

# A critical review on microplastics in edible fruits and vegetables: A threat to human health



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**Abstract** Microplastics (MPs), ubiquitous pollutants in the environment, have raised concerns about their potential impact on human health. This abstract examines the presence of MPs in edible fruits and vegetables and their potential health implications. Studies have revealed the widespread contamination of agricultural soils and water sources with MPs, leading to uptake by plants. Factors such as irrigation with contaminated water, plastic mulching, and atmospheric deposition contribute to the accumulation of MPs in crops. Once ingested, MPs can release toxic chemicals and act as vectors for harmful pathogens. Human exposure to MPs through the consumption of contaminated fruits and vegetables raises concerns about the long-term health effects including inflammation, oxidative stress, and potential carcinogenicity. Furthermore, the small size of MPs enables their translocation within the human body, potentially reaching vital organs and causing systemic damage. Mitigation strategies such as improved waste management, alternative agricultural practices, and stricter regulations are essential to minimize the threat of microplastic (MP) contamination in the food chain and safeguard human health.

**Keywords:** contamination, fruit and vegetable, health implications, human exposure, mitigation strategies, plastic pollution

## 1. Introduction

The pollution caused by plastic waste is one of the most pressing issues worldwide. The quantity of plastic present in the environment is increasing, and human contact with microplastics (MPs) has become a tangible concern (Kadac-Czapska et al., 2022). MPs can penetrate seeds, roots, culms, leaves and fruits (Dietz & Herth, 2011). Fruits and vegetables are considered vital for maintaining good health. Epidemiological, toxicological, and nutritional studies have revealed a link between consuming fruits and vegetables and a reduced risk of chronic diseases, including coronary heart disease, cancer, diabetes, and Alzheimer's disease (Río-Celestino & Font, 2020). In accordance with the Dietary Guidelines for Americans (2010), it is recommended to dedicate half of our plate to fruits and vegetables. Fruits and vegetables represent a wide array of plant-based foods that exhibit significant variation in their energy and nutrient composition (Slavin & Lloyd, 2012).

However, the presence of MPs highlights the worrying estimated daily intake of plastic particles either for adults or for children through edible fruits and vegetables (Conti et al., 2020). Hence, it is imperative to rigorously observe the food quality, particularly given the substantial presence of MPs in the environment and the lack of specific national and international regulations or standards concerning the management of plastic contamination in food. This highlights the importance of evaluating nanoparticles and MPs in food. MPs are categorized into primary and secondary forms. Primary MPs are produced, and these are characterized by a size <5 mm for several industrial applications, whereas secondary MPs result from the breakdown of larger plastic items (Conti et al., 2020).

The data were gathered through an extensive review of the literature, and the corresponding level of evidence was assessed via predefined criteria aimed at evaluating the understanding of the potential impact of MPs in edible fruits and vegetables on food safety.

## 2. Methods

This review is based on the comprehensive analysis of a few epidemiological and review studies available in the literature on MPs present in edible fruits and vegetables in PubMed, Google Scholar, and ScienceDirect, and few additional records were identified through other sources. All the citations were screened until July 2024, and 84 studies were ultimately included in the study after applying the inclusion and exclusion criteria. The databases were filtered by search terms in titles, abstracts, and keywords with the following expressions: microplastics, food, fruits and vegetables.

## 3. Results

### 3.1. Overview of MPs found in edible fruits and vegetables



MPs can be categorized on the basis of their source, with primary and secondary types being identifiable (Kwon et al., 2020; Yang et al., 2022; Man et al., 2022). Primary MPs are particles derived from manufactured products, including personal care items. They can be found as residues in products such as toothpaste, hair gel, cleansing lotions, and particulate air fresheners. They often enter the environment through the release of household sewage (Hwang et al., 2020; Anagnosti et al., 2021; Xu et al., 2022). However, secondary MPs are the unintentional debris of plastic degradation. They are obtained from “meso (5–25 mm)” and “macro (>25 mm)” plastic waste by physical, chemical, and biological processes (Olewnik-Kruszkowska, Nowaczyk, & Kadac, 2016, 2017; Olewnik-Kruszkowska et al., 2020).

