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An ecotoxicological perspective of microplastics released by face masks

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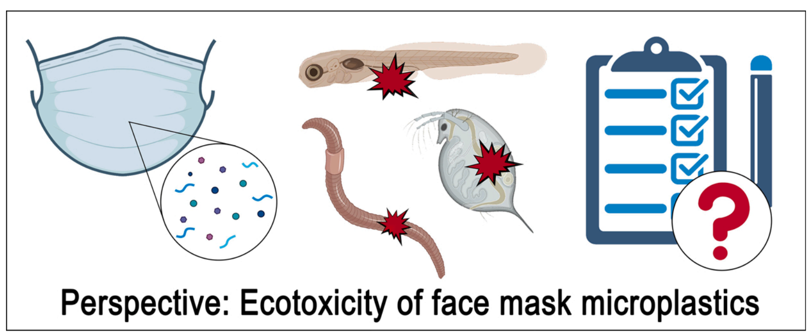
HIGHLIGHTS

- Face mask microplastics (FMP) ecotoxicity assays present several uncertainties.
- There is an uncontrolled release of tiny FMP (<10 μm) that could generate an effect.
- Determining environmentally-realistic concentrations of FMPs is extremely hard.
- We are far from understanding the contribution of FMP to the microplastic issue.

GRAPHICAL ABSTRACT



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ABSTRACT

The accelerated use, massive disposal, and contamination with face masks during the COVID-19 pandemic have raised new questions regarding their negative impact on the environment emerged. One major concern is whether microplastics (MPs) derived from face masks (FMPs) represent an important ecotoxicological hazard. Here, we discussed the shortcomings, loose ends, and considerations of the current literature investigating the ecotoxicological effects of FMPs on aquatic and terrestrial organisms. Overall, there are multiple uncertainties regarding the true impact of FMPs at a certain concentration due to the presence of uncontrolled or unknown degradation products, such as MPs of various size ranges even nano-sized (<1 μm) and chemical additives. It is apparent that FMPs may induce endocrine-disrupting and behavioral effects in different organisms. However, the results of FMPs should be carefully interpreted, as these cannot be extrapolated at a global scale, by taking into account a number of criteria such as face mask manufacturers, providers, consumer preferences, and type of face masks. Considering these uncertainties, it is still not possible to estimate the contribution of face masks to the already existing MP issue.

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1. Introduction

During the COVID-19 pandemic, several methods have been established to stop the spread of the virus, such as wearing face masks, facial protectors, and other types of personal protective equipment (PPE). Since these measures became mandatory worldwide, the use and disposal of single-use PPE increased tremendously. It is no surprise that the occurrence of a wide range of PPE products and plastics associated with the COVID-19 pandemic has been reported in natural environments all around the world, thus, contributing to the already critical state of plastic pollution. Furthermore, since most face masks, either reusable or single-use, are made of synthetic polymers, such as polypropylene (PP), polyethylene (PE), and polyester blends, they are likely to chemically and physically degrade upon entering the environment leading to the release of secondary contaminants (e.g., organic chemicals) that can be inhaled or ingested by organisms (Wang et al., 2021), possibly causing detrimental effects. On the other hand, microscopic pieces of plastic, namely microplastics (MPs; plastic particles smaller than 5 mm), may easily detach from the fibrous layers of face masks (De-la-Torre et al., 2022). Several studies reported that the number of MPs expelled from used face masks is estimated in the tens of thousands up to hundreds of millions depending on their size and environmental conditions, such as agitation, UV exposure, and mechanical stressors, among others (see Kutralam-Muniasamy et al., 2022).

In the last decade, significant efforts have been made to elucidate the sources, behavior, fate, and environmental relevance of MPs in the environment. As multiple studies confirmed that face masks are, indeed, a significant source of MPs, their arrival to natural environments in large numbers became a subject of concern. To date, it is still unclear the extent to which face masks are contributing to the already widespread MP issue. Several recent studies have evaluated the ecotoxicity of face mask-derived MPs on model organisms from various taxa, which provided the first insights into the ecological implications of face mask contamination. In this perspective article, we presented the current knowledge regarding the ecotoxicological effects induced by the MPs expelled by face masks in both aquatic and terrestrial environments and provided a critical discussion on the identified loose ends and uncertainties, as well as the long-term environmental implications of this unprecedented type of plastic pollution.

