



# Microplastic contamination in giant tiger prawn and greasyback shrimp from Malaysian waters

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Received: 12 August 2025 / Revised: 10 June 2026 / Accepted: 21 June 2026  
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## Abstract

Microplastics (MPs) are ubiquitous contaminants in the marine environment. The potential pathway through the food web to humans is a general public concern. Commonly consumed marine organisms have never been studied for the presence of MPs as an entry route into the food chain. This study selected *Penaeus monodon* (tiger prawn) and *Metapenaeus ensis* (greasyback shrimp) because of their commercial importance, high consumption rates, and consistent availability in Miri, Sarawak, Malaysia. Samples were collected from major fish markets supplied by both coastal fisheries and aquaculture farms. The gastrointestinal tracts of both species were analyzed under a microscope, and Attenuated Total Reflectance Fourier-Transform Infrared (ATR–FTIR) spectroscopy was performed on suspected MPs based on their physical characteristics. All samples contained plastic:  $280 \pm 91$  pieces/kg wet weight for *P. monodon* and  $457 \pm 171$  pieces/kg for *M. ensis*. Fibers were the dominant shape of the MPs observed, followed by fragments and pellets; black was also the dominant color. Most of the particles determined by size were within 500 to 1000  $\mu\text{m}$  in dimension. Polyester and polystyrene were the two major types of polymers by the FTIR analysis. This calls for urgent reinforcement in food safety measures accompanied by environmental policy interventions directed towards microplastic contamination in seafood that encapsulates potential health risk avenues to consumers as well as broader ecological impacts.

**Keywords** Microplastics · Marine pollution · Marine ecosystems · Shrimps · Crustaceans · Polyester · Polystyrene

## Introduction

In recent decades, emerging anthropogenic pollutants have become increasingly prevalent in various environmental compartments due to intensified human activities and industrialization (Hadibarata and Kristanti 2012; Syafuddin et al.

2020). Microplastics (MPs) are widespread pollutants with a particle size of less than 5 mm (0.5 cm) that are chemically synthesized from a polymer group composed of inorganic and organic elements such as carbon, hydrogen, nitrogen, and oxygen (Ahmed et al. 2021). According to their shapes, MPs are categorized as beads, fragments, fibers, foam, and

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films in environments (Parolini et al. 2023; Ismanto et al. 2023). These categories have different compositions; for instance, bead shape is formed by polyethylene (PE), fragments are formed by polyethylene terephthalate (PET) and polystyrene (PS), fibers are formed by polypropylene (PP), polyacrylonitrile (PAN), and polyamide (PA), foam are formed by polyurethane (PU), and films are formed by PE and PET. The shape of these MPs is mostly derived from personal products, pharmaceuticals, and medical waste. The high number of MPs in environments has attracted considerable critical attention because they have adverse negative impacts in living organisms, such as crustaceans, reefs, bivalves, and mammals, which may enter the food web. In addition, MPs can concentrate, absorb, and release other pollutants. Given these risks, understanding their abundance and distribution in various environments has become increasingly important.

MPs are often consumed by organisms at the bottom of the food web. Recent measurements in the South Yellow Sea, China, found MP concentrations as high as 1.7–47.0 items/g in benthic organisms (Wang et al. 2019). These levels are higher than those recorded in the largest freshwater lake in China, Poyang Lake, which had 0–18 items per individual wild crucians (*Carassius auratus*) (Yuan et al. 2019). Projections indicate that MPs concentrations in the ocean, especially near the Pacific Ocean, could double by 2030 and quadruple by 2060 compared with the levels in 2019 (Isobe et al. 2019), suggesting a continuous increase in MPs pollution in aquatic environments.

MPs in water environments adversely affect aquatic organisms. For example, exposure to MPs can impact the health of *Danio rerio* by increasing oxidative stress, damaging the intestinal wall, inducing inflammatory responses, and altering the activity of enzymes such as catalase (CAT), superoxide dismutase (SOD), and diamine oxidase (DAO), as well as affecting the abundance of specific gut microbiota like Proteobacteria and Fusobacteria (Qiao et al. 2019b). In a study focusing on freshwater fish, the presence of 100 µg/L MPs in surface water was found to influence the bioaccumulation of pharmaceuticals, such as roxithromycin, in tissues of *Oreochromis niloticus* (Zhang et al. 2019). The altered distribution of roxithromycin in the gut, brain, gills, and liver, corresponded with changes in the activities of key enzymes, including acetylcholinesterase and cytochrome P450 (CYP), as well as increased oxidative stress (Zhang et al. 2019). Similarly, another study reported that exposure to 100 mg/L MPs induced anemia and various biochemical changes in *O. niloticus* (Hamed et al. 2019). In marine ecosystems, MPs can accumulate in tissues such as the liver, gill, and gut of *Eriocheir sinensis*, leading to alterations in enzyme activities (acetylcholinesterase, alanine aminotransferase, catalase, aspartate transaminase,

superoxide dismutase, glutathione, and glutathione peroxidase) and changes in gene expression. While MPs pollution and its effects are now recognized globally, most research has focused on temperate regions and large freshwater systems. Similar studies are needed in tropical coastal areas, where ecological conditions and human activities may affect the distribution and effects of MPs differently. The tropical shore of Malaysia supports a great range of plant and animal life and includes a large area of great economic importance from the perspective of fisheries, especially shrimp. Shrimps play an ecological role in the marine ecosystem, and they are recognized as effective bioindicators for monitoring environmental pollutants and water quality due to their sensitivity towards contaminants (Jansen van Rensburg et al. 2020; Keshavarzifard et al. 2020). Previous studies have demonstrated the vulnerability of shrimp species, such as *Caridina nilotica* and *Metapenaeus affinis*, to xenobiotics and polycyclic aromatic hydrocarbons (PAHs) (Jansen van Rensburg et al. 2020; Keshavarzifard et al. 2020), while *Litopenaeus vannamei* has exhibited biological responses to MPs exposure (Wang et al. 2021). Shrimps can accumulate MPs from their environment, and these can be transferred through the food chain to humans, which raises concerns regarding the potential risks to human health. However, there is a lack of local-scale specificity for both aquatic biota and human consumers. Economically and ecologically important tropical prawn species, such as *Penaeus monodon* (tiger prawn) and *Metapenaeus ensis* (greasyback prawns), have been scarcely studied for MPs contamination in Malaysian waters, despite being among the most consumed seafood along the coast and harvested from potentially polluted areas. Therefore, this study aimed to assess the abundance, types, and distribution of MPs in two commercially important shrimp species, *P. monodon* and *M. ensis*, collected from markets in Miri, Malaysia. This preliminary assessment aims to provide baseline data on MP contamination in these species, evaluate potential risks to human health through seafood consumption, and address existing knowledge gaps for environmental scientists and public health stakeholders in this region.

