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Review

A Practical Guide to Risk Assessment Indices for Microplastics in Food

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Abstract

Food contamination by microplastics is a global concern driven by ocean pollution, improper plastic waste disposal, packaging, industrial processing, and the use of contaminated water in food production. Fish, seafood, crustaceans, table salt, fruits, vegetables, and drinking water are among the foods and beverages most frequently contaminated with microplastics. These particles are considered an emerging concern because they can adsorb and transport toxic chemicals, heavy metals, and pathogenic microorganisms. Continuous dietary exposure has raised concerns regarding possible adverse effects on human health. Risk assessment indices applied to microplastic contamination in food provide complementary information on dietary exposure, contamination levels, polymer-related hazards, and relative pollution risks. The Polymeric Hazard Index (PHI), Contamination Factor (CF), Pollution Load Index (PLI), and Pollution Risk Index (PRI) provide complementary information by evaluating contamination levels, pollution burden, polymer-related hazard, and integrated environmental risk. The Estimated Daily Intake (EDI) index lacks internationally accepted toxicological guideline values for microplastics. However, it allows assessment of the daily intake of this contaminant from food consumption. PHI and PRI likewise provide relative hazard or pollution-risk information and should not be interpreted as health-based toxicological thresholds. The literature search covered the period from 2016 to 2026 and retrieved 391 records, from which studies relevant to the scope of the review were critically selected. This work aims to summarize the main indices currently applied to microplastic contamination in food matrices, critically discuss their applicability and limitations in the context of human health risk assessment, and briefly address how microplastic size and shape influence toxicity. The analytical challenges associated with the determination of nanoplastics are also briefly discussed. The information presented can support researchers, regulators, and food safety professionals in interpreting contamination data and developing mitigation strategies.

Keywords: microplastic; health risk assessment; food; risk index; EDI; PHI; PLI; PRI; dietary exposure

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1. Introduction

Microplastics have been recognized as emerging contaminants that are widely distributed in the environment and can enter the human food chain through consumption of fish and seafood, table salt, drinking water, vegetables, beverages, beer, and processed foods [1–11]. These particles can be incorporated into food through environmental contamination, plastic packaging used during commercialization and transportation to consumers, and industrial processes [12–15]. On the other hand, continuous ingestion of microplastics poses a growing global concern for human health due to their ability to transport chemical contaminants, heavy metals, persistent organic pollutants, and pathogenic microorganisms [13,16]. Experimental studies suggest that microplastics, and particularly nanoplastics, may translocate across biological barriers and distribute to different tissues, where they have been associated with inflammatory responses, oxidative stress, and cellular damage [12,13,17,18]. Several studies have associated microplastic exposure with adverse effects on the digestive, respiratory, endocrine, and reproductive systems, while potential carcinogenic effects remain under investigation [13]. Recent studies have detected microplastics in human tissues, including blood [19], placenta [20], lungs [21], liver [22], breast milk [23], and brain [24], further highlighting the need to clarify their long-term health implications.

Additionally, microplastics have been shown to adversely affect agricultural soils, with potential consequences for soil quality and food safety. These tiny plastic fragments can alter the soil structure, affecting water retention and the availability of essential nutrients for plant growth. Furthermore, microplastics can accumulate toxic substances that may subsequently become available for plant uptake, thereby contaminating foods such as vegetables, fruits, and grains [3,25,26]. Studies have shown that microplastics are present in foods such as lettuce, strawberries, tomatoes, potatoes, pears, apples, and rice, highlighting a potential route of human exposure and raising concerns about possible health effects. Soil contamination by microplastics poses an urgent environmental and agricultural challenge, requiring actions to mitigate their effects [3,25,26]. Despite the increasing number of reports describing microplastics in plant-derived foods, their determination in fruits, leafy vegetables, and other vegetables remains one of the greatest analytical challenges in food contamination research. The complexity of plant matrices, generally low particle concentrations, heterogeneous microplastic distribution within plant tissues, and a lack of standardized analytical protocols compromise both the accuracy and comparability of reported results.

Furthermore, sample preparation procedures, airborne and laboratory contamination, incomplete removal of natural organic matter, and interference from naturally occurring organic and inorganic particles can lead to false-positive identifications, potentially overestimating contamination levels [27–29]. For these reasons, the determination of microplastics in food and environmental matrices has become the focus of extensive research worldwide. In this context, several indices have been applied to transform microplastic contamination data into quantitative metrics that facilitate the evaluation of contamination levels, potential human exposure, polymer-related hazards, and relative pollution risks. Depending on the index, these assessments may consider factors such as microplastic concentration, polymer composition, and associated hazard scores, or estimated dietary intake.

This review offers a comprehensive overview of the key indices used to assess microplastic contamination and associated risks in food matrices, including the Estimated Daily Intake (EDI), Polymer Hazard Index (PHI), Contamination Factor (CF), Pollution Load Index (PLI), and Pollution Risk Index (PRI). It critically evaluates the applicability, strengths, and limitations of these indices for human health risk assessment. It examines how microplastic characteristics, particularly particle size and shape, influence toxicity

and potential adverse health effects. By integrating these aspects, the review aims to help researchers, regulatory agencies, and food safety professionals interpret contamination data, harmonize risk assessment approaches, and develop effective monitoring and mitigation strategies. A literature search was conducted in the Web of Science Core Collection on 29 September 2026, using the search terms ”food” AND ”microplastic” AND “risk assessment”, covering publications from 2016 to 2026. The search retrieved 391 records. No restrictions regarding language or document type were applied. From the retrieved literature, a non-exhaustive critical selection was performed, focusing on studies reporting the application of EDI, PLI, PHI, and PRI to food and environmental matrices relevant to microplastic risk assessment. Review articles addressing the topic were also considered. Earlier publications were additionally included when they provided seminal, historical, conceptual, or methodological support for specific aspects discussed in the review.

Despite the increasing detection of microplastics in foods and the growing number of dietary exposure studies, internationally established health-based guidance values specifically for ingested microplastics are not currently available. Important uncertainties remain regarding dietary exposure, toxicological effects, dose metrics, and dose–response relationships, which limit the establishment of health-based reference values and regulatory thresholds. EFSA is currently conducting a comprehensive scientific assessment of the potential health risks associated with micro- and nanoplastics in food, water, and air, with its scientific opinion expected by the end of 2027 [30]. This regulatory and toxicological gap helps explain why contamination and hazard indices adapted from environmental studies continue to be explored as screening and comparative tools in food-related microplastic research. However, they should not be interpreted as validated measures of human health risk [30]. Although previous reviews have addressed the occurrence, exposure, and potential risks associated with microplastics in food matrices [11,13,31], important gaps remain regarding the analytical reliability and interpretation of the resulting risk estimates. In particular, limited attention has been given to the metrological quality of the analytical data used for risk assessment and to a critical comparison of the different indices proposed for microplastic pollution and polymer-related hazards. Therefore, this review integrates these complementary dimensions by examining analytical and metrological aspects together with the conceptual basis, applicability, and limitations of the main risk indices used for microplastics in foods.

2. Risk Indices in the Assessment of Microplastic Contamination in Food

Risk assessment indices are widely used as complementary tools for evaluating contamination, exposure, hazard, and potential risk associated with organic and inorganic contaminants in food and environmental matrices [32–34]. These indices are often interpreted using regulatory thresholds or reference values established by health authorities. However, reference values for microplastics are currently unavailable, and existing indices are primarily used as comparative tools to estimate contamination levels, polymer-related hazards, human exposure, and relative pollution risks. Consequently, their interpretation should be made with caution, considering the methodological limitations and assumptions underlying each index [32,34]. This review summarizes the main indices currently applied to microplastic contamination in food matrices, including the Estimated Daily Intake (EDI), Polymeric Hazard Index (PHI), Contamination Factor (CF), Pollution Load Index (PLI), and Pollution Risk Index (PRI).

2.1. Estimated Daily Intake (EDI) Index

The EDI is an index that estimates the daily ingestion of microplastics and is calculated using Equation (1), where C is the abundance of microplastics in particles per gram of food,

FCR is the daily food consumption rate, and BW is body weight. Body weight should be selected to represent the target population, with age-specific values used whenever available. The daily food consumption rate should be calculated using the per capita consumption of this food reported by the country's official agency [26,27].

