ERASMUS MUNDUS MASTER'S IN CHEMICAL INNOVATION AND REGULATION
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E02: Environmental risk of plastic materials Module
Topic – Effects of polystyrene micro and Nano plastic on Fishes (Minireview)

By Negussie Darota

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Abstract

Microplastics and Nano plastic residues originating from the polystyrene materials are considered as contaminants of emerging concern. This mini review addresses the ecotoxicological effects of polystyrene microplastics in fishes and the other factors contributing to the toxicity of micro/nanoplastics in the aquatic organisms

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1. Introduction

Plastics and plastic containing products are indispensable components in today's world. The reliance on plastic material is growing high due to the ease of use, light weight and the low cost of production. As of 2019, 368 million metric tons (MT) are produced worldwide and it is expected to double in the next 20 years. Coastal countries generate about 275 million MT of plastics out of which 4.8 to 12.7 MT enter the ocean (Usman et al.,2021). Polystyrene based plastic materials are used in wide range of products, including plastic cutlery, glasses, and packaging materials, thereby acting as major contributor for plastic contamination of the environment.

The aquatic environment acts as a major sink for the plastic waste products released from the domestic, industrial and tourism activities. The release of plastic materials in different size ranges was reported to cause many adverse effects to the biotic organism. Most of the plastic products are difficult to degrade, however mechanical wear/tear, erosion and ultraviolet radiation would fragment them into microplastics (MPs, <5 mm diameter) and Nano plastics (NPs, <1 μm diameter). Numerous studies have reported the persistence of NP's/MP's in all levels of organisms representing the aquatic ecosystems. The deepest layers of ocean are not an exception to the microplastic contamination. (Umamaheswari et al.,2021; Gu et al.,2021; Pei et al.,2022).

The MP/NP's originating from the polystyrene plastics were considered as one of the most abundant contaminants of the marine environment (Gu et al.,2021). This review explores the ecotoxicological effects posed by the NP/MP on different biotic organisms occupying various levels in the marine environment. Further it explores the potential sources for PS-MP/NPs release into the environment and the pathways of their transport in the aquatic environment.

2. Method of literature review

Literature review was conducted with the aid of the Scopus and Google Scholar databases to retrieve research articles related to the toxicity of polystyrene MPs and NPs in aquatic ecosystems. The primary search keywords used were "Polystyrene" "Microplastics", "Nano plastics "Toxicity" and "Fish". Further search was attempted using combination of keywords such as "polystyrene microplastics" and "toxic effect on fishes and "Polystyrene Nano plastics" and "toxic effect on fishes". The literature search with the key terms yielded more than 100 published articles. In order to avoid the selection bias, fifteen publications relevant to the theme of this review and those published during the last 3 years were randomly chosen for this review. The review was organised into 4 sections describing the source of polystyrene Micro and Nano plastics, trophic transfer potential in food chain, ecotoxicological implications in fishes and the final section contain the open questions pertinent to this literature review.

3. Source of Micro and Nano plastic in Aquatic system

Plastic accounts for 70% of sea and ocean pollution 8 million tons of plastic are released into the sea every year. Around 10% of plastics production reaches the oceans because of insufficient treatment effectiveness, accidental inputs, littering, illegal dumping, and coastal human activity. It does not know much about micro-plastic formed in the environment as a result of degradation processes, as well in course of production processes. Most plastic products are difficult to degrade, but mechanical wear, erosion and ultraviolet radiation leads to plastic fragmentation in the environment creating microplastics (MPs, <5 mm diameter) and nanoplastics (NPs, <1 μm diameter). Based on the source both micro and nano plastic may be classified as primary and secondary microplastic (Gu et al.,2021; Kik et al.,2020)

3.1. Primary source

Plastic particles are produced by the industry and are released into the environment. Primary sources of those particles are cosmetic products, drugs, paints, as well as medical and electronic devices. In cosmetic industry, they are mostly components of face cleansing products, exfoliating agents for hand washing, and peeling formulas (Kik et al.,2020).

3.2.Secondary sources

The secondary sources of plastic particles are those formed by fragmentation or disintegration from the large plastic material which was subjected to the mechanical or physiochemical stress. The long-term exposure of polystyrene plastics in sunlight would result in UV-light assisted fragmentation of bulk plastics to micro and nano sized particles (Kik et al.,2020). Similarly anthropogenic activities like disposal of plastics into the crushers, mechanical damage in environment media (soil, ocean tidal currents), washing the plastic containers would release different sizes of plastic particles into the environment.