## Materials and methods

### Sample collection

*P. monodon* and *M. ensis* shrimp samples were collected from seven major fish markets in Miri, Sarawak State, Malaysia. These were the Miri Fish Market (4°23'53.9"N 113°59'00.6"E), the Piasau Wet Market (4°24'34.9"N 113°59'06.4"E), the Miri Central Market (4°23'35.7"N 113°59'13.5"E), the Krokop Central Market (4°25'38.2"N

114°00'06.6"E), the Fish Market Waterfront (4°24'00.1"N 113°59'12.4"E), the Lutong Market (4°28'13.2"N 114°00'28.8"E), and the Batu 1 Fish Market (4°29'48.2"N 113°59'47.4"E). For each species, there were 7 kg total samples collected: 1 kg of *P. monodon* and 1 kg of *M. ensis* from each market. The samples were obtained from local aquaculture facilities and wild captures from adjacent coastal seas, notably the South China Sea and the Celebes Sea. To obtain a comprehensive picture of the number of MPs are in the area, shrimp samples from all the markets were mixed together and then analyzed. This pooling method gave us a sample for each species, showing the general MPs exposure that seafood eaters in Miri face, rather than differences between markets. After being bought, all samples were put in bags filled with ice to keep them fresh while being transported to the laboratory, where they were stored in a freezer until further processing. We chose these two types of shrimp because they are important for business, are often eaten in the area, and are always available in all markets. *P. monodon* is a large-sized prawn (15–25 cm), predominantly farmed in Sarawak, while *M. ensis* is a smaller, wild-caught species (7–12 cm), frequently sold fresh. The inclusion of both species allowed for the comparison of microplastic contamination across shrimp of different sizes and ecological backgrounds.

### Sample preparation and separation

Quality controls were implemented throughout the study, from sample collection to final analysis, to minimize potential contamination and ensure the accuracy and reliability of the data collected, according to Zheng et al. (2019). Glassware and metal tools were used instead of plastic wares to eliminate contact between plastics and samples during sample preparation and analysis. All apparatus used in this experiment were rinsed three times with distilled water before each trial to prevent for cross-contamination within samples. After dissecting the shrimps, the removed gastrointestinal tract was placed in clean conical flasks and immediately covered with aluminium foil. Samples that were not used were covered with aluminium foil to prevent airborne contamination. The conical flasks and the filtration apparatus were rinsed three times to remove the MPs particles from the apparatus wall, thereby minimizing the loss of MPs particles during the filtration process. The cellulose acetate filter paper used was observed under a microscope to ensure there is no background contamination of MPs.

Sample preparation was performed according to the method described. The shrimp samples were thawed at room temperature and rinsed thoroughly with distilled water to remove any contaminants and impurities. The shrimps were then deshelled and dissected using metal scissors and

appropriate tools. Their deshelled weights were measured on an electronic balance, which recorded the wet weight of each shrimp. These weighed shrimps were then grouped into replicates, totalling 200 g for *P. monodon* and 100 g for *M. ensis*. The oesophagus, foregut, midgut, and anus of the shrimp were removed with the assistance of metal instruments. To avoid the pollution of floating dust, the guts taken-out from each copy were put in separate bottles of 250 ml size and sealed with tin foil.

Minor adjustments were made to the method of Phuong et al. (2018) for the extraction of MPs. Alkali digestion was applied to extract MPs. KOH was selected as the digestion agent because it does not adversely affect the polymers in MPs; it is stable and rapidly extracts most of the MPs. The procedure started with the addition of 10% KOH solution (40 mL) to 250 ml flasks comprising shrimp stomachs for organic matter digestion. A glass rod facilitated stirring, following which these flasks were enclosed in aluminium foil and subsequently set in the shaker incubator. This was stirred with a glass rod and the flasks were then covered with aluminium foil. They were placed inside a shaker incubator. Incubation was performed at 60 °C and 90 rpm for 24 h, followed by further incubation at room temperature, maintaining the same agitation for another 24–48 h depending on the digestive conditions of the gastrointestinal tracts.

Density separation was performed after digestion to remove low-density MPs particles from high density impurities. A saturated solution of sodium chloride (NaCl) was used because most MPs have densities of less than 1.2 g/cm<sup>3</sup> (Andrady 2011). Furthermore, NaCl is nonhazardous and inexpensive (Cutroneo et al. 2021). Eighty milliliters (80 ml) of saturated NaCl solution with a density of 1.2 g/cm<sup>3</sup> was added to the digestate for density separation. After mixing thoroughly by hand, it was transferred into a separating funnel where it stood undisturbed for about 2 h so that the supernatant could be carefully decanted later on and filtered under vacuum through cellulose acetate membrane filter (47 mm diameter, 0.45 µm pore size (LabServ) using a filtration set connected to vacuum pump. A 15% solution of hydrogen peroxide was added to the paper in a clean petri dish, covered with aluminium foil to partially digest of any organic matter left on the paper. The Petri dish was then dried in an oven at 60 °C for 4 h before microscopic analysis of the extracted MPs.

