Plastics aplenty in paddy lands: incidence of microplastics in two rice cultivars of Kerala, India, and its impact on primary producers found in paddy fields

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ABSTRACT: Microplastics (MP) have received worldwide attention in recent years because of its prevalence in key ecosystems, including agroecosystems. Occurrence of MP in native paddy fields, which are critical to world's food security, is not reported till date. This study reports the abundance of MP in two different rice cultivars, one of which is the 'Pokkali' crop that is Geographical Indication tagged and is a salt-tolerant, climate-resilent variety in Kerala, India. Major MP detected in this study which was conducted in the surface water layer of paddy fields during vegetative season (transplantation) and ripening season (near harvesting) were polyethylene (PE) and polypropylene (PP). MP density in vegetative phase was more than twice the ripening phase concentrations in the tested rice cultivars. Influx of monsoon rains bringing plastic runoff and soil tilling might be the potential causes. Subsequently, impacts of MP and plastic leachates (PL) on phytoplankton which are naturally found in the rice fields were examined. Microalga, *Chlorococcum* sp., isolated from the paddy land, and cyanobacterium, *Synechococcus* sp. were tested with environmentally relevant concentrations of PE-MP and PE-PL. MP bestowed a significant hormetic effect on the specific growth rate of the microalga whereas the cyanobacterial growth was negatively impacted. Such low-dose stimulatory effect is a classic response of over-compensation to mild environmental stress in microalgae. The significantly increased catalase activity and reduced superoxide dismutase activity in the cyanobacterium corroborated the toxic impact on growth. The differential response to MP and PL stress by microalga and cyanobacterium suggests that phytoplankton and MP type and size, may play major roles in determining stress response. This study underscores the possible change in community structure and function of paddy field phytoplankton at presently prevalent environmental MP concentrations and, consequently on rice productivity.

KEYWORDS: Ecotoxicology, Phytoplankton, Algae, Cyanobacteria, Aquatic Ecosystems, Pollutants

1. INTRODUCTION

Microplastics (MP) levels in the aquatic ecosystems are quite alarming irrespective of the geographic region[1]. MP in agroecosystems is a natural extension of its presence in aquatic and terrestrial ecosystems[2–5]. Several studies have focussed on soil-plant-MP interactions in agroecosystems given their significance for impacting food security[4]. Nevertheless, there are not enough studies on the incidence of MP in the native fields of staple crops such as wheat, maize or rice[5]. To the best our knowledge, there are no studies on the incidence of MP in the water column of natural rice fields although there are several studies on terrestrial, freshwater and brackish water ecosystems from across the world.

Paddy fields are a unique agroecosystem as rice is a wetland crop, grown in artificial, shallow wetlands across the world. The geographical spread of paddy fields is concentrated in the most populous and ancient regions as it is one of the first crops to be mass cultivated by human civilization[6]. *Oryza sativa* is the major crop grown across the World now and thousands of varieties of *O. sativa* exist. In the present day context, climate resilient, indigenous varieties are desirable, and one such variety is grown in the riparian regions of the Vembanad lake, the longest lake in India and the largest in the state of Kerala[7-9]. This unique lake houses several islands which are habituated, and some such as Kuttanad, which is considered the rice bowl of the state, has the lowest altitude in India where paddy cultivation happens in brackish water below sea level. The Geographical Indication (GI) tagged, salt-tolerant ‘Pokkali’ cultivar, henceforth referred to as POKKALI, is grown here[10]. The ‘Uma’ cultivar (MO-16, GM Biotype

5, brown planthopper resistant, henceforth referred to as UMA), which is grown in about 60% of paddy fields across Kerala, is grown in the freshwater-logged, marshy, riparian regions of the lake[9]. Some rice varieties grown in the Vembanad region, in particular POKKALI, have relatively higher flood tolerance with stronger stems and kneeling ability to withstand water logged conditions. And fishes are grown in the POKKALI fields after harvesting and during the high-salinity season[9,11]. Vembanad and immediate riparian zones come under the administrative control of two districts in the state of Kerala, and city of Kochi, one of the only two metropolises in the state, is part of this region[12]. Hence, the paddy lands in this region which also serve as buffer zones during floods serve as the ideal study area to ascertain the incidence of relevant emerging pollutants such as MP in these critically important agroecosystems.

The impact of MP and plastic leachates (PL) on the phytoplankton community and by extension, on aquatic ecosystems was reviewed recently which established an escalating danger to phytoplankton community structure and function thereby altering aquatic ecosystems[13]. The primary producers are also part of paddy fields, beneficially influencing paddy productivity, and phytoplankton community is in turn influenced by factors such as pesticide and fertilizer application[14]. In this study, the MP incidence in surface waters of two rice cultivars of Kerala, POKKALI and UMA, is reported during the year 2021-2022 in vegetative and ripening seasons. The impact of one of the most dominantly observed MP in these paddy fields and its PL on the commonly found paddy phytoplankton was studied.