### 3.1.1. Classification of MPs on the basis of visual attributes (shape, size, color)

Table 1 shows the classification of MPs present in edible fruits and vegetables on the basis of their shape, including spheres, fibers, angular, rectangular, cylinders, discs, flat pieces, egg-like, elongated shapes, and rounded particles (Toussaint et al., 2019; D'Hont et al., 2021; Dahl et al., 2021; Rochman et al., 2019).

**Table 1** Classification of MPs on the basis of shape and size.

Shape name with abbreviation	Size	References
Microfoam (MFM)	1–1 µm	Kadac-Czapska et al., 2022
Microfilm (MFI)		
Microfiber (MFB)		
Microfragment (MFR)		
Microbead (MBD)		
Pellet (PT)		
Fragment (FR)		
Fiber (FB)		
Film (FI)		
Foam (FM)		
Spheres	100 µm and 2 mm	Rochman et al., 2019

Table 2 shows that MPs can also be categorized on the basis of their color (Crawford & Quinn, 2017). The color sorting system comprises ten distinct shape categories (Czapska et al., 2022; D'Hont et al., 2021; Dahl et al., 2021). The most common colors are black, blue, white, transparent, red, and green (Frias et al., 2018). Among all MPs, yellow and black MPs are the most common contaminants (Cverenkárová et al., 2021).

### 3.1.2. Chemical components of MPs

A key theme in characterizing MP particles is that no single method offers enough information for a comprehensive analysis of MPs (Microplastics Research, US EPA, 2022).

Figure 1 depicts the diverse chemical constituents of MPs found in a variety of edible fruits and vegetables, including polymers, monomers, production residues, and plastic additives.

## 4. Plastic Contaminants From the Environment

Poor plastic disposal from homes and industries results in ocean pollution. MPs in the marine environment may accumulate chemicals from surrounding areas because of their physicochemical characteristics, among which hydrophobicity may be the most crucial (FAO, 2022).

The most commonly absorbed contaminants are polychlorinated biphenyls (PCBS), dichlorodiphenyltrichloroethane (DDT), hexachlorocyclohexanes (HCHS), polybrominated biphenyls (PBDES), polycyclic aromatic hydrocarbons (PAHS) and microbial biofilms.

## 5. Adverse Effects Of Exposure to MPs on Human Health

Although the health effects of MPs are currently under investigation, few studies indicate that exposure to these minute plastic particles can potentially lead to various adverse impacts on human health (Yee et al., 2021; Wang et al., 2020).

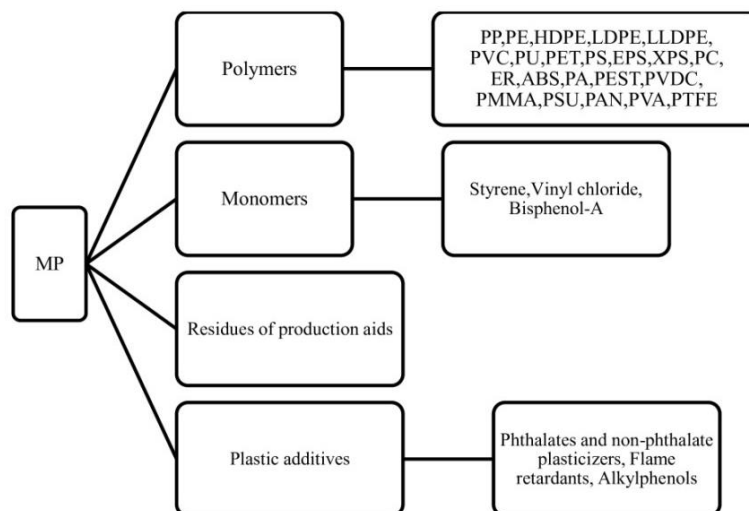
Table 3 shows that MPs can cause cytotoxicity (Hwang et al., 2019; Lee et al., 2021; Furukuma & Fuji, 2016), inhibition of ABC transporters and mitochondrial depolarization (Wu et al., 2019), destruction of the construction and function of proteins (Ju et al., 2020), a reduction in cell viability (Hwang et al., 2020; Gautam et al., 2022), genotoxicity (Çobanoğlu et al., 2021), inflammation, endoplasmic reticulum stress (Wang et al., 2020; Gautam et al., 2022; Chiu et al., 2015), changes in cellular morphology and immune responses, apoptosis (Kwon et al., 2022) and membrane damage (Zhang et al., 2022). MPs can also increase the risk of cancer, cause various metabolic changes, increase oxidative stress (Bonanomi et al., 2022; Chiu et al., 2015);



