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Review

Microplastics and Their Effect in Horticultural Crops: Food Safety and Plant Stress

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Abstract: The presence of micro and nanoplastics in the food chain constitutes an emergent multifactorial food safety and physiological stress problem, which must be approached with a strategic perspective since it affects public health when consuming products that have this pollutant, such as fish and crustaceans, fruits, and vegetables. In this review, the authors present the results by scientists from different disciplines who are dedicated to discovering their chemical constitution and origin, the contents of these microparticles in edible plants, the contamination of water-irrigated soils, the mechanisms that concentrate microplastics in these soils, methods to determine them, contamination of freshwater sources of cities, and the negative effect of nano and microplastics on various food products and their detrimental impact on the environment. Recent findings of plant uptake mechanisms complement this, but more research is needed.

Keywords: horticulture; environment; crop production; pollutant agent

1. Introduction

The contamination of nano and microplastics in the horticultural industry worldwide is a fact. Therefore, it is essential to develop this current line of research in food safety based on the contamination of inputs and materials used in horticulture and to establish public policies on control alternatives.

The pollution of the environment because of the impact generated by nano and microplastics is an emerging problem in the contemporary world. A large proportion of plastic products are disposed as waste [1]. Many urban and rural areas of the industrialized world have been adversely affected by large-scale pollution, resulting in human, material, and financial losses. Plastic is the most critical anthropogenic pollutant (35,000 tons in the ocean) that humanity faces today, and constitutes almost 80% of the sea's waste. The excessive use of plastic in industry and the world's inhabitants have generated an irreversible impact on all natural ecosystems worldwide. Some researchers have published studies related to nano and microplastics as a new contaminant present in food [2].

The existence of nano and microplastic particles in natural sources such as rivers, oceans, and lakes has recently become a concern [3]. Most of the plastic present in the environment is not biodegradable and remains as waste for many years, and approximately 10% of the total plastic produced will end up in the ocean [4]. Plastic production has increased exponentially since 1960, and because waste management has been deficient, the proliferation of microplastics (fragments smaller than 5 mm) has increased steadily [5]. These can be classified into two main categories: primary microplastics (intentionally manufactured for commercial purposes) and secondary (derived from the degradation of more extensive materials) [6]. The most relevant information published to date in popular science magazines regarding contamination by plastic micro and nanoparticles of waters with low ionic strength located in continental areas is less abundant than the information regarding these pollutants' impacts in marine systems [4].

In Europe, Asia, and North America's freshwater systems, primary and secondary microplastics (mainly of domestic origin) have been reported. The most significant number of plastics was found near densely populated, industrialized, and tourist areas, and large amounts of plastic have also been found in locations with a minor population. This may be due to the plastic's free movement through the atmosphere. On the other hand, sediment samples from estuarine coasts have been analyzed, finding many plastic nanoparticles and microparticles. Of these plastic microparticles, 65% are fragments from larger plastic pieces [7]. Various sources of water and soils contaminated with microplastics [8] are the source from where plants absorb water and nutrients. In addition to this, multiple implements made out of plastic materials would also add microplastics [9] either to horticultural products or other products for human consumption. However, its effects have not yet been consistently demonstrated, since the studies published to date vary in the evaluated and experimental conditions. Thus, microplastics' impact on plant growth is unknown, with scarce and partial results published on the absorption and translocation mechanisms in some edible species. It is also added that the methodologies used to know the origin of microplastics, particle size, and quantity in the organic matter of edible organs for human use differ.

