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Microplastics as a Threat to Meat Consumption, Review

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A B S T R A C T

The world population increasingly consumes about 300 million tonnes of meat up to 2018. As this trend continues due to the increasing world population, plastic becomes necessary to preserve meat, and to meet the corresponding demands. Plastics were benefits that have turned into an environmental burden in the meat industry. The reason for this, plastics protect meat and other products from spoilage. However, they contain many contaminants in the form of microplastics (MPs) additives and trapped carbons. These contaminants significantly contribute to the health risks caused by meat and other global environmental concerns. A further concern is that consumers may likely not be aware of the safety risks of these MPs and their additives.

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Introduction

Large polymer plastics degrade due to weathering and other environmental impacts such as shearing, attrition, UV-radiation, erosion, chemicals, and burning after their end-use into smaller plastics (Gewert, 2015). These plastics with sizes less than 5mm are microplastics (MPs) according to Kim et al. (2020). Other authors also reported MPs as plastics with particle sizes up to 5mm (Andrady, 2017; GESAMP, 2015; Hartmann et al., 2019). These MPs are found in waterbodies and farmlands (Horton et al., 2017; Xu, 2020). MPs cause several environmental burdens by leaching into the groundwater, affecting plants and humans, and animals ingest them during feeding. Animals such as buffalo, camels, pigs, cows, rabbits, cavia, etc., are processed globally into meat, milk and eggs to meet human nutritional demand (Garnett, 2014; Suman and McMillin, 2014). Meat plays a key role in global food security as livestock contributes 13% to the global energy required from nutrients (Smith et al., 2013). However, the products from these animals are not very safe from MPs contamination as they get into farms through sludge application, plastic soil cover (plastic mulching), compost and bio-waste, tires from busy roads, and stormwater (Cole et al., 2011; Khan and Strand, 2018; Knight et al., 2020). Many other authors have also tried to evaluate the quantity and abundance of these MPs on land, air, and water bodies. They also tried to develop and estimate these MPs' abundance from different global regions as well as MPs' sampling methods, identification, and characterization (Abaroa-Pére et al., 2021; Cole et al., 2011; Fuller and Gautam, 2016; Herath et al., 2022; Pagter et al., 2018; Yu et al., 2018). Furthermore, humans, plants, or animals through adsorption, inhalation, absorption, ingestion, migration, and leaching consume these MPs before they find their ways back into the environment in an endless cycle (Domenech and Marcos, 2021; Ivar do Sul and Costa, 2014). Figure 1 is a summary figure, which describes MPs' path into the meat. This also shows a partial 'microplastic-meat-environment' relationship (MME). This relationship highlights how MPs get into the meat consumed via animals, crops, and human activities before going into MP forms.

Plastic packages in the meat industry

Meat consumption as of 2018 has increased globally by above 300 million tonnes on average. Meat is a source of essential nutrients and a nutritional alternative for non-vegetarians (Parlasa and Qaim, 2022). As the demand for meat consumption increases, so also the need for reduction in meat spoilage and better packaging materials like plastics.

