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# Microplastics in Food: An Emerging Crisis and Future Challenges

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ABSTRACT :

Microplastics, defined as plastic particles less than 5 millimeters in size, have emerged as a significant environmental pollutant with profound implications for human health, particularly through their presence in the food chain. This research explores the various sources of microplastic contamination in food, including agricultural practices, packaging materials, and pollution of marine and freshwater systems. Microplastics are increasingly being detected in a variety of food products, such as seafood, salt, honey, and even drinking water, raising concerns about their potential health risks. The ingestion of microplastics poses risks due to their physical properties and the toxic chemicals they may carry, including endocrine disruptors and carcinogens. This study also examines potential health impacts such as gastrointestinal issues, immune system disruption, and long-term chronic effects. To mitigate the problem, various strategies are reviewed, including improving waste management practices, developing biodegradable packaging materials, and implementing stricter regulations on plastic production and disposal. Public awareness campaigns and technological innovations aimed at reducing microplastic pollution are also discussed as key remedies. Through a comprehensive review of existing research, this paper aims to highlight the urgency of addressing microplastic contamination in food and suggests pathways toward minimizing its presence and impact on human health.

**Keywords**: Microplastics, Transportation, Migration Measures, Pollution, Challenge, Food.

## 1.Background and Introduction

### *1.1. History*

Microplastics have a rich and complex history. This overview traces the development of plastics, highlighting significant milestones, applications, and the environmental challenges they present today. Plastics have undergone a profound transformation since their inception, evolving from rudimentary natural polymers to sophisticated synthetic materials that underpin modern society. The term "plastic" itself traces back to the early 16th century, derived from the Greek "plastikos" and Latin "plasticus," both meaning "suitable for molding" or "shaping." This etymology aptly reflects the inherent malleability that first characterized plastics. However, the modern era of plastics began in 1909 when Belgian chemist Leo Hendrik Baekeland introduced Bakelite, the first fully synthetic plastic. Unlike its predecessors, Bakelite was created without reliance on natural substances, marking the dawn of the "Plastic Age" and revolutionizing industrial applications with its heat-resistant and non-conductive properties (Freinkel, 2011).

The journey of plastics continued through the late 19th and early 20th centuries with significant milestones such as Alexander Parkes' Parkesine in 1862 and John Wesley Hyatt's celluloid in 1869. While Parkesine laid the groundwork for synthetic plastics, it was Hyatt's celluloid that achieved widespread commercial success, particularly in the film and photography industries. The subsequent invention of materials like PVC (Polyvinyl Chloride) in the 1920s and nylon in the 1930s further expanded the versatility and application of plastics across various sectors, including textiles, construction, and military equipment during World War II (Meikle, 1995).

Post-war advancements in plastic technology led to mass production and the proliferation of everyday plastic products from the 1950s through the 1970s. Innovations such as polypropylene and polystyrene became staples in packaging, automotive parts, and consumer goods, driving plastics to become integral to daily life. However, this rapid expansion also sowed the seeds for significant environmental challenges. By the 1970s, the ubiquity of single-use plastics began to raise alarms about pollution and waste management, concerns that have only intensified in the ensuing decades. The emergence of microplastics in marine environments has highlighted the long-term ecological impacts of plastic degradation, prompting global efforts to develop biodegradable alternatives and improve recycling infrastructure (Thompson et al., 2009).

Today, the plastic industry stands at a crossroads, balancing the undeniable benefits of plastics—such as durability, lightweight properties, and versatility—with the urgent need to address environmental sustainability. Innovations in bioplastics and circular economy models represent hopeful strides towards mitigating plastic pollution, yet the challenge remains formidable as production continues to escalate, projected to reach 670 million tons by 2040 (Geyer et al., 2017; Delangiz et al., 2022). The history of plastics is thus a testament to human ingenuity and the complex interplay between technological advancement and environmental stewardship, underscoring the imperative to foster sustainable practices in the ongoing narrative of this transformative material.

### *1.2. Introduction*

Plastic pollution has emerged as one of the most pressing environmental concerns in recent decades, with microplastic (MP) pollution gaining increased attention as a significant ecological and health threat. Microplastics are classified as emerging pollutants due to their widespread distribution, persistence in the environment, and adverse effects on both ecosystems and organisms, including model animals. MPs are categorized into two main types: primary and secondary. Primary MPs are deliberately manufactured as plastic particles smaller than 5 millimetres for use in household and industrial applications. Secondary MPs, however, are formed from the degradation of larger plastic items, such as bottles, packaging, and materials from activities such as fishing and agriculture. As plastics break down through physical, chemical, or biological processes, they release microplastic fragments into the environment.

MPs have been detected in various ecosystems, including freshwater, marine, and groundwater systems, and even in drinking water. Common polymers identified in MPs include polystyrene (PS), polyethylene terephthalate (PET), polyvinyl chloride (PVC), and polyethylene (PE). These particles can persist in the environment for extended periods, accumulating and causing harm to wildlife and humans. The potential toxicity of MPs is further exacerbated by their ability to adsorb harmful contaminants, such as heavy metals and persistent organic pollutants. MPs are found in various shapes, sizes, and colours, with seven distinct morphologies identified in research, contributing to their complex environmental behaviour and impact.