2. The Chemical Composition of Microplastics

According to the source, micro and nanoparticles of plastic are classified into two broad categories: primary plastics and secondary plastics. Primary microplastics are intentionally manufactured in small sizes for different industrial purposes, such as housing and transportation applications and are generally made of polyethylene or polystyrene. Primary microplastics come mainly from packaging some products, such as cleaning or personal care products, pellets manufacture, other plastic products, electronic devices, medicines, cars, airplanes, or 3D printers [10]. Secondary microplastics have more versatile chemistry due to the variety of plastics poured into water [3,4]. The plastic in contact with the environment is fragmented into smaller pieces by different mechanisms, which are (i) photo-oxidation product of UV radiation, (ii) mechanical fracture by hydrolysis (abrasion by sand or water turbulence), (iii) biological degradation, (iv) disintegration and (v) bio-assimilation by microorganisms [10]. The photodegradation induced by exposure to UV radiation, in particular, can form functional groups of the type C-O, C-OH, and CO on the surface of the plastic, and recently the release of reactive O_2 (ROS) species has been determined to a greater extent O_2^-, H_2O_2 y $OH^{\cdot}$ [11]. Nano-sized plastic particles have a considerable surface and structure compared to biological surfaces and molecules, currently showing their real biological and physicochemical impact [3,7,12]. The hydrophobic nature of nanoplastics, combined with their size, enhance their entry into cells through the breakdown of cell walls, which can cause cytotoxicity [3,13], generating various adverse health effects such as (i) growth inhibition, (ii) behavioral disorders, (iii) reproductive dysfunctions, (iv) eating disorders, (v) reduced viability and (vi) mortality [14,15].

The size of a microplastic varies from 1 to 5 mm in diameter. Particles with sizes between 5 and 25 mm are called mesoplastics, and particles with sizes greater than 25 mm are classified as macroplastics. On the other hand, nanoplastics are defined as materials with a dimension between 1 to 100 nm [3,4,7,13,16]. These are the most dangerous due to their high potential for bio-accumulation and bio-magnification [4]. The chemical composition, size, and surface characteristics of plastic microparticles can provide valuable information on their origins. For example, the primary microplastics in personal care products tend to be made primarily of polyethylene, but may contain large amounts of polypropylene (PP), polystyrene (PS), polyurethane (PUR), polyethylene terephthalate (PET), high-density polyethylene (HDPE), low-density polyethylene (LDPE), polymethylmethacrylate (PMMA) and Teflon within its composition. These polymers are often used in packaging and therefore indicate urban origin, while denser polymers such as polyvinyl chloride (PVC) and polyester are commonly used in construction and textiles, respectively. These plastics will be introduced as secondary microplastic fragments and fibers to sewage or surface effluents [4,17,18], which will surely end up in the sea.

3. Consumption of Microplastics

3.1. Contamination of Microplastics and Their Effect on Food Safety

Having safe food for the population is a global challenge. For this reason, food contaminants are permanently under study. Various investigations have determined that the level of nanoplastics and microplastics worldwide is steadily increasing [5]. There, its effect on people's health has become of great importance and study for the scientific world. In this sense, it can be noted that it is possible to find microplastics distributed throughout our environment, either in samples of marine life or in standard products such as table salt, sugar, honey, beer, bottled water, among others [19]. A study by [20] indicated that vegetable farms in suburban areas of the Wuhan region, China, were universally contaminated with microplastics, so the presence of these residues in vegetables is a potential threat.

Another study by [21] compared the different amounts of microplastics consumed depending on the age and sex of the individuals. In addition to the different concentrations of microplastics in food, the ingestion of bottled water considerably increases the exposure, unlike the consumption of tap water, which also contains these microplastics. They also indicated that the most significant source of microplastics comes from the air, which is inhaled more significantly by adult men, who inhale an average of 60,000 particles of these pollutants per year. Currently, the International Agency for Research on Cancer (IARC) has described various types of plastics, derivatives, and components as potentially carcinogenic, such as derivatives of polyvinyl chloride (PVC), polystyrene (PS), and Phthalates. However, the problem related to physical and chemical effects that these particles have in the body relates to mobilization or adsorption of other kinds of species or pollutants such as polychlorinated bipheline (PCBs), polycyclic aromatic polycarbons (PAHs), and dichloro diphenyl trichloroethane (DDT) [22]. In this sense, [23] indicated that humans are constantly exposed to these compounds, either in the form of primary or secondary microplastics, showing that the prolonged use of products that contain them, such as products of showering and makeup, among others, can generate the involuntary absorption of compounds that can damage the skin, and in the case of the consumption of these compounds, an alteration at the chromosome level could be generated, leading to infertility or cancer. Therefore, it is crucial to consider that these components' impact on health depends mainly on the concentration of exposure to them, highlighting that the body can eliminate about 90% of the micro and nano plastic ingested by the fecal route. The effect on human health depends mainly of the size, shape, type of polymer, and additive chemicals of microplastics ingested by people, determining the severity of adverse effects [24]. Although, the physical effects of these microparticles accumulated in the body in the long term are not well understood, it has been indicated that some of the possible impacts on the human body can be expressed in the form of inflammatory responses, toxicity related to the size of ingested particles and alteration of the intestinal microbiome [21,24]. In addition to this, it has been indicated that oral exposure to these pollutants has had various effects such as cardiopulmonary responses, alterations of endogenous metabolites, and oxidative stress, among others [24].

