Microplastics and Nano-plastics Contamination in Foods:Current Understanding of the Health Impact on Humanand Potential Solution

Abstract

Plastics released into the environment can be degraded by physical erosion, biodegradation, photocatalytic activity, and oxidation, resulting in smaller plastics particles. Microplastics (MPs) are plastic particles relatively smaller than 5 mm in size. Furthermore, microplastics with particle sizes less than 1000 or 100 nm are known as nano-plastics (NPs).The presence and effect of MPs and NPs in human body has not been adequately studies, thus we aim to explain the origins of MPs and NPs adept, carefully explore the pathways by which MPs and NPs enter the body system and highlight the impact of MPs and NPs on human health. Major examples include Polyethylene (PE), polypropylene (PP), polyvinyl chloride (PVC), polyamide (PA), polystyrene (PS), polyethylene terephthalate (PET), Acrylonitrile-Butadiene-Styrene (ABS), and polymethyl methacrylate (PMMA).MPs and NPs were found to have two sources (primary and secondary). The primary sources are materials purposely produced to suit household and industrial uses, such as exfoliants for skin care products, construction, and packaging materials. Secondary sources originated from the decomposition/degradation of large plastic products over time. Plastics were found in plants (fruits and vegetables), animals (fish, crab, shrimp, oysters, and mussels), water (taps, sachet, and bottled water), salt, sugar, and honey. Plastics' impact on the human ecosystem is getting increasingly severe, and it is imperative that proper attention be paid to this issue. The vast number of MPs and NPs available can influence the lives of the populace in each geographic area. In this review article, we identified three routes through which MPs and NPs gain entrance into the human body: oral ingestion, cutaneous (skin contact), and inhalation. Furthermore, we investigated and summarized the impacts of MPs and NPs on human health. The most impacted organs in the body included the lungs, blood, kidney, brain, ovary, testes, and intestines. In this review, we offered a viable solution that includes the use of biodegradable polymers, increased usage of eco-friendly biotechnology and engineering solutions, and the implementation of regulatory measures. In future, we intend toinvestigate the bioaccumulation and effect of MPs/NPs on human health.

Keywords:* *Biodegradation, Foods, Health-Effect, Microplastics, Nano-plastics, Routes.

1.Introduction

"Plastics" refer to a group of synthetic materials made from polymers, which are large molecules composed of repeating structural units called monomers. These materials have a wide range of properties and uses, making them integral to various industries and everyday life[1; 2]. Plastics can be molded into different shapes while maintaining their structural integrity, and they are often lightweight, durable, and resistant to moisture. The process of making plastics involves polymerization, where small molecules (monomers) are chemically bonded together to form long chains (polymers). The type of monomers and the polymerization process used determine the properties of the resulting plastic[3].There are various types of plastics, each with its characteristics and applications. Common types include polyethylene, polypropylene, polyvinyl chloride (PVC), polystyrene, and polyethylene terephthalate (PET)[4]. Plastics are used in a wide range of products, including packaging materials, containers, toys, medical devices, automotive components, and more.While plastics have many benefits, their widespread use has led to environmental concerns due to issues such as pollution, non-biodegradability, and the impact on ecosystems[5-8]. Efforts are being made to develop more sustainable and environmentally friendly alternatives to traditional plastics[9;10]. The manufacturing volume (measured in m^3) of plastics is greater economically and technologically than steel and aluminium in terms of production cost, weight, and durability[11]. Due to high production costs, the short lifespan of products, and poor handling of the material, three percent of manufactured plastic spills and accumulatesinto marine ecosystems as recalcitrant; this environmental challenge is steadily worsening and carries considerable significance in our ecosystem[12; 13]. Nearly 370 million tons of plastic were produced globally in the past 5 years[14], with over one-third of that plastic being used in products like packaging, culinary tools, and waste bags that are meant to be thrown away within three years of manufacture in both the United States and Europe[15]. According to some reports, a single microplastics (MPs) particle has the potential to break down into billions of nano-plastics (NPs) particles, underscoring the pervasive issue of NPs contamination[16; 17]. The projection suggests that by 2060, the annual quantity of plastic waste generated and inadequately disposed of is expected to triple, reaching a range of 155-265 million metric tons[18]. Only 9% of the total plastic ever produced has undergone recycling, with over 75% of it currently residing in landfills or other waste disposal sites[19].

Improper processing, burning, or disposal leads to a substantial accumulation of waste in the ecosystem. Over time, this waste undergoes gradual aging and degradation, breaking down into micro and nanosized particles[20-22]. The size of NPs is less than 0.1 µm, while MPs have a range of 1 µm to 5 mm[23]; [24]. According to a report,MPs and NPs are plastic-synthesized particles that are solid or matrices of polymers having consistent or erratic forms that are insoluble in water and come from either primary or secondary production[25]. MPs are small plastic particles with a size range typically between 5 mm and 1 µm.They can be the result of the breakdown of larger plastic items, such as bottles and bags, or they can be intentionally manufactured at this small size for use in products like exfoliating scrubs and some industrial applications[26].MPs can enter the environment through various means, including the degradation of larger plastic debris, the breakdown of synthetic textiles, and the fragmentation of plastic products. NPs are even smaller particles, typically measuring less than 1 µm in size. NPs can be produced through the further degradation of MPs or direct releases, such as from the breakdown of plastic films, foams, or other sources[26].The small size of NPsraises concerns about their potential to enter cellular and subcellular structures, potentially affecting organisms at the molecular level. However, research on NPs is an evolving field, and there is still much to learn about their environmental and health impacts[26].

