Problems of environmental pollution with microplastic waste and ways to solve them

Maya Yadigar Abdullayeva[1*], *Bikas Sail* Aghayev[2], and *Ramil Vasif Yaqubov*[1]

[1]Azerbaijan State Oil and Industry University, Azerbaijan
[2]Institute of Information Technology, Azerbaijan

Abstract. This review scrutinizes the pervasive presence and intricate impacts of microplastics on the environment and human health. Recognizing the limitations of plastic food packaging, we propose sustainable alternatives, including traditional materials like palm leaves and innovative options like bioplastics and edible packaging. The outlined characteristics of ideal food packaging materials provide a practical guide for transitioning away from conventional plastics.

1 Introduction

According to Directive 2008/98/EC, waste is any substance that is discarded after initial use or is useless, defective, or useless [1]. Manufacturers of plastics and plastic products are among the world's largest generators of waste. It is known that plastics, when released into the ground, break down into small particles (microplastics) and can release into the environment chemicals added to them during production, such as chlorine, various chemicals, toxic or carcinogenic anti-ignition agents, etc. Worldwide About 70% of plastic waste is disposed of in landfills as solid household or industrial waste, 15% is collected for recycling, of which 7-9% is lost in the form of microplastics. The management of synthetic or natural polymers and microplastics, which consist of monomeric structures linked into long macromolecules, differs significantly from the management of conventional solid waste. This is primarily due to the fact that plastic products, being in the solid phase, emit some toxic compounds (including microplastics) even before they become waste, also after losing their consumer properties: a) are not recommended for reuse, b) are classified as hazardous waste and must be disposed of accordingly. Therefore, the fight against macro-micro plastic pollution requires different principles that cover all stages of the plastic life cycle - from production to consumption and waste management, in order to reduce pollution and waste at each stage [2].

Unlike solid waste, international efforts to develop regulations related to plastic waste management have only begun in the last decade. These efforts were mainly focused on the development of new technologies for their processing and disposal, as well as the creation of alternative safe materials. In June 2019, the European Parliament and the European Council published the Directive on reducing the environmental impact of certain plastic products (Directive 2019/904) with the aim of preventing and reducing the negative impact

* Corresponding author: mayaabdullayeva@hotmail.com

of plastics on the environment, while facilitating the transition to a circular economy. According to the Directive, by mid-2021 a ban on the use of rapidly degradable plastics was envisaged, since they do not completely decompose into CO_2, biomass and water, but fragment into microplastics [3-4]. In 2022, UN member states passed a resolution calling for a legally binding agreement by 2024 to end plastic pollution. The resolution includes measures that take into account the entire life cycle of plastics, from production to product design and waste management [5]. Currently, a number of international organizations dealing with waste issues are exploring the application of the EPR principle (Extended producer responsibility (EPR), which is one of the basic principles of solid waste management, in the field of macro- and microplastic waste management. Recognized for their versatility, plastics have become essential materials used in many industries. However, their ubiquitous presence is detrimental to the environment, resulting in 60–80% of the world's trash, and improper disposal and lack of awareness contribute to uncontrolled pollution . In the European Union, the plastic problem is particularly acute: 80–85% of marine waste is plastic, 50% of which is single-use. A grim consequence is the formation of microplastics (MPs), defined as particles ranging in size from 0.1 to 5000 μm, which further fragment into nanoplastics (NPs) ranging in size from 1 to 100 nm [6]. In the field of plastics, their influence extends to the packaging of our food products, where the choice of polymers plays a decisive role. To shed light on the most commonly used polymers for different types of food containers, we present a detailed breakdown in Table 1.

Concerns about MP extend to a wide variety of ecosystems: from soil and freshwater to seas, oceans, snow, air, plants, and animals. These tiny particles travel up to 6000 km and enter the food chain, threatening the safety of food and beverages. The widespread use of MR is evidenced by their presence in a variety of consumer products: fish, shellfish, poultry, eggs, salt, sugar, fruits, vegetables, water, milk, honey, beer, wine, tea, energy drinks, and soft drinks, and even children's drinks mixtures [7] (Figure 1).

