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Chub Mackerel *(Scomber japonicus)* as a Potential Lipid-Based Functional Food: A Comprehensive Review

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HIGHLIGHTS

- Chub mackerel (Scomber japonicus) is a rich source of omega-3 PUFA (EPA and DHA), proteins, vitamins, and minerals
- Consumption omega-3 and vitamins are essential for cardiovascular, neurological, and cognitive health support
- More studies are needed for further scientific health benefits evidence and future cooking development of chub mackerel

ABSTRACT

Functional foods have gained a lot of attention as nutrition awareness increases. Chub mackerel is classified as one of the functional foods due to being rich in omega-3 fatty acids. This includes eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA) that are associated with health benefits, such as anti-inflammatory properties, cardiovascular health support, and cognitive function enhancement. Chub mackerel also contains high protein, vitamins, and minerals. This contributes to muscle growth, immune system support, and cognitive function improvement. Research has indicated the safety and efficacy of consuming omega-3 from chub mackerel, particularly among pregnant women and children. Various processing techniques have been applied to chub mackerel to enhance its quality as a functional food, including roasting and frying. However, non-thermal processing may reduce nutrient losses. The future for chub mackerel as a functional food includes further research into alternative cooking methods to preserve omega-3 content, the implementation of regulations, and industry collaborations to promote its utilization as a functional food, particularly in Indonesia, where it is abundant and affordable. Overall, chub mackerel shows promise as a lipid-based functional food with potential in improving public health and addressing the rising prevalence of non-communicable diseases.

INTRODUCTION

Functional food has garnered significant attention in recent years, particularly in the areas of enhancing food health and technology (Baker et al., 2022). Different institutions, such as the U.S National Academy of Sciences, Food and Nutrition Board, Institute of Food Technologists, and the Functional Food Center, define functional food differently, as there has not yet been a universally accepted definition created for this term. However, despite the differences in defining the meaning of the term, it is agreed and understood that functional food should offer health benefits that are beyond the basic nutritional effect, which should be able to contribute to the improvement of health, well-being, and reduce the risk of disease (Baker et al., 2022; Essa et al., 2023). Additionally, it is said that functional food is expected to contain bioactive compounds, whether nutrient-based (e.g., vitamins, minerals, protein) or non-nutrient-based (e.g., polyphenols, prebiotics), that positively affect the well-being and health of the body (Konstantinidi & Koutelidakis, 2019).

The increase in demand and interest in functional food is influenced by several factors. As noted by Nguyen et al. (2019), the increase in health consciousness, particularly among consumers with certain health issues, results in a positive attitude towards foods that offer health benefits. In addition, Baker et al. (2022) stated that functional food purchase behavior is strongly driven by social motivation, including social norms, social prestige, and perceived peer expectations. Adequate nutrition knowledge is also known to shape consumers' dietary habits, attitudes, and acceptance of functional foods. Additionally, educational campaigns in the media play a crucial role in shaping consumer perception of functional foods, while regulatory approval of health claims further strengthens consumer trust. Nevertheless, although awareness of the importance of functional foods is growing, many consumers remain unfamiliar with the term, partly due to the limited availability of such products in the market. To address this, the Indonesian Society for Functional Food, together with industry, academia, researchers, and government, has initiated efforts to develop more functional food products. However, progress is slow because the regulatory process remains complex, costly, and time-consuming (Purwaningsih et al., 2021).

Among the various functional food components, such as prebiotics, probiotics, dietary fiber, flavonoids, carotenoids, vitamins, and lipids; lipid-based bioactive compounds play a particularly critical role. Long-chain polyunsaturated fatty acids (PUFAs), notably omega-3s (EPA and DHA), have been shown to improve cardiovascular health, reducing plasma triglycerides, lowering LDL cholesterol, reducing blood clot formation, and lessening the inflammation (Dixit et al.,2017; Omachi et al., 2024; Sacks et al., 2017). In Indonesia, however, cardiovascular diseases (CVD) remain the leading cause of death among other non-communicable diseases (NCD). It accounts for about 48% of NCD mortality (Nurwahyuni et al., 2023). At the same time, obesity prevalence has increased from 13.6% in 2013 to 21.8% in 2018, and diabetes mellitus has also shown a rising trend over that period (Hananto et al., 2019). This burden is strongly linked to unhealthy lifestyle patterns, including excessive intake of saturated fats, trans fats, refined sugars, and energy-dense foods, along with insufficient consumption of protective nutrients such as omega-3 fatty acids, combined with physical inactivity, smoking, and genetic predisposition (WHO, 2021).