The infiltration of microplastics into the food chain is a particularly alarming issue. Humans are exposed to MPs primarily through ingestion and inhalation, with food and water as common pathways. Studies have shown that microplastics can enter the food supply through pollution of water bodies, agricultural practices, plastic packaging, and atmospheric deposition. Seafood, especially shellfish, has been highlighted as a major source of MP ingestion due to bioaccumulation in marine organisms. However, the widespread use of plastic products has resulted in extensive microplastic (MP) contamination across various food sources. One notable example is table salt, particularly that derived from seawater, which has been found to contain up to 5,400 MP particles per kilogram. These MPs are detectable down to 20 micrometers using density separation with sodium iodide, followed by microscopic analysis using Nile red or Rose Bengal staining. Seafood, including both wild-caught and farmed fish and shellfish, represents another major source of MP contamination. Detection methods for MPs in seafood typically involve the digestion of organic matrices using chemicals such as potassium hydroxide, hydrogen peroxide, sodium hydroxide, nitric acid, perchloric acid, or Fenton's reagent. This is followed by Fourier Transform Infrared (FT-IR) spectroscopy, with detection limits ranging from 1 micrometre to 5 millimetres. Additionally, MPs can originate from kitchen environments, where plastic-based utensils and cookware contribute to contamination through abrasion and heating.

Processed foods such as milk, honey, and beer have also shown concentrations of MPs, with up to 100 particles per liter detected. These MPs are typically identified through oxidation using hydrogen peroxide, followed by FT-IR analysis. Even dried foods, including processed seafood, tea bags, and traditional Chinese medicines, have not escaped MP contamination. Scanning Electron Microscopy (SEM) and X-ray Photoelectron Spectroscopy (XPS) are used to detect particles as small as 100 nanometres in these foods.

The growing trend toward plant-based diets has raised concerns about the exposure of plant-based foods to plastic environments, underscoring the need to reassess their potential contamination. The reduced detection limit for MP particles smaller than one micrometer using advanced chemical and spectroscopic techniques highlights the urgency of developing greener, more sustainable detection strategies.

A recent study using Raman micro spectroscopy found significant numbers of MP particles in the placentas of consenting patients with normal pregnancies, indicating the potential for MPs to infiltrate human biological systems. Given the serious implications of MP pollution on both human health and the environment, this review provides a comprehensive analysis of the occurrence of MPs in different food matrices and their toxicity toward human health. It also examines the current status of green analytical techniques used to detect MPs, discussing their advantages, challenges, and limitations, and proposing future research directions to address these issues.

The potential health effects of MPs are still under investigation, but early findings suggest that microplastics may cause physical damage to the digestive system, inflammation, and immune responses. They may also disrupt endocrine function and act as carriers for hazardous chemicals, including phthalates and bisphenol A (BPA). Despite the increasing awareness of MP contamination in food, the precise level of human exposure and the long-term effects on human health remain unclear. Given the pervasiveness of microplastics in the environment and their potential health risks, addressing the issue at its source is crucial.

Efforts to reduce plastic waste, improve waste management, and develop sustainable alternatives to conventional plastics are essential strategies to mitigate MP pollution. Additionally, stricter regulatory frameworks and heightened public awareness can help curb the production and disposal of plastic materials. This paper aims to explore the primary sources of MPs in food, examine their potential health effects, and propose feasible solutions to reduce their impact on human health and the environment.

Through an in-depth investigation into the pathways of microplastic contamination in the food chain, this study contributes to the growing body of research on the issue. It emphasizes the urgency of multi-level interventions, from policy reforms to technological innovations, in addressing the root causes of MP pollution. Ultimately, a comprehensive understanding of the sources, effects, and mitigation strategies related to microplastic pollution will be instrumental in minimizing its harmful impact on public health and the planet.

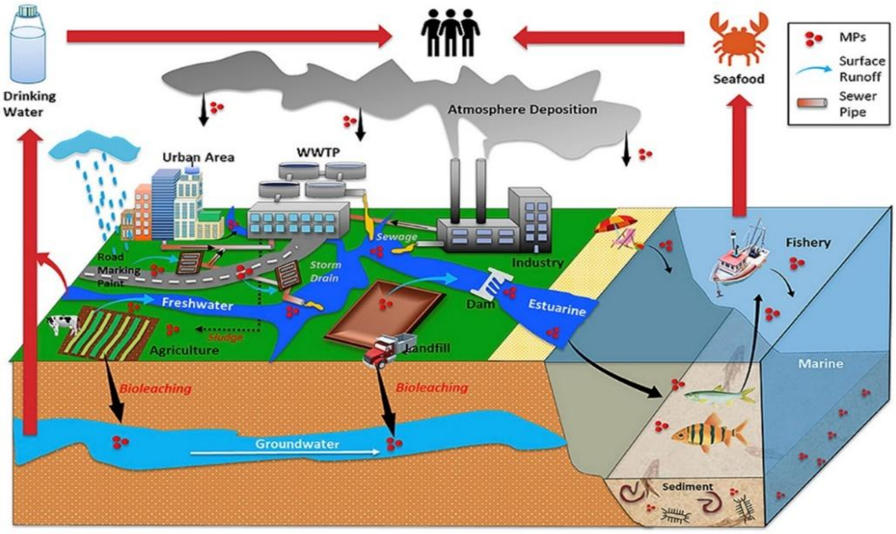

**Fig. 1 : Microplastic Journey in Environment**

## 2. Role of Plastics in Microplastic Formation

Plastics can be categorized into two main types: thermoplastics and thermosets. Thermoplastics polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polyethylene terephthalate (PET), can be remelted and reshaped. In contrast, thermoset plastics, like polyurethane, epoxy resins, and melamine, cannot be remelted after curing, making their degradation pathway slightly different. Both types, when disposed of in the environment, eventually degrade into microplastics.

### *2.1. Formation of Microplastics:*

Microplastics form through various processes, often originating from larger plastic materials that degrade over time or are intentionally manufactured as small particles. These particles, typically smaller than 5 mm, come from two primary sources: primary microplastics and secondary microplastics. The presence of microplastics in food and water raises concerns about their entry into the human food chain and the potential health risks. Here's a detailed explanation of how microplastics form, categorized by their sources and contributing factors.

