Kafkas Universitesi Veteriner Fakultesi Dergisi
Journal Home-Page: http://vetdergikafkas.org
E-ISSN: 1309-2251

Kafkas Univ Vet Fak Derg
32 (2): 189-206, 2026
DOI: 10.9775/kvfd.2026.36351

Review Article

# Microplastic Contamination in Honey: A One Health-Oriented Systematic Review and Risk Assessment

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How to cite this article?

**Başaran B, Usman AN, Kaya M, Kaban G:** Microplastic Contamination in Honey: A One Health-Oriented Systematic Review and Risk Assessment. *Kafkas Univ Vet Fak Derg*, 32 (2): 189-206, 2026
DOI: 10.9775/kvfd.2026.36351

**Article ID:** KVFD-2026-36351
**Received:** 05.02.2026
**Accepted:** 10.04.2026
**Published Online:** 14.04.2026

**Abstract**

Microplastics have become pervasive environmental contaminants with the capacity to move across ecological and biological systems. Honey represents a unique food matrix in this context because it is produced through intensive interactions between honeybees and their surrounding environment and is consumed directly by humans with minimal processing. This review synthesizes current evidence on microplastic contamination in honey, evaluates reported concentration ranges, particle characteristics, and polymer profiles, and situates these findings within a One Health framework linking environmental pollution, bee health, and human exposure. Microplastics have been reported in honey samples from multiple geographic regions worldwide, although reported concentrations vary considerably among studies. Notably, only a limited number of investigations have translated contamination data into consumption-based exposure estimates, underscoring a significant gap in quantitative risk assessment. Experimental and field studies further indicate that microplastics can affect honeybee physiology, immunity, behavior, and colony dynamics, and that contaminated bees can transfer particles to hive products, including honey. Collectively, these findings support the use of honey as a sentinel matrix for tracing environmental microplastic pollution through biological pathways to the human diet. Addressing existing knowledge gaps through standardized methodologies and integrated exposure assessments is essential for advancing risk evaluation within a One Health perspective.

**Keywords:** *Apis mellifera*, Microplastic contamination, Food safety, Bee health, Human-animal-environment Nexus

## Introduction

Plastics are widely used in modern society due to their durability and broad range of applications [1]. As a result of their persistence, plastics are recognized as long-lasting environmental contaminants that have been detected across diverse ecosystems [2]. Under environmental weathering, plastics undergo solar UV-induced photo-oxidation, oxidative chain scission, and surface microcracking, which embrittle the polymer matrix and make it susceptible to subsequent mechanical fragmentation, ultimately generating secondary micro-plastics (<5 mm) [3]. Recent studies have reported the presence that microplastics are pervasive environmental pollutants distributed across a wide range of ecosystems, including soil, glaciers, deserts, oceans, rivers, and the atmosphere, and are increasingly detected in drinking water, air, and diverse food matrices, highlighting their widespread presence in both environmental and biological compartments [4-12]. The detection of microplastics in multiple environmental components indicates that human exposure may occur via inhalation, dermal contact, and particularly through dietary intake. In this context, microplastic contamination is increasingly discussed within the context of environmental health and exposure assessment research [13].

From a human health perspective, the importance of microplastics is being increasingly debated. Evidence from human studies suggests that microplastics can be retained in the gastrointestinal tract, respiratory tract, and circulation, with their distribution likely influenced by particle size, shape, chemical composition, and surface properties [14,15]. In addition, additives used in plastic production and compounds released during polymer degradation may pose toxicological risks [16-18].

In recent years, studies have been published suggesting that microplastics may be associated with inflammation, immune system modulation, oxidative stress, endocrine effects, and cellular-level damage [19-24]. Therefore, the occurrence of microplastics in foods, their transfer through the food chain, and the resulting potential for human exposure have become major topics of scientific investigation.

Honey is consumed in many regions globally [25]. Honey is a natural product characterized by a rich biochemical composition, including simple carbohydrates, amino acids, proteins, organic acids, and a variety of phenolic and flavonoid compounds, many of which contribute to its antioxidant, antimicrobial, and anti-inflammatory properties [26,27]. Owing to this diverse composition, honey has long been associated with beneficial effects on human health and is frequently described in the literature as a functional food with preventive and supportive roles in the context of various health conditions [28,29]. Honey is a minimally processed natural product obtained directly from the environment, with its production process shaped almost entirely by the interactions between honeybees and their surrounding ecosystem [30]. This characteristic makes honey both a direct reflector of environmental contaminants and a realistic indicator of human exposure through consumption. At the same time, honey, honeybees, and the hive ecosystem have been proposed as useful bioindicators for monitoring the presence of microplastics in the environment. Indeed, a growing body of recent research has confirmed the presence of microplastics in both honey and honeybees [31-34].

The One Health perspective constitutes the theoretical foundation of this study. The One Health approach emphasizes that human, animal, and environmental health are inseparable from one another [35]. Microplastic contamination in honey represents a point of convergence among environmental exposure, animal health, and human dietary intake. Honeybees act as biological representatives of environmental exposure, honey serves as a food source for humans, and environmental conditions determine both the materials collected by bees and the level of contaminant exposure in honey. For this reason, evaluating the presence of microplastics in honey is important for understanding human health, honeybee health, and the integrated structure of ecosystems.

This study aims to systematically evaluate the levels of microplastics reported in honey and to examine variations across countries in terms of polymer types and particle characteristics. Potential human exposure through honey consumption is then assessed using the available data. In addition, the findings are integrated within a One Health framework to jointly consider environmental, animal, and human exposure dynamics. Through this approach, the study seeks to support a more comprehensive understanding of microplastic-related risks linked to honey from both scientific and public health perspectives.

# Material and Methods

## Methodology

A systematic literature search was conducted in the Web of Science, Scopus, and PubMed databases. No starting year restriction was applied, as research has predominantly emerge in recent years. The search included studies published up to 31 December 2025. A preliminary literature review was conducted to determine the keywords used during the database search. The final search strings combined microplastic- and polymer-related terms with product descriptors using Boolean operators. The keyword combinations were structured as follows: "microplastic AND (honey OR bee product)", "micro-plastic AND (honey OR bee product)", "microplastic contamination AND (honey OR bee producs)", "microplastic morphology AND (honey OR bee product)", "microplastic identification AND (honey OR bee product)", "polymer AND (honey OR bee product)", "polymer type AND (honey OR bee product)", "polymer identification AND (honey OR bee product)", "polymer composition AND (honey OR bee product)", and "polymer profiling AND (honey OR bee product)". The search strategy was designed to identify studies investigating microplastic contamination specifically in honey while excluding research focused solely on bees or hive materials. Duplicate records were removed prior to screening. These terms ensured the inclusion of all studies that investigated microplastic or nanoplastic contamination in honey while also filtering out unrelated research on bees or hive materials.

Only studies that examined the detection, quantification, or characterization of microplastics directly in honey samples were considered eligible. Studies investigating other bee-related products (e.g., pollen, propolis, beeswax, royal jelly, and bee bread) were excluded. Research focusing on bees, hive materials, foraging behavior, or environmental sampling around apiaries was excluded, as these did not align with the objective of assessing microplastic contamination in honey. The screening process was performed independently by two researchers to prevent possible errors. Review articles, conference proceedings, books, book chapters, and non-English publications were excluded. The researchers first assessed the titles and abstracts. Afterwards, they performed a full-text evaluation of potentially eligible studies. Following the selection process, a total of 13 studies were included in the systematic review. The study selection procedure is presented in detail in the PRISMA flow diagram *(Fig. 1)*.

