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A SYSTEMIC AND COMPLETE REVIEW ON NANOPLASTIC AND ITS IMPACT ON HUMAN HEALTH

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ABSTRACT

Plastics play a significant role in various aspects of daily life, including technology, medicine, and household appliances. However, the widespread single-use nature of plastics has led to a growing environmental crisis, as most discarded plastics end up in landfills, oceans, and waterways. Among the concerning pollutants are micro- and nano-plastics (MPs/NPs), which have emerged as a global environmental threat due to their persistence, accumulation, and potential risks to ecosystems. Recent studies have detected these microscopic particles in food products and air samples, raising concerns about human exposure. As plastics degrade from larger fragments to microscopic sizes, their potential toxicity to both the environment and human health becomes more alarming. Although numerous studies have explored the environmental impacts of MPs/NPs, there is still limited research on their effects at the molecular and subcellular levels in the human body. The rising concentration of NMPs, driven by increasing plastic production and consumption, highlights the urgency for comprehensive investigations into their possible health hazards. This growing issue has captured the attention of scientists, policymakers, authorities, non-governmental organizations, and the wider public.

KEYWORDS: *Micro/Nano plastics, Potential health hazard, Emerging global pollutant, Human consumption, Usage of plastic.*

INTRODUCTION

Plastic consumption is escalating globally, with production surpassing 368 million tons in 2019.[1] However, improper disposal of plastic waste remains a pressing issue. As plastic infiltrates every aspect of daily life, its gradual breakdown into micro- and nano-sized particles raises widespread concerns about its potential impacts on both the environment and human health.[2] A significant portion of plastic waste finds its way into marine ecosystems, with projections estimating that approximately 250 million tons could accumulate by 2025.[3] Consequently, plastic pollution represents a major environmental challenge.

Exposure to ultraviolet (UV) radiation accelerates plastic degradation through photo-oxidation, making the material brittle. Combined with mechanical forces like wind, waves, and abrasion, plastic fragments into microplastics (0.1–1000 μm)[4] and nanosized particles (≤0.1 μm),[5] collectively termed micro- and nano-plastics.

Microplastics can contain chemical additives introduced during manufacturing. These additives, not chemically bonded to the polymer matrix, are prone to leaching into the surrounding environment.[6] As microplastics continue to fragment, embedded chemicals may migrate along concentration gradients to the particle's surface. Upon ingestion, these pollutants can be transferred to surrounding tissues and bodily fluids, posing potential health risks.[7,8] If microplastics accumulate in biological systems, they could act as carriers of harmful chemicals, exacerbating their toxic effects.

Plastics and Co-contaminants

Plastic Stratigraphy and Its Long-Term Impact

As plastics accumulate and undergo stratification within sediment layers, they exhibit remarkable preservation potential, like that of recalcitrant organic fossils. These synthetic materials are so abundant and persistent in the environment that they have been termed "techno fossils," serving as enduring evidence of human activity on Earth.[9] Given the extensive and long-lasting nature of plastic pollution, some researchers have even proposed designating the current geological epoch as the "Plasticene" due to the profound impact of plastic waste on the planet's ecosystems.[10,11]

Microplastics (MPs) are defined as synthetic polymer particles or solid matrices with irregular or regular shapes, ranging from 1 μm to 5 mm in size. They originate either from primary manufacturing sources or as secondary fragments resulting from plastic degradation.

By their very nature, microplastics are water-insoluble and highly persistent in the environment.[12]

One of the primary concerns surrounding microplastics is their potential risk to ecosystems and human health. However, considerable uncertainty remains regarding their long-term effects. Understanding the exposure levels and toxicological impact of microplastics is essential for assessing the risks they pose. The adverse effects on organisms exposed to microplastics can be categorized into **physical** and **chemical** impacts. Physical effects are determined by the particle size, shape, and concentration of microplastics, while chemical effects stem from hazardous substances that microplastics carry.[13] Despite the increasing body of research on environmental microplastic exposure, limited data exist on the chemical contaminants associated with them.