- Primary Microplastics: Primary microplastics are deliberately manufactured in small sizes for specific purposes. These tiny plastic particles are directly released into the environment in their microplastic form.
  - Microbeads in Personal Care Products: Microbeads, once used in exfoliating scrubs, toothpastes, and facial cleansers, are small plastic particles designed for their scrubbing properties. These microbeads are too small to be filtered out by wastewater treatment plants, allowing them to enter water systems and contribute to microplastic pollution Industrial Use of Plastic Pellets (Nurdles): Nurdles, small plastic pellets, are raw materials used in the production of plastic goods. During manufacturing or transportation, spills occur, leading to the unintentional release of these particles into the environment.
  - Fibers from Textiles: Washing synthetic fabrics like polyester, nylon, and acrylic results in the shedding of microscopic plastic fibers. These fibers are too small to be captured by wastewater treatment plants and ultimately make their way into rivers, lakes, and oceans

- Secondary microplastics are formed from the breakdown of larger plastic items into smaller particles through environmental processes. These microplastics originate from plastic products that degrade due to physical, chemical, and biological factors.
  - Fragmentation of Larger Plastics: Large plastic objects such as bottles, bags, and packaging undergo photodegradation when exposed to sunlight. Ultraviolet (UV) light breaks down the chemical bonds in plastic, causing it to become brittle and fragment into smaller pieces. These fragments can continue breaking down over time into microplastics.
  - Abrasion and Mechanical by Physical forces like ocean currents, waves, and wind cause plastic waste in the environment to break apart. This form of degradation occurs in both marine and terrestrial environments. For example, car tires shed tiny particles as they wear down, contributing to microplastic pollution.
  - Decomposition of Plastic Waste in Land Plastics in landfills are subjected to temperature fluctuations, UV radiation, and microbial action. Over the course of decades, these plastics break down into secondary microplastics, which can infiltrate soil, water, or air.

### *2.2. Key Sources of Microplastic Formation:*

Several items and industries contribute significantly to the formation of microplastics:

- Plastic Packaging: Bottles, bags, and containers degrade over time, especially when exposed to sunlight and mechanical forces.
- Textiles: Synthetic clothes shed microplastic fibers washing and wear, contributing to microplastic pollution in water bodies.
- Fishing Gear: Fishing nets, lines, and other equipment degradation in marine environments
- Car Tires: Tires release microplastic particles as they wear down during use.
- Paints: Marine and industrial paints degrade over time, releasing plastic particles environment.
- Road Markings: Painted road lines contain plastic particles that wear down due to trafficking.

### *2.3. Factors influencing Microplastic formation:*

The formation of microplastics is driven by several environmental factors that accelerate plastic degradation:

- UV Radiation: Sunlight, particularly UV rays, causes the photodegradation of plastics, leading to their fragmentation over time.
- Mechanical Forces: Physical forces such as waves, wind, and abrasion from human activities accelerate the bf plastics in both marine and terrestrial environment.
- Temperature Fluctuations: Changes in temperature cause plastics to expand and contract, weakening the material and pigmentation.
- Chemical Reactions: Plastics may undergo chemical degradation when exposed to certain environmental chemicals, such as saline water, resulting in the formation of microplastics.
- Biological Activity: Some microorganisms are capable of degrading plastics to a limited extent. This process, although slow, can lead to smaller plastic particles over time. However, the degradation is often incomplete, and large amounts of microplastics remain.

## 3. How Microplastics spread in Environment: Pathways and Mechanism:

Microplastics, tiny particles less than 5 mm in size, disperse globally through numerous pathways, including air, water, soil, and the food chain. Originating from both primary and secondary sources, these particles are highly mobile due to their small size and resistance to degradation, allowing them to travel long distances and infiltrate diverse ecosystems. Facilitated by natural processes and human activities, microplastics have become pervasive across air, water, soil, and living organisms. Here's a closer look at how microplastics spread:

- Waterways and Oceans: Microplastics enter water systems through runoff, wastewater, and ocean currents, even reaching remote areas. Marine life consumes them, leading to contamination of the food chain.
- Airborne: Wind transports microplastics, which settle through rain or snow, contaminating land and water, even in isolated regions like the Arctic.
- Soil and Land: Microplastics from agricultural practices, sewage sludge, and degrading plastic waste infiltrate soil and groundwater, affecting plant and animal life.
- Human Activities: Sources include washing synthetic clothes, shedding car tires, and discarded fishing gear, all contributing to microplastic pollution.
- Food Chain: Microplastics ingested by marine and land animals move up the food chain, eventually reaching humans through contaminated seafood or livestock.
- Ocean Gyres: Large ocean systems, like the Great Pacific Garbage Patch, trap plastics that break down into microplastics, dispersing further.
- Polar Regions: Wind and currents carry microplastics to polar ice, where they are temporarily trapped but released during ice melt.

Microplastics spread through multiple pathways—air, water, soil, and the food chain—making them pervasive contaminants. Both natural forces, such as wind and ocean currents, and humas, like industrial processes and improper waste disposal, contribute to their dispersion. As microplastics accumulate in ecosystems and food chains, they pose significant risks to both environmental and human health, requiring global efforts to mitigate their spread and impact.

## 4. Sources of Microplastics in Food Chain:

Plastics can be categorized into two main types: thermoplastics and thermosets. Thermoplastics polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), and polyethylene terephthalate (PET), can be remelted and reshaped. In contrast, thermoset plastics, like polyurethane, epoxy resins, and melamine, cannot be remelted after curing, making their degradation pathway slightly different. Both types, when disposed of in the environment, eventually degrade into microplastics.