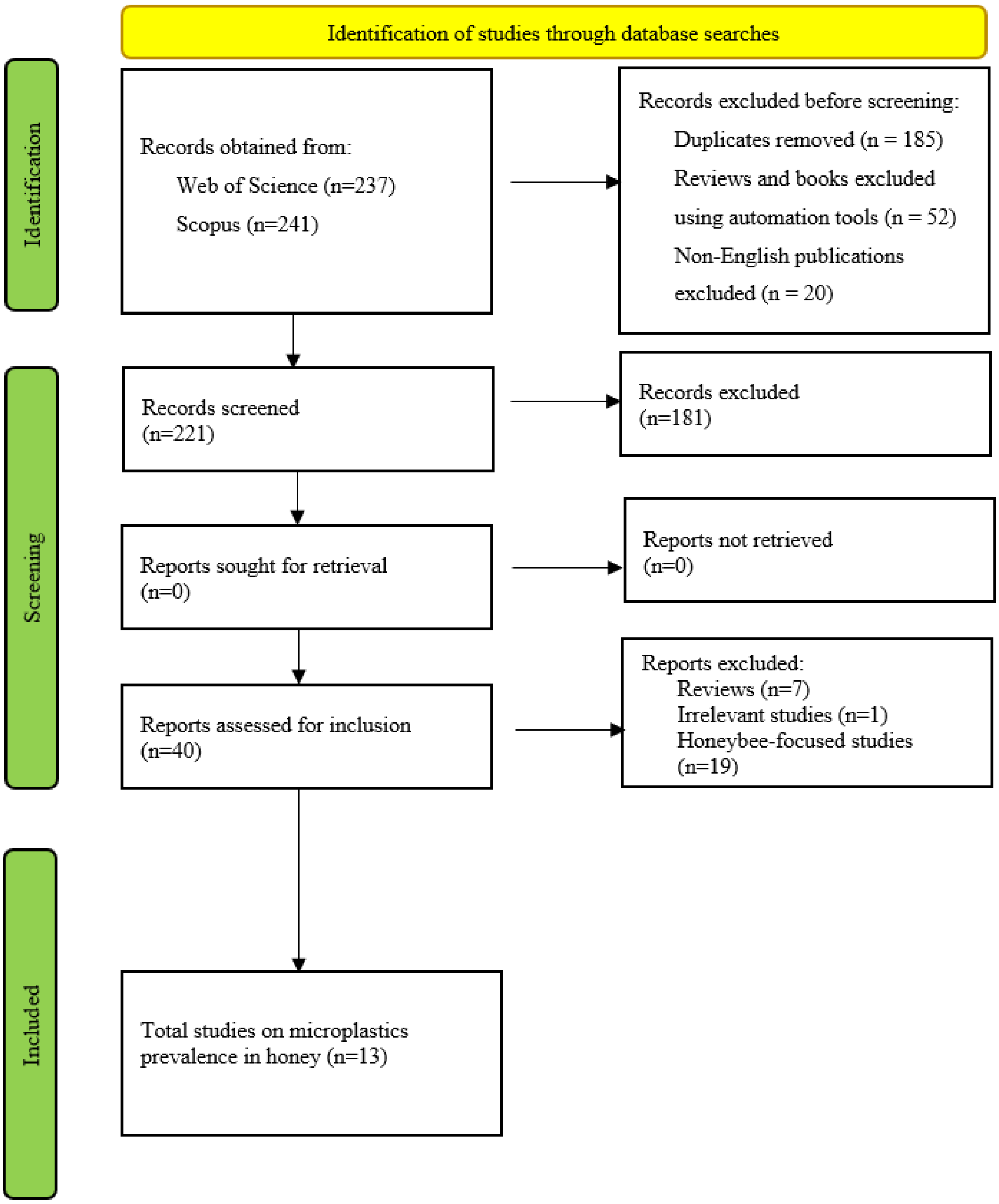


**Fig 1.** PRISMA flow diagram illustrating the study selection process

# Results

## Global Overview of Microplastic Contamination in Honey

*Table 1* presents the findings of 13 studies and provides a comparative assessment of the particle levels, physical and chemical properties of microplastics detected in honey samples.

## Sources and Pathways of Microplastics in Honey

Based on the findings of the systematic literature review, the reported sources of microplastic contamination in honey can be classified into several main categories. These include particles transported from the surrounding environment into the hive, beekeeping practices and in-hive materials, contamination arising during harvesting and processing stages, migration from packaging materials, and secondary contamination that may originate from analytical procedures *(Fig. 2)*.

## Biological and Behavioral Effects of Microplastic Exposure in Honeybees

Experimental studies indicate that microplastic exposure represents an emerging ecotoxicological concern for honeybee health. Reported effects include alterations in physiology, immune function, gut microbiota composition,

***Table 1.*** *Reported microplastic concentrations, size distributions, and polymer composition in honey*

| Location | Samples of Number | Detection | Mean (Min.-Max.) | Physical | | | Chemical | Reference |
|---|---|---|---|---|---|---|---|---|
| | | | | Shape | Size (µm) | Color | Polymer | |
| Kosovo | 28 | Microscopy, FT-IR | 124 (20-360) MPs/kg | Fragment, fiber (dominant) | 20-541<br><100: 67%<br>>100: 33% | Black (dominant), blue, transparent, green, red, brown and purple | EVA (dominant) PE, PP, PA, PET | Özçifçi et al.[30] |
| Türkiye | 32 | Microscopy, FT-IR | 314 (0-1280) MPs/kg | Fiber, fragment (dominant) | 133-19,950<br><500: 61%<br>500-1000: 22%<br>>1000: 17% | Brown (dominant), black, green, red, yellow, transparent | PE (dominant), EVA, PP, PA | Basaran et al.[32] |
| Ecuador | 14 | Microscopy, FT-IR | Craft honey:<br>67 (36-114) MPs/kg<br>Industrial honey:<br>54 (22-76) MPs/kg | Fiber, fragment (dominant) | Fiber: 85-5174<br>Fragment: 5-226<br>Fiber: 67-3303<br>Fragment: 6-183 | Not defined | PE (dominant), PP, PA | Diaz-Basantes et al.[36] |
| Malaysia | 12 | Microscopy, FT-IR | 68.5 MPs/kg | Fragment, fiber | 1000-5000 | Transparent, black, red, blue, purple, brown and yellow | PE, PET | Azmi et al.[37] |
| Italy | 10 | Microscopy, FT-IR | 10.4 MPs/kg | Fiber (dominant), fragment | Fiber: 190-3525<br>Fragment: 68-779 | Transparent (dominant), black, blue, brown, gray, red | PET (dominant), PE, EVA, PA, ABS, PTFE, PCL, PVS | Schiano et al.[38] |
| Italy | 29 | Microscopy, FT-IR | 62 (29-129) MPs/kg | Fragment, fiber (dominant) | Not defined | Not defined | PA, PE | Inaudi et al.[39] |
| Germany, France, Italy, Spain, and Mexico | 19 | Microscopy | Fibers:<br>166 (40-660) MPs/kg<br>Fragments:<br>9 (0-38) MPs/kg | Fiber (dominant), fragment | 10-9000 | Transparent (dominant), blue | Synthetic particles | Liebezeit and Liebezeit [40] |
| Switzerland, Bulgaria, Italy, Spain, Latin America, Germany, and France | 47 | Microscopy | Fibers:<br>10-336 MPs/kg<br>Fragments:<br>2-82 MPs/kg | Fiber (dominant), fragment | Not defined | Not defined | Synthetic particles | Liebezeit and Liebezeit [41] |
| Republic of Korea | 6 | Microscopy, FT-IR | 180 (10-1020) MPs/kg | Not defined | <300 | Not defined | PP (dominant), PE, PET, PS | Pham et al.[42] |
| Saudi Arabia | 5 | Microscopy, FT-IR | 198 (22-660) MPs/kg | Fragment (dominant), fiber, line, sphere | 1–>1000 | Not defined | PE, PP, PET, PVC, PC | Ahmad et al.[43] |
| Brazil | 8 | Microscopy, FT-IR | 1450 (100-2600) MPs/kg | Fiber (dominant), fragment, film | Fiber: 50-≥1000<br>Fragment: 50-699<br>Film: 50–299 | Transparent (dominant), black, brown, green, red, yellow, blue | PP (dominant), PE, PET, PS | Rani-Borges et al.[44] |
| Switzerland | 5 | Microscopy, µ–Raman | Fibers: 32-728 MPs/kg<br>Fragment: 8-8680 MPs/kg | Fiber, fragment (dominant) | Not defined | Black (dominant), white, transparent, red, blue, brown, yellow | PET, synthetic particles | Mühlschlegel et al.[45] |
| Colombia | 24 | Microscopy | Not defined | Fragment, fiber (dominant) | Not defined | Yellow, blue (dominant), white, black, purple, red, transparent, green | Not defined | Gómez-Méndez et al.[46] |

