



## THE RELATIONSHIP OF MICROPLASTIC ABUNDANCE IN GREEN MUSSEL *Perna viridis* AND THE WATERS OF MANGKANG BEACH, SEMARANG

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### ABSTRACT

Plastic, especially microplastics, currently poses a potential threat to water pollution. Microplastics are found not only in water but also in aquatic biota. Green mussels *Perna viridis* cultivated in Mangkang Wetan coastal waters may be contaminated with microplastics. This research aimed to determine the abundance of microplastics by shape, colour, and polymer type, and to examine the relationship between the abundance of microplastics in the aquatic environment and green mussels *P. viridis*. Data collection was carried out using a random sampling method to assess the distribution of green mussel cultivation by collecting water samples and green mussels, which were analyzed using quantitative methods. Data analysis was performed using ANOVA and regression analysis. The research identified 4 types of microplastic forms in the waters and 3 in green mussels, with fragment forms dominant in both. Seven colours were found (yellow, green, blue, black, transparent, brown and red), with brown being the dominant colour. Nine types of polymers were identified (polyvinyl chloride, polyethylene terephthalate, polypropylene, low-density polyethylene, high-density polyethylene, nylon, cellulose acetate, polyethersulfone and polystyrene), with polyethylene terephthalate as the dominant polymer. The abundance of microplastics in the waters and green mussels at Station 1 was  $6.33 \pm 0.45$  particles/liter and  $4.91 \pm 2.32$  particles/ind, at Station 2 it was  $2.33 \pm 0.49$  particles/liter and  $1.33 \pm 0.28$  particles/ind, and at Station 3 it was  $4.63 \pm 0.32$  particles/liter and  $2.91 \pm 1.18$  particles/ind. The ANOVA results for microplastic abundance in the waters showed a significance value of  $0.00 < 0.05$ . The ANOVA results for green mussel microplastic abundance showed a significance value of 0.072, which is  $> 0.05$ . The regression analysis showed an exponential pattern, with a coefficient of determination ( $R^2$ ) of 0.685.

### How to Cite

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## INTRODUCTION

In Indonesia, plastic waste is a major source of water pollution, especially in marine and coastal areas. According to Arifin et al. (2023) and Lestari and Trihadiningrum (2019), the issue is made worse by the nation's dense population, poor solid waste management infrastructure, and long coastlines.

Discarded plastic waste will experience fragmentation into microplastics. Fishermen's activities and waste that drifts through rivers and estuaries are also considered factors in water pollution by plastic waste. Microplastics are divided into 2 types, namely primary microplastics, which are microplastics produced by the plastic industry (Lam et al., 2018), and secondary microplastics resulting from the degradation of plastic into smaller sizes (Khoironi et al., 2020). Their micro nature means that microplastics can stick to epiphytic microbiota and other biofilms, which are then consumed by aquatic biota. Microplastics can be absorbed into biofilms which are the dominant habitat for microbes in aquatic ecosystems. Biofilms are actively involved in the food chain until they eventually accumulate in the biota that consume them. According to Kapo et al. (2020), this continues in biota at higher trophic levels through bioaccumulation.

Mangkang Wetan Beach is a coastal area in Semarang City. The Mangkang Wetan coastal area is thought to be an area polluted by waste, especially plastic waste. A notable source of waste is the material transported by the river from upstream, as well as materials from boats, crews, and docking activities (Ardiansyah et al., 2022). Pollution in Mangkang Wetan coastal waters can be measured using bioindicators. Green mussels *Perna viridis* are known as filter feeders which are often used as bioindicators to determine the quality of the aquatic environment (Sari et al., 2021). Coastal communities at Mangkang Wetan Beach, Semarang also cultivate green mussels *P. viridis* because they have economic value and are nutrient-rich. However, if green mussels contain microplastics, it will negatively impact humans who consume them. Therefore, research on the abundance of microplastics in the waters of Mangkang Wetan Beach needs to be carried out as important information in supporting the Bulan Cinta Laut (BCL) program currently launched by the government. In this regard, to support the availability of microplastic information in coastal areas, measurements of the abundance of microplastics were carried out both in the waters and in green mussels *P. viridis*. Apart from this, to evaluate the variety of microplastics, their classification is analysed based on chemical groups using FTIR (Fourier Transform Infrared) analysis.

The aim of this research is to determine the types of forms and polymers of microplastics in the waters and green mussels *P. viridis*, as well as to determine the relationship between the abundance of microplastics in the waters and green mussels *P. viridis*.

## MATERIALS AND METHODS

The materials used in this research were samples of seawater and green mussels *P. viridis* from the waters of Mangkang Wetan Beach. The tools used for taking samples in the field and processing samples in the laboratory are as follows: cool box, stationery, Garmin GPS, plastic container, Whatman Grade 40 filter paper, Petri dish, Erlenmeyer, oven, analytical balance, calipers, pH meter, thermometer, refractometer, glass funnel, vacuum pump, microscope, FTIR spectroscopy. The materials used are: green mussels *P. viridis*, seawater, concentrated NaCl, 10% KOH solution, and 30% H<sub>2</sub>O<sub>2</sub> solution.

The method used in this research is a descriptive method with a quantitative approach. This research was carried out by describing the conditions in the field without any changes to the independent variables, so that it can describe natural conditions (Hamdi and Bahrudin, 2014). The objects used in this research are seawater and green mussel biota, which is cultivated by fishermen in the coastal waters of Mangkang Wetan, Mangkang District, Semarang City.

In this research, samples were taken in several locations based on the distribution of green mussel cultivation and factors such as proximity to river estuaries and use of nearby land. In this case, 3 different sampling points were determined in the waters of Mangkang Wetan Beach, which are shown on the map in Figure 1.

Sampling was carried out to describe and carry out analysis according to the problems in the research. In this study, measurements were carried out 3 times in the waters and green mussels *P. viridis* at each station. Seawater samples were collected from the water column using passive sampling techniques at 3 stations, with 10 liters per repetition, and filtered through a plankton net with a 25- $\mu$ m mesh. After filtering, the sample is stored in a 1000 ml sample bottle in a cool box. Green mussel samples were collected using purposive sampling at 3 stations.

