From the ocean to jellies forth and back? Microplastics along the commercial life cycle of red algae

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Abstract

Red algae are increasingly exploited for direct consumption and for production of gelling agents like agar and carrageenan, widely employed in food and personal care products. In this article we identify knowledge gaps about microplastics in the whole commercial life cycle of gelling red algae, from their marine production to the final wastewater treatment. Recommendations for new research include studies of microplastics deposition on red algae at sea, during the industrial process of production of gelling agents, and indeed about improvements of microplastics retention in wastewater treatment plants.

INTRODUCTION

Marine litter studies have been on the rise for the last decades, being microplastics (MP) an emerging focus. That is because MPs act like vectors for toxic compounds such as Bisphenol A (Rochester, 2013), an endocrine disruptor, and heavy metals (Brennecke et al., 2016; Bradney et al., 2019; Pachana et al., 2010). These toxics can cause several diseases to marine fauna and finally to the human consumer (Andrady, 2011; Cole et al., 2011; Brennecke et al., 2016). MPs are the most abundant litter particles in the seas (Galgani et al., 2015; Barcelo and Pico, 2020). This is due to the continuous degradation of bigger plastic elements (like fishing nets and strains, see Figure 1) that form secondary MP (Cole et al., 2011; Carbery et al., 2018; Setälä et al., & Cole, 2018), and also to the release of primary MP in cosmetics and industrial products (Lei et al., 2017; Zhou et al., 2020). Primary release MP are incorporated in the product during the industrial process, as in personal care products, detergents, paints, abrasives, agriculture and others (European Commission (DG Environment) intentionally added microplastics in products. https://ec.europa.eu/environment/chemicals/reach/pdf/39168%20Intentionally%20added%20microplastics%20-%20Final%20report%2020171020.pdf). MPs, whose largest length is 5 mm (Arthur et al*.,* 2009), are found floating in the water column (Lavender & Thompson, 2014), deposited on the bottom (e.g. Pabortsava & Lampitt, 2020), and also associated to biota: inside animals (Cole et al., 2014) and attached to the external surfaces of marine plants (Gutow et al., 2016; Goss et al., 2018).

The presence of MP in water and biota leads to their introduction into marine food webs starting in lower levels (Setälä et al., 2014; Goss, Jaskiel, & Rotjan, 2018) and then arriving at higher levels by trophic transfer (Farrell & Nelson, 2013; Carbery, Connor, & Thavamani, 2018; Nelms et al., 2018; Zhang et al., 2019). Since MPs are not absorbed in the intestinal tract in significant quantities, they do not accumulate in animal organs and tissues (Akoueson et al., 2020); thus the trophic transfer depends on the MPs ingested by the prey at the time of predation (Priscilla, Sedayu, & Patria, 2019), and MP concentration in higher trophic levels may be diluted. For this reason, although significant MPs ingestion has been demonstrated from their presence in faeces (Schwabl et al., 2019), the risk of human consumption of MP via marine animals is debatable, especially from large fish where muscle is the main edible tissue. In contrast, ingestion of primary producers (algae) implies the ingestion of MP deposited on or adhered to their surface, which may pose a risk to the human consumer (Carbery, O'Connor, & Palanisami, 2018; Waring, Harris, & Mitchell, 2018). Many studies have been published related to MPs in the marine environment and trophic transfer in animals (e.g. Farrell & Nelson, 2013; Chagnon et al., 2018). However, some marine species that are highly consumed by humans have not yet received much attention regarding the risk of MP transfer to humans: red algae.

Figure 1: Macroplastic (Right) and Microplastic (Left) found in El Arañón and Zeluán beaches respectively (Ría de Avilés, Asturias, Northern Spain). Photographs taken by D. Menéndez.

Red algae and their gelling agents

Red algae (Rhodophyta Wettstein, 1901) is an algal division mainly comprised by macroalgae (Díaz González et al., 2004). They are highly consumed worldwide due to their nutritional benefits (Kumar et al., 2008). According to Díaz González et al. (2004), the genus *Porphyra* is the most important because its species are widely cultivated for food production: Nori in Japan, Purple Laver in Wales. *Palmaria palmata* is also intensely cultivated for its antioxidant benefits (Yuan, Bone, & Carrington, 2005; Yuan, Carrington & Walsh, 2005).

Other red algae of high interest for humans are gelling agents' producers: agarophytes and carrageenaphytes (http://www.fao.org/3/y4765e/y4765e04.htm#bm04.3). Agar and Carrageenan, respectively, are the gelling agents extracted from them (Usov, 1998). These compounds are sulphated polysaccharides present in the cell wall, where they represent 15%-30% of dry weight in Agar producers and 30%-80% in carrageenan producers (Rioux & Turgeon, 2015). Agar is principally extracted from the following species: *Gelidium sesquipedale, Gracilaria* (*G. gracilis, G. dura* and *G. bursa-pastoris*)*, Gelidiella acerosa, Pterocladia capillacea* and *Anhfeltia plicata* (Salt, 1976; Prasad et al., 2007; Lee et al., 2017; Titlyanov et al., 2017; Lebbar et al., 2018;) and carrageen from *Chondrus crispus, Mastocarpus stellatus, Kappaphycus alvarezii, Gigartina* (*G. decipiens, G. skottsbergii* and *G. stellate), Sarcothalia crispate* and *Eucheuma striatum* (Craigie, 1978; Epifanio et al., 1981; Díaz González et al., 2004; Tasende et al., 2013; Hughes et al., 2018).