*Polyamide (PA), Polyethylene terephthalate (PET), Polyvinyl chloride (PVC), Polyethylene (PE), Polycarbonate (PC), Ethylene-vinyl acetate (EVA), Polystyrene (PS), Polypropylene (PP), Acrylonitrile butadiene styrene (ABS), Polytetrafluoroethylene (PTFE), Polycaprolactone (PCL), Polyvinyl siloxane (PVS), Fourier-transform infrared spectroscopy (FT-IR)*

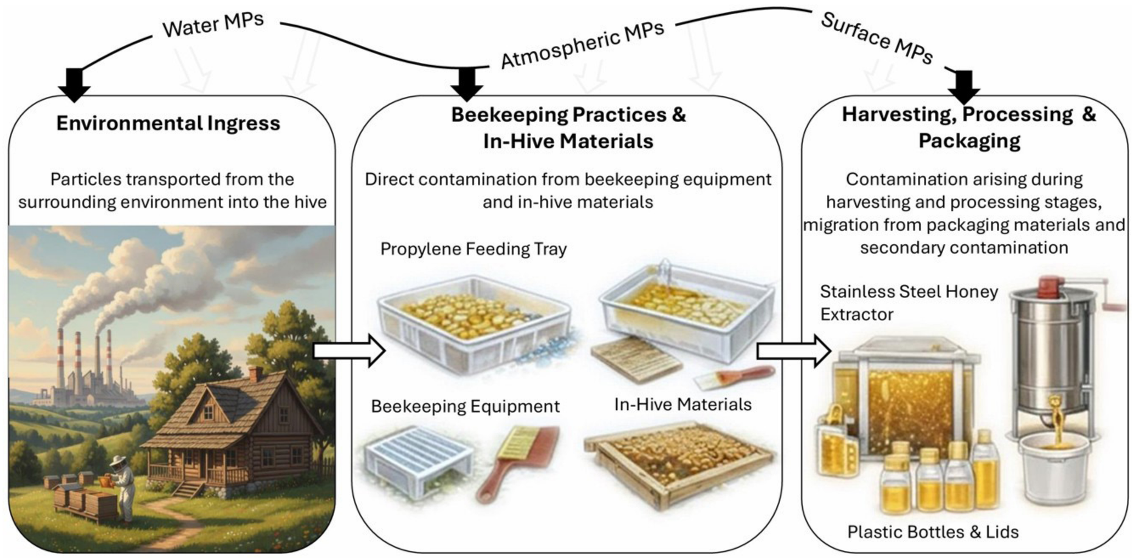

**Fig 2.** Sources and pathways of microplastics in honey

behavior, and neurobiology, with impacts influenced by particle type, shape, polymer composition, and dose *(Fig. 3)*.

### One Health Perspective

Microplastics in honey reflect their transfer across ecosystems via bee activity, creating a pathway for human exposure; thus, their assessment should be considered within a One Health perspective linking environmental, animal, and human health *(Fig. 4)*.

## Discussion

Studies reporting microplastic levels in honey can be descriptively grouped into three categories: low, moderate, and high contamination. These categories do not represent standardized thresholds, but were used only as a narrative aid in summarising the distribution of reported values.

In studies reporting low levels of contamination, mean microplastic concentrations were reported in the range of 10-70 MPs/kg [36-39]. In this group, minimum and maximum values remained within relatively narrow ranges. Although mean microplastic concentrations were not explicitly reported, the studies by Liebezeit and Liebezeit [40,41] can also be considered to reflect low-level contamination when minimum and maximum values are taken into account *(Table 1)*.

In studies reporting moderate microplastic intensities, mean concentrations generally fall within the range of 100-200 MPs/kg. In these datasets, minimum values were again reported at low levels, whereas maximum values reached the range of 500-1000 MPs/kg [30,42,43] *(Table 1)*. This pattern suggests that contamination in this group is not evenly distributed across samples. Rather, moderate mean values appear alongside a wider internal

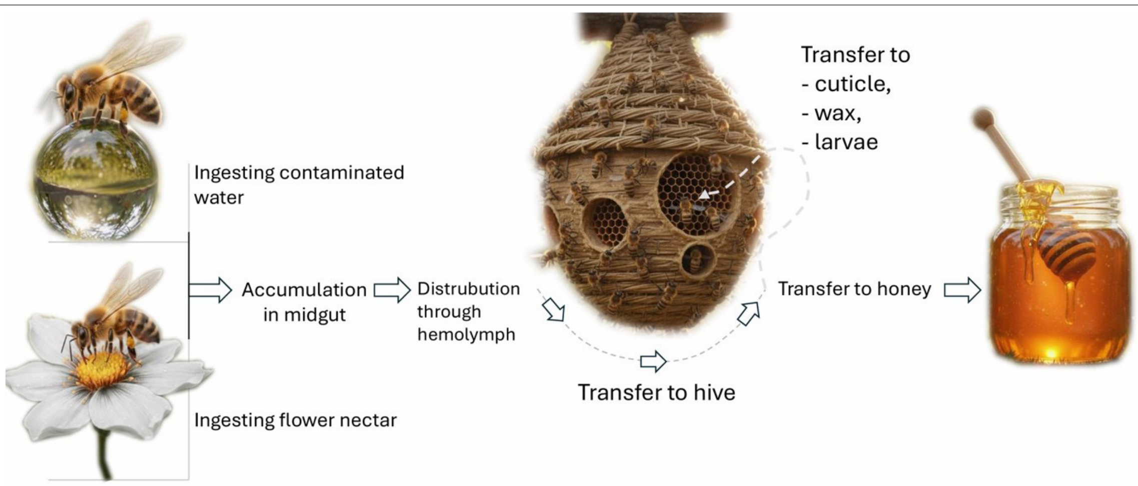

**Fig 3.** Microplastics pahtways in honeybees

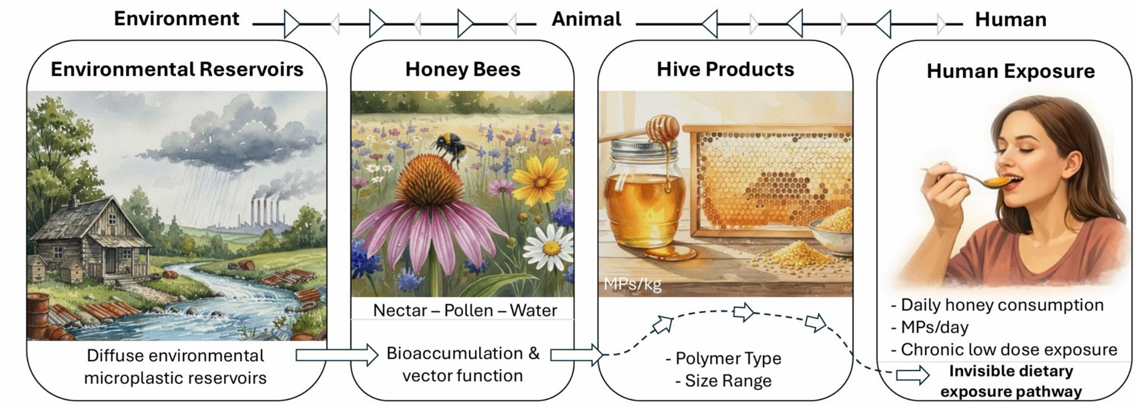


**Fig 4.** From environment to table: A One Health perspective on microplastic transfer via honey bees

spread, indicating greater variability than in the low-contamination group.