The main source of MPs contamination is the breakdown of plastic debris in the ocean. Both entire and partial portions of commercial seafood species are eaten, including bivalves, crabs, lobsters, and small fish[27]. Larger fish and animals are only eaten in part. However, marine dried fish, which are often consumed whole, may contribute to human MP ingestion, posing a major health risk[28]. The food chain and the biota at different trophic levels are just two of the many aquatic ecosystem components that are constantly contaminated by MPs, which are incredibly robust particles[29].Effects of MPs and NPs on human health have been reported with emphasis on airborne (inhalation) as a route of transmission[30], while another group of researchers reported the implication of MPs and NPs in aquatic environment and their route to human body[31]. Recently, the difficulties and potential solutions to enhance the process of chemical analysis and identification of MPs and NPs in our ecosystemhave been discussed[32].Several studies provide evidence that MPs have been found in a wide range of animal organs, including those of bivalves, crustaceans, fish, (fish intestine and flesh), mammals and their intestinal tract,livers, and gills[33-41], we intend to thoroughly investigatethe effects of MPs and NPs on the human body and the overall consequences on health.

1.1Aims and Objective: Most of the available research data provides limited information, and an extensive grasp of the impact of MPs and NPs on human health is not fullyunderstood. In this review, we aimed to explain the sources of MPs and NPs in food adept, carefully examine the routes by which MPs and NPs enter the body system and highlight the impact of MPs and NPs on human health. We sought to proffer a better understanding of the effects of MPs and NPsonthe human body which could inform our understanding of the consequences of MPs and NPs in the food chain and human health in general.

2.Sources of Microplastic and Nano-plastics

Less than 20% of MPsoriginate from marine sources, with over 80% being produced on land. Due to their lightweight, unbreakable, and buoyant nature, MPs can travel considerable distances[42]. The bulk of plastics that pollute the aquatic ecosystem originate on land, fishing, and other fish farming activities, and in beach tourism[40; 43].It is estimated that more than 800 million tons of plastics in the oceanhave originated from land sources[44]. Given that MPs and NPs are so tiny, wastewater treatment procedures cannot efficiently remove them, and as a result, these plastic particles will enter rivers, oceans, and freshwater supplies[45]. Additionally, because the soil contains MPs and NPs, these materials erode naturally and end up in rivers and oceans[46]. According toUnited Nations Environment Programme(UNEP) statistics, 275 million tons of plastic garbage were generated in 2010, with an estimated 4.8–12.7 million tons ending up in drinking water sources[47].

2.1 Primary Sources

MPs and NPs are generated from two distinct sources (primary and secondary sources), primary sources are direct products of manufacturing companies or natural occurrences[48]; [49]. These MPs and NPsare mostly generated on purpose to serve industrial and personal applications[50]. Microbeads in face scrubs, cleansers with exfoliants, cosmetics, drugs containing NP in medication delivery packaging, electronics, paints, air blasting equipment for industry,boat hulls,and pellets used in the industrial production of plasticsare a few examples of primary sources[51].

2.2 Secondary Sources

Secondary sources of MPsand NPs are the by-products of larger plastic objects such as cigarette butts, road paint, equipment for fishing, synthetic textiles and clothing, fibers, anti-corrosive paint coatings, and general plastic debris deteriorating photolytically, physically, or biologically[50]. These items disintegrate into particles that are micron-sized or smaller, creating secondary sources of MPs and NPs.Sunlight, ultraviolet radiation, and atmospheric ozone can cause deteriorated or degraded polymer surfaces to fragment or split out and form MPs or NPs[52];[53].While aquatic habitats have not undergone comprehensive sampling for NPs, reports indicate the presence of both MPs andNPs in both terrestrial and aquatic environments[35; 50; 54-59].

Table 1: Some common forms and applications of MP and NP

Common Form of MP and NP	Size (gcm^{-3})	Use / Application	Reference
Fragments, Films, Foam	1.0 – 1.2	Textiles, sport clothing and shoes, pipes, Building materials	[19; 60]
	<0.05	Cups, plastic spoons	
	1.37	Packaging materials	
	0.96 – 1.1	Food flasks and plastic water bottles	[61]; [62]
Pellets	1.06 – 1.08	Protective Gadgets, 3D printing	[63]
Fibre	0-91 – 0.96	Plastic packaging bags, sponge, straws,	[42; 64]
	1.0 -1.2	Carpet, Fishing equipment, Face masks	[19], [65]
Bead	0.2 – 0.4	Facial cleansers, toothpastes, soap	[66]

3.Are Microplasticsand Nano-plastics Omnipresent in Human Foods?

MPs and NPs can occur in the environment as well as at home[67]; [68]. Studies have shown that MPs and NPs can be found in clothing and fabrics[69] food packaging[60] and personal care products[70], but there are most likely many more potential sources of MPs and NPs that are nevertheless unknown. Consumption of foods with both plant- and animal-based origins, additives in food and beverages, and plastic containers for food all expose people to MPs and NPs[33]. Due to the probability of MPsmoving up the food web, the consumption of polluted food poses a threat to both human health and food security[26].