2. MATERIALS AND METHODS

2.1. Water and MP Sampling. Kochi is the largest metropolitan city in the state of Kerala, and two distinct agroecosystems closer to Kochi city were selected for the study: Kandanad Paddy Field and Kadamakudy Paddy Field. Kandanad paddy field (9°54'53.86"N, 76°22'50.52" E) growing the UMA variety of rice is a freshwater wetland connected to Vembanad Ramsar site with a total area of about 15-20 hectares in the Ernakulam District, Kerala. A map of UMA paddy land depicting the sampling sites is given in **Figure 1** (QGIS 3.32.3). Kadamakudy POKKALI Paddy Field (10°03'14.4"N, 76°15'13.3" E) is a brackish water wetland located closer to Kochi city and a popular tourist spot connected to Vembanad[10]. Only a few portions of the wetland are used for POKKALI cultivation[11] (**Figure 1**). Water samples were collected from five sampling sites at UMA and POKKALI during the vegetative (mid-April, 2021-22) and ripening (October-end, 2021-22) seasons of the crops (**Figure 1**). The 20L of surface water (10-20 cm of water without disturbing sediments) collected was filtered using a plankton net with 90µm pore size at sampling site, and samples thus collected were transferred to a borosilicate bottle for further processing in the laboratory. Water quality analyses were performed as per standard methods[15]. The extraction of MP was performed based on the method and standards proposed by the National Oceanic and Atmospheric Administration[16]. Each water sample underwent different processes: sieving, drying, wet peroxide oxidation, density separation, filtration, and drying[16].

2.2. Quantitative and Qualitative Analysis of MP. MP fragments extracted were collected to a petri plate in sterile conditions and were visually sorted with the help of a microscope and identified using the Fourier Transform Infrared Spectroscopy (FTIR) (PerkinElmer Spectrum Two L160000A, CT, USA). Analysis was carried out for each microplastic particle in the spectral range of 400–4000 cm^{-1} with 16 scans at 1 cm^{-1} resolution. The polymer type was identified using an open-source spectral database (Open Specsy 0.1)[17], and only the spectrum with a matching factor of 0.9 and above is considered as the respective polymer. MP in the size range of 500μm to 90μm were reported in this study. MP surface structure and elemental composition was analysed using Scanning Electron Microscope with Energy Dispersive X-ray Spectroscopy (SEM-EDX) (Jeol JSM-6390LA-Oxford XMX N, Tokyo, Japan). Control samples were used at all stages to ascertain any MP contamination in the working environment.

2.3. Toxicity Analysis of MP and PL on the Isolated Phytoplankton. MP fragments were prepared by grinding a commercially available PE polymer container, and MP between 90 μm and 500 μm were selected for this study. MP thus generated were analysed using FTIR before using them in toxicity experiments. PL was prepared by leaching prepared MP fragments at same concentrations in BG11 media at 25°C and 130 rpm in a shaker for three days, filtered and used immediately in toxicity experiments[18]. Algal strains were isolated from collected water samples and unialgal strains were obtained using methods described previously[19]. The freshwater microalga *Chlorococcum sp*. was isolated from the stem–root zone of the UMA paddy crop, and the unialgal strain was identified using taxonomic keys and using 18S rRNA based phylogenetic analysis (data not shown)[20]. Cyanobacterium *Synechococcus sp*. was isolated from a water drain and the unialgal strain was identified using taxonomic keys and using 16S rRNA based phylogenetic analysis (data not shown)[21]. These organisms have been reported to be isolated from paddy fields in earlier studies and were used as test organisms for this study[22,23]. The strains were maintained in BG11 medium in a shaking incubator under low light regime at 25°C, and 130 rpm. The MP type and concentration for toxicity experiments was determined based on the field study results. Environmentally relevant concentration (mean of the field MP concentration, MP-1 & PL-1) and a relatively higher concentration

(concentration at individual sampling point P1, MP-10 & PL-10) (**Table S1 & S2**), to assess the dose–response relationships of selected study organisms towards MP and PL[13]. The duration of the experiment was decided based on the growth curve of the organisms selected, and experimental groups included a control group in the absence of MP and PL. All experiments were performed in triplicates.

2.4. Phytoplankton cell density and physiology. The chlorophyll *a*, cell density, and carotenoid content were measured in the control and treatment groups of two phytoplankton species used in this study. Cell density was determined daily by microscopically monitoring cell number using a haemocytometer[24]. Chlorophyll *a* and carotenoids were extracted and determined spectroscopically[25]. Superoxide dismutase (SOD) activity was determined in the study organisms in the treatment and control groups, and data was represented by the method used in the previous studies[26,27]. Similarly, catalase (CAT) activity was also measured as described earlier[26,27].

