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Advances in Fish Oil Extraction and Encapsulation Techniques: Enhancing Nutritional Value and Stability

Pritha Kumar[1], Sanee Chauhan[2]

[1]Faculty of Fishery Sciences, West Bengal University of Animal and Fishery Science, Kolkata, West Bengal, India – 700094
prithaparul2[at]gmail.com

[2]College of Fisheries, Central Agricultural University (Imphal), Lembucherra, Tripura, India -799210
sunny94.chauhan[at]gmail.com

Abstract: ***Fish oil is a highly valued commercial product due to its rich nutritional profile, primarily attributed to long-chain omega-3 fatty acids such as docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA). Despite challenges related to inconsistent production and susceptibility to oxidation, its demand remains strong. To maximize yield and retain its beneficial properties, various extraction methods, including solvent extraction, supercritical fluid extraction, and wet pressing, have been developed. Encapsulation techniques like spray drying, freeze drying, and coacervation have proven effective in improving the stability and shelf life of fish oil by protecting it from oxidation. The selection of coating materials, such as maltodextrin, whey protein, and gum arabic, plays a vital role in ensuring successful encapsulation. Encapsulated fish oil exhibits enhanced nutritional retention and oxidative stability, making it well-suited for use in functional foods and dietary supplements. This paper reviews the advancements in fish oil extraction and encapsulation methods, highlighting their impact on improving the delivery and effectiveness of omega-3 fatty acids in various industries. Further research in this area is essential to continue enhancing the encapsulation processes and expanding the applications of fish oil.***

Keywords: Fish oil, extraction, encapsulation, coating material, stability

1.Introduction

Fish oil, a commercially valuable product, is rich in long-chain omega-3 polyunsaturated fatty acids (PUFAs) such as eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and docosapentaenoic acid (DPA). These PUFAs are widely recognized in the nutritional and medical fields for their therapeutic and preventive benefits. Although fish oil was once considered a mere byproduct of fishmeal used in animal feed, it is now acknowledged as the primary source of these essential fatty acids (Bonilla-Mendez and Hoyos-Concha, 2018). However, due to their high degree of unsaturation, these fatty acids are highly susceptible to oxidation. Autoxidation, which leads to the formation of secondary oxidation products, is the main factor responsible for the deterioration of fish oil quality (Venkateshwarlu *et al*., 2004). Therefore, preventing oxidation in fish oil-enriched foods is crucial to maintaining its nutritional integrity.

According to Schrooyen *et al*. (2001) and Pegg and Shahidi (2007), encapsulation is one of the proven technologies for preserving bioactive ingredients and producing distinctive food compositions with improved quality. The process of encasing or covering one material or a combination of components inside a different material or system is known as encapsulation. The ultimate goal of the encapsulation process to increase the shelf life of the product and also to improve its consumer acceptability (Dziubla *et al.,* 2008). Encapsulating fish oil into a dry powder enhances its efficiency and stability. The protective wall materials of microcapsules safeguard the core substance from environmental factors such as light, moisture, and oxygen, thereby improving the oil's stability. Various encapsulation techniques, including fluidized bed drying, freeze drying, and spray drying, can be used for this purpose (Assadpour and Jafari, 2019). Among these methods, spray drying stands out for its ability to process a wide range of coating materials, resulting in stable dried products (Haque *et al*., 2015). Spray drying is an encapsulation technique that is most effective for encapsulating bioactive compounds because of its extensive commercial use and comparatively short drying times (Liu *et al*., 2001).

One of the most important factors taken into account during encapsulation is the coating material. Selecting the right coating materials is essential. It significantly affects the powder's functional performance, including chemical stability, flowability, packing, and encapsulation efficacy (Venugopalan *et al.,* 2021). This paper deals with the significance of oil extracted from fish, the various extraction methods employed to obtain it, and the advanced encapsulation technique used to enhance its stability and effectiveness. The discussion highlights the potential of these methods to improve the delivery of omega-3 fatty acids, ensuring that the health benefits of fish oil are preserved and optimized for consumer use. Further research and development in this field are crucial for advancing the encapsulation processes and expanding the applications of fish oil in various industries.