### Characterization and identification of MPs

After the MP samples were dried, they were visually observed and identified on the filter paper using a stereo microscope (Nikon SMZ745T) and NIS-Elements microscope imaging software. The magnification ranged from 2 to 5X for observation. The digital camera was used to acquire

MPs images of various shapes and colors. Several criteria were considered for the visual identification of MPs under the microscope. These guidelines explained characteristics such as the absence of visible structural elements or tissues, the appearance of MPs as filaments, the maintenance of an equal thickness without any tapered ends or segments, and an even distribution of color (Hidalgo-Ruz et al. 2012). All suspected plastics were sorted by their shape, size, and color. The shapes consisted of filaments, miscellaneous fragments, and pellets; the colors were black, blue, transparent, red, and green (Hidalgo-Ruz et al. 2012). The size of MPs was determined by their greatest length measured in micrometers ( $\mu\text{m}$ ) with the NIS-Elements microscope imaging software and was assigned to the following size classes:  $<100\ \mu\text{m}$ ,  $100\text{--}250\ \mu\text{m}$ ,  $250\text{--}500\ \mu\text{m}$ ,  $500\text{--}1000\ \mu\text{m}$  and  $1000\text{--}3000\ \mu\text{m}$  (Hidalgo-Ruz et al. 2012).

The MPs composition of suspected MPs was analyzed by Attenuated Total Reflectance Fourier Transform Infrared Spectroscopy (ATR-FTIR; AGILENT, USA). The diamond-shaped ATR crystals were fully dried with alcohol before each run. Scanning was conducted in transmission mode over the  $4000$  to  $650\ \text{cm}^{-1}$  range at a resolution of  $4\ \text{cm}^{-1}$  with eight scans collected for each sample. Spectra were obtained using MicroLab PC software. The extracted information from this software was inputted here for interpretation, and was graphed to create an FTIR spectrum graphic. These spectra are compared to those in the literature spectra of MPs polymers to ascertain the type of MPs based on the characteristic bands it absorbs.

## Statistical analysis

MPs abundance was calculated by dividing the number of MPs per wet weight of shrimp; results are given as items per  $100\ \text{g}$  of wet weight (w.w.). To show the variation in the

samples, the data are presented as mean  $\pm$  standard deviation (SD). Descriptive statistical analysis, including mean, standard deviation, and distribution of MPs types, shapes, sizes, and colors, was performed using with Microsoft Excel. The software also generated basic visualizations, such as bar graphs, that illustrated the distribution of MPs. Because the study was exploratory, the focus was on descriptive statistics to determine the prevalence of MPs in shrimp species.

## Result and discussion

### Microplastics abundance

*P. monodon* and *M. ensis* are crustaceans that share the same taxonomic group as all other prawns and shrimps. A total of 601 MPs particles were detected in all the samples. The average number of MPs items found per kg wet weight was slightly lower in *P. monodon* at  $280 \pm 91$ , with *M. ensis* having a higher average of  $457 \pm 171$  items per kg (Fig. 1). This indicates that *M. ensis* might be more prone to MPs ingestion, which could be attributed to varying habitats, feeding behaviours, and exposure. The heightened contamination of *M. ensis* with MPs indicates that their ecological niche is nearer to the seabed, where the MPs are likely to settle. These results show that different kinds of shrimps eat MPs in different ways, and they also show the importance of both species as bioindicators for measuring MPs pollution in the marine food chain.

Both *P. monodon* and *M. ensis*, bottom-dwelling crustaceans that prefer sand/mud habitats, consume polychaetes, small crustaceans, phytoplanktons, algae, zooplankton, and sediments (Chong et al. 2021). This feeding behaviour potentially exposes them to ingesting accumulated MPs in bottom sediments (Hossain et al. 2020; Xu et al. 2020). The variance in MPs abundance between *P. monodon* and *M. ensis* may be attributed to species-specific feeding selectivity, despite their similar detritus feeding strategies. The abundance of MPs within the gastrointestinal tract of these crustaceans may correlate with MPs pollution levels in the marine environment (Wang et al. 2019). Previous studies on benthic organisms from the South Yellow Sea and on Asian clams have demonstrated correlations between MPs abundance in organisms and sediment (Kristanti et al. 2023; Su et al. 2018; Wang et al. 2019). The shrimps examined in this study were caught from coastal waters in Kuala Baram, where industrial activities (e.g., plywood manufacturing, shipyards, plastic production) and fishing/trawling may contribute to the prevalence of MPs (Silori et al. 2023).

The abundance of *P. monodon* and *M. ensis* MPs in this study aligns with findings on *Crangon crangon* from Belgium and *Paranaeopsis hardwickii* from Xiangshan Bay

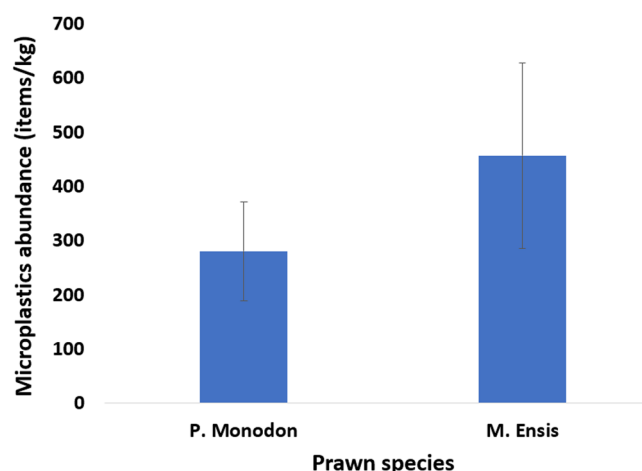


**Fig. 1** The abundance of MPs in *P. monodon* and *M. ensis*. Error bars represent the standard error of the mean

in China (Devriese et al. 2015; Wu et al. 2020). It exceeds the *Fenneropenaeus indicus* reports from India (Daniel et al. 2020) but remains lower compared with other studies (Abbasi et al. 2018; Nan et al. 2020). Higher abundance of MPs was attributed to exposure during processing in supermarkets in Singapore where *Litopenaeus vannamei* and *Fenneropenaeus vannamei* were found (Curren et al. 2020). In addition, cultured *L. vannamei* has high levels of MPs due to the use of plastic-based aquaculture equipment (Valencia-Castañeda et al. 2022). Apart from that difference in extraction protocols when analyzing crustaceans or any marine biota may result in variations in the findings (Cho et al. 2019). A harmonized protocol will enable full interstudy comparisons in MPs assessments. Table 1 presents the comparative analysis.