The third group includes studies reporting the highest mean microplastic concentrations. For example, Basaran et al.[32] reported a mean concentration of 314 MPs/kg. Within this study, minimum values decreased to 0 MPs/kg, while maximum values reached 1280 MPs/kg, indicating a wide concentration range. Another study in this group is the dataset reported by Rani-Borges et al.[44], which documented a mean concentration of 1450 MPs/kg. This value represents the highest mean concentration among all studies included in the table. The corresponding maximum values, reaching up to 2600 MPs/kg, further characterize this dataset as representing a high level of contamination *(Table 1)*.

When studies reporting wide maximum ranges are examined in more detail, the dataset reported by Mühlschlegel et al.[45] shows the widest reported range. This study reported fragment-shaped microplastics in the range of 8-8680 MPs/kg, representing the widest maximum range across all datasets and demonstrating that very high particle loads can occur in individual samples. In contrast, for fiber-shaped microplastics, the same study reported a narrower range of 32-728 MPs/kg, indicating that morphology-dependent differences can be observed even within a single dataset. Gómez-Méndez et al.[46], on the other hand, did not report quantitative information on microplastic abundance in their study *(Table 1)*.

Overall, comparative evaluation shows that even in studies reporting low mean concentrations, maximum values may extend over broad ranges; studies with moderate mean concentrations are associated with higher upper limits; and datasets reporting high mean concentrations are characterized by maximum particle numbers reaching the order of thousands. Overall, reported microplastic concentrations in honey show substantial variability across studies and within individual datasets. The consistent detection of microplastics were detected in all included studies, although reported concentrations varied considerably.

When the physical characteristics of microplastics detected in honey samples are examined, available data indicate that similar morphological categories have been reported across all studies. Fiber and fragment forms were reported in the majority of studies and appeared to constitute the primary structural classes of microplastics detected in honey [30,32,36-41,43-46] *(Table 1)*. This consistency indicates a high level of agreement in morphological classification despite differences in study periods, geographic regions, and analytical methodologies.

Although the dominant morphology varied among studies, fibers and fragments were the two most frequently reported forms of microplastics in honey. In some datasets, fibers were reported as the dominant morphology [38,40,44], whereas other studies reported a higher abundance of fragment-shaped microplastics [30,43]. This variation indicates that the relative distribution of particle morphologies differs across studies; however, fibers and fragments remain the two most consistently reported structural forms of microplastics in honey. Only two studies reported additional microplastic forms (line, sphere, film) beyond fibers and fragments [43,44] *(Table 1)*.

Particle size distributions varied markedly among studies. However, direct comparison remains limited because the included studies differed in their analytical conditions, including size detection ranges and particle recovery approaches. In the Kosovo study, for example, 67% of the detected microplastics were reported to be smaller than 100 µm, indicating that small-sized particles may predominate in some datasets [30]. Other studies reported size ranges extending from 1 µm to values exceeding 1000 µm, demonstrating that microplastics may occur across multiple size classes even within a single dataset [32,43]. More detailed morphometric analyses revealed fiber lengths ranging from 190 to 3525 µm and fragment sizes between 68 and 779 µm [38]. In addition, some datasets reported particle sizes reaching up to 19.950 µm; however, because this exceeds the commonly accepted <5 mm size criterion for microplastics, such values should be interpreted with caution [32]. The fragment size ranges reported by Mühlschlegel et al.[45] exhibit the widest reported range among the included studies *(Table 1)*.

With respect to color distribution, black and transparent particles were among the most frequently reported color categories across the included studies [30,38,44,45]. In addition, blue, red, green, yellow, and brown particles were reported in different studies [34,46] *(Table 1)*. The diversity observed in color distribution is consistent with the overall morphological heterogeneity of microplastics detected in honey.

Taken together, these findings indicate that fiber and fragment morphologies represent the most consistently reported forms across the included studies, while particle size ranges span a broad spectrum and color categories exhibit considerable diversity. From a physical perspective, microplastics detected in honey therefore display both shared structural features and a high degree of heterogeneity.

Polymer composition is one of the parameters showing the appears to vary considerably among studies. In particular, polyethylene (PE), polypropylene (PP), and polyethylene terephthalate (PET) are the principal polymers reported in the majority of studies [30,32,36-39,43,44]. These three polymers constitute a recurring compositional pattern in honey samples, although their reported abundances may vary depending on the analytical methods used. However, some studies have reported a broader range of polymers beyond these core types. Ethylene–vinyl acetate (EVA) was reported as the predominant polymer in specific studies [30,32]. Other polymers (polyamide (PA), polystyrene (PS), polyvinyl chloride (PVC), polycarbonate (PC), acrylonitrile butadiene styrene (ABS), polytetrafluoroethylene (PTFE), polycaprolactone (PCL), and polyvinyl siloxane (PVS)) were observed in isolated datasets, indicating variability in polymer composition across studies [38,43,44]. The fact that these polymers do not recur in every dataset indicates that the composition of analyzed samples may vary substantially between studies. In earlier investigations, polymer identification was more limited. Mühlschlegel et al.[45] reported PET and other synthetic particles, whereas Liebezeit and Liebezeit [40,41] employed the broader term "synthetic particles" without detailed classification. This reflects the progression from visual inspection toward advanced techniques, such as FT-IR and Raman spectroscopy, which allow more precise polymer identification *(Table 1)*.

Overall, the distribution of polymers detected in honey exhibits a two-layered structure. The first layer comprises PE, PP, and PET, which recur across all studies and constitute the core polymer composition of honey samples. The second layer consists of polymers such as EVA, PA, and other polymer classes that appear in specific studies and contribute greater compositional diversity. The coexistence of these two layers demonstrates that polymer composition in honey includes both common and variable components.

As shown in *Table 1*, microplastics have been reported in honey samples from multiple countries, indicating that this is not a location-specific finding. However, microplastic concentrations, physical characteristics, and polymer compositions show pronounced variability between countries. These differences should not be attributed solely to environmental conditions but should also be considered in relation to analytical methods, sampling strategies, beekeeping practices, and local socio-economic contexts.

In Europe, mean microplastic concentrations reported from Italy ranged between 10 and 62 MPs/kg [38,39]. These results indicate that even in countries with advanced environmental management systems and strong regulatory frameworks, microplastics are not entirely absent. By contrast, an average concentration of 180 MPs/kg reported in South Korea [42], a country with similarly high environmental governance capacity, suggests that high population density, intensive industrial activity, and the spatial overlap between urban expansion and beekeeping areas may contribute to elevated levels. The mean concentration reported from Türkiye (314 MPs/kg) [32] is notably higher than the low values observed in European examples. In Türkiye, the widespread practice of beekeeping across both rural and peri-urban settings, together with its broad ecological diversity and rich floral resources, may increase the extent of environmental contact, providing a contextual background for this variability. In Saudi Arabia, the reported mean concentration of 198 MPs/kg [43] does not fully align with the common assumption that arid climates and sparse vegetation would limit environmental exposure. This finding suggests that materials used along the production chain may also influence microplastic levels. Data from developing countries such as Colombia and Malaysia [37,46] fall within low to intermediate ranges, supporting the view that microplastic levels are not directly correlated with national development status. In contrast, the mean value of 1450 MPs/kg reported from Brazil [44] represents one of the most distinctive results in the dataset. This exceptionally high value evokes a complex environmental context shaped by intensive agricultural activity, extensive tropical biomes, and diverse production conditions. Its magnitude suggests that country-specific sampling locations, beekeeping practices, or methodological factors may also play a decisive role.

