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# Microplastics in the edible and inedible tissues of pelagic fishes sold for human consumption in Kerala, India☆

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ABSTRACT

Microplastics in commercially important seafood species is an emerging area of food safety concern. While there have been reports of plastic particles in the gastrointestinal tract of several species, presence of microplastics in edible fish tissues has not yet been reported from India. This study examined the presence of microplastics in the edible (muscle and skin) and inedible (gill and viscera) tissues of nine commercially important pelagic fish species from Kerala, India. A total of 163 particles consisting mainly of fragments (58%) were isolated. Out of 270 fishes analysed ($n = 30$ per species), 41.1% of the fishes had microplastics in their inedible tissues while only 7% of fishes had microplastics in their edible tissues. The quantity of microplastics in inedible tissue was significantly larger in filter feeders than, that in visual predators ($p < 0.05$). The average abundance of microplastics in edible tissues was 0.07 ± 0.26 items/fish (i.e., 0.005 ± 0.02 items/g) and was 0.53 ± 0.77 items/fish (i.e., 0.054 ± 0.098 items/g) in inedible tissues. The results suggest the possibility of human intake of microplastics by the consumption of pelagic fishes from this region, albeit in small quantities.

## 1. Introduction

Owing to the convenience and indispensability of plastics in modern life, global plastic production (excluding polyethylene terephthalate, polyamide and polyacryl fibres) reached about 359 million metric tons in 2018 (Plastics Europe, 2019). Simultaneously, improper plastic waste management results in an annual disposal of 4.8–12.7 million metric tons of plastic debris into the oceans, which is estimated to increase by an order of magnitude by 2025 (Jambeck et al., 2015). The fragmentation of larger plastic debris, along with the discharge of wastewater containing intentionally manufactured plastic particles into the oceans, has led to the accumulation of microplastics (plastic particles< 5 mm) in the marine environment (Arthur et al., 2009). The increase in the quantity of microplastics in marine ecosystems has brought about its uptake by a wide range of marine organisms (Cole et al., 2014; Devriese et al., 2015; Botterell et al., 2019; Zhang et al., 2019; Moore et al., 2020; Amin et al., 2020).

Microplastics have been reported in the gastrointestinal tract (GIT) of a range of fishes across continents (Rochman et al., 2015; Bellas et al., 2016; Su et al., 2019; Baalkhuyur et al., 2020). The ecological risk of plastic particles in fishes includes reduced organism level fitness due to physical blockages, false satiation, inflammation as well as reduced fecundity affecting fish populations (GESAMP, 2016). But since GIT is removed most of the time before human consumption, microplastics in fishes were not considered as a major food safety issue until recently. Microplastics are considered to be vectors of organic pollutants and the possibility of chemicals leaching into the edible tissues of seafood was proposed by some researchers, but there is still a lack of consensus among the scientific community about the same (Koelmans et al., 2014; Barboza et al., 2018; Hantoro et al., 2019). However, concerns started emerging after translocation of microplastics from GIT into other tissues were demonstrated in laboratory experiments (Browne et al., 2008; Lu et al., 2016; Jovanović et al., 2018). Of late, the issue has started receiving widespread attention, with reports of microplastics detection in various tissues such as muscle, skin and gills of wild-caught fishes across countries (Karami et al., 2017; Abbasi et al., 2018; Akhbarizadeh et al., 2019).

Microplastics have been reported in pelagic environments across the world (Cozar et al., 2014; Eriksen et al., 2014; Isobe et al., 2015) and are predicted to be doubled by 2030 (Isobe et al., 2019).

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Pelagic organisms occupy and feed near the surface and subsurface layers of the oceans and thus are vulnerable to taking in floating microplastics either directly or indirectly through contaminated prey (Lopes et al., 2020). Consequently, microplastics have been observed in several species of pelagic fishes (Rochman et al., 2015; Jabeen et al., 2017; Lefebvre et al., 2019; Lopes et al., 2020). Microplastics in pelagic fishes can either be a transitory contaminant with limited residence time within the organism (Walkinshaw et al., 2020) or be transferred up the food chain (Queiros et al., 2019; Lopes et al., 2020). Pelagic fishery is also an economically important group, which contributes about 55% of total marine fish capture in India, having about 60 species of major commercial interest (James, 2010). Fishes are an integral constituent of Indian food basket due to its affordability and high protein content. Around 60% of the Indian population consumes fish and its annual per capita consumption among the fish-eating population is estimated to be around 8–9 kg (Shyam, 2016).

India ranks fourth in the mismanagement of plastic waste (Jambeck et al., 2015), with about 3.8 million tons of uncollected domestic plastic waste per year (Ministry of Housing and Urban Affairs, 2019). Microplastics from coastal waters, sediment and beaches of India have been widely reported (Jayasiri et al., 2013; Veerasingam et al., 2016; Robin et al., 2020; James et al., 2020). Studies have also documented the presence of plastics in the gut of fishes (Benjamin et al., 2014; Kripa et al., 2014; Viswambharan et al., 2018; Kumar et al., 2018; James et al., 2020), molluscs (Patterson et al., 2019; Naidu et al., 2019; Dowaraha et al., 2020) and polychaete worms (Naidu et al., 2018) from this region. But, to the best of our knowledge, prior to this study, no study from India had reported the presence of microplastics in edible fish tissues or other organs such as gills. As India is the second largest fish producer and a major consumer cum exporter of fish in the world (GoI, 2018), assessing the microplastic load found in a range of fish species from the country, is essential to ascertain the seafood safety and quality.

