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Microplastics in food-grade salt: how bad is the problem?

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Introduction: what are microplastics

Plastic is a very recent phenomenon: bakelite, its predecessor, was invented in 1907. What became a revolutionary material thanks to its robustness, versatility and low price, among many other attributes, has now become a problem for the environment (Frias & Nash 2019). Waste plastic is too stable and does not easily degrade by itself, a process that may even take several centuries. Very few of the plastic items that have ever been manufactured, have by now been recycled by nature.

Plastic waste is one of the major pollutants of the natural environment. It is ubiquitous, abundant, and fast-growing. Microplastics are defined as plastic particles measuring between 1 µm and 5 mm in size, although some authors prefer to consider only those smaller than 1 mm. In the lower range, particles smaller than 1 µm are considered nanoplastics (Frias & Nash 2019). The main types of microplastics are irregular fragments, pellets and threadlike fibers. The sources of these pollutants are diverse (Cole *et al*. 2011, Jiang 2018). Two main categories can be distinguished: primary microplastics, which are defined as those manufactured as such and have not been through a significant transformation yet, versus secondary ones, which are those that result from a degradation process of larger items. An important source of primary microplastics is wastewater, which carries remains of cosmetics and cleaning products (Fendall & Sewell 2009). Similarly, air-blasting cleaning media (e.g. to remove paint and rust) also use microplastic pellets. Other primary sources are industrial processes which use virgin microplastics as a raw or auxiliary material (see figure 1; Lechner *et al*. 2014). Secondary plastics can be formed by exposure to sunlight, water and/or sea salt, degrading larger pieces of debris (Eriksen *et al*. 2014). They can also be found in the wastewater from washing synthetic clothes (Habib *et al*. 1998). Another important source of secondary microplastics in air (and, subsequently, in water runoff) are those resulting from the abrasion of tires on the road and fibers from clothes, sacks, and similar textiles. Plastic debris constitutes 80% of all wastes found today in marine environments (Cole *et al*. 2011). It is estimated that, by 2050, the oceans will harbor more plastic than fish (The Ellen MacArthur Foundation 2016).

Fig. 1: Virgin plastic pellets. The resemblance to salt is striking (Source: Wikimedia Commons)

Microplastics in aquatic environments

Microplastics have been found in many different environments, even in uninhabited areas, such as the Arctic or Antarctica; the summits of mountains or simply in the air (Evangeliou *et al*. 2020, González-Pleter *et al*. 2020). It has even been detected in the human stool or in the placenta (Schwabl *et al.* 2019, Ragusa *et al.* 2021). Water is a medium in which microplastics have most often been detected. Open waters worldwide present an ever-increasing abundance of this pollutant. They can be found in all types of aquatic environments and their soil, from open ocean to coastal waters, sediments, tidal zones, beaches and estuaries, but also in inland waters such as lakes, rivers and reservoirs (Jiang 2018). Even in groundwater (Re 2019).

Although the study of microplastics in marine and other aquatic environments has been ongoing since the late 1980s (Derraik 2002), the research on microplastic in saline habitats did not come off the ground until the later years of second decade of the 21st century (see reference list). In fact, very few studies focus on natural saline systems (Alfonso *et al*. 2020).

One of the main concerns of microplastics in water is how they will affect living organisms, as they degrade very slowly and their manufacturing processes often use potentially toxic chemical additives (Jiang 2018). One of the major threats of microplastics are in fact these additives. Typical hazardous substances found in them are polychlorinated biphenyls (PCB), pesticides (e.g. DDT), polycyclic aromatic hydrocarbons (PAH), and other persistent organic pollutants (POP), all of them well-known for their adverse effect on human and environmental health (Soares *et al.* 2020).

Microplastics as a threat to health

Microplastics can affect the natural environment in various degrees. Animals, mainly fish and birds, ingest them, and suffer the physical blocking of their digestive systems as well as the toxic effect of the additives (see below). Animals can also get entangled in larger plastic items, as is often seen with marine bird, reptile or mammal species (figure 2). On the other hand, drift plastic can also be a transport route for alien (and potentially invasive) species (Derraik 2002).

Fig. 2: Harbor seal (*Phoca vitulina*) with an entangled fish net around its neck (Source: NTB Norway)

Despite these examples, the long-term consequences of the presence of microplastics in the environment are not yet well understood (Burns & Boxall 2018), but there is increasing evidence of its presence and effect on human health. The main pathway of microplastics into the human body is ingestion of water or food contaminated with them. The best studied examples are tap or mineral water, fish and seafood, honey, beer and salt (e.g. Kosuth *et a*l. 2018, Zhang *et al*. 2020). Microplastics can also enter the body via inhalation, as they have been found in the air (e.g. Correia Prata 2018).