### Microplastics characterization

Under the microscope, the different forms and colors of MPs found in *P. monodon* and *M. ensis* were observed, including black fiber (Fig. 2.a), blue fiber (Fig. 2.b), red fiber (Fig. 2.c), green fiber (Fig. 2.d), transparent fiber (Fig. 2.e), blue fragment (Fig. 2.f), black fragment (Fig. 2.g), transparent fragment (Fig. 2.h), black pellet (Fig. 2.i), and transparent pellet (Fig. 2.j). The predominant of MPs shape in both species was fiber (77.05%), followed by fragments (22.47%) and pellets (0.46%). In *P. monodon*, the proportion of fiber was 79.59%, with fragment and pellet at 19.74% and 0.65%, respectively. *M. ensis* exhibited a dominance of fiber at 74.51%, followed by fragment and pellet at 25.21% and 0.26%, respectively (Fig. 3). Fiber was also dominant in *P. monodon* collected from the Northern Bay of Bengal, Bangladesh (Hossain et al. 2020), the Persian Gulf, Iran, and the Arabian Sea (Gurjar et al. 2021). *M. ensis* from the Arabian sea (Gurjar et al. 2021), Northern Persian Gulf Iran (Keshavarzifard et al. 2021), and Songkla, Thailand, were also

dominated by fiber. The comparison of the dominant shape of MPs in different shrimp species at different regions are mentioned in Table 2.

Fiber-type MPs dominate in prawns due to their high abundance in environment (Avio et al. 2020). Estimate of the annual microfibers released to the ocean range between 1,800 and 52,000 metric tons (Suaria et al. 2020) and depict their general abundance in marine ecosystems. Most MPs studies report microfiber abundance in all environmental components, such as water, sediments, and biota-including fish, bivalves, and crustaceans (Avio et al. 2020). The continuous input from textile and fishing sources and their physical characteristics that enhance suspension, transport, and ingestion corresponded to their availability (Walkinshaw et al. 2020). A major contributor to the dominance of fibers in shrimps is likely from domestic laundering activities (Salvador Cesa et al. 2017). Browne et al. (2008) showed that over 1900 fibers could be shed by a single item of clothing per wash, eventually making its way into water bodies through sewage. Fibers from fishing activities, such as the wearing out of fishing trawl nets, lines, and ropes, also contribute to the increasing abundance of fibers in marine environments. Their high surface-to-volume ratio increases their possibility of settling and sinking into sediments where MPs become more available to deposit-feeding shrimps, thereby enhancing fiber ingestion (Pohl et al. 2020). The high gastrointestinal retention of fibers in shrimps may be due to the long length-to-diameter ratio that promotes fiber accumulation within the gastrointestinal tract (Qiao et al. 2019a). Fragmented MPs are produced from larger plastic items, such as bottles and packaging materials, which have been degraded by UV light and wave abrasion, while pellets may originate from MPs containing microbeads that have been discharged directly into the marine environment through sewage (Cheung and Fok 2017), or when resin pellets are cut from raw material or during plastic manufacturing. This

**Table 1** The comparative abundance (mean  $\pm$  SD) of MPs in shrimp species

| Location                   | Species                                                            | Abundance (items/weight)               | Reference                        |
|----------------------------|--------------------------------------------------------------------|----------------------------------------|----------------------------------|
| Kerala, India              | <i>Fenneropenaeus indicus</i>                                      | 0.04 $\pm$ 0.07/gg                     | (Daniel et al. 2020)             |
| Persian Gulf, Iran         | <i>Penaeus semisulcatus</i>                                        | 1.5/g                                  | (Abbasi et al. 2018)             |
| Xiangshan Bay, China       | <i>Parapenaeopsis hardwickii</i>                                   | 0.25 $\pm$ 0.08/g                      | (Wu et al. 2020)                 |
| Hangzhou Bay, China        | <i>Parapenaeopsis hardwickii</i><br><i>Exopalaemon carinicauda</i> | 2.37 $\pm$ 1.14/g<br>3.04 $\pm$ 1.37/g | (Wang et al. 2020)               |
| Gulf of California, Mexico | <i>Litopenaeus vannamei</i>                                        | 0.9 $\pm$ 0.2/g                        | (Valencia-Castañeda et al. 2022) |
| Gulf of California, Mexico | <i>Litopenaeus vannamei</i>                                        | 1.06/g                                 | (Valencia-Castañeda et al. 2022) |
| Ecuador                    | <i>Litopenaeus vannamei</i>                                        | 13.4 $\pm$ 1.42/g                      | (Curren et al. 2020)             |
| Malaysia                   | <i>Litopenaeus vannamei</i>                                        | 20.8 $\pm$ 3.57/g                      | (Curren et al. 2020)             |
| Indonesia                  | <i>Fenneropenaeus indicus</i>                                      | 5570 $\pm$ 100/g                       | (Curren et al. 2020)             |
| Argentina                  | <i>Pleoticus muelleri</i>                                          | 7050 $\pm$ 4178/g                      | (Curren et al. 2020)             |
| Belgium                    | <i>Crangon crangon</i>                                             | 0.68 $\pm$ 0.55/g                      | (Devriese et al. 2015)           |
| Australia                  | <i>Paratya australiensis</i>                                       | 2.4 $\pm$ 3.1/g                        | (Nan et al. 2020)                |
| Miri, Malaysia             | <i>Penaeus monodon</i><br><i>Metapenaeus ensis</i>                 | 280 $\pm$ 91/g<br>457 $\pm$ 171        | This study                       |