The collection method involved taking the clam sample attached to the upper bamboo blade by hand, and approximately 16 clams per station. Green mussels taken are large or adult green mussels over 5 cm in size. Parameter measurements of water quality variables, such as pH, salinity, temperature, depth, dissolved oxygen (DO), and water organic matter/total organic matter (TOM), were also carried out as supporting research data. Analysis of microplastic samples in the waters refers to Hanif et al. (2021), Shafani et al. (2022) and Seprandita et al. (2022), namely:

- Degradation of organic material, which is carried out by preparing 100 ml of sample water and adding 30% H<sub>2</sub>O<sub>2</sub> in a ratio of 1:1, after which incubation is carried out at room temperature for 24 hours.



Fig 1. Sampling location

- Separate the density by administering a concentrated NaCl solution, then incubate again until the organic material has settled.
- Filtering is carried out using a vacuum pump with Whatman Grade 40 filter paper. Some samples were identified using microscopic analysis, while the other half was identified using FTIR spectroscopy in the laboratory.

After microscopic analysis, the samples were calculated using the formula for the abundance of microplastics in the water:

$$\text{MP abundance} = \frac{\text{number of microplastics (particle)}}{\text{volume of filtered water (liter)}}$$

Analysis of microplastic samples in green mussel *P. viridis* follows Thiele et al. (2019) and Rahim et al. (2022), comprising measuring the length and weight of the shell, weighing the wet weight of shellfish, and preparing composite mussel samples with 4 replicates per station. The shellfish composite was placed in a 250-ml Erlenmeyer flask with the addition of 10% KOH solution at a ratio of 3:1 body volume and incubated for 24 hours. Sample filtration was carried out using a vacuum pump with Whatman Grade 40 filter paper.

After that, drying was carried out using an oven for 24 hours at a temperature of 40 °C. Microscopic analysis was performed after sample drying was complete, followed by FTIR analysis in the laboratory. The results of microscopic observations were calculated using the following formula:

$$\text{MP abundance} = \frac{\text{number of microplastics (particle)}}{\text{number of individu (individu)}}$$

Data analysis was performed using One-Way Anova analysis and regression analysis with SPSS 24 and Microsoft Excel 2016.

## RESULTS

Station 1 is close to the fishing area, and there are Fish Aggregating Devices (FADs) belonging to coastal residents of Mangkang Wetan. The depth of the water at this location is around 1.7 meters. The condition at Station 2 is that FADs belong to coastal residents of Mangkang Wetan. The depth of the water at this location is around 2 meters. At Station 3, there are FADs, but not many. The depth of the water at this location is around 1.5 meters. Live green mussels are attached to bamboo spats at all three stations.

Most of the water quality parameters were suitable for aquatic biota, as stated in Indonesian Government Regulation No. 22 of 2021. Although the results indicate that 50% of the measured parameters do not meet the quality standards set out in Indonesia Government Regulation No. 22 (2021), this does not necessarily imply that the ecosystem is entirely unsuitable for aquatic biota. Some deviations, such as in pH and salinity, may be influenced by natural environmental fluctuations, tidal cycles, or local anthropogenic activities (Table 1).

**Table 1.** Results of the average measurement of water quality parameters at Mangkang Wetan Beach

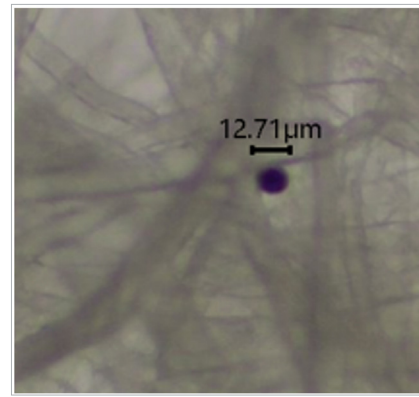
Parameter	Measuring result	Indonesia Government Relation No. 22 (2021)
pH	5.39 ± 0.66	7 - 8.5
Salinity (‰)	27.67 ± 1.58	33 - 34
DO (mg/l)	6.86 ± 0.6	> 5
Depth (m)	1.21 ± 0.24	-
Temperature (°C)	31.30 ± 0.8	28 - 32
TOM (mg/l)	15.69 ± 0.44	-

These variations can cause temporary changes in water quality without permanently disrupting ecological balance. However, continuous monitoring and management efforts are required to ensure that these parameters remain within the optimal range to support aquatic life and prevent long-term environmental degradation. Based on the results of microplastic observations obtained from this study, see Figure 2.

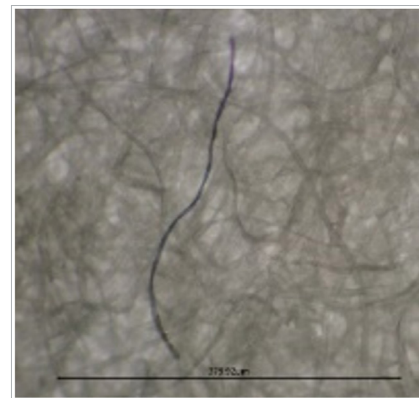
Based on Figures 2 and 3, fiber microplastics were found in the waters but not in green mussels (Table 2).