Responding to this issue, various studies on omega-3 supplementation have been carried out to lower the prevalence of CVD risk, including exploration of its natural sources. Among various food materials, marine products are known as a ubiquitous source of omega-3, the long-chain polyunsaturated fatty acid (LC-PUFA) (Zhang et al., 2019). It is particularly present in the form of docosahexaenoic acid (DHA) and eicosapentaenoic acid (EPA) (Ferreira et al., 2020). Within types of marine products, both omega-3 PUFAs are abundant in the widely consumed small pelagic fish in Indonesia, chub mackerel (*Scomber japonicus*), widely-known as *ikan kembung* (Zhang et al., 2019). While it is potentially claimed as a promising source of functional lipids, chub mackerel actually provides richer nutrients than a single omega-3. The high-quality protein, vitamins, and minerals make chub mackerel a nutrient-dense food (Afonso et al., 2023). By means of acknowledging the educational campaigns in spreading awareness of consuming functional foods, it is essential to highlight the potential of lipid-based functional food derived from chub mackerel. This action is particularly taken to promote higher omega-3 intake and further aims to raise awareness in utilizing local sources to increase the overall nutritional status in Indonesia.

NUTRITIONAL COMPOSITION OF CHUB MACKEREL

Chub mackerel belongs to the Scombridae family, which is widely known for its high nutritional value (Ferreira et al., 2020). It is considered a nutrient-dense small pelagic fish that provides high-quality protein, essential fatty acids, and micronutrients important for human health. Chub mackerel hydrolysates are reported to contain approximately 20.80% protein. This includes a complete profile of essential amino acids, including lysine, leucine, valine, and isoleucine; which contribute to muscle protein synthesis and overall nutritional adequacy (Wenno et al., 2022; Haris et al., 2023). Leucine, in particular, has been widely recognized in nutrition science as a key amino acid for stimulating muscle protein synthesis, highlighting the potential of chub mackerel as a valuable protein source for populations at risk of malnutrition or muscle loss (Haris et al., 2023).

In addition to protein, chub mackerel is rich in micronutrients such as vitamins B2 (riboflavin), B3 (niacin), B6 (pyridoxine), and B12 (cobalamin); which are essential for immune function, cognitive performance, and reducing cardiovascular risk (Afonso et al., 2023). It also provides vitamin D, which supports calcium and phosphorus absorption and contributes to bone health (Hossain & Yoshimatsu, 2014). Mineral analyses further indicate that chub mackerel flesh is an important source of selenium, a trace element with antioxidant properties that may reduce oxidative stress and lower the risk of neurodegenerative diseases such as dementia (Rego et al., 2022).

According to the Food and Agriculture Organization, the recommended daily intake of EPA and DHA ranges from 100 to 250 mg for children, 250 mg for adults, and 300 mg for pregnant women (Thompson et al., 2019). Data from the USDA show that one serving of mackerel provides approximately 430 mg of EPA and 590 mg of DHA (Rincón-Cervera et al., 2020). One of the most notable nutritional features of *Scomber japonicus* is its lipid profile, particularly its high levels of omega-3 polyunsaturated fatty acids (PUFAs). This highlights chub mackerel as an affordable and locally available source of omega-3 for Indonesian communities. Omega-3 fatty acids from chub mackerel are linked to several health benefits, starting from reducing inflammation, promoting brain health, and supporting prenatal health throughout the pregnancy. This garnered global attention in recent years due to its potential therapeutic applications against diabetes, cardiovascular disease, depression, and Alzheimer's disease (Shahidi & Ambigaipalan, 2018; Thomas et al., 2015). Given its nutritional richness and widespread availability in Indonesia, *Scomber japonicus* represents an important candidate for promoting lipid-based functional foods that can improve dietary quality and address omega-3 deficiencies at the community level.