Thus, the objectives of this study were threefold: i) to investigate the presence of microplastics in the edible and inedible part of the pelagic food-fishes sold for human consumption and to characterize the microplastics if present, ii) to determine whether there is any correlation between microplastic presence in the edible tissues and that in the inedible tissues of fishes and iii) to examine whether there is microplastic variation between species in the edible or inedible tissues of commercial pelagic fishes.

## 2. Materials and methods

### 2.1. Sample collection and preparation

In Kerala, ring seine is the major gear used for catching pelagic resources (Edwin et al., 2010). Samples of nine major commercial pelagic fish species sold for human consumption were purchased from ring seine operators of Kalamukku (9.9836° N, 76.2423° E) fishing harbour during December 2017–May 2018. The fishes collected were caught using ring seine nets operated in the near shore area within the depth zone of 10–50 m and up to 12 nautical miles from shore (between 9.050 and 10.355° N to 76.00–76.415° E). The nine species selected for this study are *Rastrelliger kanagurta, Megalaspis cordyla, Sardinella longiceps, Sardinella gibbosa, Stolephorus indicus, Dussumieria acuta, Thryssa dussumieri, Sphyraena obtusata* and *Anodontostoma chacunda,* which are among the major commercially important pelagic food-fishes of India. All the species except *M. cordyla* and *S. obtusata* are filter-feeders inhabiting the surface and subsurface layers of Indian coastal waters (Abdussamad, 2015). *M. cordyla* and *S. obtusata* are pelagic predatory fishes that uses visual foraging as the predominant feeding strategy (Sivakami, 1997; Abdussamad, 2015). Anchovies (*S. indicus)* were caught using ring seines of 8–12 mm mesh size while all other species were caught with 22 mm mesh net.

From each species, 30 fishes were randomly collected and a total of 270 fishes were investigated during the course of the study. Although a sample size of 50 individuals per species is usually recommended (Dehaut et al., 2019), due to higher number of species in this study, the number of individuals per species was limited to 30. The samples were wrapped in aluminium foil and were transported to the laboratory in ice-boxes. One batch of sample (15 fishes) was stored at 4 °C for immediate analysis and the rest were stored at −20 °C until further processing. Fishes were washed with filtered water to remove dirt, if any, present on the surface and identified to species following FAO species identification sheets (FAO, 1984). The total length and weight of individual fishes were measured and recorded (Table 1). Prior to dissection of the fishes, its outer region was washed once again with filtered water. Of each fish, the inedible part consisting of gills and viscera was carefully dissected out in a metal tray. It was pooled into a clean pre-weighed Petri dish and was covered with a lid. Then, the scales of the fishes were scrapped off and they were filleted as per the method prescribed by the United States Environmental Protection Agency (USEPA, 2000). The edible part of the fish (fillet along with skin) was kept in another Petri dish with cover. Both edible and inedible tissues were weighed (Table S1) and transferred to a separate 250 ml conical flask.

### 2.2. Isolation of microplastics

To each of these conical flasks, 120–150 ml of 10% potassium hydroxide (KOH) was added and the flask was covered with aluminium foil. The KOH solution was prepared by dissolving 100g of KOH pellets (AR grade, Nice chemicals, Kochi, India) in 1000 ml of distilled water. The edible tissue samples were incubated at 60 °C for 24 h (Dehaut et al., 2016) and the inedible tissues were incubated at 40 °C for 72 h (Karami et al., 2017) in a bacteriological incubator (Labline, India). The tissue samples were manually shaken after every 24h. Karami et al. (2017) method was used to digest inedible tissues because of the incomplete digestion of gills following the method of Dehaut et al. (2016). Both these methods are used in previous studies to digest fish tissues without polymer damage (Barboza et al., 2019). The digested mixture was cooled and the digestate was filtered by a two-stage process to prevent the clogging of the pores of the filter paper. First, it was filtered through a 0.5 mm stainless steel sieve, and the retentate (particles > 500 μm) was transferred to the Petri dish for microscopic examination. Subsequently, the filtrate from the above stage was vacuum-filtered over through a 70-mm-diameter Whatman cellulose filter (Grade 1-pore size-11μm) to isolate particles < 500 μm. Density separation was not done to preserve microplastics of all densities (Abbasi et al., 2018). The filters of both edible and inedible tissues were placed in separate clean Petri dishes with a cover and air dried before further analyses.

### 2.3. Identification and characterization of microplastics

The filters were examined under a Motic SMZ-168 Stereo microscope (Motic, China) and microplastics were counted, measured and photographed using Motic image plus 2.0 software (Motic, China). Microplastics were classified based on their morphotypes, size and colour. Hard angular pieces were classified as fragments, elongated threadlike particles as fibres and flat flexible pieces as sheets (Jabeen et al., 2017). The MPs were classified into six different size groups: 100–200 μm, 200–400 μm, 400–600 μm, 600–800 μm, 800–1000 μm and 1000–5000 μm.

It is difficult to analyse particles less than 100 μm in ATR- FTIR.