3.1 MPs in Water

MPs have the potential to spread infections and introduce new microbial species to waters where they are not naturally present[71]. MPs can enter drinking water sources from a variety of sources, such as surface runoff from rainwater, wastewater runoffs (both treated and untreated), combined drain overflows, industrial effluent, degraded plastic trash, and atmosphere deposits[51; 72]. Drinking water may contain MPs due to the use of plastic water bottles and lids[73]. Research conducted by a Penn State researcher revealed that, on average, a liter of bottled water contains 325 plastic particles, whereas tap water contains approximately 5.5 plastic particles per liter[72]. Bottled water is often marketed as if it's purer than tap water, but numerous studies indicate that it's certainly not cleaner[72]. Considering all the available data, you're likely to consume significantly fewer plastic particles by drinking tap water from a glass than if you opt for bottled water[72]. MPs have the potential to release chemicals into the environment. A more significant concern is their ability to attract and concentrate heavy metals and organic pollutants dissolved in the water[74]; [75].

3.2 MPs in Vegetables and Fruits

In a studies[76-78]it was discovered that wheat and lettuce plants both ingested 0.2- and 2.0-mm PS beads along with the fact that the sap from the xylem was used to move the beads from the roots to the shoots during transpiration. Application of SEM-EDX approach to examine MPs and NPs in a range of fruits and vegetables, such as carrots, lettuce, broccoli, potatoes, apples, and pears[79]. Apples and carrots were the most contaminated fruit and vegetable samples respectively. According to the study, it was reported that the median levels of MPs in fruit and vegetable samples were 223,000 and 97,800 particles/g respectively[79]. A lower median amount of 52,050 particles/g was seen in lettuce samples. The MPs had sizes ranging from 1.36 to 2.52 meters[79]. The authors suggested that the higher concentration of MPsfound in fruits compared to vegetables may be due to the high circulation of the fruit pulp, as well as the tree's larger and more intricate root network system[79].

3.3 MPs in Proteins

MP pollution affects plankton, aquatic invertebrates, and vertebrate species like fish and marine mammals[26; 49]. MPs have been detected in fish and shellfish, and areas with elevated consumption of these aquatic organisms tend to exhibit higher levels of oral exposure to microplastics[80]; [81]. Fish is consumed by more than 3.3 billion people globally and accounts for roughly 20% of the average per capita consumption of meat and dairy products[74]. Fish consumption, however, may be harmful to human health. Adults who consume 300 g of the understudied fish species may ingest up to 16 MPs items per week and 842 MPs items per year, or 0.054 microplastic items per gram per week and 2.8 MP items per gram per year, according to a study by the EFSA[82].To investigate the presence of MPs in canned fish samples, specifically tuna, and mackerel, and to assess their composition, potential sources, and the likelihood of ingestion, a study was conducted using Micro-Raman and scanning electron microscopy with energy-dispersive X-ray analysis[83]. These techniques were employed to identify the polymeric forms and proportions of MPs present in the samples[83]. Their findings showed that fibers were the most prevalent form of MPs and that a minimum of one plastic particle was present in 80% of the samples[83]. In samples of canned fish, polyethylene terephthalate (32.8%) was the most prevalent type of polymer. The findings revealed that 80% of the samples had at least one plastic particle, with filaments being the most common form of MPs[83]. The fish itself, additives to food, or contact materials used during cleaning and canning are possible contributors to microplastics in canned fish[83].

Van Cauwenberghe and Janssen [84] explored the number of MPs found in supermarket-purchased kinds of seafood (farm-raised mussels and oysters) across Europe, they discovered several MPs debris in mussels and oysters. They reported that individuals consuming these species could be exposedto up to eleven thousand (11,000) microplastic particles annually. MPs have been found in the intestines of important sea species like lobsters and brown shrimp, and this is becoming a public health concern[85]. MPs monofilaments were discovered in 104 out of 165 wild brown shrimps examined, accounting for 63% of the samples[86], while MPs were found in 83% of 120 wild Nephrops taken from the Clyde Sea[87]. MPs were discovered in honey in a study conducted by Liebezeit, et al. [88], and the origins of the pollution were found to be the environment, where the particles were either brought into the hives by bees or introduced during the processing of thehoney, or both.

3.4 Nano-plastics in Food

The pervasive presence of NPs in various food sources poses a challenge as there are currently no analytical techniques available to reliably detect NPs in the food consumed by humans[89]; [90]. According to laboratory tests, species like algae, oysters, and crustaceans can consume NPs, likeMPs[90]. Because of this, NPs may also possess the ability to move up the food pyramid into the human body. It will be difficult to directly compare the effects of NPs on human health to other types of effects if we are unable to estimate the number of NPs in the environment accurately. Without the development and utilization of appropriate analytical methodologies, nano scientists run the risk of misinterpreting the results of their investigations[89].

Table 2: MPs in Food Items consumed by humans.

Food Item	MP Content	Analysis Technique	Reference
Seafoods			
Canned Sardine	>149 µm	RM, EDX	91
Mussel			92
Oyster	0.4s7 MP/g		84
Shrimps			86
Canned Fish (tuna and mackerel)	>1MPs/ individual	RM, SEM/ EDS	93
Commercial Shellfish in North and South China	0.8 – 4.4 and 2.1 - 4 MPs/g		94
Salt			
Sea Salt	0 - 1674 MPs/kg	FT-IR, RM, Pyr-GC-MS, SEM/ EDS	95
Lake salt	8 – 462 MPs/kg		
Rock and well salt	0 – 204 MPs/kg		
Water			
Bottled water	0 - 4889 MPs/L	FT-IR, RM, Pyr-GC-MS, SEM/ EDS	96
Tap water	0 – 628 MPs/L,		
Fruits /Vegetables (Plants)			
Apple	223,000 MPs/g	SEM-EDX	97
Carrot	97,800 MPs/g		
Others			
Sugar	0.44MPs/g		81; 98
Honey			