In this sense, it is clear that people are exposed to microplastics in different forms and concentrations. However, the long-term effect that these particles will generate on human health, and the effect that these will continue to have on aquatic and terrestrial ecosystems, is still unknown, so the study of the proliferation of these pollutants and their effect on people should be a priority for the generation of short and long-term mitigation strategies of the adverse effects of these on the health of the people in a context of food security.

3.2. Microplastics in Horticultural Crops and Their Effect on Plant Stress

Recently published advances on different edible species are presented below. One of the first studies was performed using *Lemna minor* L., an aquatic and wild species of the Araceae family used in the pet food industry [25]. This plant was exposed to polyethylene microbeads of two types of exfoliants marketed in the cosmetic industry. The effect of microplastics was evaluated and isolated, finding that the presence of these microparticles caused stress in the plant by decreasing root growth due to mechanical blockage. Vegetative growth was not affected. In 2018, [26] published wheat research (*Triticum* spp.) grown in pots in a controlled environment under abiotic stress conditions. The plants were subjected to a nutrient solution that, apart from essential elements, contained microplastics. In this solution, low-density polyethylene and also starch-based biodegradable plastic was applied at a concentration of 1%. The results indicated that the residues of macro and microplastics stressed the vegetative and reproductive growth of the crop. The biodegradable film caused the most significant adverse effect compared to low-density polyethylene in the nutrient solution. This could be explained, considering that this biodegradable plastic film is composed of polybutylene terephthalate (PBT) and PET; however, it is not conclusive to indicate that all biodegradable coatings behave in this way. In [27], information was provided on the toxicological effect of microplastics on the plant for the same species. For this purpose, they applied two types of PVC microplastics with different concentrations (0.5%, 1%, and 2%). They evaluated their stressing effect on some physiological characteristics of the plant in both roots and leaves. The results showed that there were differences in root activity but not in leaves. There were variations in total length, surface area, root volume, and root diameter in the root system when the microplastic content varied from 0.5% to 1%. The authors indicated an effect on leaves due to the type of PVC applied in the growing medium and that 1% PVC content in the plant could reduce the ability of the plant to absorb, dissipate, capture, and transfer light energy electrons.

The study of microplastics in other species such as garden cress (*Lepidium sativum*) in 2019 [28] showed that nano and microplastics accumulated in the pores of the seed coat of this species would affect water uptake, with the consequent effect of delaying germination, producing a decrease in root growth when exposed to plastic particles with a size of 50 nm. Ref. [29] evaluated different types of microplastics in a chive (*Allium fistulosum*) crop. The microplastics used were polyester fibers, polyamide beads, and four types of fragments: polyethylene, polyester terephthalate, polypropylene, and polystyrene.

In 2020, Italian research evidenced and quantified the content of microplastics and nanoplastics in some fruits and vegetables collected from retail. This study has shown that plants can absorb these small particles of different types of plastic. The analyzed species were apple fruits (*Malus domestica*), pear (*Pyrus communis*), broccoli inflorescence (*Brassica oleracea* var. *italica*), lettuce leaves (*Lactuca sativa*), and carrot roots (*Daucus carota*) [30]. It should be noted that this group of researchers considered the recommended daily intake of fruits and vegetables in the European Union and determined the number and size of particles in these species of regular human consumption. The methodology used for the extraction of these particles was patented and observed by SEM-EDX.