### *4.1. Microplastics in Fruits and Vegetables:*

Recent studies have revealed the presence of microplastics (MPs) in various agricultural products, including fruits and vegetables. MPs contamination in these food items is a growing concern due to the potential implications for human health.

MPs in agricultural environments originate from multiple sources. One significant pathway is the use of plastic materials in agricultural practices, such as plastic mulch films, greenhouse coverings, and irrigation systems. Over time, these plastic materials degrade and release MPs into the soil, which can then be absorbed by plants. Irrigation with wastewater or water contaminated with MPs further exacerbates this issue. Moreover, sewage sludge, which is often used as fertilizer, has been found to contain high concentrations of MPs, which may be transferred to crops grown in such soils Microplastics by Plants Studies suggest that plants can absorb MPs through their roots, with these particles then traveling to other parts of the plant, such as stems, leaves, and fruits. For example, a study conducted by Li et al. (2020) demonstrated that both root crops (e.g., carrots, radishes) and leafy vegetables (e.g., lettuce) can absorb and accumulate MPs from the surrounding soil. The size, shape, and type of MPs play a role in their uptake by plants. Smaller MPs, particularly nanoplastics, are more likely to be taken up and translocated within the plant, posing potential risks for food safety.

Recent studies have expanded the focus of microplastics (MPs) research from aquatic environments to terrestrial food sources, highlighting their presence in fruits and vegetables. MP contamination can occur through various pathways, including uptake from contaminated soil and water, atmospheric deposition, and contact with plastic materials during growth and processing. A study conducted in Turkey found MPs in commonly consumed produce such as apples, tomatoes, cucumbers, onions, and potatoes, with an estimated 398,000 MP particles per person per year for tomatoes alone. Additionally, urban agriculture appears particularly vulnerable to MP contamination, as shown by research in Portugal that detected up to 29 MPs per gram in lettuce grown in urban gardens.

Studies on MP uptake in plants indicate a size-dependent absorption pattern; for example, particles as small as 1 µm can penetrate carrot root intercellular layers, while 0.2 µm particles can enter through leaves. Larger particles, up to 1220 nm, can penetrate both roots and leaves, highlighting the potential for accumulation within plant tissues. Advanced techniques, such as confocal Raman microscopy, have confirmed the presence of acrylonitrile butadiene styrene particles up to 2 µm in radish root tissues. Research has designated apples and carrots as among the most contaminated fruits and vegetables, particularly with MPs smaller than 10 µm. Plants with large, rough leaves and wide stomatal openings tend to assimilate micro- and nanoplastics more effectively, raising significant concerns regarding food safety and the health impacts of consuming contaminated plant-based foods.

The presence of MPs in fruits and vegetables raises worry about food safety and the health implications of consuming plant-based foods contaminated with MPs. While research is still in its early stages, the growing body of evidence points to the need for more thorough investigations into how MPs accumulate in terrestrial food sources and how best to mitigate these risks to protect public health.

### *4.2. Microplastics in Beverages:*

Microplastics (MPs) have emerged as a significant concern in beverages, including bottled water, tap water, milk, soft drinks, beer, and tea, raising questions about potential human health risks due to frequent consumption. The global non-alcoholic beverage consumption reached approximately 123,120 million liters in 2021, highlighting the magnitude of potential exposure. Studies have detected MPs in milk, with an average concentration of 6.5 particles per liter in Mexican brands and various types found in Turkish samples. Soft drinks, cold tea, and energy drinks also showed MP contamination, averaging 40 particles per liter in soft drinks and lower concentrations in others, likely due to plastic packaging during manufacturing.

Beer has been identified as another source of MP contamination, with studies revealing 2 to 79 fibers and 12 to 109 fragments per liter among various German brands. Bottled water, often assumed to be a cleaner alternative, exhibited significant MP levels, with a study showing that 93% of sampled bottles contained an average of 325 particles per liter, predominantly polypropylene. Even hot beverages like tea can release vast quantities of MPs from plastic teabags, with one study indicating that brewing a single teabag can introduce approximately 11.6 billion MPs into a cup of tea.

MPs in beverages primarily enter through production, packaging, and distribution, as plastics degrade and shed particles over time. Additionally, MPs can carry harmful contaminants, compounding health risks. Techniques like microscopy, spectroscopy, and chromatography are utilized to analyze and identify MPs in beverages. Given the potential cumulative health impact of MPs through regular beverage consumption, further research is needed to understand long-term risks, alongside stricter regulations on packaging materials and production methods to mitigate this issue.

### *4.3. Microplastics in Seafoods:*

The contamination of seafood by microplastics (MPs) has become a significant concern, especially given the critical role that fish and marine organisms play as primary protein sources for human consumption. Microplastic pollution is now widely documented in marine species, raising alarms about its potential effects on both marine ecosystems and human health. Marine organisms exposed to MPs, often alongside other environmental contaminants, can suffer adverse health effects, ranging from minor biological disruptions to severe health consequences such as behavioral abnormalities, growth inhibition, and neurotoxicity. These concerns are particularly pertinent when considering the contamination of seafood consumed by humans, especially fish muscle tissue, mollusks, and crustaceans, all of which serve as direct routes of MP exposure for humans.

Fish exposed to MPs exhibit negative health effects, which compromise both their well-being and their safety as food. MPs have been detected in the muscle tissue of numerous fish species, which is the primary portion consumed by humans. Several studies have confirmed MP ingestion by commercially important fish species across the world's major oceans, including the Atlantic, Pacific, Indian Ocean, and Mediterranean Sea.

Studies have reported significant MP ingestion by pelagic and demersal fish species such as herring, mackerel, cod, sole, and sardines. For example, research in the central Adriatic Sea found MPs in 26% of red mullet (Mullus barbatus) and 20% of European hake (Merluccius merluccius) samples.