2.Importance of fish oil

Globally, approximately 1 million tonnes of fish oil are produced, and this trend is expected to continue. Due to its rich content of long-chain omega-3 fatty acids, particularly EPA and DHA, fish oil serves as a valuable supplement for diets deficient in essential fatty acids (Pike and Jackson, 2010). It is highly regarded in the dietary and medical fields for its therapeutic and preventive benefits (Bonilla-Mendez and Hoyos-Concha, 2018). Venugopalan *et al.* (2021)

highlight that regular consumption of omega-3-rich lipids is associated with various health benefits, including the prevention of inflammation, cardiovascular diseases, arthritis, ulcerative colitis, and diabetes. As a result, omega-3 and omega-6 fish oils are widely used as dietary supplements and in pharmaceutical formulations.

3.Extraction of fish oil

Studies on the extraction and quality assessment of oil from different fish species and processing byproducts have been carried out in a number of ways. These methods include wet pressing, supercritical fluids, fish silage that uses enzymes, and solvent extraction techniques that can be found in fish or other sources. The procedures mainly vary according to the type of solvent and sample treatment used. The most well-known are those of Soxhlet & Bligh-Dyer, although others have also been given consideration, such as those of McGill-Moffatt and Randall and Folch (Rincón-Cervera *et. al.,* 2017).

3.1 Solvent extraction method

a) *Bligh and Dyer method* – The method is based on the formation of a monophasic solvent consisting of chloroform-methanol-water which solubilizes lipids and upon addition of further water separates into a biphasic mixture, with lipids partitioning into the chloroform phase while non-lipid components are retained in the methanol-water phase (Bligh and Dyer, 1959).
b) *Soxhlet method* – The Soxhlet method is based on perpetual hot solvent extraction. The solvent (usually hexane or petroleum ether) goes through continuous circulation through the sample dissolving lipids, while non-lipid components remain behind. Subsequently, enhanced efficiency is accomplished along with guaranteed removal of all lipids (Noor *et al.,* 2024)
c) *Folch method* – Chloroform and methanol is used as solvent. The solubilization of lipids is done using a chloroform-methanol mixture (2: 1, v/v). Upon the addition of water, phase separation occurs, whereby lipids tend to go to the organic phase (chloroform) and the proteins, sugars, and other non-lipid components remain in the aqueous phase (Folch *et al.,* 1957).
d) *Randall method* – The Randall method (1974) is a modification of Soxhlet extraction technique formulated for faster and more efficient lipid extraction from biological samples. It enhances the traditional Soxhlet method by incorporating immersion, rinsing, and evaporation steps, reducing extraction time and solvent consumption. In this method n -hexane is used as solvent.

3.2 Wet pressing method

The three fundamental processes of the fish oil extraction through wet rendering process are heating at high temperatures (85–95 °C), pressing, and centrifugation (Salih *et al.,* 2021). The heat treatment breaks down cellular structures, releasing lipids that are then mechanically separated from solids and water. The extracted oil undergoes further purification to eliminate any remaining moisture and impurities. Abd El-Rahman *et al.* (2018) state that oil obtained through the wet extraction method provides high yields and superior physical and chemical properties, making it suitable for use across various industries.

3.3 Superficial fluid extraction

Supercritical fluids (SCF) are those solvents that, at temperatures and pressures above their critical points, exhibit both liquid and gas-like properties (Anas *et al.,* 2020). Supercritical fluids behave like gases and liquids as they diffuse as a gas and solubilize lipids as a liquid. Hence, SC-CO_2 can selectively dissolve non-polar lipids under controlled temperature and pressure, removing them from the sample without any organic solvent usage. From a stability and safety standpoint, it was found that superficial fluid extraction can be a viable approach among the others because the fish oil it produced had lower levels of arsenic and improved oxidative stability (Anas *et al.,* 2020).

4.Encapsulation

Encapsulation is a technique used to enclose an active agent within a protective wall material. The enclosed substance is known as the core material, while the encasing component may be referred to as the coating material, matrix, carrier material, external phase, or membrane. This method enhances the delivery of bioactive compounds, such as antioxidants, vitamins, minerals, phytosterols, lutein, fatty acids, and lycopene, as well as living organisms like probiotics, into food products (Nedovic *et al.,* 2011).

