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Review paper

Overview of microplastics in the meat: occurrence, detection methods and health effects

Branko Velebit[a], Vesna Janković[a], Lazar Milojević[a], Tatjana Baltić[a], Jelena Ćirić[a] and Radmila Mitrović[a]*

[a] *Institute of Meat Hygiene and Technology, Kaćanskog 13, 11040 Belgrade, Serbia*

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A B S T R A C T

The exponentially increasing annual production of plastic waste at a global level has raised concerns regarding the prospective infiltration of microplastics into terrestrial ecosystems. The transport of microplastics via wind advection and stormwater runoff presents a substantial hazard to food resources. The most recent studies reveal that chicken, pork, and beef samples are contaminated with microplastic particles, encompassing polystyrene, polyethylene terephthalate, and polypropylene. However, the employment of various non-standardized detection methodologies poses a significant obstacle in the interpretation of acquired results. Furthermore, the thorough clarification of the correlation between human exposure to microplastics and various health consequences, such as carcinogenicity, infertility, metabolic disorders and pregnancy complications, remains inadequately explored and necessitates additional investigation to enhance public awareness and propose solutions and integrated strategies for the mitigation of microplastic contamination in meat chain.

1. Introduction

Microplastics (MP) refer to minuscule fragments of plastic material, characterized by dimensions ranging from 1 µm to 5 mm (*Frias and Nash,* 2019). The predominant source of microplastics is attributed to the degradation of macroscopic plastic waste from diverse origins, encompassing plastic objects, synthetic fabrics, and increased industrial activities. As a result of its favourable attributes and cost-effectiveness, coupled with its versatility for various commercial and industrial purposes, the production of plastics experienced a substantial increase of approximately 200-fold over a span of 65 years (*Klöckner et al.,* 2021). Presently, the annual production of plastic waste stands at approximately 2.1 billion metric tons, with projections indicating a surge to 3.4 billion metric tons by the year 2050 (*Khan et al.,* 2022). In conjunction with an increased likelihood of ingestion and absorption by a wide array of species and potential existence of MP within food sources, encompassing meat, the multifaceted nature of this diversity has engendered apprehension regarding the potential risk that microplastics may pose to both humans and the surrounding ecosystem (*Kedzierski et al.,* 2020; *Jin et al.,* 2021; *Koelmans et al.,* 2022; *Patil et al.,* 2022).

The term "microplastics" attained eminence during the beginning of the 21st century, as researchers commenced comprehending the magnitude of plastic contamination within the ecological milieu (*Moore et al.,* 2001; *Thompson et al.,* 2004). The observed phenomenon entailed the progressive fragmentation of plastic objects within marine and aquat-

***Corresponding author:** Branko Velebit, *branko.velebit@inmes.rs*

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ic environments. The initial investigations pertaining to the occurrence of MP in seafood (primarily fish and bivalves) and other marine organisms were documented throughout the 2010s (*Lusher et al.,* 2013; *De Witte et al.,* 2014; *Davidson and Dudas,* 2016; *Li et al.,* 2018; *Slootmaekers et al.,* 2019). These investigations brought attention to the capacity of MP to infiltrate the food chain through ingestion by marine organisms. However, since MP have capacity to be transported through various mechanisms such as wind advection, stormwater runoff, drainage systems and wastewater, they also pose a potential risk of ingestion by terrestrial fauna (*Rillig and Lehmann*, 2020). A number of studies demonstrated the presence of MP in food, such as sugar cane, honey, packaged food and beverages (*Mühlschlegel et al.,* 2017; *Liebezeit and Liebezeit*, 2013; *Oliveri Conti et al.,* 2020; *Karami et al.,* 2018).

2. Occurrence of microplastics in meat

A typical route by which microplastics could enter the meat supply chain is through the utilization of livestock feed. If animals consume contaminated water, feed, or fodder, MP could accumulate in their tissues. Current scientific data on the occurrence of MP in meat are scarce and basically rely on just a dozen or so studies.

Veen et al. (2022) observed that approximately 80% of meat and dairy products derived from farm animals in The Netherlands exhibited the presence of MP. Additionally, it has been postulated by researchers that the potential aetiology could be attributed to the feed of cows and pigs, as evidenced by the presence of plastic in all twelve examined samples of feed pellets and shredded feed. Conversely, no cases of contamination were detected in the freshly procured sustenance. In the subsequent analysis, it was observed that plastic particles were present in seven out of the eight beef samples, whereas five out of the eight pork samples exhibited the presence of at least one variant of plastic. Plastic was detected in 18 out of the 25 milk samples that underwent testing.

