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Microplastics in air: are we breathing in it?

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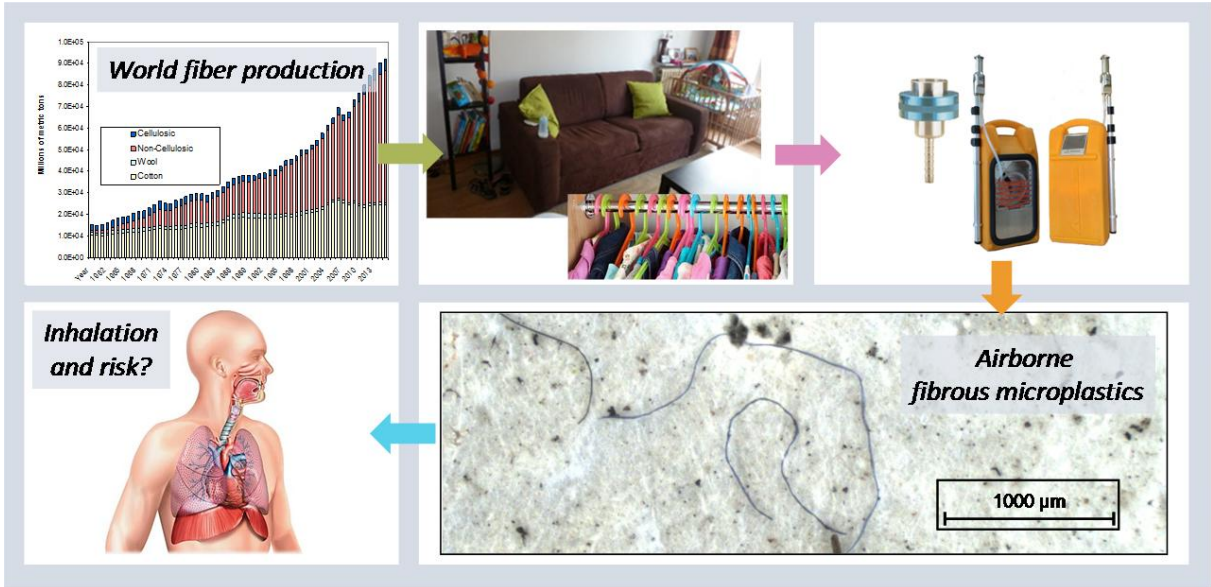
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151. ABSTRACT

16 The annual production of plastic fibers increased by more than 6% per year, reaching 60
17 million metric tons, about 16% of the world plastic production. The degradation of these
18 fibers produces microfragments. Such micro fibers have been observed in atmospheric
19 fallouts, as well as in indoor and outdoor environments. Fibrous MPs may be inhaled. Most of
20 them are likely to be subjected to mucociliary clearance; some, however, may persist in the
21 lung causing localized biological responses, including inflammation, especially in individuals
22 with compromised clearance mechanisms. Associated contaminants, like PAH, could desorb
23 and lead to genotoxicity while the plastic itself and its additives (dyes, plasticizers) could lead
24 to health effects including reproductive toxicity, carcinogenicity and mutagenicity.

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272. GRAPHICAL ABSTRACT



303. HIGHLIGHTS

- 31 • More than 60 million metric tons of plastic fibers were produced in 2016
- 32 • Microplastic fibers fragments are present in outdoor and indoor air
- 33 • The inhalation of airborne fibrous microplastics is a question of size
- 34 • Those inhaled fibrous microplastics may be durable and are likely to persist
- 35 • Airborne fibrous microplastics may also carry pollutants

36 KEYWORDS

- 37 • Fibers
- 38 • Microplastics
- 39 • Air pollution
- 40 • Health risk
- 41 • Inhalation
- 42 • Micropollutants

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49 1. INTRODUCTION

50 Plastic pollution is an emerging concern worldwide, with the majority of studies focusing on
 51 microplastics (MPs; plastic particles with a longest dimension < 5 mm) in marine, and more
 52 recently, continental environments. Whilst the ubiquity of MPs, and especially of fibrous MPs
 53 in both marine and freshwater ecosystems has been demonstrated, the dynamics of their
 54 sources, pathways and reservoirs are not well documented. Indeed, until recently, the presence
 55 of airborne MPs and associated health risks has not been adequately studied. This paper
 56 addresses both issues by reviewing work undertaken on the occurrence of MPs in the
 57 atmospheric compartment as well as discussing human exposure and the potential for
 58 subsequent health risks.