**Table 1**
- Average total length and weight (±SD) of fish species used in this study. n = 30 each.

| Common name | *Species* | Family | Total length (cm) | Total weight (g) |
|---|---|---|---|---|
| Indian oil sardine | *Sardinella longiceps* | Clupeidae | 16 ± 0.5 | 40.3 ± 5 |
| Indian Mackerel | *Rastrelliger kanagurta* | Scombridae | 17 ± 1.3 | 43.7 ± 7.7 |
| Malabar thryssa | *Thryssa dussumieri* | Engraulidae | 13.3 ± 1.6 | 24.5 ± 6.2 |
| Chacunda gizzard shad | *Anodontostoma chacunda* | Clupeidae | 14.1 ± 1.5 | 31.9 ± 8.6 |
| Goldstripe sardinella | *Sardinella gibbosa* | Clupeidae | 13 ± 0.46 | 25.7 ± 5.3 |
| Indian anchovy | *Stolephorus indicus* | Engraulidae | 10.4 ± 0.4 | 9.7 ± 0.8 |
| Rainbow sardine | *Dussumieria acuta* | Dussumieriidae | 15.7 ± 0.6 | 31.1 ± 2.8 |
| Obtuse barracuda | *Sphyraena obtusata* | Sphyraenidae | 18.2 ± 1.2 | 31.3 ± 3.7 |
| Indian horse mackerel | *Megalaspis cordyla* | Carangidae | 19.1 ± 1.6 | 48.4 ± 5.8 |

Hence, 90 particles of size >100 μm (appx 50%) were randomly selected for FTIR analysis with Nicolet iS10 FTIR Spectrometer (Thermo Scientific, USA). The number of particles investigated included all particles from edible tissues (n = 23) and 67 particles from inedible tissues. A background scan was carried out prior to running each batch of sample. Samples were scanned in absorption mode in the wavenumber range of 400–4000 $cm^{-1}$. A total of 50 scans were performed for each sample and the spectra were matched with spectral libraries of OMNIC software. Spectral match >70% similarity was automatically accepted, matches between 60 and 70% similarity was individually examined using the polymer spectra published by Jung et al. (2018) and samples with spectra match < 60% were rejected. The abundance of microplastics were recalculated by excluding non -verified items (Table. S2).

The microplastic abundance in pelagic fish was expressed as the number of microplastic items per individual (items/individual) and microplastic items per g of tissue (items/g). The amount of microplastics in edible and inedible tissues were expressed separately as microplastic items per g of edible tissue (items/g edible tissue) and microplastic items per g of inedible tissue (items/g inedible tissue). Only the particles in edible tissues that were confirmed as microplastics via FTIR analysis (n = 19) were used for calculation of dietary intake of microplastics. Microplastic concentration (items/g edible tissue) hence obtained was used as a proxy to extrapolate the per capita microplastic load consumed. This was calculated using the annual per capita fish consumption data of Indians proposed by Shyam (2016).

### 2.4. Contamination control

Filter papers were examined under stereo-microscope prior to the experiment, to ensure the absence of contamination. All reagents were filtered through Whatman no.1 filter paper before use and the filters were checked under the microscope for contamination. To avoid cross contamination between samples, all equipment was rinsed at least three times with pre-filtered water before use. Work surface was cleaned using ethanol. Three Petri dishes with unused wet control filter papers were kept open during sample collection to capture airborne microplastics. Additionally, during each batch (n = 15) of sample processing in the laboratory (dissection, tissue digestion and visual identification) two Petri dishes with distilled water and two with filter papers were kept open as controls. The control petri dishes were inspected under the stereomicroscope and particles if present were counted and recorded. Furthermore, control blanks with only 150 ml of 10% KOH (average volume of KOH added in samples) were ran along with each batch of sample processing. Clean cotton lab coats, nitrile gloves and cotton clothing were worn during all stages of experiment. Any particles detected in these blanks were characterized and similar particles were considered contamination and excluded from the analyses. The samples were analysed in a laboratory with minimised air circulation and restricted access to prevent airborne contamination. Data were corrected by the subtraction of blanks. Care was taken to expose the samples to the air for the absolute minimum period required to transfer them between containers. At all other times containers were kept covered.

### 2.5. Statistical analysis

The normality of data set was tested using the Shapiro Wilk test and since the data were not normally distributed, non -parametric methods were used. Mann Whitney *U* test was performed to analyse the variation between microplastics of the edible and inedible tissues of each species. The variation of abundance in microplastics among species was evaluated using Kruskal–Wallis (KW) test. On obtaining a significant difference ($p < 0.05$) in KW test, Dunn's multiple comparison tests was done as post hoc test. Spearman Rank Correlation was conducted to examine the relationship between the number of microplastics in the edible and inedible tissues. The statistical significance was accepted at $p < 0.05$. Analyses were carried out using statistical analysis software, PAST v 3.25 and SPSS version 23.

## 3. Results

### 3.1. Abundance of microplastics in edible and inedible tissues of pelagic fishes

Procedural blanks contained three white fibres and thus, similar white fibres were excluded from microplastic calculation. After excluding non-verified items and items similar to those obtained in blanks, a total of 163 particles were considered to be microplastics from the nine fish species (Table S2). Of the 270 fishes examined, microplastics were found in the inedible tissue of 41.1% of them while only 7% of them had microplastics in their edible tissues. Microplastics in the inedible tissues were approximately 8 times that of microplastics present in the edible tissues (Table 2). The average abundance of microplastics in edible tissues was 0.07 ± 0.26 items/fish (i.e., 0.005 ± 0.02 items/g) and in inedible tissues was 0.53 ± 0.77 items/fish (i.e., 0.054 ± 0.098 items/g). There was significant difference between the numbers of microplastics in edible and inedible tissues of all species (Mann Whitney *U* test; $p < 0.05$) except *S. obtusata* (Mann Whitney *U* test; $p > 0.05$) (Table S3). A moderately positive correlation was found between the microplastic presence in edible and inedible tissues of fishes ($r_s = 0.328$, $p < 0.01$) (Table S4). Photographs of microplastics obtained in the study are shown in Fig. 1.