Microcapsules, varying in size from a few nanometers to several millimeters, are created by encapsulating tiny solid or liquid particles (the core) within a protective layer or wall material (the matrix) (Jeyakumari *et al*., 2016). This is one method of protecting delicate materials and producing active molecules with improved properties. It has proven successful to encapsulate a wide range of active ingredients, including proteins, lipids, vitamins and minerals, enzymes, and flavours. The selection of wall material and manner of microencapsulation procedure is crucial for producing effective encapsulated products, and it also depends on the product's intended purpose and the processing conditions. Depending on the encapsulated substance, microcapsules release their contents at an optimal rate and time through different release mechanisms, enhancing food quality. In the food and pharmaceutical industries, a variety of encapsulation methods are employed, including spray drying, spray chilling, spray cooling, coacervation, fluidized bed coating, rotational suspension separation, liposome entrapment, extrusion, and inclusion complexation (Risch, 2017).

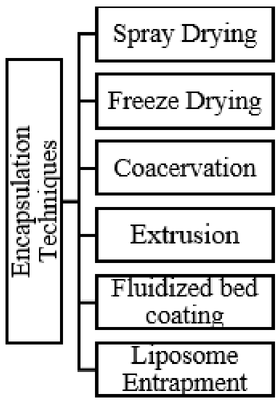

Figure 1: Major encapsulation techniques

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5.Encapsulation of fish oil

Encapsulation remains one of the most widely used techniques for protecting fish oil against oxidation, degradation, and rancid flavors, thereby improving its stability, bioavailability, and shelf life. Polyunsaturated Fatty Acids (PUFAs) have a low water solubility, a susceptibility to oxidise quickly, and a variable bioavailability, making it difficult to fortify food with them. Advanced encapsulation techniques can be used to overcome these difficulties (Venugopalan *et al.,* 2021). Fish oil can be effectively protected against oxidation and have its fishy smell covered up via encapsulation. Linke *et al.,* (2020) stated that by encapsulating droplets of oil in a solid matrix, encapsulation tries to shield polyunsaturated fatty acids from oxidation. The separation of internal oxygen from external oxygen (found in the environment) is made possible by such a mechanism. The external oxygen was the primary determinant of autoxidation, while the internal oxygen was of modest influence. One method for creating fish oil microcapsules is to create an oil-in-water (O/W) emulsion, which is then spray dried (Ramakrishnan *et al.,* 2014).

Norziah *et al.* (2009) used the technique of spray drying fish oil powder and discovered that sufficient spray-dried fish oil powder was obtained by microencapsulating 50% oil loading using a mixture of 25% dextrose equivalent and 10% sodium caseinate. Whey protein isolate and soluble corn fiber were used as coating material for encapsulating fish oil, using spray drying and freeze drying, the spray dried encapsulates show better properties and protection of the core. Fadini *et al.* (2018), studied the application of integrated encapsulation technologies for food safety in fish oil. By using spray drying, the microparticles were initially produced. The resulting microparticles had a strong fish oil flavour but no offensive fragrance, which is probably related to high solubility belonging to the wall components. The challenge was overcome by a second shell created using spray cooling. Charles *et al. (*2021), microencapsulated tuna fish oil with maltodextrin and arrowroot starch using freeze-drying technique. In a study conducted by Debbarma *et al.* (2022), oil was recovered from Basa (*Pangasius bocourti*) fish wastes (bones, head, and viscera) and encapsulated using alginate as a covering material utilising a straightforward extrusion technique.

6.Spray drying for Encapsulation of Fish oil

The food industry has been using spray drying of food emulsions since the late 1950s, and it is a tried-and-true method for producing vast quantities of material. Spray drying is a widely used and highly effective encapsulation technique in both the pharmaceutical and food sectors due to its advantages over other encapsulation methods. It offers a cost-efficient, highly automated process that ensures high-quality output. One of its most notable benefits is its ability to process a diverse range of materials, producing dried powders with precisely defined characteristics (Haque *et al.*, 2015). With its broad commercial application and rapid drying process, spray drying is particularly well-suited for encapsulating bioactive compounds (Liu *et al.,* 2001). Four steps make up encapsulation with spray drying: (1) preparing the emulsion solution; (2) homogenising; (3) atomizing the emulsion through the dryer nozzle; and (4) evaporating the water in the emulsion droplet.

