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THE IMPACT OF MICROPLASTICS ON HUMAN HEALTH THROUGH FOOD CHAIN

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dedication

This work is dedicated to my esteemed family members, Mr. Abdelmajid Boujnir and Mme Najat Malki, whose unwavering support and encouragement have played a pivotal role in facilitating my academic journey.

I would like to express my gratitude towards my sister, Wijdane Boujnir, for her steadfast faith in my abilities and the immense happiness and resilience she contributes to my existence.

I would like to express my sincere gratitude to my supervisor, Professor Maria Cristina Lavagnolo, for her invaluable guidance and wisdom throughout the entire process of developing this thesis.

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Table of Contents

REFERENCES

ANNEXES

Abstract

Microplastics (MPs) are a significant environmental concern on a global scale, as they infiltrate many ecosystems and pose risks to human health. The present study aims to examine the origins, pathways, and health impacts of microplastics (MPs), with a particular focus on their abundance in agricultural soils and their potential for contamination in the human food chain. This study conducts a comprehensive review of the abundance and characteristics of microplastics (MPs) in organic compost and sewage sludge, employing an analysis of existing research papers. This study also investigates the effects of MPs on soil qualities, plant development, and therefore, human health. A noteworthy finding is that although sewage sludge contains an important amount of MPs, which are primarily composed of fibres, fragments, and films made of Polyethylene (PE), Polystyrene (PS), and Polypropylene (PP), there is a lack of research that specifically investigates the presence of MPs in compost. This knowledge gap underscores the necessity for further research to fully understand the mechanisms by which MPs originating from compost enter the food chain and the subsequent health consequences that ensue.

Exposure of humans to microplastics (MPs), has the potential to induce adverse health effects such as respiratory and gastrointestinal disorders, oxidative stress, and carcinogenesis. This study advocates for a thorough evaluation of plastic utilization and waste management strategies in the agricultural sector, in accordance with the growing discourse surrounding issues of environmental contamination and the safeguarding of food quality.

Keywords: Compost, Food chain, Human Health, Microplastics, Sewage sludge

Astratto

I microplastici (MP) rappresentano una preoccupazione ambientale significativa su scala globale, in quanto infiltrano molti ecosistemi e rappresentano rischi per la salute umana. Il presente studio mira ad esaminare le origini, le vie e gli impatti sulla salute dei microplastici (MP), con particolare attenzione alla loro abbondanza nei terreni agricoli e al loro potenziale di contaminazione nella catena alimentare umana. Questo studio conduce un esame completo dell'abbondanza e delle caratteristiche dei microplastici (MP) nel compost organico e nel fango delle acque reflue, impiegando un'analisi dei documenti di ricerca esistenti. Questo studio esamina anche gli effetti dei deputati sulle qualità del suolo, sullo sviluppo delle piante e quindi sulla salute umana. Una constatazione degna di nota è che, sebbene il fango delle acque reflue contenga una quantità importante di MP, che sono composti principalmente di fibre, frammenti e pellicole di polietilene (PE), polistirene (PS) e polipropilene (PP), c'è una mancanza di ricerca che esamina specificamente la presenza di MP nel compost. Questo divario di conoscenze sottolinea la necessità di ulteriori ricerche per comprendere appieno i meccanismi attraverso i quali i deputati provenienti dal compost entrano nella catena alimentare e le conseguenti conseguenze per la salute.

L'esposizione degli esseri umani a microplastiche (MP), ha il potenziale di indurre effetti negativi sulla salute come disturbi respiratori e gastrointestinali, stress ossidativo e carcinogenesi. Questo studio sostiene una valutazione approfondita delle strategie di utilizzo delle materie plastiche e di gestione dei rifiuti nel settore agricolo, in linea con il crescente discorso che circonda le questioni di contaminazione ambientale e di salvaguardia della qualità degli alimenti.

Parole chiave: Composto, Catena alimentare, Salute umana, Microplastiche, Fumo di scarico

1. Introduction

Plastic products are everywhere around us, due to the advantages of; low cost, malleability, and durability, now, they are used in our daily life as well as the demand is increasing day by day.

Global production increased 4% in 2021 to exceed 390 million tonnes, indicating a robust and sustained demand for plastics. According to the most recent data, Europe's proportion of global plastics production, which topped 15% in 2021 after reaching 57.2 million tonnes, is continuing to drop, while China's share grew to 32% in 2021. (*Plastics - the Facts 2022 • Plastics Europe*, n.d.) There is no denying that the issue of plastic waste is a serious environmental concern. People are becoming more aware of how important it is to recycle plastic, but in 2015, about 250 million tonnes of plastic was released into the ocean, showing that plastics are still harmful to humans as well as the environment, even though humans are recycling them.

Plastics can degrade in the environment through ultraviolet (UV) radiation, wind or water erosion, and other physical, chemical, and biological drivers that generate smaller pieces of plastic waste: Microplastics, nanoplastics, and mesoplastics are distinct categories of plastic debris differentiated by size. Microplastics are defined as particles smaller than 5 millimeters, (*Proceedings of the International Research Workshop on the Occurrence, Effects, and Fate of Microplastic Marine Debris*, 2009). Nanoplastics, considerably smaller, are classified as being under 100 nanometers, (Gigault et al., 2018). Mesoplastics, falling between microplastics and larger plastic debris, are typically sized from 5 millimeters to 20 millimeters, (Barnes et al., 2009) and they can originate from primary or secondary production (Frias & Nash, 2019) Microplastics (MPs) are usually categorized as particles that range in size between 5 mm-1 μm (Figure 1.). Notably, microplastic particles are not the end products of plastic waste as they decompose into nanoplastics.

Polyethylene (PE), polyvinyl chloride (PVC), polypropylene (PP), polyethylene terephthalate (PET), and polystyrene (PS) are the plastics that are most often found in the environment (Rochman et al., 2013). How different plastics are made directly affects how they react with other pollutants and the damage they do to the world (Amelia et al., 2021). Low-density polyethylene (LDPE), PVC, PS, PP, and PET are the plastics that are used the most and are in large amounts. About 75% of all plastic used in Europe and 90% of all plastic used in the world comes from these materials. (Plastics - the Facts 2022 • Plastics Europe, n.d.).

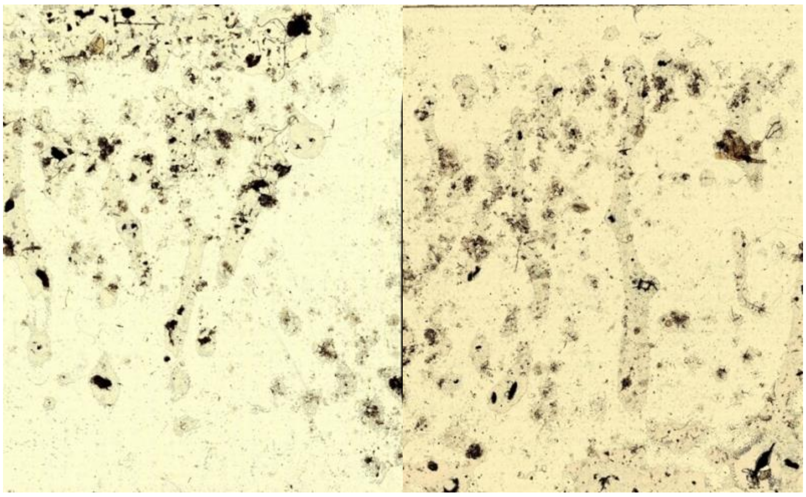

Figure 1. A micro-Raman of glass microscope specimens containing fragments of MPs. (University of Padova, Department of Environmental Engineering)

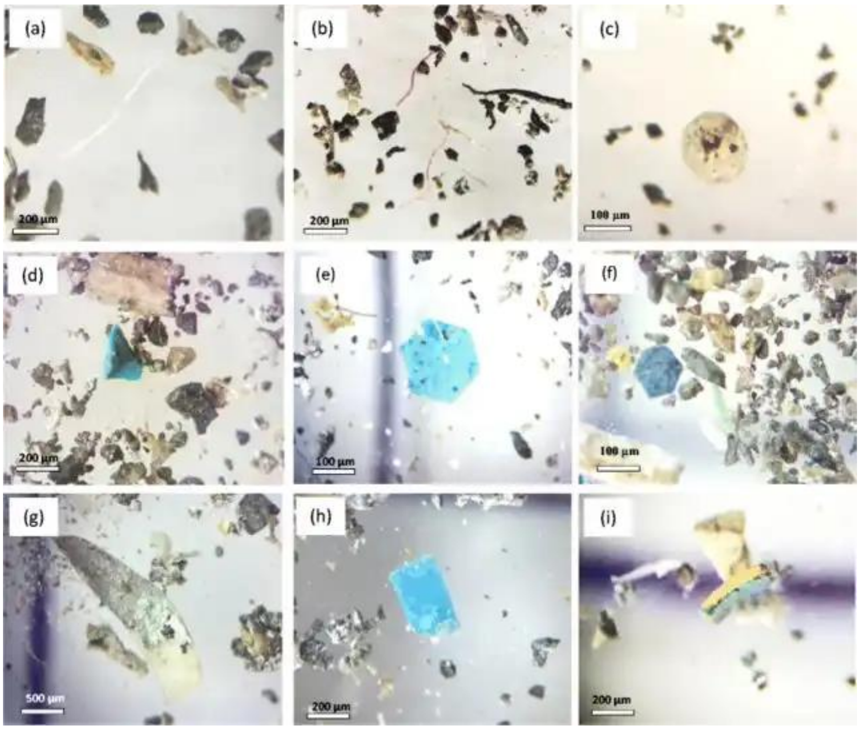

Figure 2. The optical microscope image of microplastics (Dehghani et al., 2017)

Considering the source of microplastics, they are divided into two types, primary and secondary (Cole et al., 2011). Primary Microplastics may reach individuals directly through inhalation of airborne particles, via food products, and via dermal exposure.

personal care products, such as facial scrubs and shower gels, are a significant source of microplastic pollution in the environment (Hernandez et al., 2017); (Bashir et al., 2021); (K. Lei et al., 2017). These products often contain microbeads made of polyethylene, which can fragment into smaller, potentially more hazardous nanoplastics (Hernandez et al., 2017). In China, the use of personal care and cosmetic products is estimated to release 39 tons of microplastics into the environment (K. Lei et al., 2017).

Other sources of MPs are synthetic fibers from clothing and the laundry process, the manufacturing and processing industries, and the breakdown of larger plastic debris (X. Li et al., 2018); (Mahon et al., 2017) (Figure 3).

