Microplastics in Food: Health Risks

Qun Zhang, Yaping Zhao, Jiana Li, and Huahong Shi

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Abstract The presence and ecological risks of microplastics (MPs) are increasingly reported, whereas the impacts of MPs on human health remain largely unknown. Recent studies have confirmed the MP contamination in food items, including seafood, table salt, drinking water, etc. Dietary exposure is one of the inevitable exposure pathways of MPs, which causes concern about the potential human health risks. Whether we assess health risks or try to reduce food MP contamination, the prerequisites are to figure out the contamination pathways of MPs and their actual level in food items. At present, territorial system is facing serious environmental problems, with soil, freshwater, and air suffering from MP pollution. This leads to diversity and complexity of MP sources in food items. Therefore, we should not be

Q. Zhang and Y. Zhao
Shanghai Key Laboratory for Urban Ecological Process and Eco-Restoration, School of Ecological and Environmental Sciences, East China Normal University, Shanghai, China

J. Li
College of Oceanography, Hohai University, Nanjing, China

H. Shi (✉)
State Key Laboratory of Estuarine and Coastal Research, East China Normal University, Shanghai, China
e-mail: hhshi@des.ecnu.edu.cn

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confined to the food itself when considering MPs in food, but should take all pollution possibilities into account. In this chapter, we reviewed the literature concerning MPs in seafood, table salt, drinking water, and other food items. The potential MP sources of food items during the whole process from food acquisition to human ingestion were analyzed, with related human intake of MPs estimated. We also discussed possible translocation and accumulation pathways of MPs within human body. Given the lifetime inevitable exposure to MPs through multiple pathways, we urgently call for a better understanding of the potential MP sources in food items and a comprehensive assessment of human intake.

Keywords Drinking water, Health risks, Microplastics, Seafood, Table salts

1 Introduction

Since the concept of "microplastic" was introduced in 2004 [1], microplastics (MPs) have been found in various environmental media and organisms globally [2–6]. More recently, the threats of MPs to human health have gained increasing public interests and media attention due to the wide detection of MPs in human-related food.

As the marine environment attracted much attention, seafood has become the most studied food [7–9]. More than 690 marine species have been reported to be contaminated by MPs, including edible and nonedible ones [10, 11]. Since inedible species do not normally enter human body, their contribution to MP intake by human is negligible. Until now, MPs have been found in 202 edible species, including 201 marine species and 1 terrestrial species [12]. Subsequently, MPs are also observed in table salt and other food such as honey, sugar, beer, and drinking water [13–16]. Consumption of these food products will undoubtedly cause MP exposure through human digestive tract. Numerous experiments have demonstrated toxic effects of MPs, such as growth inhibition, oxidative damage, and immune stress [17, 18]. A recent study shows that MPs of high concentration may have caused evolutionary adaptations of some species (e.g., D. magna and G. pulex) [19]. Mammal experiments have proved that polystyrene microplastic can induce gut microbiota dysbiosis and hepatic lipid metabolism disorder in mice [20]. MP particles can also accumulate in marine organisms and transfer through the food chain to higher trophic levels including humans [10]. Despite that ample evidence suggests the MP contamination of human-related food and the related toxicological effects on animals and cells, there is, however, large unknown fields.

Food is indispensable energy supplier for human survival. Therefore, it is necessary to survey our current knowledge on direct human exposure concentration to MPs via food consumption. Related topics have been discussed previously. For example, seafood, as a carrier of MPs, should be treated cautiously considering the influence on human health through biological accumulation and biological amplification [21, 22]. At the same time, some believe that the risk to higher trophic levels is negligible due to the rapid depuration of MPs [23]. In fact, the issue of MPs in food items is no longer about single investigation of MPs in food itself due to inevitable MP contamination in water and air for human consumption in terrestrial environment. During the whole process from food acquisition, production, packaging, and transportation to food intake, extra MPs may be introduced in any link [16]. This is a complex problem that needs to be dissected in depth. When all factors are taken into consideration, we will have more realistic data for risk assessment. Only in this way can we put forward more effective measures to control the main links of food contamination.

2 Microplastics in Seafood

Various foods are summarized in terms of contamination levels of MPs. Since these data have been reported in detail in previous studies [12, 24–26], partial data are listed in Table 1.

MPs have been found in fish from many countries and regions, ranging from 0 to 48 items/individual [40–42]. The reason that “items/individual” is used instead of “MPs/individual” is that MPs in seafood are usually characterized by their sizes, shapes, and colors, whereas compositions are not universally identified. Among these studies that have completed particle identification, relatively high concentrations occurred in China (13.54–22.21 items/individual) [43], Turkey (9.4 items/individual) [44], and Malaysia (14 items/individual) [45]. However, different methods among studies lead to poor comparability of the results. Therefore, direct comparisons and accurate conclusion cannot be made, and such situation occurs in shellfish and all the other food items.