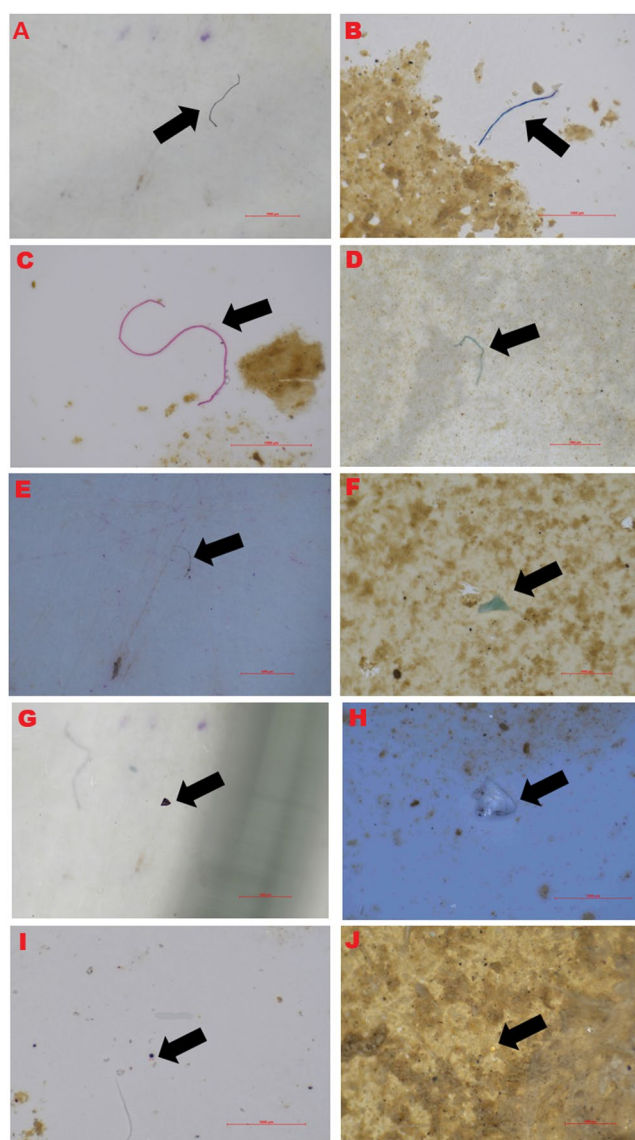


**Fig. 2** MPs with different shapes and colors (a) black fiber (b) blue fiber (c) red fiber (d) green fiber (e) transparent fiber (f) blue fragment (g) black fragment (h) transparent fragment (i) black pellet (j) transparent pellet. Arrow signs represent MPs shape

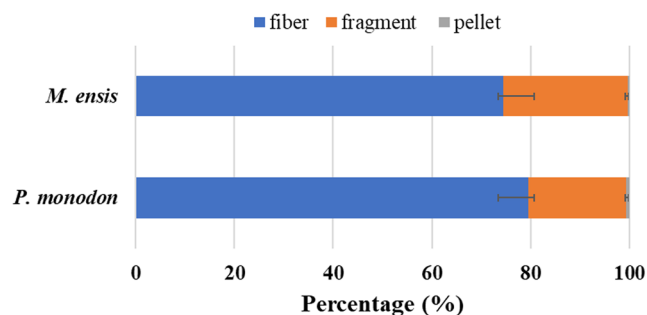


**Fig. 3** Shape composition of MPs found in *P. monodon* and *M. ensis*. Blue, orange, and gray squares indicate fibers, fragments, and pellets, respectively. Error bars represent the standard error of the mean

ties into the timelines over which plastics decompose and subsequently impact marine ecosystems.

Among the detected MPs color in the shrimps, black MPs were mostly abundant at 42.05%. Transparent and blue MPs were 33.16% and 17.87%, respectively. Red and green MPs comprise smaller percentages, at 4.13% and 2.79%, respectively. Black MPs were dominant in both *P. monodon* and *M. ensis*, accounting for 40.33% and 43.77% of the total, respectively. This is followed by transparent > blue > red and green. Figure 4 shows the distribution of MPs colours in the gastrointestinal tract of *P. monodon* and *M. ensis* samples from different markets.

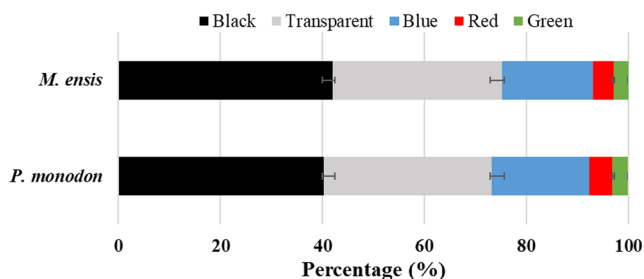
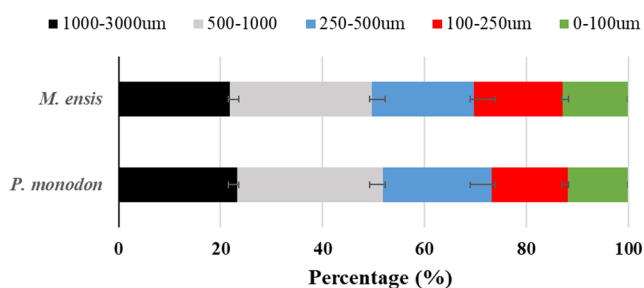
The color of MPs can determine their bioavailability (Sukmono et al. 2024; Wang et al. 2020). Black MPs can be more resistant and altered in the environment. Therefore, they are abundant in marine systems. This predominance is due to largely due to the fact that black products such as tire wear particles, fishing gear, and industrial products are used extensively, and carbon black chemicals are incorporated to extend the lifespan and increase UV resistance (Kole et al. 2017; Lambert and Wagner 2016). Darker coloring from photodegradation, oxidation, and biofouling can darken plastics over time (Abaroa-Pérez et al. 2022). The accumulation of organic matter and pollutants on plastic surfaces also contributes to this discoloration (Chen et al. 2025). Those that resemble natural prey items of the shrimps are more likely to be mistaken as food, hence increasing the possibility of shrimp ingestion. Black MPs in the shrimps could therefore also be due to discoloration resulting from weathering effects brought about by prolonged exposure to seawater (Hidalgo-Ruz et al. 2012).

