Veteriner Farmakoloji ve Toksikoloji Derneği Bülteni

Bulletin of Veterinary Pharmacology and Toxicology Association

e-ISSN: 2667-8381

MICROPLASTICS, A NEW EMERGING CONTAMINANT IN FOODS

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Geliş Tarihi: 13.02.2024
Kabul Tarihi: 16.03.2024

15 (1): 47-57, 2024
DOI: 10.38137/vftd.1436289

Makale atıf

Çakıroğlu, E. C. ve ark. (2024). Microplastics, A New Emerging Contaminant in Foods, Veteriner Farmakoloji ve Toksikoloji Derneği Bülteni, 15 (1), 49-57. DOI: 10.38137/vftd.1436289.

ABSTRACT. The increasing presence of microplastics in the environment exposes living organisms to microplastics through the food chain by consuming food contaminated with microplastics. In this review, we include important topics such as the presence of microplastics in food as environmental contaminants and detection methods with the final aim properly assessing and managing this emerging risk. Numerous studies have investigated microplastic presence in seafood, fruits and vegetables, milk and milk products, bottled water, table salt and sugar. The ingestion of microplastics plastic particles, additives, and contaminants through oral intake, respiration, dermal intake stresses the need for comprehensive risk assessment and regulatory measures for public health. To address these concerns, there is a need for interdisciplinary collaboration, increased research efforts and the development of guidelines for microplastic consumption to protect public health in the face of microplastic contamination in the food chain.

Keywords: Microplastics, food, environment, environmental contaminant, public health.

GIDALARDA YENİ ORTAYA ÇIKAN KİRLETİCİ MİKROPLASTİKLER

ÖZET. Çevrede artan mikroplastik varlığı, mikroplastiklerle kontamine olmuş gıdaları tüketerek canlı organizmaları besin zinciri yoluyla mikroplastiklere maruz bırakmaktadır. Bu derlemede, ortaya çıkan bu riskin doğru bir şekilde değerlendirilmesi ve yönetilmesi nihai amacı ile çevresel kirleticiler olarak gıdalarda mikroplastiklerin varlığı ve tespit yöntemleri gibi önemli konulara yer veriyoruz. Çok sayıda çalışma, deniz ürünleri, meyve ve sebzeler, süt ve süt ürünleri, şişelenmiş su, sofra tuzu ve şekerde mikroplastik varlığını araştırmıştır. Mikroplastiklerin, plastik parçacıkların, katkı maddelerinin ve kirleticilerin oral alım, solunum, dermal alım yoluyla yutulması, halk sağlığı için kapsamlı risk değerlendirmesi ve düzenleyici önlemlere duyulan ihtiyacı vurgulamaktadır. Bu endişeleri gidermek için, gıda zincirinde mikroplastik kontaminasyonu karşısında halk sağlığını korumak için disiplinler arası işbirliğine, artan araştırma çabalarına ve mikroplastik tüketimine yönelik kılavuzların geliştirilmesine ihtiyaç vardır.

Anahtar Kelimeler: Çevre, çevresel kontaminant, gıda, halk sağlığı, mikroplastikler.

INTRODUCTION

Plastic production is increasing rapidly day by day, but the lack of strict regulations for the elimination of plastic waste leads to serious environmental problems (Derraik, 2002; Chae et al., 2018). Particles usually smaller than 5 mm formed as a result of the breakdown of these plastic wastes are defined as microplastics (MPs). Microplastics have been known as an organic pollutant that has attracted a lot of attention since 2014. As a result of research, it has been revealed that this newly emerging pollutant species is a major concern for the ecosystem and public health. Microplastics can be found in resilient, diverse ecosystems, and can remain intact in nature for long periods of time, which is a cause for global concerns (Ivleva et al., 2017). Microplastics are found in seas, oceans, freshwater sources and beaches, but they have also been found in various foods (Li et al., 2018a). As a result of recent research, it has been revealed that microplastics even get into drinking water, which is a major concern for human health (Novotna et al., 2019). It is estimated that the number of microplastics consumed by humans through food varies between 203 and 302 particles per person per day on average (Cox et al., 2019). It is very important for governments to develop certain regulations and solutions to reduce the harmful effects of microplastics and their presence in the environment. In this article, current knowledge on the presence of microplastics in foods, which have gained importance as an environmental contaminant, is reviewed.

WHAT ARE MICROPLASTICS?

Microplastics are very small synthetic organic polymers that vary in size from 1 µm to 5 mm (Frias and Nash, 2019). Microplastics have been found to have negative effects on both the environment and human and animal health as a result of studies. The concept of "microplastics" first emerged in the UK in 2004 when studying plastic pollution in the oceans (Thompson et al., 2004). Plastics entering water sources undergo degradation processes induced by exposure to sunlight, oxygen reactions, and physical forces, leading to their fragmentation into smaller pieces of diverse types and sizes (Çakmak and Acaröz, 2021). Microplastics are quite common in ecosystems such as marine, ocean, freshwater, and terrestrial (Peixoto et al., 2019). In addition to these ecosystems, their use in industries also poses a significant risk to the environment (Osman et al., 2020; Qasim et al., 2020). Microplastics are examined in two groups. Primary microplastics are deliberately produced small circle-shaped microbeads that are often used in cosmetics, personal care products, and cleaning supplies (Wang et al., 2019). At the same time, groups of primary microplastics are deliberately added to paints, diapers, medicines, and even pesticides (Duis and Coors, 2016). On the other hand, secondary microplastics; it occurs as a result of unintentional deterioration of plastic bags, bottles, crates and even large plastic parts such as ropes and nets due to physical, biological and chemical factors (Andrady, 2017). Microplastics are also not easily degradable and highly stable; this makes them remain in the environment for hundreds of years (Xiang et al., 2022).