For EDI calculation, the units used for microplastic abundance and food consumption should be mutually consistent. For solid foods, concentrations expressed as particles per unit mass should be combined with consumption rates expressed on the corresponding mass basis, whereas for beverages and other liquid matrices, concentrations expressed as particles per unit volume should be combined with consumption rates expressed on the corresponding volume basis. Conversion from particle abundance to a mass-based exposure metric is not straightforward because it requires additional information or assumptions regarding particle size distribution, morphology, volume, and polymer density. Therefore, particle-number- and mass-based exposure estimates should be regarded as complementary metrics rather than directly interchangeable quantities, and the metric adopted should be clearly reported.

$$\mathrm{EDI} = \frac{(\mathrm{C} \times \mathrm{FCR})}{\mathrm{BW}} \quad (1)$$

Although EDI is widely used, its application depends on reliable data on food consumption and accurate analytical determination of microplastic concentrations in the food being analyzed. EDI has limitations because it does not account for parameters such as absorption, bioavailability, and dose–response effects [35,36]. Furthermore, the data sources used in the calculation, particularly consumption rates, can vary significantly across countries, potentially leading to discrepancies across studies. Therefore, EDI should be applied when consumption data are representative of the target population, and when microplastic quantification follows reliable analytical protocols.

The EDI index is generally higher in children than in adults because EDI is normalized by body weight. Consequently, children's lower body weight leads to higher exposure estimates per unit body weight, even when their absolute consumption of contaminated food is lower than that of adults. Because body weight appears in the denominator of the EDI equation, lower body-weight assumptions result in higher EDI estimates for the same microplastic concentration and food intake; age-specific body weights should therefore be used whenever available. EDI values are generally calculated deterministically using point estimates, which do not explicitly account for variability in exposure parameters. Probabilistic approaches may address this limitation, although their application to microplastics in food depends on the availability of suitable and comparable input data.

The EDI allows comparison of exposure levels associated with different food samples or species. A higher EDI value indicates greater estimated dietary exposure to microplastics; however, without health-based reference values and established dose–response relationships, it should not be interpreted as direct evidence of increased adverse health risk.

Some authors have employed the EAI index, defined as the estimated annual intake calculated as EDI × 365 days [28,31]. In this review, EAI denotes Estimated Annual Intake, whereas the term "annual dietary intake" is written in full when it is used in the original study.

Results from different studies should be considered alongside dietary consumption rates since exposure depends not only on microplastic levels in food but also on the quantity consumed. Foods with lower microplastic concentrations, such as bottled water, milk, or popular fish, can still have higher EDI values if consumed in larger amounts [34,37,38]. Therefore, comparing EDIs across studies requires accounting for differences in eating habits, population groups, and national consumption patterns, as these can lead to significant variations in estimated exposure.

EDI is a commonly used index to estimate dietary exposure to microplastics from food samples, such as evaluating microplastic abundance in commercially sold fish species in India. The EDI was used to compare estimated dietary exposure associated with different microplastic concentrations across the fish species analyzed [39]. In another study involving commercial fish species from India, the chemical compositions of the microplastics were determined using Fourier Transform Infrared Spectroscopy, identifying the polymers polyethylene (PE), polyethylene terephthalate (PET), polystyrene (PS), and polypropylene (PP). The EDI was used for risk assessment, and the calculation accounted for the number of microparticles of each polymer, enabling a more critical evaluation given differences in their toxicities [40]. Microplastic particles were also quantified in the muscle tissues of fish, mollusks, crabs, and lobsters from the Persian Gulf, and EDI was employed to assess the risks to human health associated with consuming these foods [41]. Annual fish consumption was used to evaluate health risks after assessing microplastic abundance in fish muscle tissues and accounting for the number of microplastic items per gram of fish [34].

In addition to fish and shellfish, other food types have been evaluated for microplastic contamination risk. Al Naggar et al. detected microplastics in 10 honey samples from the Asir region, Saudi Arabia. The EDI values were very low ($\leq$0.00453 particles kg^{-1} body weight day^{-1}), indicating relatively low estimated dietary exposure through consumption of the analyzed honey samples [42]. Aydin et al. investigated microplastics in fruits and vegetables consumed in Turkey. Potatoes (*Solanum tuberosum*), apples (*Malus domestica*), pears (*Pyrus communis*), cucumbers (*Cucumis sativus*), onions (*Allium cepa*), and tomatoes (*Solanum lycopersicum*) were analyzed. Microplastics were detected in all samples, with the highest concentrations in tomatoes. Risk assessment was performed using the EDI and EAI indices. The authors concluded that microplastic contamination results from the production phase, agricultural activities, and transportation [26]. A review critically evaluated microplastic data from eleven types of packaged foods using the risk assessment indicators: estimated daily intake (EDI), chemical risk, and pollution load. The study found the highest EDI values in bottled water and milk samples, owing to higher daily consumption of these foods [31].

The determination of microplastics in foods packaged in plastic bottles, especially mineral water, is increasingly important given their high consumption and the potential for human exposure through ingestion. Microplastics may originate from both environmental contamination and the plastic packaging itself during bottling, storage, and transportation. In this sense, Altunisik determined the microplastic content in 150 samples of bottled natural and mineral waters consumed in Turkey. EDI was used to estimate dietary exposure, and the values obtained were low compared with those reported in other studies, which indicated that mineral water consumption should not adversely affect the population, as the results were negligible compared with those of other studies [43]. Investigating microplastics in bottled mineral water is essential for assessing food safety, supporting quality control, guiding regulatory actions, and encouraging the development of safer packaging materials and manufacturing practices.

The marked variation in food consumption rates (FCR) reported in Table 1 primarily reflects differences in food type, population, geographical region, and the consumption assumptions or dietary data adopted by the original studies. These differences should be distinguished from analytical factors affecting the measured microplastic concentration. Because EDI is calculated from both microplastic abundance and food consumption rate, differences among reported EDI values may result from the combined influence of dietary consumption patterns, measured particle abundance, and the body-weight assumptions adopted in each study. In addition, differences in analytical procedures, including the

particle-size range investigated and the detection and identification methods employed, may affect the reported microplastic abundance and therefore indirectly influence the calculated EDI. Consequently, direct comparison of EDI values among studies should consider both dietary assumptions and methodological differences.

Table 1. Estimated Daily Intake (EDI) of microplastics in food matrices and beverages. EDI = (C × FCR)/BW, where C is microplastic abundance expressed per unit mass for solid foods or per unit volume for liquid matrices, FCR is the corresponding daily mass- or volume-based consumption rate, and BW is body weight (kg). EDI values are expressed as particles kg^{-1} body weight day^{-1}. CR: consumption rate; MP: microplastic; ATR-FTIR: attenuated total reflectance-Fourier transform infrared spectroscopy; LDIR: laser direct infrared spectroscopy; OM: optical microscopy; RM: Raman spectroscopy; SM: stereomicroscopy.

Sample	FCR: (g day^{-1})	MP (mps g^{-1})	Body Weight (kg)	Size Range Studied	Method	EDI	Country	Ref.
Fish—*T. ilisha*	24.36	0.18	70 (men)	0.11–5 mm	OM and ATR-FTIR	0.06	India	[39]
Fish—*T. ilisha*	24.36	0.18	65 (women)			0.07		
Fish—*S. guttatus*	24.36	0.36	70 (men)			0.13		
Fish—*P. pangasius*	42.86	0.79	66	<0.5 mm	ATR-FTIR	0.51	Bangladesh	[44]
Fish—*M. gulio*	42.86	1.24	66			0.80		
Mollusk—*A. pharaonis*	68.5	0.41	70	50–100 µm	OM and RM	0.40	Iran	[41]
Crab—*P. armatus*	68.5	0.18	70			0.18		
Tomato	300	3.6	70	0.1–1000 µm	SM and ATR-FTIR	15.60	Turkey	[26]
Tomato	300	3.6	16 (children)			68.24		
Potatoes	140	1.5	70			3.01		
Cultured seabass	42.86	1.92	66	<0.5 mm	SM and ATR-FTIR	1.24	Bangladesh	[45]
Soft drinks	2.1 L	183.07	70	4.54–1490 µm	SM and FTIR	5.49	Iran	[46]
Water—plastic bottle	2.0 L	8.75	70	20–1000 µm	SM and FTIR	0.25	Italy	[47]
Water—plastic bottle	1.85 L	65.62	60.6	10–50 µm	LDIR and spectral mapping	2.00	China	[48]
Honey	1.586	0.200	70	300–499 µm (42%); 700–999 µm (25%) and 1000–1999 µm (17%)	SM and FTIR	0.00453	Saudi Arabia	[42]
Water—bottle	2.0 L	4.67	70	500–1000 µm	SM and FTIR	0.133	India	[49]