The dominance of black MPs in *P. monodon* and *M. ensis* is consistent with the findings of other studies (Abbasi et al. 2018; Gurjar et al. 2021). Hossain et al. (2020) reported similar colour compositions for *P. monodon* and *M. monoceros*, where black MPs were predominant (48% and 51%, respectively). Akhbarizadeh et al. (2019) and Abbasi et al. (2018) found a predominance of black MPs in *Penaeus semisulcatus* from the Persian Gulf, constituting around 70%. Similarly, Gurjar et al. (2021) found a prevalence of black MPs, including *Metapenaeus monoceros*, *Parapenaeopsis stylifera*, and *Penaeus indicus*, in shrimps from the Arabian Sea. Black MPs accounted for 30.16%. Table 2 provides a summary of MPs studies that reported high black MPs occurrences in shrimps.

The detected MPs were categorized into five size classes: 1000–3000 µm, 500–1000 µm, 250–500 µm, 100–250 µm, and < 100 µm. Most abundant were the MPs particles within a size range of 500 to 1000 µm, accounting for 27.81% of the shrimp samples, followed by those MPs particles sized 1000–3000 µm (21.89%) and 250–500 µm (20.07%). Whereas, the size of 250–100 µm and < 100 µm constituted

**Table 2** The dominant shape of MPs in different shrimp species at different regions

| Location                           | Species                                                                                  | Dominant Shape | Dominant Colour | Dominant Size | Reference                        |
|------------------------------------|------------------------------------------------------------------------------------------|----------------|-----------------|---------------|----------------------------------|
| Kerala, India                      | <i>Fenneropenaeus indicus</i>                                                            | Fiber          | Black           | 500–1000 µm   | (Daniel et al. 2020)             |
| Northern Bay of Bengal, Bangladesh | <i>Penaeus monodon</i>                                                                   | Fiber          | Black           | 500–1000 µm   | (Hossain et al. 2020)            |
| Persian Gulf, Iran                 | <i>Penaeus semisulcatus</i>                                                              | Fiber          | Black           | 500–1000 µm   | (Akhbarizadeh et al. 2019)       |
| Arabian Sea                        | <i>Metapenaeus monoceros</i><br><i>Parapeneopsis stylifera</i><br><i>Penaeus indicus</i> | Fiber          | -               | 500–1000 µm   | (Gurjar et al. 2021)             |
| Xiangshan Bay, China               | <i>Parapeneopsis hardwickii</i>                                                          | Fiber          | Black           | 500–1000 µm   | (Wu et al. 2020)                 |
| Hangzhou Bay, China                | <i>Parapeneopsis hardwickii</i><br><i>Exopalaemon carinicauda</i>                        | Fiber          | Black           | 500–1000 µm   | (Wang et al. 2020)               |
| Northern Persian Gulf, Iran        | <i>Metapenaeus affinis</i>                                                               | Fiber          | Black           | 500–1000 µm   | (Keshavarzifard et al. 2021)     |
| Bahía Blanca Estuary, Argentina    | <i>Pleoticus muelleri</i>                                                                | Fiber          | Black           | 500–1000 µm   | (Severini et al. 2020)           |
| Gulf of California, Mexico         | <i>Litopenaeus vannamei</i>                                                              | Fiber          | Black           |               | (Valencia-Castañeda et al. 2022) |
| Gulf of California, Mexico         | <i>Litopenaeus vannamei</i>                                                              | Fiber          |                 |               | (Valencia-Castañeda et al. 2022) |
| Australia                          | <i>Paratya australiensis</i>                                                             | Fiber          |                 |               | (Nan et al. 2020)                |
| Songkhla, Thailand                 | <i>Metapenaeus elegans</i><br><i>Fenneropenaeus indicus</i>                              | Fiber          | Black           | 500–1000 µm   | (Goh et al. 2021)                |
| Songkhla, Thailand                 | <i>Parapeneopsis hardwickii</i><br><i>Metapenaeus brevicornis</i>                        | Fiber          | Black           | 500–1000 µm   | (Pradit et al. 2021)             |
| Miri, Sarawak, Malaysia            | <i>Penaeus monodon</i><br><i>Metapenaeus ensis</i>                                       | Fiber          | Black           | 500–1000 µm   | This study                       |

**Fig. 4** Color composition of MPs presents in *P. monodon* and *M. ensis*. Error bars represent the standard error of the mean**Fig. 5** Size distribution of MPs presented in gastrointestinal tract of *P. monodon* and *M. ensis*. Black, gray, blue, red and green squares represent MPs size of 1000–3000 µm, 500–1000 µm, 250–500 µm, 100–250 µm, and < 100 µm, respectively. Error bars represent the standard error of the mean

17.38% and 12.82%, respectively. For *P. monodon*, the most abundant MPs size was 500–1000 µm, accounting for 28.51%. Following this, MPs sized 1000–3000 µm, 250–500 µm, 100–250 µm, and < 100 µm made up 23.32%, 21.39%, 14.93%, and 11.82%, respectively. In *M. ensis*, the highest prevalence was in MPs sized 500–1000 µm (27.11%), followed by 1000–3000 µm, 100–250 µm, 250–500 µm, and < 100 µm, constituting 20.46%, 19.83%, 18.76%, and 13.82%, respectively. Size distribution of MPs in the gastrointestinal tract of *P. monodon* and *M. ensis* is presented in Fig. 5.