HEALTH BENEFITS OF CHUB MACKEREL

Consumption of long-chain saturated fatty acids has been linked to various health problems. Diets rich in these fatty acids are considered energy-dense, making them contain more calories in the same portion size. Thus, consistent intake of such diets may lead to weight gain and, in the long term, increase the risk of obesity (Wali et al., 2020). Furthermore, Nettleton et al. (2017) stated that consumption of saturated fat also causes the promotion of CVDs (Cardiovascular Diseases) as it increases the LDL (low-density lipoprotein) cholesterol level. It is known as one of the risk factors contributing to the increase in heart disease and stroke risk. Although Praagman et al. (2016) showed that the effect of saturated fat depends on the type of dietary sources, replacing saturated fat with high-carbohydrate foods may increase the risk of ischaemic heart disease. On the other hand, a meta-analysis study showed that consuming marine omega-3 has been associated with a lower risk of cardiovascular diseases and can promote the health of the consumer (Hu et al., 2019).

In addition, sufficient intake of omega-3 is also known to reduce the risk of suffering from ischemic stroke (Chen et al., 2021). It mainly happens due to the brain's lack of a sufficient amount of oxygen in the brain tissue. In many cases, the blood clotting blocks and reduces the amount of oxygen-containing blood transported to the brain, causing ischemic stress (Wang et al., 2018). These mechanisms can be prevented by omega-3 activity as anti-inflammatory and antiplatelet compounds. The action includes blood vessel regulation by enhancing the function of the endothelial lining, promoting vasodilation, reducing arterial stiffness, and reducing blood viscosity (Peter et al., 2013; Colussi et al., 2017). An important cardiovascular benefit also comes from their anti-arrhythmic effects, as EPA and DHA modulate cardiac electrophysiology. It works by improving autonomic nervous system balance, particularly by increasing parasympathetic tone. In simpler terms, both help keep the heart’s rhythm steady and regular, reducing the likelihood of arrhythmias such as atrial fibrillation and sudden cardiac death (Peter et al., 2013).

A clinical study of an 8-week period of omega-3 daily supplementation containing 480 mg DHA and 720 mg EPA supports the mentioned claim. The findings show a reduction in LDL cholesterol level and blood triglycerides by approximately 5% and 18%, respectively (Sharifzadeh et al., 2024). A similar study indicates changes in the lipid profile, particularly lipid mediators, following a year of omega-3 supplementation. Reduction in pro-inflammatory PGD2 is observed in those supplemented with omega-3 containing 380 mg DHA and 460 mg EPA, while the placebo shows the opposite (Oakes et al., 2024). This particular study also shows the comparison of the effect of fish consumption rate on lipid mediator profiles in humans. Those with low fish intake experience greater pro-inflammatory PGD2 downregulation (47.5%) than those with high fish intake (32.2%) (Oakes et al., 2024). While PGD2 is involved in resolving acute inflammation, its massive production is often linked to the severity of coronary artery disease in humans (Kong & Yu, 2022). Thus, its greater downregulation indicates a more substantial corrective effect of omega-3 in low fish consumers. However, it should not discredit the high fish consumption, in which the smaller PGD2 downregulation rate indicates a sufficient initial dietary omega-3 intake.

Chub mackerel is rich in omega-3, which consumption may contribute to a considerable amount of dietary intake fulfillment. Although the amount of omega-3 in chub mackerel fluctuates depending on geographical factors and season, the average values are relatively high. Zhang et al. (2019) reported that the sum of EPA and DHA in chub mackerel is approximately 41.96% of the total fatty acids. Another study reported that the sum average of EPA and DHA was mostly higher than 500 mg/100 g of the chub mackerel, which led to a recommendation in which ingestion of 9-65 g chub mackerel per day is more than enough to supply the daily need of omega-3 (Ferreira et al., 2020). Aside from that, the efficacy of omega-3 is also supported by other complex components in chub mackerel, namely the presence of vitamin B12. It plays a significant role in maintaining proper neurological function and potentially preventing or delaying the onset of cognitive decline and dementia. Knowing that chub mackerel is rich in vitamin B12, which concentration could reach 18 µg/100 g, a weekly intake of 160 g in a meal may suffice the B12 requirement (Rego et al., 2022).