Microplastics enter the food chain of terrestrial and aquatic organisms and are bioaccumulated and consumed by small fish and other organisms. Consumption of these pollutants by fish, sea turtles, clams, and mussels compromise the digestive system and is even known to lead to deaths (Matsuguma et al., 2017; Caron et al., 2018; Hipfner et al., 2018). As a result of the consumption of contaminated fish and other aquatic creatures living in the water, it also mixes with the human food chain and this situation directly affects human health. In recent years, the production of microplastics has increased considerably and the concentrations of microplastics found on some coasts have reached thousands of particles per cubic meter. Due to their small size, it becomes very difficult to remove microplastics from the environment by conventional means (Hou et al., 2021).

MICROPLASTICS AS AN ENVIRONMENTAL POLLUTANT AND THEIR SOURCES

Since products made of plastic are low cost and durable, they are frequently used in many areas such as cosmetic products, textiles, and industry. Globally, plastic production is 300 million tons or more per year and is increasing annually (Wang et al., 2017). According to the studies, the regions that emit the most plastic into the environment regionally are India with 18.3% and South Asia, followed by North America with 17.2% and Europe with 15.9% (Boucher et al., 2017). The reason for this is thought to be the high population in these regions and the excessive emergence of plastic wastes depending on consumption habits. In addition, because of the inability to consciously separate plastic products, the inability to ensure proper waste management and limited recycling, plastics mix with both terrestrial and aquatic ecosystems and disrupt the natural balance (Aydin et al., 2023). Transportation: it is also mixed into the environment due to the plastics used during the transportation of vehicles, vehicle tires, roads, products, etc. (Sharma et al., 2017).

The dissolution times of plastics are very slow. Under normal conditions, it takes more than 50 years for a plastic material to dissolve, and even after that time, it does not dissolve completely (Müller et al., 2001). In marine environments, the decomposition of plastics into microplastics is accelerated by factors such as sea water, wave movements and, abrasion while in terrestrial environments, effects such as temperature fluctuations and increased exposure to UV rays (Andray, 2011; Karbalaei et al., 2019). Data from the World Health Organization show that microplastic species are present in food, soil, bottled drinking water, tap water, fresh and salt water, wastewater, and soil (WHO, 2019). These microplastics can accumulate in the aquatic and terrestrial ecosystems for many years and disrupt the ecosystem balance by preventing the growth and development of organisms (Chae et al., 2018).

The presence of microplastics in the environment affects all living things, from the smallest part of the ecosystem to the largest part. In a study conducted in Europe, sludge prepared to be used as agricultural fertilizer is among the factors that cause microplastic accumulation in the soil. It has been determined that high amounts of microplastics pass into the soil using fertilizers prepared with waste and sewage water (Horton et al., 2017). At the same time, factors such as burying solid wastes in the soil and throwing plastic materials into the soil individually cause the accumulation of microplastics in the soil. Microplastics in the soil affect the organisms and macrofauna activities in the soil, and it is seen that they change their physical, chemical, and biological properties (Chae et al., 2018; Yurtsever, 2019). Microplastics can progress towards the lower layers of the soil due to factors such as agriculture, cracks in the soil, and the deterioration of various organisms. Microplastics that progress to the deep layers of the soil can mix with groundwater from there (Rillig et al., 2017). This reveals that microplastics can pass into plant seeds and fruits, so they can be taken into the human body through food consumption. This suggests that the absorption of microplastics by plants could have potential effects on food safety and human health.

The transport of microplastics does not only occur between soil and groundwater. It is possible to transport microplastics from small bodies of water to large bodies of water in many ways, such as wave action, winds, and human interactions. Microplastics, which accumulate especially in aquatic ecosystems, are very suitable for microorganisms to form biofilms. Bacteria, algae, and fungi colonize microplastics in water and form biofilms (Hoellein et al., 2014). In addition, microplastics accumulating in the environment can act as carriers for other environmental pollutants and heavy metals that are toxic to human health (Aydin et al., 2023). Transportation of micro-organism biofilms and microplastics that have absorbed toxic substances is a very dangerous situation for human, animal and ecosystem health. For all these reasons, there is a need for multidisciplinary research against microplastics, comprehensive risk assessments and the development of strategies to reduce microplastics.

The increase in the concentration level of microplastics in foods is considered a threat to public health. Not only should its presence in food be taken into account; at the same time, products that we frequently encounter in daily life are a source of threat to public health in terms of microplastics.