2. Ecotoxicity of microplastics expelled from face masks

Upon disposal, face masks make their way into natural environments and release MPs, which are likely ingested or inhaled by multiple organisms (Fig. 1). Ecotoxicological techniques have been widely applied to evaluate the impact of contaminants on flora and fauna. This field focuses on the toxicological effects of certain contaminants on wildlife at different levels, ideally conducted at biological organization levels, from biochemical to ecosystem alterations (Belden, 2020). Ecotoxicological research has been applied to MPs derived from face masks aiming to understand the biological impacts generated by these unprecedented contaminants (Table 1).

Face mask-derived MP (FMP) exposure assays have been investigated in both aquatic and terrestrial organisms, as summarized in Table 1. Most FMPs used in these studies are PP-based, fiber-like, and are a few tens of micrometers in length. Lethality is not observed in any organism from terrestrial or aquatic origin, even at high FMP concentrations, which is in agreement with previous ecotoxicological research (Vázquez and Rahman, 2021). Based on the recent literature, it is apparent that reproduction and growth effects are primarily induced by FMPs. Regardless, multiple studies found no significant effects on the reproduction and growth of various aquatic invertebrates exposed to different types of MPs (e.g., Redondo-Hasselerharm et al., 2018), suggesting that MP exposure may present higher risks for sensitive species under highly contaminated environments.

Although FMPs exposure studies in terrestrial organisms provided some interesting insights, there are still some loose ends. Firstly, MP uptake and translocation in plants have been reported to occur with MPs that are tens or a few hundreds of nanometers in size (e.g., Lian et al., 2021), while those used in the FMP studies are considerably larger. Thus, FMP translocation is unlikely to be the main toxicity pathway in the study by Mészáros et al. (2022). Overall, the majority of MP phytotoxicity studies reporting physiological and genetic changes are carried out with MPs that are measured in nano- or micrometers. However, almost no previous study investigated PP fiber-like MPs, like those expelled from face masks. It should be noted that the source of MPs plays an important role in the accuracy and comparability of the studies (for both FMPs and conventional MPs). For instance, in most ecotoxicity studies, MPs are purchased from suppliers providing certified MPs beads with specific size ranges, shapes, and polymeric composition. MPs

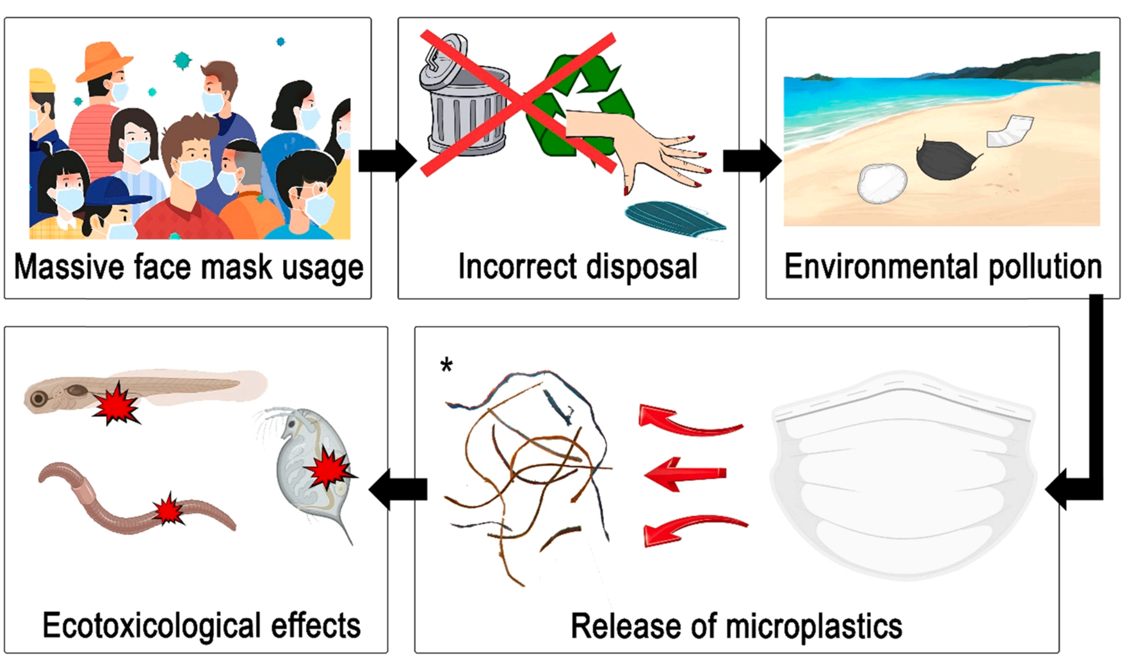

Fig. 1. Graphic representation of the environmental implications of face masks during the pandemic. * : Photographs of MPs expelled from surgical face masks.