Environmental factors, including wind, waves, and ultraviolet light, contribute to the decomposition of large plastic items, which generates secondary microplastics. (Cooper & Corcoran, 2010); (Rocha-Santos & Duarte, 2014). Moreover, they originate from additional sources, such as mulching, organic compost, and sewage waste. After wastewater treatment, sewage sludge has been shown to include microplastics, which are then used as compost in fields on land. Similarly, municipal solid waste contributes to microplastics found in organic compost. Mulching stands out as another noteworthy source of microplastics in terrestrial environments.

Another significant source of microplastics in terrestrial fields is mulching, and it is noteworthy that there is a scarcity of studies examining microplastics from mulching. Existing research predominantly concentrates on sewage sludge as a primary source, overshadowing the considerable impact of microplastics on terrestrial fields. (Huang et al., 2020) initially proposed the mulching hypothesis. The research substantiates this hypothesis, providing concrete evidence that extensively employing plastic mulching films is directly associated with the presence of both macroplastics and microplastics in agricultural soils, particularly in China. The investigation establishes a clear correlation between the consumption of plastic mulching films and the presence of microplastics in the soil. Additionally, areas with a prolonged history of plastic mulching exhibit a consistent increase in microplastic abundance over time. Fourier transform infrared analyses further verify that the composition of microplastics aligns with that of the mulching films, establishing a direct link between the two. These collective findings affirm that plastic mulching significantly contributes to both macroplastic and microplastic contamination in terrestrial environments. However, our study will specifically focus on two primary sources—organic compost and sewage sludge—due to the limited studies addressing the mulching source of microplastics. Nowadays, the extensive use of plastics and their widespread occurrence in the environment has resulted in the presence of MPs in the food chain and exposure of consumers.

A recent review of the human intake of MP from food gave an estimate of 39,000 to 52,000 particles per year. (Cox et al., 2019)

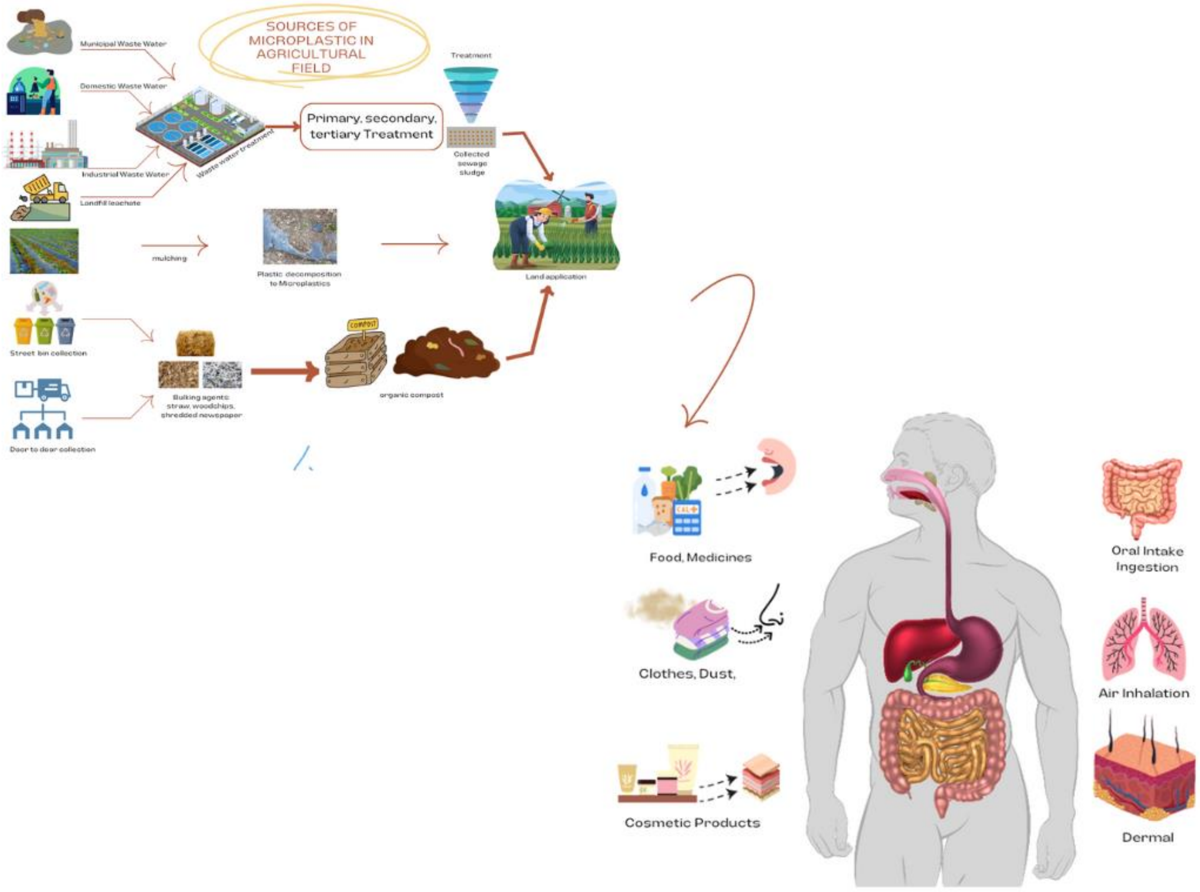

Figure 3. The sources of microplastics and the Potential exposure routes on humans. (Manal Boujnir., 2023)

MPs may be beads, pellets, granules, films, foams, fragments, or microfibrils, among other variations in size, shape, structure, additives, and surface topography (Figure 4). Such physical properties of soil as bulk density, aeration, and water-holding capacity, among others, may be affected by these various varieties of MPs. In addition to changing the soil's physical structure, MPs may also change the biogeochemistry of the soil in different ways. Soil-dwelling microflora and fauna may be impacted by chemical additives utilised in the manufacturing of MPs.

While many studies have explored the impact of MPs on oceans, research on their effects on soil and humans is limited.

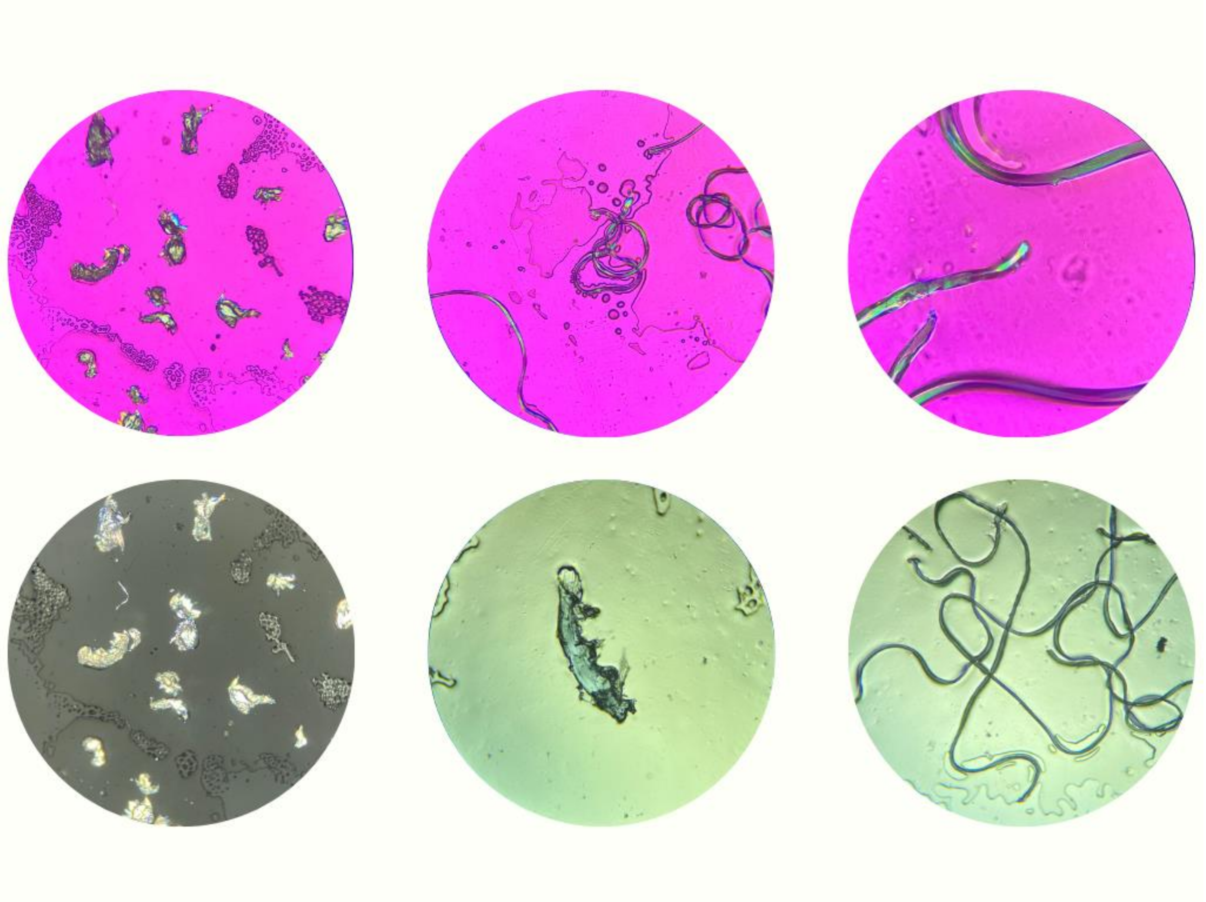

Figure 4. Several shapes of Microplastics: Fibers and some Fragments (University of Padova, Department of Environmental Engineering)

2. MATERIALS AND METHODOLOGY

2.1 Objectives of the research

Microplastics (MPs) are persistent environmental contaminants with the capacity for long-term persistence. Understanding their fate and transformation in agricultural soils, their passage through plant systems, and their potential impact on human health along the food chain is imperative. This study seeks to elucidate the pathways taken by MPs to reach plants and their potential impact on human health. This study is driven by several key objectives:

- Identification of sources:

To conduct a comprehensive literature review to identify the main sources of microplastics in agricultural soils, whether from sewage sludge or organic compost. This objective aims to provide a clear understanding of the genesis of MPs in agricultural environments.

- Impact on agricultural soils:

To investigate the effects of microplastics on agricultural soils, in particular their impact on soil physical and chemical properties. By investigating these effects, it will be possible to determine how the presence of microplastics may affect soil quality and fertility.

- Pathways to human health:

To investigate the pathways by which microplastics affect human health through the food chain. This objective aims to identify the various pathways by which MPs can enter the human body through the consumption of contaminated crops.

- Assessing health impacts:

Assessing the potential health consequences of exposure to microplastics through the food chain. By assessing the impact on human health, the aim is to raise awareness of the risks associated with the contamination of agricultural products by microplastics.