Not limited to their potencies in preventing diseases, consumption of chub mackerel is also beneficial to support brain and visual function. The contained DHA is essential for neuronal membranes and retinal cells. An adequate intake enhances synaptic plasticity, improves membrane fluidity, and supports neurotransmission; all of which are critical for optimal brain function (Innis, 2007; Calder, 2017). Maternal DHA intake during pregnancy is strongly associated with improved visual and cognitive development in infants, highlighting its role throughout the lifespan (Gow & Hibbeln, 2014). In children, DHA and EPA are critical for neuronal growth, synaptogenesis, and visual function. On the other hand, observational studies in adults suggest that low omega-3 intake may be linked to increased risk of depression and cognitive decline (Lange, 2020; Larrieu & Layé, 2018). Earlier studies support these findings, which stated that DHA supplementation can improve memory performance and reduce cognitive decline in older adults (Yurko-Mauro et al., 2010).

The enhancement of cognitive function is also supported by the presence of vitamin D in chub mackerel. This fat-soluble vitamin plays a pivotal role as a neurosteroid hormone. It regulates neurotransmitter activity and promotes neurotrophin production, supporting both growth and maintenance of cognitive function (Groves et al., 2014). Low vitamin D status has been associated with cognitive impairment, dementia, Alzheimer's disease, and other neurodegenerative disorders (Landel et al., 2016). That being said, sufficient intake of chub mackerel contributes not only to structural brain health by DHA, but also to neuroprotection by the support of vitamin D.

BIOACTIVITY AND MECHANISMS OF ACTION

The omega-3 PUFA content in chub mackerel is significant, with DHA and EPA representing 75% of the total PUFA and 84% of omega-3 PUFA in chub mackerel (Strobel et al., 2012). EPA and DHA have a crucial role in human health through their incorporation into cell membranes, particularly in organs such as the brain, heart, and liver. In the heart, both fatty acids may enhance membrane fluidity and affect the function of membrane proteins and receptors, leading to improved heart rate variability, reduced blood pressure, and decreased risk of arrhythmias; which are critical factors in cardiovascular health maintenance (Kar et al., 2023; Maulucci et al., 2016). Additionally, the incorporation of omega-3 PUFAs into neuronal membranes makes a major contribution to membrane composition and the production of signaling lipids that have functions to improve neuronal survival and cognitive function (Dyall, 2015). Besides that, the metabolism and conversion of omega-3 PUFAs are also mainly associated with the liver. Generally, this organ will regulate the availability of the fatty acids and their incorporation in body tissues (Wang & Huang, 2015).

Furthermore, omega-3 PUFAs are precursors to bioactive lipid mediators, such as resolvins and protectins, which have been shown to play a role in the resolution of inflammation (Oppedisano et al., 2020). According to Parolini (2019), these specialized pro-resolving mediators (SPMs) are essential for terminating the acute inflammation responses and promoting the return to tissue homeostasis. In the context of autoimmune diseases, such as thyroiditis, omega-3 PUFAs may decrease the production of chemokines and increase the intracellular levels of resolvins, leading to tissue protection from inflammation (Benvenga et al. 2022). This is particularly significant as chronic inflammation is a hallmark of many autoimmune diseases, and the ability of omega-3 PUFAs to modulate this process offers potential therapeutic benefits (Schunck et al., 2018). The anti-inflammatory action of omega-3 PUFAs is further supported by their role in modulating the immune system. A recent study conducted by Noureddine et al. (2022) has shown that omega-3 PUFA-rich emulsions can elicit a pro-resolution lipid mediator profile in mouse tissues and in human immune cells, characterized by higher concentrations of SPMs and endocannabinoids. This supports the notion that omega-3 PUFAs can modulate the inflammatory response and promote the resolution of inflammation, which is essential for maintaining health and preventing the progression of inflammatory diseases (Sansbury et al., 2016; Ferreira et al., 2022).

