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ARTICLE

Sustainability innovation and circular economy of freshwater hybrid catfish oil extraction

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ABSTRACT

Integrating sustainability innovation and a circular economy model in extracting freshwater hybrid catfish oil can lead to economic, environmental, and social gains, aligning closely. Fish oil is an industrial product of great nutritional value due to its having long-chain polyunsaturated fatty acids. Moreover, it is highly valued for its prophylactic and therapeutic properties in nutritional and health fields. Moreover, these fatty acids are related to different neuronal functions, and their absence is associated with diverse inflammatory processes and the precarious development of neurons in human patients. Fish oil from the body parts of the hybrid catfish' frozen adipose tissue was extracted using the conventional cooking method, and a screw compressor squeezed the prepared sample and then steamed it to separate solid and oil portions to determine quantitative yield. The GC-MS method characterized the obtained total extracts for the qualitative and quantitative determination of the presence of fatty acids. Oil contents of adipose tissues were saturated fatty acids, monounsaturated fatty acids, and unsaturated fatty acids 37.99±0.41%, 48.43±1.75%, and 13.58±1.33%, respectively. The oil was allowed to examined physical-chemical properties and microbial activities. The results show that the hybrid catfish studied are a rich source of omega-3, omega-6, and omega-9 polyunsaturated fatty acids.

1. Introduction

Aquaculture is the fastest-growing food-production sector in the world. Aquaculture supplies 50% of all fish consumed globally today (Whangchai et al., 2020), and it is predicted that by 2030 it will be the prime source of fish. Aquaculture expansion has made using and validating fish health monitoring tools increasingly evident (Tongmee et al., 2020). Worldwide, fish has an increasingly important role in the health of both developed and developing nations. Demand for sustainability has increased production capacity through aquaculture (Whangchai et al., 2018). Freshwater aquaculture production in 2011 was 44.3 million tons or 29% of world fisheries production, and approximately one-third of all seafood (freshwater and marine) production globally comes from aquaculture, and the most considerable portion (42%) of this is freshwater fish.

Universal aquaculture has grown significantly over the past 50 years to around 52.5 million tonnes (68.3 million, including aquatic

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plants), accounting for around 50 percent of the world's fish food supply. Asia dominates this production, accounting for 89% by volume and 79% by value (Bostock et al., 2010). The rapid growth in this region has been driven by various factors, including pre-existing aquaculture practices, population and economic growth, flexible regulatory framework, and expanding export opportunities (Abomohra et al., 2020). Fabrice (2018) stated that global aquaculture production was dominated in 2016 by the farming of freshwater fish species (58%, i.e., 46.4 million tons) followed by the production of mollusks (21.4%), crustaceans (9.8%), diadromous fishes (6.2%), marine fishes (3.4%), and various aquatic animals (1.2%). Various carp species dominate freshwater fish production; tilapia and catfish have become more significant (Ataguba et al., 2018). Thailand is known for native species such as Giant Mekong Catfish, Barramundi, Siamese Carp, Giant Snakehead, and other, more common species. The Mekong giant catfish is the official freshwater heavyweight champion of the world. According to the Guinness Book of Records, a nine-foot-long individual caught in northern Thailand in 2005 weighed an astounding 646 pounds, making it the largest exclusively freshwater fish ever recorded.

Also, *P. hypophthalmus* is much smaller than P. gigas, weighing 2 to 10 kg. These are commercially crucial freshwater fish, serving as a food source for mainland Southeast Asian countries, for example, Thailand, Laos, Cambodia, and Vietnam (Phadphon et al., 2019). The most commonly cultured species include a hybrid of the African catfish (*Clarias gariepinus*) and the native catfish (*C. macrocephalus*), snakehead (*Ophicephalus striatus*), sepat siam (*Trichogaster pectoralis*), Javanese carp (*Puntius gonionotus*), sand goby (*Oxyeleotris marmoratus*), striped catfish (*Pangasius* sp.), Nile tilapia (*Oreochromis niloticus*), grass carp (*Ctenopharyngodon idella*), and freshwater prawn (*Macrobrachium rosenbergii*). The hybrid catfish, one of the most economically important freshwater fish, was successfully reproduced in 1989. Hybrid catfishes grow faster and more disease-resistant than the local variety (Rahman et al., 2019). Fish is an essential dietary component due to its contribution to valuable nutrients. In addition to the high-quality protein and micronutrients provided, fish is the primary source of long-chain omega-3-6-9 fatty acids found in oils of "fatty" fresh/marine water fish.