**Table 2.** Number of microplastics formed in the waters

Station	Point	Microplastic form			
		Fragment	Pellet	Film	Fiber
1	1	39	11	6	3
	2	37	22	5	4
	3	43	15	4	1
2	1	11	8	1	-
	2	16	13	-	-
	3	11	7	3	-
3	1	24	17	3	-
	2	46	3	1	-
	3	23	13	8	1
<b>TOTAL</b>		<b>250</b>	<b>109</b>	<b>31</b>	<b>9</b>



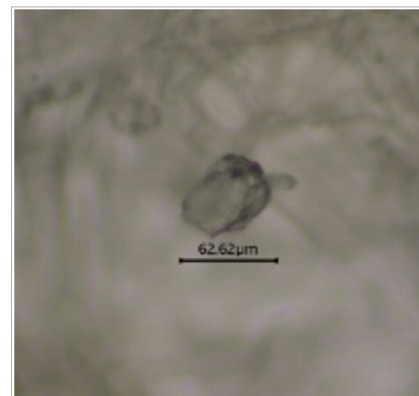
(a) pellet



(b) fiber

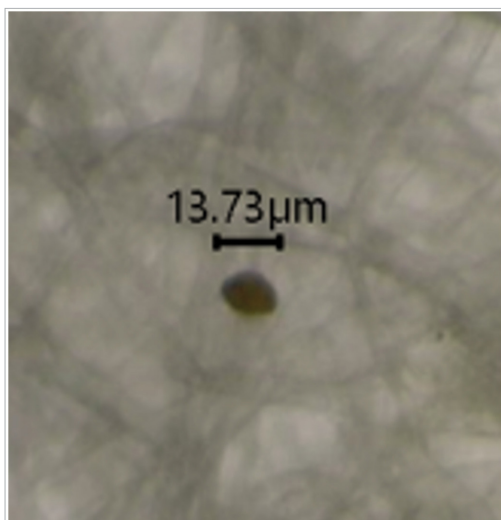


(c) fragment

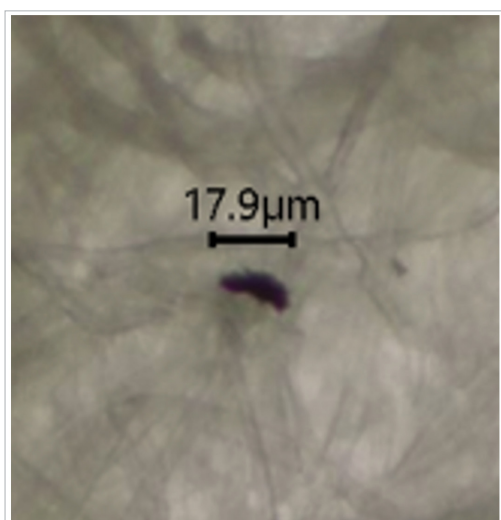


(d) film

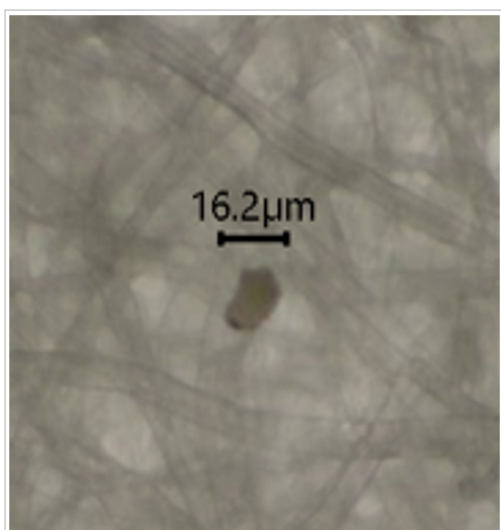
**Fig 2.** Microplastic form in the waters



(a) pellet



(b) fragment



(c) film

Based on microscopic identification, fragments, pellets, films, and fibers were found, with fragments being the dominant form (Table 3).

**Table 3.** Number of microplastics form in *P. viridis*

Station	Point	Microplastic form			
		Fragment	Pellet	Film	Fiber
1	1	5	4	3	-
	2	7	8	2	-
	3	17	7	6	-
2	1	2	4	-	-
	2	2	2	-	-
	3	4	1	1	-
3	1	3	5	-	-
	2	5	2	3	-
	3	6	11	-	-
<b>TOTAL</b>		<b>51</b>	<b>44</b>	<b>15</b>	<b>0</b>

Based on microscopic identification, the fragment was found to be the dominant form.

The dominant colours of microplastics are brown and black, while green is the least common (Table 4).

**Table 4.** Colour of microplastics in the waters and *P. viridis*

Colour	Number of microplastics	
	Waters	<i>P. viridis</i>
Yellow	17	4
Green	7	2
Blue	33	12
Black	76	23
Transparant	58	21
Brown	191	46
Red	17	2
<b>TOTAL</b>	<b>399</b>	<b>110</b>

The highest abundance of microplastics in the waters was found at Station 1, with an average of  $6.33 \pm 0.45$  particles/liter, followed by Station 3, with an average of  $4.63 \pm 0.32$  particles/liter, and Station 3, with an average of  $2.33 \pm 0.49$  particles/liter (Table 5).

**Fig 3.** Microplastic form in *P. viridis*

**Table 5.** Microplastic abundance in the waters

Station	Point	Number of microplastic particles	Volume of filtered water (liter)	Microplastic abundance (particle/liter)
1	1	59	10	5.9
	2	68	10	6.8
	3	63	10	6.3
2	1	20	10	2
	2	29	10	2.9
	3	21	10	2.1
3	1	44	10	4.4
	2	50	10	5
	3	45	10	4.5

The highest abundance of microplastics in *P. viridis* was found at Station 1 with an average of  $4.91 \pm 2.32$  particles/ind, followed by Station 3 at  $2.91 \pm 1.18$  particles/ind and Station 2 at  $1.33 \pm 0.28$  particles/ind.