4.Routes of Microplastics and Nano-plastics into the Human Body

It has been reported that MPs and NPs (due to their sizes) can infiltrate and interact with human cells membranes in a variety of ways[99]. Because of their small size and ability to slip through cell membranes, NPs are thought to be more hazardous than MPs[100]. Due to NPs small specific surface area, it tends to interact differently with cells in a manner different from larger particles. Endocytosis, which takes place when NPs cling to channel or transport proteins or passively enter the cell membrane, is one of the main methods of NPsingestion. According to Kaksonen and Roux [101] a number of endocytotic mechanisms have been discovered, including "clathrin and caveolae-mediated, micropinocytosis, and phagocytosis". According to recent ecological examinations and environmental reports, there are three main routes that MPs and NPs can enter the human body: oral / ingestion (through the consumption of food or liquids), inhaled, and dermal. However, each of these three routes is responsible for only a fraction of the MPs and NPs found in the human body[102; 103].

4.1 Ingestion

Expectedly, MPs will be ingested since they are abundantly found in the food chain and water sources[104]. When this connection was initially suggested, the discovery of this ecological link underscored a potential health risk associated with the consumption of marine and aquatic organisms that had ingested plastic particles, with the subsequent transfer of these particles up the food webs[105;106]. NPs can be transported from the gut into the blood by M cells, where they can subsequently enter the lymph system, liver, and gall bladder[107]. It is evident that processed and plastic packagedfoods have a big impact on MPs and NPs migration[81; 108]. Some studies indicated that items such as extremely refined canned foods and less refined sources including salt, honey, rice, and granulated sugar, leads to the ingestion of varying degrees of anthropogenic particles[109; 110]. An average person is said to ingest over 5800 particles of synthetic debris from sea, tap water, and beer. The largest contribution comes from tap water[111].

Additionally, MPs and NPs have been found in a variety of beverages, including tap and bottled water, beer, wine, and bagged tea[70; 72; 102; 110; 112]. It has been reported that packaged tea had the highest nano materials, with one cup of tea containing an estimated 14.7 billion MPs and NPs[113]. Tap water was reported to have 4 microparticles per liter,while bottled water has 94 microparticles per liter[81]. This implies that the source and initial processing of the drinking water individuals use, whether it's bottled or tap water, will have a considerable impact on their ingestion of MPs and NPs. The MPs detected in bottled water spans through a very wide range, from 0.33 particles per liter[114] to 325.33 particles per liter[47].The minute size of these particles enables them to traverse various organs, posing a potential threat to human health[51]. Although MPs and NPs particles are detrimental to our health, they can be eliminated through human feaces[115].

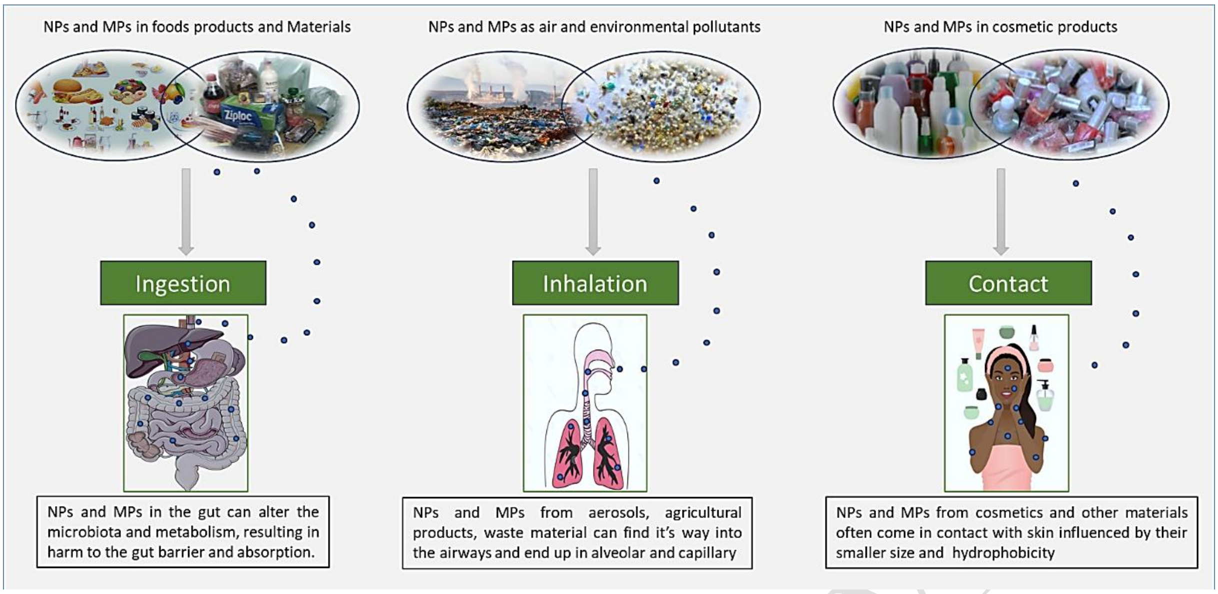

Figure 1: Routes for Microplastics and Nano-plastics into Human Body

4.2 Dermal Route

Numerous studies reveal that even when the skin barrier appears to be too thin for MPs or NPs to penetrate, there are still potential entry points for these particles, such as injuries, sweating pores, or hair follicles[116-118] Occasionally, using aesthetic and personal-care items that contain microbeads designed for exfoliation can result in cutaneous interaction with microfibers and MPs/NPs[119]. These consumer products may contain polymeric components, which may interact negatively with substances in our body's resin-based system and cause adverse reactions[120]. Due to the physiochemical characteristics of MPs and the requirement for stratum corneum infiltration to transport NPs across the skin, which is only possible for particles smaller than 10 nm and 100 nm, uptake via the skin is not certain[121]. Some reports has suggested that MPs could be exposed to atmospheric dispersal as a dermal contact through skin deposition[122; 123]