More than 80% of microplastics are found in land-based sources rather than water (Duis and Coors, 2016). Examples of land-based sources are food and beverage packaging, and construction materials, in which plastic widely used (Kedzierski et al., 2020; Yang et al., 2021). Personal care products (face wash gels, shower gels, hand soap, makeup, and toothpaste) also pose a high risk that they may contain microplastics that can be used as drug carriers or ingredients (Rochman, 2018; Guerranti et al., 2019). Microplastics released by damage to automobile tires are also a very important source. In addition, disposable products (cutlery, plates, plastic bottles) that we frequently encounter in daily life and disposable masks made of plastic polymers during the COVID-19 pandemic also pose a risk (Fadare and Okofo, 2020). The remaining 10-20% is waterborne microplastics. Microplastics created by marine tourism and fishing sectors are extremely important in the summer months (Li, 2018; Karbalaei et al., 2019). More than 600,000 tonnes of fishing gear (fishing line, fishing net) end up in the seas annually (Good et al., 2010; Naji et al., 2017). As a result, all these microplastic sources have become a global problem considering food production and consumption and need to be controlled in order to reduce them.

TRANSMISSION ROUTES OF MICROPLASTICS TO HUMANS AND THEIR HEALTH EFFECTS

People are exposed to a wide variety of plastics every day. These plastics enter the body mainly through oral, respiratory, and dermal routes and accumulate in the body. Due to their persistence, wide size range, and complex structure, microplastics exhibit different particle properties with a different and broader toxicity profile compared to other media particles.

Today, especially due to the increase in the consumption of packaged foods and plastically packaged beverages, foods contaminated with micro or nanoplastics are taken into the human body orally. It can occur not only due to packaged foods, but also to contamination during transportation and storage conditions in foods sold unpackaged. In particular, the transportation of fish and fish products with polystyrene plastic containers causes contamination. Although fish and crustaceans are seen as the biggest source of microplastic accumulation that may occur in the human body, microplastics have been detected in many different foods. However, it is known that low-density microplastics accumulate on the surfaces of seas, rivers and oceans and high-density microplastics accumulate at depths due to mishaps in wastewater treatment, fishing and industrial factories. As a result of the use of these microplastic-laden waters in agricultural activities, their mixing with the soil and their degradation by microorganisms cause the accumulation of microplastics in agricultural products. The consumption of these products affects animals, therefore animal foods and consumers (Esmeray et al., 2020; Domenech and Marcos, 2021).

Once ingested, microplastics can transfer and release these toxic chemicals into their digestive tract (Tickner, 1999). Microplastics ingested through digestion can affect the enzymatic activities of the digestive system. It can inhibit lipid digestion. It is a condition that poses a potential risk to digestive health (Tan et al., 2020). According to some studies conducted on mice, it has been determined that metabolic disorders develop due to oral microplastic ingestion, intestinal functions and bile acid metabolism are impaired. Data suggest that people may experience gastrointestinal disorders that they are at risk for, but more studies on this topic are recommended (Esmeray et al., 2020).

The main sources of airborne microplastics are synthetic textiles, erosion of synthetic rubber tires, and urban dust (Prata, 2018; Chen et al., 2020). Other sources include construction materials, industrial emissions, plastic parts from furniture, particle suspension, landfills, traffic particles, waste incineration, machine exhausts, synthetic particles used in soils (Liebezeit et al., 2015; Dris et al., 2017). There is limited information on the concentration of microplastics in the air. The presence of microplastics in the outer atmosphere varies under the influence of several factors, including the speed and direction of the wind, the vertical pollution concentration gradient, the amount of precipitation, and temperature.

Humans are exposed to 26 to 130 microplastics per day through inhalation. However, many microorganisms that are carried by respiration and cause infection can maintain their viability for a long time by keeping these microplastics in the air (Brodie et al., 2007). The transport of microplastics in the inhaled air to the lungs varies depending on the size of the microplastics (Enyoh et al., 2019). Particles smaller than 2.5 µm in size are transported to the lungs, and due to the size, nanoplastics are transported more than microplastics, causing adverse effects in the respiratory system (Rist et al., 2018). Patients with respiratory system problems, the elderly, children and immunosuppressive individuals are in the risk group in terms of health problems that may occur due to microplastic ingestion through the respiratory tract (Esmeray et al., 2020).

The skin, which is the largest organ of the body, encounters many external factors every day. Many microplastic-contaminated products, from water to cosmetic products, first encounter the skin and people are exposed to microplastics dermally. Substances of 10 nm and smaller in size are absorbed through the skin and penetrate the human body through the dermal route. For this reason, microplastics are difficult to absorb directly, but nano plastics are much smaller in size, so they can be absorbed through the skin. Cosmetic products with ingredients that increase absorption from the skin increase the absorption of nano plastics and accelerate their accumulation in the body. However, they have been shown to accumulate in hair follicles and microplastics have been reported to be taken up by Langerhans cells. In addition, skin damaged by an injury or illness is more porous than normal skin, making it suitable for the ingress of microplastics (Çakmak and Acaröz, 2021).

There are a lot of researches on the damage caused by microplastics to humans, animals, and ecosystems. Recent research shows that the human body ingests microplastics in various ways. However, there is no clear data on the rate at which microplastics accumulate and the hazards that may occur accordingly, and it is predicted that organisms will be significantly affected because of microplastic accumulation. Infections may develop due to microorganisms, heavy metals and other pollutants that can be transported by microplastics, and toxicity-related damages may occur.