3. RESULTS AND DISCUSSION

The agroecosystems selected in this study are very unique as they constitute a part of the wetland ecosystem which is below sea level (**Figure 1**). In particular, the POKKALI paddy is a salt-tolerant, highly nutritious, and climate resilient crop which needs to be encouraged among the farming community[10,28,29]. Therefore, these agroecosystems are critical from a climate change mitigation and adaptation, and food security perspectives. Water quality data from the paddy fields confirmed that POKKALI field had higher salinity, dissolved solids, and nutrient levels in the vegetative season which follows the fish farming season in POKKALI field during the non-paddy period (**Table 1**)[9,29]. Salinity and total dissolved solids levels decreased significantly in the ripening season because of the possible influx of freshwater during the monsoon season, while the nitrate levels increased, perhaps because of fertilizer application or nitrate in the runoff during the growth period. A similar trend was observed in the freshwater UMA paddy field (**Table 1**). The MP concentration likewise was higher during the vegetative stage which is accompanied by monsoon rainfall and preceded by a harsh summer which is known to aid fragmentation of the macroplastics[30]. Vegetative season is immediately preceded by tilling and soil preparation for transplantation which might aid MP surge to the water column. PE and PP MP were equally distributed in both the paddy fields. The total MP fragments in the POKKALI was slightly higher than that of UMA (**Table 1**). Such dominance of PE and PP MP has been reported from the sediments of Vembanad Lake, which is connected to the selected agroecosystems, and form a part of the lake's riparian zone[31]. All MP fragments were sorted, and their identity was confirmed using FTIR. The MP reported as 'Others' during the ripening season in the UMA paddy field were principally Elastomers. The representative FTIR spectra and SEM images of the PE and PP fragments have been depicted in **Figure 2**. The water quality and MP data of individual sampling points are provided in the Supplementary Tables. The sampling points U1 and P1 are exposed to human activities, U1 is located near a railway track with human settlements in the proximity. Likewise, P1 is located near a popular tourist destination and has road access frequented by tourists (**Figure 1, Table S1 & S2**).

Figure 1. The selected paddy lands in the state of Kerala, India, Kandanad Paddy Field (‘UMA’ Cultivar) and Kadamakudy Paddy Field (‘POKKALI’ Cultivar)

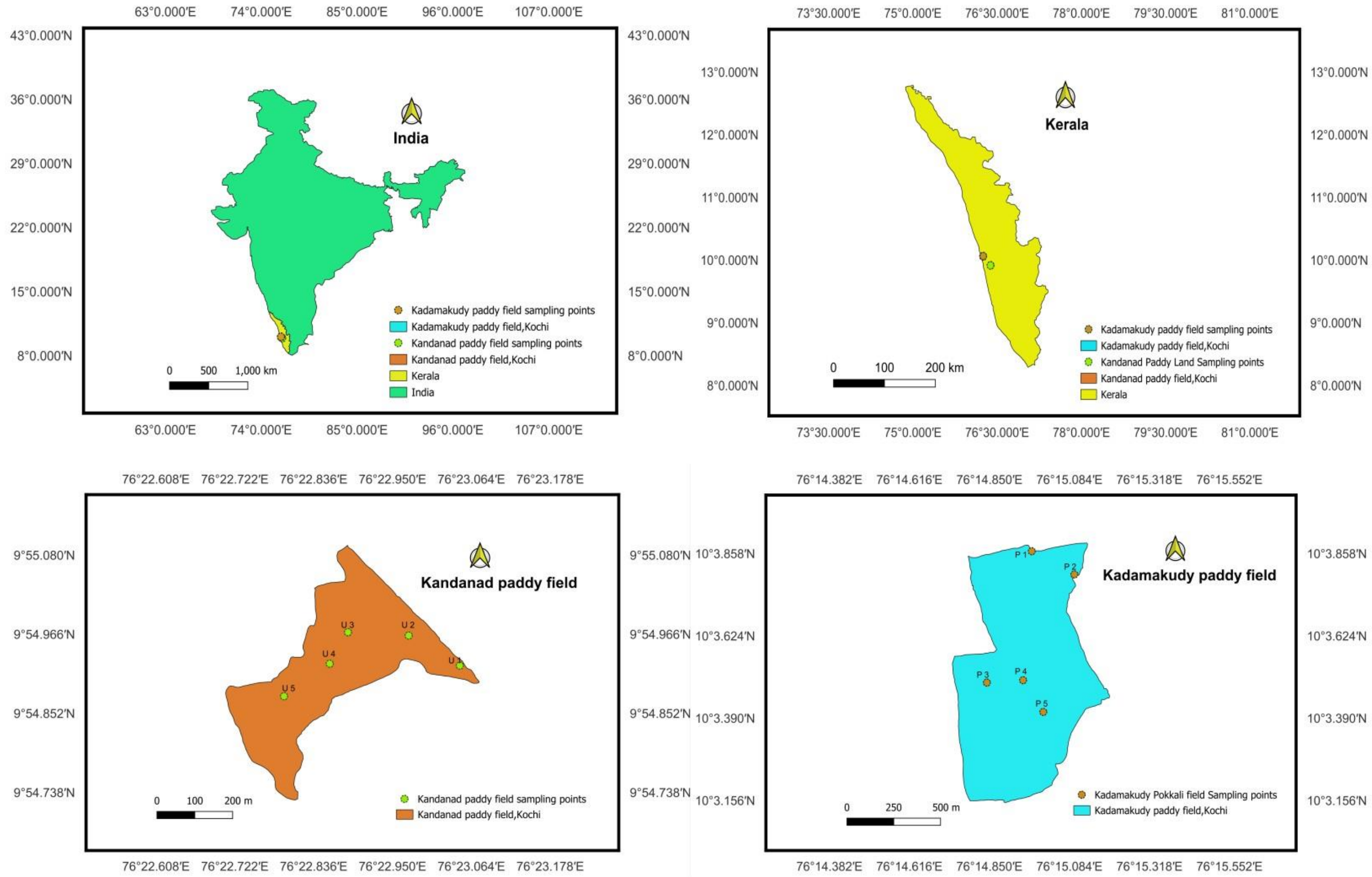
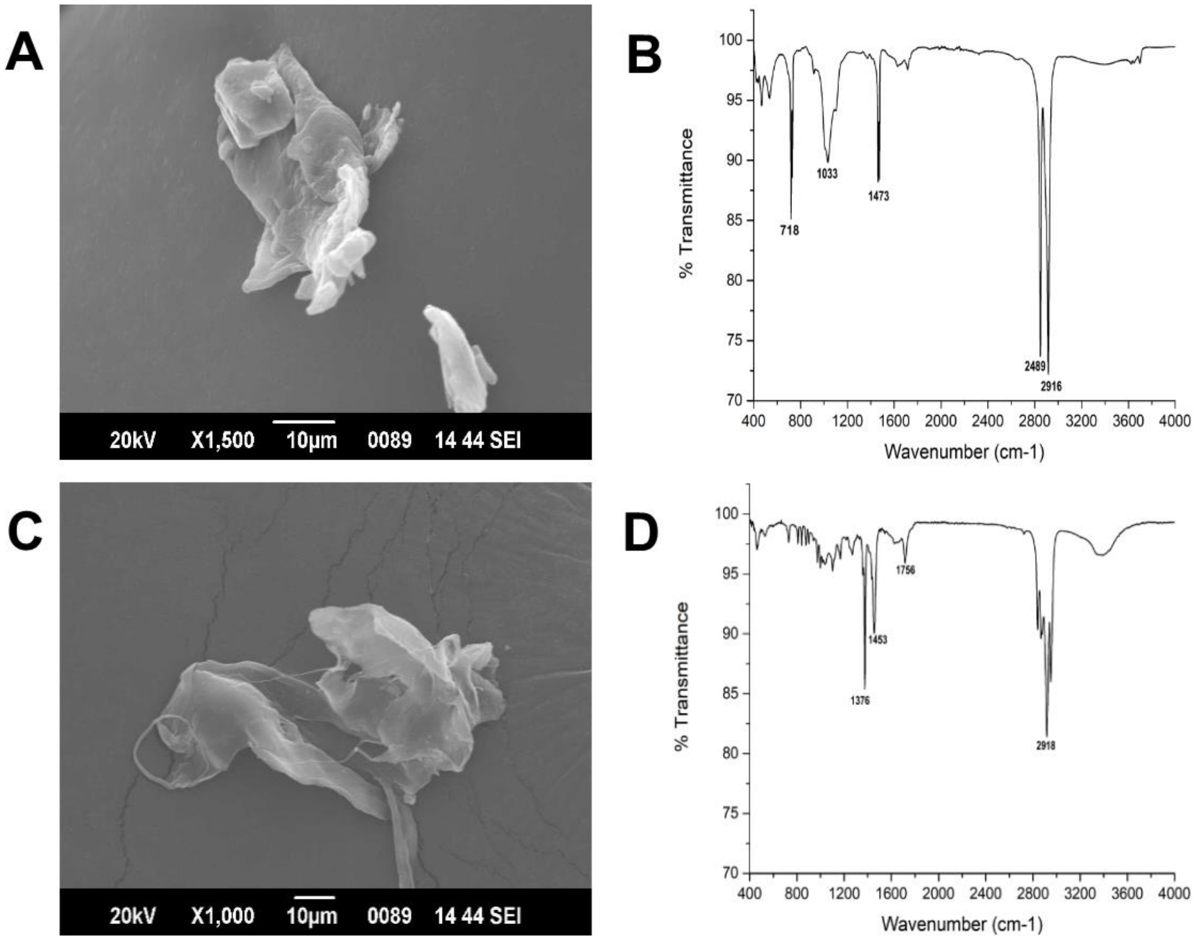