Chemical Composition of Microplastics and Their Toxicological Concerns

Microplastics serve as carriers of two main types of chemicals:

1. **Additives and Polymeric raw materials** – These include monomers, oligomers, and chemical substances incorporated during plastic production.
2. **Adsorbed environmental pollutants** – Microplastics can attract and absorb harmful chemicals from their surroundings.

Additives in Plastics and Their Environmental Risks

Plastics are formulated with a wide range of chemical additives to enhance their functionality and durability. These substances improve resistance to external factors such as temperature fluctuations, ozone, humidity, microbial activity, and mechanical stress.[13] Some of the key additives found in plastics include:

- **Fillers and Reinforcing agents:** Materials like wood flour, kaolin, graphite, glass Fibers, cellulose pulp, and rock dust are incorporated to alter the mechanical properties of plastics. According to ASTM-D-883 definitions, inert fillers enhance workability and reduce shrinkage, whereas reinforcing fillers improve the strength and modulus of plastic materials. Examples include carbon black in rubber and various silica- or chalk-based fillers, which significantly enhance mechanical properties such as tensile and impact strength.[14,15]

- **Plasticizers:** These chemical compounds reduce the intermolecular forces between polymer chains, thereby improving flexibility and durability. Plasticizers are chemically stable, possess low volatility, and are insoluble in liquids. Their primary role is to increase plastic resilience during processing and usage.[16]

- **Stabilizers:** Given that plastics are susceptible to degradation from UV radiation and heat, stabilizers play a crucial role in preventing thermal decomposition, oxidation, and polymer chain breakage. These stabilizers commonly consist of organic or inorganic salts containing lead, cadmium, or barium.[17]

- **Dyes and Pigments**: Colorants used in plastics can be either organic or inorganic. Soluble dyes allow plastics to retain transparency, while insoluble pigments provide opacity. Some inorganic pigments contain toxic heavy metals, while organic pigments belong to diverse chemical families such as azo pigments, phthalocyanines, and anthraquinone chromophores.[18]

- **Lubricants and Anti-Adhesives:** Substances like calcium and magnesium stearates are added to enhance the flow properties of plastics during manufacturing.[19]

- **Flame retardants:** These additives help reduce the flammability of plastic materials by interfering with combustion processes. Some flame retardants release halogenated compounds (e.g., chlorine and bromine) upon exposure to flames, while others (e.g., phosphorus-based compounds) promote char formation, reducing the material's combustibility. Aluminium hydroxide is also used, as it generates water vapor and CO_2 at high temperatures, thereby slowing down fire spread.[19]

Toxicological Concerns and Environmental Impact of Additives

One of the major concerns regarding plastic additives is that most of them are not chemically bound to the polymer matrix. This means they can leach into the environment over time. Only a few flame retardants are chemically incorporated into plastic structures, forming stable polymeric chains.[18]

Despite their functional benefits, many of these additives are potentially toxic. They can enter soil, water, and air, leading to widespread environmental contamination. The long-term impact of these substances on human health and ecosystems remains an area of active investigation.[18] Studies suggest that aquatic organisms are particularly vulnerable to additive exposure, as they met microplastics through ingestion.[20,21]

Microplastics as contaminant carriers

Microplastics not only introduce hazardous additives into ecosystems but also act as vectors for environmental pollutants. Their high surface-area-to-volume ratio allows them to absorb and concentrate toxic substances such as persistent organic pollutants (POPs) and heavy metals. Over time, these pollutants can be released into air, water, and food supplies, increasing the risk of human exposure.

Given the complexity of microplastic pollution—including the variety of polymer types, sizes, and associated additives—humans and wildlife are potentially exposed to a mixture of chemical contaminants. These contaminants may accumulate in body tissues, leading to adverse health effects. Continuous research is needed to fully understand the implications of microplastic exposure on both environmental and human health.