2.2. The Polymer Hazard Score

The polymer hazard score (S_n) was first proposed by Lithner et al. to assess the intrinsic hazard of different polymer types based on the hazardous properties of their constituent monomers [50]. The method was based on the toxicological classifications of the monomers used to produce each polymer, applying the criteria established by the European Classification, Labeling and Packaging (CLP) Regulation, which is aligned with the United Nations Globally Harmonized System of Classification and Labeling of Chemicals (GHS). Based on these classifications, each polymer was assigned a hazard score, with the highest values attributed to polymers derived from monomers classified as carcinogenic, mutagenic, or toxic to reproduction. These hazard scores have since been widely adopted in microplastics risk assessment and incorporated into indices such as the Polymer Hazard Index (PHI).

The application of the hazard score depends on identifying the polymers present in the sample, which requires spectroscopic techniques such as FTIR or Raman. The index is particularly useful for comparing the intrinsic hazard potential of different polymers. However, the hazard score has limitations because it does not account for factors that can influence actual toxicity, such as polymer particle degradation, additives or adsorbed contaminants, or particle form [50,51]. The data used for the calculation are derived from the toxicological classifications of monomers rather than from experimental studies on microplastics, reinforcing the view that the score represents only a theoretical hazard.

2.3. Polymer Hazard Index (PHI)

The Polymer Hazard Index (PHI) is an integrated approach used to assess the potential hazard associated with different polymer types identified in the studied food matrix, taking into account their relative chemical hazard [39,50]. This index is calculated using Equation (2), where S_n is the chemical toxicity score for each plastic polymer. Table 2 presents the hazard scores for the polymers.

Table 2. Hazard score for polymers found in microplastics [50].

Polymer	Hazard Score
Polyurethane (PUR)	13,844
Polyacrylonitrile (PAN)–acrylonitrile (97%)	12,379
Polyacrylonitrile (PAN)–acrylonitrile (100%)	11,521
Polyvinyl chloride (PVC), plasticized	10,551
Polyvinyl chloride (PVC), rigid	10,001
Acrylonitrile-butadiene-styrene (ABS)	6552
Polyvinyl chloride (PVC), 50%	5001
Unsaturated polyester (UP),	1414
Polycarbonate (PC)	1177
Polymethyl methacrylate (PMMA)	1021
Polyphenylene sulfide (PPS)	897
Polyacrylic acid (PAA)	230
Polyamide 6.6-Nylon 6.6	63
Polyamide 6-Nylon 6	50
Polystyrene (PS)	30
Low-density polyethylene (LDPE)	11
High-density polyethylene (HDPE)	11
Ethylene vinyl acetate (EVA)	9
Polyethylene terephthalate (PET),	4
Polyvinyl acetate (PVAc)	1
Polypropylene (PP)	1

In Equation (2), Pn represents the proportion of microplastic particles composed of polymer *n*, calculated as the number of particles of a given polymer divided by the total number of microplastic particles identified in the analyzed sample [50,52].

$$PHI = \sum P_n \times S_N \quad (2)$$

The interpretative classification of polymer-related hazards has evolved progressively in the microplastic literature. Lithner et al. established polymer-specific hazard scores based on chemical composition, which provide the chemical-hazard basis of the PHI [50]. Xu et al. subsequently incorporated these scores into a polymer risk index and proposed four interpretative categories (<10, 10–100, 100–1000, and >1000) [53]. Fang et al., applying this approach to commercial fish and bivalves, subsequently used a five-level classification, further distinguishing the higher hazard range by introducing levels IV and V at 1000 and 10,000, respectively [54]. This five-level framework has subsequently been adopted in microplastic risk-assessment studies, including investigations involving aquatic organisms and seafood.

Accordingly, PHI values are commonly interpreted using five hazard categories: very low (PHI $<$ 10), low (10 $\leq$ PHI $<$ 100), moderate (100 $\leq$ PHI $<$ 1000), high (1000 $\leq$ PHI $<$ 10,000), and very high (PHI $\geq$ 10,000) [39,50,52,55]. These categories should be regarded as a semi-quantitative framework for interpreting relative polymer-related hazard rather than as toxicologically validated thresholds or food-safety limits.

The PHI is applicable when the aim is to integrate the sample's polymer composition with its chemical hazard potential, enabling comparisons across foods or regions. However, its interpretation must account for the index's reliance on polymer identification and the representativeness of the calculated proportions. Furthermore, the PHI does not incorporate physical particle characteristics, such as size or shape, that influence interactions with biological systems [16]. The data used for the calculation are derived from particle counts by polymer type and pre-established hazard scores; consequently, the index reflects only the relative chemical hazard, not the actual toxicological risk.

Because PHI is based on particle-number fractions, identical particle counts may represent markedly different polymer masses or total surface areas when particle-size distributions differ. Mass-based metrics may better describe the amount of polymeric material present, whereas surface-area-related metrics may be relevant to interfacial interactions; however, no single dose metric is currently established as universally superior for dietary microplastic risk assessment. In addition, PHI does not explicitly incorporate surface charge, additives, adsorbed contaminants, weathering, or the potential carrier ('Trojan horse') behavior of particles. Accordingly, PHI should be interpreted as a relative polymer-composition hazard indicator rather than a comprehensive measure of particle toxicity or human health risk.

An additional limitation of the PHI approach is that the polymer hazard scoring matrix proposed by Lithner et al. does not encompass all polymer types currently reported in microplastic studies [50]. For example, polymers such as polytetrafluoroethylene (PTFE) and some biodegradable polymers, including polylactic acid (PLA) and poly(butylene adipate-co-terephthalate) (PBAT), may not have directly applicable hazard scores within the original classification. Consequently, the absence of a polymer from the scoring matrix should not be interpreted as evidence of negligible hazard, but rather as a limitation of the current PHI framework. Assigning arbitrary or extrapolated scores to such polymers could introduce additional uncertainty and reduce comparability among studies. Therefore, expansion and periodic updating of polymer hazard scoring systems, supported by appropriate toxicological evidence, are needed to accommodate emerging and alternative polymer materials.

2.4. Contamination Factor

The contamination factor (CF) is an index frequently used to assess the degree of contamination by comparing the concentration observed in a sample with a reference (background) concentration [56]. However, applying the contamination factor to assess

microplastic contamination in food has an important methodological limitation. Unlike chemical contaminants, such as heavy metals and persistent organic pollutants, for which regulatory agencies have established background concentrations or maximum permissible limits, no internationally accepted reference values exist for microplastic concentrations in food or environmental matrices. Consequently, CF calculations generally rely on reference concentrations reported for relatively unpolluted areas or sites considered baseline conditions. However, these baseline values vary considerably across studies due to differences in sampling strategies, analytical methods, particle-size detection limits, polymer identification techniques, and regional environmental characteristics. As a result, CF values obtained for the same food species collected from different geographic regions are not directly comparable because the reference concentration used in each study may differ substantially. This limitation reduces the CF's robustness as a comparative indicator. It limits its applicability in large-scale risk assessments because the data used in the calculation depend on the measured sample concentration and the chosen reference concentration, reinforcing the view that the index should be interpreted solely as a relative measure of contamination.

CF and PLI were originally developed for environmental contamination assessment, and their subsequent application to microplastics in food represents an adaptation rather than a health-based validation. Processes governing contaminant accumulation in sediments differ fundamentally from those affecting microplastic occurrence and retention in biological tissues and food products, where ingestion, egestion, translocation, processing, and the edible fraction may influence the measured burden. Therefore, CF and PLI should be used to describe relative contamination against an explicitly defined reference condition and should not be interpreted as direct indicators of human health risk.