They then made the respective estimates based on the recommended intake for children and adults. The estimated values are higher for fruits compared to vegetables, with values of 223,000 (52,600–307,750) and 97,800 (72,175–130,500) respectively. In this study, apples and carrots showed a higher content of microplastics in their edible organs. In contrast, the lowest average level (IQR) was observed in lettuce samples and reached a value of 52,050 (26,375–75,425). A wide variability characterized the microplastics levels of the fruit and vegetable samples. The smallest size of microplastics was found in carrot roots (1.51 μm). On the contrary, the largest particles were found in lettuce leaves (2.52 μm). The authors hypothesize that the microplastic uptake and translocation mechanism would be such as that reported for carbon nanomaterials. With this information, [31] suggested the urgent need to carry out new studies in other species and in those already evaluated to compare according to the growing season, the chosen cultivar, the productive system, and the content of microplastics in the irrigated waters, among other multiple factors. This article opens the way to a new line of research in food safety. In 2020, for cucumber (*Cucumis sativus* L.), ref. [29] found polystyrene nanoplastics accumulated in this crop's roots. In turn, these nanoparticles were translocated to the stem, leaves, flowers, and fruits. They also reported that nanoplastics would significantly increase soluble protein and decrease Ca, Mg, and Fe concentrations. To date, there are no other studies that indicate these findings. As can be seen from the articles reviewed, horticultural crops are exposed to contamination by microplastics due to multiple factors that are not yet fully defined, nor their origin or degree of causality. The above is an interdisciplinary challenge to be addressed, including by scientists, technicians, field professionals, and local and global leaders to reach agreements in favor of food safety. Fruits and vegetables represent part of the diet to obtain a healthy life, especially the WHO's Mediterranean diet [30,32]. Therefore, it is contradictory to ignore this serious food safety problem due to the lack of knowledge of how much microplastic we ingest, whether under conventional cultivation, integrated or organic management.

3.3. Microplastic in Irrigation Water

Numerous studies have reported the appearance and toxicity of plastic microparticles in soils and water; however, the presence and impact of plastic nanoparticles (<100 nm) in natural systems has been largely ignored [3,33]. Seawater is the most abundant electrolyte on earth; Almost 97% of the planet is covered by seawater, where only 2.5% is fresh water, and 98.8% of this portion is freshwater ice (except ice in clouds) and groundwater. At present, various studies have highlighted contamination by microplastics in the aquatic environment. In general terms, it is indicated that these types of plastics can be found on multiple surfaces, such as the ocean, coasts, seabed, and freshwater, among others [5]. In this sense, [28] indicate that each year between 0.8 and 2.5 million tons of these microparticles end up in the ocean, and in addition to this, they suggest that even after treating wastewater, 95% of them are retained in the resulting biosolids, which are used as fertilizers in agriculture; however, the flow of microplastics between these environments is still unknown [5], which raises alarm due to the limited availability of information related to the movement of microparticles within the different types of water sources.

Additionally, it is estimated that humans are exposed to about 27 types of micropollutants by consuming fruits and vegetables derived from irrigation water contaminated with these compounds [34]. The presence of these compounds has also been reported in rivers. For example, a study by [35] compared the concentration of microplastics in different world rivers, where the highest concentrations were found in rivers in England, Mexico, and Germany, with other cases being reported in countries such as China, Canada, and Portugal, among others. The above agrees with what is mentioned by [36], who indicate that the concentration of microplastics in freshwater sources used for various activities tends to be higher in sectors with high population densities with intense anthropogenic activities. Consideration of this is crucial, since it has also been indicated that freshwater sources function as a means of transporting microplastics to marine ecosystems, carrying between 70% and 80% of these materials [37]. Various studies have also reported the presence of microplastics in freshwater sources [38–40]. These investigations indicate that the microplastics present in freshwater sources have very small sizes, so they are not visible to the naked eye. This highly heterogeneous distribution implies that the consumption of microplastics through freshwater, directly or indirectly, cannot be easily controlled.