In essence, this research project is designed to shed light on the complex interactions between microplastics in agricultural soils and their potential impact on human health. By addressing these fundamental objectives, it is envisaged that valuable insights will be contributed to the broader discourse on environmental pollution, food safety and sustainable agricultural practices.

2.2 Methodology and instruments

The methodology employed in this research centered on a comprehensive literature review to investigate the abundance, size, shape, and color characteristics of microplastics (MP) in organic compost and sewage sludge across different countries. The study covers publications available up to 2023 and utilizes several scientific databases, including PubMed, Web of Sciences, and Scopus. The detailed steps and search strategies used are described below:

- **Search Databases**

Web of Sciences: A search was conducted using the following keywords: "microplastics," "compost," and "soil." This search produced 8 relevant articles.

- **PubMed**

Extensive keyword combinations were used to ensure full coverage: "microplastics" and "pollutant," "microplastics" and "soil," "compost" and "pollution," "compost with microplastics," "microplastics in compost," "microplastics" and "compost," "microplastics" and "sludge" and "wastewater," "microplastics" and "sludge" and "concentration," "microplastics" and "sludge" and "soil," "microplastics" and "sludge." This exhaustive search yielded 91 relevant publications.

- **Scopus**

A targeted search using the keywords "soil," "microplastics," and "compost", yielded 1 relevant publication.

2.3 Process of the research

Given the limited number of studies specifically on microplastics in organic compost, a multi-database approach was used. PubMed proved to be the main source of data, using a variety of keywords to ensure comprehensiveness.

- Identification of Publications

The number of publications on compost was 50 (41 from PubMed, 1 from Scopus, and 8 from Web of Sciences).
The number of publications on sewage sludge was 55 from PubMed.

- Selection Process

The selection process consisted of a careful assessment of titles and abstracts for each outcome. Articles were considered eligible if they met the predefined criteria. In cases where it was unclear from the title and abstract whether the article was eligible, a more detailed examination of the article content was undertaken. Literature reviews were excluded, with an emphasis on publications providing empirical data on PM abundance, size, shape, and color.

- Final Selection Criteria

Out of 50 published studies, only 10 were selected for their relevance to the abundance of MPs in organic compost.

From the 55 publications related to sewage sludge, 16 studies were selected based on their focus on microplastics.

- Data Compilation

The selected literature was further reviewed to meet the inclusion criteria. Relevant information from the selected studies was systematically collected and organized in a dedicated database. The resulting dataset includes both organic compost and sewage sludge, each with its own table. Key data includes title, authors, year of publication, DOI, country of study, sample size, source of compost or sludge, MP frequency, size, shape, and color characteristics.

This research uses a rigorous and comprehensive methodology to collect and analyze critical data on microplastics in organic compost and sewage sludge. The resulting database provides a valuable resource for understanding the prevalence and characteristics of PM in these environmental matrices, contributing to the wider discourse on plastic pollution and environmental sustainability.

The last portion of our study also included a review of the literature on the investigation of microplastics in soil and their impacts on microorganisms, plants, and human health. We used PubMed as our main source of data and followed the previously outlined method. To guarantee accuracy and relevancy, the chosen articles were carefully examined. We carefully extracted and then examined the data relevant to our research question. After conducting this study, a comprehensive table was produced that clearly states whether or not microplastics have an effect on human health. Our results were presented in an understandable and succinct manner thanks to our methodical methodology.

2.4 Limitation of the research

The present study has several limitations that need to be acknowledged and explored in the future. Firstly, there is a critical need for the development and application of analytical methods specifically tailored to detect microplastics in different types of food.

In addition, a limitation of our research is the paucity of studies assessing the abundance of microplastics in organic compost. While our results showed a significant presence of microplastics in sewage sludge, it is imperative to recognise the underrepresentation of research focusing on the occurrence of microplastics in organic compost. Conducting thorough laboratory tests on different samples of compost, whether organic or sewage sludge-based, would contribute to a more nuanced understanding of the distribution and abundance of microplastics in these waste streams.

In addition, the origin, and sources of microplastics in agricultural fields may vary considerably from one geographical location to another. To address this, it is recommended that region-specific studies be conducted to identify the unique sources contributing to microplastic contamination in agricultural soils.

The impact of microplastics on human health remains an area of uncertainty and further studies are essential to elucidate the pathways by which these particles may affect human physiology.

While our research provides valuable insights into the prevalence of microplastics in organic compost and sewage sludge, the limitations identified highlight the need for more comprehensive and targeted investigations. Addressing these limitations will not only improve our understanding of the presence of microplastics in different environmental matrices but also promote informed strategies to mitigate their impact on ecosystems and human health.

There is no limit or maximum value, so it is impossible to estimate the potential hazard of the number of MPs that have been found. Considering this, we propose further research be done in order to set a limit on the number of MPs, which would signal potential harm to the soil ecosystem.

The sources, fate, and interactions of MPs with soil flora, food crops, and microorganism are all now poorly understood. To fully comprehend MPs' impacts on the environment and how they affect agriculture, we must assess their dispersion, conveyance, and deterioration.

3. RESULTS AND DISCUSSION

3.1 Microplastics in organic compost and sewage sludge

The analysis of 16 studies focusing on microplastics (MPs) in sewage sludge and another 10 studies examining MPs in organic compost, spanning 15 diverse countries including China, Spain, Ireland, Turkey, Thailand, Australia, India, Iran, France, Germany, Netherlands, Lithuania, and the Czech Republic, has yielded several noteworthy insights. (Figure 5).
Notably, China emerged as a prominent subject of study with 7 research projects dedicated to it. This preponderance can be attributed to China's vast geographical expanse and its concurrent heightened risk of pollution, which has instigated a surge in research endeavors to both comprehend the issue more comprehensively and identify effective mitigation strategies.

Figure 5. The countries of the selected case studies (Manal Boujnir., 2023)

We certainly notice a lack of information about African countries, but this doesn't mean there aren't any studies regarding the presence of microplastics. Especially considering that many African countries may not have advanced wastewater treatment systems, and waste disposal rates are often very high. However, there hasn't been a study that includes the specific information we need for our current research, which is why there are no case studies in Africa for the current research project we are conducting. Nevertheless, it's crucial to conduct precise studies in African countries to assess the risk of microplastics and determine their exact prevalence.

To facilitate an effective comparison of the data culled from these 26 studies, we've thoughtfully organized it into two comprehensive tables. The first of these tables is devoted to juxtaposing the abundance of MPs in distinct global regions, with the results thoughtfully represented in Figure 6 and Figure 7. It's pertinent to note that our inclusion criteria were stringent; solely studies reporting MPs abundance in specific units such as particles per kilogram, items per kilogram, or MPs numbers per kilogram were considered. Values presented in the format of N° of MPs per gram were deliberately omitted to ensure data uniformity. With the elimination of the articles that mentioned the values in mg or g/kg.

In figure 6. is reported that the average of MPs abundance in 10 countries. The countries with the star (*) mean that it is the average value of several studies conducted in the same country: for China, 74000 items/kg (Z. Chen et al., 2020) 9790 items/kg (Yuan et al., 2022) 561050 items/kg (L. Jiang et al., 2022) 27200 items/kg (B. Zhang et al., 2023) 41300 items/kg (J. Jiang et al., 2020). The average value is 142668 items/kg.

For Spain, 183000 items/kg (Edo et al., 2020) 30940 items/kg (Hernández-Arenas et al., 2021), and 25035 items/kg (Van Den Berg et al., 2020). The average value is 79659 items/kg.

The highest value recorded in China is 561050 items/Kg in Ningbo city.

Ningbo City has a remarkable prevalence of microplastics (MPs) in its sewage sludge due to several interrelated factors. Rapid urbanization and a dense population contribute to increased plastic consumption and waste generation. For example, Ningbo's population will exceed 9 million by 2020 (*Population: Census: Zhejiang: Ningbo | Economic Indicators | CEIC*, n.d.), resulting in significant plastic consumption. The city's status as an industrial center is significant, with over 10,000 industrial enterprises operating in the area (Population: Census: Zhejiang: Ningbo | Economic Indicators | CEIC, n.d.), contributing to the release of MPs directly into the environment. Inefficient waste management practices, including a low recycling rate and improper disposal of plastics, also play a role. Stormwater runoff during heavy rain events carries MPs from urban surfaces into the wastewater treatment system. With an average annual rainfall of 1,650 mm (*Ningbo Climate: Weather Ningbo & Temperature by Month*, n.d.), the city is vulnerable to such runoff. The lack of advanced filtration systems in some treatment plants allows MPs to accumulate in the sludge. In addition, the large population leads to the widespread use of personal care products containing microplastics by residents, which further introduces these particles into the wastewater stream. Rivers flowing into Ningbo City from upstream areas can transport MPs, and resuspension of settled particles during disturbances further increases their presence.

In stark contrast, India registers the lowest MPs abundance (830 items/kg). knowing that this region has a large population number, but it was recorded the lowest abundance, and it can be explained by the waste management in this area, and the wastewater treatment used, as well as due to the lack of data, one study only, which is an insufficient number to understand the extent of MP pollution for the entire region.

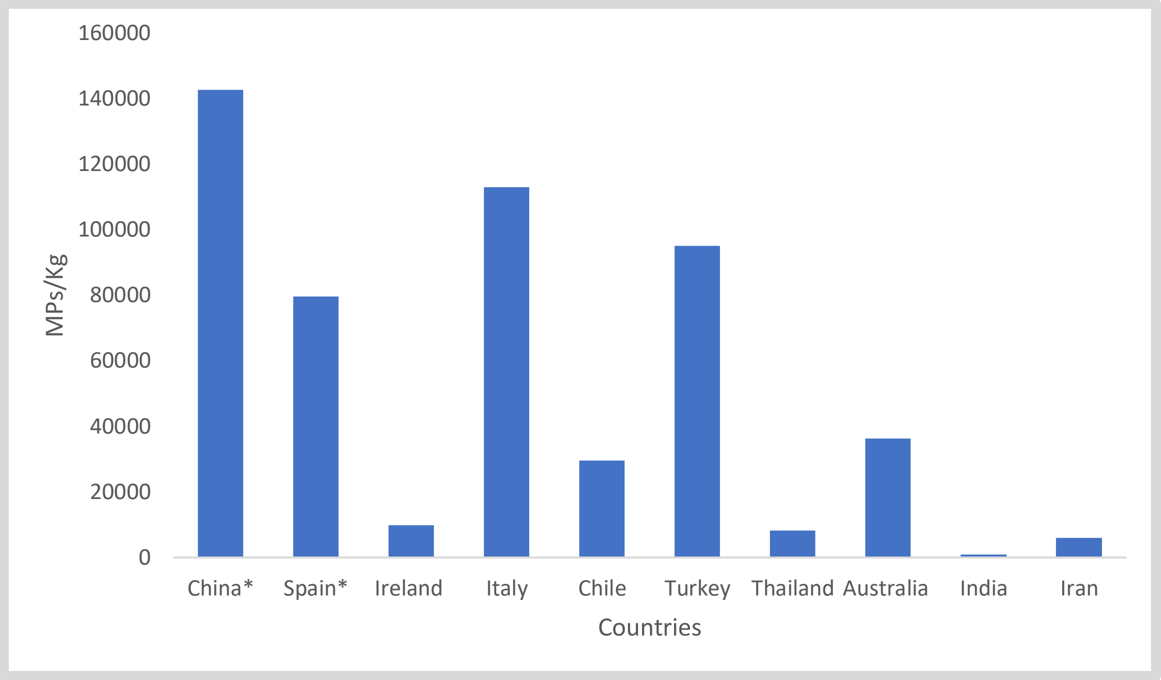

Figure 6. The abundance of Microplastics (items/kg) in sewage sludge in 10 countries