The size of MP particles is very important in terms of their bioavailability (Lin et al. 2021). MPs of below 1000 µm are commonly found in the marine environment because they represent an intermediate stage in the fragmentation process of larger plastic debris (Zhao et al. 2025). Physical forces such as UV radiation, wave action, and abrasion, gradually break down larger plastic items, producing particles in the 1000 µm size range before they are further degraded into even smaller fragments (Aoki and Furue 2021). Additionally, many primary microplastics, such as pellets and microbeads from personal care products, are originally manufactured around the size and can enter marine systems directly through wastewater or accidental spills (Harmayani et al. 2025; Yuniarto et al. 2025; Karbalaeei et al. 2018; Kristanti et al. 2018; Hadibarata et al. 2018). These factors

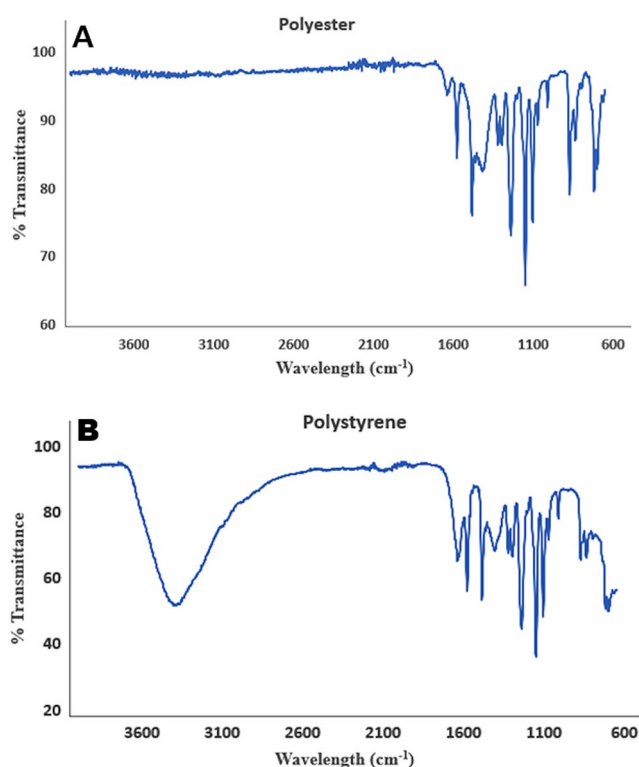


**Fig. 6** ATR-FTIR spectra of MPs particles isolated from shrimp samples. (A) Polyester was confirmed by the presence of strong absorption bands at  $1638\text{ cm}^{-1}$  (C=O stretching),  $1485\text{ cm}^{-1}$ ,  $1152\text{ cm}^{-1}$ , and  $1105\text{ cm}^{-1}$  (C–O stretching), and  $719\text{ cm}^{-1}$  (aromatic C–H out-of-plane bending). (B) Polystyrene was identified by absorption bands at  $3388\text{ cm}^{-1}$  (aromatic ring stretching),  $1638\text{ cm}^{-1}$  and  $1578\text{ cm}^{-1}$  (aromatic ring stretching),  $1485\text{ cm}^{-1}$  (aromatic ring stretching),  $1407\text{ cm}^{-1}$  ( $\text{CH}_2$  bending),  $1239\text{ cm}^{-1}$ ,  $1150\text{ cm}^{-1}$ ,  $1105\text{ cm}^{-1}$ ,  $1012\text{ cm}^{-1}$  (aromatic C–H bending), and  $699\text{ cm}^{-1}$  (aromatic C–H out-of-plane bending). Characteristic peaks are indicated in the spectra to highlight the identification of each polymer type

combined make  $1000\text{ }\mu\text{m}$  MPs a persistent and abundant size fraction in aquatic ecosystems.

Smaller MPs, particularly those below  $1000\text{ }\mu\text{m}$ , show a higher propensity for ingestion by shrimps (Birch et al. 2020). The smaller MPs are preferentially ingested because their size is closer to that of the natural prey items of the shrimps (Wright et al. 2013). Microplastics less than  $500\text{ }\mu\text{m}$  may translocate from the gut into other tissues of shrimps (Jovanović et al. 2018). *M. ensis* recorder had a higher abundance of MPs less than  $250\text{ }\mu\text{m}$  compared to *P. monodon*, which may be related to the fact that *M. ensis* has a smaller body; hence, it may be associated with an available surface area and volume ratio for MPs distribution among shrimp species (Hossain et al. 2020). For both, *P. monodon* and *M. ensis*, the MPs present were the least at less than  $100\text{ }\mu\text{m}$ , probably due to identification constraints at that size. The present results agree with those of other studies that reported a high prevalence of MPs within the size range of  $500$  to  $1000\text{ }\mu\text{m}$  (Daniel et al. 2020; Wu et al. 2020). For

instance, Daniel et al. (2020) reported that 72% of the MPs size distribution for *Fenneropenaeus indicus* from India was within this range. In another study, Keshavarzifard et al. (2021) reported that *P. semisulcatus* from the Persian Gulf were accumulating MPs with sizes ranging between  $500$  and  $1000\text{ }\mu\text{m}$  and it constituted 36% of the total. A summary of MPs studies found in shrimps along with a highlight on results showing prevalence  $500$  to  $1000\text{ }\mu\text{m}$  MPs size is presented in Table 2.