Schirinzi et al., 2017; Hwang et al., 2019), cause endocytosis and increase the activity of osteoclasts (Liu et al., 2015). BPA-containing MPs can cause neurotoxicity and disrupt the endocrine system (Landrigan et al., 2023).

**Table 2** Classification of MPs based on color.

Color	Abbreviation	Shape of MP	References
Any color	ALL		
All opaque	AO		
All transparent	AT	All shapes	Kadac-Czapska et al., 2022
Amber	AM		
Beige	BG	Fiber, fragment , film	
Black	BK	Fiber, angular, elongated, irregular, pellet	Kadac-Czapska et al., 2022; D'Hont et al., 2021
Blue	BL	Fiber, angular, elongated, irregular, film, rectangular	Kadac-Czapska et al., 2022; D'Hont et al., 2021; Dahl et al., 2021
Brown	BN	Irregular	Kadac-Czapska et al., 2022; Dahl et al., 2021
Bronze	BZ		
Charcoal	CH		
Clear	CL	Fiber, fragment , film	Kadac-Czapska et al., 2022
Dark	DK		
Gold	GD		
Green	GN	Fiber, angular, irregular, film	Kadac-Czapska et al., 2022; D'Hont et al., 2021
Gray	GY		
Ivory	IV		
Light	LT		
Metallic	MT		
Olive	OL	Fiber, fragment , film	Kadac-Czapska et al., 2022
Opaque	OP		
Orange	OR		
Pink	PK		
Purple	PR		
Red	RD	Fiber, angular, elongated, irregular, film	Kadac-Czapska et al., 2022; D'Hont et al., 2021
Silver	SV		Kadac-Czapska et al., 2022
Speckled	SP	Fiber, fragment , film	
Tan	TN		
Transparent	TP	Fiber, angular, elongated, irregular, film, sphere	Kadac-Czapska et al., 2022; D'Hont et al., 2021; Dahl et al., 2021
Turquoise	TQ	Fiber, fragment , film	Kadac-Czapska et al., 2022
Violet	VT	Spherical	
White	WT	Fiber, angular, elongated, irregular, film, sphere	Kadac-Czapska et al., 2022; D'Hont et al., 2021
Yellow	YL	Fiber, angular, irregular	Kadac-Czapska et al., 2022; D'Hont et al., 2021; Dahl et al., 2021



\* polypropylene (PP), polyethylene (PE), high-density polyethylene (HDPE), low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), polyvinyl chloride (PVC), polyurethane (PU), polyethylene terephthalate (PET), polystyrene (PS), expanded polystyrene (EPS), extruded polystyrene (XPS), polycarbonate (PC), epoxy resin (ER), acrylic, acrylonitrile butadiene styrene (ABS), polyamides (PA)(nylon), polyester (PEST), polyvinylidene chloride (PVDC)(Saran), poly methyl methacrylate (PMMA), poly aryl sulfone (PSU), polyacrylonitrile (PAN), polyvinyl alcohol (PVA) and polytetrafluoroethylene (PTFE, Teflon) (FAO, 2017; Plastic Europe, 2019)

**Figure 1** Depicts the diverse chemical constituents of MPs found in a variety of edible fruits and vegetables, including polymers, monomers, production residues, and plastic additives.