MP abundance in shellfish (0–57.2 items/individual, 0–75 items/g) is generally higher than that in fish, with blue mussels being the most studied species [46, 47]. The largest numbers occurred in mussels from Canada (34–75 items/g) [29], followed by China (0.9–4.6 items/g) [48] and Equatorial mid-Atlantic area (2 items/g) [49]. In addition to wild mussels, some ones from fishery farms, as well as supermarket, have also been confirmed to be contaminated by MPs. Li et al. have investigated commercial bivalves from fishery farms and supermarket and found that all mussels were contaminated by MPs [27, 28].

3 Microplastics in Table Salt

MPs have been widely identified in table salt of more than 100 brands all over the world [16, 33, 36, 50], with their concentrations varying widely. The highest concentration was reported in Croatia (1.35×10^4–1.98×10^4 MPs/kg salt),

Table 1 Microplastics in food items

Food type	Abundance	Location	Reference
Shellfish (items/g)	2.1–10.5	China	[27]
	0.2 ± 0.3	France	[5]
	0.7–2.9 (coastal), 0.9–1.4 (supermarket)	UK	[28]
Fish (items/ individual)	0.3–1.1 (GIT)	Indonesia	[29]
	0.57–1.85 (muscle)	Iran	[30]
	1.9 (liver)	Spain	[31]
Table salt (MPs/kg)	7–681	China	[16]
	13,500–19,800	Croatia	[32]
	98–232	Korea	[33]
	5–280	Spain	[34]
Drinking water (MPs/L)	338–628 (DWTP)	Czech	[35]
	3.66–13 (tap water)	England	[36]
	2,649–6,292 (bottled water)	Germany	[37]
	58.2–1,410 (bottled water)	USA	[38]
Honey	166 ± 147 fibers/kg, 9 ± 9 frag-ments/kg	Germany, France, Italy, Spain, Mexico	[13]
Sugar	217 ± 123 fibers/kg, 32 ± 7 frag-ments/kg	Germany, France, Italy, Spain, Mexico	[13]
Beer (MPs/L)	2–89 fibers/L, 12–109 frag-ments/L	Germany	[14]
	0–14.3	USA	[36]
Canned sar-dines and sprats	–	Canada, Germany, Iran, Japan, Latvia, Malaysia, Morocco, Poland, Portugal, Russia, Scotland, Thailand, Vietnam	[39]

followed by Indonesia (1.36×10^4 MPs/kg), Italy (1.57×10^3–8.23×10^3 MPs/kg) [32, 33], the USA (0.47×10^2–8.1×10^2 MPs/kg), and China (5.5×10^2–6.8×10^2 MPs/kg) [16, 36]. A recent study compared MP concentrations in table salts collected from different regions, using sea salt as a seawater MP pollution indicator, which indicated a significant higher MP concentration in Asia than in other continents [38]. The lowest concentrations of MPs were reported by Karami et al. [51]. This was probably due to its filters with larger pores (149 μm), which allowed smaller-sized MPs to escape in the filtration process and thus underestimated the MP abundance.

4 Microplastics in Drinking Water

Compared to seafood and table salt, relatively few studies reported MP contamination in drinking water. The available data cover raw and treated water from drinking water treatment plants (DWTP), tap water, and bottled water [37, 38, 52]. According to the MP abundance in raw and treated water, particles larger than 50 μm can be removed from water at the treatment plants. The removal rate of MPs by traditional drinking water treatment processes varied from 25 to 90%, depending on treatment technologies [35]. For tap water samples, the lowest abundance was observed in Italy and Denmark (0 MPs/L), while the highest abundance (9.24 MPs/L) was found in the tap water of the USA [36]. The abundance of MPs in bottled water varied from 0 to 5.4×10^7 MPs/L [37, 38, 52]. Water in returnable-used plastic containers had significantly more MPs compared with that in single-used bottles [37].

The difference of detection limits among studies in the drinking water field is obvious. MPs in tap water were often analyzed by micro-Fourier transform infrared spectroscopy (μ-FTIR), capturing MPs > 20 μm [45]. All bottled water and the water from Czech DWTP were analyzed using non-FTIR or μ-FTIR combined with other method [43, 47]. These methods included μ-Raman, dyeing method combined with μ-FTIR, and "method for the extraction and determination of MPs in organic and inorganic matrix samples," making "small-sized MPs (< 10 μm)" detectable. The MP concentration in tap water samples may be underestimated due to the non-detectable smaller MPs using μ-FTIR, which leads to the biased result that the higher concentrations of MPs were detected in bottled water than in tap water. The identification of "small-sized MPs (<10 μm)" is in an urgent need for accurate recognition of MPs and the relative risk assessment, regarding not only drinking water but other food items [37].