Biomedical evidence supports the importance of nutrients in fish and fish oil in promoting normal nutrition for growth, development, and health maintenance. Also, fish and fish oil have been shown to lower the risk of progressive chronic disorders, including cardiovascular, metabolic, and inflammatory diseases, and may be helpful in disease treatment. Fish consumption has been shown to reduce coronary heart disease mortality because n–3 fatty acids from fish oil improve cardiovascular health by decreasing risk factors such as triglyceride concentrations, blood pressure, platelet aggregation, and heart arrhythmias (Kris-Etherton et al., 2002). Catfish are comprised of different species with different oil content. Catfish farming has been the most improved aspect of aquaculture. Recently, catfish have had high demand in marketplaces since catfish contribute much nutritional value to humans and other industries. The fish oil supplements benefit healthy people and those with heart disease. The study aimed to develop a continuous and efficient oil extraction system from the freshwater hybrid catfish (*Pangasius* sp.). This study focuses on developing cost-effective, rapid, energy-efficient, and reliable extraction systems for fish oil and fatty acids composition analysis to investigate the beneficial influence of the oil extraction performance and the effect of operating parameters on oil yield and quality continuously.

2. Material and methods

2.1 Material collection and experimental site

The samples of freshwater hybrid catfish (*Pangasius* sp.) were collected from the "Pla-Buk knowledge" fishery research field, Faculty of Fisheries Technology and Aquatic Resources, Maejo University, Chiang Mai, Thailand. The experiment was conducted at the Center of Excellence in Agricultural Innovation for Graduate Entrepreneurs, Maejo University, Chiang Mai 50290, Thailand. All chemicals and solvents used in this experiment were analytical grades.

2.2 Sample preparation for the experimental procedure

The fresh samples were immediately de-headed and washed with copious amounts of cool water to separate the skin. Then the skin was separated using a de-boner. Immediately, the experimental sample was stored overnight in a freezer at −18°C and then freeze-dried at a constant drying temperature of −47°C. The frozen adipose tissues of hybrid catfish samples were allowed to dry and then vacuumed at 0.133 bar. The dried samples were ground using a blender and stored in an airtight glass bottle in a cold room at 6°C pending laboratory use. This procedure was adopted by Habib and Sarkar (2016).

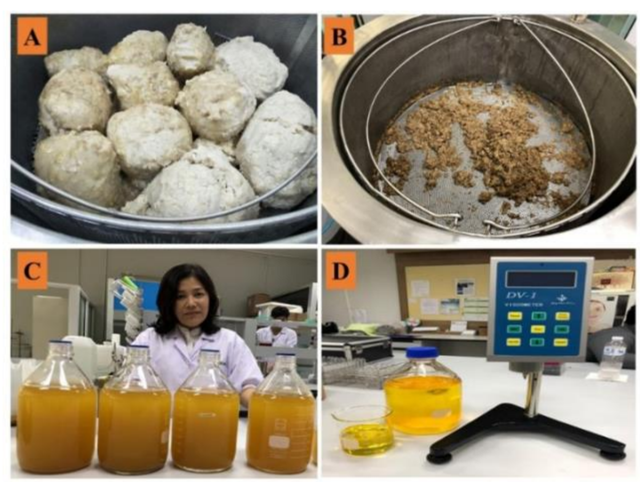

Figure 1. Fish oil preparation processes (A-D)

The prepared samples were steamed at 90°C for 30 minutes. The oil (liquid) was filtered with the help of a filtering sack and then squeezed by a screw compressor. Solid and liquid were separated, and the attained liquid was centrifuged at 4500 rpm at 25°C for 10 minutes. The Fish oil preparation processes (A-D) are shown in Figure 1.