Table 1. Water quality, polypropylene and polyethylene microplastics density in the surface waters of the selected agroecosystems during the vegetative and ripening seasons.

Sample Site	Seasons	pH	Conductivity (µS)	Salinity (mg/L)	TDS (mg/L)	COD (mg/L)	Total Phosphorus (mg/L)	Nitrate (mg/L)	PP/m^3	PE/m^3	Others/m^3	Total Fragments/m^3
POKKALI	Vegetative	8.08±0.45	1296.60±511.34	340.04±465.39	921.0±363.94	12.32±6.75	0.02±0.00	10.63±4.17	700±285.04	670±198.75	0	1370±468.51
	Ripening	6.65±0.19	278.34±100.14	241.34±87.69	196.29±72.15	4.37±0.81	0.03±0.03	20.57±10.73	240±221.92	160±114.02	0	400±196.85
UMA	Vegetative	6.41±0.48	50.8±6.26	52.3±4.74	77.12±61.77	14.94±5.57	0.00116±0.0	4.28±2.96	560±167.33	550±158.11	0	1110±304.96
	Ripening (2022)	6.24±0.10	95.08±26.46	84.22±24.16	67.52±18.80	81.84±45.13	0.114±0.07	13.57±9.70	190±22.36	180±57.00	0	370±57.00
	Ripening (2021)	6.27±0.28	50.77±5.84	51.47±5.24	36.57±4.56	2.90±1.767	0.502±0.79	10.41±2.01	200±50	166.67±76.38	50±50	416.67±125.83

