more complex: P2 and P3 were not significantly different, whereas P4 was significantly different from P2 but not from P3.

These results indicate a clear inverse relationship between microplastic concentration and shrimp survival, supporting the hypothesis that chronic microplastic exposure negatively affects

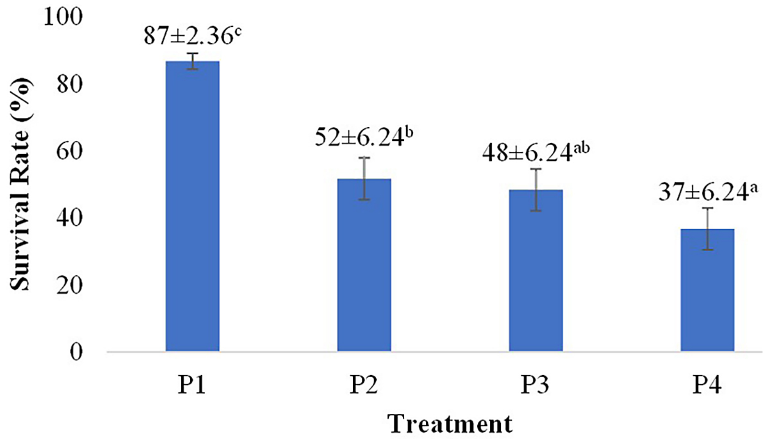

Figure 6. Survival rate of whiteleg shrimp

the viability of shrimp. The significant decline in survival rate from 87% in control to only 37% in the highest exposure group demonstrates that microplastics can act as a critical environmental stressor. The digestive blockage and internal injuries caused by ingested microplastics are likely key drivers of mortality, especially under prolonged exposure.

Despite differing doses, the lack of significant difference between P2 and P3 suggests the onset of acute physiological impacts at even low concentrations (3 mg/L). However, the notably lower survival in P4 (10 mg/L) suggests a dose-dependent exacerbation of mortality, potentially due to cumulative tissue damage or systemic organ failure. According to Korez et al. (2020), exposure to microplastics can cause internal organ damage, increased stress responses, and ultimately death, especially when the particles are persistent and non-biodegradable, as in this study.

Furthermore, these findings are critical from an aquaculture perspective. The sharp reduction in SR across all exposed groups implies that even environmentally realistic microplastic levels seriously threaten shrimp farm productivity. This supports the broader aim of the study—to evaluate the biological consequences of microplastic ingestion in cultured species—and provides direct evidence that microplastic contamination in aquaculture environments compromises shrimp survival through digestive obstruction, energy imbalance, and increased susceptibility to disease or systemic failure.

Water quality

Water quality is critical in aquaculture as it directly affects cultured species' growth performance, health status, and survival, including *Litopenaeus vannamei*. This study measured key physical and chemical water quality parameters weekly during the 45-day rearing period to ensure that any observed effects on shrimp performance were attributable to microplastic exposure rather than environmental fluctuations. Table 4 compares the measured values for temperature, dissolved oxygen (DO), pH, salinity, and ammonia with their optimal ranges.

All measured parameters remained within the optimal range for whiteleg shrimp cultivation throughout the experiment. The temperature was stable (27.7–29.7 °C), supporting enzymatic and metabolic activities in shrimp (Supriatna et al., 2020). The dissolved oxygen levels, though slightly dipping near the lower limit (minimum 4.2 mg/L), were maintained by continuous aeration,

Table 4. Measurement of water quality parameters

Parameters	Measurement value	Optimum value	References
Temperature (°C)	27.7–29.7	27.2–32	Supriatna et al. (2020)
Dissolved oxygen (mg/L)	4.2–6.1	5.0–9.0	Wyk & John (2020)
pH	7.2–7.22	7–8.3	Hamzah et al. (2021)
Salinity (ppt)	32–33	25–35	Manullang et al. (2023)
Ammonia (mg/L)	0–0.05	< 0.1	Wulandari et al. (2015)

ensuring sufficient oxygen for respiration and microbial decomposition of organic matter.

The pH values (7.2–7.22) were neutral and stable, aligning with the optimal range of 7–8.3 (Farabi and Latuconsina, 2023). These values are not expected to cause gill damage or metabolic stress (Hamzah et al., 2021). Salinity (32–33 ppt) was also ideal for marine shrimp growth, while ammonia levels (0–0.05 mg/L) were well below the toxic threshold of 0.1 mg/L (Wulandari et al., 2015), minimizing risks of gill swelling or reduced oxygen transport.

These optimal water conditions confirm that environmental stressors were effectively controlled, allowing microplastic exposure to be isolated as the primary treatment variable. Consequently, the observed decline in shrimp survival and growth in treatments P2–P4 can be directly attributed to microplastic ingestion and accumulation rather than to water quality fluctuations. The absence of water quality anomalies strengthens the internal validity of the experimental design and reinforces the conclusion that microplastics, not environmental degradation, are responsible for adverse biological effects.

Thus, water quality data ensures the reliability of treatment effects and contextualizes the biological responses of shrimp under standardized conditions. These findings highlight the ecological risk of microplastic contamination in aquaculture systems, even when optimal environmental conditions are maintained.

CONCLUSIONS

This study demonstrates that sublethal exposure to PVC microplastics significantly impairs the physiological performance of whiteleg shrimp (*Litopenaeus vannamei*), evidenced by altered swimming and feeding behaviors, reduced growth (length and weight), decreased feed efficiency (higher FCR), lower SGR, and diminished survival rates. These impacts, occurring even at environmentally relevant concentrations, highlight microplastic pollution's grave threat to shrimp aquaculture productivity and sustainability. The accumulation of microplastics in the digestive tract and hepatopancreas may also pose food safety risks, emphasizing the urgent need for tighter regulations on plastic waste management and the use of polymer-based materials in aquaculture systems. From a policy perspective, this study supports formulating environmental quality standards for microplastic concentrations in aquaculture waters and encourages the adoption of alternative, biodegradable materials in shrimp farming infrastructure. Future research should investigate long-term generational effects and tissue-specific histopathological impacts and explore mitigation strategies, such as probiotic supplementation or system filtration technologies, to reduce microplastic bioavailability. These findings provide a scientific foundation for more sustainable aquaculture practices and contribute to broader environmental policy dialogues on microplastic pollution in coastal ecosystems.

Acknowledgment

The authors gratefully acknowledge the financial support provided by the DIPA BLU Research Capacity Building Scheme, University of Mataram, Fiscal Year 2025, under Contract No. 3762/UN18.L1/PP/2025. This support, facilitated through the Institute for Research and Community Service (LPPM) at the University of Mataram, has completed this research.

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