5 Microplastics in Other Food Items

MP contamination also occurred in other food products according to the literature. These rarely reported food types include beer, sugar, honey, chicken, tea, as well as canned sardines and sprats [13–15, 39, 53–55]. Besides, we have found MPs in edible seaweed (unpublished data). However, the data of these food items are so limited that more investigations are needed on a broader range, covering more regions and food types.

In recent years, MP pollution has been widely recognized in soil, where the crops and edible vegetables we eat grow. This undoubtedly poses a risk to land plants. Although there is no evidence from field investigations, laboratory studies have shown that polystyrene microsphere (0.2 μm) can be absorbed by lettuce roots and then migrate to shoots and accumulate in edible stems and leaves [56]. Although larger MPs are difficult to enter root cortex, they may adhere to plant surface and be ingested by human [57].

6 Source, Human Burden, and Potential Health Risks

6.1 Source Diagnostics

To date, MPs are ubiquitous in terrestrial environment. Together with the whole process from food acquisition to ingestion, the sources of MPs in food become diverse and complex. Figure 1 shows the potential MP sources during the whole process of seafood consumption, and other food items experience similar processes to seafood.

In the beginning, the main factor affecting food contamination is the pollution degree of the surrounding environment. Typical examples are table salt and seafood. MPs in the surrounding environment can fuse into, adhere to, or be ingested by marine animals [58, 59]. Several studies found that the abundance of MPs in sea salt was higher than that in rock salt or lake salt, which could be explained by the high level of MP pollution in coastal zones [16]. Besides, both mussel and sea salt are proposed as indicators of MP pollution in marine environment [6, 33]. There are also some plastic appliances and ropes acting as pollution sources of MPs in cultured seafood. Another MP source of farmed seafood is the feeding materials produced from MP-contaminated fish or other animals [21].

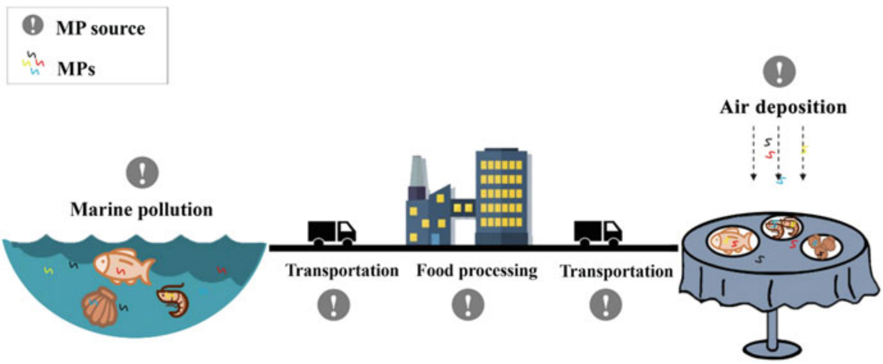

Fig. 1 Potential microplastic sources of seafood from marine environment to the table

After acquisition, food items commonly experience food processing. The presence of MPs in table salt suggests that MPs might be introduced during collection, transportation to surface water, concentration, drying, crystallization, or refinement processes [16]. Some food items are processed with additional substances such as salt or water. If these additives have been already contaminated, MPs will be introduced. Moreover, food packaging materials are often made of plastics, causing the possibility of food contamination. According to the latest research, a single plastic tea bag can release approximately 11.6 billion MPs and 3.1 billion nanoplastics into a single cup of the beverage [55]. The staggering data reminds us to pay more attention to food packaging and all external factors that may have similar effects. For instance, takeout food industry is booming in today's quick living pace, resulting in more plastic packaging for food. Such situation makes food more likely to be contaminated.

There is also an important source that needs special emphasis, which is airborne MPs. Air contact exists almost throughout the entire process of food consumption, from food acquisition to human ingestion. To date, atmospheric MPs have been discovered in many countries and regions, both indoor and outdoor environments [60, 61]. Airborne MPs may have greater contribution to food MP pollution than other sources. The risk of plastic exposure caused by mussel has been confirmed to be minimal compared to fiber ingestion through air fallout during a meal [62].

6.2 Human Body Burden

Contaminated food items are undoubtedly sources of gastrointestinal exposure for human. A preliminary estimate on the body burden of MPs was made based on detected MP concentrations in table salt, seafood, and drinking water. MP intake through other food items cannot be estimated due to scarce data. The abundance of MPs in table salt ranges widely from 0 to 2.0×10^4 MPs/kg. Considering the global mean intake of table salt of 10.06 g/day [63], the intake of MPs ranges from 0 to 198 MPs per day, equivalent to 0 to 7.3×10^4 MPs per year. The highest value is calculated according to the data of salt from Croatia [32]. The actual MP exposure through salt intake depends on the types and brands of table salts, as well as the study regions.