Gelling agents are commonly used in research (functional biology, pharmaceutics, molecular biology…) (Bhattacharya, Dey & Bhattacharyya, 1994; Shilpa et al., 2011) and in cosmetics and food industry (Aliste et al., 2000; Joshi et al., 2018). Moreover, algal gelling agents are a perfect substitute for animal gelatine. Both Agar (E-406) and Carrageenan (E-407) are commonly used as food additives due to their gelling, thickening and nutritional properties (Rioux & Turgeon, 2015; Cunha & Grenha, 2016; Lee et al., 2017). Seaweed species are harvested to elaborate vegan, vegetarian and religion-friendly products (e.g. halal, kosher), and to reduce animal exploitation. The industry of gelling red algae products is estimated to produce more than 370 million dollars in benefits according to FAO (http://www.fao.org/3/y5600s/y5600s07.htm). Due to their wide use, it is important to know their role in the transfer of hazardous elements like MP from the ocean to consumers.

MP and red algae, what do we know?

Figure 2 represents the cycle of red algae where MP can be transported. The cycle starts with the adhesion of MP to the algal surface (step 1), which, although not much studied yet, has been demonstrated *in Fucus vesiculosus* (Gutow et al., 2016*), Pyropia* sp. (Li et al., 2020*), Endocladia muricata* (Saley et al., 2019) and others. Then the algae production (step 2) will introduce more MP because nets, boxes and other tools employed to cultivate or harvest red algae are made of different types of plastic (Li et al., 2016; Simeonova & Chururkova, 2020). Red algae can be directly consumed – sold fresh or dry for human consumption, so humans will directly ingest MP carried by them. Alternatively, they can be industrially processed (step 3) to extract the gelling compounds and use them in different fields (cosmetics, food). Those compounds will contain the MP carried by red algae, and others may be added purposely (primary MP), for example in cosmetics like tooth paste and scrubs (Napper et al., 2015; Duis & Coors, 2016; Anagnosti et al., 2021). Finally, either consumed directly or as part of gelling industry, MP contained in red algae will be part of wastes/debris present in wastewater to be treated in Wastewater Treatment Plants (WWTP). Hospido et al. (2004) call WWTP "ecological treatment systems" where pollutants are removed from water before it is returned to the environment. Although their efficiency of MP retention can be up to 90% or even higher, a part of them escapes their retention systems (Murphy et al., 2016; Masiá et al., 2020), and will return to the sea (step 4).