### 3.2. Variation in microplastic load among species

Abundance of microplastics in edible tissues was not significantly different among the fish species (Kruskal-Wallis, H = 1.68,

**Table 2**
– Number and percentage of microplastics obtained from inedible and edible tissues of fishes across species.

| Species | *S. longiceps* | *R. kanagurta* | *T. dussumieri* | *A. chacunda* | *S. gibbosa* | *S. indicus* | *D. acuta* | *S. obtusata* | *M. cordyla* | Total (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| No: of MPs in inedible tissue | 26 (16) | 19 (11.7) | 18 (11) | 21 (12.9) | 19 (11.7) | 15 (9.2) | 17 (10.4) | 2 (1.2) | 7 (4.3) | **144 (88.4)** |
| No: of MPs in edible tissue | 3 (1.84) | 4 (2.45) | 3 (1.84) | 1 (0.6) | 3 (1.84) | 2 (1.2) | 3 (1.84) | 0 (0) | 0 (0) | **19 (11.6)** |
| **Total (%)** | 29 (17.8) | 23 (14.1) | 21 (12.9) | 22 (13.5) | 22 (13.5) | 17 (10.4) | 20 (12.3) | 2 (1.2) | 7 (4.3) | **163 (100)** |

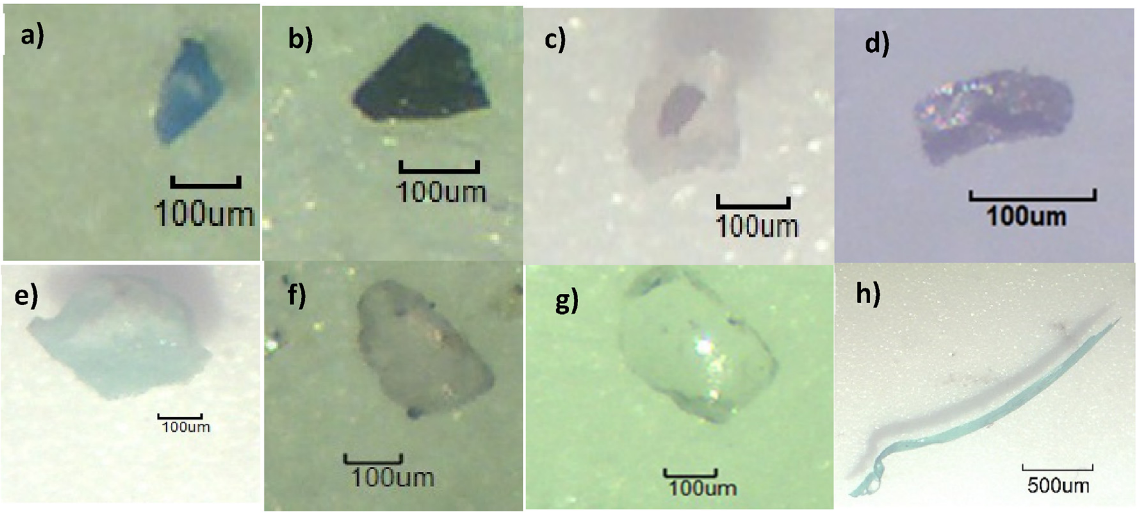

**Fig. 1.** Photographs of microplastics obtained in i) edible tissues (a)–(d) and ii) inedible tissues (e)–(h) of pelagic fishes investigated.

df = 8, $p > 0.05$). However, there was significant variation in the number of microplastics (Kruskal-Wallis, H = 22.02, df = 8, $p < 0.01$) obtained from inedible tissues among the nine fish species. Dunn's multiple comparison tests found higher microplastic content in inedible tissues of *S. obtusata* and *M. cordyla* than in *S. longiceps*, *A. chacunda* and *S. indicus* (Dunn's test - Bonferroni corrected $p < 0.05$). Relatively more microplastics were found in filter feeders such as *S. longiceps*, *A. chacunda* and *S. indicus* as compared to visual predators *S. obtusata* and *M. cordyla* (Fig. 2). On an individual basis, the highest microplastic abundance was found in *S. longiceps* (0.97 ± 0.9 items/fish) while on mass basis it was in *S. indicus* (0.06 ± 0.07 items/g). The lowest in both cases was found to be in *S. obtusata* (0.07 ± 0.2 items/fish; 0.002 ± 0.009 items/g).