Plastic and edible films are integral components in the packaging of meat, as they offer a multitude of advantages that contribute to the preservation of meat products' quality, safety and shelf life. These films serve as a protective barrier, effectively separating the meat from the external environment. By maintaining a controlled atmosphere around the meat, they extend its shelf life. Additionally, they provide protection against physical damage and enhance convenience for both retailers and consumers by offering resealable bags or individually portioned packages. Nevertheless, there are growing concerns that packaging materials have the potential to liberate plastic particles, leading to the subsequent contamination of our food with MP fragments. *Kedzierski et al.* (2020) evaluated migration of plastic particles from extruded polystyrene trays (MP-XPS) used to pack chicken and demonstrated that these type of microplastics are highly adherent to the meat surface, despite the thorough rinsing of the surface of the meat, and are likely to be eaten by consumers. While polystyrene trays are composed of food-grade polystyrene, the presence of MP-XPS on the food surface poses potential concerns due to the toxicity of the microparticles, the possibility of styrene desorption, and the formation of degradation products during the cooking process. Furthermore, some studies have demonstrated that bisphenol A microplastic particles can migrate from the inner layer of plastic packaging into beef and chicken *(Thomson and Grounds,* 2005*; Sajiki et al.,* 2007, *Siddique et al.,* 2021*).* The levels exhibited a range of 4 µg/kg to 10 µg/kg. In a similar vein, *Stojanovic et al*. (2019) conducted an investigation into the levels of bisphenol A present in canned meatballs following the sterilization procedure. The samples were subsequently stored at two distinct temperatures (20 and 40°C) for a duration spanning 15 to 105 days. In their study, the researchers noted a significant increase in the concentration of bisphenol A from 5 to 23.5 µg/kg (at 20°C) and from 20 to 30 µg/kg (at 40°C) during a period of 15 days. Subsequent storage resulted in a gradual and minimal rise in the level of this type of MP.

The recent findings of a study conducted by *Habib et al.* (2022a, 2022b) revealed that plastic cutting boards were identified as the primary origin of polythene microplastic contamination in commercially sold cut meat at both butchers and a supermarket chain in the Middle East. Consequently, these cutting boards serve as a direct contributor to the presence of MP in wastewater. The average size of the microplastic particles found in the raw meat was determined to be 1.2 mm. However, after subsequent heat treatment, the authors observed that the size of these particles decreased due to melting, and this was followed partial recrystallization upon cooling. Washing the meat for a short duration (around 10 seconds) resulted in a negligible reduction in MP contamination. Only when the meat was subjected to a more thorough washing process lasting

3 minutes did a significant decrease in microplastic count to 0.07 MP/g meat occur. The same researchers also demonstrated that the average MP contamination of packed chicken commercially available on the Middle East was 1.19 MP/g, while in fish, the contamination level was 2.60 MP/g. In a study conducted by *Katsara et al*. (2022), it was discovered that low-density polyethylene microplastics (LDPE MPs) were present in bacon, salami and mortadella. The migration of LDPE was seen in the aforementioned samples, commencing after a period of 9 days and persisting throughout the duration of the 28-day investigation. The low-density polyethylene microplastics (LDPE MPs) exhibited migration into the meat samples, even when stored at a temperature of 4°C.

3. Microplastics detection methods

To date, there is a lack of a universally accepted and standardized approach for the sampling, pretreatment, identification and quantification of MP in meat and other food products. This phenomenon results in a lack of coherence in the interpretation and comparison of data derived from different meat products. The second obstacle in accurately measuring the ingestion of MP through dietary intake is in the inherent uncertainty around the levels of MP contamination present in both raw and heat-treated meat. The amounts of MP in meat and meat products are frequently found to be minimal, necessitating laborious pretreatment procedures to isolate the MP. Also, shape and size of MP play critical role in detection. MP particles are often classified as fibres, fragments, pellets, or films. Fibres stand out as the most frequently found and also critical form because they are more easily ingested by humans and animals, retained in their bodies and cause toxic effects at lower doses than spherical particles (*Ziajahromi et al.,* 2017; *Cverenkárová et al*., 2021; *Scopetani et al.,* 2022). Due to their susceptibility to loss during digestion and filtration, fibres necessitate additional precautions for their retrieval from food matrices (*Thiele et al.,* 2019).

Pretreatment of meat and meat products usually includes digestion as a necessary step to remove large amounts of organic impurities from the solid samples. Various digestion processes encompass acid digestion, alkaline digestion, and enzyme digestion. Typically, a mixture consisting of 30% hydrogen peroxide and 65% nitric acid has been employed for the purpose of digesting organic interference. In addition, the digestion of biological tissues usually involves the utilization of nitric acid, perchloric acid, hydrochloric acid, or a combination thereof. Nitric acid (69%) is extensively employed as a reagent in acid digestion processes, particularly in scenarios involving elevated temperatures. Additionally, the process of alkaline digestion is employed to break down more delicate muscle and connective tissues, utilizing a heated solution of 10% potassium hydroxide (KOH) at a temperature of 40°C (*Dowarah et al.,* 2020; *Oliveri Conti et al.,* 2020;). Enzyme digestion is also applicable. Furthermore, the utilization of enzymes, such as proteinase-K, lipase and cellulase, has been employed for the breakdown of organic substances (*Jin et al.,* 2021). This is particularly relevant in cases when the presence of microplastics can be readily destroyed through chemical means.