Aghbashlo *et al. (*2013), microencapsulated fish oil by spray drying at different inlet temperature i.e., 140°C, 160°C and 180°C. They found out that as the temperature increased, the encapsulation efficiency and peroxide value of microencapsulates increased, whereas, the bulk density and moisture decreased. Nguyen *et al.* (2017), used spray dryer at different inlet temperature to prepare powder of gum arabic and maltodextrin. They found out that inlet temperature of spray dryer had high effect on the properties of the resultant product and the feed flow rate of spray dryer depended on the ratio of maltodextrin and gum arabic. Geranpour *et al.* (2019), examined the impact of feed pump rate, aspirator rate, and spray dryer inlet temperature on the encapsulation of the pumpkin seed oil. Consequently, the air inlet temperature of 141.51°C, the aspirator rate of 75%, and the feed pump rate of 15% were discovered to be the ideal process conditions for encapsulating pumpkin seed oil.

7.Encapsulation coating materials

Selection of an appropriate coating material is the first stage in encapsulating a dietary ingredient. As stated by Asha *et al., (*2018), three carrier systems have been used for encapsulating peptides and fish oil: lipids, polysaccharides, and proteins. While the lipid-based systems aim to improve the bioavailability and biostability of encapsulated peptides, the polysaccharide and protein systems are primarily focused on masking the bitter taste and reducing the hygroscopicity of the protein hydrolysates. While film hydration is used to create liposomes for lipids, encapsulation is mostly achieved by a spray drying technique for fish oils, proteins, and polysaccharide systems. Venugopalan *et al*. (2021) assert that the fluidity, packing, encapsulation efficiency, and chemical stability of the powder are all significantly influenced by the coating material. The food industry utilizes various coating materials for encapsulation, primarily classified into:

a) Carbohydrates – Examples include maltodextrin, corn syrup solids, sucrose, pectin, modified starch, agar, gum arabic, alginates, carrageenan, and chitosan.
b) Proteins – Common options include whey protein, soy protein, sodium caseinate, gelatin, and skimmed milk powder.

Rusli *et al.* (2006), used whey protein and soy protein isolate along with dried glucose syrup in combination for encapsulating tuna oil. The results of the study showed that whey protein isolate in combination with dried glucose syrup was better than soy protein isolate in combination with dried glucose syrup, in terms of microencapsulation efficiency and oxidative stability of microencapsulates. Bae and Lee (2008), used whey protein isolate only and in combination at different ratio with maltodextrin and found that higher the whey protein isolate smoother and more spherical were encapsulates with higher encapsulation efficiency. Paulo *et al.,* 2021, explored the key variables affecting the oxygen barrier characteristics of spray-dried emulsions based on maltodextrin with various surface-active components (like whey protein isolates). These coating materials were used to encapsulate unsaturated fish oil. The results of this study showed that maltodextrin encapsulates were more prone to oxidation than surface active compounds like whey protein isolates. Antioxidant capacity in the protein matrices was evident and may also help to provide significant levels of protection.

A newly developed wall material that could microencapsulate and prevent the oxidative rancidity in tuna fish oil was examined in comparison to maltodextrin with whey protein (WP) mixtures using arrowroot starch (AS), which was derived out of a tropical plant (*Maranta arundinacea*) (Charles *et al.,* 2021). The outcomes showed that combinations of arrowroot starch and maltodextrin effectively encapsulated the tuna fish oil, enhanced its shelf-life, and exhibited oxidative stability. Additionally, when freeze-drying, arrowroot starch acted as a cryoprotectant.

8.Conclusion

Fish oil is an important commercial product due to its high nutritional value, particularly its rich content of long-chain omega-3 fatty acids such as EPA and DHA, which are known for their preventive and therapeutic benefits against various health conditions including inflammation, cardiovascular disease, and diabetes. Despite its uneven production and rapid oxidation due to unsaturated fatty acids, fish oil's demand remains high. Studies have shown that encapsulated fish oil retains its nutritional value and oxidative stability better than non-encapsulated oil, making it more suitable for inclusion in functional foods and dietary supplements. The choice of coating material and encapsulation method is crucial for achieving the desired stability and bioavailability of the encapsulated product. Further research and development in this field can continue to improve the effectiveness of fish oil encapsulation and its application in various industries.