### *3.3. Size, morphotype, colour and chemical composition of microplastics*

Particles of four different morphotype was found in the inedible tissues, while only three were found in the edible tissues (Fig. 3a). Fragments were the most common morphotype in both edible (57.8%) and inedible tissue (55.6%) followed by fibres (31.6%) in edible tissue and sheets (28.5%) in inedible tissue. Foam morphotype was present only in inedible tissue. Particles of six different colours were obtained from inedible tissue and five from edible tissue (Fig. 3b). Most of the microplastics isolated were transparent-white. Particles in the size class of 200–400 μm formed the major share (28%) in inedible tissue while in edible tissue it was 100–200 μm (Fig. 3c). Microplastics in the edible tissue ranged from 115 to 210 μm while that in inedible tissues from 136 to 4010 μm. There was no significant correlation between length of fish and size of particles ($r = 0.098$, $p > 0.05$) (Table S5) but a very weak correlation was found between length of fish and number of particles ($r = 0.178$, $p < 0.05$) (Table S6). Seven polymer types were identified using FTIR Spectroscopy (Fig.S1). The most abundant polymer was polyethylene (PE) in both edible (30.4%) and inedible tissues (22.4%), followed by polypropylene (PP) (17% in edible and 18% in inedible tissues) (Fig. 3d). A copolymer of ethylene and propylene - Ethylene propylene diene monomer (EPDM, 9%) and Polystyrene (PS, 10.5%) was found only in inedible tissue samples. Fragments formed 54.5% of total PE identified and 43.8% of identified PP. About 31% of the sheets analysed by FTIR were PE and 30.8% of fibres were PP. Foams were found to be of only 2 polymer types-polystyrene (66.6%) and polyurethane (33.3%).

## 4. Discussion

This study documented microplastic presence in the edible and inedible tissues of nine species of pelagic fishes from the Cochin coast, that are commonly used for human consumption. Microplastics were found in the inedible tissues of all nine species and in the edible tissues of seven of them. About 41% of the total fishes examined had microplastics in their inedible tissue. Similar levels of microplastic ingestion have been recorded for commercially targeted pelagic fish species from North Pacific Central Gyre (35%; Boerger et al., 2010), English Channel (36.5%, Lusher et al., 2013), Portugese coast (36.5% Neves et al., 2015) and Coast of Ghana (26–41%, Adika et al., 2020). However, a direct comparison among studies is difficult as most of the results are expressed as microplastic incidence from digestive tissues alone whereas in the present study it is reported from viscera and gills combined. On comparing the present results with two other similar studies of Karami et al. (2017) and Karbalaei et al. (2019) it was observed that the abundance of microplastics in inedible tissues (0.53 ± 0.77 items/fish) of Cochin coast was higher than that found in the viscera and gill of fishes from Malaysian fish markets. Variability in the microplastic reporting among studies is mainly attributed to the highly variable ingestion rate among habitats, species, feeding habits and locations (Lusher et al., 2016). Compared to reports of