The presence of MPs in seafood has been widely recognized [27, 28, 48]. In 2014, van Cauwenberghe and Janssen first estimated the potential MP intake through seafood consumption. It showed that in Europe, where shellfish consumption was high, an adult may ingest up to 11,000 MPs per year [22]. In countries with low shellfish consumption, consumers ingest an average of 1800 MPs per year, which is still a considerable exposure. The annual intake of MPs through seafood consumption worldwide has been estimated by Hantoro et al., ranging from 11 to 3.5×10^4 particles per person [64]. Since MPs are mostly detected in gastrointestinal tracts (GITs), which are normally removed before seafood consumption, species that we eat whole pose greater threats than gutted ones. However, MPs in the eviscerated flesh of two commonly consumed dried fish species were significantly more than in excised organs, evidencing that the evisceration does not necessarily eliminate the risk of MP intake [45]. Moreover, MPs were also detected in the muscle of commercial fish [30]. These findings raise concerns about possible implications for human consumers.

With around 1.4 L water intake per day [65], the annual MP ingestion through drinking water, including tap water and bottled water, could be in the range of 0–2.8×10^{10} MPs. However, the MPs detected in bottled water have different size fractions (<10 μm) from those detected in tap water, seafood, and table salt. The abundance, as well as the potential human risk of particles with different size ranges, is not comparable. Therefore, when estimating the MPs in the three media, we only calculated human MP intake through drinking tap water (0–4.7×10^3 MPs per year), without considering the data of bottled water.

Despite that we have estimated the intake of MPs by human through food consumption, these data cannot represent the real situation. When calculating it, we mostly take MP level of food itself into consideration but ignore other contamination possibilities (from food processing, air, package, etc.). Thus, more attention needs to be paid to these areas. When all factors are taken into consideration, the total amount of MPs ingested by human through food is likely to rise by orders of magnitude. However, excessive panic is uncalled-for before there is sufficient toxicological evidence related to human body. Our body is in a process of dynamic metabolism, and the unabsorbed MPs will be discharged with feces. Therefore, the absorbed MPs and the amount of pollutants (organic pollutants and heavy metals) released during MP metabolism are needed to make clear.

6.3 Translocation and Accumulation in Human Body and Health Risks

After ingestion, MPs are capable of translocating and accumulating in different organs and tissues. MPs have been found to be internalized in the gastrointestinal tract, and the unabsorbed portion is excreted with human feces [66]. The studies on other nano-sized particles provided evidence of penetration in the blood-brain barrier and placenta and even crossing the cell membrane [67, 68]. However, there is still no direct evidence showing the exact distribution and accumulation of MPs in human organs such as the liver and kidney or in human blood.

Our current knowledge is very poor about whether MPs will reach human organs and cause adverse health impacts. The available animal experiment results may have some implications for human health effects of MPs. Ingestion of MPs caused inflammatory responses in the digestive system of *Mytilus* [69]. The immune system of fish was the target of MP attack [70]. Inflammations including chemokine expression and pulmonary hypertension were induced by intrajugular injection of polystyrene (PS) microspheres in rats, probably due to the increased blood coagulability or vascular occlusions [71, 72]. In vivo experiments showed that PS could be internalized in macrophages, erythrocytes, as well as rat alveolar epithelial cells, showing damages to intracellular structures [73, 74]. Moreover, persistent organic pollutants, metals, and pathogenic microorganisms can be adsorbed on MPs, and the leaching of chemical additives can also aggravate the toxic effects of MPs [75–78]. MPs have been verified to be transport vectors for hydrophobic organic chemicals (HOCs) in aqueous environments [79, 80]. Apparent enrichment coefficients of HOCs on MPs might be up to five or six orders of magnitude higher than the background concentration in the surrounding seawater. MPs may then transport HOCs over long distances and affect the environmental and biological systems [80]. The debate on the harmfulness of MPs to human health remains. Some researchers emphasized the danger posed by food chain transfer, while others claimed no adverse effect caused by MPs or MP additives [78, 81]. The controversies mostly lie in the uncertainty of MP intake estimate, which calls for more precise MP intake measurements or stimulating analysis. More research is urged to quantify the concentrations of MPs in the tissue and to understand the mechanisms of the induced human symptoms [82].

7 Conclusions

Food safety is an important issue closely related to human health. MP-contaminated food poses a global concern, and humans are vulnerable to MP exposure through consumption of these food items. The related information is scarce, and there may be more kinds of food contaminated by MPs. What's more, broader range of research subjects and the detection technologies of small-sized particles are required in addition to the uniformity of methods when we are assessing food safety. Besides, we should take all pollution sources and possibilities into consideration. On this basis, the human intake we calculate will be closer to the actual value.

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