The presence of microplastics in food reduces its nutritional value, as microplastics may prevent proper digestion of nutrients. Once inside, microplastics have the capacity to translocate through the circulatory and lymphatic systems, thereby accessing virtually any part of the body. In addition, they cause oxidative stress and, consequently, inflammation of the tissues. Also, the immune system becomes less capable of removing synthetic substances (Prata *et al.* 2020). According to the type of material, the polymers can have different specific health outcomes on humans. Considering the most common materials in salt packaging, polyethylene (PE) has hormone disrupting effects. On the other hand, polypropylene (PP) causes damage to liver and brain functions as well as changes insulin resistance. Lastly, polyethylene terephthalate (PET) causes eye and respiratory irritation and is a carcinogenic substance (Smith *et al*. 2018).

Fig. 3: Plastic debris comes in all sorts and sizes, making it extremely difficult to eliminate from the environment

Since the microplastics ingested are of diverse origin and type (figure 3), they may show not only adverse but also synergic effects between them and with other potentially toxic substances from other sources (e.g. hydrocarbons, heavy metals), thereby increasing the negative health outcomes. They can even inhibit the action of medicines (Peixoto *et al.* 2019). Having said this, it has been shown that humans excrete 90% of ingested microplastics via feces (Wright & Kelly 2017). Therefore, the health effects of microplastics in the human body are not yet fully understood and require further research (Galloway 2015, Sivagami *et al.* 2021). One of the main challenges of salts containing microplastics is the difficulty in removing them during the production process (Zhang *et al*. 2020). Whereas this is relatively easy to do in the case of other food and drinking items, the salt making process has a variety of challenges that need to be addressed. As a possible solution, filtration of brine or seawater prior to entering saltworks has been proposed, as a cost effective strategy (Seth & Shriwastav 2018). As will be seen below, the problem of microplastics entering saltworks seems more complex and challenging.

Microplastics in salinas: a vulnerable activity

Salinas are a special type of aquatic environments in which salt is being obtained, usually by evaporating the water in which it is dissolved. In figure 4, a summary of natural sources of salt and salt making processes can be seen. For the record, rock salt (non-aquatic by definition) is also included. In this specific case, salt may be produced by classical mining techniques, that blast the rock and facilitate collection and grinding. Salt is then refined, that is, washed, to obtain a higher quality product. Rock salt can also be dissolved and then evaporated, either by vacuum techniques or by solar evaporation. In both cases it is also refined afterwards. In all other situations (lake, well and sea) the salt is already dissolved in water and needs to be recrystallized, usually by solar evaporation. Other methods exist, such as seething (a form of forced evaporation by adding an artificial source of heat underneath large pans, filled with brine and letting it seethe in them) or graduation (i.e. evaporation by the wind, which is only used to concentrate brine but not crystallize the salt). The latter two are not so common as solar evaporation, but from the point of view of microplastics present similar challenges. Other minor methods exist, like washing the ashes of burnt halophytes or filtrating salt-laden sands, but these are very marginal (Hueso Kortekaas 2019).

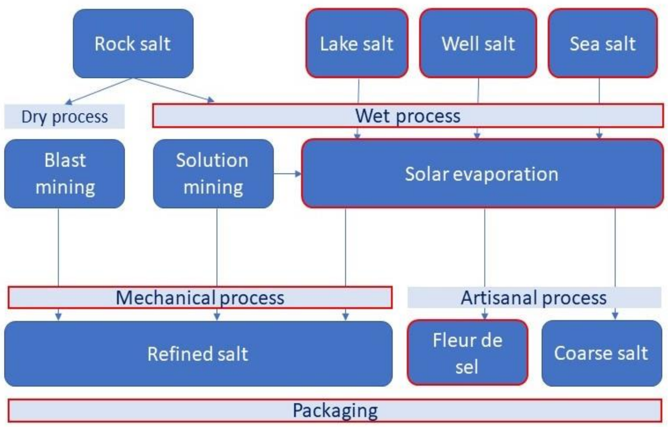

Fig. 4: Types of salt according to source and type of process. With red contour, parts of the salt making process more vulnerable to plastics pollution (Source: own elaboration)

In figure 4, the most vulnerable stages of the salt making process are indicated in red. Soils are important sinks of plastic pollution, that reach both surface as groundwater via runoff and seepage. In the case of wells, the process of pollution is more complicated: if the life cycle -from runoff to seepage- of the groundwater is short (weeks to months), the chances are higher than wells with long replenishment cycles. Microplastics in open waters such as lakes can also be brought by air currents and deposition.

Wet processes, that is, those in which there is presence of water (solar evaporation, solution mining), the presence of microplastics in water may be a threat. In solar evaporation, whatever the source of the brine is, exposure to the wind may also increase chances of airborne plastic pollution.