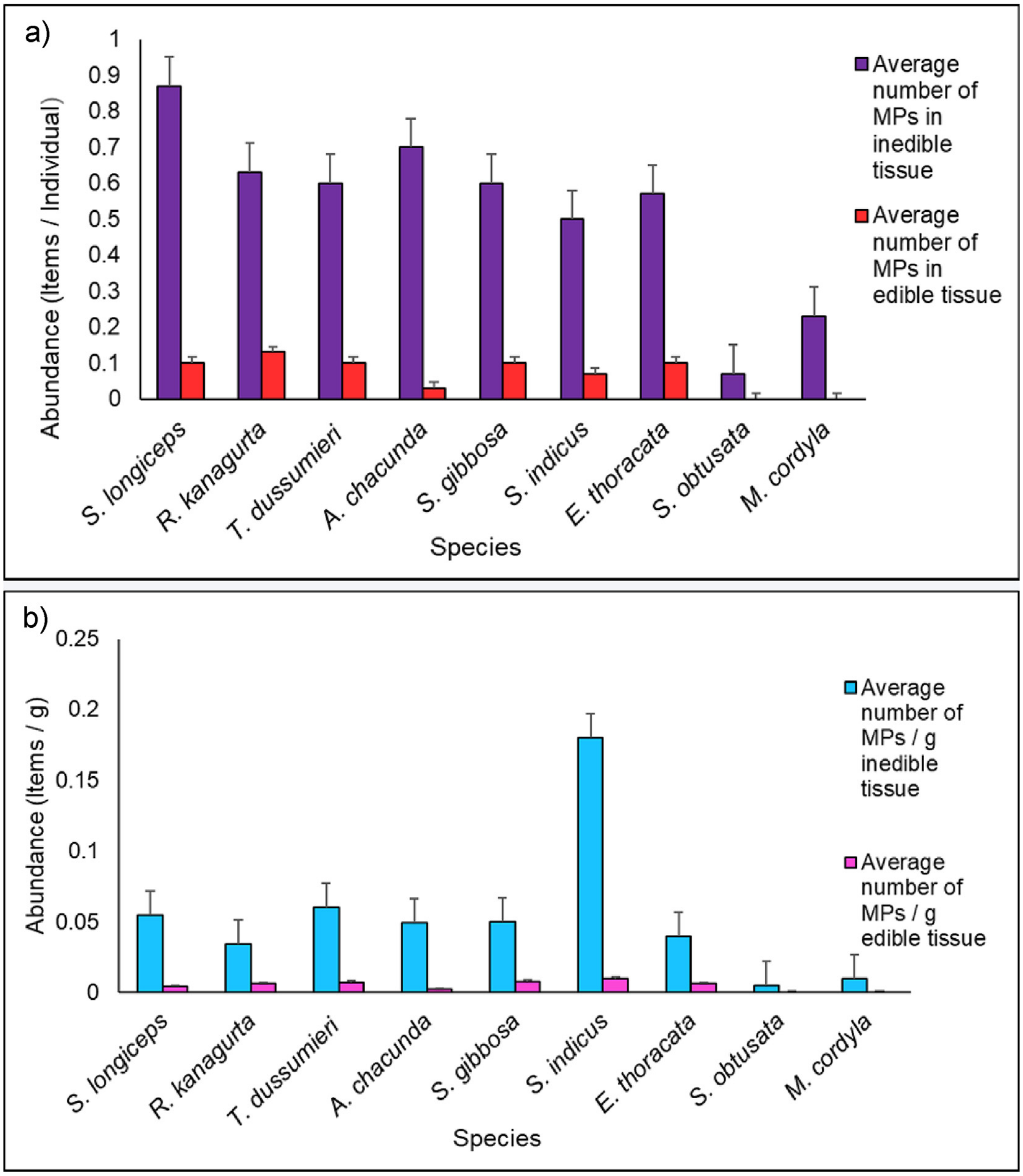

**Fig. 2.** Bar graph showing abundance of microplastics (Mean ± SE) in edible and inedible tissue of different species a) Items/individual fish b) Items/gram of tissue.

microplastic in gastrointestinal tract of fishes, its presence in fish edible tissues is relatively understudied. In the present study, 7% of total fishes had microplastics in their edible tissues. The abundance of microplastics in edible tissue (0.07 ± 0.26 items/fish) was comparable to those in the edible tissues of pelagic dried fish species reported by Karami et al. (2017) but was considerably lower than those reported by Abbasi et al. (2018), Akhbarizadeh et al. (2018) and Barboza et al. (2019). The results were also in contrast with the studies by Su et al. (2019) and Akoueson et al. (2020) where significant microplastic contamination was found only in inedible tissues (guts and gills) and not in the edible tissues of fishes. Microplastics in the inedible tissues were approximately 8 times that of microplastics present in the edible tissues. This contrasted with the findings of Karami et al. (2017) where microplastics in eviscerated flesh (muscle and skin) was higher (approximately four times) than that of excised organs (viscera and gills) in dried fishes.

The variation in microplastic load among species is generally attributed to the feeding strategy, gastrointestinal tract structure, and microplastic contamination of the habitat (Romeo et al., 2015; Abbasi et al., 2018; Lopes et al., 2020). Overall, most of these field studies have related microplastic ingestion to the different feeding strategies of fishes (Romeo et al., 2015; Jabeen et al., 2017). In the present study relatively more microplastics were found in filter feeders such as *S. longiceps*, *A. chacunda* and *S. indicus* as compared to visual predators, *S. obtusata* and *M. cordyla*. Filter feeding pelagic fishes engulf large volume of water containing planktonic prey through the mouth and pass it out by the gills. During this process, food and other micro-particles are retained by entrapment structures, such as gill rakers, which is then transferred to the oesophagus (Ningrum & Patria, 2019). This passive intake of food items by filter feeders make them prone to accidental ingestion of microplastics and could be a reason for higher microplastic concentration in the viscera and gills of filter feeding species (Rummel et al., 2016; Feng et al., 2019). Even among filter feeders there is difference in