4. Route and Trophic Transfer of micro and Nano plastic

The entry of MPs in fish may occur via feeding, respiratory exposure, skin absorption. However, trophic transfer appears to be the predominant route of MPs uptake in aquatic environments (Dimitriadi et al.,2021). MPs were found to be transferred tropically from Scombrus scombrus to Halichoerus grypus, reported by Nelms et al. (2019). Chae et al (2018) Studied the trophic transfer, individual impact, and embryonic uptake of fluorescent nano-sized polystyrene plastics (Nano plastics) through direct exposure in a freshwater ecosystem with a food chain encompassing four species. The test species were the *alga Chlamydomonas reinhardtii*, *Daphnia magna*, the secondary-consumer fish *Oryzias sinensis*, and the end-consumer fish *Zacco temminckii*. In the trophic transfer test, algae were exposed to 50 mg/L nanoplastics, defined as plastic particles <100 nm in diameter; higher trophic level organisms were exposed through their diet. Microscopic examination indicated that the Nano plastics stuck to the surface of the primary producer and were present in the digestive organs of higher trophic level species.

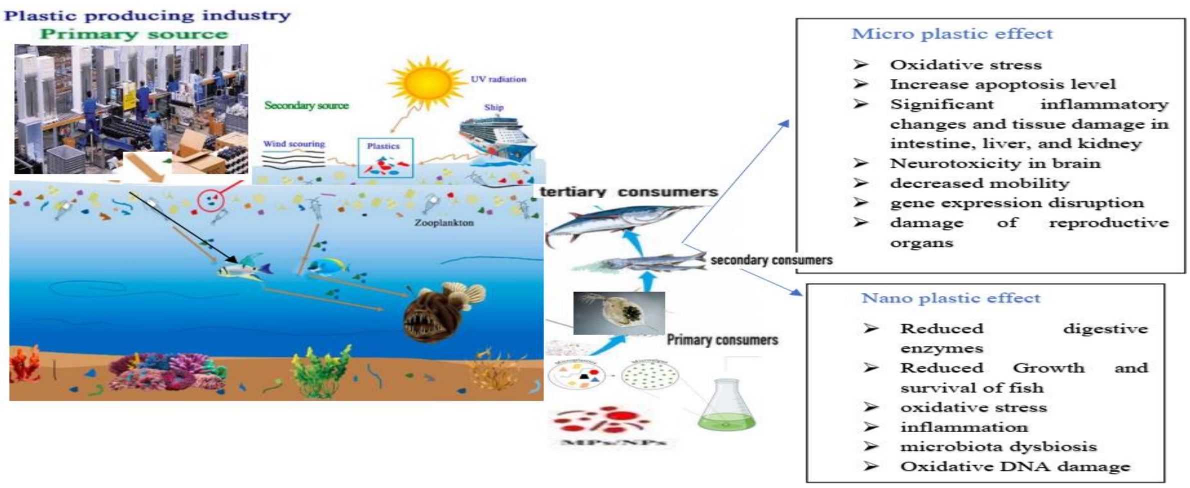

Figure 1: The environmental Sources, Trophic Transfer and effect of Micro and Nano plastics in Fishes (Modified from Bhuyan,2022, Elizalde-Velázquez et al., 2021 and Rani-Borges et al ,2021).

5. The effect of polystyrene nano and microplastic and on Fish

5.1. Effect of microplastic

research on the effects of MPs on fish had been undertaken in the laboratory. Most of the studies were conducted on Danio rerio. Oxidative stress, decreased mobility, gene expression disruption and damage of reproductive organs are the most common effects of MPs in Zebrafish (Danio rerio) (Table 1). (Qiang and Cheng, 2021) reported that exposure to microplastics induce molecular responses and histological alterations in fish gonad and it contribute to potential adverse impact on fish reproductive organs. The study by Usman et al.,2021 conducted on Javanese medaka fish which was exposed to polystyrene microplastics (PS-MPs) beads for a period of 21 days. The polystyrene microplastic exposure contributed to the multiple organ effect (intestine, liver, kidney, and brain). High concentrations of MPs have been reported at the laboratory work. Thus, more field work is needed to get conclusive toxic effect of polystyrene microplastic on the fish species.

5.2 Effect of Nano plastic

Like microplastic, Nano plastics have negative impact on the fishes (Table 1). Gu et al. (2020) investigated the effects of Nano plastics on the intestinal health and growth performance of the juvenile *Larimichthys crocea*. After 14-d exposure, the reduced digestive enzyme activities indicated that nano-PS had a negative impact on the digestion and absorption of juvenile fish. In addition, lysozyme activity and specific growth rate (SGR) were significantly reduced, and total mortality of juvenile fish was significantly increased. On top of that Gu et al. (2021) evaluated the oxidative stress responses induced by NPs (10, 104 and 106 particles/l) in juvenile *Larimichthys crocea* during 14-d NPs exposure followed by a 7-d recovery. After exposure, the activities of antioxidant enzymes (SOD, CAT, GPx) and Malondialdehyde (MDA) level is commonly known as a marker of oxidative stress levels increased in the liver of fish at the highest NPs concentration. juvenile fish in NPs treatments exhibited a lower survival rate than the control during both exposure and recovery. Pei et. al., 2022 investigated polystyrene nano/microplastics with diameter sizes of 50um and 100 nm and concentrations of 100 and 1000 μg/mL on gut microbiota, antioxidant activity and innate immune. Results indicated that zebrafish polystyrene nano/microplastics induced inflammation, microbiota dysbiosis and caused oxidative stress-mediated responses. Likewise, Sokmen et al.,2020 microinjected polystyrene Nano plastics (PNP) (20 nm) to the zebrafish embryo to study PNP bioaccumulation and immunochemical toxicity (8-OHdG) in the brain of zebrafish larvae at 120^{th} hour. According to the findings, PNP with a diameter of 20 nm can enter the brain and bioaccumulate there, causing oxidative DNA damage in the brain regions where it accumulates.