For food samples, the Contamination Factor (CF) is calculated using Equation (3), where C_i is the concentration of microplastic particles measured in the food sample under investigation and C_{0i} is the reference (background) concentration adopted for the same food species, expressed in the same units (e.g., particles g^{-1}).

$$CF_i = \frac{C_i}{C_{0i}} \quad (3)$$

The CF values are commonly interpreted according to the classification originally proposed for environmental contaminants, in which $CF < 1$ indicates low contamination, $1 \leq CF < 3$ indicates moderate contamination, $3 \leq CF < 6$ indicates considerable contamination, and $CF \geq 6$ indicates very high contamination [39,56].

2.5. Pollution Load Index

The Pollution Load Index (PLI) integrates multiple contamination factors (CFs) through their geometric mean. In its original environmental application, the index was used to summarize the combined contamination burden associated with multiple contaminants at a defined sampling unit or site. When adapted to food matrices, the level of aggregation should therefore be explicitly defined. In this review, the food sample, or a group of comparable samples of the same food item, is considered the primary assessment unit. Polymer-specific CFs may be combined only when the study explicitly defines polymers as the individual contamination components; such an adaptation should not be interpreted as directly equivalent to the original environmental formulation. Regional aggregation may subsequently be performed across comparable sampling units, provided that the same reference basis and analytical criteria are maintained. The PLI is calculated using the geometric mean of the CF values, as described in Equation (4).

$$PLI = (CF_1 \times CF_2 \times CF_3 \times CF_4 \times \ldots \times CF_n)^{\frac{1}{n}} \quad (4)$$

PLI values > 1 indicate contamination above the baseline level, whereas PLI ≤ 1 suggests low or no significant contamination [39,55]. This index also does not account for differences in polymer toxicity, particle characteristics, or human exposure; therefore, it should be interpreted alongside other indicators. Neither the CF nor the PLI can be used to compare microplastic contamination and pollution between food items of different natures.

PLI is applicable when the objective is to integrate multiple contamination factors into a single metric, enabling evaluation of the total pollution load in a sample or region. However, the index has limitations: it depends on the choice of CFs, can be influenced by the predominant polymers, and does not account for toxicological differences among them [39]. Furthermore, the PLI does not consider the particles' physicochemical characteristics, such as size, shape, and degree of degradation. The data used in the calculation derive from previously established CFs, reinforcing the interpretation that the PLI should be considered an indicator of contamination load rather than a direct measure of health risk.

When PLI is based on the geometric mean, it provides an overall view of contamination but may underrepresent low-abundance polymers and be skewed by a dominant polymer. An arithmetic mean reflects the additive contribution of all polymers, but it is a different statistical approach and not equivalent to PLI. Thus, PLI should be seen as a complementary indicator, not a complete measure of total polymer burden.

An additional mathematical limitation should be considered when PLI is calculated as the geometric mean of individual contamination factors. If any CF value is zero, the product of the contamination factors, and consequently the calculated PLI, becomes zero, irrespective of the magnitude of the remaining CF values. This may lead to an underrepresentation of the overall contamination burden. Similarly, when contamination is strongly dominated by a single polymer, aggregation through the geometric mean may attenuate the influence of that polymer on the resulting PLI. Therefore, individual CF values and polymer composition should be examined together with the aggregated PLI, particularly in datasets containing zero values or highly uneven polymer distributions. The treatment of non-detected polymers and zero values should also be explicitly reported to improve transparency and comparability among studies.

2.6. Pollution Risk Index

The Pollution Risk Index (PRI) integrates the Pollution Load Index (PLI) and the Polymer Hazard Index (PHI), combining the overall contamination level with the relative hazard associated with the identified polymer types. The index enables comparison of potential pollution risk among different samples or food products, providing a quantitative measure of the relative pollution hazard associated with microplastic contamination. Higher PRI values indicate a greater potential pollution hazard associated with the analyzed food, thereby supporting the prioritization of monitoring studies and the implementation of strategies to control microplastic contamination throughout the food chain.

$$\mathrm{PRI} = \mathrm{PLI} \times \mathrm{PHI} \tag{5}$$

The PRI value allows classification into five categories: low risk (PRI < 150), medium risk ($150 \leq$ PRI < 300), considerable risk ($300 \leq$ PRI < 600), high risk ($600 \leq$ PRI < 1200), and very high risk (PRI ≥ 1200) [52,55]. Although PRI is useful for relative comparisons, it does not directly estimate human health risk because it does not account for bioavailability, absorption, exposure duration, or contaminants associated with microplastic particles. Therefore, PRI should be interpreted as a comparative indicator of potential pollution risk rather than as a quantitative estimate of toxicological risk [57].

2.7. Applications of PHI, PLI, and PRI to Microplastic Contamination in Food Samples

The studies summarized in Table 3 show that PHI, PLI, and PRI have been widely used to assess microplastic contamination in fish, seafood, eggs, and other food products across regions [58–61]. The indices indicate that samples containing polymers such as PE, PET, PP, PVC, PA, and PS may pose risks ranging from low to very high, depending on polymer composition, abundance, and the food matrix [45,62–64]. Therefore, the results highlight that foods from both aquatic and terrestrial sources can contribute to human exposure, with contamination patterns influenced by environmental conditions, packaging, fishing activities, agricultural practices, and industrial processing.

Table 3. Risk assessment indicators for polymer/microplastic contamination in food matrices. PHI: polymer hazard index; PLI: pollution load index; PRI: pollution risk index; MP, microplastic; GIT, gastrointestinal tract; PE, polyethylene; PP, polypropylene; PET, polyethylene terephthalate; PVC, polyvinyl chloride; PS, polystyrene; PA, polyamide; EVA, ethylene vinyl acetate; PMI, microplastic particles; annual dietary intake; EDI, estimated daily intake; EAI, estimated annual intake; CF, contamination factor; MPCF, microplastic contamination factor; MPLI, microplastic pollution load index; IAE, intake annual estimate.

Sample	MPs per g	Polymers	PHI	PLI	PRI	Conclusion	Country	Ref.
Scylla serrata	0.97 items/g (hepatopancreas)	PPS, PUR, PET, PP, PTFE, PEEK, PVC, PS, PPO	—	2.31	—	Showed high contamination in the hepatopancreas and the highest PLI among the three species, indicating strong vulnerability to microplastic pollution	India	[58]
Glossogobius giuris	0.7 particles/fish in GIT; water: 313.33 ± 252.11 particles/m3	PA, EVA, PP, PET, HDPE, PVC, TPU	—	2.03 (overall lake average)	—	The lake was contaminated with microplastics throughout, and the fish ingested PMs in proportion to their availability in the Environment; the overall ecological risk was classified as minor.	Philippines	[59]
Meretrix aurora	0.44 ± 0.12 (Site 1) and 0.81 ± 0.16 (Site 2), items/individual; water: 22.33 ± 5.86 and 15.67 ± 7.02 items/L; sediment: 28.33 ± 8.00 and 20.67 ± 6.66 items/kg	PE, PP, PA, PES, PS	—	1.42 (Punnakayal) and 1.21 (Tuticorin)	69.5 (Punnakayal) and 26.4 (water)	Promising sentinel species; Punnakayal showed higher contamination, and Tuticorin bivalves accumulated more PMs than expected by the Environment	India	[61]
Marine trash fish (10 species; most emphasis on *Cynoglossus arel*)	C. arel: 2.00 ± 0.25 MP/g in muscle and 5.00 ± 0.29 MP/g in GIT; other species ranged from 0.20 to 2.00 MP/g in muscle and 0.20 to 5.00 MP/g in GIT	PE, PET, PP, PS, EVA, PVA, nylon	5.2 to 21.2	1.10 to 3.89; mean 2.18	268.5 to 402.1	Moderate to high contamination, with higher risk in species with a higher fraction of PET and PS; Consumption and use in fishmeal may increase human exposure and aquaculture	Bangladesh	[60]