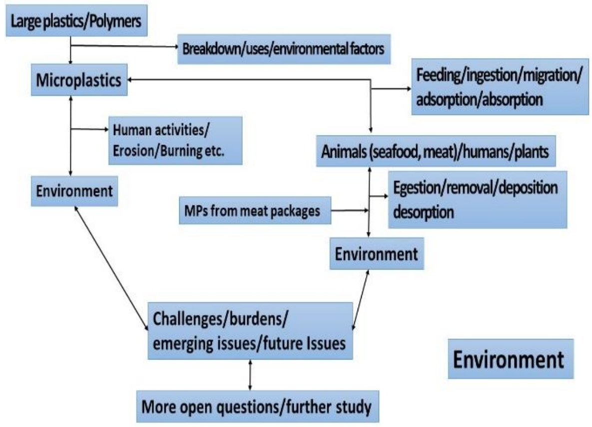

Figure 1. Microplastic paths to meat consumption

Plastics are cheap, easily used to transport meat, extend its shelf life and protect it from environmental impacts (Andrady and Neal, 2009). Plastics are forms of controlled atmosphere for meat by providing protection against moisture, microbial communities, and atmospheric oxygen (Alessandroni et al., 2022). They protect meat and meat products from becoming waste and consequently prevent greenhouse gases that would arise from this waste (Billiet and Trenor, 2020). However, most meat packaging is from petrochemical, containing additives that are toxic and can leach out of the plastics (Barrick et al., 2021). These plastic packages can take the desired shape under thermal treatment. They also contain high carbon content. Such include polyvinyl chloride (PVC), polyamide (PA), polyvinylidene chloride polypropylene, and polyethylene (PE) considered for their strength and durability (Guerreiro et al., 2018; Marsh and Bugusu, 2007). Katsara et al. (2022) discussed other properties of why these plastics are in use in the meat industry. However, these plastics are not very environmentally friendly and contain high carbon. Already, around 57% of the total global greenhouse gas (GHG) emissions are from meat products as of 2010 (Xu et al., 2021). Moreover, it is possible that GHG from plastics to transcend 56000 Mt by 2050 (Shen et al., 2020). Although, concerns are some of the carbons temporarily held by meat plastic packages will escape into the environment if not properly processed at the end of their lifecycle. Already study shows that the more plastics are produced the more significant possibility of an increase in CO_2 emission in the environment (Oktavilia et al., 2020). These are mostly high-volume single-used plastics discarded due to bloodstains and concern about microbial contamination during reuse (Taufik et al., 2020; Nemat et al., 2022). Plastics used for extending bacon shelf life have more carbon trapped in them than regular plastic packaging. They are multilayer plastic packaging that prevents bacon thawing and reliantly provides oxygen and puncture-free requirements during handling and sales. Table 1 shows some meat packaging used in extending its shelf life. It is troubling that most meat producers sacrifice plastic packaging circularity for meat shelf life (Dong et al., 2014; Pauer et al., 2020).

Most plastics used in the meat industry are petrochemical and mostly non-degradable; thus, they have a lasting effect on the environment. Therefore, most consumers and concerned stakeholders are searching more into bio-based plastics for meat packaging to reduce the environmental burden contributed by MPs (Bishop et al., 2021). Bioplastics are environmentally friendly alternatives to petrochemical plastic packaging. However, they have challenges of lesser duration and strength compared the petrochemical plastics. Ruban (2009) reported some of these bioplastics' classifications, their derivation, and their applications. Song et al. (2021) explained the chemistry and production processes of these edible films and their different applications in processing meat. An important note in this review is that plastic films get into the layers of packaged meat in smaller plastic forms or MPs. Although, they have no nutritional purpose and are alien to meat's nutritional composition. Some might not necessarily be toxic but pose a nutritional conflict of interest between consumers and meat producers. Reports and studies show that they are edible, but the concern remains that consumers eat MPs and their derivatives due to standard meat industry practices (Ruban, 2009). Consumers' understanding of bioplastics and their health implications are important while packaging meat with bioplastics. This will reduce the possibility of mishandling these plastics packages during further meat processing such as refrigeration and microwaving which could cause MPs moving into the meat. More so, Puscaselu et al. (2020) believe that edible films are not food and have no nutritional or physicochemical properties that describe them as food even if some industrial standards regard them as food. They are mostly for meat protection even if they are from organic sources (Cenci-Goga et al., 2020).

Researches show that petrochemical plastics pose a health risk. While edible films such as sodium alginate may pose no health risk, consumers of protein polymers may experience allergies (Anderson et al., 1991; Tolouie et al., 2017). Plasticizers are another group of additives that make plastic to be easy to shape. They can migrate into the meat through plastic packaging. Hahladakis et al. (2018) extensively reported more than eight other plasticizers, additives, heavy metals, volatile organic compounds, organic compounds and their migration rate into meat and food items. All these compounds pose a serious threat to meat consumers via packaging. Plasticizers can cause cancer and disrupt the regular function of the body system. Additives or plasticizers, like phthalates, diphthalates, and benzene alcohol from plastics have been found to affect animals' immune systems and cause hormonal imbalance and the possibility of asthma in humans. In addition, the prolonged polyvinyl chloride (PVC) MPs exposure by humans during its use to package meat caused respiratory issues such as breathing difficulty, cough, and asthma (Jaakkola and Knight, 2008).

Microplastic in meats, seafood, and health concerns

Microplastics can get into living animals from the environment and their derived products during their processing into consumable meat products via plastic packages. Katsara et al. (2022) found LDPE MPs in bacon, salami, and mortadella. LDPE in these samples via migration appeared after 9 days and continued until their 28 days study. These LDPE MPs migrated into the meat samples even at 4°C. Polystyrene from 6.4 µm-104 µm has been found to leach out of meat trays and other food containers made with PS (Ajaj et al., 2021).