In examining Figure 7, which illustrates the abundance of microplastics (MPs) in organic compost across six different countries; two studies were conducted in China (Gui et al., 2021; J. Zhang et al., 2023), two in France (Colombini et al., 2022; Watteau et al., 2018), to be noted that the results of (Watteau et al., 2018) were not recorded in Figure 7. Due to different unit (g/kg), and one study in the Netherlands with two different sources of microplastics; Compost samples from municipal organic waste and Compost from garden and green house wastes (van Schothorst et al., 2021). The data reveals consistently lower values for MP abundance in all studies, with the lowest recorded in Germany (Schwinghammer et al., 2021) at 39-102 items of MPs per kilogram and the highest in Lithuania and Spain (Edo et al., 2022; Sholokhova et al., 2022).

The research conducted in France by (Colombini et al., 2022). evaluated the amount of microplastics in a mix of samples made up of municipal solid waste (MSW), biowaste-green waste mixture (BIO), and sewage sludge-green waste blend (GWS). This allowed for the estimation of the microplastic concentration in the mixed compost, which is shown in the accompanying chart. On the other hand, the German study conducted by (Schwinghammer et al., 2021), used a distinct methodological framework to study composted digested and sludge separately. As a result, our chart only includes information related to the digestate and does not include any statistics regarding sludge. Due to interest in the amount of microplastics in the organic fraction of municipal solid waste (OFMW), composted digestate from two different biogas plants was included as well.

The analysis of factors influencing plastic concentrations in compost brings attention to several key determinants. Population density, door-to-door collection fraction, and the fraction of impurities were identified as significant influencers. Higher plant capacity and lower door-to-door collection fractions correlated with increased plastic content. Moreover, the presence of impurities and higher population density were also associated with elevated plastic concentrations (Edo et al., 2022).

Acknowledging the limited number of studies available, which comprises only 10 sources, it is crucial to recognize the inherent challenges in drawing comprehensive analyses from such a restricted dataset. The results presented here are based on personal conclusions derived from these studies. It's noteworthy that a majority of research in this domain tends to concentrate on microplastics (MPs) in wastewater, leaving a gap in our understanding of their presence and dynamics in organic compost. Hence, while insights can be gained from the available studies, it is strongly encouraged that further research be conducted to delve deeper into this subject and broaden our comprehension of microplastics in compost.

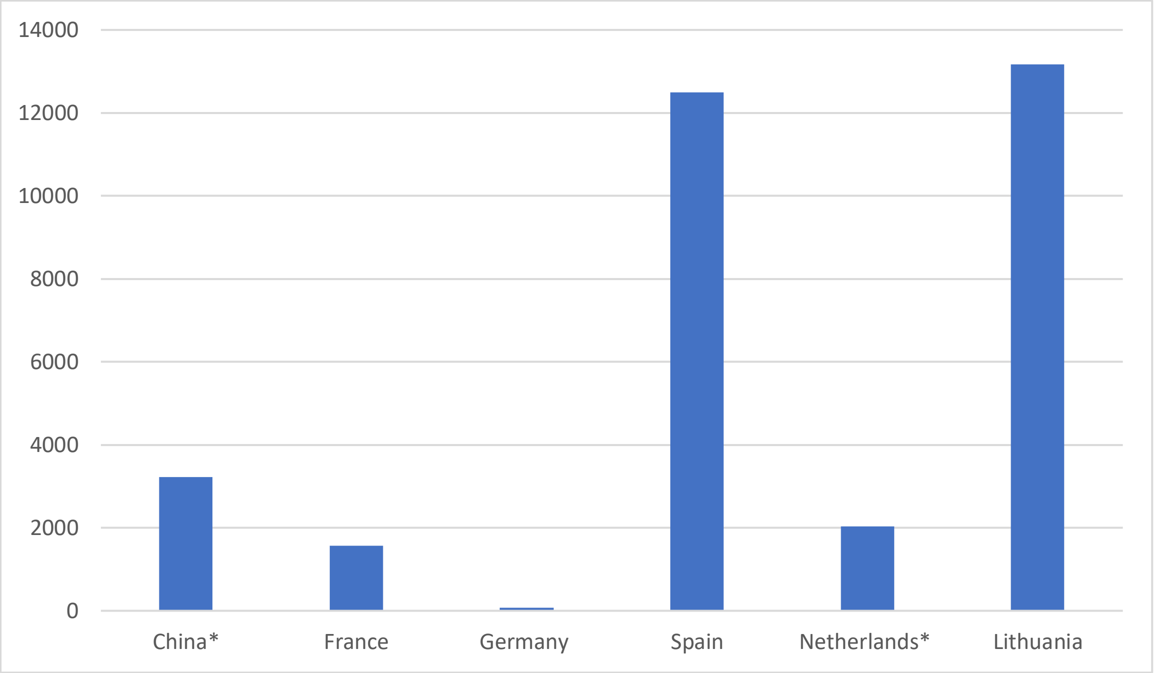

Figure 7. The abundance of Microplastics (items/kg) in organic compost in 6 countries

Higher abundance of microplastics (MPs) in sewage sludge compared to organic compost.

The apparent disparity in microplastic abundance between sewage sludge and organic compost can be attributed to several key factors. Sewage sludge, originating mainly from domestic and industrial wastewater treatment plants, serves as a primary reservoir for microplastics due to the significant influx of these particles through various pathways. The inadequate filtration capacity of wastewater treatment processes, designed primarily for larger debris, allows microplastics to escape efficient removal. Regions with high levels of industrial activity and urbanization contribute to the increased prevalence of microplastics in sewage sludge, as industrial processes and the widespread use of plastic products in urban environments release these particles into wastewater. In addition, erosion of sewer pipes further introduces microplastics into the wastewater stream, especially in ageing infrastructure.

Once introduced into wastewater, microplastics settle in the sludge phase, a process influenced by factors such as particle size, density and flow conditions. The long-term accumulation of microplastics in the environment and wastewater systems contributes to the higher concentrations observed in sewage sludge, establishing it as a reservoir for persistent particles. The inherent challenges in effectively removing microplastics from sewage sludge, due to their small size and diverse composition, exacerbate their accumulation in this waste stream. In addition, the recycling of sewage sludge as agricultural or landscaping fertilizer, a common practice in some regions, introduces microplastics into agricultural soils, potentially affecting the environment and the food chain. This intricate interplay of different processes underlines the complexity associated with the dynamics of microplastics in different waste streams.

The utilization of organic waste for compost in agricultural fields is a multifaceted strategy that addresses both waste management challenges and promotes sustainable agricultural practices. By repurposing organic waste into nutrient-rich compost, this approach contributes significantly to waste reduction. Instead of allowing organic waste to contribute to landfills and environmental degradation, it transforms these materials into a valuable resource. This not only mitigates the burden on waste disposal systems but also lessens the environmental impact associated with the decomposition of organic waste in landfills.

Moreover, the incorporation of organic compost into agricultural fields enhances soil health and fertility. The compost, rich in organic matter, acts as a natural fertilizer, improving soil structure, water retention, and nutrient content. This, in turn, reduces the need for synthetic fertilizers, curbing the environmental repercussions often linked to their production and application.

This dual benefit underscores the importance of adopting a holistic approach to waste management one that integrates environmental sustainability with agricultural resilience. By embracing organic waste as a resource for compost, societies can move closer to circular economy principles, where waste is viewed as a valuable input rather than a disposable byproduct. This symbiotic relationship between waste reduction and sustainable agriculture highlights the potential for innovative solutions to address pressing environmental challenges.

3.2 Comparison of shape, color, size of Microplastics

In the analysis of both organic compost and sewage sludge, a significant presence of fibers, fragments, and films was observed, with these components constituting a significant percentage in both waste types. Polyethylene (PE), polystyrene (PS), and polypropylene (PP) were consistently identified in all samples. Notably, a wide range of colors including white, blue, transparent, green, and red were recorded in the majority of samples, indicating a diverse composition of microplastics in both organic compost and sewage sludge.

The shapes of microplastics found in organic composts exhibited a resemblance to those discovered in sewage sludge compost, with prevalent forms including fragments, fibers, and films. Nevertheless, some studies unveiled the presence of pellet-shaped microplastics, a category frequently encountered in everyday personal care items such as toothpaste and facial cleansers. This variance could be attributed to regional disparities in consumer habits concerning daily commodities.

Typically, fragments result from the decomposition of larger plastic items, which can also undergo further breakdown due to the relatively high temperatures during composting (Colwell et al., 2023). Fibers, on the other hand, are primarily generated through processes like textile washing and weathering (Hernandez et al., 2017), and they are commonly identified in environments such as livestock breeding farms (Wu et al., 2021) and sewage treatment facilities (Mahon et al., 2017) film-shaped microplastics, likely stemming from the degradation of food packaging materials, plastic wraps, and plastic bags, for this reason we can clarify the presence of fibers in sewage sludge more than the organic compost.

The diversity of microplastic colors observed in organic composts also translated into the detection of colorful microplastics in soils enriched with compost. In our literature study, white, transparent, and blue microplastics constituted the majority. The varied colors of microplastics are indicative of distinct sources of pollution. White or transparent microplastics are likely derived from extensively used plastic packaging materials, these are often sourced from extensively used plastic packaging materials such as plastic bags, food packaging, and transparent containers. These types of plastics are commonly used for storage and packaging in various industries and households. Therefore, white and transparent microplastics are frequently found in composts and soils as a result of the breakdown of these packaging materials.

We can notice the black as well in sewage sludge and other colors in organic compost such as red and green. Colored microplastics, including black ones, are typically associated with specific products and materials. For instance, colored microplastics can originate from colored garments, plastic commodities, or products that incorporate dyes or pigments for aesthetic or functional reasons. When these colored items break down, they release colored microplastics into the environment.