Once harvested, the mechanical processing of salt usually involves washing, in which case there is a risk of exposure to plastics in the water. Also, transportation of salt within the premises of the salt making site usually involves throughs, conveyor belts and other mechanical devices, often made of rubber or with plastic coatings. Material decay of these devices may cause contamination of the salt. Refined salt is, in theory, more prone to being polluted than artisanal salt. However, fleur de sel -an unrefined type of salt that is typically produced on the surface of the crystallizers- is, on the other hand, most exposed to airborne plastic pollution, as well as capturing floating particles. Also, its flat shape (as occurs with other gourmet salts such as scales) allows to trap more particles. In addition, open air storage of salt (figure 5), very common in solar evaporation salinas, is also a risk of capturing airborne microplastics.

Fig. 5: Some salt mounds are too large to store indoors

Naturally, packaging of salt is a potential source of contamination (figure 6), depending on how it is being done (mechanically or by hand) and, most importantly, what type of material is chosen to be in direct contact with the salt. Being a hygroscopic and corrosive material, this limits the choice of materials for packaging. Paper, cardboard and metals are generally ruled out, leaving the most obvious choice to plastic. Even artisanal salt, usually presented in sleek glass, cardboard or even cork packaging often have part of the it made of plastic. The handling and storage of packaged salt is also relevant: fresh packaged salt will have less risk of pollution than salt that has rested for months or years in its package. The salt itself has not expiry date and will not degrade, but so does the material around it.

In summary, figure 4 shows how, for one reason or the other, all types of salt are vulnerable to plastic pollution, due to a combination of the origin of the salt, the type of processing and the location (most often outdoors) and the packaging.

Fig. 6: Packaged salt usually comes in plastic, thereby risking pollution form the material (Photo: KHueso/IPAISAL)

Microplastics in food grade salt: some findings

This contribution looks at a set of studies on microplastics in food grade salt. Microplastics have been found in most of the samples obtained: up to 94% in Lee *et al*. 2019 and 98.5% in a review by Peixoto *et al*. 2019, in more than 100 commercial brands (Zhang *et al.* 2020). The majority of the studies reviewed here have searched for microplastics in commercial table salts that are already packaged, coming from a large diversity of sources and locations (e.g. Yang *et al.* 2015, Iñiguez *et al.* 2017, Karami *et al.* 2017, Gündoğlu 2018, Kim *et al*. 2018, Kosuth *et al*. 2018, Renzi & Blašković 2018, Seth & Shriwastav 2018, Fischer *et al.* 2019, Peixoto *et al.* 2019, Renzi *et al*. 2019, Narmatha Satish *et al.* 2020, Sivagami *et al*. 2021).

Some studies distinguished between low-end and high-end salts, finding no apparent correlation between the scale of production and the amount of microplastics (Renzi & Blašković 2018, Fischer *et al.* 2019, Renzi *et al.* 2019, Soares *et al*. 2020). However, *fleur de sel* type salts (figure 7) were more polluted than coarse salts, when these were compared at site level (Fischer *et al.* 2019, Soares *et al*. 2020).

Fig. 7: Artisanal salt maker collecting *fleur de sel.* Note he could be shedding fibers while harvesting the salt.

While the majority of the samples across the world were from sea salt, some studies included rock and well salt (Yang *et al.* 2015, Iñiguez *et al.* 2017, Kim *et al.* 2018, Soares *et al*. 2020, Zhang *et al*. 2020). In general, the amount of microplastics was lower in the latter, but not inexistent (see Table 1).

Identifying the type of microplastics was mostly done by Micro Fourier Transform Infrared Spectroscopy (µFTIR) or FTIR, depending on the size of the particles analyzed, which allowed to identify the predominant polymers. Quantification of the abundance of microplastics was also tried in most studies, mainly by filtrating the samples and visual observation. Most abundant were three polymer types: polyethylene terephthalate (PET), polypropylene (PP) and polyethylene (PE), not surprisingly, very common packaging materials. Other polymers found more rarely were teflon, cellophane, polyamide (PA), polystyrene (PS), polyvinyl chloride (PVC) and polyarylether (PAR), depending on the location (Yang *et al*. 2015, Iñiguez *et al*. 2017, Karami *et al.* 2017, Gündoğlu 2018, Kim *et al*. 2018, Kosuth *et al*. 2018, Fischer *et al.* 2019, Peixoto *et al*. 2019, Renzi *et al.* 2019). The proportions of these polymers varied according to the source of the salt (Kim *et al*. 2018). This variability also point at the difficulties interpreting the origin of the plastic pollution.