The most extreme value is the maximum concentration of 8680 MPs/kg reported in Switzerland [45]. Observing such a high maximum value in a country characterized by strong environmental indicators and strict regulations underscores the high spatial variability of microplastic occurrence under local environmental conditions. This finding represents an exceptional case, illustrating that national-level environmental quality alone is insufficient to explain maximum microplastic values in honey and that local sampling contexts are critical determinants.

The evaluation of inter-country differences represents a central scientific rationale of this study. Microplastic contamination does not occur uniformly across regions. Factors such as population density, industrial production, agricultural practices, waste management capacity, climatic conditions, and beekeeping traditions vary substantially between countries, and these differences are directly reflected in honey samples. Accordingly, comparing microplastic levels in honey across countries provides valuable insight into both the spatial distribution of environmental contamination and potential human exposure. Moreover, variations in honey production chains, including equipment use, packaging practices, and storage conditions, may further influence microplastic diversity. Systematic integration of these environmental and methodological determinants is essential for developing a standardized and globally comparable assessment framework.

The studies summarised in *Table 1* employed different analytical approaches for the detection and characterisation of microplastics in honey, and these methodological differences should be taken into account when interpreting the reported findings. Most studies used microscopy combined with FT-IR (Kosovo, Türkiye, Ecuador, Malaysia, two studies from Italy, Republic of Korea, Saudi Arabia, and Brazil), whereas three studies relied on microscopy alone (Germany/France/Italy/Spain/Mexico; Switzerland/Bulgaria/Italy/Spain/Latin America/Germany/France; and Colombia), and one Swiss study used microscopy together with μ-Raman. This distribution shows that the current evidence base is dominated by microscopy-supported spectroscopic confirmation rather than by visual identification alone.

These differences are important because the analytical technique directly influences the level of particle characterisation that can be achieved. Studies using microscopy alone generally provided limited chemical detail, often reporting particles broadly as "synthetic particles" or leaving polymer identity undefined. By contrast, studies combining microscopy with FT-IR or μ-Raman were able to identify specific polymers such as PE, PP, PET, PA, EVA, PS, PVC, and PC, thereby offering a more detailed chemical profile of contamination. A similar pattern is also visible in the reporting of particle properties: spectroscopy-supported studies tended to provide more specific information on polymer composition, while microscopy-only studies were more restricted to visual categories such as shape, colour, and approximate size.

From an interpretive standpoint, this methodological heterogeneity limits strict cross-study comparability. Reported differences in microplastic occurrence may reflect not only geographical or environmental variation, but also differences in analytical sensitivity, particle confirmation, and reporting detail. For this reason, the findings in *Table 1* should be read comparatively but cautiously. At the same time, the fact that microplastics were detected across studies using different analytical approaches strengthens the broader conclusion that honey is a relevant matrix for investigating environmental microplastic contamination and potential exposure pathways.

Literature findings indicate that microplastics in honey originate mainly from environmental exposure, beekeeping materials, processing stages, packaging, and potential analytical contamination *(Fig. 2)*.

From an environmental perspective, honeybees represent the initial biological interface in the transfer of microplastics into honey [47]. Microplastics that are widely documented in air, water, and soil can enter the matrices encountered by bees through plant surfaces, nectar, pollen, and water sources [40,41,48,49]. Through the ingestion of contaminated nectar and water, or the inadvertent collection of particles resembling pollen in size and morphology, microplastics may adhere to the bee cuticle or enter the digestive tract and subsequently be introduced into hive products [50]. In a field study conducted by Alma et al.[51], colonies fed with a sucrose solution containing polyester microfibers showed the presence of these fibers on the cuticle and within the digestive tract of adult worker bees, as well as in larvae, wax, and honey samples, experimentally demonstrating that environmentally derived or feed-associated particles can be directly transferred into the honey matrix. Similarly, recent studies emphasize that a substantial proportion of microplastics reported in honey and other bee products may be linked to an indirect exposure chain originating from environmental particles accumulated in soil, water, and plant tissues [34,47,52]. The geographic distribution of environmental load is also relevant: Diaz-Basantes et al.[36] reported higher microplastic counts in honey samples collected from urban and industrial areas compared with rural regions, suggesting that the observed contamination was primarily environmentally driven.

Beekeeping practices and in-hive materials constitute a second major source of microplastic contamination in honey. Artificial feeding, synthetic textile fibers from protective clothing, and plastic hive components -including frames and feeders- may introduce microplastics through mechanical degradation or fiber shedding [32,51,53,54]. Mühlschlegel et al.[45] attributed the low-level microplastic contamination detected in commercial honey samples particularly to synthetic textile-derived fibers associated with beekeepers' clothing, interpreting this pathway as one of the main potential sources. A striking example in this context is the use of microfiber sheets applied to control the small hive beetle *(Aethina tumida)*. Buteler et al.[55] demonstrated that non-woven microfiber covers placed inside hives were chewed by bees, leading to fiber fragmentation, and that after three months of application, the abundance of blue microfibers on the cuticle and within the digestive tract of bees, as well as in honey samples, increased significantly compared with control hives. This finding indicates that such widely used pest management practices can become a direct source of microplastic contamination in honey.

Harvesting and processing stages also represent potential points of contamination. Inappropriate plastic containers, buckets, filters, uncapping tools, and centrifuges used during honey extraction, transport, and storage may release microplastic particles under surface abrasion and mechanical stress, allowing direct contact with honey [30,34,36]. Fuente-Ballesteros et al.[47] noted that direct contact with "inappropriate plastic cups, containers, honey extraction machines, and uncapping devices" represents an additional contamination pathway for hive products, including honey. This observation indicates that, beyond environmental exposure, human-controlled stages of the production chain also play a role in shaping the microplastic load of honey.

Packaging materials and storage conditions represent another major source of microplastic contamination in honey, particularly when considering the final product reaching consumers. Indeed, many researchers have emphasized that packaging materials may act as a secondary source of microplastic contamination for foods, including honey, and have highlighted the need for further studies specifically addressing migration processes under realistic storage conditions [42,56-58]. Katsara et al.[59] further stressed that plastic packaging used for honey and other foods can undergo abrasion under environmental conditions, transferring microplastics and associated chemical additives into food, and therefore should be considered an independent contamination source for honey. The absence of such migration in studies using glass packaging supports the notion that packaging-related contributions are primarily associated with plastic-based systems.

Finally, contamination arising from analytical procedures represents a critical methodological limitation that must be carefully considered when interpreting findings on microplastic detection in honey. Numerous studies have emphasized that microplastic quantification in food matrices is highly susceptible to laboratory-derived contamination due to the widespread use of plastic consumables, synthetic filter materials, textile fibers from laboratory clothing, and background airborne particles [60-62]. This concern is further reinforced by the fact that recovery rates have not been reported in a substantial proportion of existing studies. The lack of recovery calculations creates a critical gap in assessing laboratory-derived contamination as well as the sensitivity, accuracy, and validity of analytical methods. Consequently, particularly for studies reporting low microplastic levels, uncertainty regarding whether the observed load originates from the actual matrix or from analytical processes becomes increasingly important.

Overall, microplastic contamination in honey appears to arise from a multilayered network of sources, including particles transported into hives through environmental exposure of bees, plastic- and textile-based materials used in apicultural practices, plastic equipment employed during harvesting and processing stages, plastic packaging systems utilized at the consumer level, and background contamination introduced during analytical procedures. The existing literature demonstrates that each of these sources can independently contribute to increasing the microplastic burden of honey, indicating that contamination represents a complex process that cannot be explained by a single factor.