Two phytoplankton species were used for ecotoxicity experiments against a commercially available PE polymer container. Both the phytoplankton tested, microalga *Chlorococcum* sp. and cyanobacterium *Synechococcus* sp. are freshwater species and were grown in BG11 media (**Figure 3A&B**). The concentration of MP and PL used for ecotoxicity experiment, and for laboratory PL preparation, was determined as mentioned in Section 2.3. The cell density of both the phytoplankton species were monitored in control and treatment groups. While *Chlorococcum* sp. showed a statistically significant increase in the specific growth rate when exposed to MP in a dose dependent manner, PL treatment resulted in increased growth of the microalga, albeit insignificantly (**Table 2**). Interestingly, chlorophyll *a* and carotenoid concentrations decreased in the treatment groups (**Figure S1**). On the other hand, both treatment groups (MP & PL) showed a statistically significant decrease in specific growth rate of *Synechococcus* sp., while chlorophyll *a* and carotenoid concentrations did not show any consistent pattern with respect to dose or treatment time (**Table 2, Figure S2**). Overall, the microalga showed a hormetic response towards both MP and PL, whereas the experimented concentrations were extremely toxic to the cyanobacterium. In both the phytoplankton, however, the response was dose dependent. Such mixed responses have been observed among different algal species, especially hormetic effect of MP and PL has been reported in earlier studies which may have ecological implications on the global carbon cycling[13, 32–34]. As the phytoplankton used in this study differ in size and morphology, MP size might elicit different responses depending upon the relative size-ratio[35]. Therefore, MP may cause a stronger toxicity on smaller cyanobacteria than a relatively larger and naturally flocculated eukaryotic green alga like *Chlorococcum* sp[32,33].

Figure 2. Representative scanning electron microscopic images and fourier transform infrared spectra of polyethylene (A&B) and polypropylene (C&D) microplastics isolated from paddy fields, respectively.



The mixed toxicity response among phytoplankton certainly impacts phytoplankton community dynamics by encouraging species within the community which are resilient, and hydrocarbon degraders are known to be prevalent in MP impacted regions[13,36]. The impact on phytoplankton may also differ depending upon the MP type. Harmful algal blooms (HABs) may also be manifested because of the hormetic effect of MP on certain dominant phytoplankton species or the toxin production might be enhanced in HABs[13,37]. When the phytoplankton community is altered, the associated phycosphere bacterial community which constitute rhizobacteria may also be impacted[38,39]. Therefore, MP may have serious implications for rice productivity, especially in the case of climate-resilient crops such as POKKALI, which is conferred salt-tolerance by endophytic microorganisms associated with its rhizosphere[28].

The experimental results, when viewed in isolation, show that phytoplankton species that are larger, and perhaps flocculated may might resist MP and PL stress better, thereby encouraging shift in phytoplankton community. However, this response may also be dynamic and may change with higher doses of MP and PL, and in the presence of other environmental stressors[13]. Therefore, considering the several factors associated with ecotoxicity of MP and PL on paddy field phytoplankton, further studies must be undertaken. Notwithstanding the significant change in growth parameters of the treatment groups especially in the presence of MP, the photosynthetic pigments were not significantly and consistently affected by the presence of MP or PL. Therefore, the concentrations of antioxidant enzymes, CAT and SOD were measured in the experimental groups (**Figure 3**). The CAT and SOD activities were significantly influenced in the treatment groups especially in the case of cyanobacterium, which is in concurrence the specific growth rate where MP and PL had a markedly toxic effect on *Synechococcus* sp. compared to the hormetic response of *Chlorococcum* sp. CAT activity in *Synechococcus* sp. showed a significant increase within a short duration of exposure to MP and PL (3h) with the response to PL being stronger than MP (p-value>0.05). Moreover, the response was dose-dependent for both MP and PL exposure at 3h and 24h (**Figure 3C&D**).