## Polymer composition

The ATR-FTIR spectroscopy was employed to characterize the MPs polymer composition in *P. monodon* and *M. ensis*, revealing the presence of polyester (PES) and polystyrene (PS). However, limitations in the FTIR equipment might hinder the detection of smaller MPs ( $<20\text{ }\mu\text{m}$ ), especially thin fibers, potentially impacting the accuracy of identifying other polymer types. The ATR-FTIR spectra of PES and PS, show distinct absorption bands for each polymer type. Polyester was confirmed by the presence of strong adsorption bands at  $1638\text{ cm}^{-1}$  (C=O stretching),  $1485\text{ cm}^{-1}$ ,  $1152\text{ cm}^{-1}$  and  $1105\text{ cm}^{-1}$  (C–O stretching), and  $719\text{ cm}^{-1}$  (aromatic C–H out of plane bending) (Fig. 6A). This results align with the study of Ogunola et al. (2022) in prawn from the Australian seafood market. Polystyrene was identified by adsorption bands at  $3388\text{ cm}^{-1}$  (aromatic ring stretching),  $1638\text{ cm}^{-1}$ ,  $1578\text{ cm}^{-1}$  (aromatic ring stretching),  $1485\text{ cm}^{-1}$  (aromatic ring stretching),  $1407\text{ cm}^{-1}$  ( $\text{CH}_2$  bending),  $1239\text{ cm}^{-1}$ ,  $1150\text{ cm}^{-1}$ ,  $1105\text{ cm}^{-1}$ ,  $1012\text{ cm}^{-1}$  (aromatic C–H bending), and  $699\text{ cm}^{-1}$  (aromatic C–H out of plane bending) (Fig. 6B). The band is similar to that reported by Morris et al. (2025). Polyester and polystyrene, with densities of  $1.38\text{ g/cm}^3$  and  $1.06\text{ g/cm}^3$  respectively, exceed the density of seawater. Consequently, they tend to sink and settle in sediments, increasing their bioavailability to bottom-dwelling shrimps, aligning with their deposit-feeding habits (Daniel et al. 2020). This substantiates the detection of these polymers in the gastrointestinal tract of *P. monodon* and *M. ensis*.

The dominance of polyester in the marine environment could be because polyester fibers from our clothes are released into wastewater during domestic washing and eventually make their way to marine waters. This is in line with the high occurrence of fibers found in shrimp (Dalla Fontana et al. 2020). On the other hand, polystyrene is more in packaging materials, fishing and aquaculture gear, and personal care products. Its presence in the marine environment could largely result from the improper disposal of polystyrene containers and packaging that breaks down into MPs in rivers and seas. These findings indicate the inadequacy of waste management practices or policies for Miri City, which may also be compounded by industrial wastewater

from plastic manufacturing facilities. This study provides baseline information for better waste management practices and a strict regulation policy on MPs release into the marine environment to eventually curb ingestion by organisms such as shrimps.

Nowadays, more edible marine organisms, such as bivalves and fish, are found with MPs inside them, in addition to shrimps (Daniel et al. 2021; Zeytin et al. 2020). This growing occurrence means these contaminants can easily enter the human diet through various food web pathways. Ingestion of MPs may act as a carrier, transporting surface-associated pollutants or chemical additives, which may be incorporated into human tissues or provoke physiological stress responses (Bhuyan et al., 2022; Rahman et al. 2021; Smith et al. 2018). These findings highlight the need to view MPs pollution not only as an environmental challenge, but also as challenge to food safety and human health, necessitating strong systems for ecological monitoring and risk assessment with both environmental and human health issues in view. The evidences indicate that targeted efforts that address all pathways of how MPs compromised seafood reach markets, for example, control of contamination, sustainable harvest limits, more selective fishing gear and practices, better monitoring, and transparent reporting protocols are required to be addressed. Aquaculture farms should be designed to include multitrophic systems and enhanced biosecurity protocols that will limit the transfer of MPs across trophic levels. Legislations must provide incentives to drive sustainable practices and get communities involved in management actions. Increasing community engagement can improve surveillance quality, assist in citizen science projects, and ease compliance with new regulations. Public awareness campaigns and education are critical to converting scientific research into practice. Consumers need to understand the health dangers associated with consuming unsustainably harvested seafood and the benefits of eating sustainably sourced seafood.

Cross-disciplinary research is urgently needed to determine the human health implications of chronic exposure to microplastics within the food web, including the potential for harm and bioaccumulation. The threat imposed by the ingestion of plastics via seafood consumption should be met with comprehensive mitigation measures involving scientists, regulators, industry players, and the public.

## Conclusion

This study presents a detailed investigation of MPs contamination in commercial crustaceans (*P. monodon* and *M. ensis*) from Miri, Malaysia, focusing on abundance, shape, color, size, and polymer composition. MPs contamination

was found in both species, but the average abundance was higher for *M. ensis* ( $457 \pm 171$  pieces/kg wet weight) than *P. monodon* ( $280 \pm 91$  pieces/kg wet weight). Fibrous MPs were the most common in both species, with black and transparent particles being the most common, and MPs were mostly under 1 mm. FTIR analysis indicated that polyester and polystyrene were the dominant polymers types present in both species. The presence of MPs in all samples underscores the pervasive nature of plastic contamination in local waters, raising significant concerns about food safety and environmental health. This is an important baseline data for the area and indicates that shrimp and other crustaceans are good bioindicators for monitoring MP contamination. It is also important to study the fate, transport, and potential health impacts of MPs on humans through seafood consumption, as well as the modes of their toxicity. Such information is important for the development of effective means for monitoring and managing human and environmental health risks.

**Acknowledgments** The authors would like to express their sincere gratitude to Curtin Malaysia for providing financial support under the Curtin Malaysia Collaborative Research Scheme (CMCR) 2022 (Grant Number: 004032), which made this research possible.

**Funding** Open Access funding enabled and organized by CAUL and its Member Institutions. This research was funded by the Curtin Malaysia Collaborative Research Scheme (CMCR) 2022 (Grant Number: 004032).

**Data availability** The data supporting the findings of this study are available from the corresponding author upon reasonable request.

## Declarations

**Ethics approval** This study did not require ethical approval.

**Competing interests** The authors declare no competing interests that could influence the work reported in this paper.

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