The importance of clean water is invaluable, considering the relative amount available. A rapidly growing population, intensive agriculture, and changing weather patterns have increased the depletion of freshwater sources worldwide [2]. At the current population growth rate, humans will consume 90% of available freshwater by 2025, at which point the world's population living in water-scarce areas is expected to rise to 3.9 billion. The desalination of saline and hypersaline waters is becoming the most viable and accessible source of obtaining freshwater; for this reason, the desalination of the sea, brackish, or brine water has constantly increased in recent years due to the concern to accommodate human demands and agriculture. In Spain, Saudi Arabia, Italy, Qatar, the USA, and Israel, desalinated water for agriculture has been reported. The highest proportion of desalinated water use in agriculture occurs in Spain, where the current capacity is 1.4 million m^3 $day^{-1,}$ and 22% is used in agriculture for high-value crops. Countries such as Chile, China, and Australia are currently integrating desalination technologies in agriculture [41]. Nowadays, the desalination of solutions is the most promising alternative to obtain water with a low concentration of plastic nano and microparticles [33]. However, these particles are commonly detected with extremely high seawater concentrations, including flora, fauna, and sediments [42], alluding that brackish water discharges from the reverse osmosis process could further impact the concentration of nano and microplastic particles and Cl- ions. Rivers are dynamic systems that can retain or transport plastic nano and microparticles, but quantitative evidence of retention and discharge rates to rivers remains limited. It is believed that rivers can act as temporary sinks, delaying microplastic release into the ocean, while the transport of these materials can increase rapidly during rainfall events due to increased flow. In Asia, a study at Lake Hovsgol in Mongolia reported an average density of plastic microparticles of 20,264 elements/km^2 [43]. Similarly, at Lake Taihu in China, plastic microparticles' abundances were the highest reported worldwide, ranging from 0.01×106 to 6.8×106 elements/km^2 [44]. Additionally, microparticle plastic pollution has been reported in Japan, Korea, and urban estuaries in China [45–47].

Also, they have been reported in the United Kingdom (Thames River basin), Italy (Chiusi Lake), and Canada (Ottawa River), where they recorded 660 elements/kg, 2.68 to 3.36 elements/kg, and 0.22 fragments/g, respectively [48]. Studies in drinking water generally aim to determine microparticles in small size ranges compared to those for freshwater. The concentration of microplastics (>1 μm) in the treated water was determined in three different plants, located in the Czech Republic, determining concentrations of 443 ± 10, 338 ± 76 and 628 ± 20 microparticles/liter of water, respectively [49]. For centuries, wastewater has been misused in agriculture because it presents potential risks to public health and the environment. Drinking water and wastewater plants are also considered a pathway for microplastic particles (<5 mm) [50] to release up to 1010 elements/day to the effluent, where the removal efficiency can reach 99% in some cases [51]. Recent scientific developments suggest using special wastewater consideration because it could reduce pressure and uncertainty about access to water use [52]. In New York, discharges of 109,556, 81,911, and 1,061,953 particles/day were reported in three different wastewater treatment plants [53], while in Germany, an average annual discharge of 9×108 particles was reported, respectively [54].

Wastewater treatment plants are used to remove organic compounds and pathogens to produce through different unit operations potable or reusable water in agriculture through a specific treatment designed to remove specific compounds from the water. The unit operations present in this type of treatment unit are coagulation, electrocoagulation, compressed air flotation, electro flotation, water hydrolysis, and sedimentation processes to eliminate large solid particles. A filtration process follows these to collect suspended impurities, biological reaction systems known as aerobic/anaerobic reactors, and, finally, a disinfection process, which ensures or guarantees the safety (free of bacteria or viruses) of the recovered water. On the other hand, the water treatment processes have been designed to eliminate impurities from the water, such as clay, metal, or wood, not considering eliminating nano and microplastic particles [51]. However, global studies have shown that current wastewater treatment systems can reduce the microplastic concentration of raw water by over 95% [50].

4. Determination of Microplastics in Different Matrices

Table 1 shows the different instrumental methodologies for determining and quantifying microplastics in different matrices such as water, fruits and vegetables, and soils. Most of these techniques are focused on a physical type (non-destructive) determination; that is, the composition of the microplastic of the polymer that was separated from the sample by different analytical procedures is visualized. Different authors referenced in Table 1 report similar techniques and reagents for separating the microplastics from the samples, where among the most used reagents are dilute acids and bases (HCl, HNO_3, NaClO, KOH, NaOH), salts (NaCl), alcohols (COH_4 and C_2OH_6), and hydrogen peroxide (H_2O_2) among others [55–58].