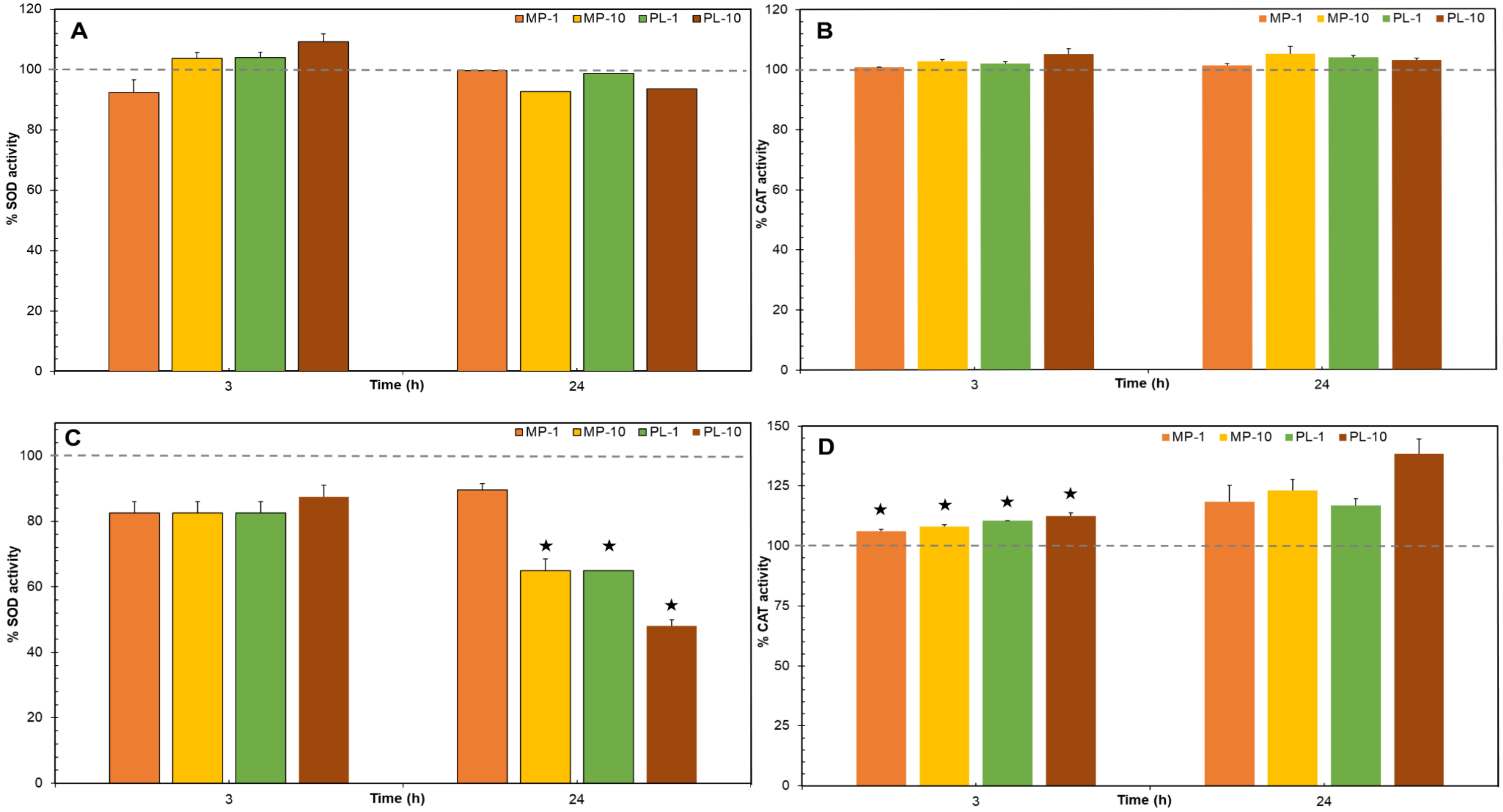
Likewise, in the case of SOD activity, the cyanobacterium displayed reduced activities at 3h and 24h, but significantly in the case of PL at 24h and MP at high concentration at 24h (p-value>0.05). On the contrary, in the case of *Chlorococcum* sp., the microalga did not display any significant difference in the SOD or CAT activities in short term and day-long exposures consistent with the robust growth observed (**Figure 3A&B**). It must be noted that CAT enzyme serves as one of the first generic toxic response to hydroxyl radical generation[40]. Increase in CAT activity along with decreased growth parameters indicates a substantial challenge to the growth of the cyanobacterium imposed by MP and PL. Similarly, a notable reduction in SOD activity in the cyanobacterium indicates quenching of the enzyme by the superoxide radicals or a compromised SOD anti-oxidant machinery in *Synechococcus* sp. when exposed to MP and PL even at low concentrations. Only environmental concentrations of MP were used in this study which may explain the relatively insignificant change in SOD levels, especially in the case of *Chlorococcum* sp. Such responses have also been observed in other studies at the concentration studied in the case of PE[40–42]. On the other hand, it is important to note that the PE was only MP tested for ecotoxicity analyses, whereas PP was also equally prevalent in the paddy fields studied here. Taken together, MP and PL may have an extensive impact on the health, structure and possibly function of the phytoplankton community found usually in the paddy fields.

This is the first study to report the presence of MP in the surface waters of paddy fields. One of the rice cultivars used in this study (UMA) is the most popular rice variety in the state of Kerala, India and accounts for nearly 60% of rice consumption in Kerala[43]. The other cultivar (POKKALI) is a climate-resilient, organic variety with the best nutritional qualities among the popular varieties of Kerala[9]. The incidence of MP in these paddy fields highlight the issue of urbanization and unscientific plastic waste disposal in the state[44]. The toxic impact of MP and PL on the paddy field phytoplankton calls for an exigent intervention from the policy makers not only in the study area but also world over considering the mounting prevalence of MP reported in varied aquatic and agro-ecosystems, and it’s threat to food security.

Table 2. Growth and physiological parameters studied in the phytoplankton species when exposed to microplastics (MP) and plastic leachates (PL)