Plastics and Human health

Microplastics, Co-Contaminants and Their implications for human health

Plastic polymers are generally considered to be inert and of low concern to human health, and health risks relating to their use are attributed to the presence of the wide range of plastic additives they may contain, together with residual monomers that may be retained within the polymer structure.[22]

Plastics are synthesised from monomers, which are polymerised to form macromolecular chains. A range of additional chemicals may be added during the manufacturing process, including initiators, catalysts, and solvents. Additives that can alter the nature of the final plastic include stabilisers, plasticisers, flame retardants, pigments, and fillers. Additives are not bound to the polymer matrix and because of their low molecular weight, these substances can leach out of the plastic polymer.[23] Into the surrounding environment, including into air, water, food, or body tissues.

Microplastics and nano plastics can enter the human body through three primary pathways: inhalation, ingestion, and skin contact.[24,25] Airborne microplastics, primarily originating from urban dust, synthetic textiles, and rubber tyres[26] are inhaled and potentially accumulate in the respiratory system. Additionally, ingestion remains a significant route of exposure, as microplastics are widely present in food and water sources.[27] While the skin generally acts as a barrier to these particles, they may still penetrate the body through wounds, sweat glands, or hair follicles.[28] Among these exposure routes, ingestion—particularly through seafood and environmental contamination—poses the highest risk. This is due to prolonged environmental degradation of plastics, the release of chemical additives, residual monomers, and the presence of pollutants and harmful microorganisms, all of which contribute to increased human exposure over time.[29-33]

Potential Toxic Effects of Microplastics and Nano plastics on Human Health

Extensive **in vitro** and **in vivo** research has demonstrated that microplastics and nano plastics can have detrimental effects on human health. These include cellular stress, tissue damage, programmed cell death (apoptosis), necrosis, inflammation, oxidative stress, and immune system disturbances.[34-37]

Inflammatory responses

Studies indicate that the size and composition of microplastics significantly influence their inflammatory potential. An **in vitro** study investigating polystyrene particles of varying sizes found that larger particles (202 nm and 535 nm) triggered a more pronounced inflammatory response in human A549 lung cells compared to smaller 64 nm particles.[38] The elevated inflammatory activity was evident through increased IL-8 expression. Additionally, both unmodified and carbonylated polystyrene nanoparticles caused a substantial upregulation of IL-6 and IL-8 genes in human gastric adenocarcinoma, leukaemia, and histiocytic lymphoma cells. This suggests that the inflammatory response may be attributed to the physical presence or composition of these particles rather than their surface charge.[39-40]

Oxidative Stress and Apoptosis

Exposure to polystyrene-based nanoparticles has been associated with oxidative stress, apoptosis, and autophagic cell death in a cell-specific manner. Certain amine-modified polystyrene nanoparticles have been observed to interact strongly with mucin, leading to apoptosis in both mucin-secreting and non-mucin-secreting intestinal epithelial cells. These findings suggest that nano plastics have the potential to disrupt cellular integrity and induce cell death via oxidative stress mechanisms.[41]

Disruption of metabolic homeostasis

Beyond inflammation and apoptosis, recent research highlights the impact of microplastics and nano plastics on cellular metabolism. Investigations using in vitro and in vivo models suggest that polystyrene nanoparticles can alter cellular signalling pathways, particularly in the respiratory system. Exposure to negatively charged, carbonylated polystyrene nanoparticles (20 nm) has been found to activate basolateral potassium (K^+) ion channels in human lung cells, potentially affecting ion homeostasis and overall cell function.[42]

CONCLUSION

The increasing global production and improper disposal of plastics have led to their pervasive presence in the environment, with significant concerns over their breakdown into microplastics and nano plastics. These particles not only persist in ecosystems but also pose potential risks to human health through ingestion, inhalation, and skin contact. Their ability to accumulate in biological systems raises concerns about their role as carriers of harmful additives and environmental pollutants. Microplastics and nano plastics have been linked to adverse biological effects, including oxidative stress, inflammation, apoptosis, and metabolic disruptions. Their small size allows them to penetrate cells, cross biological barriers, and interfere with vital physiological processes. Despite growing evidence on their toxicological impact, the long-term consequences of human exposure remain largely unknown. Further research is essential to fully understand the mechanisms of microplastic toxicity, their potential degradation within the human body, and their broader implications for health and the environment. Addressing plastic pollution through improved waste management and policy interventions is crucial to mitigating its long-term effects.

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