When evaluating the existing literature on the presence of microplastics in honey, it is observed that the vast majority of primary studies report their findings in terms of concentrations measured in the honey matrix, whereas studies that quantitatively calculate the daily micro-plastic intake attributable to honey consumption remain limited. Of the 13 primary studies reviewed, only four numerically reported human exposure based on honey consumption [30,32,42,43]. This indicates that, in most studies, microplastic exposure specific to honey has been confined solely to contamination levels, while consumption-based human exposure has not yet been addressed systematically in the literature, revealing a clear methodological gap in this area.

A comparative evaluation of studies that report daily intake values demonstrates considerable variability across countries. The value of $2.5\times10^{-3}$ MPs/day calculated by Ahmad et al.[43] (Saudi Arabia) reflects an approach in which microplastic intake from honey consumption is reported at very low levels, whereas the $9.0\times10^{-2}$ and $3.7\times10^{-1}$ MPs/day values reported by Pham et al.[42] and Özçifçi et al.[30] (Republic of Korea and Kosovo, respectively) correspond to studies in which exposure is considered measurable but relatively limited. In contrast, the 1.05 MPs/day reported by Başaran et al.[32] (Türkiye) provides an example in which the daily intake calculated from honey consumption is evaluated at a higher level. In particular, the fact that the microplastic levels reported in honey vary markedly across countries suggests that this difference is closely related to environmental conditions, production and processing practices, as well as variations in honey consumption amounts across societies. This contextual diversity causes honey consumption–based microplastic exposure calculations to yield different results from study to study and makes it difficult to consolidate the reported daily intake values under a single representative level. Although direct evidence showing that honey-derived microplastic exposure alone is sufficient to produce these effects remains limited, the documented presence of microplastics in human biological samples and tissues suggests that dietary intake may contribute to the overall body burden of microplastics. In this context, honey consumption can reasonably be considered one potential component of cumulative dietary exposure, even if a direct causal link has not yet been established.

Interpreting calculated daily microplastic intake levels in terms of potential human health implications requires a multidimensional framework that extends beyond particle number alone. In addition to particle number, the size, shape, polymer type, and the additives or environmental contaminants carried by microplastics stand out as key factors determining the direction of interactions with biological systems and the nature of potential effects. In this context, an increasing number of studies in recent years have demonstrated that microplastics can access biological environments in the human body, and the reporting of microplastics in human blood, urine, and feces [63-65], as well as in certain tissue samples [66], has brought the possibility of systemic uptake via multiple exposure routes, including diet, to the forefront.

Reports documenting microplastics in the skin, lungs, liver, spleen, kidneys, colon, blood, saliva, placenta, and breast milk suggest that these particles may enter systemic circulation following different exposure pathways and potentially distribute to various tissues [67-69]. In this regard, understanding the absorption, distribution, metabolism, and excretion (ADME) characteristics of microplastics is considered a fundamental requirement for interpreting possible toxicological outcomes [20]. Data from different populations show that the presence of microplastics has been reported in feces, colon, lungs, bronchoalveolar lavage fluid, sputum, blood, placenta, and breast milk together with polymer types and size ranges; in particular, it is emphasized that fractions below 10 μm can interact more easily with cell membranes and have the potential to be transported to different tissues via circulation [70-74]. One of the notable findings for human health is that microplastics have also been detected in biological structures associated with the cardiovascular system [75]. Human studies demonstrating the presence of microplastics and nanoplastics in atheroma plaques have strengthened debates suggesting that these particles may not only be indicators of environmental exposure but also potentially represent a biological burden that can be linked to clinical outcomes [76,77].

The most frequently reported mechanistic framework associated with microplastic exposure is the triggering of oxidative stress and inflammatory responses and linking this to cellular damage processes. Experimental studies suggest that exposure to microplastics can activate pathways such as Toll-like receptors, NF-κB signaling, and the NLRP3 inflammasome, leading to increased production of reactive oxygen species and progression of inflammatory cascades [78-83]. In parallel, it has been reported that different PS micro- and nanoparticles can increase the production of reactive oxygen species, trigger endoplasmic reticulum stress, and are associated with apoptosis and autophagic cell death in many cell types, including human lung and intestinal cell models [84-86]. It also indicates that microplastic exposure can lead to impairment of intestinal barrier integrity, microbiota dysbiosis, and changes in bile acid and amino acid metabolism [87-90].

In the context of dietary exposure, the digestive system represents the primary site where microplastics first interact with the human body. Available data show that microplastics can accumulate in the intestine and that this accumulation is associated with intestinal barrier dysfunction, changes in microbiota composition, and deviations in bile acid metabolism [83,91,92]. From a systemic perspective, microplastic exposure has been linked to gastrointestinal inflammation, endocrine disruption, dysregulation of lipid and energy metabolism, as well as non-alcoholic fatty liver disease and hepatocarcinogenesis. It is stated that most of these effects develop through multiple mechanisms such as oxidative stress, chronic inflammation, immunosuppression, and disruption of hormonal regulation [93-95]. In addition, it is emphasized that toxicity is sensitive to particle size and that mixture exposures can further amplify biological effects [75]. Effects of microplastic exposure via the respiratory route have also been reported to extend beyond local tissues, potentially impacting inter-system interaction [77,96]. From the perspective of reproductive and developmental health, the reporting of microplastics in the placenta and breast milk provides important evidence strengthening the possibility of exposure in early life periods [67,97,98].

Overall, while the current literature accepts that the presence of microplastics in human biological systems has been clearly demonstrated, it also shows that there remains a significant gap between evidence of "presence" and clinical-level "causality" in interpreting health effects. Although detection of microplastics in various tissues suggests that systemic access is possible, reaching definitive health outcomes requires the generation of multilayered evidence that jointly considers exposure level, particle characteristics, and mixture effects. Accordingly, mechanistic toxicology data should be interpreted in conjunction with human biomonitoring findings within a cautious, holistic framework.