Rates: In Sardinia, MP ingestion rates were shown to vary by species' habitat. Surface-dwelling species demonstrated the highest ingestion rates at 41%, compared to 22% for mid-water species and 19% for bottom-dwelling species.

Mollusks, particularly mussels and oysters, and crustaceans like shrimp, contribute significantly to human MP exposure through seafood consumption. As filter feeders, mollusks are particularly vulnerable to MP ingestion since they process large volumes of water daily, leading to MP accumulation in their tissues. Studies on Mussels and Oysters across Europe have documented MP contamination in Mytilus edulis and Mytilus galloprovincialis. Belgian mussels, for instance, were found to contain up to 0.51 MP particles per gram of tissue. Similarly, research in the on found 790 plastic particles per oyster (Crassostrea gigas) and 270 plastic particles per mussel. These particles were primarily composed of nylon and polyamide in mussels and polypropylene in oysters. A study on the shrimp species Fenneropenaeus indicus in Cochin, India, revealed an average of 0.39 ± 0.6 MP particles per shrimp, with 83% of the detected particles being fibers. Canned Fish: Research on canned fish market found MPs in all analyzed samples, with polyolefin being the most common contaminant. This highlights the role of seafood processing and packaging in MP contamination.

The ingestion of microplastics (MPs) through seafood consumption is a growing concern due to the potential for these particles to carry harmful chemical additives like phthalates and bisphenol A (BPA), which are linked to endocrine disruption, reproductive toxicity, and other health issues. MPs can also act as carriers for toxic substances from the marine environment, further exacerbating the health risks when consumed through contaminated seafood. The contamination of fish, mollusks, and crustaceans by MPs poses significant risks to both marine ecosystems and human health, as these organisms serve as primary sources of protein for humans. With increasing evidence of MP presence in various seafood species, there is an urgent need for more research to assess the long-term health effects of MP exposure through diet. Efforts to mitigate plastic pollution in the oceans, as well as stricter regulations on seafood packaging and processing, are critical steps to reduce MP contamination and protect public health.

### *4.4. Microplastics in Drinking Water:*

The presence of microplastics (MPs) in drinking water is a growing public health concern due to their detection in various water sources, including groundwater, surface water, and treated water. Factors contributing to MP contamination include pollution in source waters, limitations in water treatment technologies, degradation of distribution systems, and leaching from packaging materials. MPs' hydrophobic nature allows them to attract harmful substances like heavy metals and pollutants, increasing potential health risks. This highlights the need for improved treatment methods and further research on the long-term impacts of MP exposure in drinking water.

Source Water Contamination: Drinking water is often sourced from rivers, lakes, or underground aquifers, which may already be contaminated with MPs from environmental pollution, agricultural runoff, or industrial discharges. Surface waters, in particular, tend to have higher concentrations of MPs due to their proximity to human activities. Limitations in Water Treatment Processes: Traditional water treatment plants are designed to remove biological, chemical, and particulate contaminants, but they are not optimized to filter out MPs, particularly those smaller than 100 µm. Some MPs can bypass conventional filtration systems, ending up in treated water.

Degradation of Distribution System Components: As water travels through distribution systems, aging pipes and components can degrade, shedding microplastic particles into the water supply. This is particularly concerning in older infrastructure, where materials such as plastic piping may contribute to MP contamination. Leaching from Packaging Materials: Bottled water, packaged in plastic containers, is another source of MPs contamination. Over time, plastic bottles can release microplastic particles into the water they hold, particularly under conditions of heat or prolonged storage. Research has shown that even well-known bottled water brands contain microplastics.Hydrophobic Nature of MPs: MPs are hydrophobic, meaning they can attract and bind to other harmful substances such as heavy metals, organic pollutants, and microbial pathogens. This ability to adsorb contaminants increases the risk of human exposure to these harmful compounds through drinking water. Recent advancements in analytical techniques have allowed researchers to detect and characterize MPs in drinking water with greater precision. These studies provide valuable insights into the types, sizes, and concentrations of MPs present in different water sources. The most common methods used for MP detection include Raman microspectroscopy, Fourier Transform Infrared (FTIR) spectroscopy, and scanning electron microscopy (SEM). The health impacts of ingesting microplastics (MPs) through drinking water are not fully understood, but there is concern about their potential to carry hazardous chemicals like phthalates and BPA, which can disrupt endocrine function and cause reproductive toxicity. MPs may also damage cells, generate oxidative stress, and trigger immune responses. More research is needed to understand their effects in the body. Addressing MP contamination in drinking water will require advancements in water treatment, stricter packaging regulations, and efforts to reduce plastic pollution. Further studies are essential to fully assess the health risks of MP exposure.

### *4.5. Microplastics in Home Kitchen:*

The study by V.K. Snekkevik et al. (2024) highlights various sources of microplastic contamination in home kitchens, with key pathways summarized as follows:

- Food Preparation: Mechanical stress and temperature shifts in kitchens can lead to plastic degradation and microplastic release during food preparation. Activities like cutting, mixing, and heating plastic kitchenware contribute to this, with cutting boards being a notable source of microplastics. Studies found that chopping style, material, and food type influence the release, with polyethylene boards producing more microplastics than polypropylene ones. Mechanical stress from tools like blenders and mixers also releases microplastics, especially with harder foods or abrasive materials like salt. Older kitchenware tends to release more microplastics due to wear. Using plastic bowls under mechanical stress, such as mixing with a hand mixer, can also release microplastics. Factors like the material of the bowl and the presence of granular substances (e.g., salt) exacerbate the release. Research on melamine-based utensils revealed concerns about toxic chemicals like formaldehyde under UV exposure, though risks remain low according to FDA guidelines.