Table1. The effects of plastic packaging on meat

Packaging	Meat	Effects	References
PVC	Cured meat	Extend shelf life	Marsh and Bugusu (2017)
Low-density polyethylene (LDPE) coated with bacteriocin	Oyster, Beef	Shelf-life extension up to approximately two weeks. Reduce microbial loads	Kim et al. (2002)
Polylactic acid	Pork	Reduced L. monocytogenes by almost 29% for about 12 days	Yang and Song (2016)
Polybutylene succinate	Chicken	Microbial reduction, Colour stability	Yusof et al. (2021)
Etin-vinyl-acetate, PE bags	Goat	Tenderness, pH and redness preservation, microbial preservation	Fernandes et al. (2013), Sabow et al. (2016)
PE, LDPE	Bacon, Salami, Mortadella	Extend shelf life	Katsara et al. (2022)

Table 2. The effect of plastic packages on the environment

Plastics packages	Microplastic contaminants	Environmental Impact	References
Conventional/Petroleum-based (Meat packaging)	Phthalic Anhydride, Stearamide, Diisooctyl phthalate, Polyethylene glycol, PVC, etc.	Persistent, GHG emission, toxic, aquatic biodiversification depletion and death, etc.	Guerreiro et al. (2018); Bishop et al. (2021)
Biobase/Edible films (Meat packaging)	Sodium alginate, cellulose, agars, starch, carrageenan, chitosan, pectin gum, plasticizers, and collagen, etc.	Biodegradable, low toxicity or non-toxic, GHG emission, etc.	Ruban (2009); Puscaselu et al. (2020); Song et al. (2021)
Meat and Non-meat packages (Others)	PS, PP, PE, PET, etc.	Chemical toxicity, carbon emission, gut clogging, digestive stress in the animal, organism weight loss and aquatic, death, etc.	Weis (2020); Ivar do Sul and Costa (2014); Guerreiro et al. (2018)

Polystyrene poses a health risk. Extruded polystyrene MPs fiber of a range of 300–450 µm was found in chicken (Cverenkárová et al., 2021). Similarly, according to Siddique et al. (2021), bisphenol A (BPA) MPs were found to leach into beef and chicken (between 9 µg/kg to 10 µg/kg and, 4 µg/kg respectively). They reported BPA to have migrated from the inner layer of plastic packaging into the meat. Dioctylphthalate and dioctyladipate (from PVC) in the range 0.12 mg/dm^2-4.8 mg/dm^2 after a week were detected in ground meat (Kondyli et al., 1992). Stojanović et al. (2019) also reported beef goulash and meatballs to have contained BPA in the range 3.2-64.8 µgkg^{-1} and 21.3-31.2 µgkg^{-1} respectively. Microplastics also have the tendency of adsorbing other pollutants like polybrominated diphenyl ether (PBDE) thereby increasing their bioaccumulation and toxicity in meat (Brennecke et al., 2016). Sometimes, an extra agent such as pediocin and nisin is added to regular plastic bags for packaging meat. These extra additives added to plastic that industrially contains plasticizers already, pose more health risks. The question of whether such meat should reach consumers is a regulatory issue in different countries (Quintavalla and Vicini, 2002; Ming et al., 1997). As it is of concern, it may have adverse effects like the release of antibiotics and food poisoning in humans. Already these MPs have been found in human feces (50-500 µm) and placenta (5-10 µm) (Ragusa et al., 2021; Cverenkárová et al., 2021). De-la-Torre's (2020) also reported that MPs (<150 µm) can get into the human circulatory system. While MPs of size less than 20µm might get into some other organs causing cytoxicity or inflammation. Polyester, polyurethane, and chlorinated PE (in the range 44.67-210.64µm) were found in the human sputum. While PS, PE, PVC, and PE terephthalate according to Tan et al. (2020) affects the human gastrointestinal system by inhibiting nutrient assimilation. It is worth noting that meat itself carries some potential health risks for humans like obesity and heavy metal accumulation (Grosso et al., 2017; Shaheen et al., 2016). Therefore, MPs' migration into meat may further increase the potential health damage likely caused by meat. These MPs have the possibility of introducing microorganisms into the body and damaging human organs such as the kidney, spleen, intestinal tract, and liver (Katsara, 2022; Wright and Kelly, 2017). They can cause oxidative stress in human cells after exposure (e.g., PE, PS, and other MPs) in the range10 ng/ml - 10 µg/ml (Schirinzi et al., 2017). Wright and Kelly (2017) reported MPs' migratory mechanisms, effects, and environmental supporting factors into the human organs, blood, and body tissues and their role in harboring microbes and their consequential immune system damages. Some of the other food processing factors aiding easy migration of MPs into the meat are the meat fat, temperature, and exposure duration (Ajaj et al., 2021; Katsara et al., 2022; Petersen et al., 2004).