59 2. OCCURRENCE OF MICROPLASTICS IN THE ATMOPHERIC 60 COMPARTMENT

61 2.1. Airborne MPs: is there an issue?

62 Worldwide plastic production increases annually by approximately 3%, and, excluding plastic
 63 fiber production, reached 322 million metric tons in 2016 [1]. More than 60 million metric
 64 tons of plastic fibers (also called synthetic fibers, Table 1) were produced in 2016 – two thirds
 65 of the worlds fiber production, representing a yearly growth rate of about 6.6% over the last
 66 decade. Other fibers include cellulosic fibers (6%) and natural fibers (27%, mainly cotton)
 67 [2].

68 Table 1: Simplified classification of fibers

Natural Fibers		Man-made Fibers	
Vegetal	Animal	Cellulosic Fibers	Synthetic Fibers
Cotton, flax, etc.	Wool, silk, etc.	Viscose/rayon, acetate, etc.	Polypropylene, acrylic, polyamide, polyester, polyethylene

70 The commercial use of fine-diameter (1 – 5 μm) plastic fibers has increased, such as in the
71 sports clothing industry [3]. These small fibers may be shed and released as the clothing
72 wears or during washing [4,5] and drying . Furthermore, the industrial chopping or grinding
73 of synthetic material can result in respirable aerosol formation. Furthermore fibrous MPs too
74 large for inhalation may undergo photo-oxidative degradation in the environment, along with
75 wind shear and/or abrasion against other ambient particulates, and may eventually fragment
76 into particles with respirable aerodynamic diameters. Fibrous MPs can also settle on the floor
77 and children – indeed owing to crawling and frequent hand-to-mouth contact, are daily
78 ingesting settled dust. The risk of inhaling fibrous MPs following widespread contamination
79 within different environmental compartments deserves special attention owing to both the
80 scale of worldwide production and their potential to fragment into smaller, more bioavailable
81 fibers. The human exposure to MPs can occur also through ingestion.

82 2.2. Can we find fibrous microplastics in the atmosphere?

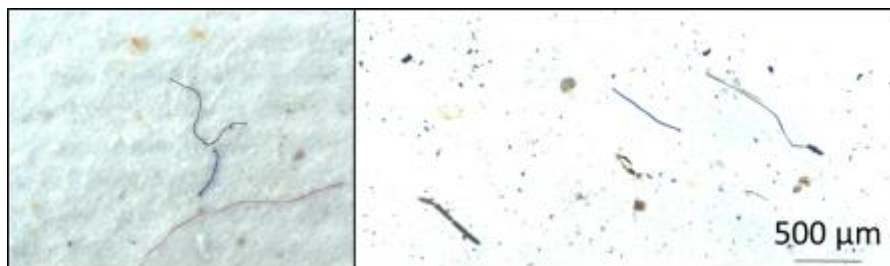
83 To date, and to the best of our knowledge, only two studies have demonstrated the presence of
84 fibrous MPs in the atmospheric compartment [6,7], thereby suggesting potential human
85 exposure. An earlier study [8] highlighted the existence of respirable organic fibers in the
86 indoor and outdoor environment but did not discriminate between natural and synthetic
87 materials. Whilst other studies have suggested the occurrence of atmospheric MPs , no direct
88 evidence was provided [9,10].

89 Dris *et al.* (2016) evaluated the presence of fibrous MPs in total atmospheric fallout (TAF -
90 including dry and wet deposition) at one urban site and one suburban site in the Paris
91 Megacity [5]. TAF was collected continuously on the roofs of buildings. Fibrous material
92 accounted for almost all of the material collected (Figure 1), the remaining being rare small
93 plastic fragments (smaller than 100 μm). Based on a 1-year and a 6-month monitoring period,
94 respectively on two sites, atmospheric fallout of between 2 and 355 fibers/ m^2/day was

95 calculated. TAF fluxes were systematically higher at the urban site than at the suburban one,
96 probably linked to the density of the surrounding population. Rainfall also appears to be an
97 important factor influencing the fallout flux. Despite no significant quantitative correlation
98 between the concentrations of fibers and the characteristic of the rain events (rainfall depth,
99 intensity, etc.), TAF during wet weather periods are always substantially larger than during
100 dry weather periods.