- Storage Equipment: Plastic storage containers, particularly polystyrene (PS), can release microplastics due to their softer structure and surface wear, which is intensified by temperature fluctuations and friction with food. Heating food in plastic containers, especially polypropylene (PP) and polyethylene terephthalate (PET), significantly increases microplastic release, especially in acidic or heated conditions.
- Serving Equipment: Although little research exists, utensils like ladles, forks, and pizza cutters, often made of plastic, are in direct contact with food, potentially releasing microplastics.
- Cooking Equipment: Non-Stick Pans: Coated with polytetrafluoroethylene (PTFE), these pans release microplastics when abraded by utensils. Scratches or damage can lead to the release of millions of particles.
- Cleaning Equipment: Sponges and Cloths: Cleaning sponges, especially those made from synthetic materials (nylon, polyester), release microplastics through abrasion during cleaning. Older sponges tend to release more particles.
- Food Preservation: Plastic coverings like clingfilm and silicone wraps have become integral to food preservation by protecting food from oxygen, water vapor, and microorganisms. They are widely used in tasks such as reheating leftovers in microwaves, covering food in refrigerators, or baking. However, these materials, which come into direct contact with food at varying temperatures, may also be sources of micro- and nanoplastics. While regulatory measures exist to ensure the safety of these materials, they tend to focus on the release of additives and chemicals rather than plastic particles themselves. Research on microplastic release from these food-preservation materials is limited, with only one identified study on clingfilm. This study found that polyethylene (PE) particles were released from clingfilm when exposed to deionized water at temperatures ranging from 50°C to 95°C, suggesting that high temperatures may cause micro- and nanoplastics to be released. Given the common use of these materials, more research is needed to fully understand their impact on food safety and human health.
- Appliances: Several common kitchen appliances, such as kettles, microwaves, ovens, and more, have the potential to release microplastics, yet research in this area is limited. Shi et al. conducted one of the few studies on plastic kettles, finding that micro- and nanoplastic release decreases over time. This reduction is attributed to a "natural passivation phenomenon," where a protective film forms on the kettle's surface due to local water ions. This film acts as a barrier, reducing the release of plastic particles. However, research on other appliances remains sparse, highlighting a need for further investigation.
- Plastic Kettles and Blenders: Boiling water in plastic kettles and blending hard substances in blenders have been identified as sources of microplastics due to thermal degradation and mechanical stress.

The study emphasizes that microplastic release is influenced by the type of plastic, the age and condition of kitchen tools, temperature variations, and food contact. It also calls for further research on less-studied sources like serving utensils and plastic covers.

## 5. Potential Health Effects of Microplastics:

Microplastics, tiny particles less than 5 mm in size, have become widespread contaminants, entering the human body through ingestion, inhalation, and possibly skin contact. Although research on their health effects is still emerging, evidence suggests several potential risks. Microplastics can trigger inflammation and oxidative stress, leading to chronic health issues such as cardiovascular diseases, diabetes, and autoimmune disorders. They carry toxic chemicals, like endocrine disruptors and heavy metals, which may cause hormonal imbalances, cancer risks, and DNA damage. Inhalation of microplastics can lead to lung inflammation, fibrosis, and respiratory issues, while prolonged exposure may also affect the immune and nervous systems, potentially causing immune suppression, neurotoxicity, and behavioural disorders. Additionally, microplastics may bioaccumulate in organs, raising concerns about long-term health impacts. As their presence in the environment grows, reducing exposure and understanding the full extent of their health effects is crucial.

### *5.1 Effect of Microplastics on Digestive System:*

The ingestion of microplastics (MPs) through food and water has significant implications for the digestive system. Studies indicate that seafood, salt, honey, and beverages are primary sources of MPs entering the human food chain. Although extensive research has documented MPs toxicity in animal models, direct data on human ingestion remains limited. MPs affect the gastrointestinal tract and are internalized through adsorption, paracellular transport, and M cell-mediated mechanisms. Once internalized, MPs may enter systemic circulation, leading to adverse effects in various organs. MPs disrupt gut function, affecting metabolism, digestion, and immunity, while also unbalancing the gut microbiome, potentially causing intestinal inflammation and abnormal metabolism.

MPs in the intestine can induce oxidative stress, decreasing probiotic content and altering nutrient metabolism. This imbalance in intestinal microflora promotes harmful bacteria, triggering intestinal inflammation. MPs also accumulate in the intestinal crypts and villi, leading to cell reduction and immune cell infiltration, which compromises intestinal barrier function and causes severe inflammation. The liver is another critical organ affected by MPs. Accumulation of MPs induces oxidative stress, inhibiting antioxidant enzyme activity, which leads to inflammation, liver cell damage, and disruptions in glucose and lipid metabolism. In severe cases, this oxidative damage can cause genotoxicity and protein oxidation, contributing to metabolic diseases like fatty liver disease. Moreover, mitochondrial dysfunction caused by MPs exposure reduces ATP production, further impairing liver function and energy regulation.