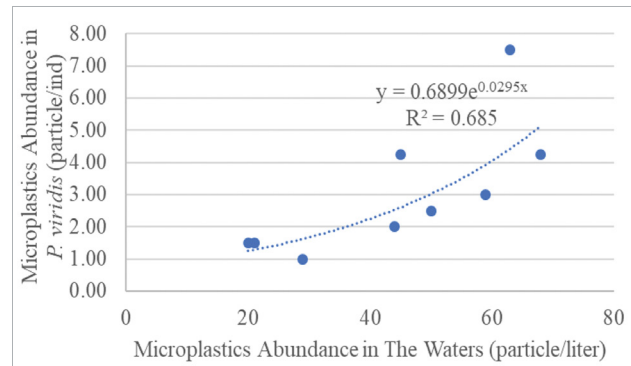
**Table 6.** Microplastic abundance in *P. viridis*

Station	Repetition	Microplastic abundance (particle/ind)
1	1	3
	2	4.25
	3	7.5
2	1	1.5
	2	1
	3	1.5
3	1	2
	2	2.5
	3	4.25
<b>TOTAL</b>		<b>27.5</b>

The results of cumulative microplastic identification in the coastal waters of Mangkang Wetan Beach show varying numbers. In this case, the highest is Station 1, with an average microplastic abundance of  $6.33 \pm 0.45$  particles/liter, followed by Station 3 at  $4.63 \pm 0.32$  particles/liter, and the lowest at Station 2 at  $2.33 \pm 0.49$  particles/liter. Furthermore, after conducting a difference test using analysis of variance, significant differences in microplastic abundance were found between stations ( $\alpha < 0.05$ ).

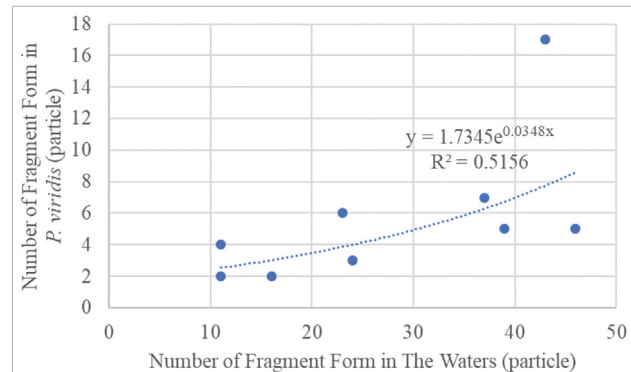
The results of cumulative microplastic identification in green mussels *P. viridis* show varying numbers. In this case, the highest is Station 1, with an average microplastic abundance of  $4.91 \pm 0.32$  particles/ind, followed by Station 3 at  $2.91 \pm 1.18$  particles/ind, and the lowest at Station 2 at  $1.33 \pm 0.28$  particles/ind. Furthermore, after conducting a difference test using analysis of variance, no difference in microplastic abundance was found between stations ( $\alpha > 0.05$ ).

Based on the data obtained, the following are the regression analysis results, presented in Figure 4.

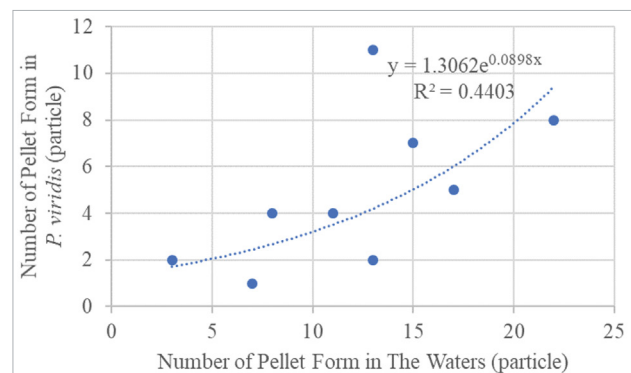


**Fig 4.** The relationship between microplastic abundance in the waters and *P. viridis*

The relationship between the abundance of microplastics in fragment and pellet form is presented in Figures 5 and 6.



**Fig 5.** Relationship between the abundance of microplastic fragments formed in the waters and green mussels



**Fig 6.** Relationship between the abundance of microplastic pellet form in the waters and green mussels

The results of FTIR analysis at stations 1 – 3 using an FTIR spectroscopy tool are shown in Figure 7. The obtained absorbance values are 9, 12, and 7, respectively.

Interpretation of FTIR absorbance values obtained in the waters at stations 1, 2, and 3 can be seen in Table 7.

**Table 7.** Interpretation of FTIR absorbance values in the waters at stations 1 - 3

No	Absorbance (cm <sup>-1</sup> )	Value from references (cm <sup>-1</sup> )	Bonds formed	Suspected type of polymer	References
<b>STATION 1</b>					
1	617.49	616	C – Cl stretch	PVC	Jung et al., 2018
2	1059.42	1094	C – O stretch	PETE	Jung et al., 2018
3	1112.9	1094	C – O stretch	PETE	Jung et al., 2018
4	1163.23	1166	CH bend, CH <sub>3</sub> rock, C – C stretch	PP	Jung et al., 2018
5	1370.05	1377	CH <sub>3</sub> bend	LDPE/LLDPE	Jung et al., 2018
6	1641.43	1634	C = O stretch	Nylon	Jung et al., 2018
7	2904.08	2915	C – H stretch	HDPE/LDPE/LLDPE/PP	Jung et al., 2018
8	3420.72	3410	O – H	CA	Seftianingrum et al., 2023; Jung et al., 2018; Coates, 2000;
9	3737.84	3728	-	PES	Sawalman et al., 2021
<b>STATION 2</b>					
1	559.73	537	Aromatic ring out-of plane bend	PS	Jung et al., 2018
2	617.81	616	C – Cl stretch	PVC	Jung et al., 2018
3	1033.82	1027	Aromatic CH bend	PS	Jung et al., 2018
4	1059.76	1094	C – O stretch	PETE	Jung et al., 2018
5	1113.31	1094	C – O stretch	PETE	Jung et al., 2018
6	1163.67	1166	CH bend, CH <sub>3</sub> rock, C – C stretch	PP	Jung et al., 2018
7	1281.97	1274	NH bend, C – N stretch	Nylon	Jung et al., 2018
8	1370.7	1377	CH <sub>3</sub> bend	LDPE/LLDPE	Jung et al., 2018
9	1430.64	1427	CH <sub>2</sub> bend	PVC	Jung et al., 2018
10	1637.14	1634	C = O stretch	Nylon	Jung et al., 2018
11	2902.64	2915	C – H stretch	HDPE/LDPE/LLDPE/PP	Jung et al., 2018; Coates, 2000
12	3370.37	3410	O – H	CA	Seftianingrum et al., 2023; Jung et al., 2018; Coates, 2000
<b>STATION 3</b>					
1	690.84	694	Aromatic CH out-of-plane bend	PS	Jung et al., 2018
2	1061.26	1094	C – O stretch	PETE	Jung et al., 2018
3	1370.39	1377	CH <sub>3</sub> bend	LDPE/LLDPE	Jung et al., 2018
4	1638.76	1634	C = O stretch	Nylon	Jung et al., 2018
5	2914.74	2915	C – H stretch	HDPE/LDPE/LLDPE/PP	Jung et al., 2018; Coates, 2000
6	3422.25	3410	O – H	CA	Seftianingrum et al., 2023; Jung et al., 2018; Coates, 2000;
7	3737.56	3728	-	PES	Sawalman et al., 2021