According to the reports of the World Health Organization, microplastics are most ingested with contaminated food (Alomar et al., 2017; Jeong et al., 2017). Microplastics that accumulate in the body are biologically resistant and may be responsible for negative biological responses such as inflammation, genotoxicity, oxidative stress, cell apoptosis and tissue necrosis in humans, and thus localized cell and tissue damage, fibrosis and potentially carcinogenicity. Due to their small size, microplastics can interact with a wide variety of organisms that cause blockage, inflammation and accumulation in organs after translocation (chromosome mutation) (Esmeray et al., 2020). In a study by Leslie et al., it was determined that plastic fragments pass into the bloodstream, and the rate of passage to the kidneys or organs was slower than the rate of absorption into the bloodstream (Leslie et al., 2022).

PRESENCE OF MICROPLASTICS IN FOODS

The presence of microplastics has been reported in various types of food. Including especially fish and fishery products, fruits and vegetables (Alberghini et al., 2022; Aydın et al., 2023). In addition, processed foods like milk and milk products, bottled water, table salt and sugar (Kutralam-Muniasamy et al., 2020; Gambino et al., 2022; Makhdoumi et al., 2023). Despite a study, MPs interact with human intestinal cells and food components such as proteins and lipids within the gastrointestinal track. MPs and lipid interaction played more significant role in reducing lipid digestion. These findings highlights potential risks of microplastics on human digestive system and nutrient absorption (Tan et al., 2020).

The widespread occurrence of MPs in fish and fishery products comes from the most regions of the world. Penino et al. (2020), found that the microplastic ingestion frequencies are reported 58% for sardines and 60% for anchovies. Besides, MPs have been found in bivalves ranged from 0.5 to 0.3 items/individual (Ding et al., 2021). Recent studies have found microplastics have contaminated table salt and sugars all over the world. Average amounts of microplastics observed in the different brands of salt and sugar were 55.2 ± 43.7 MP/kg (Makhdoumi et al., 2023).

Microplastics are also found in freshwater and drinking water. Martin et al. (2018) studies show the presence of MPs was confirmed in all water samples, with average abundances ranging from 1473 ± 34 to 3605 ± 497 particles L-1 in raw water and from 338 ± 76 to 628 ± 28 particles L-1 in treated water. The microplastic content of battled water can be affected by the type of packaging material used for bottled water (Oßmann et al., 2018).

Food trays often made of XPS, microplastics trapped between the meat and sealing film. The average amounts of XPS and MPs observed on the external surface of the food packaging ranged between 1 ± 0.9 and 10.8 ± 6.0 MP-XPS per kilogram of packaged meat (Kedzierski et al., 2020).

DETECTION METHODS OF MICROPLASTICS IN FOODS

Microplastic characterization involves naked eye observations without magnifying tools such as microscopes. Due to simplicity and reachability, this method has been widely used. The use of optical microscopy to visualize microplastics has become more common in recent years because it provides higher magnification and resolution than naked eye observations. Manual or microscopic counting can lead to miscalculations. There may be challenges in separating of microplastics (Sridhar et al., 2022).

Electron beam interaction with microplastics produces images of specified resolution, allowing particle sizes to be identified down to microscale. An energy dispersive spectroscopy (EDS) detector is used to distinguish these characteristic X-rays from different elements in sample (Schawaferts et al., 2019). SEM-EDS is a tool for the rapid sorting of plastic pellets from non-plastic pellets, as well as for the detection of small particles that are missed by visual inspection. This method uses backscattered electron images and elemental spectra to analyze the presence of strong carbon signals and other elements on pellets (Blair et al., 2019). By examining the morphology, size and elemental composition of the particles using SEM, it supports the classification of microplastics (Renner et al., 2018). Du et al. (2020) analyzed microplastics observe the effect of hot water on the container surface by using SEM. They found that surface changes in polypropylene and polyethlyne containers after hot water treatment.

Fourier Transform Infrared Spectroscopy (FTIR) is widely regarded as the most commonly used technique for detecting microplastics offering the key advantages of directness, reliability and non-destructiveness. FTIR spectroscopy enables the identification of different plastic materials based on their unique spectral signatures by generating individual band patterns through infrared spectra specific to different types of microplastic samples, contributing to their wide adaption in microplastic research (Sridhar et al., 2022). FTIR operates in three different modes: transmission, reflection and attenuated total reflection. Due to sample size requirements, it is typically limited to detecting microplastics down to about 20 μm. Sample characterization below 10 μm can be performed with micro-FTIR (Löder et al., 2015; Li et al., 2018). Diaz et al. (2020) used FTIR to examine microplastics in honey, beer, milk and refreshments. They found that the amounts of microplastics (including PPs, HDPE/LDPE and PAMs) in these foods varied from 10 to 100 pg/l, with a mean concentration of about 40 pg/l. The size of the microplastics varied from 2.48 to 6742.48 μm.

Raman spectroscopy is another widely used method for the identification of microplastics (MPs). It involves a scattering technique using a laser of defined wavelength to excite the targeted molecules. The frequency of the radiation scattered by the sample provides information about its elemental composition. Compared to other techniques such as FTIR, Raman spectroscopy has the potential to study particles of much smaller size. This is due to the ability to achieve spatial resolutions of less than 1 μm due to the scattered frequencies produced by the sample (Imhof et al., 2016). Raman detection methods primarily enable the chemical characterization of microplastics. They do not enable visualization. The detection of microplastics in food samples using Raman spectroscopy has been investigated in several studies. Laser beam with a wavelength of 785 nm was employed for holographic imaging and Raman spectrum analysis of microplastics within a large volume of water sample. This allowed for concurrent structural and chemical quantification of the MPs (Chakraborty et al., 2023).