Aside from its anti-inflammatory properties, omega-3 PUFA has been implicated in the modulation of metabolic and endocrine functions (Wu et al., 2022). According to a study conducted by Kuberskaya & Podgurskaya (2023) has shown that omega-3 PUFAs influence pancreatic β-cell function and insulin action, which are critical for maintaining glucose homeostasis. Omega-3 PUFAs can stimulate insulin secretion and prevent cytokine-induced cell death in pancreatic islets, thereby preserving β-cell function and enhancing glucose regulation (Oh et al., 2018). This mechanism underscores the potential of omega-3 PUFAs in managing diabetes and metabolic syndrome, further emphasizing the broad spectrum of health benefits associated with these fatty acids (Bi et al., 2017). Additionally, the high EPA and DHA content in sources like chub mackerel suggests potential benefits for the prevention of coronary heart disease, given the crucial role of these fatty acids in brain development and cardiovascular health (Ferreira et al., 2020).

SAFETY AND EFFICACY IN HUMAN STUDIES

The safety of omega-3s present in chub mackerel on human health has been widely investigated by several scientists in recent years. Based on the study by Rincón-Cervera et al. (2020) on quantification of omega-3 fatty acids in South Pacific fish species using a gas chromatography coupled with flame ionization detection (GC-FID) method, the result showed that raw fillet mackerel contains the highest amount of EPA and DHA contents with the value of 414.7 mg/100g and 956.0 mg/100g, respectively. These omega-3 fatty acid content values are higher compared to those of other fish species analyzed, such as red cusk eel, hake, and corvina drum. This study mentioned that consuming two servings of mackerel per week may provide a sufficient amount of EPA and DHA needed by the body in order to meet the recommended minimum intake for both types of omega-3 fatty acids. Furthermore, mackerel is deemed safe and highly encouraged to be consumed by populations that have high sensitivity. For example: pregnant women, children, and elderly.

Another study by Afonso et al. (2023), in an investigation of fatty acid content in chub mackerel between seasonal variations, revealed that the chub mackerel fillets collected in October showed higher EPA and DHA concentrations compared to March and June mackerel. In addition, this study also supported that chub mackerel is an effective source of omega-3, which can provide several positive effects on human health. Furthermore, the examination of omega-3 fatty acids of chub mackerel during storage was also done by Andhikawati & Pratiwi (2020). From this research, it can be concluded that the concentration of omega-3 in chub mackerel will decrease in cold temperature storage, whereas the saturated fatty acid concentration increases. This occurred as omega-3 is not stable in low temperatures, causing the declining omega-3 content.

On the other hand, Wenstrom (2014) states that consuming fish that are high in omega-3, such as mackerel, is beneficial for achieving an adequate intake of EPA and DHA for breastfeeding and pregnant women. Based on the findings, omega-3 fatty acids are an important component of membrane cells that contribute to the development of brain and retinal tissues and have been linked with better communication skills and IQ scores of children. However, despite its advantages, the consumption of mackerel containing high mercury levels may cause a harmful effect for pregnant and nursing women. Therefore, the quality of the mackerel needs to be highly monitored to ensure the safety of the fish for consumption.

POTENTIAL DEVELOPMENT

Several studies have explored processing techniques utilizing chub mackerel as the primary ingredient, aiming to enhance its qualities as it can be used as a functional food. In a study conducted by

Rana et al. (2021), a processing technique combining superheated steam roasting and hot smoking with various sawdust types was employed; resulting in improved shelf life, sensory attributes, reduced microbial activity, and heightened nutritional content. The process commenced with pretreating the chub mackerel through steam roasting at 270°C, followed by storage at 4°C. Subsequently, the chub mackerel was coated with an 8% NaCl solution and dried for 30 minutes to remove excess moisture. The findings indicated that treatment with oak sawdust for 25 minutes yielded optimal sensorial characteristics, chemical properties, microbiological attributes, and nutritional content.