101 2.3. What are the characteristics atmospheric fibrous microplastics ?

102 After chemical characterization, it appeared that 29% of the fibers evaluated in TAF are
103 plastic, with the majority constituting cellulosic or natural origin [5]. The length distribution
104 of fibers collected larger than 50 μm was assessed. On measuring fiber length, smaller size
105 classes [200-400 μm] and [400 – 600 μm] were predominant whilst fibers in the larger size
106 ranges were rare. Few fibers measuring between 50 μm (observation limit) and 200 μm in
107 length have been detected. The diameter of the fibers varied mainly between 7 and 15 μm .



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Figure 1: fibrous microplastic observed in atmospheric fallout

110 2.4. Are we exposed to airborne fibrous microplastics?

111 Dris *et al.* (2017) investigated fibers in indoor and outdoor air, as well as indoor settled dust
112 [6]. Three indoor sites comprising two apartments and one office were selected within a dense
113 urban area of Paris. Outdoor air was sampled in close proximity to the office site, which was
114 also where TAF monitoring took place. A pump sampled 8 L/min of indoor air onto quartz
115 fiber filters (1.6 μm). Sampled volumes varied depending on occupants' presence. The same
116 method was used for the assessment of outdoor air. Overall, indoor concentrations ranged
117 from 1.0 to 60 fibers. m^{-3} . Outdoor concentrations were significantly lower, ranging between

118 0.3 and 1.5 fibers.m⁻³. The deposition rate of the fibers in the indoor environments ranged
119 between 1,586 and 11,130 fibers.d⁻¹.m⁻². Settled dust was collected using a conventional
120 vacuum cleaner and analysis revealed a concentration of fibers ranging from 190 to 670
121 fibers/mg.

122 2.5. What are the characteristics of fibrous microplastics in indoor environments?

123 According to chemical characterization, 67% of indoor fibers were made of natural material,
124 primarily cellulosic, while the remaining 33% fibers contained petrochemicals with
125 polypropylene being predominant [6]. A similar size distribution was determined for indoor
126 air, outdoor air and TAF with slight differences. These differences between compartments lie
127 in the size of the longest observed fibers: while fibers in the range of 4,650-4,850 µm can be
128 found in dust fall, no fiber longer than 3,250 µm is observed in indoor air almost the double of
129 the size of the longest fibers in outdoor air (1,650 µm). Larger fibers are observed in dust fall
130 because they settle more rapidly and accumulate on the floor. While fibers under 50 µm were
131 not counted due to the observation lower limit, the size distribution pattern suggests that much
132 smaller fibers might be present.

133 3. IMPACTS ON HUMAN HEALTH?

134 3.1. Are airborne fibrous microplastics breathable?

135 The likelihood that airborne fibrous MPs enter our respiratory system will be dependent upon
136 size. First, it is important to discriminate between the terms inhalable and respirable. Particles
137 and fibers able to enter the nose and mouth and deposit in the upper airway are inhalable,
138 whilst those able to reach and deposit in the deep lung are respirable. Deposition in the airway
139 is a function of aerodynamic diameter and within the respiratory zone, deposition falls off
140 above 5 µm diameter [11].

141 The World Health Organisation defines a fiber as any particle that has a length > 5 µm, with a
142 diameter < 3 µm and an aspect (length-to-diameter) ratio > 3:1 [12]. Fibrous MPs that exceed

143 these criteria may be inhaled, but are likely to be subjected to mucociliary clearance in the
144 upper airways, leading to gastro-intestinal exposure. Some fibrous MPs may however avoid
145 the mucociliary clearance mechanisms of the lung, especially in individuals with
146 compromised clearance mechanisms.

147

148 3.2. Do fibrous microplastics accumulate in the human body?

149 Another factor contributing to toxicity is the biopersistence of inhaled fibrous MPs, which is
150 related to durability in and clearance from the lung [13]. *In vitro* tests have found plastic
151 fibers to be extremely durable in physiological fluid: polypropylene, polyethylene and
152 polycarbonate fibers showed almost no dissolution or changes to surface area and
153 characteristics in a synthetic extracellular lung fluid after 180 days. This suggests plastic
154 fibers are durable and likely to persist in the lung [14]. Biopersistence is also connected to
155 length, with longer fibers more likely to avoid clearance [3].