PREVENTION AND CONTROL OF MICROPLASTICS

Reducing the production and use of conventional plastics and microplastics is one of the most effective strategies for controlling their environmental release. Removing microplastics from aquatic ecosystems, where they often end up, is the main focus of management strategies for microplastics. Categorizing microplastic control strategies into short-term and long-term, and considering factors such as infrastructure, economic conditions, microplastic types, alternatives and public will, is critical for effective decision-making (Osman et al., 2023).

In the United States, the Microbead-Free Waters Act is primarily aimed at microplastic pollution and, by extension, pollution caused by plastic bags. This regulations bans the manufacture, packaging and distribution of rinse-off cosmetic products that microplastics.

In France, the Law on the Circular Economy has banned single-use plastics. However, microplastics are still allowed to remain used in human and veterinary medicine (Conti et al., 2021). In 2018, during the G7 (Group of 7) meeting, several countries including Germany, Italy, Canada, the UK, France, Germany and the European Union signed the ‘Ocean Plastic Charter’. Among the measures proposed were ones such as ensuring that by 2030, 100 per cent of the plastic materials used will be recyclable or recoverable. Minimize the unnecessary use of single-use plastics. Encouraging the use of alternatives to plastic and promoting the use of alternatives to plastic (European Commission, 2017).

WWF-Turkey is implementing the National Zero Waste Programme, which was launched in 2017 under the leadership of the Presidency. The aim is to implement the zero-waste project across the country in 2023. According to 2017 data, Turkey ranks 12 th in the world in the production of plastic products, with exports worth $13 million, and 9 th in the export of plastic bags. The Law on the Amendment of the Environmental Law and Certain Laws stipulates that plastic shopping bags will be subject to a fee from 1 January 2019.

Plastic producers and industrial users are obliged to recycle 54% of their production, according to the 2017 Packaging Waste Control Regulation. Turkey's target is a 40% reduction in the use of plastic bags by 2025. It aims to recycle 65% packaging and 35% other recyclable waste by 2023 (Kanlı et al., 2019).

CONCLUSION

Microplastic contamination can be in different environmental compartments, especially in the food chain. Microplastics have been found to adsorb a range of chemicals and microorganisms, increasing contamination. There are food microplastic isolation and identification methods to ensure accurate detection and quantification in different food matrices. Efforts to minimise contamination can include preventing microplastics from entering food products during manufacturing and distribution by implementing best practices in food handling, packaging and storage. In addition, the risk of contamination can be reduced through strategies such as using alternative materials for packaging and processing equipment and implementing strict quality control measures.

REFERENCES

Akçay, S., Törnük, F. & Yetim, H. (2020). Mikroplastikler: Gıdalarda bulunuşu ve sağlık üzerine etkileri. *Avrupa Bilim ve Teknoloji Dergisi*, (20), 530-538.

Alberghini, L., Truant, A., Santonicola, S., Colavita, G. & Giaccone, V. (2022). Microplastics in Fish and Fishery Products and Risks for Human Health: A Review. *International journal of environmental research and public health*, 20(1), 789.

Alomar, C., Sureda, A., Capo, X., Guijarro, B., Tejada, S. & Deudero, S. (2017). Micro-plastic ingestion by Mullus surmuletus Linnaeus, 1758 fish and its potential for causing oxidative stress. *Environmental Research*, 159*,* 135–142.

Andrady, A. L. (2017). The plastic in microplastics: A review. *Marine Pollution Bulletin,* 119, 12–22.

Aydın, R. B., Yozukmaz, A., Şener, İ., Temiz, F. & Giannetto, D. (2023). Occurrence of Microplastics in Most Consumed Fruits and Vegetables from Turkey and Public Risk Assessment for Consumers. *Life (Basel, Switzerland)*, 13(8), 1686.

Blair, R. M., Waldron, S., Phoenix, V. R. & Gauchotte-Lindsay, C. (2019). Microscopy and elemental analysis characterisation of microplastics in sediment of a freshwater urban river in Scotland, UK. *Environmental Science and Pollution Research International*, 26(12), 12491–12504.

Boucher, J. & Friot, D. (2017). Primary microplastics in the oceans: A global evaluation of sources (Vol. 10). Gland, Switzerland: IUCN.

Brodie, E. L., DeSantis, T. Z., Parker, J. P. M., Zubietta, I. X., Piceno, Y. M. & Andersen, G. L. (2007). Urban aerosols harbor diverse and dynamic bacterial populations. *Proceedings of the National Academy of Sciences*, 104 *(*1), 299-304.

Campanale, C., Massarelli, C., Savino, I., Locaputo, V. & Uricchio, V. F. (2020). A detailed review study on potential effects of microplastics and additives of concern on human health. *International Journal of Environmental Research and Public Health*, 17 (4), 1212.

Caron, A. G., Thomas, C. R., Berry, K. L., Motti, C. A., Ariel, E. & Brodie, J. E. (2018). Ingestion of microplastic debris by green sea turtles (Chelonia mydas) in the Great Barrier Reef: Validation of a sequential extraction protocol. *Marine Pollution Bulletin,* 127*,* 743–751.

Chae, Y. & An, Y. J. (2018). Current research trends on plastic pollution and ecological impacts on the soil ecosystem: a review. *Environmental Pollution,* 240, 387–395.