The reagents identified here fulfill different functions concerning the polymer that is in contact with the matrix. The NaCl in solution fulfills the function of separating the microplastic by density, when the density is between 1.2–1.9 g/cm^3; the MP with densities lower than these are separated and then extracted by filtration [59]. Another reagent that fulfills this same function are the solutions of KI at 50%, C_2OH_6l at 96% *v*/*v* and $ZnCl_2$ at 90% *v*/*v* [59,60]. H_2O_2 is used mostly to dissolve organic particles, with different characteristics from microplastics, to act as an oxidizing agent and clean the sample to be studied as much as possible by quantification techniques [61]. Diluted acid and base solutions such as HCl, HNO_3, NaClO, NaOH, and KOH, are used to carry out digestion processes, especially for those sample matrices with cellular tissues (marine species) and samples with a high concentration of organic matter, where their action is to destroy the organic matter and release the microplastics from the matrix in order to later be separated by filtration processes [62–65]. Enzymatic digestion is a higher-cost technique than those already mentioned, where K-proteinase is used, which can digest a high percentage of the organic matter in which the microplastic is found, causing damage to this type of microplastic [66].

Table 1. Identification and quantification techniques of microplastics and nanoplastics in different matrices.

Type	Technique (Quantification Method)	Application	Size	Type of Microplastic	References
Fruits and vegetables	Isotope Ratio Mass Spectrometer (IRMS)	Maize grown in hydroponics	–	Polyethylene microbeads	[67]
	Scanning Electron Microscopy–Energy Dispersive X-ray spectroscopy (SEM-EDX)	Fruit and vegetables	<10 um	–	[31]
	Epifluorescence and confocal microscopy	*Lepidium sativum* L.	Nanoplastics < 100 nm y microplastics < 5 mm	–	[68]
	Raman spectroscopy	Sewage sludge applied to agriculture fields and tomato plants	0.4–2.6 mm	Microfibers, HDPE, PP and LDPE	[69]
	Scanning electron microscopy (SEM) and Laser Confocal Raman Spectrometer (LCRS)	Seed germination and seedling growth of wheat	88 nm	Spherical PSNPs	[70]
	Scanning electron microscopy (SEM) and Transmission electron microscopy (TEM)	Lettuce (*Lactuca sativa* L.)	SPS, 100–1000 nm LPS, >10,000 nm	Small polystyrene(SPS) large polystyrene(LPS)	[58]
	Electron microscopy	Lettuce (*Lactuca sativa* L.)	PVC-a with particle sizes from 100 nm to 18 µm PVC-b with particle sizes from 18 to 150 µm	PVC	[27]
	Scanning electron microscopy (SEM) and laser confocal scanning microscope (LCSM)	Cucumber plants	100, 300, 500, and 700 nm	Polystyrene nanoplastics (PSNPs)	[71]
Water	Attenuated total reflection (ATR)–Fourier-transform infrared spectroscopy (FTIR)	Wastewater	1 mm–1.5 um	PVC, PP, LDPE, PA, PET, PMMA, ABS, NYLON, PU, PS, and PE	[50]
	Attenuated total reflection -Fourier-transform infrared spectroscopy (ATR-FTIR)	Bottled water and water	<100 um	PP (54%)	[72]