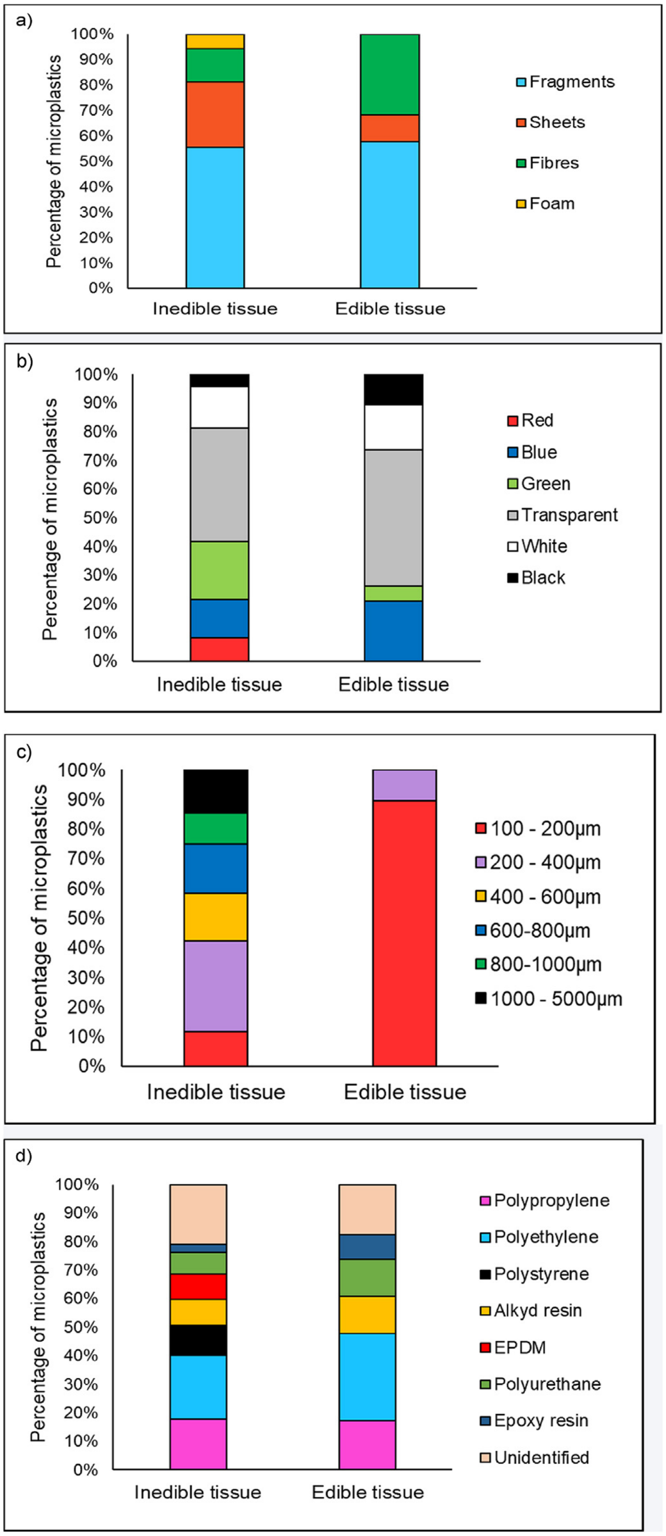

**Fig. 3.** Stacked bar charts showing composition of microplastics obtained a) Morphotype b) Colour c) Size d) Chemical composition. (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

quantity of particle intake from water according to the morphology, stickiness and physical or behavioural alteration capabilities of the mesh size of filtering apparatus (Lazzaro, 1987). Mode of particle transportation from the filter to the oesophagus and ability to modify the cleaning rate of the filter are also factors affecting microplastic abundance in different filter feeding organisms (Lazzaro, 1987). For instance, specialized structures called pharyngeal pockets are present in certain Clupeiformes like *A. chacunda* and *S. longiceps*. These structures assist in the process of concentration of minute food organisms ingested by the gill processes and aid in passing them into the oesophagus (Bensam, 1964). Such special structures in certain species could have a role in higher microplastic contamination of its organisms. Additionally, some species of fishes such as northern anchovies demonstrated increased aggregation and reduced rheotaxis to plastic debris odour, which increased their microplastic ingestion (Savoca et al., 2017). Such species specific structural or behavioural differences are considered to be the reason for higher microplastic contamination found in *S. longiceps*, *A. chacunda* and *S. indicus* in the present study. In contrast, visual predators attack single individual prey item which they visually select from the water column. They are still prone to occasional ingestion of microplastics attached to their food or misidentified as prey (Nadal et al., 2016) and secondary ingestion via prey items (Romeo et al., 2015). However, due to the non-selective feeding strategy, filter feeders are generally considered to be more prone to microplastic ingestion as compared to the predatory species (Rummel et al., 2016; Wesch et al., 2016).

The dominance of fragments in the fishes examined is in consonance with other studies on fishes (Karami et al., 2017; Karbalaei et al., 2019; Robin et al., 2020; James et al., 2020). Fragments are reported to be the major component in floating microplastics in coastal waters of south west coast of India (Robin et al., 2020; James et al., 2020), thus the higher proportion of fragments in pelagic feeders is expected. The presence of comparatively smaller sized microplastics in the muscle and skin tissues as compared to viscera and gill is consistent with the findings of Abbasi et al. (2018) and Barboza et al. (2019). Since particles less than 100 µm were excluded from microplastic calculation in the present study, an underreporting of the microplastics especially those in edible tissues. Suitable methodological modifications are thus, recommended for future studies, to account for smaller sized particles. The presence of microplastics of various shapes, sizes and colours obtained in the study indicates the possibility of its origin from diverse sources (Rochman et al., 2019). Major share of white and blue colour is consistent with the dominant microplastic colours reported in water and sediments from this region (James et al., 2020; Sathish et al., 2020). PE and PP were the dominant microplastic polymers among the examined fishes. This was in agreement with reports of its predominance in environment and fish guts from South India (Veerasingam et al., 2016; Robin et al., 2020; James et al., 2020) as well as pelagic fishes of other parts of the world (Tanaka and Takada, 2016; Wang et al., 2020). High quantity of PE and PP in pelagic environment is due to its large share in global production and consumption, along with its floatation characteristics like low density (Andrady 2011). High density particles such as Polyurethane (PU) can also be found in pelagic environment and organisms by re-floatation or bioturbation (GESAMP, 2016). Fragments and sheets of PE and PP could have entered the marine environment from a wide range of sources like packaging, consumer goods, automotive parts, and pharmaceuticals (Jambeck et al., 2015; An et al., 2020). PP and PE microfibers are reported as a degradation product of abandoned lost and discarded fishing gear (Wang et al., 2019a). EPDM rubber is used for a variety of terrestrial applications such as electrical insulation, water-hoses, sealant in automotive and construction industries (Haave et al., 2019). PU, alkyd and epoxy resin which are a major component of synthetic paints could have originated from marine sources like fishing vessels, recreational boats and ships or from architectural/automotive coatings, and road-marking paints via terrestrial run off

(Lassen et al., 2015; Wang et al., 2019b). Packaging materials and food service items such as foam cups, fast food boxes etc. are a major source of PS foams (An et al., 2020) whereas major contributor of PU foams are upholstery and mattresses (Lassen et al., 2015).