**Table 3** Impacts of MPs on human health.

Name of Human Body Part/Systems/Cells	MP		Health impacts	References
	Type	Size		
Peripheral blood mononuclear cells	PP	20 µm	Cytotoxic effects	Hwang et al., 2019
Intestinal epithelial Caco-2	PS	0.1 µm 5 µm	Inhibition of ABC transporter Mitochondrial depolarization	Wu et al., 2019
Serum albumin	PVC	5 µm	The destruction of the construction and function of proteins	Ju et al., 2020
Dermal fibroblasts	PS	3 µm	The reduction of cell viability (40%)	Hwang et al., 2020
Peripheral blood lymphocytes	PE	10–45 µm	Genotoxic effects	Çobanoğlu et al., 2021
Umbilical vein endothelial cells HUVEC		0.5 µm	Cytotoxicity, autophagy	Lee et al., 2021
Kidney Proximal Tubular Epithelial Cells HK-2	PS	2 µm	The inflammation, higher protein levels of LC3, Beclin 1, mitochondrial protein Bad, higher endoplasmic reticulum stress	Wang et al., 2020
Microglial HMC-3 cells (macrophage)		0.2 and 2 µm	Changes in cellular morphology and immune responses, apoptosis	Kwon et al., 2022
Intestinal epithelial Caco-2			Reduction of cell viability	Gautam et al., 2022
Lung epithelial A549 cells	PE	6.2 ± 2.0 and 30.5 ± 10.5 µm	Pro-inflammatory effects	
HaCaT keratinocyte cells (epidermis)			The membrane damage	Zhang et al., 2022
Small intestinal epithelial cell HIEC-6		0.1 and 0.5 and 1.5 µm		
Colonic epithelial cell CCD841CoN	PS		Risk of cancer, metabolic changes	Bonanomi et al., 2022
Intestinal CCD-18Co cells		2 µm		
Neurons	BPA-containing MP	<5 mm	Neurotoxic effect	
Estrogen, androgen, or thyroid hormone receptors			The endocrine disruptors	Landrigan et al., 2023
Human bronchial epithelial cells (BEAS-2B)	PS	60 nm	Oxidative stress(ROS production), alterations in protein folding, endoplasmic reticulum stress, induction of autophagic cell death	Chiu et al., 2015



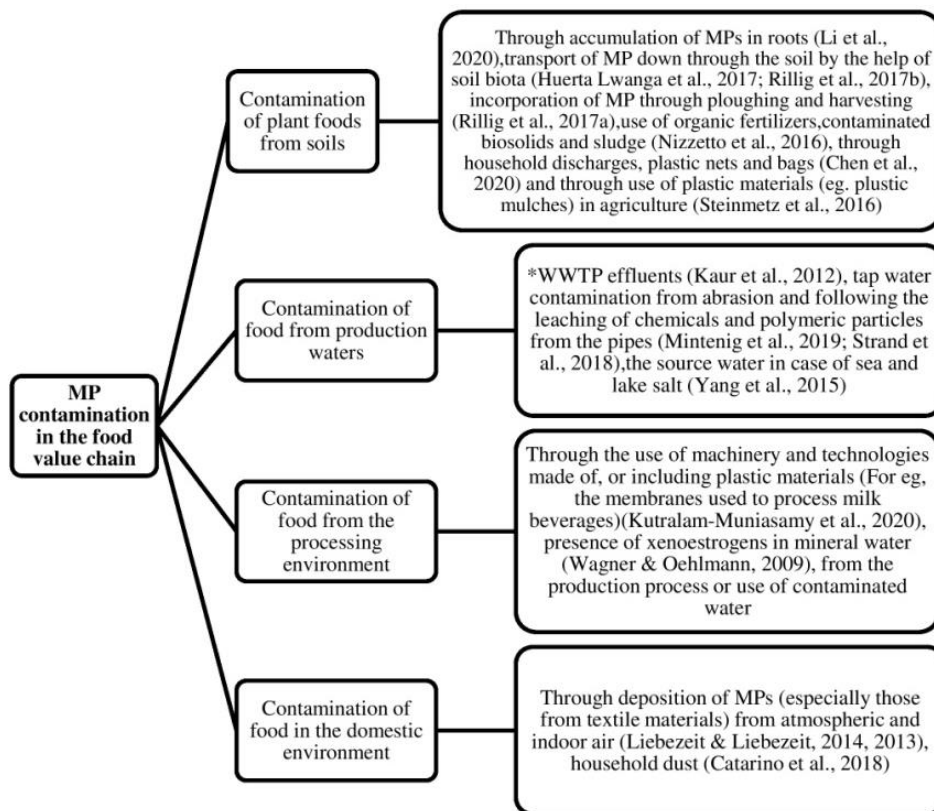
Human lymphoblastoid cells (TK6)	Marine plastic debris	≤ 1 mm	Cytotoxicity	Furukuma & Fuji, 2016
Human brain cells (T98G)	PE	3, 16 μm, 100, 600 nm	Oxidative stress(ROS production)	Schirinzi et al., 2017
Epithelial cells (HeLa)	PS	10 μm, 40, 250 nm		
Human cell lines: PBMCs, RAW 264.7, HDF, HMC-1	PP	~20, 25, 200 μm	Oxidative stress (ROS production), histamine release, stimulation of the immune system (inflammation, release of cytokines TNF-α and IL-6)	Hwang et al., 2019
Human cells (PBMN)	PS	20 nm, 40 nm, 200 nm, 1 μm	Increased activity of osteoclasts (osteolytic cytokine release: TNF-α, IL-1β, IL-6, IL-8) Internalization by energy-dependent (endocytosis) and energy-independent pathways, accumulation in the perinuclear region	Liu et al., 2015
Human renal cortical epithelial cells (HRCE)		44 nm		Monti et al., 2015