Table 1. *Cont.*

Type	Technique (Quantification Method)	Application	Size	Type of Microplastic	References
	Fourier transformed InfraRed (FT-IR) and Raman spectroscopy, Scanning electron microscopy (SEM) and Dynamic Light Scattering (DLS)	Water	Nanoplastics and microplastics de 13 a 690 nm	PE	[51]
	Dynamic light scattering (DLS)	Water	Nanoplastics and microplastics de 13 a 690 nm	PE	[51]
	Scanning electron microscopy (SEM) and Malvern Nano ZS Zetasizer (Malvern Instruments, St. Laurent, QC, Canada)	Water (nanoplastic removed)	Nanoplastics average 217 nm and less than 400 nm	–	[73]
	FTIR microscopy and Raman spectroscopy	Wastewater treatment	Nanoplastics and microplastics	Membrane bioreactor (MBR); Microplastic fiber (MPF); microplastic particle (MPP); Polyamide (PA); Polyester (PES); Polyethylene terephthalate (PET) and PP.	[74]
	Stereomicroscope (visual count) and Attenuated total reflection -Fourier-transform infrared spectroscopy ATR-FTIR (identification)	Seawater	Fragment, pellet, and fiber	PS, PP, and PE	[75]
	Field emission scanning electron microscope (FE-SEM) and light microscope (Zeiss Option, Axioskop, Germany, camera Leica DFC290 HD)	Natural water and wastewater treatment	1–20 um	Polyethylene microplastics	[76]
	Micro-Raman spectroscopy	Surface water	0.05–5 mm	Polyamide, cellophane, polypropylene, and polyethylene	[77]

Table 1. *Cont.*

Type	Technique (Quantification Method)	Application	Size	Type of Microplastic	References
	Micro-Raman spectroscopy	Surface waters	0.5–5 mm	Polystyrene, polypropylene, and polyethylene.	[78]
	Raman microscope and scanning electron microscopy (SEM)	Surface waters Lake	<330 µm	PE and PP	[79]
	Fourier Transform Infrared spectroscopy (FT-IR)	Surface waters Lake	<5 mm	Polyethylene, polystyrene, and polypropylene	[80]
Other	Transmission electron microscopy (TEM.), Scanning Transmission Electron Microscopy Bright Field (STEM-BF), and High-angle annular dark-field scanning transmission electron microscopy (STEM HAADF)	3D printer waste	Nanoplastics. 1 um–300 nm	Alcohol/resin mixture	[57]
	Stereomicroscope and scanning electron spectroscope.	Growth of sediment-rooted macrophytes	20–500 um 50–190 nm	PS microplastic PS nanoplastic	[81]
	Scanning electron microscopy (SEM), X-ray Photoelectron Spectroscopy and Fourier Transform Infrared Spectroscopy	Personal care products	24–52 nm	NP polyethylene microbeads	[3]
	Stereoscopic microscope	Vegetables grown at the field	<0.2 mm	Fibers and microbeads. Polyamide (32.5%) and polypropylene (28.8%)	[20]
	Scanning electron microscopy (SEM), and laser confocal scanning microscope (LCSM)	Farms	100, 300, 500, and 700 nm	Polystyrene nanoplastics (PSNPs)	[72]
	Fourier-transform infrared spectroscopy (FTIR) and Spectrometer	Edible and inedible tissues of pelagic fishes	100–200 µm, 200–400 µm, 400–600 µm, 600–800 µm, 800–1000 µm y 1000–5000 µm	PE, PP, EPDM	[82]

Table 1. *Cont.*

Type	Technique (Quantification Method)	Application	Size	Type of Microplastic	References
	Scanning Electron Microscopy (SEM) and field emission scanning electron microscope (FE-SEM)	Human-derived cells	~20 µm and 25–200 µm	PP	[83]
	Micro-Raman spectroscopy and energy-dispersive X-ray spectroscopy (EDX).	Fish meals	180 µm	Plastic polymers, pigment particles, non-plastic items,	[84]
	Scanning electron microscopy (SEM)	Fish muscle	Less than 300 µm	Microplastics	[56]
	Fourier-transform infrared micro spectroscopy (micro-FT-IR)	Mussels sampled from coastal waters and supermarkets	8 µm a 4, 7 mm	Polyester, polypropylene, and polyethylene,	[85]
	Stereo-microscope	Terrestrial snails	200 µm and 2500 µm	PM	[55]
	Attenuated total reflection mid-infrared (ATR-MIR)	Chicken meat	3 µm and 100 µm	Polystyrene (PS), and polyvinyl chloride (PVC)	[12]
	Scanning electron microscopy (SEM) and Fourier-transform infrared spectroscopy (FTIR)	Beaches	0.8 to 6.5 mm	Polyethylene and polypropylene	[86]

High-Density Polyethylene (HDPE); Polypropylene (PP); Low-Density Polyethylene (LDPE); Copolymer of Ethylene and Propylene–Ethylene Propylene Diene Monomer (EPDM); Polyethylene (PE); Particulate Matter (PM).