There were 800 bits of MPs in total on the skin as a result of its presence in several tissues[124; 123]. Additionally, it was demonstrated in vivo how skin interaction with MPs and NPs might cause oxidative damage to the efficient functioning of the dermis layer(epidermal cells) as the main physical and chemical barrier (skin's epidermis mechanisms) in humans[121; 125;126]. This mechanism allows for the penetration of external compounds into the skin as well as the expulsion of endogenous chemicals from the skin[125]. Consequently, MPs and NPs may not reach the human skin's deeper layers, but they may stick to the epidermis instead. However, contact with MPs or NPs that have chemical substances that have been contaminated may cause irritation and deeper absorption. As a result, study into the potentially hazardous effects of NPs and prolonged skin contact with plastic particles such as those found in dust, microbeads, and liquid hand cleansers is critical.

4.3Inhalation

MPs and NPs particles have been located and measured in indoor as well as outdoor air. In addition to synthetic textiles (such as carpeting, furniture, and clothing), automobile tire abrasion, and particles degraded from garbage, landfills, and emissions, dispersed plastic fragments can also come from sources other than these[122]. According to some reports, wind transfer has been identified as a possible cause for Alpine and Antarctic plastic particles inside snow samples[127; 128]. In atmospheric fallout, plastic microfibers have been detected and quantified as a mean concentration[129]. However,rainfall during these sampling has resulted into fluctuation of values. While outdoor environmental exposures are a significant cause for worry, interior air has been found to contain higher levels of plastic particle concentrations[129]. Depending on the indoor environment (house or workplace) and activity (such as blow drying vs. air drying of cloth; air filtration of heating or cooling units), indoor air measurements have recorded deposit rates that range from 1,600-11,000 MPs fibers/m^2 for each day[129].

Given the fact that humans are predicted to spend between 70% and 90% of their time indoors, this is particularly worrying[130]. In accordance with the human body and particulate attributes, inhaling plastic particles permits nose and lung deposition. Smaller and lower-density particles, like micro and nanosized plastic particles, are more likely to enter the lower airways and alveolar regions of the lung, while bigger particles may be eliminated through the conciliary escalator. Due to their large surface area and great potential for penetration, plastic fibers may be particularly challenging to eliminate from the respiratory tract[131].The operation of 3D printers may result in unintended plastic material losses, which in turn release NPs into the environment. Consequently, this plastic-polluted air will be breathed in by people living in the surroundings[132]. Furthermore,it reportedthat urban dust, as well as the decomposition of tires made of rubber and polyester fabrics, can be the source of airborne MPs that are inhaled[102]. It is significant to highlight that both unintentional releases from 3D printers and urban dust cause individuals to breathe in MPs and NPs. MPs were found in the human placenta[133]; [134]. These investigations also investigated the toxicity of being exposed to atmospheric MPs. In a simulated approach[135], it was reported that a notable presence of MPs, with 272 MPs/day detected in indoor air samples that humans inhale. Utilising mFTIR, MPs were also identified in human lungs, including nodules of powdered glass[136].

Reflecting on earlier research into plastic and its impact on health[137], plastic fibers were discovered in 99 out of 114 fresh human lung specimens, obtained from both non-neoplastic and cancerous lung tissues with more often occurring plastic fiber observations in the cancerous tissues. According to their subsequent study[137], inhalation of bio-resistant and bio-persistent plastic fibers could lead to allergic reactions, persistent inflammation, and the development of either cancerous or non-cancerous lung illnesses in humans. It was hard to distinguish between the MPs seen coming from natural fibers or synthetic polymers using the study's methods. More recently, RM spectroscopy was used to find MPs in human lungs obtained from autopsies[138]. The limitations of the approaches currently utilized to analyse MPs exposure in the air, as well as paucity of MPs exposure data, have impeded the development of MPs inhalation toxicology. Exposure characterization methodologies must be developed in the future to assess the dangers associated with MP exposure by inhalation.

5.Effect of Microplastic and Nano-plastics on Human Health

MPs have the potential to accumulate within the cellular and tissue structures of organisms, thereby presenting prolonged adverse effects on biological well-being and potentially endangering human health. These potential risks encompass the development of ailments such as cancer, infertility, digestive complications, respiratory issues, impaired immune system functioning, and modifications in genetic material[139]. According to a study[140], MPs could serve as an ideal environment for potentially hazardous microorganisms. Upon entering water or food sources, MPscan support the survival, proliferation, and potentially impact the pathogenicity of bacteria, thus posing a potential risk to human health. In their review of 20 studies on the overall toxic effects of microplastics and nanoparticles in animal experiments[141], unveiled substantial evidence pointing towards genetic alterations, inflammation in various organs such as the gut, gills, liver, intestines, kidneys, and muscle tissues, accumulation of particles within bodily cells and organs, impaired digestion, disrupted circulation, and physiological processes, as well as changes in organ function.