Experimental data suggest that microplastics pose a growing ecotoxicological risk to honeybees, affecting physiology, immunity, gut microbiota, behavior, and neurobiology depending on particle characteristics and döşe *(Fig. 3)*. Several laboratory studies indicate that PS and PE microplastics affect honeybee physiology. In a 14-day laboratory exposure study, Wang et al.[99] used 50 mg/L of PS microplastics, but it was not stated whether this corresponded to an environmentally realistic level. Environmental reference is needed for ecosystem risk assessment. However, despite the absence of marked survival effects, PS microplastics exposure led to a reduction in gut bacterial diversity and induced pronounced alterations in the bee gut microbiome, accompanied by changes in the expression of genes associated with oxidative stress, detoxification pathways, and immune responses. In contrast, Balzani et al.[50] observed that oral exposure to PE microplastics at 50 mg/L increased honeybee mortality, whereas lower doses had no significant effects. The results indicated that exposure to PE at 50 mg/L resulted in a significant increase in mortality, whereas no significant effects on survival were observed at the lower concentrations. Deng et al.[100] exposed honeybees to spherical PS microplastics under two complementary designs. First, mixed-size PS (0.5:5:50 μm = 1:1:1) was tested at 0.1, 1, 10, and 100 mg/L for 14 days. In this concentration-response experiment, survival was significantly reduced in *Apis mellifera* at 1 mg/L ($P<0.05$), 10 mg/L ($P<0.01$), and 100 mg/L ($P<0.01$), and in *Apis cerana* at 10 and 100 mg/L ($P<0.05$). Based on the survival curves, the final survival proportions at day 14 were approximately 62% in controls, 50% at 0.1 mg/L, 48% at 1 mg/L, 45% at 10 mg/L, and 38% at 100 mg/L for *Apis mellifera*, and approximately 62% in controls, 50% at 0.1 mg/L, 55% at 1 mg/L, 45% at 10 mg/L, and 42% at 100 mg/L for *Apis cerana*. Second, a size-response experiment was performed in *Apis mellifera* using 0.5, 5, and 50 μm PS at 10 and 100 mg/L for 21 days. In this experiment, cumulative mortality was significantly higher particularly in the 0.5 μm PS group at 100 mg/L compared with the control ($P<0.05$); visually, survival at the end of the experiment was approximately 5% in the 0.5 μm/100 mg/L group versus about 28% in the control group. The study further showed that 0.5 μm PS caused more pronounced midgut damage and stronger tissue translocation than larger particles. In addition, combined exposure to 5 μm PS (10 mg/L) and Israeli acute paralysis virus (IAPV) reduced survival to approximately 20% in *Apis mellifera* and 27% in *Apis cerana* by day 7, compared with roughly 33% and 38%, respectively, in the virus-only groups, while viral titers increased by more than fourfold on days 6 and 7 in *Apis mellifera* and by more than fourfold, twofold, and sixfold on days 5, 6, and 7 in *Apis cerana*. Buteler et al.[101] investigated the effects of acute exposure to polyester microplastic fibers on the foraging behaviour of *Apis mellifera carnica*. In the acute oral toxicity assay, honeybees fed with 100 mg MPs/L in 50% sucrose solution showed no increase in short-term mortality compared with the control group, with mortality remaining 0% at 24 h and 3.33% at 48 h in both groups. In the behavioural assays, control and MP-containing dishes were presented simultaneously, and bees showed no significant preference or avoidance when MPs were offered in sucrose solution or water (blue fibers: sugar solution, $t=0.7$, $P=0.49$, $n=12$; water, $t=0.21$, $P=0.83$, $n=18$; yellow fibers: sugar solution, $t=1.13$, $P=0.27$, $n=12$; water, $t=0.04$, $P=0.96$, $n=18$). Likewise, proportional consumption did not differ significantly among sucrose solutions containing 0, 10, and 100 mg MPs/L (GLMM, $\chi^2=0.54$, $df=2$, $p=0.76$, $n=180$), although MP-free solutions were consumed more rapidly ($\chi^2=8.31$, $df=2$, $p=0.01$, $n=20$). These results indicate that acute microfiber ingestion did not cause immediate mortality, but honeybees did not avoid microplastic-contaminated food or water, suggesting that repeated exposure may still contribute to longer-term risk. Wang et al.[102] investigated, under controlled laboratory conditions, the effects of PS nano- and microplastics on *Apis mellifera*, focusing on body weight, intestinal development, particle accumulation, gut microbiota, and susceptibility to bacterial infection. Using PS particles of 100 nm, 1 μm, and 10 μm, the study showed that the smallest particles, particularly 100-nm PS, caused the most pronounced adverse effects, including intestinal dysplasia, reduced body weight, accumulation in the rectum, and increased susceptibility to *Hafnia alvei*, leading to a fivefold higher mortality rate. With respect to the gut microbiota, no significant difference in alpha diversity was found in either the Chao1, Shannon, or Simpson indices ($P>0.05$). However, compositional changes were still evident: the initial relative abundance of *Lactobacillus* and *Bifidobacterium* was 72% and 12.33%, respectively, whereas in the PS-100 nm group *Lactobacillus* declined to 54.3% on day 10 and *Bifidobacterium* declined to 6.35% on day 15. These microbiota changes were accompanied by altered expression of genes related to immune regulation, detoxification, and energy metabolism. However, these findings were obtained using selected PS particles under laboratory exposure conditions and should therefore be interpreted as evidence of potential biological effects rather than as a direct representation of the full diversity of microplastics present in natural environments. These different results demonstrate the determining effect of particle shape on toxicity and suggest that microplastics with different shapes lead to varying biological interactions.

Recent studies also demonstrate that microplastics impact honeybee cognition and behavior. Pasquini et al.[103] investigated the effects of short-term oral exposure to spherical microplastics on cognitive functions in *Apis mellifera*. Bees were exposed for 48 hours to PS, polymethyl methacrylate (PMMA), and their combination at concentrations of 0.5, 5, and 50 mg/L. Exposure to PS at 50 mg/L resulted in reduced sucrose responsiveness, indicating impaired ability to detect and respond to nectar sources. While PMMA alone did not produce significant effects, combined exposure led to pronounced reductions in sucrose responsiveness at 5 and 50 mg/L, suggesting potential synergistic interactions. Furthermore, all treatments negatively affected learning and memory, with PS inducing the most marked cognitive impairment. This is critically important in that it shows microplastics have biological accessibility in the nervous system and that behavioral impairments are neurologically based. Behavioral effects constitute some of the most critical outcomes in terms of bee ecology. Ferrante et al. [104] evaluated the effects of PS, PMMA, and their combination on the survival and immune responses of *Apis mellifera*. Bees were orally exposed to three concentrations (0.5, 5, and 50 mg/L). Exposure to both materials resulted in reduced food consumption and increased mortality at medium and high concentrations compared with controls. In addition, alterations in cuticular chemical profiles were observed, particularly for PMMA. Despite these changes, exposed workers were not discriminated against by guard bees and were allowed to re-enter the colony, suggesting that contaminated individuals may act as vectors for the spread of particulate matter within the hive. Overall, the findings indicate that microplastic exposure can impair individual health and pose potential risks to colony integrity.

The accumulation of microplastics in the bee body and their transport to the hive are noteworthy in terms of both ecology and food safety. Alma et al.[51] experimentally investigated whether honeybees ingest microplastics through feeding and how these particles are subsequently transferred to different matrices within the colony, including adult bees, larvae, honey, and beeswax. Colonies were fed a sucrose solution containing polyester microfibers at an environmentally relevant concentration (50 mg/L) based on levels reported in drinking water. After one month of exposure, microfibers were detected in the bristles and digestive tracts of adult worker bees and were shown to be redistributed to other hive components. The results demonstrated that microfibers accumulated predominantly in beeswax, whereas lower amounts were detected in honey and in the digestive systems of bees. Mitton et al.[105] examined the effects of microplastics alone and in combination with glyphosate on honeybee larvae. While exposure to MPs alone did not significantly affect larval survival or body weight, combined exposure to microplasticsand glyphosate resulted in reduced survivorship and lower larval weight. At the molecular level, the combined treatment suppressed immune-related gene expression and increased catalase activity, indicating enhanced oxidative stress. These findings suggest that microplastics may exert synergistic adverse effects on honeybee larval development when co-occurring with other environmental pollutants. Al Naggar et al.[54] state that immune weakening, behavioral impairments, nutritional inefficiency, and larval developmental disorders may weaken colony health in the long term and increase the risk of colony collapse.

These findings provide strong field-based evidence that plastic particles present in the environment can be transferred directly to hive products through honeybee behavior, confirming a structural link between bee exposure and microplastic contamination in honey. They further indicate that microplastic exposure under natural ecological conditions frequently co-occurs with other chemical and biological stressors, and that such combined exposures may amplify toxic effects. Although most available studies have been conducted at the individual level, they raise the possibility that microplastics may also affect colony-level processes; however, this remains to be confirmed by direct colony-scale evidence. This integrated assessment demonstrates that microplastics represent more than a superficial environmental contaminant for honeybees; rather, they act as a complex biological stressor capable of exerting multifaceted effects on immune function, neurophysiology, behavior, and colony organization. Their transfer into hive products, especially honey, underscores the relevance of microplastics for both ecosystem integrity and food safety research.