References

[1] Aghbashlo M, Mobli H, Madadlou A, Rafiee S. Influence of wall material and inlet drying air temperature on the microencapsulation of fish oil by spray drying. Food and Bioprocess Technology.2013 Jun; 6: 1561-9.
[2] Anas KK, RG Kumar L, Tejpal CS, Mathew S. Supercritical fluid extraction of fish oil–recent perspectives. Int. J. Current Micro. App. Sci.2020 9: 730-735.
[3] Asha KK, Chatterjee NS, Lekshmi RGK, Mathew S, Microencapsulation of fish nutrients for high value product development. Retrieved from-ICAR-Central Institute of Fisheries Technology.2018.
[4] Assadpour E, Jafari SM. Advances in spray-drying encapsulation of food bioactive ingredients: From microcapsules to nanocapsules. Annual review of food science and technology.2019 10: pp.103-131.
[5] Bae EK, Lee SJ. Microencapsulation of avocado oil by spray drying using whey protein and maltodextrin. Journal of microencapsulation.2008 Dec 1; 25 (8): 549-60.
[6] Bonilla-Méndez JR, Hoyos-Concha JL. Methods of extraction refining and concentration of fish oil as a source of omega-3 fatty acids. Ciencia y Tecnología Agropecuaria.2018 Dec; 19 (3): 645-68.
[7] Charles AL, Abdillah AA, Saraswati YR, Sridhar K, Balderamos C, Masithah ED, Alamsjah MA. Characterization of freeze-dried microencapsulation tuna fish oil with arrowroot starch and maltodextrin. Food Hydrocolloids.2021 Mar 1; 112: 106281.
[8] Debbarma A, Kumar V, Mishra PK, Kakatkar AS, Gautam RK, Umra F, Chatterjee S. Valorisation of Basa fish (Pangasius bocourti) waste: Oil extraction and encapsulation. International Journal of Food Science and Technology.2023 May; 58 (5): 2764-71.
[9] Dziubla TD, Shuvaev VV, Hong NK, Hawkins BJ, Madesh M, Takano H, Simone E, Nakada MT, Fisher A, Albelda SM, Muzykantov VR. Endothelial targeting of semi-permeable polymer nanocarriers for enzyme therapies. Biomaterials.2008 Jan 1; 29 (2): 215-27.
[10] El-Rahman A, Mahmoud N, Badawy AE, Younis S. Extraction of fish oil from fish viscera. Egyptian Journal of Chemistry.2018 Apr 1; 61 (2): 225-35.
[11] Fadini AL, Alvim ID, Ribeiro IP, Ruzene LG, da Silva LB, Queiroz MB, de Oliveira Miguel AM, Chaves FC, Rodrigues RA. Innovative strategy based on combined microencapsulation technologies for food application and the influence of wall material composition. Lwt.2018 May 1; 91: 345-52.
[12] Geranpour M, Emam-Djomeh Z, Asadi G. Investigating the effects of spray drying conditions on the microencapsulation efficiency of pumpkin seed oil. Journal of food processing and preservation.2019 Jul; 43 (7): e13947.
[13] Haque MA, Chen J, Aldred P, Adhikari B. Denaturation and physical characteristics of spray-dried whey protein isolate powders produced in the presence and absence of lactose, trehalose, and polysorbate-80. Drying Technology.2015 Jul 27; 33 (10): 1243-54.
[14] Jeyakumari A, Zynudheen AA, Parvathy U. Microencapsulation of bioactive food ingredients and controlled release-A review. MOJ Food Process Technol.2016; 2 (6): 214-224.
[15] Linke A, Linke T, Kohlus R. Contribution of the internal and external oxygen to the oxidation of microencapsulated fish oil. European journal of lipid science and technology.2020 Aug; 122 (8): 1900381.
[16] Liu XD, Atarashi T, Furuta T, Yoshii H, Aishima S, Ohkawara M, Linko P. Microencapsulation of emulsified hydrophobic flavors by spray drying. Drying Technology.2001 Jul 31; 19 (7): 1361-74.
[17] Nedović V, Kalušević A, Manojlović V, Lević S, Bugarski B. An overview of encapsulation technologies for food applications. In11th International Congress on Engineering and Food (ICEF11) 2011 (Vol.1, pp.1806-1815). Elsevier Science Bv, Amsterdam.
[18] Nguyen DQ, Mounir S, Allaf K. Optimization of the spray drying operating conditions for producing the powder mixture of gum Arabic and maltodextrin. International Journal of Food Engineering.2017 Aug 28; 13 (8): 20160271.
[19] Norziah MH, Al-Hassan A, Khairulnizam AB, Mordi MN, Norita M. Characterization of fish gelatin from surimi processing wastes: Thermal analysis and effect of transglutaminase on gel properties. Food hydrocolloids.2009 Aug 1; 23 (6): 1610-6.
[20] Paulo BB, Alvim ID, Reineccius G, Prata AS. Barrier