expelled from face masks show great variability in terms of size and shape depending on the shredding or milling method, among other variables, such as manufacturing characteristics and layer selection (middle layers generally display thinner fibers and larger surface area than the inner and out layers). MPs found in the environment display an even greater physical variability, although fiber-like MPs are generally the most abundant. Considering that environmentally relevant studies must not only assess realistic MP concentrations but also MPs that are similar in terms of morphology, size distribution and polymeric composition, it is imperative to understand whether face mask degradation and FMP release are significantly changing the composition of environmental MPs. Evidently, achieving this may be a rather difficult task, requiring baseline pre- and post-pandemic MP data and sufficient chemical-analytical power to determine the source of MPs with certainty. All in all, several barriers remain to achieve environmental relevancy in ecotoxicological studies, particularly during times of unusual large-scale plastic and MP inputs, like the COVID-19 pandemic.

Expelled FMP size distribution may be another important barrier in ecotoxicological studies. The number of particles (and their size distribution) per gram of extracted FMPs is uncertain because face masks are able to release particles as small as 1–10 μm, and even nanoplastics (<1 μm), as reported by Ma et al. (2021). In their study, the analysis of scanning electron microscopy (SEM) and atomic force microscopy (AFM) micrographs was applied to quantify MPs and NPs from 100 μL samples of face mask leachates. While there was a notorious occurrence of particles compared to the controls, this method exhibits some shortcomings. For instance, the reduced volume of the subsamples generates some uncertainty when extrapolating the data obtained and the chemical composition of the particles counted in the micrographs cannot be confirmed, which may overestimate the number of NPs and small MPs upon extrapolation (assuming that not all the expelled particles are polymer-based). Although it is clear that advanced quantification techniques are required to estimate the number of very small MPs or NPs found in face mask leachates, there are still notable analytical limitations to achieving accurate data. Despite this, it is fairly likely that FMPs prepared for ecotoxicological assays include a significant number of unquantified nano-size particles, possibly inducing an uncontrolled toxic effect.

Table 1
Summary of the ecotoxicity studies on MPs derived from face masks.

Type of mask	Type of organism	Species	Growth stage	Fiber concentration	Fiber length	Exposure time	Effect	Reference
Surgical face mask (poorly degraded)	Aquatic	*Danio rerio*	Larvae	10 mg L^{-1}	3.10 mm	10 d	Downregulation of genes associated with reproduction (more pronounced in highly degraded masks). No effects on survival were observed.	(Sendra et al., 2022)
Surgical face mask (highly degraded)				10 mg L^{-1}	1.25 mm			
Surgical face mask (leachate)				–	–			
Surgical face mask	Aquatic	*Daphnia magna*	Neonates	1 mg L^{-1} 10 mg L^{-1} 100 mg L^{-1}	42.0–55.6 μm	24–48 h	The organisms ingested MPs. No effects on survival were observed.	(Jemec Kokalj et al., 2022)
Surgical face mask	Aquatic	*Tigriopus japonicus*	Nauplii	1 MP L^{-1} 10 MP L^{-1} 100 MP L^{-1}	< 10 μm (33%) 10–50 (42%) > 50 μm (25%)	~10 d	Maturity time and birth spacing were significantly longer at higher concentrations. The length of the droppings was greater at medium and high concentrations.	(Sun et al., 2021)
White face masks (middle layer was used)	Terrestrial	*Folsomia candida*	Juveniles	1000 mg kg^{-1}	< 300 μm	28 d	Significant reduction in the ratio of reproduction and growth. No effects on survival, esterase activity, oxidative stress, and behavior were observed.	(Kwak and An, 2021)
	Terrestrial	*Eisenia andrei*	Adults			21 d	Intracellular esterase activity and spermatogenesis in the seminal vesicles were significantly reduced. No effects on survival or other pathological effects were observed. Lysosomal stability and oxidative stress in coelomocytes were not affected.	
Surgical face mask (Inner, middle, outer layers used)	Terrestrial	*Enchytraeus crypticus*	Adults	0.02% (w/w) 0.06% (w/w) 0.17% (w/w) 0.5% (w/w) 1.5% (w/w)	42.0 μm 45.1 μm 55.6 μm	21 d	No effects on reproduction and survival were observed.	(Kokalj et al., 2022)
		Porcellio scaber		0.06% (w/w) 0.5% (w/w) 1.5% (w/w)			Significant reduction in hemocyte viability at high concentrations depending on layer type. No effects on survival were observed.	
		Tenebrio molitor	Larvae				Significant alterations in available energy (equivalents of lipids, carbohydrates, and proteins) and activity of the electron transfer system. No effect on survival.	
Surgical face mask	Terrestrial	*Brassica napus L.*	Seedlings	0.5% (w/w) 1% (w/w)	2.5, 2, 1, 0.5, < 0.5 cm	14 d	Inhibition of root length depending on the size of the plastics. Increase in the number of leaves and alterations in the length of the shoot. No significant changes were observed in leaf size and shoot/root ratio. No changes in catalase and dehydrogenase activity were observed. Significant increase in the number of heterotrophic bacteria.	(Mészáros et al., 2022)
			Seed	0.5% (w/v) 1% (w/v)		5 d	Inhibition of root elongation.	