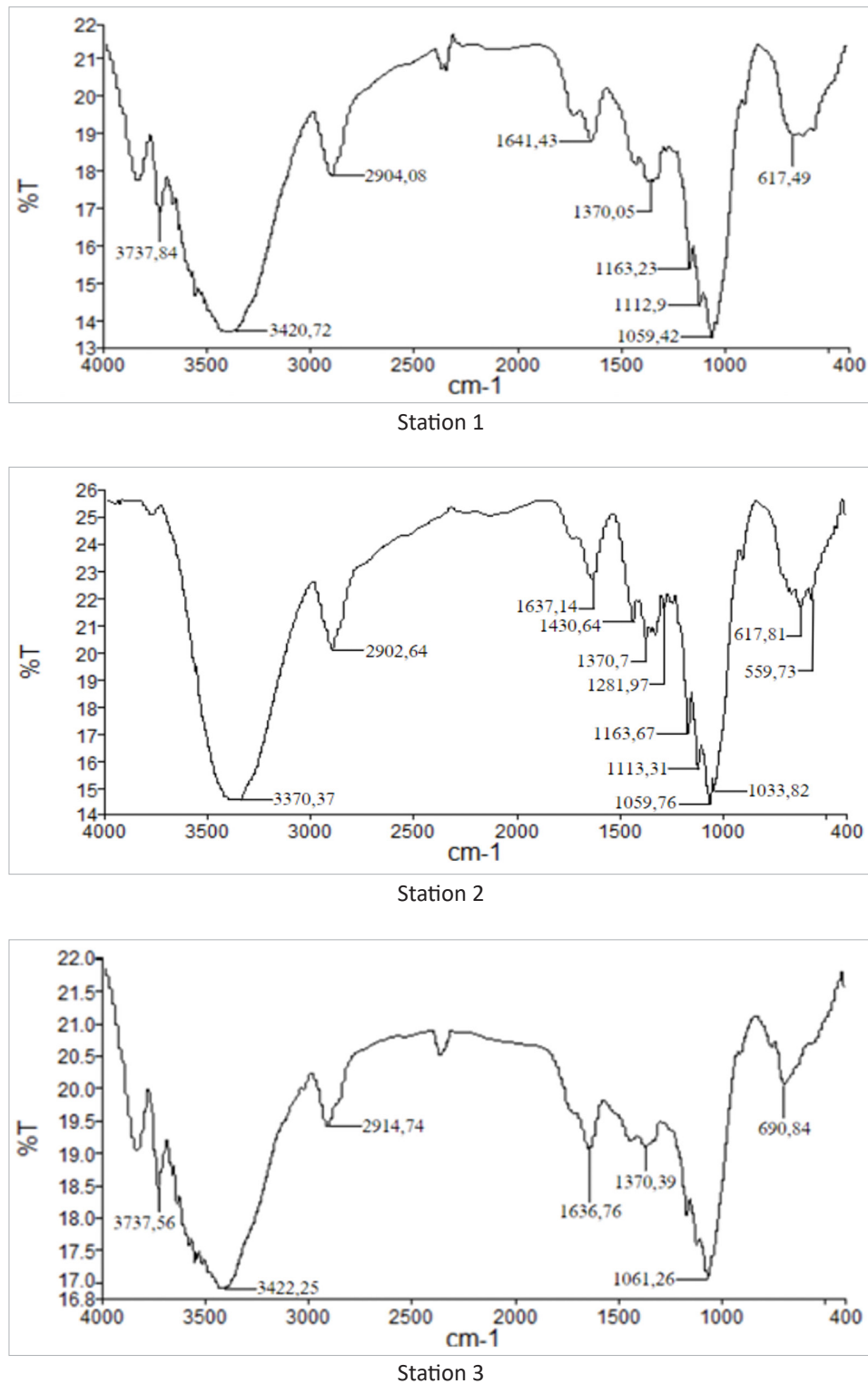


Fig 7. Result of FTIR analysis in the waters

Based on the results of FTIR analysis of the waters at stations 1–3, the type of plastic polymer detected was dominated by polyethylene (HDPE, LDPE/LLDPE, PET/PETE). The number of each polymer, in descending order, is as follows: PET polymer with 4 particles; PVC, nylon and PS with 3 particles; PP, LDPE/LLDPE, HDPE and CA with 2 particles; and PES with 1 particle.

The results of FTIR analysis on green mussels at stations 1 – 3, using an FTIR spectroscopy tool, are shown in Figure 8. The obtained absorbance values are 9, 12, and 7, respectively. Interpretation of absorbance values obtained on green mussel samples at stations 1, 2 and 3 can be seen in Table 8.