Table 3. *Cont.*

Sample	MPs per g	Polymers	PHI	PLI	PRI	Conclusion	Country	Ref.
Hong Kong fish and shellfish (9 species)	up to 8.83 items/individual; higher concentration in organs than in muscle	PS, PE, PP, nylon 66, PVC	535	—	annual dietary intake 352.8 items/year; EDI 4.99 items/kg/year (males) and 6.15 items/kg/year (females)	Contamination present in fish and shellfish; potential risk to human health, although the intestinal barrier assay showed no significant acute harm	Hong Kong	[62]
Three fish species from the northern Bay of Bengal	42.13 ± 13.58, 38.38 ± 7.56 e 41.63 ± 4.81 MPs/ind	EVA, nylon, PE, PP	EVA 3.99; nylon 11.11; PE 2.44; PP 0.11	CF 1.02–1.89; PLI 0.92–1.35-	—	Significant general contamination; fibers, particles < 0.5 mm, and violet color predominated; Potential high human intake	Bangladesh	[63]
Shucked bivalve products from Vietnam	0.04–0.48 item/g; average 0.24 ± 0.21 item/	g-EVOH, PA, CP, PE, PES, PP, EP, PET-261.34	—	MPCF 1.00–10.82; Average MPLI 3.99-EDI	0.29 item/kg/day; EAI 4085 items/person/year	Detected in 92% of samples; low MPLI risk but high PHI and potential relevant human exposure.	Vietnam	[64]

It is important to emphasize that CF, PLI, PHI, and related indices were not originally developed as health-based metrics for assessing human dietary exposure to microplastics. Nevertheless, these indices continue to be applied in recent microplastic studies, including investigations involving food matrices and aquatic organisms [10,60,65,66]. Their current use largely reflects the absence of specific, internationally harmonized, and toxicologically validated indices for assessing the potential risks associated with microplastic contamination in foods. Therefore, their application should not be interpreted as evidence that these indices provide direct measures of human health risk. Rather, they currently serve as pragmatic tools for describing relative contamination, comparing samples or matrices, and identifying situations that may warrant further investigation. Their continued use in the recent literature also highlights an important methodological gap. It reinforces the need to develop microplastic-specific risk-assessment frameworks supported by exposure and toxicological data relevant to human health [10,60,65,66].

Although the selected studies vary in species, matrices, analytical methods, and index calculations, they consistently show that PHI, PLI, and PRI are complementary tools for interpreting microplastic contamination data. Thus, these indices provide a more integrated interpretation of microplastic contamination than particle counts alone and enable relative comparisons among food samples and categories.

It should be noted that Table 3 was designed to illustrate applications of PHI, PLI, PRI, and related indices reported in the literature and does not imply that all analyzed biological matrices represent the edible fraction consumed by humans. Some studies included in the table evaluated microplastics in the gastrointestinal tract (GIT) of aquatic organisms. Such studies are relevant for demonstrating the application of these indices and for characterizing microplastic contamination in the investigated organisms; however, GIT-based microplastic abundance should not be directly interpreted as dietary exposure when the gastrointestinal tract is normally removed before consumption. Therefore, the biological matrix analyzed and the edible fraction should be explicitly considered when risk indices are interpreted in the context of human dietary exposure.

An additional limitation of currently available indices is that they generally rely on total microplastic abundance, polymer composition, or estimated dietary intake and do not account for the bioaccessibility or bioavailability of microplastic particles and associated contaminants [67,68]. Consequently, these indices should be interpreted as indicators of exposure, contamination, or relative hazard rather than direct measures of the fraction available for absorption after ingestion. Incorporating bioaccessibility and bioavailability into future risk assessment frameworks may contribute to more realistic estimates of the potential health risks associated with dietary exposure to microplastics [67,68].

2.8. Worked Example: Comparative Application of EDI, PHI, CF, PLI, and PRI

To illustrate the complementary information provided by the indices discussed in this review, a hypothetical dataset comprising 10 food portions of 5 g each was constructed. The numbers of microplastic particles detected in portions P1–P10 were 1, 2, 2, 3, 3, 4, 5, 5, 7, and 8, respectively, corresponding to 40 particles in a total sample mass of 50 g. This example is intended solely for methodological demonstration and does not represent an actual food sample or a direct estimate of human health risk.

Estimated Daily Intake (EDI)

For each portion, microplastic concentration (C) was first expressed as particles per gram, C = N/5, where N is the number of particles detected in the 5-g portion. EDI was calculated using a hypothetical food consumption rate (FCR) of 25 g day^{-1} and body weight (BW) of 70 kg:

$$EDI = (C \times FCR) / BW$$

For example, P5 contained three particles: C = 3/5 = 0.6 particles g^{-1}, giving EDI = $(0.6 \times 25)/70 = 0.214$ particles kg^{-1} BW day^{-1}. For the integrated dataset, C = 40/50 = 0.8 particles g^{-1} and EDI = $(0.8 \times 25)/70 = 0.286$ particles kg^{-1} BW day^{-1}.

Polymer Hazard Index (PHI)

PHI was calculated from the relative contribution of each polymer and its corresponding hazard score (Sn):

$$PHI = \Sigma(Pn \times Sn)$$

where Pn is the proportion of polymer n in the sample; in this hypothetical example, hazard scores of 4, 30, 230, 1021, and 10,001 were assigned to PET, PS, PAA, PMMA, and PVC, respectively. For P3, containing one PET and one PMMA particle, PHI = $(1/2 \times 4) + (1/2 \times 1021) = 512.5$.

The integrated PHI was recalculated from the aggregated polymer composition rather than obtained by averaging the individual PHI values. Across the 40 particles, the polymer distribution was 26 PET, 10 PS, 2 PAA, 1 PMMA, and 1 PVC. Thus:

$$PHIintegrated = (26/40 \times 4) + (10/40 \times 30) + (2/40 \times 230) + (1/40 \times 1021) + (1/40 \times 10{,}001) = 297.15$$

Individual and integrated PHI values, therefore, provide information at different analytical levels. P5 contained only three particles but had a PHI of 3336.3 because one particle was PVC, whereas P10 contained eight particles but had a PHI of only 10.5 because its polymer composition consisted of six PET and two PS particles. Thus, greater particle abundance does not necessarily imply a higher PHI.

Contamination Factor (CF) and Pollution Load Index (PLI)

For this hypothetical worked example, the reference condition was deliberately defined as one particle in a 5-g portion. Because all portions have the same mass of 5 g, this reference corresponds to C0 = (1 particle)/(5 g) = 0.2 particles g^{-1}. The value of one particle was selected solely for didactic simplicity, so that the calculation of CF can be followed transparently. It does not represent a universal background concentration, a regulatory threshold, or a recommended reference value for microplastics in food. In an

actual study, C0 must be explicitly defined and scientifically justified according to the reference or background condition adopted.

For each portion, the measured concentration (Ci) is first calculated independently from the number of particles detected and the sample mass. For example, P7 contained five particles in a 5-g portion: CP7 = (5 particles)/(5 g) = 1.0 particles g^{-1}. CF is then obtained by comparing this measured concentration with the hypothetical reference concentration: CFP7 = CP7/C0 = (1.0 particles g−1)/(0.2 particles g^{-1}) = 5. Thus, CF = 5 means that the particle concentration in P7 is five times the reference concentration adopted for this example; it does not mean that CF is a particle count. As expected from the ratio of two concentrations expressed in the same units, CF is dimensionless.

In this particular dataset, the CF values (1, 2, 2, 3, 3, 4, 5, 5, 7, and 8) happen to be numerically identical to the particle counts. This occurs because two conditions were deliberately combined: (i) every portion has the same mass of 5 g, and (ii) the reference concentration corresponds exactly to one particle per 5 g. Mathematically, CFi = [Ni/(5 g)]/[1 particle/(5 g)] = Ni, when Ni is expressed as the number of particles in each 5-g portion. Therefore, the numerical equality between the particle counts and CFs is a specific consequence of the values selected for this worked example and is not a general property of CF. If a different reference concentration or a different sample mass were used, the CF values would no longer necessarily coincide with the particle counts.

The integrated PLI was then calculated as the geometric mean of the 10 CF values:

$$PLI = (CF1 \times CF2 \times ... \times CF10)^{\wedge}(1/10)$$

$$PLI = (1 \times 2 \times 2 \times 3 \times 3 \times 4 \times 5 \times 5 \times 7 \times 8)^{\wedge}(1/10) = (201{,}600)^{\wedge}(1/10) = 3.39$$

Pollution Risk Index (PRI)

PRI was calculated at the integrated level by combining the integrated PLI and PHI:

$$PRI = PLI \times PHI$$

$$PRI = 3.3919469617 \times 297.15 = 1007.92$$

According to the classification presented above, this value falls within the high-risk category ($600 \leq PRI < 1200$). However, as emphasized throughout this review, this classification reflects the relative risk category defined within the PRI framework. It should not be interpreted as a direct quantitative estimate of human health risk.