In another investigation by Tirtawijaya et al. (2021), vacuum frying was employed to process and produce fried chub mackerel, resulting in improved product quality characterized by reduced oxidation. The method of the research began with preparing the batter to coat the chub mackerel pieces. Furthermore, the chub mackerel underwent vacuum frying or conventional deep-frying methods, followed by performing several analyses on the fried chub mackerel product. The results of the study showed that chub mackerel that had been exposed to vacuum frying exhibited superior preservation by maintaining product quality for up to nine months of storage at 18°C. Other than that, this cooking method could maintain nutritional composition and give a positive impact on sensory properties, chemical attributes, and microbiological characteristics.

Heat-based processing techniques such as frying and baking can reduce nutritional value by promoting oxidative decomposition of unsaturated fatty acids (particularly EPA and DHA), as well as causing water loss and altering fatty acid composition, effects that have been observed in studies on fish like salmon and red mullet (Leung et al., 2018; Biandolino et al., 2023; Secci et al., 2016). To mitigate this decline in nutritional quality, non-thermal processing methods may be employed. These include high-pressure processing, ozone treatment, ionizing radiation, pulse electric field, cold plasma, ultraviolet irradiation, pulsed light, and ultrasound technology (Chacha et al., 2021). Therefore, non-thermal processing may be used to minimize the nutrients that were lost due to the processing technique applied. High-pressure processing is one of the non-thermal techniques that can be applied to fish. A journal article by Teixeira et al. (2014) applied high-pressure processing for sea bass, which resulted in the delay of fish muscle degradation, which caused the minimization of loss of nutrients, mainly in omega-3 fatty acids, and prolonging the shelf life of the fish. Therefore, the application of high-pressure processing may also be applied to the chub mackerel to minimize the omega-3 fatty acids.

Another possibility of potential development of chub mackerel as a functional food is the enrichment of the major nutrients that are able to bring health benefits, like EPA, DHA, and omega-3 fatty acids. The enrichment of the major nutrients can be applied to the thermally processed chub mackerel to replace the nutrients that were lost due to the processing. Enrichment of the processed mackerel aims to have a more conventional product that is related to chub mackerel and also has the major nutrients that are needed. However, there were no journal articles that enriched the major nutrients in processed chub mackerel.

FUTURE OUTLOOKS

One main interest is to increase the effectiveness of cooking methods especially due to the factors of cooking time, temperature, and storage to increase effective preservation of omega-3 content inside the fish. According to Bastías et al. (2017), chub mackerel and other fish are very prone to lipid oxidation; this might happen due to the unsuitable factors such as temperature, time, and storage. Which accelerates the lipid oxidation to occur and further affect the quality of the fish and the omega-3 content as well. Different cooking methods, including canned, microwave, steamed, oven cooking, and grilling, were evaluated to see which of them can preserve omega-3 content the most in fish. However, none of them can actually preserve the omega-3 content high enough due to the presence of heat treatment in all of the cooking methods. Hence, the future outlook is to search for potential alternatives for cooking methods with high heat to the method using non-thermal processing, such as high-pressure processing (Chacha et al., 2021). Additionally, creating regulatory measures including guidelines, health claim regulations, and labeling requirements of omega-3 content for chub mackerel can help broaden the utilization of omega-3 content of chub mackerel and help promote this type of lipid-based functional food to society, especially to people live in Indonesia who can easily find chub mackerel at a lower price.

CONCLUSION

Chub mackerel (*Scomber japonicus*) stands out as a nutrient-dense source with a high level of omega-3 polyunsaturated fatty acids, particularly eicosapentaenoic acid (EPA) and docosahexaenoic acid (DHA), alongside essential proteins, vitamins, and minerals. The presence of these bioactive compounds positions chub mackerel as a potential lipid-based functional food capable of offering health benefits beyond basic nutrition, contributing to the improvement of health and well-being, and reducing the risk of disease, with significant implications for improving public diet and addressing the rising concerns of non-communicable diseases. Future research and development efforts should focus on optimizing processing techniques to preserve the nutritional integrity of chub mackerel, thereby maximizing its health benefits and promoting it as a viable component of a health-conscious diet.

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