Chakraborty, I., Banik, S., Biswas, R., Yamamoto, T., Noothalapati, H. & Mazumder, N. (2022). Raman spectroscopy for microplastic detection in water sources: a systematic review. *International Journal of Environmental Science and Technology,* 20.

Chen, G., Feng, Q. & Wang, J. (2020). Mini-review of microplastics in the atmosphere and their risks to humans. *Science of the Total Environment*, 703, 135504.

Conti, I., Simioni, C., Varano, G., Brenna, C., Costanzi, E. & Neri, L. M. (2021). Legislation to limit environmental plastic and microplastic pollution and their influence on human exposure. *Environmental Pollution,* 288, 117708.

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F. & Dudas, S. E. (2019). Human consumption of microplastics. *Environmental Science & Technology,* 53, 7068–7074.

Çakmak, Ö. & Acaröz, U. (2021). Su kaynaklarında mikroplastiklerin varlığı ve insan sağlığı açısından önemi. Veteriner Farmakoloji ve Toksikoloji Derneği Bülteni, 12 (2), 79-88.

Derraik, J. G. (2002). The pollution of the marine environment by plastic debris: a review. *Marine Pollution Bulletin,* 44, 842–852.

Díaz Basantes, M., Conesa, J. A. & Fullana, A. (2020). Microplastics in honey, beer, milk, and refreshments in Ecuador as emerging contaminants. *Sustainability,* 12(14), 5514.

Ding, J., Sun, C., He, C., Li, J., Ju, P. & Li, F. (2021). Microplastics in four bivalve species and basis for using bivalves as bioindicators of microplastic pollution. *Science of The Total Environment*, 782, 146830.

Domenech, J. & Marcos, R. (2021). Pathways of human exposure to microplastics, and estimation of the total burden. *Current Opinion in Food Science*, 39, 144-151.

Du, F., Cai, H., Zhang, Q., Chen, Q. & Shi, H. (2020). Microplastics in take-out food containers. *Journal of Hazardous Materials,* 399, 122969.

Duis, K. & Coors, A. (2016). Microplastics in the aquatic and terrestrial environment: sources (with a specifc focus on personal care products), fate and efects. *Environmental Sciences Europe,* 28, 1–25.

Enyoh, C. E., Verla, A. W., Verla, E. N., Ibe, F. C. & Amaobi, C. E. (2019). Airborne microplastics: A review study on method for analysis, occurrence, movement and risks. *Environmental Monitoring and Assessment*, 191 (10), 668.

Esmeray, E. & Armutcu, C. (2020). Mikroplastikler, çevre-insan sağlığı üzerine etkileri ve analiz yöntemleri. *Düzce Üniversitesi Bilim ve Teknoloji Dergisi*, 8 (1), 839-868.

Fadare, O. O. & Okoffo, E. D. (2020). Covid-19 face masks: A potential source of microplastic fibers in the environment. *Science of the Total Environment,* 737, 140279.

Frias, J. P. & Nash, R. (2019). Microplastics: Finding a consensus on the definition. *Marine Pollution Bulletin*, 138, 145–147.

Gambino, I., Bagordo, F., Grassi, T., Panico, A. & De Donno, A. (2022). Occurrence of Microplastics in Tap and Bottled Water: Current Knowledge. *International Journal of Environmental Research and Public Health*, 19(9), 5283.

Good, T. P., June, J. A., Etnier, M. A. & Broadhurst, G. (2010). Derelict fishing nets in Puget Sound and the Northwest Straits: Patterns and threats to marine fauna. *Marine Pollution Bulletin,* 60, 39–50.

Guerranti, C., Martellini, T., Perra, G., Scopetani, C. & Cincinelli, A. (2019). Microplastics in cosmetics: Environmental issues and needs for global bans. *Environmental Toxicology and Pharmacology,* 68, 75–79.

Hipfner, J. M., Galbraith, M., Tucker, S., Studholme, K. R., Domalik, A. D., Pearson, S. F., Good, T. P., Ross, P. S. & Hodum, P. (2018). Two forage fishes as potential conduits for the vertical transfer of microfibres in Northeastern Pacific Ocean food webs. *Environmental Pollution,* 239, 215–222.

Hoellein, T., Rojas, M., Pink, A., Gasior, J. & Kelly, J. (2014). Anthropogenic litter in urban freshwater ecosystems: Distribution and microbial interactions. *PLoS One*, 9, e98485.

Horton, A. A., Walton, A., Spurgeon, D. J., Lahive, E. & Svendsen, C. (2017). Microplastics in freshwater and terrestrial environments: Evaluating the current understanding to identify the knowledge gaps and future research priorities. *Science of the Total Environment*, 586,127-141.

Hou, L., Kumar, D., Yoo, C. G., Gitsov, I. & Majumder, E. L. W. (2021). Conversion and removal strategies for microplastics in wastewater treatment plants and landflls. *Chemical Engineering Journal,* 406, 126715.

Imhof, H. K., Laforsch, C., Wiesheu, A. C., Schmid, J., Anger, P. M., Niessner, R. & Ivleva, N. P. (2016). Pigments and plastic in limnetic ecosystems: A qualitative and quantitative study on microparticles of different size classes. *Water*

Research, 98, 64-74.

Ivleva, N. P., Wiesheu, A. C., & Niessner, R. (2017). Microplastic in aquatic ecosystems. *Angewandte Chemie International Edition,* 56 (7), 1720-1739.