PRI was not calculated separately for each portion in this worked example. The individual CF values were first integrated through their geometric mean to obtain PLI, while the integrated PHI was independently recalculated from the aggregated polymer composition of all 40 particles. The final PRI therefore combines these two integrated metrics. The application of the proposed indices (EDI, PHI, CF, PLI, and PRI) is illustrated through a hypothetical dataset, allowing comparison between individual and integrated values (Table 4).

Overall, this example demonstrates that EDI, PHI, CF/PLI, and PRI describe different but complementary dimensions of microplastic contamination. EDI reflects estimated dietary exposure based primarily on particle concentration and food consumption; PHI incorporates differences in polymer composition and polymer-specific hazard scores; CF and PLI express contamination relative to a defined reference condition; and PRI combines integrated contamination load with polymer-related hazard information. Accordingly, these indices should not be treated as interchangeable metrics, and none should be interpreted independently as a direct quantitative estimate of human health risk.

Table 4. The Estimated Daily Intake (EDI), Polymer Hazard Index (PHI), Contamination Factor (CF), Pollution Load Index (PLI), and Pollution Risk Index (PRI) are compared using a hypothetical dataset of 10 food portions (5 g each). Individual values are reported for each portion, while integrated values are derived from the aggregated dataset (40 particles in 50 g). The example is intended solely for methodological demonstration and does not represent actual food contamination or provide a direct estimate of human health risk.

Portion	No. Particles	EDI (Particles kg^{-1} BW day^{-1})	PHI	CF
P1	1	0.071	4.0	1
P2	2	0.143	17.0	2
P3	2	0.143	512.5	2
P4	3	0.214	12.7	3
P5	3	0.214	3336.3	3
P6	4	0.286	67.0	4
P7	5	0.357	54.4	5
P8	5	0.357	14.4	5
P9	7	0.500	11.4	7
P10	8	0.571	10.5	8
Integrated (10 portions; 50 g)	**40**	**0.286**	**297.15**	**—**

3. Metrological Assurance and Analytical Quality

Metrological assurance and analytical quality are fundamental to ensuring that the data used to calculate risk indices reliably represent microplastic contamination in food matrices. Because indices such as EDI, PHI, CF, PLI, and PRI are derived from particle abundance, polymer identity, or both, uncertainties and biases introduced during sampling, sample preparation, particle identification, and quantification can propagate directly into the calculated indices. Therefore, the interpretation of risk indices should consider not only the mathematical formulation of each index but also the analytical quality of the underlying microplastic data [69–72].

(i) Sampling design and contamination control. Sampling should be sufficiently representative of the food matrix under investigation. It should consider the number of samples and replicates, randomization, different production lots, seasonality, geographical origin, and production conditions, when applicable. Attention should also be given to contamination control because airborne fibers, laboratory clothing, equipment, consumables, reagents, and water can introduce particles during sampling and analysis. Field, procedural, and laboratory blanks, as appropriate, together with the use of filtered reagents, covered glassware, reduced use of plastic laboratory materials, and appropriate laboratory clothing, are important measures for identifying and minimizing external contamination [69,70]. Blank results and the procedures adopted for blank correction should be clearly reported.

(ii) Sample preparation, digestion, and recovery. Food matrices frequently require digestion or purification before microplastic isolation and identification. The selected treatment should efficiently remove the matrix while minimizing particle loss and alterations in polymer integrity. The performance of digestion and extraction procedures depends on the food matrix, reagent composition, treatment conditions, polymer type, particle size, and morphology [69,70]. Consequently, recovery experiments using representative polymer particles are important for evaluating the efficiency and potential selectivity of the analytical procedure. Information on digestion conditions, filtration, recovery, and the particle-size range effectively evaluated should therefore accompany microplastic abundance data used for risk assessment. A recent Foods study evaluating digestion of mussels demonstrated

that digestion conditions can materially affect recovery and polymer integrity, reinforcing the importance of recovery assessment and method-specific validation [73].

(iii) Polymer identification and spectral quality. Reliable polymer identification is particularly important for indices incorporating polymer-specific information, such as PHI and PRI, because erroneous classification of a particle can alter the calculated hazard contribution. Spectroscopic techniques such as micro-FTIR, LDIR, and Raman microscopy provide chemical information for polymer identification [71,72]. The analytical technique, reference spectral library, software, and data-processing procedures, when applicable, should therefore be reported together with the criteria adopted for accepting polymer identification.

Spectral library matching is frequently used to support polymer assignment. However, reported match criteria vary among analytical approaches and data-processing procedures, and the numerical match value should not be considered independently of spectral quality and the characteristics of the reference library [71,72]. Therefore, rather than assuming a universal acceptance threshold, studies should explicitly report the criterion used and, when necessary, complement automated matching with evaluation of characteristic spectral features. This consideration is particularly relevant for spectra affected by matrix residues, fluorescence, additives, pigments, degradation, or low signal quality [71,72].

(iv) Particle-size range and inter-study comparability. The particle-size range covered by the analytical procedure is an important factor when comparing microplastic data among studies [69,71]. D. Differences in sample preparation, filtration, detection, and polymer-identification procedures may result in different lower particle-size limits being investigated. Because particle abundance can be strongly influenced by the size range considered, studies reporting microplastic concentrations and risk indices should clearly state the particle-size interval effectively evaluated. Consequently, comparisons among studies should take differences in the investigated size range into account, particularly for indices based on particle abundance or polymer proportions.

Differences in the particle-size ranges considered among studies remain an important source of limited comparability. Koelmans and co-workers have described approaches based on particle-size distributions and probability density functions to rescale and align microplastic concentration data obtained over different size ranges [12,36]. Such approaches represent a potentially useful strategy for improving data comparability before risk characterization. However, their application requires assumptions regarding particle-size distributions and appropriate information on the analytical size range. Therefore, although size-range harmonization should be considered when comparing studies or applying risk indices, correction factors should not be regarded as universally applicable to all food matrices.

(v) Reporting and traceability. For risk indices to be reproducible and meaningfully compared across studies, reports should provide sufficient information on sampling, contamination control, sample preparation, recovery, particle-size range, polymer identification, spectral acceptance criteria, and data treatment [69–71]. Harmonized reporting of these parameters is particularly important considering the methodological variability that still characterizes microplastic analysis in food matrices. Transparent reporting of analytical quality parameters can help distinguish differences arising from actual contamination patterns from those resulting from methodological variability [70,71]. Table 5 summarizes the principal analytical quality information that should accompany microplastic data used for risk-index calculations. Table 6 presents a comparison of the main indices used to assess microplastic contamination and dietary exposure in food matrices.

Table 5. Analytical quality assurance and quality control requirements for microplastic data used in risk-index calculations.

Analytical Step	Recommended QA/QC Information	Relevance to Risk Indices
Sampling	Sampling design, replicates, lots, seasonality, and geographical origin, when relevant	Representativeness of contamination data
Contamination control	Field/procedural blanks, filtered reagents, contamination-prevention measures, and blank correction	Reduces false-positive particle counts
Digestion/extraction	Reagents, treatment conditions, filtration, and recovery experiments	Evaluates particle loss and possible polymer alteration
Particle-size range	Particle-size range effectively evaluated and reported	Important for comparison of abundance-based indices
Polymer identification	Analytical technique, spectral library, software, and data-processing procedure	Directly affects polymer-dependent indices
Spectral acceptance	Match criterion and complementary spectral evaluation when required	Reduces polymer misidentification
Data reporting	Units, recovery information, blank treatment, and calculation procedure	Improves traceability and inter-study comparability

Table 6. Comparative summary of the principal indices used to assess microplastic contamination and dietary exposure in food matrices.