Abbreviations: PS: polystyrene; PE: polyethylene; PP: polypropylene; PVC: polyvinyl chloride; BPA: bisphenol A; MP: microplastics.

### 6. MP Contamination in the Food Value Chain

MPs may be introduced into the food value chain by anthropogenic activities (e.g., food production) and bioturbation (disturbance of sediments by living organisms causing MP displacement). In food production, MPs can infiltrate the food value chain at various stages, from primary production to processing, packaging, transport/distribution, consumption, and even disposal (FAO, 2022).

Figure 2 illustrates multiple pathways of MP contamination in the food value chain, including contamination of plant foods from soils, contamination of food from production water, contamination of food from the processing environment, and contamination of food in the domestic environment.



\*WWTP= Wastewater treatment plants

**Figure 2** Illustrates multiple pathways of MP contamination in the food value chain, including contamination of plant foods from soils, contamination of food from production water, contamination of food from the processing environment, and contamination of food in the domestic environment.



### 6.1. Ways to contaminate fruits and vegetables with MPs

The presence of nano- and MP particles in our natural water bodies has recently emerged as a significant concern (Hernandez et al., 2017). In freshwater systems in Europe, Asia, and North America, primary and secondary MPs (mainly of domestic origin) have been reported. The highest concentrations of plastics were detected near densely populated, industrialized, and tourist regions. However, substantial amounts of plastic have also been discovered in sparsely populated areas, likely because of the free movement of plastic through the atmosphere. Additionally, sediment samples from estuarine coasts have been examined, revealing numerous plastic nanoparticles and microparticles. Among these plastic microparticles, 65% are fragments from larger plastic pieces (Mattsson et al., 2015). Various sources of water and soils contaminated with MPs are the sources from which plants absorb water and nutrients (Ho et al., 2020). In addition, multiple implements made of plastic materials add MPs either to horticultural products or other products for human consumption, and this practice is known as plastic culture (Patel & Tandel, 2017).