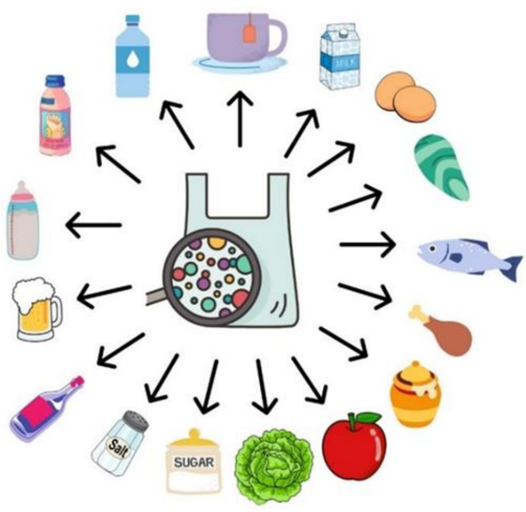

Fig. 1. Presence of microplastics in food and drinks.

The effects of MP intake are far-reaching and affect the digestive, respiratory, and circulatory systems . Accumulating in the body, MPs cause inflammation, oxidative stress, DNA damage, immune reactions, metabolic disorders, intestinal dysbiosis, and increase the risk of cancer, respiratory and neurodegenerative diseases. As plastic breaks down into smaller particles, microplastics (<5 mm) become a critical environmental and health issue.

Table 1. Commonly used polymers for various types of food contain.

Polymer Type		Packaging Application
PP	Polypropylene	Food packaging, sweet and wrappers, hinged caps
HDPE	High-density polyethylene	Milk bottles
LDPE	Low –density polyethylene	Food packaging film, food containers, and trays
PS	Polystyrene	Dairy and fishery food packaging
PET	Polyethylene terephthalate	Water bottles, soft drink cartons, and juice containers

Recently,attention has focused on human health risks, with estimates of daily particle intake ranging from 203 to 332 particles per person through air and common food [8].

External sources such as precipitation and food packaging are significant contributors, and plastic containers contribute to the contamination of salt and bottled water. This growing problem has prompted extensive research into microplastic contamination from sources ranging from tap and bottled water to food packaging containers. The rise of the takeaway food industry is exacerbating the problem, with takeaway containers becoming a potent source of human exposure to microplastics, especially when used to deliver hot food. Microplastics enter the human body through food, as evidenced by their presence in human feces [9]. Seafood, a well-studied environment, has raised concerns about the transmission of microplastics to humans.

The complexity of microplastics lies in their diverse chemical compounds originating from primary and secondary sources. Arising from both primary and secondary sources, MPs are further broken down into nanoparticles (NPs), which requires an in-depth analysis of their sources, formation, transport, degradation, and effects. These particles have unique shapes, sizes, and polymer compositions that reflect a wide range of plastic products and their degradation processes. The type of structure of polymers, whether thermoplastics or thermosets, adds another layer of complexity, influencing their properties and applications [10]. Challenges in assessing exposure to microplastics, including their potential health risks, are further compounded by their multiple physical and chemical properties, composition, and concentrations [11-12].

Research around the world highlights the ubiquity of microplastics in these sources, adding to public health concerns. Recognizing the urgency of the situation, the European Drinking Water Directive aims to list microplastics as emerging compounds by 2024 [13]. Our review of articles published from 2018 to 2022 aims to clarify the current state of knowledge about microplastic concentrations in tap water, bottled drinking water, and food containers worldwide.

Although plastic production is rapidly increasing, microplastics continue to pose a threat to human health by entering the food chain through various channels, including food [14]. The rise of food culture driven by online businesses is heightening concerns about the safety of plastic food packaging. The impact of various plastic materials used to make containers, especially in high-temperature environments, on the prevalence of microplastics has been studied. This study examines four types of removal containers from five Chinese cities, simulates real-life scenarios, and estimates human consumption of microplastics from such containers[15].

As plastic permeates our daily lives, its environmental harms become increasingly apparent, with microplastics becoming a serious threat [16]. Despite global efforts to regulate plastic production, the rise of plastic packaging, especially for takeaway food, is contributing to the microplastic crisis. The dominance of plastic in various industries, especially as packaging material, is exacerbating the microplastic environmental crisis.