The composition of microplastic polymer types in composts and sewage sludge exhibited similarities. Predominantly, the polymers identified encompassed PE (polyethylene), PP (polypropylene), and PET (polyethylene terephthalate) and PS (polystyrene). This alignment can be attributed to the widespread utilization of PP and PE in industrial processes, agricultural activities, and daily consumer products (Geyer et al., 2017) Notably, PET, while not extensively used in agricultural contexts, was still detected.

Polyethylene terephthalate (PET) is a versatile material used in various applications, including food packaging and synthetic textiles (Li-Na, 2013). Due to its exceptional attributes such as being tasteless, non-toxic, possessing good heat insulation properties, plasticity, strength, and wear resistance.

The dominance of PE in MSW composts most likely resulted from the tearing and fragmentation of polyethylene waste bags contained in MSW, during the composting process. To better understand the complex issue of microplastic contamination, table 1 is the result of an extensive literature review, drawing from numerous articles and studies that examine the prevalence, sources, and characteristics of various polymers.

Table 1. The Sources of Polymers (literature review)

The Polymer	The symbol	The chemical Formula	The source
Polyethylene	PE	$(C_2H_4)_n$	PE is one of the most commonly used polymers in various industries, including packaging (e.g., plastic bags, bottles), construction (e.g., pipes, containers), and consumer goods (e.g., toys). The presence of PE suggests contamination from everyday plastic products.
Polypropylene	PP	$(C_3H_6)_n$	PP is widely used in packaging, textiles, automotive parts, and various consumer products. The presence of PP microplastics can signal contamination from items like packaging materials, textiles, and everyday products.
Polyethylene Terephthalate	PET	$(C_{10}H_8O_4)_n$	PET is commonly found in beverage bottles, food containers, textiles, and synthetic fibers. Detecting PET microplastics can indicate the breakdown of PET-containing products. PET is known for its recyclability

Polystyrene	PS	$(C_8H_8)_n$	PS is used in disposable food containers, packaging materials, and insulation. Meaning: PS microplastics may result from the degradation of single-use items like foam cups and food containers. Their presence might reflect inadequate disposal practices and the persistence of PS in the environment.
Polyvinyl Chloride	PVC	C_2H_3Cl	PVC is used in pipes, vinyl flooring, cables, and some medical devices. Meaning: PVC microplastics could originate from products like construction materials or discarded PVC items. The detection of PVC microplastics may raise concerns about the release of additives used in PVC production.
Acrylic Polymers	-		Acrylic polymers are used in paints, adhesives, textiles, and various consumer goods. The presence of acrylic polymer microplastics may be linked to the breakdown of products containing acrylics.

3.3 The pathway of Microplastics to plant

Microplastics (MPs) are a major threat to soil ecosystems because of their abundance, diversity, variability, long-lasting effects, and prevalence. Their effects on oceans have been well-documented, but it is still possible that they could have an effect on soil as well.

Microparticles (MPs) come in a wide range of shapes, sizes, structures, additives, and colors, including microfibrils, beads, pellets, granules, films, foams, and fragments. Many different kinds of microplastics (MPs) may affect soil physical properties including bulk density, aeration, and water-holding capacity.

The negative effects of MPs on earthworms, microorganisms, and vegetation have already been shown in a number of studies (Qi et al., 2018; Rodríguez-Seijo et al., 2018; H. T. Wang et al., 2019; Yi et al., 2021).

It is noteworthy that MPs have also been found in species that are frequently ingested by people and have important ecological functions (Panebianco et al., 2019) Numerous studies have been conducted on the transfer of MPs from the aquatic environment to human habitats (Rillig, Ingraffia, et al., 2017; W. Wang et al., 2019). Micro and macroplastics can be conveyed through the food chain, according to studies on the transfer of MPs in terrestrial ecosystems (Huerta Lwanga et al., 2017). According to (Huerta Lwanga et al., 2016) earthworms in terrestrial settings have been observed ingesting MPs from the soil. Because many creatures, including humans, rely on soil for survival, people need to be aware of soil contamination. MPs in soil affect not only soil physical and chemical qualities, but also the microbes and food safety of many animals and humans (Akhtar, 2015; De Souza Machado et al., 2019a).

How do microplastics (MPs) enter soil and what are the common transport mechanisms?

What is the effect of MPs on the physical and chemical properties of soil? How do MPs impact microorganisms in terrestrial ecosystems?

We will provide answers to these questions in upcoming sections of our research. Our main goal is to comprehend how microplastics (MPs) enter the human body through the food chain. Plastic particles may either accumulate on the soil's surface or seep into the subsoil when they come into contact with it (Chae & An, 2018). According to (Born & Brüll, 2022), UV rays and increased temperatures can cause plastics in the topsoil, even small MPs (5 mm), to degrade. The actions of soil-dwelling animals, such as insects, annelid worms, and plant roots, can also transport plastic fragments and MPs mixed in the surface soil deeper into the soil (de Souza Machado et al., 2018; Rillig, Ziersch, et al., 2017; Y. Zhou et al., 2020)

The size of MPs has a direct impact on whether they can be absorbed by plants or not. MPs as small as a millimeter or a micron can enter plant cells. In cell culture, tobacco BY-2 cells were found to endocytose 20 nm or 40 nm polystyrene microspheres while excluding 100 nm nanospheres (Bandmann et al., 2012a).

Nanoscale plastic particles can enter the plant body through the cell wall despite the wide variations in the characteristics and permeability of plant cell walls (Z. Zhang et al., 2022; Zhao et al., 2017) Two additional factors, in addition to MP size, also influence how well plants absorb MPs. Plant species come first because many plant species have unique anatomical and physiological structures (Z. Zhang et al., 2022).

The second is plant traits that influence the uptake of organic chemicals, such as root traits (volume, density, surface area), because various ion channels in plant roots have various affinities for various substances (Vezza et al., 2018) Plant roots mostly absorb MPs and nanoplastics (NPs) using the crack-entry mechanism (L. Li et al., 2020; C. Q. Zhou et al., 2021) Pollutants can enter food webs through soil, which can result in contamination that lasts for many years (Chae & An, 2018) Nematodes and earthworms are frequently employed as "model organisms" to evaluate the biomass, health, and contamination of soil. Through feeding, digestion, excretion, secretion (of mucus), and burrowing, earthworms aid in the movement of materials and the transfer of energy in soil processes (L. Lei et al., 2018; Q. Wang et al., 2022) According to (Capowiez et al., 2021) soil invertebrates are often regarded as "ecosystem engineers" and play a significant influence in determining soil fertility.

We already replied to the question about the main source of MPs in terrestrial ecosystems, and we found the answer is sewage sludge from wastewater treatment. However, there is a secondary source of microplastics. Due to a variety of processes, including exposure to UV radiation, wind, tillage, biological activity, and chemical/mechanical degradation, bigger plastic items become fragmented and produce secondary microplastics (Guo et al., 2020; Karbalaei et al., 2018)

According to (Bradney et al., 2019; Galafassi et al., 2019) landfills are one source of these particles, as are plastic mulches, greenhouse materials, soil enhancements, irrigation water, municipal solid waste, atmospheric inputs, and littering. Plants utilize several systems, including endocytosis, apoplastic transport, and the recently identified crack-entry method, to take up and distribute particle plastics.

- **Endocytosis**

Due to the small size of the endocytic vesicles, plant cells quickly internalise nanoparticles (20 nm and 40 nm) while rejecting bigger particulate plastics (above 100 nm). BY-2 protoplast cells and other cells with larger endocytic vesicles are capable of internalising larger nanoparticles up to 1000 nm. Clathrin-dependent endocytosis facilitates this uptake (Bandmann et al., 2012b)

- **Apoplastic**

When particle plastics reach plant roots, apoplastic transport starts, with some of the plastics being caught by root mucilage and accumulating on the root surface. Transpiration, which is fueled by water evaporation, promotes the mobility of particulate plastics within plants.

Forcing the pollutants to travel via the endodermal plasmalemma, the Kasparian strip in the endodermal layer serves as a barrier for the apoplastic transfer from the cortex to the vascular bundle. Studies using PS beads (200 nm) revealed that they were primarily found in the veins and on the cortical tissues of lettuce roots.

With variables like long alkyl chains and high molecular weight playing a role, plastics' size and molecular structure have an impact on how well plants absorb them through apoplastic transport (Sun et al., 2020; F. Wang et al., 2020)

- **Crack-Entry Mode**

According to recent studies by (L. Li et al., 2020) particulate plastics can penetrate wheat plants by forming a physical conduit using a newly identified technique known as the Crack-Entry Mode. When cells are actively dividing, meristematic tissues near the shoot tip exhibit great porosity, in contrast to cell wall pores and plasmodesmata, which are often too small to allow the passage of plastics larger than 5 nm or 60 nm. Microplastics 2.0 m in size can enter the stele through cracks that form between epidermal cells after cell separation. Once inside the stele, particulate plastics are carried by the transpiration stream via the xylem and towards above-ground plant structures. Plastics must be mechanically flexible in order to be absorbed via the crack-entry mode.

Although endocytosis and apoplastic transport are frequently seen and well-established in the most recent body of scientific research, the prevalence of these pathways may differ. The presence of these mechanisms may also be influenced by certain experimental setups as well as the properties of the polymers and plants under investigation.

The microplastic pathway into plants is not yet entirely clear, and further mechanisms may be discovered later. Nonetheless, the current aim is to simplify the understanding of this process, and three distinct mechanisms have been identified. It should be noted that variations in these mechanisms may occur between different plant species and depend on the size of the microplastics.

3.4 The Impact of Microplastics on Plant

According to various studies (De Souza Machado et al., 2019a; Qi et al., 2018) microplastics in soil can alter its qualities such as wetness, density, structure, and nutrient content. This can affect how well plants can absorb nutrients and how their roots develop. Numerous plant species, including wheat, spring onions, cress, and lava beans, have been studied to understand better how different plant species, soil properties, and microplastics amounts affect plants' behavior.

Microplastics (MPs) of various sorts behave differently in soil. For instance, microplastic microfibres have been shown by (De Souza MacHado et al., 2018) to reduce soil bulk density, which may then improve soil aeration and encourage root penetration. But these microfibres might also tangle young roots, which might obstruct seedling growth.

Additionally, enhanced soil aeration can cause surface aridity, which could harm seedling development (Wan et al., 2019).

On the other hand, microplastic films create water channels that speed up percolation and cause desiccation fissures to appear on the soil's surface (Wan et al., 2019).