Table 1 results from a review of data from different studies. The average concentration of microplastic particles per kilogram of salt is shown, for salts being produced in coastal, lakeshore and inland salinas, the latter including both rock salt mines and brine wells. Please note that the concentration is expressed in qualitative terms, that is, in number of particles per kilogram, which still does not indicate the amount of microplastics in quantitative terms (be it volume or weight).

Considering that the average human intake of salt is ca. 10.06 g/day[1] (Powles 2013) and a global average of 506 MPs/Kg of salt (Kim *et al.* 2018), each person ingests 1,857 MPs per year, although this figure is of course highly variable. Table 1 also shows the average composition of microplastics according to the source, with slight variations among the most predominant polymers.

Table 1: Concentration of microplastics in particles per kilogram (MPs/kg) in different sources of salt

Source	Concentation[1]	Average composition[2]
Sea	0-1674 MPs/kg	PE 35% / PP 30% / PET 30%
Lake	8-462 MPs/kg	PE 48% / PP 28% / PET 11%
Inland	0-204 MPs/kg	PE 41% / PP 26% / PET 23%

Sources: [1]Danopoulos *et al.* 2020, [2]Kim *et al.* 2018 (predominant polymers)

From the point of view of shape, the three predominant types are fragments, fibers and films, with variable proportions depending on the location. Other, non-synthetic, particles found are cellulose and cotton (Renzi *et al*. 2019, Selvam *et al.* 2020). Typical colors detected were transparent, blue and black (Soares *et al*. 2020). The size of the particles ranged from 10 µm to 5 mm (Barboza *et al.* 2018). A study in the saltworks of Tuticorin (Tamil Nadu, India), using Scanning Electron Microscope (SEM), also found non naturally occurring elements such as iron (Fe), nickel (Ni) and arsenic (As) adhered to the microplastics, thereby indicating other sources of environmental pollution in the seawater, such as industrial and urban sewage, fly ash from a nearby thermal power plant and a refinery in the area (Narmatha Satish *et al.* 2019).

[1] This figure considers both table salt as salt processed in food, as it is obtained by looking at sodium concentration in urine. This value is well above the recommendation of the WHO, which is 5 g/day.

Future research needs

Following the review of the studies on microplastics in salt, there are several aspects that need further attention by research, which are highlighted and briefly explained below:

• In the studies reviewed here, it is often unknown whether the microplastics come from the environment (water, air), from the salt making and refining process (infrastructures, devices) or the packaging itself (materials), although there seems to be a correlation between the levels of pollution at the source and the amount of microplastics found in salt, at least in coastal salinas (Kim *et al.* 2018). However, detailed knowledge of the salt making process and the materials that are being used in the different stages, including the packaging, is deemed paramount to determine the potential sources of pollution.

• Another important factor is the type, size, shape and color of the microplastics, which is very variable and may affect the outcomes of their quantification and identification efforts across different studies. Given the facts that these microplastics are of very diverse origin and even source (primary vs. secondary), have been subject to different environmental conditions and during different lengths of time, it is very challenging to have a precise idea of the amount of microplastics (in terms of density) found in salt (Lee *et al*. 2021).

• The effects of microplastics on human health are diverse and adverse; however, the role of the size of the particles, their toxicity and the pathway of entrance to the body are very relevant. It is also unknown how the combination of salt and substances found in microplastics may enhance or otherwise affect the health outcome. Further research into these aspects is needed.

• Very few studies have focused on inland salinas (Iñiguez *et al.* 2017), which typically are less exposed to plastic pollution, whether from the source of the brine as from the salt making process. The analysis of sources of plastic pollution in brine wells, requires an understating of groundwater hydrodynamics, as the salt itself is free from them. Underground salt deposits typically are millions of years old and protected by the soil and rock layers on top, hence plastic-free. Wells are replenished by seepage of runoff and groundwater flows and life cycles of groundwater can run from weeks to centuries, as said earlier and can follow complex routes across different soil and rock layers before surfacing. Therefore, there is considerable room for research to be done in the field of groundwater pollution risk by microplastics. Abandoned inland salinas (figure 8) can also give interesting clues as to the pathways of microplastics, given their remoteness, isolation and low predominance of plastic during their activity in the past.

Fig. 8: Could abandoned salinas provide insight into the pathways of microplastic pollution? (Photo: KHueso/IPAISAL)

• Most authors stress the importance on finding strategies to prevent microplastic pollution in salt and understand the difficulty of removing these particles from the source, especially seawater. To do that, it is essential to understand the pathways by which microplastics access salinas. Again, further research is needed to prevent microplastic pollution at the different stages of the process.

In conclusion, microplastics in salt is a concerning global environmental and public health issue that requires further research into a number of aspects. It is necessary to pinpoint the pathways of pollution (air and water), the natural sources of salt and brine (sea, lake, well, rock), the types of salt (refined, unrefined), and the stages of the salt making process that are most vulnerable to microplastics.

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