Table 4 shows the extensive use of various MPs in different edible fruits and vegetable crops in diverse processes involved in horticulture production. Plastic mulch film is used for mango, litchi, guava, ber, pineapple, papaya, and bananas well as for cabbage, cauliflower, tomato, chilli, okra, bitter gourd, brinjal, and broccoli (Patel & Tandel, 2017; Bhattacharya et al., 2018). High-density polyethylene is used for drip irrigation for the production and processing of muskmelon, watermelon, banana, pomegranate, guava, fuji apple, muscat grape, canopy fruit, papaya, lime, litchi, green chilli, tomato, brinjal, capsicum, cabbage, pointed gourds and cauliflower (Patel & Tandel, 2017; Reddy et al., 2017). Polyethylene film is used for soil solarization to prevent weed growth, and the occurrence of bacteria, fungi, nematodes and other soil-borne pathogens and pests (Patel & Tandel, 2017; Hartz et al., 1993; Díaz-Hernández et al., 2017; Pinkerton et al., 2002; Stapleton et al., 1985). Both polyethylene film and high-density polyethylene, are used for protected cultivation processes for greenhouse effects (Patel & Tandel, 2017; Negi et al., 2021) and for producing shed nets (Chen et al., 2020; Negi et al., 2021). Polyethylene is also used in horticultural production for propagation and nurseries for strawberry, blackberry, raspberry, blueberry, grape, gooseberry, and kiwifruit as well as for tomato, brinjal, chilli, bean, okra, broccoli, cabbage, carrot, cauliflower, cucumber, etc. (Maandi et al., 2022; Chauhan et al., 2021; Zimmerman et al., 1986). Low-density polyethylene, linear low-density polyethylene, polyvinyl chloride, polypropylene and high-density polyethylene are extensively used in horticultural packaging (Patel & Tandel, 2017). Cylindrical polyethylene bags are used for the sleeving process to protect the skin of fruit against insects and damage (Patel & Tandel, 2017; Negi et al., 2021).

**Table 4** Use of MPs in Horticulture Production (Cropwise).

Name of the process	Details	Reason of use	MP		Used in Fruit Crops	Used in Vegetable Crops	References
			Type	Size			
Mulching	Plastic mulch film-a protective covering (as of plastic film, sawdust, compost, grass, hay, dry leaves, or stones) spread or left on the ground	To reduce evaporation, maintain soil temp, prevent erosion, control weeds, enrich soil, keep fruits and vegetables clean	LDPE, LLDPE	25-40 µm	Mango, Litchi, Guava, Ber, Pineapple, Papaya, Banana	Cabbage, Cauliflower, Tomato, Chilli, Okra, Bitter gourd, Brinjal, Broccoli	Patel & Tandel, 2017; Bhattacharya et al., 2018
Drip Irrigation	Precise and regulated application of irrigation water and plant nutrients at low pressure and frequent intervals through drippers/emitters directly into the root zone of plant with the help of close network of pipes	To improve quality, ensure early maturity of the crops, water saving up to 40% - 70%, control weed growth, saving of fertilizer (30%) and labor cost (10%), increase the production of vegetables and fruit crops	HDPE	0.5 to 2 mm	Muskmelon, Water melon, Banana, Pomegranate, Guava, Fuji apple, Muscat Grapes, Canopy fruit, Papaya, Lime, Litchi	Green chilli, Tomato, Brinjal, Capsicum, Cabbage, Pointed gourds, Cauliflower	Patel & Tandel, 2017; Reddy et al., 2017
Soil Solarization	Normally done during summer months when the air	It can prevent weed growth, occurrence of bacteria, fungi,	PE Film	25 µm	Strawberry, Red Raspberry	Tomato, Radish, Pepper and Chinese cabbage	Patel & Tandel, 2017; Hartz et al., 1993; Díaz-

	temperature more than 35°C. This is done by covering the moist soil with a transparent polyethylene film exposed to sunlight	nematodes and other soil borne pathogens and pests, helps in reducing usage of weedicides/herbicides and pesticides						Hernández et al., 2017; Pinkerton et al., 2002; Stapleton et al., 1985
Protected Cultivation	Greenhouse is a framed structure covered with glass or plastics film (transparent and translucent) in which plants are grown under the partially or fully controlled environment	The plastics film used in greenhouse act as selective radiation filters	PE Film	25 µm	Peach, Papaya, Strawberry	Cucurbits, cabbage, capsicum, cauliflower, chilli, coriander, spinach, tomato		Patel & Tandel, 2017; Negi et al., 2021
	Shed net	To reduce light intensity, also helps to control pests and diseases, manipulation of microclimate and provides insect proof feature	HDPE	0.5 to 2 mm				Chen et al., 2020; Negi et al., 2021
Propagation	Plastics are generally used in layering and grafting. In grafting polythene strips are used to tie stock and scion	Etiolation effect which is essential for cell division and cell enlargement	PE	25 µm	Strawberry, Blackberry, Raspberry, Blueberry, Grapes, Gooseberries, Kiwifruit	Tomato, Brinjal, Chilli, Bean, Okra, Broccoli, Cabbage, Carrot, Cauliflower, Cucumber		Maandi et al., 2022; Chauhan et al., 2021; Zimmerman et al., 1986
Nursery	Plastics are used in form of nursery bag, plug tray, crate and hanging basket	Easy to handle, planting, transplant and transport	PE	25 µm				
		Flexible, light weight, cost effective, hygienic, transparent, easily printable, reusable, increases shelf-life of the product. It provides invaluable support during processing, used in making of different packaging materials like flexible plastic films, tray with over wrap, punnets, net bag, foam sleeve, crates and used in storing, preserving and transporting of fresh as well as	LDPE and LLDPE, PVC, PP, HDPE	25-40 µm, 5 µm, 20 µm, 0.5 to 2 mm	Mostly all fruits	Mostly all vegetables		Patel & Tandel, 2017
Packaging	Packaging is one of the most critical areas in the distribution and marketing of agricultural produce							