3.4.1 The physical impact

Because they interfere with particle cohesion and aggregate formation, microplastics (MPs) have the power to change the physical characteristics of soil. 72% of MPs actively participate in the production of aggregates, according to (G. S. Zhang & Liu, 2018) who underline the critical role that microfibers play in this process. According to (Lozano & Rillig, 2020) soil contaminated with microfibers altered the organization of the plant community, which affected biomass and species dominance. Polyester fibers (PFs) greatly aid in the agglomeration of soil particles and boost water-holding capacity.

However, their efficacy varies depending on the type of soil, being better in some soils but less successful in sandy soils (de Souza Machado et al., 2018; Lehmann et al., 2019; M. Zhang et al., 2019) Other kinds of microplastic particles, such as beads, fragments, or polyacrylic fibers, may have less of an effect on the ability of soil to accumulate or to hold water. In contrast, PLA and HDPE both directly affect how soil particles bind, which results in the production of trustworthy soil aggregates. This encourages improved soil porosity and aeration in turn (Boots et al., 2019)

Numerous research has shown how microplastics' impact on the physical characteristics of soil is intricate and multifaceted. The research examines the effects of various microplastic kinds and concentrations on soil properties like bulk density, water-stable aggregates, aggregate size, water stability, and water-holding capacity.

As a result of HDPE and PLA treatments, (Boots et al., 2019; G. S. Zhang & Liu, 2018) found complex effects on aggregate size and water stability, where microaggregate linkages changed and size distribution shifted. Studies by (M. Zhang et al., 2019) showed that the presence of high-density polyethylene (HDPE) fragments, PES fibers, polyethylene terephthalate (PET), polypropylene (PP), and polystyrene (PS) decreased the bulk density of the soil.

While linear PES microfibers facilitated the aggregation of particles and the production of large pores, fine PES fibers prevented the formation of smaller holes and improved water repellency (M. Zhang et al., 2019) In contrast, compared to soils lacking microplastics, microplastic films resulted in lower water content (Wan et al., 2019) Microplastic films enhanced the creation of pores and prevented the formation of bigger aggregates in water-stable aggregates, where the contamination of PS and PES resulted in a considerable decrease (Lehmann et al., 2021) Microfibres in the soil produced a variety of consequences, including a decrease in the development of big aggregates but an increase in aggregate stability. Additionally, adding PES fibers increased the material's ability to store water (De Souza Machado et al., 2019a; M. Zhang et al., 2019)

Furthermore, (M. Zhang et al., 2019) pot experiment revealed an increase in water-stable macroaggregates with higher concentrations of PES microfibres that persisted through many drying and wetting cycles. In their investigation of the hydraulic effects of microplastics on soil, de Souza Machado et al. (2019) showed that polyamide (PA) beads and PES increased evapotranspiration, suggesting that there may be more water available.

3.4.2 The chemical impact

Research on the impact of microplastics on the chemical characteristics of soil is complicated, with varying results from different investigations. It is noteworthy that the pH of the soil was somewhat impacted by exposure to various forms of microplastics. In contrast to the HDPE-treated group, which after one month of exposure showed a minor but statistically significant decline in pH(Boots et al., 2019) revealed a minimal reduction in pH levels of soil treated with PLA. The impacts of microplastics are polymer-specific and soil-dependent, as shown by the fact that contamination with LDPE and bio-plastics increased soil pH (Qi et al., 2020) Furthermore, polyethylene microplastics altered the pH of acidic soil while raising it in alkaline soil, highlighting the complex diversity that microplastics introduce to various soil environments (C. Li et al., 2022; H. Z. Li et al., 2021)

Microplastics affect soil nutrient availability and biogeochemical processes in a variety of ways in addition to altering soil pH. For instance, PA particles acted as a form of fertiliser by leaching nitrogen into the (De Souza Machado et al., 2019a) Additionally, polymer-based primary pellets emitted organic phosphite antioxidants that eventually degraded into organic phosphate, limiting the soil's ability to cycle carbon. Biogeochemical processes could become more complex as a result of the carbon found in microplastics, which is typically thought of as being inactive (De Souza MacHado et al., 2018; Rillig et al., 2019)
Over time, the degradation of polymers, such LDPE, makes it difficult to estimate the amount of soil carbon stored and may cause microbial immobilisation of nutrients. As soil carbon is held in place by microplastics, projections for its precise retention may be affected. In order to ensure effective policymaking, microplastics must be excluded from estimations (Rillig et al., 2019; Rillig & -Brandenburg, 2018).

It is questionable how microplastics affect the chemical characteristics of soil as a whole, despite evidence that they can change soil microbial populations and disrupt nutrient cycle. Further research is needed to determine the mechanisms behind pH changes in soil brought on by microplastics. To further understand these effects, field and laboratory research that include a variety of soils and microplastics at environmental-relevant concentrations are essential. The difficulties in sampling, classifying, and analysing microplastics in soil (Gong & Xie, 2020; Provencher et al., 2020) further emphasise the necessity of standard methodologies for reliable evaluations.

Due to their complexity and dependence on numerous variables, it is difficult to reach firm conclusions about how microplastics affect the chemical characteristics of soil. For a complete understanding of the complexities raised by microplastics in soil settings, more research using sound approaches and considering a variety of scenarios is required.

To understand how different crops react to microplastics, more study is needed on the interactions between microplastic properties, soil factors, and plant responses. Investigating the consequences of microplastic pollution on regional food webs is important since the accumulation of microplastic in plants provides potential risks to terrestrial organisms through trophic transfer (Kumar et al., 2020).

3.5 Impact on Microorganisms

Microplastics (MPs) wield a significant influence on critical microbial properties within soil, fundamentally impacting soil structure, organic matter decomposition, and nutrient cycling. Alterations in soil habitat conditions triggered by MPs, including changes in porosity, moisture, and pH levels, adversely affect both aerobic and anaerobic microorganisms. Diverse types of microplastics, such as PES, polyacrylic, PE, and PA, interact with soil physical environments, resulting in heightened microbial activity and enhanced soil aggregate structure (De Souza MacHado et al., 2018)

According to laboratory research (Miyazaki et al., 2014; Nomura et al., 2016), microplastics may have harmful effects on yeasts and fungi in the wild, altering their distribution and abundance. This complex interaction between microbial communities and microplastics emphasises the subtle influence MPs have on crucial facets of soil biology.

Additionally, exposure to LDPE-MPs causes earthworms to experience oxidative stress, which is demonstrated by changes in antioxidant systems such elevated catalase activity and malondialdehyde levels (H. Chen et al., 2020) This reveals how chemicals affect cellular functions. The amount of DNA damage caused by MPs depends on their size and concentration, with larger particles harming earthworms' genetic makeup more severely (J. Jiang et al., 2020; Xu et al., 2021) Additionally, polystyrene-based MPs (PES-MPs) have genotoxic effects and affect how many genes in earthworms are expressed (Prendergast-Miller et al., 2019; Xu et al., 2021) These discoveries support a chemical influence on soil organisms' genetic composition.

Studies by (Ding et al., 2020; Ju et al., 2019; W. Wang et al., 2019; Zhu et al., 2018) investigating the gut microbiota composition of soil animals in response to MPs also reveal a chemical impact on the microbiota, which has important implications for the health and biology of these creatures.

Tissue damage stands out as a prominent effect in terms of physical effects on soil fauna, especially in earthworms exposed to LDPE MPs (Y. Chen et al., 2020) Skin ulcers, fissures, and creases are visible signs of this immediate physical injury, highlighting the real effects of MP exposure on bottom-dwelling species. The ingestion of MPs poses a threat to the interior organs and tissues of soil-dwelling organisms, resulting in wounds such skin ulcers and mucous membrane damage in earthworms (Y. Chen et al., 2020) Additionally, genotoxicity occurs, and in earthworms, bigger MPs affect the expression of genes that are stress biomarkers (Prendergast-Miller et al., 2019; Xu et al., 2021) This emphasises the direct physical impact of MPs on organisms' genetic composition.

Despite these revelations, the influence of microplastic on the physical characteristics of soil is still minor and conditional. The quantity and kind of microplastics have an impact on variations in bulk density, water stability, and other aspects. To fully comprehend the effects of microplastics on soil, more research is necessary due to the complex interaction of various elements.

Complexity is introduced into the link between MPs and root growth since MPs alter soil structure, which in turn creates ideal conditions for root growth, but there are also concerns due to indications of decreased root growth (Boots et al., 2019) Therefore, more investigation is required to fully comprehend the effect of MPs on soil-plant systems.

In conclusion, there are still questions about the overall impact of microplastics on the microbiological characteristics of soil. Diverse study findings point to potential risks or negligible effects on soil organisms, necessitating further study that takes into account elements like the type and form of microplastics, their particle size, genetic variation in plants, soil conditions, and interactions between microplastics and soil organisms. In order to assess the effects of microplastics in both naturally occurring and anthropogenically altered ecosystems, a thorough understanding of the interactions between microplastics and soil biota is essential ((Rillig & Bonkowski, 2018) Understanding how MPs affect soil biogeochemistry, particularly microbial activity, and thermal characteristics, is crucial given the increased accumulation of MPs in the environment.

3.6 The impact on human health

The presence of microplastics (MPs) in aquatic and oceanic environments has been demonstrated by prior research. Using this information as a foundation, our recent research shows that microplastics are also prevalent in terrestrial ecosystems. Given that humans rely on a wide variety of food sources, such as fruits, vegetables, fowl, beef, and fish that come from both aquatic and terrestrial environments, it seems sense that these food items contain microplastics. Consequently, the complex web of the food chain exposes humans to microplastics.

The presence of microplastics in soil has the potential to cause substantial changes in various aspects of plant biology, including plant biomass, tissue elemental composition, root traits, and microbial activities (De Souza Machado et al., 2019b). There is evidence indicating that various food products and cooking ingredients have been found to be contaminated with microplastics.

The presence of microplastics has been detected in various consumable products, including drinking mineral water (Welle & Franz, 2018) in beer, tap water (Myszograj, 2020) table salts (Renzi & Blašković, 2018) canned food (Karami et al., 2018), and honey and sugar (Liebezeit & Liebezeit, 2013). These reports provide evidence of the widespread presence of microplastics in human food and beverages. The potential risk to human health arises from chronic exposure and ingestion of microplastics, despite their low concentration..
Research has shown that microplastics can be broken down into even smaller particles, known as nanoplastics, through ingestion by organisms such as Antarctic krill (Dawson et al., 2018) These nanoplastics, which are distinct from both microplastics and engineered nanoparticles, have unique properties that can impact their environmental fate and potential effects on biota and human health. The toxicity of microplastics (MPs) and nanoparticles (NPs) in human cells is a complex and multifaceted issue, with conflicting results reported in the literature. While most studies suggest some degree of toxicity or pathological changes, a few studies indicate no significant cellular toxicity except at high concentrations.