**Table 8.** Interpretation of FTIR absorbance values in *P. viridis* at stations 1 - 3

No	Absorbance (cm <sup>-1</sup> )	Value from references (cm <sup>-1</sup> )	Bonds formed	Suspected type of polymer	References
<b>STATION 1</b>					
1	617.11	616	C – Cl stretch	PVC	Jung et al., 2018
2	1059.79	1094	C – O stretch	PETE	Jung et al., 2018
3	1113.33	1094	C – O stretch	PETE	Jung et al., 2018
4	1163.46	1166	CH bend, CH <sub>3</sub> rock, C – C stretch	PP	Jung et al., 2018
5	1375.3	1377	CH <sub>3</sub> bend	LDPE/LLDPE	Jung et al., 2018
6	1642.54	1634	C = O stretch	Nylon	Jung et al., 2018
7	2918.1	2915	C – H stretch	HDPE/LDPE/LLDPE/PP	Jung et al., 2018
8	3393.86	3410	O – H	CA	Seftianingrum et al., 2023; Jung et al., 2018; Coates, 2000
<b>STATION 2</b>					
1	617.46	616	C – Cl stretch	PVC	Jung et al., 2018
2	1059.91	1094	C – O stretch	PETE	Jung et al., 2018
3	1113.41	1094	C – O stretch	PETE	Jung et al., 2018
4	1163.34	1166	CH bend, CH <sub>3</sub> rock, C – C stretch	PP	Jung et al., 2018
5	1374.94	1377	CH <sub>3</sub> bend	LDPE/LLDPE	Jung et al., 2018
6	1424.84	1427	CH <sub>2</sub> bend	PVC	Jung et al., 2018
7	1647.98	1634	C = O stretch	Nylon	Jung et al., 2018
8	2914.72	2915	C – H stretch	HDPE/LDPE/LLDPE/PP	Jung et al., 2018
9	3367.8	3410	O – H	CA	Seftianingrum et al., 2023; Jung et al., 2018; Coates, 2000
<b>STATION 3</b>					
1	560.24	537	Aromatic ring out-of plane bend	PS	Jung et al., 2018
2	1058.68	1094	C – O stretch	PETE	Jung et al., 2018
3	1112.66	1094	C – O stretch	PETE	Jung et al., 2018
4	1162.64	1166	CH bend, CH <sub>3</sub> rock, C – C stretch	PP	Jung et al., 2018
5	1374.24	1377	CH <sub>3</sub> bend	LDPE/LLDPE	Jung et al., 2018
6	1643.48	1634	C = O stretch	Nylon	Jung et al., 2018
7	2916.83	2915	C – H stretch	HDPE/LDPE/LLDPE/PP	Jung et al., 2018; Coates, 2000;
8	3394.35	3410	O – H	CA	Seftianingrum et al., 2023; Jung et al., 2018; Coates, 2000
9	3565.6	3570	O – H stretch	-	Coates, 2000
10	3736.95	3728	-	PES	Sawalman et al., 2021