Fourier transform infrared spectroscopy (FT-IR) and Raman spectroscopy are frequently employed for the identification of MP, i.e., the determination of their chemical composition. The infrared spectrum of the measured microparticles exhibits distinct peaks that correspond to particular chemical bonds. The spectrum that is acquired can be utilized for the purpose of identifying the chemical compositions by means of comparing it with the reference spectrum derived from a library of spectra. *Huang et al.* (2020) employed attenuated total reflection mid-infrared spectroscopy in conjunction with chemometric methodologies to rapidly identify and quantitatively assess the presence of MP (polystyrene and polyvinyl chloride) that were introduced or contaminated within chicken samples. The Raman spectrum is acquired through the collection of scattered light, which is directly correlated to the unique molecular structure and atomic composition of the food samples. In contrast to the FT-IR technique, Raman spectroscopy exhibits superior spatial resolution capabilities, since it can analyze MP greater than 1 μm in size. Nevertheless, Raman spectroscopy is susceptible to interference triggered by fluorescence resulting from interaction between bacteria and MP (*Cverenkárová et al*., 2021; *Jin et al.,* 2021). Raman spectroscopy is more sensitive to nonpolar symmetric bonds than Fourier-transform infrared (FTIR) spectroscopy (*Lenz et al.,* 2015), whereas FTIR is more sensitive to the identification of polar groups.

MP can also be quantified in the environmental samples, albeit with variable success when testing food. Pyrolysis, in conjunction with gas chromatography-mass spectrometry (py-GC-MS), has garnered interest as a quantitative analytical technique for assessing the mass of MP (*Fries et al.,* 2013). While this method is inherently destructive in nature, its efficacy and potential applications have captured the scientific community's attention. The utilization of chemical fingerprints subsequent to pyrolysis enables the concurrent determination of both plastic materials and key additives.

4. Human health risks

Comprehensive understanding of the impact of ingested microplastics on human health remains limited (*Rahman et al.,* 2021; *Brouwer et al.,* 2023). It is established, however, that MP has been detected in the human population. There are primarily two chief mechanisms via which humans might be exposed to MP: inhalation and ingestion. MP are introduced into the human food chain predominantly through the consumption of contaminated food sources, hence posing possible implications for human health (*Patil et al.,* 2022). After entering the gastrointestinal system, over 90% of the total MP (mainly polypropylene, polyethylene terephthalate, and polystyrene) is expelled by defecation (*Schwabl et al.,* 2020). However, the remaining 10% of MP (size < 100 μm) have the potential to be absorbed by enterocytes and a fraction of MP, smaller than 1 μm, translocate to several organs, with the extent of this translocation being influenced by their size and shape (*EFSA*, 2016). The propensity for translocation is contingent upon various parameters, including as the adsorption of particles, the hydrophobicity of the surface, the intercellular space available for particle passage, surface functionalization, and the protein profile (*Peters et al.,* 2022).

Once absorbed by the epithelial cells of the small intestine, MP enter the bloodstream and are easily distributed throughout the body. The liver and gallbladder are primary organs for accumulation but nano-MP can even pass the blood-brain and placental barriers (*Grodzicki et al.,* 2021; *Ragusa et al.,* 2021; *Medley et al.,* 2023). The precise modus operandi by which these entities penetrate the placental barrier remains elusive, concomitant with the yet undetermined ramifications for gestation and embryonic maturation (*Ragusa et al.,* 2021). Clinical manifestations of MP-accumulated organs are primarily driven by generation of reactive oxygen species during the inflammatory response, resulting in the initiation of oxidative stress and subsequent cytotoxic effects (*Patil et al.,* 2022). The symptomatology encompasses carcinogenicity and inflammation in the liver, renal dysfunction and decline due to phthalate accumulation in kidneys, circulatory distress in the heart, thyroid disfunction caused by polybrominated diphenyl ethers, bisphenol A-mediated male infertility and spermatogenesis distress, metabolic disorders and so on (*Lee et al.,* 2023).

5. Conclusion

MP can easily contaminate various environmental compartments, encompassing the entirety of the meat chain. Due to their diminutive size, MP possess a heightened propensity for ingestion, thereby provoking harmful consequences upon the well-being of animals, including humans. While the scientific knowledge pertaining to the prevalence of MP in meat is expanding, lack of standardized methodology and variability in methodological approaches across individual studies necessitates a nuanced evaluation of MP contamination, rendering its interpretation complex and challenging. Furthermore, the correlation between exposure to MP and specific health impacts in humans has not been fully determined. The preliminary findings have substantiated the classification of MP as a growing hazard inside the food chain. Nevertheless, further research should be conducted with the objective of raising the general public's awareness and coming up with strategies for mitigation.

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