		processed fruits and vegetables					
	It involves a plastic bag having both end open and is useful for protection of banana bunch from wind, rain, hail, dust, pest etc.	Protects the skin of the fruit against leaf insect and bird damage as the fruit matures. Due to sleeving fruit size is more uniform and larger throughout the bunch and fruit gets better color	Cylindrical PE Bags	16-18 $\mu$ m	Apples, Muskmelon, Water melon, Banana, Pomegranate, Guava, Fuji apple, Muscat Grapes, Canopy fruit, Papaya, Lime, Litchi	–	Patel & Tandel, 2017; Negi et al., 2021

Abbreviations: LDPE (low-density polyethylene); LLDPE (linear low-density polyethylene); HDPE (high-density polyethylene); PE (polyethylene); PVC (polyvinyl chloride); PP (polypropylene).

### 6.2. Plastic migration from food-contact materials and packaging

The demand for plastic packaging stems from the essential requirement to safeguard food from chemical, physical, or biological deterioration, thereby prolonging its shelf life (Lee, 2010). Plastics have become widely utilized in this sector because of their advantageous properties, which also facilitate global trade and enhance the quality of food products. Approximately 40% of all plastics produced are utilized for packaging. The main polymers used in this sector include polyethylene (especially LDPE), polystyrene (including high-impact polystyrene or HIPS and general-purpose polystyrene or GPPS), polypropylene (PP), polyethylene terephthalate (PET), polycarbonates (PCs), and polyamides (PAs) 6, 6.6, 6.10, 10, and 11, as well as polyurethane (PU), which are utilized in adhesives. Polyvinyl chloride (PVC) and polytetrafluoroethylene are also significant polymers in this industry (Bhunia et al., 2013; Plastic Europe, 2019). Other polymers include polytetrafluoroethylene (PTFE or Teflon, used in cookware), polyvinylidene chloride (PVDC, used as a barrier layer) and ethylene copolymers (Bhunia et al., 2013).

Synthetic particles in bottled drinking water primarily originate from packaging material, as the polymers detected are typically those used in the production of bottle caps (e.g., PP, PE) or in labels, carton linings, and PET bottles (Mason et al., 2018; Oberbeckmann et al., 2018; Schymanski et al., 2018).

In addition to potential contamination with MPs, the migration of leachable chemicals from plastic packaging into foods is a notable concern (Groh et al., 2019). Although chemical migration is outside the scope of this report, some aspects are highlighted, such as the possibility of migration occurring from MPs found in food.

### 6.3. Presence of micro- and nanoplastics in edible fruits and vegetables

The International Agency for Research on Cancer (IARC) has classified various types of plastics, derivatives, and components, including polyvinyl chloride (PVC) derivatives, polystyrene (PS), and phthalates, as potentially carcinogenic. Additionally, concerns regarding the physical and chemical effects of these particles in the body include the mobilization or adsorption of other pollutants, such as polychlorinated biphenyls (PCBs), polycyclic aromatic hydrocarbons (PAHs), and dichlorodiphenyl trichloroethane (DDT) (Pastor et al., 2019).