5.1Additives and Polymer: Toxic Effect on Human Health

The functional qualities of elasticity, rigidity, ultraviolet stability, flame retardants, and colour are provided by additives, which also act as catalysts for polymer operations[142]. The average amount of additives in plastics discovered in MPs is 4% of the total weight of the material, although the number of additives in some plastics can reach 50%. The health of individuals can be negatively impacted by some additives, particularly catalysts composed of metals e.g., Sb and Zn[143]. Polymers that have been exposed to contaminants and bacteria that are pathogenic for a long time begin to deteriorate and become activated within human surroundings[144]. Studies conducted by some researchers have demonstrated that the leakage of the chemical bisphenol A (BPA) from food containers into consumables can potentially contribute to the development of a range of diseases, notably obesity and cardiovascular ailments[145-147]. BPA functions as a hormone disruptor by mimicking or interfering with the normal functioning of hormones in the human body. This compound is a widely used industrial chemical employed in the production of polycarbonate (PC) plastics and epoxy resin, commonly found in the internal coatings of food and beverage containers.

BPA is known to harm developing foetuses by affecting how their brains develop in the womb[148]; [149]. Additionally, the exposure to microplastics and nanoparticles has been linked to alterations in reproductive and neurological processes, changes in insulin resistance and liver function, fetal damage, and adverse effects on the developing fetal brain[150]. The utilization of polycarbonate baby bottles resulted in significant leaching of BPA. It is worth noting that new-borns are expected to experience a higher internal accumulation of BPA compared to adults, which is reflected in their blood or plasma levels[151]. This discrepancy can be attributed to factors such as increased absorption or slower elimination of BPA in new-borns. According to research conducted[152], BPA has been found to alter the activity of pancreatic beta cells. Additionally, BPA acts as an agonist for receptors that interact with estrogen, thereby affecting their normal function. It has also been observed to suppress the production of thyroid hormones by acting as a neutralizer[153].Furthermore, BPA inhibits the activity of estrogen receptors. Human exposure to BPA at concentrations of 0.2 - 20 ng/mL has been linked to an increased likelihood for weight gain and heart failure[154], as well as several various reproduction and developmental disorders[155].

Phthalate esters are commonly used as plasticizing agents in the manufacture of polyvinyl chloride (PVC) polymer and plastisol to improve their durability and malleability[107; 156]. Studies have proven that being exposed to phthalate esters in humans is linked to abnormal genital growth and abnormalities in reproductive hormone balances[157]. In addition, certain phthalate esters, such as butyl benzyl phthalate (BBP) and di-2-ethylhexyl phthalate (DEHP), have been associated with an increased risk of tumour development in individuals, suggesting their potential carcinogenicity[50]. It was reported that human monocytic cells exhibit a high susceptibility to the absorption of 20 nm Polystyrene (PS) particles, indicating a significant hazard[158]. Interestingly, larger nanoparticles (100 and 1000 nm) could induce a measurable respiratory burst in monocytes and stimulate the release of chemokines and cytokines, such as IL-6 and IL-8, from macrophages and monocytes. Additionally, MPs-induced toxicity was found to inducethe production of reactive oxygen species (ROS) in T98G and HeLa cells, albeit at modest but detectable levels[159]. In their experimentation using Caco-2 cells, NPs measuring 0.1 and 5 µm induced relatively low levels of toxicity[160]. However, these NPs were found to cause dehydration of mitochondria and hinder the functioning of the toxic substance removal pump, thereby intensifying the toxic effects of NPs. Similarly, examined various cell types derived from humans and mice and discovered that high levels of 20 µm MPs triggered the production of ROS and resulted in cytotoxicity[161]. Furthermore, MPs were found to stimulate the production of inflammatory cellular histamine and increase the levels of inflammatory cytokines, including IL-6 and TNF, from human blood vessel mononuclear cells[161]. In a study of cytokinesis-block micronucleus assay, it was observed that 100 nm Polystyrene nanoparticles in NPs led to an elevation in ROS generation, induced cellular stress, and caused DNA damage[162].

5.2 MPs and NPs in the Brain

MPs and NPs can enter the brain after ingestion, however there is minimal evidence on the quantity of particles that reach the brain and the potential neurotoxicity of these small plastic particles[163-165]. Although the data is limited, it appears that exposure to MPs and NPs might cause oxidative stress, potentially leading to cellular damage and an increased risk of neurological diseases[163-165]. Small plastic particles havebeen found in the organs and tissues of zooplankton, mussels,crustaceans,and the brain of fish[164; 166]. However, the reported absorption in aquatic species is typically minimal (30-50 particles per aquatic species[139]. The exposure of Japanese rice fish to fluorescent polysterene nanoparticles revealed that the particles were detected in the brain demonstrating that NPs could traverse the blood brain barrier (BBB). Unfortunately, particle concentrations in the brain have not been quantified[141]. In a comprehensive review on the neurological risks associated with MPs and NPs[141] compared their findings to previous research focusing on metallic and metallic oxide nanoparticles, specifically gold (Au) and titanium dioxide (TiO2), which could enter the brain and giverise to various detrimental consequences[141]. Additionally, the review examined the evaluation of MPs and NPs in relation to these particulates. Furthermore, exposure to MPs and NPs might result in acetylcholinesterase inhibition and changed neurotransmitter levels, both of which may contribute to the reported behavioral abnormalities. In recent research, young and old C57BL/6J mice were assessed using behavioural assays such as open-field and light-dark preference after a three-week exposure to water treated with fluorescently labelled pristine polystyrene MPs, followed by tissue analyses using fluorescent immunohistochemistry, Western blot, and qPCR[167]. Thefindings demonstrate that short-term exposure to MPs causes behavioural changes as well as changes in immunological markers in both liver and brain tissuesand the effects of exposure appear to be age-dependent[167].