Index	Required Input Data	Output and Unit	Interpretation Thresholds	Main Assumption	Main Limitation	What It Answers/What It Does Not Answer
EDI	Microplastic concentration, food consumption rate, body weight	Estimated intake; commonly particles kg^{-1} body weight day^{-1} when particle-number data are used	No internationally accepted health-based threshold for ingested microplastics	Input concentration and consumption data are representative of the target population	Does not account directly for absorption, bioavailability, dose–response, particle size, or morphology	Answers: How much microplastic is estimated to be ingested? Does not answer: Does that intake constitute a validated human-health risk?
CF	Measured microplastic concentration and a defined reference/background concentration	Dimensionless contamination factor	Depends on the classification/reference scheme adopted	The selected reference concentration is appropriate and comparable	Strongly dependent on the chosen baseline; does not represent toxicity or dietary exposure	Answers: How elevated is contamination relative to a reference? Does not answer: What is the toxicological or dietary risk?
PLI	Multiple CF values defined for a comparable assessment unit	Dimensionless pollution-load index	PLI > 1 indicates contamination above the selected baseline; PLI ≤ 1 indicates low or no significant contamination under the adopted scheme	CFs are comparable and combined at an explicitly defined aggregation level	Sensitive to reference selection, aggregation rules, zero values, and uneven contamination; does not account for toxicity or exposure	Answers: What is the integrated contamination load relative to the reference? Does not answer: What is the human-health risk?

Table 6. *Cont.*

Index	Required Input Data	Output and Unit	Interpretation Thresholds	Main Assumption	Main Limitation	What It Answers/What It Does Not Answer
PHI	Relative abundance (%) of identified polymers and polymer hazard scores	Dimensionless polymer hazard index	Classification categories depend on the hazard-score convention adopted	Polymer identity and relative abundance adequately represent polymer-related hazard	Hazard scores are inherited from polymer/constituent classifications and do not incorporate exposure, particle size, morphology, or bioavailability	Answers: What is the relative hazard associated with the polymer profile? Does not answer: What health effect will occur at the observed exposure?
PRI	PLI and PHI	Dimensionless pollution risk index	Low < 150; medium 150–<300; considerable 300–<600; high 600–<1200; very high ≥ 1200, under the adopted classification	Contamination load and polymer-related hazard can be integrated as a relative pollution-risk metric.	Not a validated human-health risk metric; does not account for bioavailability, absorption, exposure duration, size, or morphology	Answers: Which samples show higher relative pollution risk under the adopted framework? Does not answer: Is a food safe or unsafe for human consumption?

4. Microplastic Size and Its Adverse Effects on Human Health

Although microplastic size is not included in the weighting of risk indices, particle size information is essential for understanding the environmental behavior, biological uptake, and potential adverse effects of micro- and nanoplastics. Based on the classification adopted in this review, plastic particles may be categorized as macroplastics (>25 mm), mesoplastics (5–25 mm), large microplastics (1–5 mm), small microplastics (1 µm–1 mm), and nanoplastics (<1 µm) [74]. However, these size categories are operational definitions, and the upper size limit used for nanoplastics may vary among studies and regulatory frameworks. Particle size is an important determinant of the biological behavior of micro- and nanoplastics. In general, smaller particles have greater potential for cellular uptake and translocation across biological barriers. However, these processes also depend on particle shape, polymer composition, surface chemistry, aggregation state, route of exposure, and dose. Smaller particles also exhibit a greater specific surface area, which may enhance their interaction with chemical contaminants, metals, additives, biomolecules, and microorganisms. Nevertheless, adsorption and transport processes are influenced by several physicochemical and environmental factors and cannot be predicted solely from particle size. Therefore, particle size should be considered together with particle morphology, composition, surface properties, and exposure conditions when evaluating the potential human health effects of micro- and nanoplastics [15,17,74]. Therefore, knowledge of particle size is fundamental to understanding the effects of microplastics. Figure 1 presents the size classification adopted in this work, along with the potential biological fate and health risks associated with plastic particles. The biological pathways illustrated in Figure 1 represent potential or experimentally investigated routes reported in the literature and should not be interpreted as established pathways of adverse health effects in humans. Their biological relevance may depend on particle characteristics, exposure conditions, and the experimental model considered.

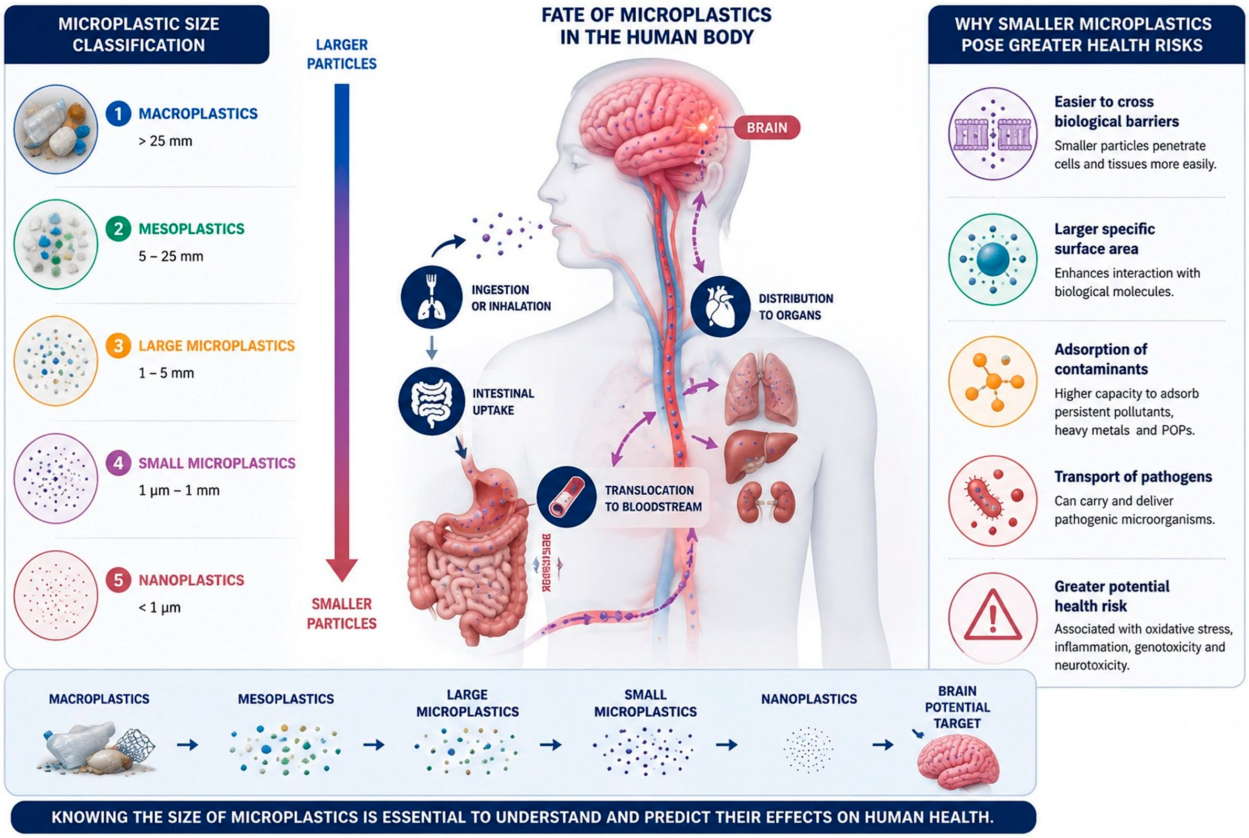


Figure 1. Size classification and potential biological fate of plastic particles. The pathways shown are schematic and include potential, experimentally investigated, and hypothetical routes discussed in the literature; they should not be interpreted as established pathways of adverse health effects or as evidence of established human health risk.

Future risk-assessment frameworks could potentially incorporate particle size and morphology as additional weighting factors, since particles with different dimensions and shapes may exhibit distinct biological interactions. Conceptually, size- and shape-dependent terms could complement information on polymer identity and abundance. However, the development of quantitative weighting factors would require robust toxicological evidence establishing reproducible relationships between specific particle characteristics and biological effects. At present, the lack of harmonized dose metrics, standardized size and shape classifications, and validated dose–response relationships prevents the assignment of scientifically supported numerical weighting factors. Therefore, such an approach should currently be regarded as a conceptual direction for future model development rather than as a validated modification of existing risk indices.