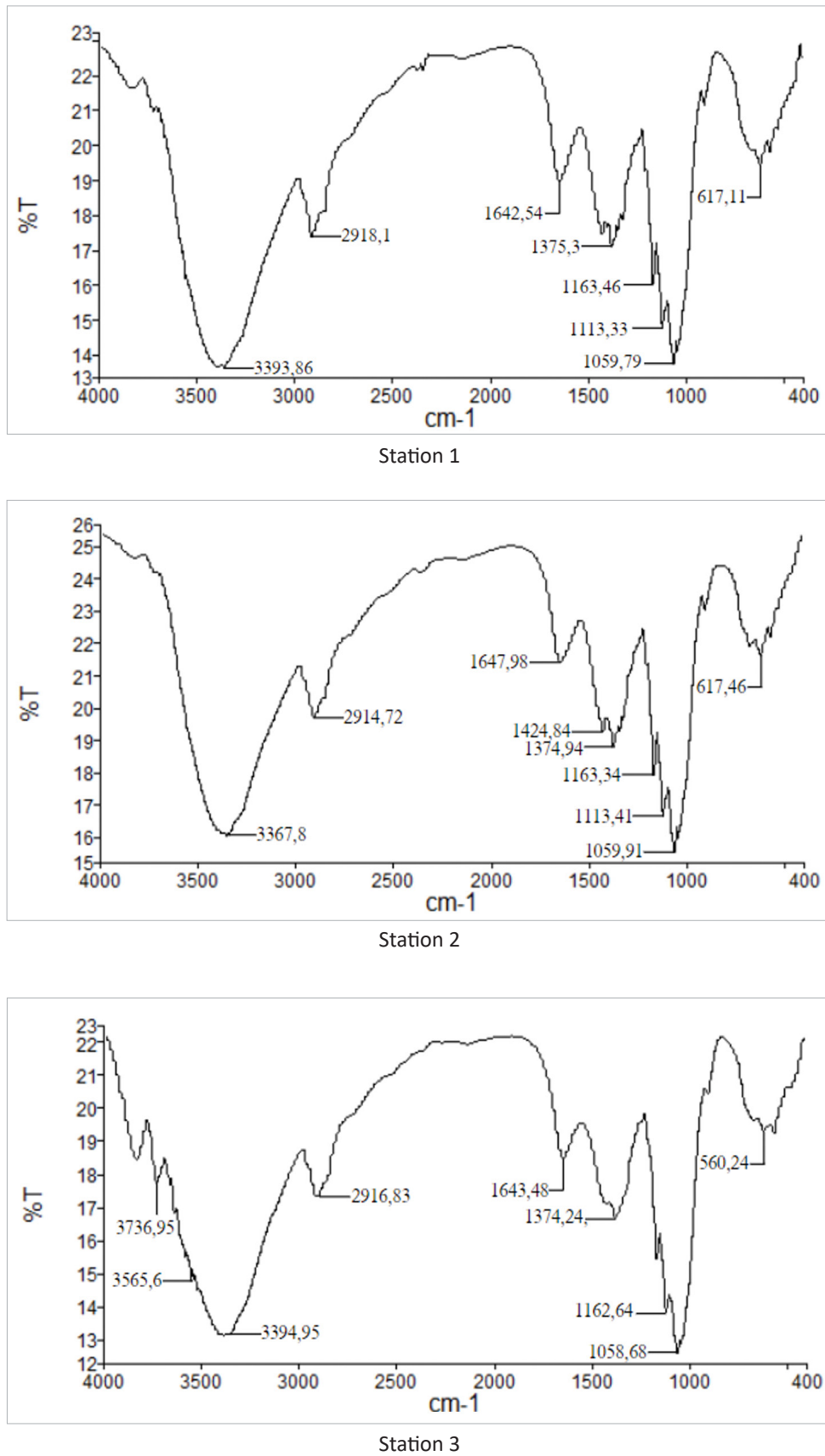


Fig 8. Result of FTIR analysis in *P. viridis*

Based on the results obtained from FTIR analysis on samples of green mussels *P. viridis* found at stations 1 – 3, the type of plastic polymer found in the bodies of green mussels *P. viridis* is dominated by polyethylene polymer (HDPE, LDPE/LLDPE, PET/PETE). The number of each polymer, in descending order, is as follows: PET with 6 particles; PVC, PP, LDPE/LLDPE, and CA with 3 particles; nylon and HDPE with 2 particles; and PS and PES with 1 particle.

## DISCUSSION

Four forms of microplastic shapes were found in analysis (fragment, pellet, film and fiber) and three types of shapes in green mussels (fragment, pellet and film). The dominant form of microplastics is the fragment form. This was also found in research by Seprandita et al. (2022). The forms of microplastics found were fibers, fragments, pellets and films, and the dominant form was the fragment. According to Aulia et al. (2023), microplastics in the form of fragments and fibers come from secondary microplastics produced from plastic fragmentation. According to Jung et al. (2018), microplastics in fragment form can be classified as high-density polyethylene (HDPE), low-density polyethylene (LLDPE), and polyvinyl chloride (PVC). The presence of microplastics in the bodies of green mussels is caused by their habit of filtering water (filter feeders). Green mussels feed on zooplankton, phytoplankton, and organic materials or compounds. The size of microplastics, which resemble zooplankton and phytoplankton, is a supporting factor in the presence of microplastics in the bodies of green mussels *P. viridis*. The presence of microplastics in green mussel biota does not directly harm the host, according to Yudhantari et al. (2019). Microplastics have hydrophobic properties, which can transfer them into the aquatic ecosystem food chain. The colour of microplastics found in the waters and green mussels is predominantly brown and black, as stated by Salsabila et al. (2023). The dark or deep colour of microplastics indicates they are still in a pure state or have not undergone significant colour change. The dark colour of microplastics indicates the level of contamination in microplastics and other materials or particles, as dark colours tend to absorb pollutants more readily. The dominant colour of microplastics found in Mangkang waters is characteristic of polyethylene polymers (Hiwari et al., 2019). According to Yona et al. (2022), green mussels probably consume microplastics while searching for food because the colour of the microplastics resembles that of their prey. Based on the results, the highest microplastic abundance is at Station 1, with  $6.33 \pm 0.45$  particles/liter, followed by Station 3 with  $4.63 \pm 0.32$  particles/liter. Station 2 had an abundance of  $2.33 \pm 0.49$  microplastics per liter. This figure shows the high abundance of microplastics in Mangkang Wetan waters. Station 1 has the highest microplastic abundance due to the large number of anthropogenic activities in

the area surrounding the research site. The presence of a fishing area around Station 1 allows visitors to dispose of waste, such as leftover food or drink packaging. Microplastics contain chemical components that are toxic or poisonous; this will have a harmful impact if consumed by biota. Apart from biota, it also has potential negative effects on humans who can be contaminated through consumption or physical contact with the skin. According to Jamika et al. (2023), microplastics can also degrade into nanoplastics if physical and chemical processes occur continuously over a long period. Long-term exposure to sunlight will cause photo-degradation of plastic; the radiation from this exposure will cause oxidation of the matrix of the microplastic polymer, so that the matrix bonds experience cleavage. Plastic waste originating from the coast, with its high oxygen content, exposure to sunlight, and marine phenomena such as abrasion and waves, will make the plastic brittle and its structure more susceptible to fragmentation. According to Aulia et al. (2023), microplastics and nanoplastics that come into direct contact with the skin can enter the human body through open wounds, sweat glands, and hair follicles.

Station 1 had the highest microplastic abundance, with  $4.91 \pm 0.31$  particles/ind, based on the microplastic content in green mussels. Followed by Station 3 with a microplastic abundance of  $2.91 \pm 1.18$  particles/ind, and Station 2 with a microplastic abundance of  $1.33 \pm 0.28$  particles/ind. Microplastic abundance in the waters at Station 1 was the highest among the stations. Based on the results showing the abundance of microplastics, it is evident that microplastics in the waters have contaminated the bodies of biota, especially green mussels. Humans who consume this biota will also be affected. Excessive contamination can cause physical harm to humans. Laksmita et al. (2023) stated that exposure to microplastic contamination in the human body can cause toxic effects, including disturbances of the respiratory system, irritation or inflammation, cell damage, and harm to the circulatory system.

The results of the regression analysis of the relationship between microplastic particles in the waters and in the bodies of green mussels *P. viridis* are presented in Figure 4. It shows the regression analysis curve, and the coefficient of determination ( $R^2$ ) value obtained is 0.685, indicating that the influence exerted by the level of the abundance of microplastics in the waters on the level of microplastic abundance in green mussels was 68.5%. The regression coefficient value is 0.338 with a significance value of  $F$  ( $P$  value) of 0.006. This shows that the regression coefficient has a positive direction. Namely, the greater the amount of microplastics in the waters, the higher the number of microplastics in green mussels *P. viridis*. The results of the regression test show  $F_o > F_{\alpha}$ , specifically  $15.22 > 5.98$ , and a  $P$ -value  $< 0.05$ , specifically  $0.006 < 0.05$ . This indicates that as the amount of microplastics in the waters increases, there is a more significant increase in the number of green mussels between stations.