5.3 MPs and NPs in the Ovary

Studies have found that MPs can cause reproductive harm in animals[168; 169]. 2.0 mg/kg of polystyrene microplastics (PS-MPs) significantly raised the atretic follicle ratio in the ovary and significantly decreased blood levels of estrogen and progesterone[168]. Furthermore, the activity of oxidative stress markers such as superoxide dismutase and catalase were significantly decreased[168], indicating that PS-MPs exposure could induce ovarian injury associated with oxidative stress. PS-MPs was detected in different components of ovarian tissue[170]. The toxicity of accumulating PS-MPs was evidenced by decreased relative ovarian weights, changes in folliculogenesis and estrous cycle length, and decreased blood estradiol concentrations[170].MPs could exhibit negative effects on the ovary and might be a risk factor for female infertility, providing fresh insights into the toxicity of MPs on female reproductivity[171; 172]. Several investigations in female mice revealed that exposure to PS-MPs increased the likelihood of bigger ovaries with fewer follicles, lowered the number of embryos generated, and decreased the frequency of pregnancies. It also altered sex hormone levels and generated oxidative stress, both of which might affect fertility and reproduction[171; 172].

A reduction in the activity of glutathione peroxidase (GSH-Px), catalase (CAT), and superoxide dismutase (SOD) coupled with an elevated expression level of malondialdehyde (MDA) in ovary tissue suggests that oxidative stress might activate this mechanism[173; 174]. According to a similar report, MPs produce fibrosis via the Wnt/-Catenin signaling pathway and granulosa cell death via oxidative stress, both of which result in a loss in ovarian reserve capacity in rats[175; 176]. PS-MPs induced granulosa cell death by apoptosis and pyroptosis via activation of the NLRP3/caspase pathway and disruption of the Wnt-signaling pathway[175; 176]. The activation of TL4/NOX2 resulted in uterine fibrosis and endometrial thinning[175; 176]. The PS-MPs reduced ovarian capacity, oocyte maturation, and oocyte quality[177]. According to research on two different kinds of nanoparticles composed of polystyrene and mesoporous silicate[178]. The data they acquired for their investigation proved that ovarian cancer cells assimilated the two kinds of nanoparticles through various endocytotic routes. These nanoparticles showed distinct changes in cellular absorption pathways in human ovarian cancer cells[178].

5.4 MPs and NPs in the Lung

The epithelial layer cells engage in the process of endocytosis, which is accountable for the retention of MPs within the lungs. These MPs, upon inhalation, can induce significant oxidative stress as highlighted[179; 180]. In individuals with compromised lung clearance mechanisms, the inhalation of these MPs can result in both acute and chronic inflammations in the lungs[167]. Notably, studies involving human cadavers have provided evidence of MPsaccumulation in the lungs, where the lengths of these accumulated particles have been found to exceed 250 μm[181]. NPs possess a small size that enables them to bypass most lung filtering mechanisms and penetrate deep into lower layers of the human respiratory system, including the alveoli[182]. Additionally, it has been observed that both MPs and NPs can be found in the bloodstream, indicating their ability to traverse biological barriers and circulate within the body[182; 183]. Numerous studieshave documented the interaction between blood proteins, including globulin and albumin, with nanoparticles, resulting in the formation of protein-plastic compounds[184]. Accumulation of these protein-plastic aggregates, if present in substantial quantities, could potentially lead to vascular obstruction[182]. When red blood cells

(RBCs) were loaded with NPs at a relatively low ratio of 1:50, no adverse effects on RBC activities were observed[185]. However, higher loads of NPs, ranging from 10 to 50 times greater, caused impairments in RBC function due to various stressors such as mechanical, osmotic, and oxidative stress[185]. Nevertheless, it is highly unlikely for a significant and severe accumulation of NPs to occur in a person's bloodstream under normal circumstances[185].

Table 3: The effect of MPs on Human Health

Body Part	Health Effect	Polymer/Additive Identified	Reference
Liver, bladder, kidneys, lungs, skin, intestine	Carcinogen, gastrointestinal damage, Liver and Insulin dysfunction.	LDPE, BPA, BBP, DEHP, PVC,	[186187188]
Breast	Breast cancer	PBT, PE, PVC, PET	[18952]
Brain	Disruption of DNA, mental disorder, and brain damage in the fetus	PU, BPA	[190150]
Blood	Anaemia (less Hb)	All types of plastics with red pigments	[191], [192]
Heart	Cardiovascular disease including Hypertension.	PE, PVC, PP	[193], [149]
Bone	Variations in metabolic rate, bone osteocalcin, and bone fractures in postmenopausal women	PVC, all plastic type with red pigments	[188]; [191]
Ovary, Testes	Fetus damage, birth defects, Congenital abnormalities; Infertility	PVC, BPA, BBP	[194], [157]

6.Management Microplastics and Nano-plastics in our Ecosystem

6.1Legislative measure

Prioritizing the regulation of MPs/NPs production and implementing measures to eliminate their presence in water systems are important goals[195]. Legislative efforts to control the generation of MPs and NPs have already been initiated in various countries. A significant contributor to the presence of MPs in the environment is the use of these materials in cosmetics and personal care products. In 2017, the United States banned the use of MPsand NPsbeads in the production of cosmetics, demonstrating a proactive approach. Similarly, other nations, including the European Union, Australia, and Canada, are considering appropriate actions to minimize the inclusion of MPs in products, indicating a global trend toward reducing the impact of MPsand NPs in the environment[195].