Jeong, C. B., Kang, H. M., Lee, M. C., et al. (2017). Adverse effects of microplastics and oxidative stress-induced MAPK/Nrf2 pathway-mediated defense mechanisms in the marine copepod Paracyclopina nana. *Scientific Reports*, 7, 41323.

Kanlı, İ. & Kurt, Y. (2019). Türkiye'nin Çevre Politikaları Kapsamında Mikroplastik Kirlilik Üzerine Bir Değerlendirme. *Journal of International Scientific Researches.* 495-514.

Karbalaei, S., Golieskardi, A., Hamzah, H. B., Abdulwahid, S., Hanachi, P., Walker, T. R. & Karami, A. (2019). Abundance and characteristics of microplastics in commercial marine fish from Malaysia. *Marine Pollution Bulletin,* 148, 5–15.

Kedzierski, M., Lechat, B., Sire, O., Le Maguer, G., Le Tilly, V. & Bruzaud, S. (2020). Microplastic contamination of packaged meat: Occurrence and associated risks. *Food Packaging and Shelf Life,* 24, 100489.

Kutralam-Muniasamy, G., Pérez-Guevara, F., Elizalde-Martínez, I. & Shruti, V. C. (2020). Branded milks- Are they immune from microplastics contamination. *The Science of the total environment*, 714, 136823.

Leslie, H. A., Velzen, M. J. M., Brandsma, S. H., Vethaak, A. D., Garcia-Vallejo, J. J. & Lamoree, M. H. (2022). Discovery and quantification of plastic particle pollution in human blood. *Environment International*, 163, 107199.

Li, J., Liu, H., & Paul Chen, J. (2018a). Microplastics in freshwater systems: a review on occurrence, environmental effects, and methods for microplastics detection. *Water Research,* 137, 362–374.

Li, J., Zhang, K. & Zhang, H. (2018). Adsorption of antibiotics on microplastics. *Environmental Pollution,* 237, 460–467.

Li, L., Luo, Y., Li, R., Zhou, Q., Peijnenburg, W. J. G. M., Yin, N., Yang, J., Tu, C. & Zhang, Y. (2020). Effective uptake of submicrometre plastics by crop plants via a crack-entry mode. *Nature Sustainability*, 3 (11), 929–937.

Liebezeit, G. & Liebezeit, E. (2013). Non-pollen particulates in honey and sugar. *Food Additives & Contaminants: Part A*, 30 (12), 2136-2140.

Löder, M. G. J. & Gerdts, G. (2015). Methodology Used for the Detection and Identification of Microplastics—A Critical Appraisal. In M. Bergmann, L. Gutow, & M. Klages (Eds.), *Marine Anthropogenic Litter* (pp. 201-227). Springer.

Makhdoumi, P., Pirsaheb, M., Amin, A. A., Kianpour, S. & Hossini, H. (2023). Microplastic pollution in table salt and sugar: Occurrence, qualification and quantification and risk assessment. *Journal of Food Composition and Analysis*, 119, 105261.

Matsuguma, Y., Takada, H., Kumata, H., Kanke, H., Sakurai, S., Suzuki, T., Itoh, M., Okazaki, Y., Boonyatumanond, R., Zakaria, M. P., Weerts, S. & Newman, B. (2017). Microplastics in sediment cores from Asia and Africa as indicators of temporal trends in plastic pollution. *Archives of Environmental Contamination and Toxicology,* 73, 230–239.

Müller, A., Becker, R., Dorgerloh, U., Simon, F. G. & Braun, U. (2018). The effect of polymer aging on the uptake of fuel aromatics and ethers by microplastics. *Environmental Pollution*, 240, 639-646.

Naji, A., Esmaili, Z. & Khan, F. R. (2017). Plastic debris and microplastics along the beaches of the Strait of Hormuz, Persian Gulf. *Marine Pollution Bulletin,* 114, 1057–1062.

Novotna, K., Cermakova, L., Pivokonska, L., Cajthaml, T. & Pivokonsky, M. (2019). Microplastics in drinking water treatment – Current knowledge and research needs. *Science of The Total Environment,* 667, 730-740.

Osman, A. I., Farrell, C., Al-Muhtaseb, A. H., Al-Fatesh, A. S., Harrison, J. & Rooney, D. W. (2020). Pyrolysis kinetic modelling of abundant plastic waste (PET) and in-situ emission monitoring. *Environmental Sciences Europe*, 32, 112.

Osman, A. I., Hosny, M., Eltaweil, A. S., Omar, S., Elgarahy, A. M., Farghali, M., Yap, P-S., Wu, Y-S., Nagandran, S., Batumalaie, K., Gopinath, S. C. B., John, O. D., Sekar, M., Saikia, T., Karunanithi, P., Hatta, M. H. M. & Akinyede,

K. A. (2023). Microplastic sources, formation, toxicity and remediation: a review. *Environmental Chemistry Letters.* 21(4), 2129-2169.

Oßmann, B. E., Sarau, G., Holtmannspötter, H., Pischetsrieder, M., Christiansen, S. H. & Dicke, W. (2018). Small-sized microplastics and pigmented particles in bottled mineral water. *Water Research*, *141*, 307–316.