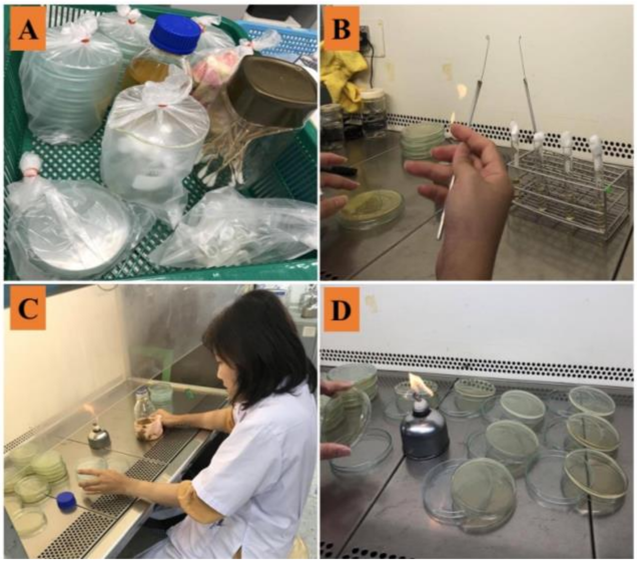

Figure 2. Culturing bacteria preparation processes (A-D)

2.3 Analytical methods

Oil extracted by the steamed system was assessed for total fat gravimetrically and by capillary gas chromatography (GC) for total fat, lipid classes, and trans fat. All squeezed, steamed, and centrifuged results were compared with parallel determinations using the standard AOAC Method 996.01 or a modified version for trans fatty acids. For gravimetric and gas chromatographic evaluations, the steamed system results were equivalent to those using the standard AOAC Method (Wangcharoen et al., 2005).

Relevant physical and chemical properties were analyzed. Tri measured the oil color- Stimulus Colorimeter (JUKI: model JC801) and Viscotester (ROIN: model VT-04) were used for checking viscosity. Turbidimeter measured turbidity (HACH: model 2100 N). A specific gravity bottle was used for measuring specific gravity. Melting point/softening and smoke point were analyzed using the AOCS method (Wangcharoen et al., 2005). The saponification and peroxide values were examined using standard methods AOCS Method 920.160C and d 8-53, respectively (AOCS 1993). 2013.06 and 999.10 methods verified heavy metal contents. Furthermore, bacterial contamination was examined using the 991.14 and ISO 6578-1:2017 (E) standard methods (AOAC 2016).

2.4 Statistical analysis

All data were analyzed using SPSS 16.0 software. ANOVA was performed to determine differences in the FA content. Tukey's Studentized range test was performed for post hoc multiple comparisons. All analyses were done at $\alpha = 0.05$.

3. Results and discussion

Usually, fish oils are more complex than land-animal or vegetable oils due to long-chain unsaturated fatty acids. Fish oils are unique in the variety of fatty acids they are composed of and their degree of unsaturation; fish oils are rich in the linoleic acid family's polyunsaturated fatty acids. Fish oil production deals with separating fatty substances (lipids) from other fish constituents (Eke-EJiofor & Ansa, 2018).

The separation starts with preparing the raw material up to the product's purification, which is the final stage of the process. This study extracted oil from the adipose tissue of the freshwater hybrid catfish (Pangasius sp.). The quality of the oil obtained by the extraction method of squeezed, steamed and centrifuged system results was evaluated by determining several parameters, i.e., color, viscosity, turbidity, specific gravity, melting point (softening), smoke point, saponification value, peroxide value-neutral lipid composition, fatty acid profile, compounds profile, and trace metals. The fatty acids composition of freshwater hybrid catfish oil results is shown in Figure 3.