Like most plastics, PP-based face masks include several chemical additives in their polymer matrix. The type of additive and concentration may vary among manufacturers and are not generally considered but are crucial to understanding the toxic effects of FMPs. For instance, it has been reported that the toxic effects of face mask leachates containing endocrine-disrupting degradation products induced a similar effect to FMPs alone (Sendra et al., 2022). Although many of the leachable chemicals are recognized for their toxic effects on a wide range of aquatic and terrestrial organisms, they are not always accounted for in ecotoxicological studies. On the other hand, as the pandemic progressed, several unconventional face masks became widely available to the public. Some included metal-based antimicrobial agents, such as Zn-, Cu- and Ag-nanoparticles (NPs), claiming to be more effective against SARS-CoV-2. However, these types of face masks have been found abandoned in the environment, expressing concern due to the possible leaching/detachment of NPs into the environment. Overall, the multiple types of face masks and manufacturing processes specific to each brand could alter the ecotoxicological effects that degradation products, such as FMPs and leachates, induce. In this sense, the results from previous studies should be interpreted with care.

It is still premature to say that FMPs are more toxic than conventional MPs. This is mainly due to the several uncertainties and uncontrolled variables involved during experimental procedures. Considering the great variability of FMPs in terms of physical characteristics (e.g., size-distribution) and NPs (apparently, several orders of magnitude higher than FMPs), ecotoxicological studies must carry out significant efforts to account for the smallest MP fractions (including NPs), which normally pass undetected. Although there are still significant technical difficulties to quantify the smallest MPs, studies could seek methodological strategies. For instance, an additional control group can be included considering filtered face mask leachates free from larger MPs (e.g., 50 – 5000 μm) to better understand the influence of unaccounted MPs and the smallest particles, accompanied by advanced microscopic techniques (e.g., SEM, AFM) to preliminarily quantify the number of particles in the controls. In a similar matter, studies must compare the effect of FMPs with that of the chemical additives leached from the polymer matrix, similar to the methodological approach by Sendra et al. (2022). On the other hand, investigating and determining environmentally-realistic concentrations of FMPs is challenging, mainly because it is hard to determine the exact proportion of the MPs found in the environment that are derived from face masks. To the best of our knowledge, no previous study has attempted to quantify MP abundance and composition under pre- and post-pandemic conditions, particularly in areas highly impacted by PPE pollution. It is imperative that researchers seek to elucidate the influence of the pandemic on MP stocks in both aquatic and terrestrial environments while aligning ecotoxicological designs (e.g., test MP composition and concentrations) with their results. Taking into account these recommendations, we believe that ecotoxicological studies could land on environmentally relevant results while serving as a reference for future studies.

In the present discussion, we addressed several aspects of the current literature regarding the toxicity of FMPs, identifying loose ends, uncertainties, and considerations. While it is indisputable that face mask contamination is contributing to the already alarming MP pollution, we are still far from being able to determine its real contribution to the issue, from an environmental and ecotoxicological point of view. The proposed toxicological pathways must go in hand with the physiological characteristics of the test organism and MPs and degradation products expelled while accounting for the environmental relevancy of the experimental conditions.

CRediT authorship contribution statement

Urpi Cabrejos-Cardeña: Software, Investigation, Formal analysis, Writing – original draft. **Gabriel Enrique De-la-Torre:** Conceptualization, Methodology, Project administration, Investigation, Data curation, Software, Formal analysis, Writing – original draft. **Sina Dobaradaran**: Conceptualization, Formal analysis, Writing – original draft. **Selvasembian Rangabhashiyam**: Conceptualization, Formal analysis, Writing – original draft.

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.

Data availability

No data was used for the research described in the article.

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