This section aims to explore the effects of microplastics (MPs) on human health through the food chain, without accounting for their origins (aquatic, terrestrial, or through inhalation). The objective is to determine whether MPs impact human health and clarify the nature of such an impact. Our main aim is to highlight the possible dangers of microplastic exposure and its effects on human health (Table 2) and (Figure 8).

Table 2 – Literature review to illustrate the impact of microplastics on human health.

Author	HumanHealth risk	The Risk
Landrigan PJ 2020	yes	affecting human health with risks of developmental disorders, reduced IQ, autism, ADHD, learning disorders, dementia, and cardiovascular disease. And risks for cardiovascular disease and dementia.
Wright SL 2017	yes	N.D
Smith M 2018	yes	Nanoplastics can cause harmful effects on organs like the liver and lungs, with in vitro toxicity affecting lung, liver, and brain cells. Systemic distribution can lead to cardiopulmonary reactions, metabolite changes, genotoxicity, inflammatory reactions, oxidative stress, and reproductive effects.
Patil PB 2022	yes	Polyvinyl chloride, bisphenol A, phthalates, and styrene in plastics are carcinogenic substances, while PBDEs and flame retardants may leach out, causing toxic effects and anti-androgen activity.
Jung YS 2022	yes	Polystyrene microplastics increase reactive oxygen species, cytotoxicity, and inflammation in human lung epithelial cells, while causing decreased cell viability and dysregulation of inflammatory and oxidative stress markers.
Ma ZF 2020	yes	Microplastics contain harmful chemicals that can disrupt the endocrine system, increase the risk of diseases like metabolic disorders, obesity, and diabetes, and cause cancer. Some microplastics may

		accumulate in the digestive tract, causing disruption and obstructing blood flow. Inhalable microplastics may cause respiratory tract irritation and cardiovascular illnesses.
Carbery M 2018	yes	Microplastic particles, passing through cell membranes, blood-brain barrier, and placenta, can cause oxidative stress, cell damage, inflammation, and energy distribution issues, causing direct and secondary harm.
Emenike EC 2023	yes	Ingestion: Gastrointestinal problems, Endocrine disruption, Microplastics as a pathogen vector
Bonanomi M 2022	yes	Polystyrene nanoparticles can cause metabolic changes in human colon cells, potentially increasing the risk of cancer due to long-term exposure.
Vital SA 2021	yes	N.D
Barboza LGA 2020	yes	Microplastics' effects on human health are not yet known, but scientific evidence links bisphenols to reproductive cancers, fertility issues, sexual dysfunction, hypertension, cardiovascular disease, obsessive-compulsive diabetes, mental health issues, and developmental disorders.
Bošković N 2023	yes	MP enters the gastrointestinal tract and circulatory system, interacting with organs and cells. Continuous exposure can cause inflammation, cytotoxicity, hemolysis, granulomatous lesions, and lung cancer.
Zhang Y 2022	yes	Polystyrene microspheres (PS-MPs) showed low toxicity to cells, with varying sizes causing oxidative stress and mitochondrial membrane potential depolarization, with higher uptake in HIEC-6 cells causing more toxic effects.
Joseph A 2023	no	No potential health hazard was identified due to the consumption of fluoride through hot beverages in paper cups.
Kim J 2021	no	Exposure to w-PP microplastics in real-life situations may not cause any adverse effects, as the particle size is 2.82 × 105 particles/kg.
Enyoh CE 2023	yes	Low daily intake of specific PTEs (Co, Ni, Cu) poses high noncarcinogenic risks for children, while MPs have low non-carcinogenic risk, while Ni and Cr have carcinogenic risks.

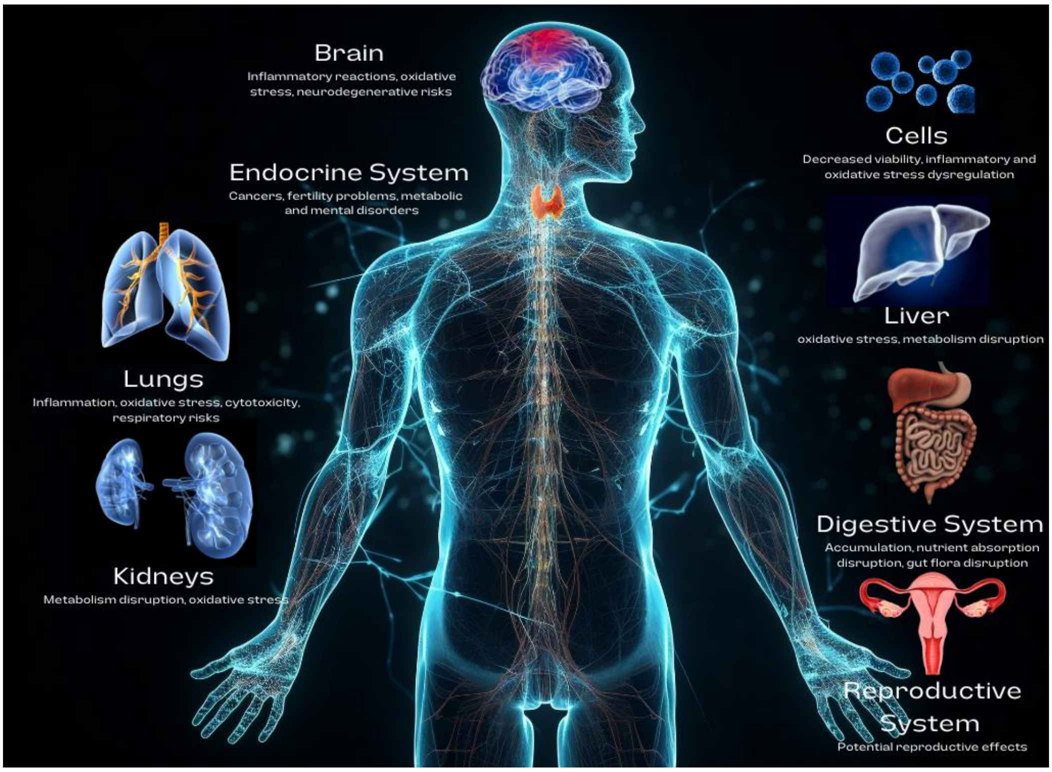

Figure 8. Potential impact of MNPs on human health (Manal Boujnir; 2023)

Studies have shown that MPs can accumulate in the body, leading to oxidative stress, changes in metabolic stability, DNA damage, immune reactions, and an increased risk of cancer, respiratory, and neurodegenerative diseases (Alimba et al., 2021; Deng et al., 2017; Kim et al., 2021; Prokić et al., 2019).

These effects are dependent on the size and dose of the MPs, as well as their interaction with other substances.

Very fine particles are capable of crossing cell membranes, the blood-brain barrier, and the placenta, with documented effects including oxidative stress, cell damage, inflammation, and impairment of energy allocation (Vethaak & Leslie, 2016).

Polystyrene particles have a big impact on human health, they can be absorbed by the body, leading to proinflammatory effects, genotoxicity, and the development of antibiotic resistance (González-Acedo et al., 2021)

Once ingested, nanoplastics can travel through the body and reach important organs like the liver and lungs. (*SOURCES, FATE AND EFFECTS OF MICROPLASTICS IN THE MARINE ENVIRONMENT: PART 2 OF A GLOBAL ASSESSMENT Science for Sustainable Oceans*, n.d.) Specialised cells enable this migration through the circulation and lymphatic system, which could be harmful. Nanoplastics' toxicity has been proven in vitro, including negative effects on lung, liver, and brain cells. Following oral exposure, systemic distribution is linked to a number of negative health effects, such as cardiopulmonary reactions, metabolite changes, genotoxicity, inflammatory reactions, oxidative stress, effects on nutrient absorption, disruption of gut microflora, and potential reproductive effects. (“Presence of Microplastics and Nanoplastics in Food, with Particular Focus on Seafood,” 2016)

A range of in vitro and in vivo studies have highlighted the potential health impacts of microplastics. In vitro studies with human lung epithelial cells show increased reactive oxygen species, cytotoxicity, and inflammation in response to polystyrene microplastics (Dong et al., 2020). Interaction with mammalian cells in vitro environments leads to decreased cell viability and dysregulation of inflammatory and oxidative stress markers (Palaniappan et al., 2022) (Prata, 2018) estimates that human lungs may be exposed to 26–130 microplastics daily, posing significant health risks due to challenges in clearing particles from the respiratory system, potential interactions with other organic materials, and the release of hazardous chemicals. The accumulation of microplastics in the liver and kidney leads to disruptions in energy and lipid metabolism, along with oxidative stress (Deng et al., 2017).

Evidence confirms the entry and presence of microplastics in the human system, with studies detecting microplastics in human stool (Schwabl et al., 2019). Polymer types, including PP (63%) and PET (17%), were identified, suggesting potential excretion rates of 1.1–29.36 mg/week (Schwabl et al., 2019)

Research has shown that small plastic particles, particularly those from polystyrene (PS) and polyvinyl chloride (PVC) smaller than 150 µm, can move from the intestines into the bloodstream when humans consume seafood (Smith et al., 2018)

Microplastics' exact impact on human health is still uncertain (Barboza et al., 2018), but mounting research has connected bisphenols to a host of issues, such as a variety of cancers (testicular, prostate, ovarian, etc.), issues with fertility (low sperm count, decreased sperm quality), sexual dysfunction (premature ejaculation, decreased sexual desire), hypertension, cardiovascular disease, obesity, type 2 diabetes with insulin resistance, mental illness (autism spectrum disorder, increased attention deficit hyperactivity disorder), and developmental disorders (Cunha & Fernandes, 2010; Rochester, 2013; Ma et al., 2019)

The translocation of microplastic residues to the circulatory and lymphatic systems, as well as their potential to stimulate a chronic inflammatory response, have also been highlighted (Almeida & de Souza, 2021). However, further research is needed to fully understand the impact of microplastics on human health.

In simple terms, (Bonanomi et al., 2022) show that tiny pieces of polystyrene, like those found in plastics, can get inside human colon cells and change how these cells work. When normal human colon cells are exposed to these plastic particles, their usual ways of working become similar to what happens when they're treated with a cancer-causing substance (AOM) or when we look at colon cancer cells (HCT15). Specifically, these cells show four signs often seen in cancer metabolism:

- They use more glucose, turning it into lactate, even when there's enough oxygen.
- The activity of their mitochondria (the energy-producing parts of cells) decreases.
- Nutrients like glucose and glutamine are used separately.
- There's a specific way of using glutamine called reductive carboxylation.