According to the World Health Organization (WHO) and the World Organisation for Animal Health (WOAH; formerly the World Organisation for Animal Health/ OIE), One Health is an integrated and unifying approach that recognizes the interdependence of human, animal, plant, and ecosystem health and promotes coordinated action across sectors and disciplines [106,107]. In the context of microplastics, this approach is particularly relevant for understanding the transfer of plastic particles across ecological and biological systems and their potential impacts on health at multiple levels. Honey constitutes a food matrix in which environmental microplastics are concentrated through bee foraging activity. This provides a biologically mediated route for human exposure. Consequently, the assessment of microplastics in honey should be regarded not solely as a matter of food safety, but also as a component of a comprehensive One Health framework encompassing environmental, animal, and human health *(Fig. 4)*.

It is evident that bees interact with a variety of substances, including pollen, nectar, water, and airborne particulate matter. These substances are present in a variety of geographic areas, and it is therefore suggested that bees function as biological sentinels, reflecting environmental microplastic loads. Due to these characteristics, they function as biological receivers that passively reflect the presence of microplastics in the environment. From a One Health perspective, the environmental microplastic load is not only a source of exposure for bees but also an interface that functions in the transfer of this load into biotic systems. Bees' feeding and foraging behaviors make it possible for microplastics to be transported from natural ecosystems to biological material and ultimately into the food chain. Environmental microplastics can enter the food chain via biological vectors without direct detection [108].

Honey can be defined as the biochemical product of the interaction between bees and their environment. The physiological and behavioural changes reported in bees due to microplastic exposure are analogous to the ecosystem-level disruptions that have been observed. This finding indicates that microplastics are not merely environmental pollutants but can produce functional outcomes by interacting with biological systems. In this context, the presence of microplastics in honey reflects not merely environmental pollution itself, but the outcome of an environment–animal interaction through which bees collect and transfer microplastic particles from the surrounding environment into the hive and, ultimately, into honey [47]. This unique position of honey indicates that microplastic pollution should be monitored not only through environmental measurements but also through biological products.

Within the One Health framework, physiological and behavioural changes in animals may serve as early warning indicators of environmental disturbances that could also have indirect implications for human health [109]. Physiological and behavioral changes reported in bees due to microplastic exposure reflect the biological counterparts of ecosystem-level disruptions. This reveals that microplastics are not merely environmental pollutants but can produce functional outcomes by interacting with biological systems. The observed effects on bee health suggest the presence of a risk line that may indirectly impact human health through the consumption of bee products, such as honey.

Within the One Health framework, honey consumption represents a pathway through which environmentally derived microplastics may contribute incrementally to human exposure. Although exposure to microplastic is frequently characterised as low-level and chronic, it possesses the capacity to generate a cumulative health burden due to the uninterrupted nature of this exposure. From a One Health perspective, honey-derived microplastic exposure should be evaluated not as an isolated risk on its own but as a component of an individual's total environmental and dietary exposure. This approach demonstrates that, despite honey's status as a "natural" product, it is not entirely independent from contemporary environmental contamination. This underscores the necessity for novel assessment frameworks to be developed in order to ascertain its impact on human health.

The One Health approach provides a useful framework for interpreting microplastic pollution in honey beyond contamination measurements alone. By considering environmental microplastic load, biological effects on bee health, and human exposure through honey together, it highlights the interconnected nature of this issue across ecosystem, animal, and human health. This holistic standpoint indicates that the presence of microplastics in honey should be regarded as a matter of One Health concern, with implications for both food safety and environmental sustainability, as well as ecosystem health.

## Knowledge Gaps and Future Directions

Although the number of studies addressing the presence of microplastics in honey and exposure associated with bee products is increasing, significant knowledge gaps that limit a holistic evaluation within the One Health approach continue to persist. Chief among these gaps is the fact that studies converting microplastic concentrations reported in honey into human-consumption–based exposure calculations remain quite limited. The vast majority of existing studies report microplastic contamination levels, but these data are rarely evaluated in terms of defined consumption scenarios, such as average versus high consumers, different age groups, or body weight-adjusted exposure metrics such as Estimated Daily Intake (EDI; particles/day or particles/kg bw/day). As a result, microplastic contamination data reported for honey are still rarely translated into probabilistic exposure modelling or cumulative dietary exposure assessment. At the same time, formal risk characterization remains constrained because harmonized health-based benchmark values for microplastics have not yet been established, and current datasets are still considered insufficient for a robust risk assessment [110,111]. Another fundamental shortcoming is methodological incompatibility. Differences in sample preparation, lower size cut-offs, particle size thresholds, identification techniques, and quality control practices significantly restrict comparability across studies. In particular, the lack of harmonized size cut-offs, the limited detection of nanoplastics (<1 µm), inconsistent polymer confirmation techniques, and the absence of standardized QA/QC frameworks further increase uncertainty. The failure to report recovery rates, procedural blanks, and blank-correction practices in many studies creates additional difficulty in interpreting results, especially those reporting low-level contamination [10,112,113].

From a biological standpoint, causal links between environmental microplastic load, effects on bee health, and human exposure through honey consumption have not yet been sufficiently elucidated. Although the potential of bees as bioindicators of environmental pollution is increasingly recognized, long-term and multi-center studies that address environmental measurements, biological effects, and dietary exposure within the same framework are still limited. Future research should focus on harmonizing analytical methods, establishing standard exposure metrics, and developing consumption-based exposure models that account for age group, body weight, and consumption scenario. It should also promote interdisciplinary study designs integrating analytical chemistry, ecotoxicology, food safety, exposure science, and epidemiology in order to assess the environment-bee-honey-human pathway more comprehensively. Such efforts would support a more robust evaluation of microplastic pollution in honey within a One Health framework.

# Conclusion

This study reveals that the presence of microplastics in honey is not an isolated finding but one that has been consistently reported across different geographies. However, the reported particle levels do not cluster around a single typical value, and wide maximum ranges accompanying low averages indicate that microplastic contamination in honey varies in a spatially and production-context-sensitive manner. This positions honey as a biotic reflection of the environmental microplastic load. Morphological and chemical profiles have been demonstrated to support the structural basis of this variability. The uniform reporting of fibre and fragment forms across all studies suggests the presence of a specific morphology for microplastics in honey. The presence of a wide size range and recurring PE, PP, and PET polymers indicates that contamination carries both shared and context-specific components. Cross-country comparisons suggest that microplastic levels cannot be explained solely by environmental quality or economic development and that local production practices, sampling points, and exposure pressures are determinative. It is evident that there is a discernible absence of literature addressing the subject of human exposure. Only a limited portion of studies reporting microplastics in honey have calculated consumption-based daily intake, and most studies have left the evaluation at the concentration level. However, the health implications of microplastics in humans and experimental animals suggest that microplastics can interact with biological systems, emphasising the necessity for a comprehensive One Health approach to address this issue. Consequently, honey serves as a compelling exemplar, illustrating the manner in which contemporary environmental contamination impacts the perception of a "natural product". Microplastic pollution in honey is not merely a measured number; it is a risk signal circulating along the environment-bee-food-human line and produced in a multilayered manner. Consequently, research focusing on honey and microplastic contamination emerges as a strategic research domain, necessitating concurrent deliberations on food safety and ecosystem health.

# Declarations

**Availability of Data and Materials:** Data and materials for this research are available upon request.

**Acknowledgements:** The authors declare no acknowledgements.

**Competing Interests:** The authors have no conflicts of interest to declare.

**Declaration of Generative Artificial Intelligence (AI):** The article and tables and figures were not written/created by AI and AI assisted technologies.

**Authors Contributions:** BB: Investigation, Methodology, Formal analysis, Writing - Original Draft, Review & Editing. ANU: Visualization, Review & Editing. MK: Review & Editing. GK: Concept Design, Visualization, Writing, review and editing. All authors approved the final version of the manuscript and accept responsibility for the scientific integrity of the work in accordance with the journal's Ethical Principles and Authorship Policy.

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