properties of spray-dried emulsions containing flavorings or unsaturated triglycerides. Lwt.2021 May 1; 142: 111040.

[21] Pegg RB, Shahidi F. Encapsulation, stabilization, and controlled release of food ingredients and bioactives. InHandbook of food preservation 2007 Jul 16 (pp.527-586). CRC Press.

[22] Pike, I. H. and Jackson, A., 2010. Fish oil: production and use now and in the future. *Lipid Technology*, 22 (3), pp.59-61.

[23] Ramakrishnan S, Ferrando M, Aceña-Muñoz L, Mestres M, De Lamo-Castellví S, Güell C. Influence of emulsification technique and wall composition on physicochemical properties and oxidative stability of fish oil microcapsules produced by spray drying. Food and Bioprocess Technology.2014 Jul; 7: 1959-72.

[24] Rincón-Cervera MÁ, Villarreal-Rubio MB, Valenzuela R, Valenzuela A. Comparison of fatty acid profiles of dried and raw by-products from cultured and wild fishes. European Journal of Lipid Science and Technology.2017 Sep; 119 (9): 1600516.

[25] Risch SJ. Encapsulation: overview of uses and techniques. ACS. Sympo. ser.2017; 590: 2-7.

[26] Rusli JK, Sanguansri L, Augustin MA. Stabilization of oils by microencapsulation with heated protein-glucose syrup mixtures. Journal of the American Oil Chemists' Society.2006 Nov; 83 (11): 965-72.

[27] Salih AW, Najim SM, Al-Noor JM. Some physical, chemical and sensory properties of fish oil extracted from fish wastes by physical and chemical methods. Biological and applied environmental research.2021; 5 (1): 152-62.

[28] Schrooyen PM, van der Meer R, De Kruif CG. Microencapsulation: its application in nutrition. Proceedings of the Nutrition Society.2001 Nov; 60 (4): 475-9.

[29] Venkateshwarlu G, Let MB, Meyer AS, Jacobsen C. Chemical and olfactometric characterization of volatile flavor compounds in a fish oil enriched milk emulsion. Journal of Agricultural and Food Chemistry.2004 Jan 28; 52 (2): 311-7.

[30] Venugopalan VK, Gopakumar LR, Kumaran AK, Chatterjee NS, Soman V, Peeralil S, Mathew S, McClements DJ, Nagarajarao RC. Encapsulation and protection of omega-3-rich fish oils using food-grade delivery systems. Foods.2021 Jul 6; 10 (7): 1566.

[31] Bligh EG, Dyer WJ. A rapid method of total lipid extraction and purification. Canadian journal of biochemistry and physiology.1959; 37 (8): 911-917.

[32] Folch J, Lees M, Stanley GS. A simple method for the isolation and purification of total lipides from animal tissues. Journal of biological chemistry.1957 May 1; 226 (1): 497-509.

[33] Noor M, Nisa Basharat MA, Naveed K, Hussain R, Arif MS, Qadir G, Khalid S, Hussein S, Asif A, Rehman FU, Shaukat MF. Extraction techniques and purification methods: Precision tools for pure innovation. Pure and Applied Biology. Vol.14, Issue 2, pp224-248 [Internet].2024

[34] Randall JM. Improved methods for fat extraction using an automated Soxhlet extractor. Journal of Food Technology.1974; **9**: 123–127.