Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

Elsevier hereby grants permission to make all its COVID-19-related research that is available on the COVID-19 resource centre - including this research content - immediately available in PubMed Central and other publicly funded repositories, such as the WHO COVID database with rights for unrestricted research re-use and analyses in any form or by any means with acknowledgement of the original source. These permissions are granted for free by Elsevier for as long as the COVID-19 resource centre remains active.
An ecotoxicological perspective of microplastics released by face masks

Urpi Cabrejos-Cardeña a, Gabriel Enrique De-la-Torre b,*, Sina Dobaradaran c,d,e, Selvasembian Rangabhashiyam f

a Faculty of Engineering, San Ignacio de Loyola University, Lima, Peru
b Biodiversity, Environment, and Society Research Group, San Ignacio de Loyola University, Lima, Peru
c Systems Environmental Health and Energy Research Center, The Persian Gulf Biomedical Sciences Research Institute, Bushehr University of Medical Sciences, Bushehr, Iran
d Department of Environmental Health Engineering, Faculty of Health and Nutrition, Bushehr University of Medical Sciences, Bushehr, Iran
e Instrumental Analytical Chemistry and Centre for Water and Environmental Research (ZWU), Faculty of Chemistry, University of Duisburg-Essen, Universitätsstr. 5, Essen, Germany
f Department of Biotechnology, School of Chemical and Biotechnology, SASTRA Deemed University, Thanjavur 613401, Tamil Nadu, India

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.

ARTICLE INFO

Editor: Dr. R. Teresa

Keywords:
COVID-19
Personal protective equipment
Nanoplastics
Polypropylene

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.

* Corresponding author.
E-mail address: gabriel.delatorre@usil.pe (G.E. De-la-Torre).

https://doi.org/10.1016/j.jhazmat.2022.130273
Received 16 August 2022; Received in revised form 22 October 2022; Accepted 25 October 2022
Available online 27 October 2022
0304-3894/© 2022 Elsevier B.V. All rights reserved.
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 Mézérios 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 F MPs 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<sup>-1</sup> | 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) | Aquatic | Daphnia magna | Neonates | 1 mg L<sup>-1</sup> | 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 | 10 MP L<sup>-1</sup> | < 10 µm (33%) | -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<sup>-1</sup> | < 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. 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. | (Kwak and An, 2021) |
| Surgical face mask (Inner, middle, outer layers used) | Terrestrial | Enchytraeus crypticus | Adults | 0.02% (w/w) | 42.0 µm | 21 d | No effects on reproduction and survival were observed. | (Kokalj et al., 2022) |
| | | Porcellio scaber | | 0.06% (w/w) | 1.5% (w/w) | 45.1 µm | | | |
| | | Tenebrio molitor | Larvae | 0.05% (w/w) | 1.5% (w/w) | 55.6 µm | | | |
| Surgical face mask | Terrestrial | Brassica napus L. | Seedlings | 0.5% (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. | (Meszéros et al., 2022) |
| | | | | 1% (w/w) | | | | |
| | | | 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 MP. 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 MP 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 MP 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 MP degradation products expelled while accounting for the environmental relevance 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 Dobaranadar: 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 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.

Acknowledgments

The corresponding author is thankful to Universidad San Ignacio de Loyola for financial support.

References

Belden, J., 2020. Introduction to ecotoxicology. In: Pope, C.N., Liu, J. (Eds.), An Introduction to Interdisciplinary Toxicology. Academic Press, pp. 381–393.

De-la-Torre, G.E., Dioses-Salinas, D.C., Dobaranadar, S., Spitz, J., Nabipour, I., Kenarzade, M., Akhtarizadeh, R., Targamine, M., Abedi, D., Javanfekr, F., 2022. Release of phthalate esters (PAEs) and microplastics (MPs) from face masks and gloves during the COVID-19 pandemic. Environ Res 215, 114337. https://doi.org/10.1016/j.envres.2022.114337.

Jemec Kokalj, A., Dolar, A., Drobnè, D., et al., 2022. Environmental hazard of polypropylene microplastics from disposable medical masks: acute toxicity towards Daphnia magna and current knowledge on other polypropylene microplastics. Micro Nanoplastics 2. https://doi.org/10.1186/S43591-021-00025-0.

Kokalj, A.J., Dolar, A., Drobnè, D., et al., 2022. Effects of microplastics from disposable medical masks on terrestrial invertebrates. J. Hazard Mater. 438, 129440 https://doi.org/10.1016/J.JHAZMAT.2022.129440.

Kutramal-Muniasamy, G., Pérez-Guerrera, F., Shriti, V.C., 2022. A critical synthesis of current peer-reviewed literature on the environmental and human health impacts of COVID-19 PPE litter: New findings and next steps. J. Hazard Mater. 422, 126945 https://doi.org/10.1016/J.JHAZMAT.2021.126945.

Kwak, J.II, An, V.J., 2021. Post COVID-19 pandemic: Biofragmentation and soil ecotoxicological effects of microplastics derived from face masks. J. Hazard Mater. 416, 121649 https://doi.org/10.1016/J.JHAZMAT.2021.121649.

Lian, J., Lui, W., Meng, L., et al., 2021. Foliar-applied polystyrene nanoplastics (PSNPs) reduce the growth and nutritional quality of lettuce (Lactuca sativa L.). Environ. Pollut. 280, 116978 https://doi.org/10.1016/J.ENVPOL.2021.116978.

Ma, J., Chen, F., Xu, H., et al., 2021. Face masks as a source of nanoplastics and microplastics in the environment: Quantification, characterization, and potential for bioaccumulation. Environ. Pollut. 288, 117748 https://doi.org/10.1016/J.ENVPOL.2021.117748.

Mézaszórs, E., Bodor, A., Szírer, Á., et al., 2022. Indirect effects of COVID-19 on the environment: How plastic contamination from disposable surgical masks affect early development of plants. J. Hazard Mater. 436, 129255 https://doi.org/10.1016/J.JHAZMAT.2022.129255.

Redondo-Hasselherrarn, P.E., Falahudin, D., Peeters, E.T.H.M., Koelmans, A.A., 2018. Microplastic Effect Thresholds for Freshwater Bentic Microinvertebrates. Environ. Sci. Technol. 52, 2278–2286. https://doi.org/10.1021/ACS.EST.7B05367/ASSET/IMAGES/LARGE/ES-2017-05367N_0003.JPEG.

Sendra, M., Pereiro, P., Yeste, M.P., et al., 2022. Surgical face masks as a source of emergent pollutants in aquatic systems: Analysis of their degradation product effects in Danio rerio through RNA-Seq. J. Hazard Mater. 428, 128186 https://doi.org/10.1016/J.JHAZMAT.2021.128186.

Sun, J., Yang, S., Zhou, G.-J., et al., 2021. Release of Microplastics from Discarded Surgical Masks and Their Adverse Impacts on the Marine Copepod Tigrigopus japonicus. Environ. Sci. Technol. Lett. https://doi.org/10.1021/ACS. ESTLEET.ICO00748.

Vázquez, O.A., Rahman, M.S., 2021. An ecotoxicological approach to microplastics on terrestrial and aquatic organisms: A systematic review in assessment, monitoring and biological impact. Environ. Toxicol. Pharm. 84, 103615 https://doi.org/10.1016/J.ETAP.2021.103615.

Wang, X., Okofii, E.D., Banks, A.P., et al., 2021. Phthalate esters in face masks and associated inhalation exposure risk. J. Hazard Mater., 127001 https://doi.org/10.1016/J.JHAZMAT.2021.127001.