156 Plastic fibers have been observed in pulmonary tissue [15], suggesting that the human airway
157 is of a sufficient size for plastic fibers to penetrate the deep lung. Histopathological analysis
158 of lung biopsies from workers in the textile (polyamide, polyester, polyolefin, and acrylic)
159 industry showed foreign-body-containing granulomatous lesions, postulated to be acrylic,
160 polyester, and/or nylon dust [16]. These observations confirm that some fibers avoid
161 clearance mechanisms and persist.

162 3.3. Occupational health risks

163 Studies among nylon flock (fiber) workers suggest there is no evidence of increased cancer
164 risk, although workers had a higher prevalence of respiratory irritation [3]. Interstitial lung
165 disease is a work-related condition that induces coughing, dyspnoea (breathlessness), and
166 reduced lung capacity in workers processing either para-aramid, polyester, and/or nylon fibers
167 [17–19]. Workers also present clinical symptoms similar to allergic alveolitis [16]. These

168 health outcomes are indicative of the potential for MPs to trigger localised biological
169 responses, given their uptake and persistence.

170 Whilst these effects are distinct from those seen after asbestos exposure, the legacy of
171 asbestos toxicology can in-part help predict health effects of fibrous MPs. In silicate-based
172 fibers, length and biopersistence in the airway/lung are the characteristics that govern toxicity
173 and the mechanisms of that toxicity. Whether the same is true for fibrous MPs remains to be
174 determined.

175 3.4. What are the potential mechanisms of toxicity?

176 3.4.1. Particle Effects: Inflammation and Secondary Genotoxicity

177 Beyond a certain exposure level/dose, all fibers seem to produce inflammation following
178 chronic inhalation [13]. The general paradigm for fibrous particle toxicity, based on asbestos
179 and manmade vitreous fibers is that upon cell contact, intracellular messengers and cytotoxic
180 factors are released leading to lung inflammation, and potentially secondary genotoxicity
181 following the excessive and continuous formation of reactive oxygen species (ROS). Fibrosis,
182 and in some cases cancer, can manifest after prolonged inflammation [13]. Toxicity is greater
183 for longer fibers [13] as they cannot be adequately phagocytosed, stimulating cells to release
184 inflammatory mediators [20] that contributes to fibrosis.

185 Poorly-soluble low-toxicity particles have been found to cause lung tumours and
186 inflammation in rats ([21], however information on whether this translates to humans is
187 lacking. Plastic is typically considered inert, yet its biopersistence and the shape of fibrous
188 MPs could lead to inflammation.

189 3.4.2. Chemical Effects

190 3.4.2.1 Associated Contaminants

191 Airborne fibrous MPs may carry pollutants adsorbed from the surrounding environment due
192 to their hydrophobic surface [22]. In urban environments, where they co-occur with traffic
193 emissions, they may carry polycyclic aromatic hydrocarbons (PAHs) and transition metals.

194 Detrimental pulmonary outcomes could then ensue following desorption of associated
195 contaminants leading to primary genotoxicity amongst other effects. For example, stable and
196 unstable DNA lesions may arise after metabolism of fibrous-MP-associated PAHs [13].

197 3.4.2.2 Intrinsic Contaminants

198 Plastic may contain unreacted monomers, additives, dyes and pigments, many of which could
199 lead to health effects including reproductive toxicity, carcinogenicity and mutagenicity [23],
200 should they leach or volatilize and accumulate. For example, the contamination of house
201 settled dust with polybrominated diphenyl ethers [23–25] or phthalates [26] is widely
202 documented worldwide, possibly owing to emissions from fibrous MPs resulting from the
203 wear of plastic household textiles.

204 4. RECOMMENDATIONS

205 There is an urgent need for data on the human health impacts of fibrous MPs. However,
206 before this is determined, it is important to better assess whether and if so, how we are
207 exposed. To this end, collaboration between environmental, epidemiological and air quality
208 communities is required to set up a relevant research programme, which will include a
209 specific monitoring strategy. Both length and diameter should be included when reporting on
210 the presence of MPs since diameter is crucial to respirability, whilst length plays an important
211 role in persistence and toxicity. The full spectrum of fibers (both natural and petrochemical-
212 based structures) must also be considered. Within the studies conducted to date, the limit of
213 observation was 50 μm but detection at a smaller scale ($< 10 \mu\text{m}$) is crucial. The potential of
214 inhaling these fibers must also be determined and all potential impacts urgently identified.

215

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218 *Papers of outstanding interest (••) : [6,7]*

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