Suspects related to the discovery of a positive correlation between total abundance in the waters and in the body are also indicated by the tendency of the shapes. The types of fragments and pellet shapes are the types found in all stations, so regression analysis was carried out for two kinds of shapes. This can be seen in Figures 5 and 6. Based on data on the abundance of microplastic fragment types in research conducted on water samples and samples of green mussels *P. viridis*, a determination value ( $R^2$ ) of 0.515 was obtained, which means that the influence exerted by the level of abundance of microplastics in the waters on the level of microplastic abundance in green mussels is 51.5%. The results of the regression test indicate that  $F_o > F_\alpha$  ( $7.45 > 5.98$ ) and that the  $P$ -value is  $< 0.05$  ( $0.02 < 0.05$ ), indicating that the level of abundance of microplastic fragments in the waters significantly influences the abundance of this type of fragment in green mussels between stations. The curve shown forms an exponential pattern between data on the waters and data on green mussels *P. viridis*, indicating that the levels of abundance of microplastic fragment types in the waters and in green mussels *P. viridis* are significantly interconnected.

Based on data on the abundance of pellet-type microplastics in research conducted on water samples and samples of green mussels *P. viridis*, a determination value ( $R^2$ ) of 0.440 was obtained, which means the influence exerted by the level of abundance of pellet-type microplastics in the waters on the level of abundance of pellet-type microplastics in green mussels was 44%. The regression test obtained results in the form of  $F_o < F_\alpha$ , namely  $5.5 < 5.98$ , and  $P$ -value  $> 0.05$ , namely  $0.051 > 0.05$ , which means that the level of abundance of pellet-type microplastics in the waters does not significantly influence the abundance of pellet-type microplastics in green mussels between stations. The curve displayed shows an exponential pattern between data on the waters and data on green mussels *P. viridis*, or the level of abundance of pellet-type microplastics in the waters and green mussels *P. viridis*, which are interconnected but insignificant. Both types of microplastic particles, fragments and pellets, yield the same result: a relationship between the abundance of microplastics in the waters and in green mussels. Still, the waters and the bodies of green mussels *P. viridis* do not have a significant effect.

Fragments dominate the waters of Mangkang Wetan Beach, as reported by Arifin et al. (2023) in their research on microplastics in *Anadara granosa* at Tambak Lorok, Semarang. The results, in the form of fragments, indicate that microplastics dominate these waters. The abundance of microplastic fragments indicates that the pollution originates from household waste, which is thought to come from the river, which then flows into the waters of Mangkang Wetan Beach. The river that borders Mangkang Wetan Beach is the Bringin River. Human activities around the Bringin River can generate plastic waste, which is then washed away by the river's flow

into the waters of Mangkang Wetan Beach. According to Pratiwi and Umroh (2023), fragments are produced by anthropogenic activities, such as shards from bottles and plastic food containers. According to Johan et al. (2020), household plastic waste is the most common and significant contributor to water pollution.

The research on the abundance of microplastics in green mussels at Mangkang Wetan Beach concludes that the condition of the aquatic environment, as indicated by water quality parameters aligned with quality standards, remains suitable for green mussel survival. The microplastics found in the waters and green mussels vary in form, including fragments, pellets, films, and fibres.

The identified polymer was predominantly polyethylene, with seven colour variations observed. There is a correlation between the amount of microplastics in the waters and in green mussels, indicating that higher levels of microplastics in the waters are associated with increased levels in green mussels.

## ODNOS KOLIČINE MIKROPLASTIKE U ZELENOJ DAGNJI *Perna viridis* I VODAMA PLAŽE MANGKANG, SEMARANG

### SAŽETAK

Plastika, posebno mikroplastika, trenutno predstavlja potencijalnu prijetnju onečišćenju vode. Mikroplastika se nalazi ne samo u vodi već i u akvatičnim životinjama. Zelene dagnje *Perna viridis* uzgajane u obalnim vodama Mangkang Wetan mogu biti kontaminirane mikroplastikom. Cilj ovog istraživanja bilo je utvrditi količinu mikroplastike prema obliku, boji i vrsti polimera te ispitati odnos između količine mikroplastike u vodenom okolišu i zelenih dagnji *P. viridis*. Prikupljanje podataka provedeno je metodom slučajnog uzorkovanja kako bi se procijenila distribucija uzgoja zelenih dagnji prikupljanjem uzoraka vode i zelenih dagnji, koji su analizirani kvantitativnim metodama. Analiza podataka provedena je pomoću ANOVA i regresijske analize. Istraživanjem su identificirane 4 vrste oblika mikroplastike u vodama i 3 u zelenim dagnjama, s dominantnim fragmentnim oblicima u obje. Pronađeno je sedam boja (žuta, zelena, plava, crna, prozirna, smeđa i crvena), s dominantnom smeđom bojom. Identificirano je devet vrsta polimera (polivinil klorid, polietilen tereftalat, polipropilen, polietilen niske gustoće, polietilen visoke gustoće, najlon, celulozni acetat, polietersulfon i polistiren), s polietilen tereftalom kao dominantnim polimerom. Količina mikroplastike u vodama i zelenim školjkama na Postaji 1 bila je  $6,33 \pm 0,45$  čestica/litri i  $4,91 \pm 2,32$  čestice/ind, na Postaji 2 bila je  $2,33 \pm 0,49$  čestica/litri i  $1,33 \pm 0,28$  čestica/ind, a na Postaji 3 bila je  $4,63 \pm 0,32$  čestice/litri i  $2,91 \pm 1,18$  čestica/ind. Rezultati ANOVA za količinu mikroplastike u vodama pokazali su značajnu vrijednost od  $0,00 < 0,05$ . Rezultati ANOVA za brojnost mikroplastike zelenih dagnji pokazali su značajnost

od 0,072, što je > 0,05. Regresijska analiza pokazala je eksponencijalni obrazac, s koeficijentom determinacije ( $R^2$ ) od 0,685.

**Cljučne riječi:** filtratori, zagađenje vode, polietilen tereftalat, zagađenje okoliša, biodepozicija

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## CONFLICT OF INTEREST

The authors have declared no conflict of interest.

## DATA AVAILABILITY STATEMENT

The datasets generated and/or analysed during the current study are not publicly available but are available from the corresponding author on reasonable request.

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