Consequently, the omission of particle size may lead to similar index values for samples with markedly different size distributions. Thus, an index based on particle abundance or concentration should not be interpreted as representing equivalent biological exposure when the underlying particle-size profiles differ substantially.

5. Microplastic Shape and Its Effects on Human Health

Microplastics occur in a variety of morphological forms, including fibers, fragments, films, spheres (beads), and foams (Figure 2). Although microplastic shape is not included in the weighting of risk indices, microplastic morphology, including particle shape and physical structure, is an important factor influencing environmental behavior and potential biological effects. However, toxicity results from the combined influence of multiple characteristics,

including particle size, polymer composition, surface chemistry, weathering, associated contaminants, exposure dose, and morphology. Microplastics occur as fibers, fragments, films, spheres, and foams, each of which may interact differently with biological systems. Fibers have received particular attention because their high aspect ratio may favor retention in the respiratory tract after inhalation and promote inflammatory responses under certain exposure conditions [75,76].

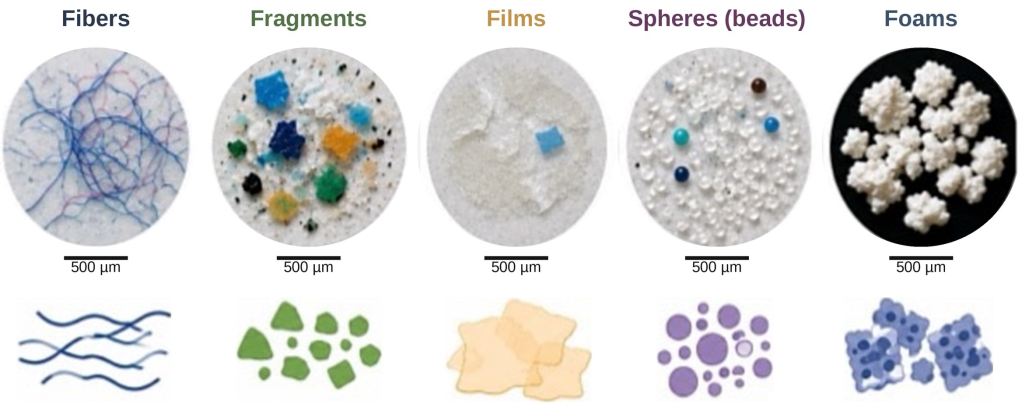


Figure 2. Representative morphologies of microplastics, including fibers, fragments, films, spheres (beads), and foams [15,75,76].

Although dietary ingestion has been the primary focus of human exposure studies, inhalation of airborne microplastics has also emerged as a potentially important exposure pathway, particularly in indoor environments where airborne particle concentrations may be elevated. However, the relative contribution of inhalation versus oral ingestion remains uncertain because studies that directly evaluate both exposure routes under comparable experimental conditions and use harmonized sampling, analytical, and exposure assessment methods are still scarce. Therefore, current evidence is insufficient to establish the relative importance of these exposure pathways to overall human exposure.

Still, regarding the morphology of microplastics, irregular fragments and sharp-edged particles may also induce mechanical irritation in experimental models. However, the relevance of these findings to human health remains uncertain. Morphology may influence particle surface area, hydrodynamic behavior, and interactions with contaminants; however, adsorption of pollutants, heavy metals, and microorganisms depends on multiple physicochemical properties rather than shape alone. Therefore, evaluating morphology together with particle size, polymer composition, and surface characteristics is essential for understanding exposure pathways and toxicity mechanisms. Nevertheless, direct evidence linking specific microplastic morphologies to adverse human health outcomes remains limited and requires standardized experimental protocols and robust epidemiological studies [15,51,77].

Similarly, the omission of particle shape may result in comparable index values for samples with substantially different morphological profiles. Therefore, the numerical value of an index does not capture potential differences associated with the predominance of fibers, fragments, films, or other particle shapes.

6. Analytical Challenges in Nanoplastics Determination

Nanoplastics (NPs) pose substantially greater analytical challenges than microplastics (MPs), making their detection, identification, and quantification among the major unresolved issues in environmental and food contamination research. NPs are generally defined as plastic particles smaller than 1 µm, with particular concern for those below 100 nm because of their distinct physicochemical properties and potential for enhanced biological interactions. Their extremely small dimensions are below the resolution limit of conventional optical microscopy, requiring analytical techniques with higher sensitivity and spatial resolution [78–80].

Analytical methods routinely used for microplastic analysis have important limitations when applied to NPs because of their low particle mass, weak spectroscopic signals, limited spatial resolution, and interference from complex environmental and biological matrices. Consequently, nanoplastic characterization requires advanced and costly analytical approaches. Sample preparation also remains a critical challenge, as isolating, concentrating, and preserving NPs without contamination, aggregation, or particle loss is methodologically demanding. These limitations currently restrict the accurate detection, characterization, and quantification of nanoplastics in environmental and food matrices [78–80].

Emerging analytical approaches may further contribute to the characterization of micro- and nanoplastics in complex matrices. Thermo-analytical techniques such as pyrolysis-gas chromatography-mass spectrometry (Py-GC/MS) provide polymer-specific chemical information and enable mass-based quantification of selected polymers, offering an important complementary approach to particle-based spectroscopic methods. However, because the polymer is thermally decomposed during analysis, Py-GC/MS does not directly provide particle number, size, or morphology, which limits its direct use for indices based on particle abundance. Optical trapping approaches, including optical tweezers, also represent promising tools for manipulating and investigating very small plastic particles and may be coupled with spectroscopic characterization. Nevertheless, their application to complex food matrices remains an emerging area. Consequently, these approaches should be regarded as complementary to, rather than replacements for, established particle-based characterization methods, with the choice of technique depending on the information required for the intended risk-assessment framework.

7. Conclusions

This critical review examines the main indices currently used to assess microplastic contamination in food matrices. It presents applications, strengths, and limitations for assessing dietary exposure and the potential health implications of microplastic ingestion. Current evidence suggests that these indices serve as complementary tools. Thus, they are not interchangeable measures of human health risk, as each is designed to address a distinct aspect of the assessment process. The Estimated Daily Intake (EDI) estimates dietary exposure; the Polymer Hazard Index (PHI) characterizes relative polymer-related hazard; the Contamination Factor (CF) and Pollution Load Index (PLI) describe contamination levels and pollution burden; and the Pollution Risk Index (PRI) integrates contamination and polymer-related hazard into a relative measure of potential pollution risk. The purpose of the study should therefore guide index selection, and combining multiple indices provides a broader understanding of microplastic contamination in food.

From a regulatory perspective, the currently available indices should not be used as health-based operational action thresholds for food safety in the absence of validated toxicological reference values and established dose–response relationships for dietary exposure to microplastics. The EDI, PHI, CF, PLI, and PRI can nevertheless provide useful screening and prioritization tools for comparing contamination patterns, identifying matrices or poly-

mer profiles requiring further investigation, and supporting monitoring programs. Their regulatory value therefore currently lies primarily in relative assessment and prioritization rather than in defining safe or unsafe levels of dietary exposure. Establishing health-based action thresholds will require harmonized analytical methodologies, improved exposure assessment, and toxicological evidence capable of linking relevant microplastic dose metrics with adverse biological outcomes.

Important limitations remain. Direct comparisons among studies are complicated by variability in sampling, extraction, particle identification, size ranges, polymer identification, and reporting practices. In addition, the indices do not fully incorporate particle size and morphology, bioavailability, or validated health-based toxicological reference values; these limitations should be considered when interpreting index values.

Based on the limitations identified in this review, future research should prioritize: (1) harmonization of particle-size ranges to improve comparability among studies; (2) updating and expanding polymer hazard scores as toxicological evidence evolves; (3) improving the integration of exposure-related factors into risk assessment; and (4) establishing minimum reporting requirements for studies applying microplastic risk indices to food.

No single index currently provides a comprehensive characterization of the potential human-health implications of dietary exposure to microplastics. Progress in these priority areas would strengthen the interpretation of contamination data and the scientific basis for food-safety monitoring and future regulatory assessment.

Accordingly, high index values should not automatically be interpreted as evidence of adverse human-health effects in the absence of internationally accepted health-based reference values and established dose–response relationships for dietary exposure to microplastics.

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