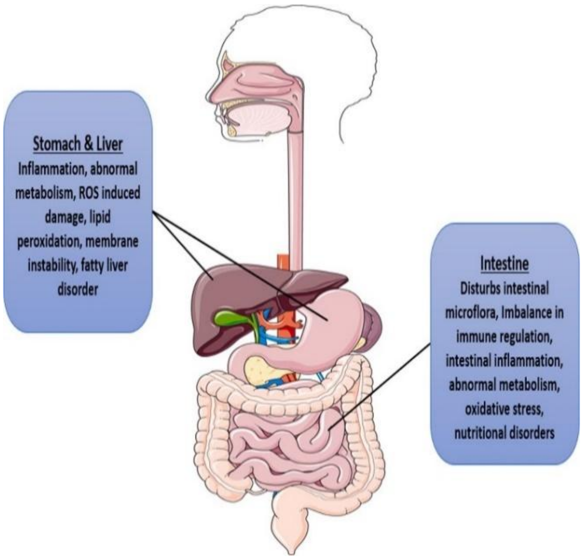

**Fig. 2 - Depiction of Effect of MPs on Human Digestive System**

### *5.2 Effect of Microplastics on Reproductive System:*

Continuous exposure to microplastics (MPs) has been linked to adverse effects on both male and female reproductive systems. In males, MPs exposure is associated with reduced sperm motility, viability, and DNA integrity, primarily due to oxidative stress from increased reactive oxygen species (ROS), pyroptosis, and autophagy. Disturbances in gut microbiota caused by MPs can also disrupt spermatogenesis and sex hormone synthesis pathways. MPs harm germ cells through inflammation, DNA fragmentation, and necroptosis, and they can damage Sertoli cells, which are essential for maintaining the blood-testis barrier. This damage allows small MPs to penetrate the seminiferous epithelium, further compromising germ cell protection. While the impact of MPs on Leydig cells is still being studied, exposure has been linked to mitochondrial disfunction and reduced ATP production, potentially disrupting androgen regulation and secondary sexual characteristics in males. In females, MPs exposure is associated with ovarian dysfunction and altered sex steroid hormone levels, primarily due to ROS-induced oxidative stress that leads to diseases.

### *5.3 Effect of Microplastics on Nervous System:*

Microplastics (MPs) from food and water can enter the nervous system through the bloodstream after being absorbed during digestion, potentially causing neurotoxicity. The severity of this neurotoxicity depends on the size and nature of the MPs. Key mechanisms include oxidative stress-induced damage and inhibition of acetylcholinesterase (AChE), an enzyme crucial for nerve signal transmission. Studies in animal models, like zebrafish, have shown that MPs can cause brain damage, including necrosis, inflammation, and neuronal degeneration. MPs also exacerbate mitochondrial dysfunction, DNA damage, and neuronal cell death. Their interaction with environmental pollutants, like heavy metals, can intensify these toxic effects. However, there is limited research on MPs' neurotoxicity in humans, highlighting a critical need for further investigation to understand their impact and develop protective strategies.

## 6. Analytical methods for detection of Microplastic (MPs) and sample preparation:

Detecting microplastics (MPs) in food samples involves various testing methods, each with its unique advantages and limitations. Below are the main approaches briefly described:

- Visual and Microscopic Techniques: Visual inspection and microscopic analysis are among the most straightforward methods for detecting MPs in food. Stereomicroscopes and electron microscopes are used to identify and count MPs based on their size, shape, and color. However, this method is limited by its inability to detect very small particles (less than 10 µm) and the potential for misidentification due to organic debris that may resemble MPs.
- Spectroscopic Methods: Techniques such as Fourier Transform Infrared (FTIR) spectroscopy and Raman spectroscopy are widely used to identify MPs by analysing their chemical composition. FTIR works by detecting the unique absorption spectra of plastics, while Raman provides vibrational information about molecular bonds. Although these methods are highly accurate, they are expensive, time-consuming, and can struggle with samples containing water, as water can interfere with the spectra.
- Thermal Detection Methods: Thermal methods, such as Pyrolysis-Gas Chromatography-Mass Spectrometry (Py-GC-MS), involve heating samples to break down MPs into their molecular components. This method is beneficial for identifying the polymer type and quantifying MPs in complex food matrices. However, it requires calibration and can be biased by the presence of larger MPs molecules, making it a time-intensive process.

- Fluorescent Tagging and Staining: Fluorescent dyes like Nile Red are used to stain MPs, making them easier to detect under fluorescent microscopy. This method allows for the rapid identification of MPs, but it is not specific to plastic polymers and may result in false positives if other organic materials in the sample are stained.
- Mass Spectrometry (MS) Methods: Advanced mass spectrometry techniques, such as Liquid Chromatography-Mass Spectrometry (LC-MS) or Matrix-Assisted Laser Desorption/Ionization-Time of Flight (MALDI-TOF), can be used to detect and quantify MPs by analyzing their molecular composition. These methods provide detailed chemical information but are costly and require sophisticated equipment and technical expertise.

Each detection method has trade-offs in terms of accuracy, sensitivity, cost, and time, making the choice of method dependent on the specific requirements of the study.

## 7. Strategies to Minimize MPs in the Food Chain:

Microplastics (MPs) are a growing environmental concern, especially due to their contamination of ecosystems and food chains. MPs have been detected in seafood, salt, honey, water, and agricultural soils, raising alarms about potential human health risks. While completely eliminating MPs from the environment may be unfeasible, several strategies can help reduce their presence in the food chain. Additionally, biobased alternatives to conventional plastics provide promising solutions to mitigate future MP generation.

### *7.1. Reducing Plastic Pollution at the Source:*

Governments can curb plastic pollution by introducing legislation that bans single-use plastics like bags, straws, and cutlery. Such policies can significantly reduce the volume of plastics entering the Environmental Producer Responsibility (EPR) programs hold manufacturers accountable for plastic waste, incentivizing the design of recyclable or biodegradable products. Additionally, a circular economy approach encourages plastic reuse and recycling, limiting the fragmentation of larger plastics into MPs.

### *7.2. Agriculture and Aquaculture:*

Reducing plastic use in farming, such as switching from plastic mulch and irrigation systems to biodegradable alternatives, can prevent MP contamination of soil and water. Improved wastewater treatment systems can filter out MPs, especially microfibers from washing machine effluent, before they enter aquatic environments. Sustainable aquaculture practices minimize the use of plastic equipment can also help reduce MPs in seafood.