Not all the studies confirmed that Microplastics have a negative impact on human health, while (Y. Zhang et al., 2022) mentioned that Polystyrene microspheres had no significant effect on cell viability and apoptosis. Low overall toxicity of PS-MPs to cells was observed and (J. H. Kim et al., 2021) affirms that 2.82 × 105 particles/kg, human exposure to w-PP microplastics in a real-life situation may not have any adverse effects.

4. Conclusion

The environmental pollution caused by Microplastics can have effects on soil, plants, and human by affecting their health and well-being. These tiny particles, known as micro and nanoplastics (MNPs) have been found in the terrestrial food chain, coming from sewage sludge and compost used in land applications, based on the literature review that has been done in this study, a significant observation is the higher abundance of MPs in sewage sludge compared to organic compost.

Limited studies have reported the adverse effects of MPs on plants, highlighting the need for further research and detailed studies to understand the complexity of this interaction.

Microplastics and nano plastics, once they are inside the body can cause a risk to human health targeting several body organs; brain, cells, kidneys, lungs, liver, digestive system, and reproductive system. However, some studies confirmed that microplastics have no health impact.

The predominance of polystyrene and PVC as polymers within the human body underscores the specific threats they pose. However, significant knowledge gaps remain, about other types of polymers and their impact on human health.

This risk might be long-lasting, and as we make more plastic, the next generation could face unknown consequences. Even though we know all this, plastic is still a crucial part of our daily lives, especially in communication technology and healthcare, which are essential for social development. Also, technologies promoting a sustainable lifestyle depend on the versatile properties of plastics. How much harm plastics cause to the environment depends on how products are designed, how responsibly retailers handle them, and how well waste is managed.

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Annex 1

Reference	Country	source of compost	MPs abundance	shape of MPs	polymers	Size of Mps	color of MPs
Zhang J 2023	China	organic compost (dried pig manure and cow manure composts)	3547- 4520 items/kg	fibers (29.3 %–42.9 %), fragments (26.6 %–37.9 %), films (15.0 %– 28.3 %), and pellets (3.9 %–8.6 %)	PE, PP, PET, PP/PE copolymer, polyacrylonitrile (PAN), polyester, PS, polyamide (PA), rayon, and polyvinyl chloride (PVC)	MPs <1.0 mm (31.0 %), followed by 1–2 mm (25.0 %), 2–3 mm (17.7 %), 3–4 mm (16.7 %), and 4–5 mm (9.6 %)	white (17.6 %–42.9 %), blue (16.1 %–35.9 %), transparent (8.6 %–28.3 %), black (5.2 %–22.1 %), yellow (2.1 %–8.3 %), red (1.3 %–5.2 %), gray (0–3.3 %), and green (0–3.3 %)
Colombini G 2022	France	mix	1566 particles /kg	films 80% and fragments 19% and foam 1%in compost	PE 71% PS 15% PP 4% PET 3% PVC 2% PA 2% other 3%	2–5 mm size fraction	N.D
Edo C 2022	Spain	Composted Organic Fraction of Municipal Solid Waste (OFMSW)	5000–20 000 items/kg of DW	Fibres (25% < 500 µm); and then fragments and films	PE, PS,PET, PP, PVC, and acrylic polymers	almost all fibres and filaments (97.4%) were below 5 mm. Plastic particles with equivalent diameter < 2 mm represented 89.6% and 37.7% of the total amount of fibres-filaments and fragments-films respectively	white, red polyamide fibre, yellow acrylic fibre, two black and transparent
Gui J 2021	China	The rural domestic waste (RDW) compost	2400 ± 358 items/kg (DW),	fibers and films	PET, PP and PE	0.05-0.5 mm (73.53%) 0.5-1.0 (10.29%) 1.0-3.0 (8.82%) 3.0-5.0 (7.35)	Red, Blue, Green, Black, transparent
Van S 2021	The Netherlands	Compost samples from municipal organic waste	2800 ± 616 MPs/kg	N.D	PE and PP plastics	0.03–2 mm	N.D
Van S 2021	The Netherlands	Compost from garden and green house wastes	1253 ± 561 MPs/kg	N.D	PE and PP plastics	0.03–2 mm	N.D
Sholokhova A 2022	Lithuania	Municipal solid waste (MSW) during the mechanical-biological treatment (MBT) process.	8925 to 17407 Particles/kg.	fragments 51.752% films. 31,5% Other shapes such as spheres 3.7%, fibers 5.9%, and foams	dominant: PP, PE, PS,then PMMA , PES, PA, expanded polystyrene (EPS) foam, PU, and PET	<0.1 mm and 0.1–0.2 mm	N.D
Watteau et Al 2018	France	MSW composts)	253.6-280.2 g/kg 464-502.5 g/kg	fragments, fibers or membranes	PS and styrene derivatives	<0,05 mm and 0,2-2 mm	white, red, green, blue;
Růžičková J 2022	Czech Republic	green waste, including urban green waste from households and collection yards	432 mg/kg.	fibers fragments films microbeads	PS, PET, PE, PC and PP	N.D	N.D
Schwinghammer L 2021	Germany	mix	39-102 MPs/Kg	films and fragments	PE, PVC	1-5 mm	N.D

Annex 2

Title of the research	country	MPs Abundance	shape of MPs	polymers	Size of Mps	color of MPs
Chen Z 2020	Beijing, China	74000 ± 17000 particles/kg dry sludge	Fibers 78,3%, shaft 7%, flake 6,3%, Film 5,2%, Foam 2,8%, others 0,4%	PP 34.7%, PE 33.8%, PES 6.8%, PS 6.4%, PET 4.5%	62.16% (0,3-0,5) and 16,21% (0,5-1,25) and 6,75% (1,25-2) and 9,5% (2-5mm)	white 65.1%, orange 26.9%, red 3.2%, green 1.3% black 3% other 0.5%
Edo C 2020	Madrid, Spain	183000 ± 84000 particles/kg	clear fibres 67%, coloured fibres 17%, white fragments 11%, and coloured fragments 5%.	PE, PP, PS	48%(0,025-0,104) and 28%(0,104-0,375) and 23% (>0,375,<0,5mm)	Black and red fibres on a white mass of cellulose fibres, Orange fibre, Blue fragments, Red fibre
Mahon AM 2017	Ireland	4196 - 15385 particles/kg (dry weight)	Fibers 78.5% fragments 18.4% films 1.9% spheres 0.3% others 0.9%	HDPE, PE, PS, acrylic, PET, PP, and polyamid, PVC	N.D	N.D
Magni S 2019	Italy	113000 ± 57000 MPs/kg sludge dw	films 51%, fragments 34% and lines 15%	Co-polymers of acrylonitrile-butadiene 27%, followed by PE 18% and PS 15%	10%(5-1mm) and 12%(1-0.5) and 54% (0.5-0.1) and 24%(0.1-0.01)	N.D
Corradini F 2019	chile	18000 to 41000 particles/kg	fibers, then films, pellets and fragments	LDPE, PS, PVC , Nylon, Acrylic	2.7 ± 1.4, and 1.60 ± 1.1, and 2.30 ± 0.8	N.D
Üstün GE 2022	Bursa, Turkey	95000 ± 23000 N/kg	fragment 57.9%, fiber 26.4%, granular 18.4% and film 11.1%	PE 38.5%, PP 30.6%, PS 17.2%, PET 6.1%	53.13% (0,5-1 mm) 24.6% (0,3-0,5) 18.43% (1-3 mm) 3.9% (3-5 mm)	black, transparent, blue, white, red, yellow, green, pink
Yuan F 2022	Nanjing, china	9 790 ± 3 250 MP/kg	fragments followed by fibrous, granular and film-like microplastics	PE, PP and PET	N.D	transparent colors, followed by black and white, while the red, green, blue and yellow microplastics
Tadsuwan K 2021	Bangkok, thailand	$8.12 \pm 0.28 \times 10^3$ particles/kg dry weight	Fibers, fragments, films	polyester fibres, followed by PP, PE, silicone polymer and PS	0.5–0.05mm	Transparent plastics, then black, red, blue, white and yellow
Ziajahromi S 2021	australia	15900 to 56500 particles/kg dry weight	fibres followed by fragments	PET; PE, PP and nylon with fibres mainly composed of PET and PP	0,500-0,025 mm	fibres black, blue and transparent in colour, followed by fragments, which were mainly black, white, blue and transparent in colour
Patil S 2022	Maharashtra, India	830 MPs/kg	fibers 63% , followed by fragments 25%, films 4% and spheres 8%	LDPE, PP, PS, PVC, PVA, PU, CA, RY	N.D	transparent 53%, followed by black 24%, red 10%, green 6%, blue 5%, and orange 2%
Naji A 2021	Bandar Abbas city, Iran	6070 (±807.25) MPs/kg	Fiber 50% followed by films 32%, fragments 17% and granule 1%	PE, PP and polyamide (i.e. Nylon)	0.003-1.0 mm, 1.0-2.5 mm 2.5-5.0 mm	white 34%, black 14.75%, red 8.25%, blue 11.75% , yellow 10.5%, green 6.75%, brown 3.75%, pink 4.75%, grey 3.5% and orange 1.5%
Jiang L 2022	Ningbo, China	226100 ± 95700–896000 ± 144000 items/g dry weight	the proportion of fibers and fragments varied from 76.2% to 84.6% and 9.5% to 12.4%.	N.D	<2.0 mm, 62.5%–81.5%	black, red, transparent, white, blue,green, others
Hernández-Arenas R 2021	Murcia, Spain	30940 ± 8589 particles/ kg dry weight	microfibers followed by fragments, films and microbeads	High presence of PE, limited presence of PP	0.31-2.11 mm	N.D
Zhang B 2023	Guiyang, china	27200 ± 3100 N/kg	highly presence of fragment, fibrous, and thin film	20% acrylic, 20% PEVA, 20% PEVA, 13,3% PE, 13,3% PP, 13.3% other	0,030–0,100 mm	black, transparent, white, blue, red, green, and yellow. the proportion of black MPs exceeded 50%
Jiang J 2020	Harbin, China	36300 ± 5700 and 46300 ± 6 200 particles/kg (dry sludge)	fragment 49.0% and 43.8%, respectively, followed by fiber 14.0% and 36.1% and pellet 16.0% and 9.1%.	PET of 25.4% followed by PA 19.4%, polyester 17.9%, PS 13.4%, PE 7.5%, and PP 9.0%	0.1–0.5 mm and 0.02–0.1 mm	white 59.6%, followed by black (17.6%), red (9.0%), orange (3.3%), green (2.3%), blue (1.7%) and others (6.5%).
van den Berg P 2020	Valencia, in the east of Spain	average of 18,000 ± 15,940 light density MPs/kg and 32,070 ± 19,080 heavy density MPs /kg .	fragments, fibers, films	N.D	0.050-0.250 mm	N.D