Samples/ Treatment	**Specific Growth Rate (h^{-1}) [*p-value*]**	**Doubling Time (d^{-1}) [*p-value*]**	**Chlorophyll *a* (ug/mL)**	**Total carotenoids (ug/mL)**
Chlorococcum sp.	0.218 ± 0.004	3.173 ± 0.055	15.686 ± 1.249	4.660 ± 0.417
Chlorococcum sp. + MP–1	0.246 ± 0.000 [*0.0046*]	2.817 ± 0.006 [*0.0066*]	19.632 ± 5.471 [*0.4123*]	5.708 ± 2.243 [*0.6763*]
Chlorococcum sp. + MP–10	0.263 ± 0.012 [*0.0384*]	2.645 ± 0.119 [*0.0343*]	13.992 ± 0.025 [*0.3006*]	3.290 ± 0.118 [*0.0976*]
Chlorococcum sp. + PL–1	0.269 ± 0.030 [*0.1205*]	2.599 ± 0.286 [*0.1003*]	20.160 ± 4.392 [*0.3195*]	5.524 ± 1.060 [*0.4538*]
Chlorococcum sp. + PL–10	0.232 ± 0.053 [*0.7189*]	3.093 ± 0.689 [*0.8683*]	14.046 ± 0.239 [*0.3632*]	3.842 ± 0.111 [*0.2726*]
Synechococcus sp.	0.362 ± 0.011	2.246 ± 0.057	16.907 ± 3.563	7.419 ± 1.696
Synechococcus sp. + MP–1	0.325 ± 0.010 [*0.0003*]	2.464 ± 0.063 [*0.0003*]	17.193 ± 3.222 [*0.9483*]	7.589 ± 1.507 [*0.9341*]
Synechococcus sp. + MP–10	0.255 ± 0.007 [*0.0005*]	3.058 ± 0.071 [*0.0001*]	11.159 ± 3.688 [*0.0631*]	4.380 ± 1.561 [*0.0491*]
Synechococcus sp. + PL–1	0.347 ± 0.004 [*0.0599*]	2.330 ± 0.022 [*0.0515*]	10.631 ± 5.271 [*0.0909*]	4.424 ± 2.549 [*0.1108*]
Synechococcus sp. + PL–10	0.344 ± 0.007 [*0.0144*]	2.345 ± 0.041 [*0.086*]	17.282 ± 2.379 [*0.9195*]	7.604 ± 1.448 [*0.9254*]

Figure 3. The percentage superoxide dismutase (SOD) and catalase (CAT) activities in the treatment groups with respect to the control group (normalized to 100%, dashed line) in *Chlorococcum* sp. **(A&B)** and *Synechococcus* sp. **(C&D)**. Asterisk (*) symbol indicates P-values of >0.05 calculated using paired t-test.



AUTHOR CONTRIBUTIONS

C.A. performed sampling, experiments, and drafted the manuscript. R.R. conceptualized the study, drafted and revised the manuscript, and supervised the project. H.S.K. contributed to data interpretation and revised the manuscript. All authors have given approval to the final version of the manuscript. The authors declare no competing financial interest.

ACKNOWLEDGMENTS

This research is supported by the projects awarded to R.R by State Wetland Authority Kerala (SWAK), Government of Kerala, and the Early Career Research Award of Science and Engineering Research Board (DST-SERB), Government of India. R.R. and H.S.K thank the National Research Foundation (NRF) funded by the Ministry of Science and ICT (MSIT), Republic of Korea (RoK), for the award of Brainpool fellowship to R.R, and to H.S.K.'s host laboratory (Grant No. 2021H1D3A2A0204337411); H.S.K. acknowledges NRF grant received from the MSIT, RoK, as part of "Carbon to X Project" (Grant No. 2020M3H7A1098291); and funds from KRIBB Research Initiative Program (http://www.kribb.re.kr). C.A. thanks University Grants Commission for the award of Senior Research Fellowship. R.R. and H.S.K. are grateful to Prof. (Dr.) Hee-Mock Oh, KRIBB, who superannuated recently, for his guidance, inspiration and encouragement.

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Table S1. The water quality parameters and microplastics abundance in all the sampling points of Kandanad UMA paddy field.

Sl. No.	Sampling points	pH	Conductance (µS)	Salinity (mg/L)	TDS (mg/L)	COD (mg of O2/L)	Phosphate (mg/L)	Nitrate (mg/L)	PP/ m3	PE/ m3	Others/ m3	Total Fragments/m3
Vegetative Season												
1	U-1	6.71	48.4	51.5	34.8	12.45	0.0003	0.833	600	700	0	1300
2	U-2	6.78	53.9	54.4	38.3	12.45	0.0013	5.5	600	600	0	1200
3	U-3	6.78	41.5	45	29.5	12.45	0.0018	4.5	400	300	0	700
4	U-4	5.99	58.1	57.9	115	24.9	0.0013	8.417	800	650	0	1450
5	U-5	5.79	52.1	52.7	168	12.45	0.0011	2.167	400	500	0	900
Ripening Season (2021)												
1	U-1	5.95	55	55.3	40.43	0.9	1.41	10.98	200	250	100	550
2	U-2	6.4	44.1	45.5	31.53	3.55	0.022	8.17	250	100	50	400
3	U-3	6.47	53.2	53.6	37.73	4.25	0.075	12.07	150	150	0	300
Ripening Season (2022)												
1	U-1	6.27	93	84.4	66.1	BDL	0.056	5.392	150	200	0	350
2	U-2	6.33	69.5	55.5	49.3	BDL	0.064	7.892	200	250	0	450
3	U-3	6.28	69.1	65.2	49.1	BDL	0.075	6.270	200	150	0	350
4	U-4	6.26	126	111	89.4	89.28	0.156	23.568	200	100	0	300
5	U-5	6.05	117.8	105	83.7	74.4	0.219	24.716	200	200	0	400

Table S2. The water quality parameters and microplastics abundance in all the sampling points of Kadamakudy POKKALI paddy field.