### *7.3. Public Awareness:*

Public awareness and behaviour educating consumers about plastic pollution can encourage behavioural changes, such as reducing plastic consumption, using reusable products, and participating in recycling programs. Promoting sustainable diets, such as buying from local source, organic foods with minimal plastic packaging, can also reduce MP ingestion.

### *7.4. Biobased Alternatives to Minimize Microplastic Pollution:*

Several biobased plastics offer alternatives to conventional plastics. Polylactic Acid (PLA), derived from plants like corn or sugarcane, is biodegradable and commonly used in packaging and disposable products. It breaks down into carbon dioxide and water under proper conditions. Polyhydroxyalkanoates (PHAs), produced by microorganisms, biodegradable in both marine and terrestrial environments, making them ideal for reducing oceanic MPs. Starch-based plastics and cellulose-based materials are other biodegradations, commonly used in food packaging and cutlery. Emerging algae-based plastics offer renewable, biodegradable alternatives to sings.

### *7.5. How Biobased Plastics Minimize MP Generation:*

Biobased plastics degrade naturally, reduces the risk of breaking down into MPs over time. They are also less toxic, often containing fewer harmful chemicals compared to traditional plastics. By relying on renewable resources, these materials also reduce reliance on fossil fuels and help lower the environmental footprint of plastic production.

### *7.6. Challenges and Considerations for Biobased Alternatives:*

- Composting Infrastructure: For bio break down effectively, industrial composting facilities are required, but such infrastructure is lacking in many areas. Without these facilities, bioplastics may persist in landfills.
- Public Misconceptions: Many consumers mistakenly believe that all bioplastics degrade in natural environment education is needed to ensure proper disposal of bioplastics through composting rather than mixing with conventional waste.
- Cost and Scale: Biobased plastics are currently more expensive than petroleum-based plastics, limiting their widespread. However, increased production and consumer demand could help lower costs and make bioplastics more accessible.

## 8. Reducing MPs and Nanoplastics with Modern technologies and artificial intelligence (AI):

The increasing prevalence of microplastics (MPs) and nanoplastics in the food chain poses significant threats to human health and environmental sustainability. Modern technologies and artificial intelligence (AI) are being harnessed to tackle this issue through various innovative methods.

### *8.1. Modern Technologies for Reducing MPs and Nanoplastics*

Technologies like membrane filtration (e.g., nanofiltration, reverse osmosis) and electrocoagulation effectively remove MPs and nanoplastics from water, preventing their entry into food systems. Emerging solutions like biofiltration utilize microorganisms to trap or degrade MPs in wastewater, further reducing contamination at the source. The adoption of biodegradable bioplastics (PLA, PHA) and edible coatings made from natural materials like algae or starch can reduce plastic waste and prevent MPs from entering the food chain. Smart packaging integrates sensors that monitor food safety and promote composting, improving plastic lifecycle management. Using biodegradable mulching films in farming replaces traditional plastic mulching, minimizing MP contamination in soils. Precision agriculture leverages sensors and data analytics to optimize inputs, reducing plastic use in irrigation and synthetic fertilizers. Micro-robots and nanocoatings in filtration systems are being developed to capture and remove MPs from water. These technologies offer advanced solutions by collecting MPs through electrostatic or adsorption processes, preventing their spread in ecosystems.

### *8.2. AI and Machine Learning in Tackling MPs*

AI-powered sensors in water treatment plants can detect MPs at low concentrations and optimize filtration processes. Image recognition algorithms improve the accuracy and speed of MP detection in food and water samples, while AI-driven satellites and drones monitor plastic pollution in large ecosystems. AI models simulate MP pathways through ecosystems and predict their impact on food chains and human health. Predictive analytics identify MP contamination hotspots, helping prioritize mitigation and cleanup efforts. AI-driven waste management systems enhance plastic sorting and recycling, reducing waste that could contribute to MP pollution. Additionally, AI accelerates the development of sustainable bioplastics by analysing material properties and environmental performance.

### *8.3. The Future of AI and Technology in Addressing MPs*

The integration of advanced technologies and AI offers significant potential to minimize MPs in the food chain. As these systems evolve, they will play an increasingly critical role in monitoring, managing, and reducing plastic pollution, creating safer and more sustainable food systems for future generations.

## Conclusion :

The presence of microplastics (MPs) in the food chain has emerged as a growing concern, posing significant threats to both human health and environmental sustainability. MPs enter the human body through contaminated food sources, water, and air, with potential impacts ranging from gastrointestinal inflammation to systemic oxidative stress, and possibly even contributing to metabolic and liver diseases. The current body of research, although still developing, underscores the urgent need for more comprehensive studies on human exposure and long-term health effects. To mitigate the spread of MPs in food systems, modern technologies and innovations must be adopted. Advanced water treatment solutions, biodegradable bioplastics, and smart packaging represent significant strides towards reducing MPs in our food supply. In agriculture, biodegradable mulching and precision farming techniques can minimize plastic use, while robotics and AI can enhance MP detection and removal. However, technological advances alone will not suffice; they must be supported by stricter regulations, such as bans on single-use plastics and policies enforcing extended producer responsibility. Innovation in biodegradable materials and the development of new plastic alternatives must be accelerated to ensure long-term sustainability. Additionally, it is crucial to enhance public awareness of the impacts of MPs and advocate for behavioural changes that reduce plastic consumption and promote recycling. The current regulatory framework needs to be updated with stricter enforcement and more comprehensive waste management systems to address this emerging threat effectively. By embracing modern technology, fostering innovation, and enforcing robust policies, we can mitigate the risks posed by MPs and protect human health and the environment. A future that prioritizes human and environmental health over convenience requires not only technological innovation but also a strong commitment to stricter policies and systemic change.

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