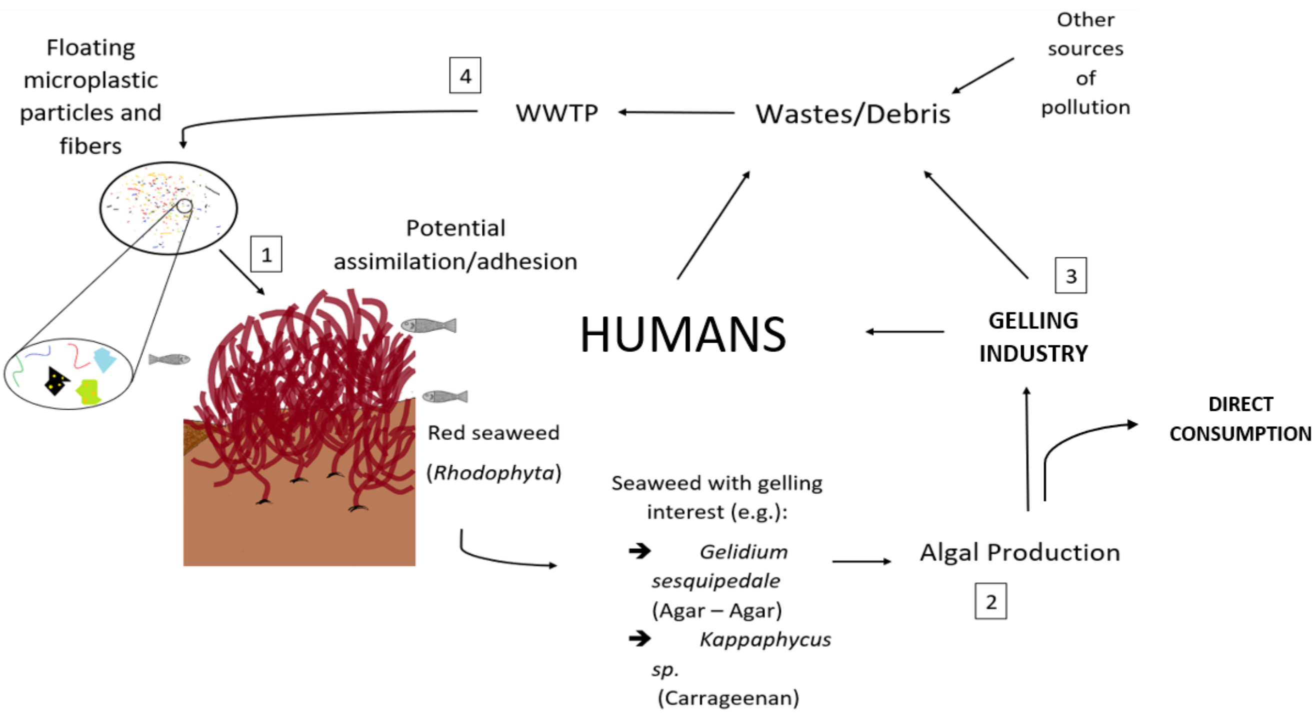

Figure 2: The MPs cycle through red algae used by humans. Steps *1, 2, 3* and *4* are critical for MP increase or retention.

Here we consider only the regular, legal cycle; in addition, we could add those industrial and household wastes that are irregularly treated, directly dumped, or accidentally deposited in rivers and seas. These have been estimated to be the majority of wastewater volumes in some regions (https://www.unwater.org/water-facts/quality-and-wastewater-2/)

MP and red algae, what do not we know?

The first gap of knowledge in step 1 (Figure 2) is the lack of information of MP content in many species of red algae exploited for direct human consumption and for gelling compounds. Due to their use in food and cosmetic industry (Duis and Coors, 2016; Welden & Cowie, 2017) their study from the point of view of MP contents is considered essential (Guerranti et al., 2019). However, according to Li et al. (2020), very few studies have been published to evaluate how MPs affect macroalgae and how those MPs are transferred to the food web. Studies reporting MP on red algae at sea are limited to a few edible species such as *Porphyra* sp. (Li et al., 2020). Many more studies are needed about MP content in red algae, especially in important genera such as *Gelidium, Gracilaria, Kappaphycus*, *Euchema* and others.

The second knowledge gap occurs in Step 2 (Figure 2). The MPs produced during the extraction of red algae (and in general of seaweed) are still not well known. Plastic nets and protection gloves (made of neoprene) are commonly used in fishing and aquaculture industry to manipulate all products, and are considered sources of MP (Montarsolo et al., 2018). Elements used in red algae harvesting and handling processes could be considered MP pollution sources, but currently there is another lack of information here (Duis & Coors, 2016).

In step 3 (Figure 2) there is another gap. Although gelling products are widely used, MPs non-intentionally introduced during their industrial life cycle have not been considered yet. For example, air floating MP are a pollution source in all environments (Gasperi et al., 2015; Gasperi et al., 2018), and is logically expected to occur in the industry of gelling products. It is difficult in the industrial environment to avoid this pollution due to the current great dependence on plastic. Also, post-industrial processes such as packaging in plastic bags can be considered as a MP source (Wagner, 2017; Gerritse et al., 2020). Moreover, although products with primary MP have been thoroughly studied (e.g. Leslie, 2014; Duis and Coors, 2016; Guerranti et al., 2019), Agar and Carrageenan have yet to be examined as potential sources of MP in human diet to date.

Knowledge gaps about MPs, summarized in Table 1, occur at the WWTP level too (step 4 in Figure 2). Indeed, these gaps are not specific of MP derived from red algae but general and can be applied to all MPs. As explained above and in other studies (Ziajahromi, Neale, & Leusch, 2016; Edo et al., 2020), the improvement of WWTP systems for MP retention is needed to ensure they do not enter into running waters and arrive in the sea.

Table 1: Summary of needs and gaps in the cycle of gelling agents' producers. WWTPs: wastewater treatment plants.

	STEP 1	**STEP 2**	**STEP 3**	**STEP 4**
What do we know	Microplastics are commonly adhered to algal surfaces.	Plastic gear may add microplastics to the production chain in fishing and aquaculture.	Gelling agents can contain microplastics due to industrial handling and processing.	WWTPs are sources of microplastics because they are not specifically prepared to retain them.
What we have to focus on	Algae producing gelling agents are widely exploited but are not studied as microplastic vectors.	Microplastic input during algae harvesting and handling is not well known.	All steps in the industrial processing of algae, from microplastics in the air to the packaging of the final product.	The improvement of microplastics retention systems in WWTPs.

Conclusions and recommendations

Red algae production is in great demand because their derived products are widely employed in daily life. Here we have detected knowledge gaps in several steps of the life cycle of commercial red algae regarding their content of MP, from primary production to the treatment of final wastes. Recommendations for future studies begin with the analysis of MP deposition on or adherence to all exploited species of red algae. Subsequent studies could address their industrial handling during harvesting and aquaculture, as well as the sources of contamination in the process of obtaining agar and carrageenan. The amount of MP in agar and carrageenan should be analysed given their wide use in food products. Finally, WWTPs should continue to be studied in order to improve their efficiency of MP retention systems.

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