Packaging waste increased from 0.2 million tons to 1.5 million tons from 2015 to 2017, highlighting the urgency of tackling microplastics. Microplastics, ubiquitous in oceans, soils, glaciers, and deserts, are insidiously infiltrating our food sources, from fish to table salt and even human tissue [17]. This study examined the direct measurement of microplastics in popular foods from Southern China, examining their prevalence, characteristics, and potential health risks. By carefully examining the factors that influence the presence of microplastics, our research contributes to the understanding of food contamination levels, an important step in ensuring food safety and reducing potential health risks.

Packaging materials occupy a large share of the vast plastics industry, with food and beverage packaging leading the way. (Figure 2) . The packaging is based on plastic containers made from various polymers such as PET, HDPE, LDPE, PP, PVC, and PS. However, this prevalence leads to an unintended consequence - the spread of microplastics. These tiny particles, less than 5 mm in size, penetrate various environments, from oceans and soils to glaciers and deserts. Moreover, microplastics insidiously penetrate our food supplies, posing a hidden threat to human health [18]. This study delves into the direct measurement of microplastics in popular takeaway foods from Southern China, identifying their prevalence, characteristics, and potential health risks. By analyzing the factors influencing the presence of microplastics, our study expands the understanding of contamination levels of takeout food, serving as an important reference for assessing the health risks associated with microplastics in Chinese takeout food.

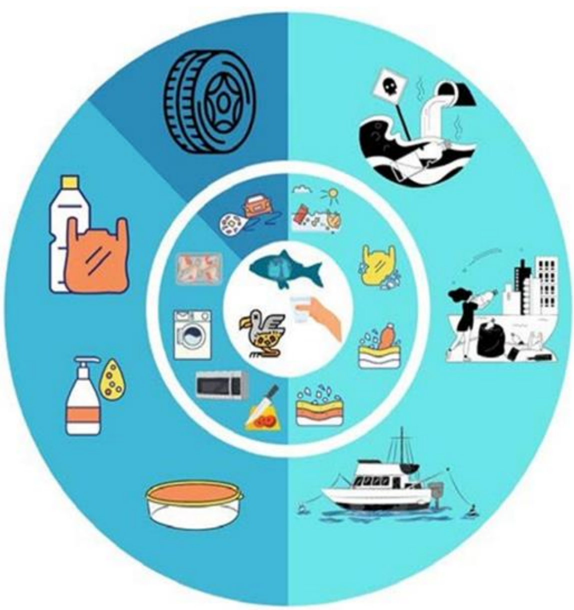

Fig. 2. Ways of food contamination with microplastics (MP).

The article examines the impact of plastic and its waste on packaged food products, the migration paths of microplastics into the human body and the dangers they pose to health, as well as strategies for creating alternative packaging methods.

2 Materials and methods

2.1 Food packaging

Plastic products have become extremely popular due to their cost-effectiveness, lightness, ease of use, and durability. Approximately 39.6% of plastic is used for packaging [19]. Food packaging serves various functions such as protection, encapsulation, convenience, and communication with consumers. It protects food products from mechanical damage, and microbiological and chemical contamination, and facilitates storage, processing, and transportation.

Although there are regulations regarding food contact plastics, the issue of microplastics (MPs) is not directly addressed. The regulations focus on substances used during processing, and European Commission Regulation No. 10/2011 defines criteria including molecular weight limits and permissible migration limits. The main focus is on assessing the risk of substances released from packaging, except secondary MPs resulting from the decomposition of plastic waste in the environment.

Commonly used packaging materials include containers, bottles, films, bags, and cups, typically made from high-density polyethylene (HDPE), low-density polyethylene (LDPE), polypropylene (PP), polyesters (such as polyethylene terephthalate (PET)), and polystyrene (PS) [20-22]. Each type of polymer has special properties that determine its application. For example, PE is ideal for films and bags, PET is dominant in water bottles, and PP is commonly used for caps.

2.2 Microplastics in bottled water

In recent decades, bottled water consumption has grown to more than 6 billion gallons per year [23]. Bottled water is popular around the world for its purity, natural taste, and portability and is usually packaged in plastic and glass materials. Common bottle materials include polycarbonate (PC), polyethylene terephthalate (PET), and high-density polyethylene (HDPE), while caps are typically made from HDPE, polystyrene (PS), and low-density polyethylene (LDPE) [23].