Peixoto, D., Pinheiro, C., Amorim, J., Oliva-Teles, L., Guilhermino, L. & Vieira, M. N. (2019). Microplastic pollution in commercial salt for human consumption: A review. *Estuarine Coastal and Shelf Science*, 219, 161–168.

Pennino, M. G., Bachiller, E., Lloret-Lloret, E., Albo-Puigserver, M., Esteban, A., Jadaud, A., Bellido, J. M. & Coll, M. (2020). Ingestion of microplastics and occurrence of parasite association in Mediterranean anchovy and sardine. *Marine Pollution Bulletin,* 158*,* 111399.

Pivokonsky, M., Cermakova, L., Novotna, K., Peer, P., Cajthaml, T. & Janda, V. (2018). Occurrence of microplastics in raw and treated drinking water. *Science of The Total Environment*, 643, 1644-1651.

Prata, J. C., da Costa, J. P., Lopes, I., Duarte, A. C. & Rocha-Santos, T. (2020). Environmental exposure to microplastics: An overview on possible human health effects. *Science of the Total Environment*, 702,134455.

Qasim, U., Osman, A. I., Al-Muhtaseb, A. H., Farrell, C., Al-Abri, M., Ali, M., Vo, D. N., Jamil, F. & Rooney, D. W. (2020). Renewable cellulosic nanocomposites for food packaging to avoid fossil fuel plastic pollution: a review. *Environmental Chemistry Letters,* 19, 613–641.

Renner, G., Schmidt, T. C. & Schram, J. (2018). Analytical methodologies for monitoring micro(nano) plastics: Which are fit for purpose*? Current Opinion in Environmental Science & Health,* 1, 55-61.

Rillig, M. C., Ziersch, L. & Hempel, S. (2017). Microplastic transport in soil by earthworms. *Scientific Reports*, 7 (1), 1362.

Rist, S., Almroth, B. C., Hartmann, N. B. & Karlsson, T. M. (2018). A critical perspective on early communications concerning human health aspects of microplastics. *Science of The Total Environment*, 626, 720–726.

Rochman, C. M. (2018). Microplastics research—from sink to source. *Science,* 360, 28–29.

Schwaferts, C., Niessner, R., Elsner, M. & Ivleva, N. P. (2019). Methods for the analysis of submicrometer- and nanoplastic particles in the environment. *TrAC Trends in Analytical Chemistry,* 112*,* 52-65.

Sharma, S. & Chatterjee, S. (2017). Microplastic pollution, a threat to marine ecosystem and human health: A short review. *Environmental Science and Pollution Research*, 24(25), 21530–21547.

Sridhar, A., Kannan, D., Kapoor, A. & Prabhakar, S. (2022). Extraction and detection methods of microplastics in food and marine systems: A critical review. *Chemosphere,* 286 (Part 1), 131653.

Tan, H., Yue, T., Xu, Y., Zhao, J. & Xing, B. (2020). Microplastics Reduce Lipid Digestion in Simulated Human Gastrointestinal System. *Environmental Science & Technology*, 54(19), 12285–12294.

Thompson, R. C., Olsen, Y., Mitchell, R. P., Davis, A., Rowland, S. J., John, A. W. G., McGonigle, D. & Russell, A. E. (2004) Lost at sea: where is all the plastic? *Science,* 304*,* 838–838.

Tickner, J., Rossi, M., Haiama, N., Lappe, M. & Hunt, P. (1999). The use of di-2-ethylhexyl phthalate in PVC medical devices: Exposure, toxicity, and alternatives. Lowell Center for Sustainable Production, University of Massachusetts, Lowell*,* 72.

Vethaak, A. D. & Legler, J. (2021). Microplastics and human health. *Science*, 371 (6530), 672-674.

Wang, C., Zhao, J. & Xing, B. (2021). Environmental source, fate, and toxicity of microplastics. *Journal of Hazardous Materials*, 407, 124357.

Wang, T., Zou, X., Li, B., Yao, Y., Zang, Z., Li, Y., Yu, W. & Wang, W. (2019). Preliminary study of the source apportionment and diversity of microplastics: taking foating microplastics in the South China Sea as an example. *Environmental Pollution,* 245, 965–974.

Wang, W., Ndungu, A. W., Li, Z. & Wang, J. (2017). Microplastics pollution in inland freshwaters of

China: A case study in urban surface waters of Wuhan, China. *Science of The Total Environment*, 575, 1369–1374.

World Health Organization (2019). Microplastics in Drinking-water (Geneva. License: CCBY-NC-SA 3.0 IGO).

Xiang, Y., Jiang, L., Zhou, Y., Luo, Z., Zhi, D., Yang, J. & Lam, S. S. (2022). Microplastics and environmental pollutants: key interaction and toxicology in aquatic and soil environments. *Journal of Hazardous Materials,* 422*,* 126843.

Yang, Z., Lü, F., Zhang, H., Wang, W., Shao, L., Ye, J. & He, P. (2021). Is incineration the terminator of plastics and microplastics? *Journal of Hazardous Materials* 401*,* 123429.

Yurtsever, M., Kaya, A. T. & Bayraktar, S. Ç. (2018). A Research on Microplastic Presence in Outdoor Air. In M. Cocca, E. Di Pace, M. Errico, G. Gentile, A. Montarsolo, & R. Mossotti (Eds.), Proceedings of the International Conference on Microplastic Pollution in the Mediterranean Sea (pp. 159-167). Springer Water. Springer, Cham.