6.2 Use of Recycle Mechanism

Given that 50% of plastic goods are created for one-time-use purposes and are quickly thrown away, the build-up of plastics and their by-products of breakdown in our surroundings has consistently increased over the past few years[196]. Plastics from thrown-away packaging constitute a sizeable portion of all solid refuse that is dumped in landfills. As microbial heat is produced, they either remain unmodified or disintegrate into fragments (micro or nano plastics), which then metabolize into the air or aquatic environments, producing carbon dioxide as well as water[197]. Therefore, recycling waste made of plastic is a useful method for getting rid of or reducing MPs and NPs pollutions[64].

6.3 Improve the use of Biodegradation.

Another successful strategy to lessen the amount of plastic in ecosystems is to use recyclable materials[53]. This involves physical, chemical, or biological techniques used to degrade environmental contaminants, notably MPs and NPs[77; 198]. According to earlier research, micro or nano contaminations can be removed or reduced using chemical and physical approaches; however, these techniques can create fresh contaminants or have partial degrading effects[53; 199]. The limitations of the conventional methods of pollutant degradation can be solved by using biodegradation[94]. Due to its great efficiency and lack of adverse reactions, biodegradation is a key factor in the removal or reduction of MPs or NPs contamination from the environment. According to Sharma, *et al*. [200] materials that degrade are often made from reusable raw materials such as starches, cellulose, ethanol from biomass, and phenol. Several compostable bioplastics that degrade easily can be broken down by microbial into nutritious cellulose in three months with no poisons or waste after disintegration[195].

6.4 Improved Biotechnological and Engineering Use of Polymers

Extracellular carboxylesterases are helpful in the decomposition of recyclable polyesters[201]. Various kinds of plastics can be degraded by certain microbes; for instance, PET can be degraded by '*Ideonellasakaiensis'*, and PE can be degraded by the marine fungus '*Zalerionmaritimum'*[202]. Precipitation and wind both affect how quickly MPs are cleared from the surrounding air[203; 204]. According to a report, the concentration of airborne MPs decreases with increasing height, and the resulting emission of MPs positively correlates with moisture[179].

6.5 Adoption of Separation Techniques

Nano-plastics in food can still be detected using currently-under-development technologies. However, the analytical method employed for researching nanomaterials is believed to be inappropriate[82]. This method entails separating the NPs in the dietary matrices, subsequently, the size is isolated after being detected which is often referred to as the process of identifying and quantifying NPs[205]

7. Conclusion

The buildup of MPs and NPs in our foodscausesworries about food safety and possible health consequences.Apart from the possible health dangers, the buildup of NPs and MPs in food webs may have an environmental impact. These plastics particles may infiltrate the environment through food production and processing, contaminating the land and water sources.Information about the danger of MPs/NPs in human health and the environment remains paucity. However,some studieshaveindicated the potential ofMPs/NPs to enter biological systems, it is important to note that the specific impact of MPs and NPs on human health remains still uncertain. Nevertheless, it is widely acknowledged that MPs and NPs pose various adverse effects on human health, including illness, disease, and potential organ damage leading to mortality. The study highlights the presence of MPsand NPsin processed foods and its implications for human health, emphasizing the need for further investigation in this area.

8. Future prospect

The prospects for MPs and NPs are worrying due to their widespread prevalence in the environment and potential effects on ecosystems and human health. Here are some important elements about their future:1) Collaborative efforts between government, industrialists, ecologists, and epidemiologists are required to investigate the bioaccumulation and effect of MPs/NPs in humans through the food chain across geographical areas. 2) Since the current quantitative methods has a lot of limitation, the role of artificial intelligent (AI) should be exploredtoquantify MPs and NPs in both environment and human body. 3) Since MPs and NPs are recalcitrant, the use of biological control such as microorganisms should be employed to degrade MPs and NPs in our environment.

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Appendix

ABBREVIATION	FULL MEANING
ABS	Acrylonitrile-Butadiene-Styrene
Au	Gold
BBB	Blood-brain barrier
BBP	Butyl benzyl phthalate
BPA	Bisphenol A
CAT	catalase

DEHP	Di-2-ethylhexyl phthalate
DNA	Deoxyribonucleic acid
EDX	Energy-dispersive X-ray spectroscopy
ETSA	European Textile Service Association
FT-IR	Fourier-transform infrared spectroscopy
GSH-Px	Glutathione peroxidase
LDPE	Low-density polyethylene
MDA	Malonaldehyde
MP	Microplastics
NP	Nanoplastics
PBT	Polybutylene terephthalate
PC	Polycarbonate
PE	Polyethylene
PET	Polyethylene terephthalate
PP	Polypropylene
PP	Polypropylene
PS	Polystyrene
PS-MP	Polysterene microparticles
PS-MPs	Polystyrene Microplastics
PU	Polyurethane
PU	Polyurethane
PVC	Polyvinyl chloride
Pyr-GC-MS	Pyrolysis gas chromatography/mass spectrometry
RBC	Red blood cells
RM	Raman spectroscopy
RM spectroscopy	Raman spectroscopy
ROS	Reactive oxygen species
SEM/ EDS	Scanning electron microscopy plus energy-dispersive X-ray spectroscopy
SOD	Superoxide dismutase
TiO_2	Titanium dioxide

TNF	Tumour Necrosis Factor
UNEP	United Nations Environment Programme