Studies of microplastic contamination in bottled water have identified varying concentrations and types of polymers. For example, a study in Thailand found 140 ± 19 microplastics per liter of disposable water in PET bottles, with the predominant polymers being PE, PET, PP, and PA [24]. In Germany, 2649 ± 2857 pieces/l of microplastics, mainly PET, were found in mineral water bottles [25]. A global study that collected 259 mineral water bottles from 11 countries found polypropylene to be the most common polymer, with an average microplastic content of 0–10,000/L. Similar studies conducted in Iran, Malaysia, and Australia also reported microplastic contamination in bottled water, highlighting global concern [26].

2.3 Sources of microplastics in bottled water

Despite efforts to ensure the safety of bottled water, microplastic contamination can occur at various stages of production and use. Identified sources include leaching from bottle cases and caps, and during the washing process . Research suggests that reusable PET bottles may have higher concentrations of microplastics due to the "stressing" of internal surfaces during washing . Suspected sources include mechanical stress from frequent opening and closing, as well as settlement. UV exposure and thermal reactions during transportation and storage also contribute to the leaching of microplastics. Ongoing research is examining the degradation of bottles due to direct sunlight and storage time, emphasizing the need to drink bottled water before its expiration date and avoid exposure to direct sunlight [27] (Figure 3).

Fig. 3. Pathways of microplastic contamination from drinking bottles.

3 Results and Discussion

Plastic food packaging has been recognized as a concern for both consumer health and environmental well-being. The primary objectives of food packaging—protection, containment, convenience, and communication—emphasize the need for materials that are not only effective but also non-toxic to the human body. Figure 4 shows the characteristics of ideal food packaging materials that contribute to human health and the environmen.

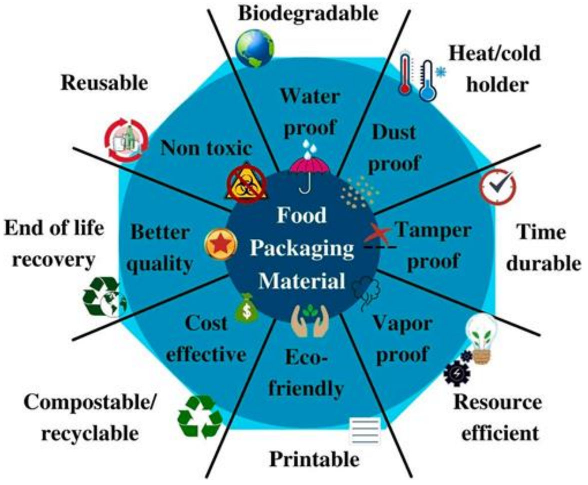

Fig. 4. Requirements for good food packaging material.

Studies exploring alternatives have highlighted the importance of traditional materials such as palm leaves. Bioplastics have also been widely researched with modifications using nanocomposites to improve their functionality. By-products from processing fruits, vegetables, and fermented grains have been repurposed for food packaging, overcoming challenges such as water solubility and moisture sensitivity through innovative processes such as crosslinker blends and nanocomposite production. Nanomaterials also impart antimicrobial properties to these films.

Among the innovative alternatives, edible packaging stands out. Edible packaging uses natural polysaccharides, proteins, and lipid materials derived from plants, animals, marine sources, and microbes. Many of these materials exhibit antimicrobial activity, extending the shelf life of food products. Edible packaging is not only cost-effective and resource-efficient compared to plastic polymers but is also non-toxic and healthy for human consumption [28].

Traditional materials such as glass and metal continue to be a versatile choice for food packaging due to their chemical inertness and non-reaction with food. They have favorable physical, thermal, mechanical, recyclable, and renewable properties. Paper and cardboard, mainly composed of wood pulp, are used to package dry food products. Coating or lining paper with wax and bioplastics instead of plastic resins expands its use for storing wet and dairy products. Metalized paper films are recyclable and compostable, and natural bioplastic packaging coated with metalized film increases barrier properties. These materials have excellent water, oil, and vapor barrier properties, which help extend shelf life [29].

4 Conclusion

In conclusion, solving the microplastic crisis requires a shift to sustainable practices, regulations, and global cooperation. Our research advances our understanding of this important issue, calling for collective action to protect ecosystems, food sources, and well-being. Only through global efforts will we be able to mitigate the widespread impact of microplastics and build a sustainable future.

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