One study compared the different amounts of MPs consumed according to the age and sex of the individuals. (Cox et al., 2019). In particular, apples were the most contaminated fruit samples, whereas carrots were the most contaminated vegetable among the apples (*M. domestica*), pears (*P. communis*), broccoli (*B. oleracea italica*), lettuce (*L. sativa*) and carrot (*D. carota*) samples. Conversely, a lower median level was observed in lettuce samples (Conti et al., 2020).

The predominant mode of exposure to MPs is thought to involve the digestive system. They can be ingested involuntarily. Table 5 shows the estimates of dietary exposure (derived MP intake) to MPs in fruits and vegetables. It is estimated that individuals worldwide might consume between 0.1 and 5 grams of these particles weekly (Senathirajah et al., 2021).

## 7. Understanding International Standards and Relevant Regulations

Currently, there are no strict regulations for monitoring MPs in fruits and vegetables, leading to limited knowledge about their presence and associated risks. While some guidelines exist for plastic from food packaging, specific laws addressing MPs in fruits and vegetables are lacking (Gamarro & Costanzo, 2022).

The European Commission Directive (2002/72/EC) regulates the types of plastics allowed in food packaging and sets specific migration limits (SMLs) for chemicals moving from the packaging to the food. These limits are based on the assumption that an average adult consumes 1 kg of packaged food per day. The Commission Regulation (EU) No 10/2011 outlines these limits (Gamarro & Costanzo, 2022).

**Table 5** Estimates of dietary exposure (derived MP intake) to MPs in fruits and vegetables.

Fruits and Vegetables	Consumption	Derived MP intake	Reference
Apples	165.3 g/day	4.62x10 <sup>5</sup> MP/kg of body weight per day (adults)	Conti et al., 2020
	115.7 g/day	1.41x10 <sup>6</sup> MP/kg of body weight per day (children)	
Pears	165.3 g/day	4.48x10 <sup>5</sup> MP/kg of body weight per day (adults)	
	115.7 g/day	1.37x10 <sup>6</sup> MP/kg of body weight per day (children)	
Broccoli	53.0 g/day	9.55x10 <sup>4</sup> MP/kg of body weight per day (adults)	
	24.2 g/day	1.91x10 <sup>5</sup> MP/kg of body weight per day (children)	
Lettuce	53.0 g/day	3.83x10 <sup>4</sup> MP/kg of body weight per day (adults)	
	24.2 g/day	7.65x10 <sup>4</sup> MP/kg of body weight per day (children)	
Carrots	20.3 g/day	2.96x10 <sup>4</sup> MP/kg of body weight per day (adults)	
	18.0 g/day	1.15x10 <sup>5</sup> MP/kg of body weight per day (children)	

## 8. Conclusions

We recognize widespread concern about MPs and their potential effects on public health. However, there are not enough comprehensive data concerning their presence in all edible fruits and vegetables except fishery products. The evidence suggests that the amount of MPs in food is generally low, although knowledge about their toxicity remains limited, and many studies rely on model organisms to infer their potential impacts on humans. Concerns persist about the leaching of harmful chemicals from plastics into food. This information is valuable for future exposure assessments and for creating laws and guidelines to address MP contamination in food (Gamarro & Costanzo, 2022).

Standardized sampling, analysis, and reporting methods enhance dataset usability. Addressing knowledge gaps in MP toxicity and investigating their presence in various foods is important. Risk assessments for compounds in food-contact plastic materials are necessary, along with more data on the constituents and potential toxic effects of plastic packaging materials (Gamarro & Costanzo, 2022).

There are few suggestions for regulatory bodies and essential contributors to food safety practices:

1. Provide detailed information to consumers about plastic-packaged food.
2. Understand how packaging affects food quality.
3. Exploring the inclusion of MPs in the human food supply in innovative ways.

To limit human exposure to substances, specific limits can be set to reduce MP intake through food, monitor intake levels, and promote the use of biodegradable plastics (Gamarro & Costanzo, 2022).

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## Ethical Considerations

Not applicable.

## Conflict of Interest

The author declares no conflicts of interest.

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