Several studies have explained the presence of microplastics in edible muscle tissues by mechanisms of translocation via endocytosis and persorption (Karami et al., 2017; Abbasi et al., 2018; Akhbarizadeh et al., 2018; Barboza et al., 2019). However, this is still subjected to debate among researchers and the exact mechanism of the translocation of particles >100 μm is not well understood yet (Burns and Boxall, 2018; Jovanović et al., 2018). Observation of translocation is very challenging, and the route of microplastic entry into the non-digestive tissues is not yet identified (EFSA, 2016; Paul-Pont et al., 2018). Apart from the above mechanisms, adherence have been demonstrated as a possible route of microplastic presence in the edible tissues (Kolandhasamy et al., 2018). In a recent study, total number of microplastics on skin of fishes exceeded that in gills and gut, suggesting that adherence to fish skin is also an important route of microplastics contamination of fishes (Feng et al., 2019). Microplastics were also found in the skin of *Platycephalus indicus, Saurida tumbil, Sillago sihama* and *Cynoglossus abbreviates* from the Persian Gulf (Abbasi et al., 2018). These studies noted that microplastics adhered to the fish skin are not easily removed by washing (Feng et al., 2019; Abbasi et al., 2018). Since the edible tissues investigated in the present study included flesh and skin, the bigger microplastics isolated could be those adhered to the fish skin. This is significant because small fishes are commonly consumed without removing its skin in India. Hence, edible tissues of fishes can act as a pathway of dietary intake of microplastics in the fish-eating population.

Assuming the average quantity of microplastics in pelagic fishes to be 0.005 ± 0.02 items/g across fish species and considering the annual per capita fish consumption of 8–9 kg, Indians are at a risk with exposure of 40–45 microplastics per year. This can vary according to the species consumed, with zero microplastic intake in *S. obtusata* or *M. cordyla* to up to 90 microplastic consumption in *S. indicus*. However, since only 7% of the examined fishes had microplastic in their edible tissues, this higher incidence of microplastic exposure may not affect a substantial part of the population. Even though there is a lack of data on the threshold limit for a potential adverse health effect by microplastic ingestion, the current level of microplastics in pelagic fishes (1 microplastic per 200g of edible fish tissue) seems considerably low to create much of a health hazard. Comparatively higher concentration of microplastics were reported from shellfishes that are consumed whole (Van Cauwenberghe et al., 2014; Li et al., 2015). and other foodstuffs like salt (Iñiguez et al., 2017; Gündoğdu, 2018), beer (Liebezeit and Liebezeit, 2014), honey (Liebezeit and Liebezeit, 2013) and drinking water (Mason et al., 2018). Therefore, human uptake of microplastics might occur by several routes and can be considerably higher than the estimates based on just fish consumption (Cox et al., 2019). However, even when properly cleaned fish fillets may not be a major source of microplastic exposure to humans at present, consumption of improperly gutted and whole dried fishes (especially small fishes such as anchovies) can increase the risk of microplastic intake. Long-term exposure to multiple microplastic sources and its cumulative effect in the body can be a cause of health risks (Karami et al., 2018). Additionally, the possibility of desorption of chemicals and additives from microplastics to fishes and subsequently to human beings cannot be ruled out (Barboza et al., 2018), even when there is insufficient research confirming the same at present. Furthermore, fish meals produced from fish waste containing microplastics pose additional risks of transfer of microplastics to culture fish species (Hantoro et al., 2019). Knowledge about the possible effect of cooking/heating microplastic contaminated seafood and the long-term effect of microplastics in the human body is needed for a comprehensive risk assessment of microplastics in seafood.

## 5. Conclusion

Owing to increasing production and consumption of plastics, microplastics are becoming prevalent in the environment and biota and is causing a potential threat to seafood safety. This study is the first of its kind to report the detection of microplastics in the edible tissues of pelagic fishes sold for human consumption from India. The average quantity of microplastics in edible tissues was 0.07 ± 0.26 items/fish (i.e., 0.005 ± 0.02 items/g) and was 0.53 ± 0.77 items/fish (i.e., 0.054 ± 0.098 items/g) in inedible tissues. Of the 270 fishes analysed ($n = 30$ per species), 41.1% of them had microplastics in their inedible tissues while only 7% had microplastics in their edible tissues. Microplastics in inedible tissues were approximately eight times the amount of that in edible tissues. A moderately positive correlation was found between the microplastic presence in edible and inedible tissues of fishes ($p < 0.01$). There was no significant species variation in the microplastics of edible tissues. Microplastics in inedible tissues were significantly higher in filter feeders such as *S. longiceps*, *A. chacunda* and *S. indicus* as compared to the visual predators, *S. obtusata* and *M. cordyla* ($p < 0.05$). Fragments of PE and PP polymer composition were the most abundant microplastic obtained in both edible and inedible tissues. The results suggest a possibility of human intake of microplastics by consumption of pelagic fishes, albeit in small quantities. Even though the current level of microplastics in fish is unlikely to be a human health hazard, the presence of microplastics in edible tissues of seven out of nine species investigated points to the possibility of microplastics becoming a seafood safety threat in future.

## CRediT authorship contribution statement

**Damaris Benny Daniel:** Conceptualization, Methodology, Data curation, Writing - original draft. **P. Muhamed Ashraf:** Software, Validation. **Saly N. Thomas:** Conceptualization, Supervision, Writing - review & editing.

## Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.envpol.2020.115365.

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