5. Use of Green Nanotechnology in Agriculture as a Control Alternative to Avoid Microplastic Contamination

Plastic is present in many processes related to agricultural production, from the roofing of greenhouses to modern food storage and preservation systems. Its massive use began in the 1950s, bringing significant benefits for the development and growth of agriculture in the world [12,87]. However, with modern materials, quantification and identification techniques, it has been discovered that different types of plastics persist in the environment as non-biodegradable micro and nanoparticles, which has triggered global alarms, given the potential negative impact that this type of particle can have on living organisms and public health [83,88].

Micro and nanometric particles can interact with biological and synthetic systems due to their small size, enormous specific surface area, and high functionalization capacity, capable of even permeating biological membranes [28]. This has prompted the study of nanotechnological applications for agriculture and the agri-food industry in the last decade. Thus, the use of nanomaterials has presented positive effects for the productivity and defense of crops [89–91], for food processing and preservation [92,93], for animal feed [94,95], and the recovery of contaminated soils [96]. However, because many of the nanomaterials produced are still in the process of research and development and given the lack of studies that show that they are harmless to agroecosystems, their massive use is still restricted [97]. Also, most of the nanomaterials used in agriculture are synthesized from synthetic polymers, such as polyethylene, polypropylene, or polystyrene, which can form extremely thin structures used to encapsulate or coat chemical compounds, allowing greater control over the release of said products to the environment and, consequently, increasing the effectiveness of the applications. However, these materials are the main components of the micro and nanoplastics accumulated in the terrestrial and marine ecosystems of the planet [12,20]. Therefore, the concern surrounding the widespread adoption of nanotechnology in agriculture is understandable, being necessary to advance towards the discovery of alternative methods of food production that allow minimizing the introduction of these non-biodegradable materials to the environment where they are produced, commercialized, and consumed; at the same time, they are low-cost methods of easy commercial scaling, and do not compromise the future capacity of production systems [98].

In this way, the use of organic compounds extracted from fungi, microbes, or plants seems to be an excellent alternative for the synthesis of nanoparticles and thus face the challenges of agriculture in a more safe and sustainable way [99]. Biopolymers such as chitosan, cellulose, and starch, among others, have been used for the synthesis of "green nanoparticles", whose production methods are simple, inexpensive (they do not require controlled temperatures or high pressure), and their application represents greater safety for the environment, given the biodegradable nature of its components [100], which could help reduce the presence of micro and nanoplastics in agricultural systems. Despite being a relatively recent technology, the use of green nanoparticles has had promising results in various areas related to agriculture, such as fertilization and mineral nutrition [101–106] and the control of pests and diseases [107,108] while in the food industry, the use of biopolymers has made it possible to improve the solubility, stability, bioavailability and antioxidant activity of nano-encapsulated bioactive compounds [109,110]. However, no studies have yet been carried out relating the synthesis and application of green nanoparticles to reduction of micro and nanoplastics in the environment and the food chain, which would be vital for food safety and sustainable intensification of production systems.

6. Conclusions

Horticultural products marketed in retail chains and for export comply with protocols that ensure traceability and compliance with food safety standards. However, none of them include a record of microplastic content in fruit and vegetables. With the recent evidence that both fruits and vegetables contain microplastics with consequent adverse health impacts, the question arises: has the paradigm shifted? What is the role of agriculture today in the face of this major challenge? The impact of micro and nanoplastics from intensive horticultural waste would be the main environmental pollution problem facing global horticulture. In case of new international regulations on microplastics in the short and medium term, the horticulture industry would be directly affected, putting the foreign economic activity of many countries at risk. There is evidence of other contaminants such as nitrates that have become barriers to entry into the European market. It is advisable to look for new control methodologies at field level, and to integrate treatment systems that ensure the absence of plastic in production processes.

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