Sl. No.	Sampling points	pH	Conductance (µS)	Salinity (mg/L)	TDS (mg/L)	COD (mg of O2/L)	Phosphate (mg/L)	Nitrate (mg/L)	PP/m3	PE/m3	Others/m3	Total Fragments/m3
Vegetative Season												
1	P-1	7.7	1227	111	871	12.32	0.019	13.667	1100	1000	0	2100
2	P-2	7.91	1009	904	719	BDL	0.014	13.167	400	500	0	900
3	P-3	7.68	2180	203	1550	12.32	0.025	13.5	800	700	0	1500
4	P-4	8.43	1174	105	832	12.32	0.02	8.667	750	550	0	1300
5	P-5	8.67	893	792	633	BDL	0.013	4.167	450	600	0	1050
Ripening Season												
1	P-1	6.32	298.3	257.7	211	5.15	0.06	18.785	600	50	0	650
2	P-2	6.75	262.7	226.3	178.3	4.9	0.015	13.052	50	50	0	100
3	P-3	6.7	284.7	243.3	202	4.65	0.017	19.52	100	300	0	400
4	P-4	6.7	132.7	116.7	94.467	4	0.0134	12.605	300	150	0	450
5	P-5	6.8	413.3	362.7	295.7	3.15	0.069	38.91	150	250	0	400

Figure S1. Photomicrograph of *Chlorococcum sp.* (A) isolated from the stem-root zone of the UMA paddy crop; The impact of MP and PL concentrations on growth (B), chlorophyll content (C), and carotenoid content (D) of the isolated *Chlorococcum* sp.

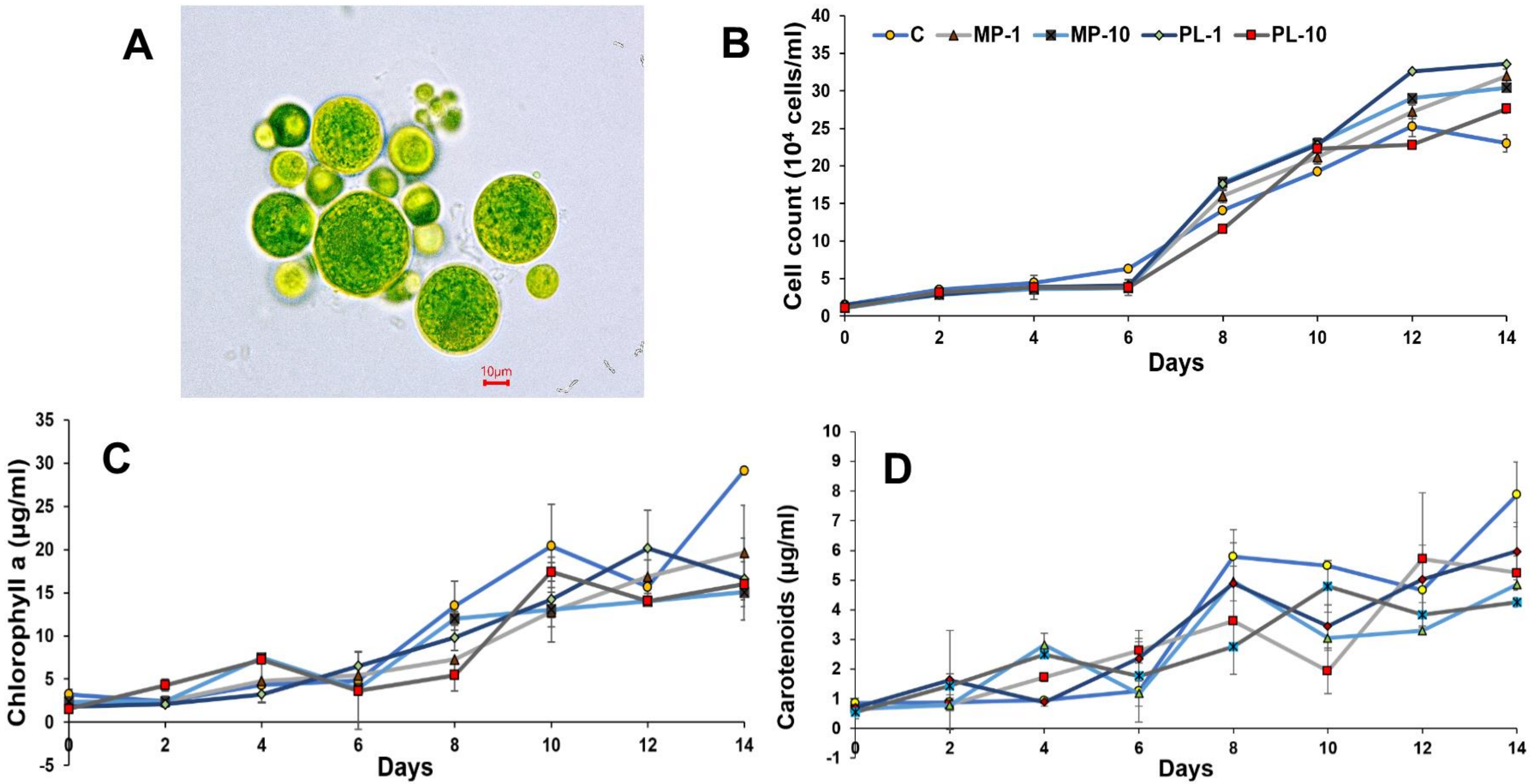

Figure S2. Photomicrograph of the unialgal *Synechococcus* sp. strain (A) used in this study; The impact of MP and PL concentrations on growth (B), chlorophyll content (C), and carotenoid content (D) of the isolated *Synechococcus* sp.