Aside from meats, almost all seafood consumed by every family around the world contains MPs. Mostly these MPs resulted from human activities, which are currently a burden on all life forms. Of these MPs consumed by marine organisms, humans consume about 53,864 of these particles yearly (Nicole, 2021). Microplastic additives contaminate and greatly accumulate in animal body tissues when ingested. Triclosan, nonylphenol in PVC, and phenanthrene affect the feeding pattern, and oxygen intake, and more than 55% death rate in lugworms (Browne et al., 2013). Franceschini et al. (2021) reported that MPs ingestion affects the mortality rate, biodiversity, and feeding pattern of *N. norvegicus.* Microplastic threatens humans via marine bodies. The reason is that, larger fishes ingest more microplastics up to 2.79 mm and some of which end up in humans. Other marine life like *M. edulis*, mussels, *Calonectris leucomelas*, *Puffinus tenuirostris*, *carcinus maenas, Dosidicus gigas,* barnacles, and Holothuria, etc. at certain period ingested MPs as reported in various studies. Microplastics ingested were from high-density polyethylene (HDPE), PVC, polychlorinated biphenyls (PCBs), and polybrominated diphenyl ethers among others. These MPs caused challenges such as feeding and breathing difficulties and eventual death (Ivar do Sul and Costa, 2014). Smith et al. (2018) also elaborated more on these MPs found in the marine environment. Table 2 shows these MPs and their environmental effects. In addition, seafood reared in monitored and controlled farms is not safe from MPs contamination (Feng et al., 2019; Lu et al., 2019). Lv et al. (2020) reported MPs ingestion by Asian swamp eels raised in a controlled environment from fertilizer and animal feed. The death of these organisms means the deposition of their carcasses. Either humans or animals continuing the chain of microplastic environmental threats eat these carcasses.

Consumer Awareness

Consumers' understanding of meat packaging goes a long way in how consumers view meat safety (Liana et al., 2010). Therefore, educating consumers on meat handling and consumption can also help in controlling MPs' intake during meat consumption. Regulations such as the EC 852/2004 in the EU are also in place around the world to mitigate challenges posed by additives and external factors to meat quality. Autio et al. (2018) explained some of these directives in detail. Some of these regulations do not compel meat processors to reveal every packaging material involved in meat production as they are voluntary labeling. This is a moral conflict of interest between producers and consumers. In a study by Mehlenbacher et al. (2011), commercially package raw meat for pets had *Salmonella* contamination without packaging warnings of this possibility. So that consumers can be well informed of processing options to eliminate such food threats. In addition, these labeling packages have bioplastic or recyclable logos on them (Kadellis et al., 2021). Data on the extent of consumer warning about labels on commercial meat packaging about MPs' migration are not available. However, most consumers are concerned more about moral obligations regarding animal welfare and information about the animals such as the meat source and rearing system. Others are concerned about expiration dates, freshness, nutritional attributes, price, and other attributes associated with meat quality (Barone and Aschemann-Witzel, 2022; Bernués et al., 2003; Lagerkvist, 2013). While some consumers of packaged meat do not completely consider the information on meat, packages and some consider them too much information (Stranieri and Banterle, 2015). According to Stranieri and Banterle (2015), of 999 consumers researched, 41%, 18%, and 6/% do not check for traceable labels, origins, and feeding systems of cattle processed into meat respectively. As regards consumers' awareness of edible packaging films, most consumers are not aware of these edible films, their safety risks, benefits, or if they are edible or not (Wan et al., 2006).

Conclusion

There is a moral need to report plastic composition on meat packages in easily understandable language by consumers and not through industry terminologies. If there is a need to process or handle meat with plastics, it is advisable to process lean meat or low-fat meat with plastic packaging to reduce the migratory effects of MPs into such products. Stakeholders should carry out more research on the extent of public awareness available about meat MPs migration. Stakeholders should also research how much of the allowable additives or edible films recommended by regulation, consumers are willing to allow in their diets.

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