Table 1:Polyethylene Nano and MPs toxic effects on Fish.

Fish species	**Duration**	**Size of MP**	**Concentration**	**Method**	**Effect**	**References**
Zebrafish (*Danio rerio*)	21 days	3–12 µm		FTIR	Increased levels of oxidative stress indices and metabolic adjustments.	Dimitriadi et al.,2021
Zebrafish	21 days	1um	10 µg/L 100 µg/L 1000 µg/L	FTIR	Increased reactive oxygen species increased apoptosis levels	Qiang and Cheng, 2021
Avanese medaka fish	21days	5 um	100 µg/L 500 µg/L 1000 µg/L	SEM	Significant inflammatory and tissue changes **in intestine, liver and kidney -** Neurotoxicity characterised by a significant induction of oxidative stress, lipid peroxidation and the inhibition of acetylcholinesterase enzyme	Usman et al.,2021
Zebrafish	35 days	0.10–0.12 µm	(10 µg L^{-1} as Treatment I and 100 µg L^{-1}	FTIR SEM	Increase in the cellular oxidative and enzymatic damage and leading to apoptosis	Umamaheswari et al.,2021
Juvenile Larimichthys crocea	14-dayse	100 nm	Conc. (0, ,$5.50*10^{-12}$ mg/L, ($5.50*10^{-9}$ mg/L, ($5.50*10^{-7}$ mg/L)	µ-FTIR	- Lysozyme, trypsin and lipase of fish were reduced - Growth and survival of fish were reduced under nano-PS exposure	Gu et al.,2020
Juvenile Larimichthys crocea	during 14-d NPs exposure followed by a 7-d recovery	100 nm	NPs (10, 10^4 and 10^6 particles/l)	-	-Nanoplastics induced oxidative stress in the liver --Nanoplastics showed latent effects on antioxidant responses in fish liver.	Gu et al.,2021
Zebrafish	-	50um and 100 nm	100 and 1000 µg/mL	-	-Polystyrene nano/microplastics induced microbiota dysbiosis -Plastics induced inflammation in size/concentration-dependent manner	Pei et al.,2022
Zebrafish embryo	120 h	20 nm		TEM	-cause oxidative DNA damages in the brain.	Sökmen et al.,2020

6. Open questions in the field

1. Are there any analytical methods to detect nanoplastics in Aquatic system?

currently no validated (i.e., recognized and tested) methods for identifying and quantifying nanoplastics. The wide range of plastics makes qualitative (i.e., identifying the plastic substance) and quantitative (i.e., looking at the number of microparticles measured) analysis more complex. Like microplastics, Nano plastics have negative impacts on the aquatic environment. Owing to the limitation of detection techniques, there is little information about Nano plastics in the marine environment. Currently, scientists are exploring several analytical methodologies for determining and measuring nanoplastics.

2. Are there any method to exactly identify the source of microplastic?

The shape and chemical of the MPs may reveal some information about their source, although it will not help to reach a conclusive decision. It is tough to trace their source even after determining their polymer composition.

3. The present minireview identifies that majority of the ecotoxicity studies are focused on the short-term toxicity effects in fish species. There is not concrete information on the toxicity in long term (chronic exposure) and effects in real environmental scenario. This needs to be addressed.

4. The potential toxic effects of NPs and MPs were so far been investigated mainly in model species like zebrafish. Therefore, the major question arises on what is the toxicity of polystyrene micro and nano plastic in other fish species? Is there any species level difference in toxicity seen?

5. The majority of investigations have focused on the toxicity of commercial plastic microparticles (also known as pristine MP) with uniform types, shapes, and sizes. As a result, any extrapolation of results from these studies would not be appropriate for real world conditions. Different contaminants are disseminated in the environment (persistent organic compounds and heavy metals) and they are likely to adsorb to MPs (Guimarães et al,2021). Whether the toxicity reported for MPs are due to the naïve MPs or combined effect of adsorbed contaminants?

Conclusion

The reliance on plastic materials like polystyrene Mciroplastics would continue to inflict negative effects on the aquatic organisms. It Is the need of the hour to remediate the plastic contaminants in the environment and people should realise and reduce the use of plastic products in life.

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