Omega-3 polyunsaturated fatty acids:
Essential nutrients in high demand whose production will now go circular

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The regular assumption of essential nutrients omega-3 long chain polyunsaturated fatty acids (PUFA) abundant in oily fish is critical for both physical and mental health of both adults and children (1). Health authorities recommend healthy adults to increase their intake of omega-3 fats by regularly eating fish twice a week or, in case of lack of regular consumption of fish, by assuming a 2 g fish oil supplement several times a week. Depending on the position of the first double bond from the methyl end group (ω end) of the fatty acid, the main long-chain PUFA belong to ω-6 or to ω-3 families. In order to reestablish a better balance between ω-3 and ω-6 fats, the WHO recommends a daily intake of eicosapentaenoic acid (EPA, 20:5 ω-3) plus docosahexaenoic acid (DHA, 22:5 ω-3) of 250 mg in primary prevention of coronary heart disease and 2 g in secondary prevention. The European Food Safety Authority recommends daily intake of 250 mg for EPA plus DHA.

Accordingly, fish oil is the most popular dietary supplement in numerous countries. In 2016, consumers across the world spent $31 billion on products with added EPA and DHA (2). In that year, the global EPA/DHA ingredient volume reached 91,321 tonnes. Historically, most of the oil used to produce dietary supplements originated from Peruvian anchovies, even though today a numer of other fish species and even *krill* small crustaceans are used as a source of omega-3 nutrients for use in food and dietary supplement products.

With a daily dosage of 250 mg, about 1,625 t of EPA and DHA would be needed every *day* to meet the global needs for these nutrients. As mentioned above, the current *yearly* production of EPA and DHA enriched oils slightly exceeds 90,000 t. On the other hand, even at these levels,

A FULLY BIOBASED APPROACH TO OMEGA-3 EXTRACTION

Fish oil rich in polyunsaturated omega-3 fatty acids and in health beneficial alpha-tocopherol (Vitamin E) can now be extracted in high yield from anchovy filleting waste using *d*-limonene as green biosolvent (Figure 1) (4). Being the main component of orange essential oil widely used in the food industry, limonene (5) is also a safe food ingredient whose antimicrobial, antifungal, antioxidant, anti-inflammatory and anti-carcinogenic properties make it use ideally suited to produce omega-3 extracts from fish and seafood processing waste.

Figure 1. The anchovy leftover oily extract obtained after evaporating limonene under reduced pressure. (Reproduced from Ref.1, photograph of the Author).

The extraction consists of a simple solid-liquid extraction performed by mechanically stirring and maceration carried out at room temperature, followed by limonene removal via evaporation under reduced pressure.

As limonene is renewably obtained from waste orange peel, this protocol establishes a circular bioeconomy method closing the materials cycle and opening the route to valorisation of an important biological resource so far mostly discarded as waste from biowaste available worldwide in several million t/year amount. First demonstrated with anchovies, *i.e.* the world's largest fish catches, the method can be extended to other fish processing waste, particularly rich in omega-3, such as tuna, salmon, mackerel, herring and cod.

Significant economic, social and environmental opportunities benefiting local communities, the ecosystem and public health are anticipated.

the harvesting of tiny fish for omega-3 supplements is leading to less healthy and bountiful seas (3).

Clearly, a new circular economy approach to omega-3 extraction from marine resources must be developed, closing the current wasteful materials cycle that currently sees a huge amount (several million tonnes per year) of fish and seafood waste such as head, skin, trimmings and bones being discarded in landfills or directly thrown away into the sea (6).

Furthermore, the main extraction process currently employed based on molecular distillation at ultralow pressures and high temperatures needs to be replaced by milder extraction processes based on green solvents, possibly biobased (7).

The few companies which already collect and recycle fish and seafood leftovers, converting them into valued fish oil and fishmeal, such as the German company Lipromar, purchase the by-products from local fish producers and produce fish oil (and functional proteins for human consumption) which is then successfully sold to omega-3 dietary supplement producers.

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