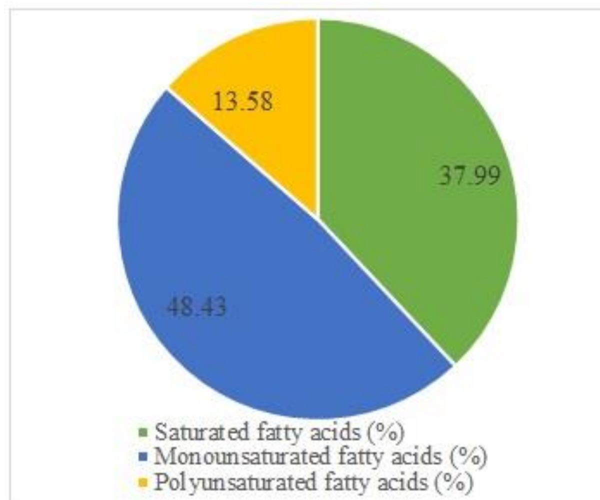

Figure 3. Fatty acids composition of freshwater hybrid catfish oil

Hybrid catfish extracted oil has rich saturated fatty acids (37.99±0.41%) and unsaturated fatty acids, including mono-unsaturated fatty acids (48.43±1.75%) and polyunsaturated fatty acids (13.58±1.33%). Saturated fatty acids are derived from animal fats and plant oils (). Rich sources of dietary saturated fatty acids include butterfat, meat fat, and tropical oils. Saturated fatty acids are straight-chain organic acids with even more carbon atoms (Grundy, 2012). Moreover, saturated fatty acids contain no double bond; the body can synthesize this type of fat. Hybrid catfish oil differs from other oils because of the unique variety of fatty acids, including high unsaturated fatty acids. According to their chain length, there are numerous saturated fatty acids (containing 4–16 carbon atoms). Saturated fatty acids contains caprylic acid (C8:0, 0.04%), lauric acid (C12:0, 0.10%), pentadecanoic acid (C15:0, 0.17%), palmitic acid (C16:0, 26.82%), heptadecanoic acid (C17:0, 0.35%), stearic acid (C18:0, 6.78%), arachidic acid (C20:0, 0.13%), heneicosanoic acid (C21:0, 0.08%), behenic acid (C22:0, 0.16) and lignoceric acid (C24:0, 0.02). Many researchers reported that palmitic acid was the major saturated fatty acid (Li et al., 2011; Durmuş, 2018); in this current study, the results agreed because palmitic acid is a dominant saturated fatty acid. Stearic acid is the second most important saturated fatty acid.

Essential mono-unsaturated fatty acids detected in the fatty acids are including palmitoleic acid (C16:1n7, 3.34%), trans-9-elaidic acid (C18:1n9t, 0.16%), cis-9-oleic acid (C18:1n9c, 43.35%), cis-11-eicosenoic acid (C20:1n11, 1.35%), erucic acid (C22:1n9, 0.12%), nervonic acid (C24:1n9, 0.06%). Jabeen and Chaudhry (2011) stated that oleic acid dominated mono-unsaturated fatty acid in all freshwater fish species. Dietary intake of unsaturated fatty acids has been shown to reduce the risk of cardiovascular disease and possibly the incidence of some cancers, asthma, and diabetes, among other conditions.

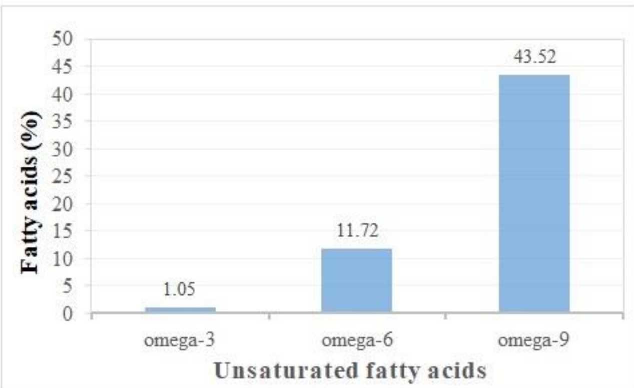

Figure 4. Unsaturated fatty acids composition of freshwater hybrid catfish oil

Hybrid catfish oil contains polyunsaturated fatty acids, including cis-9,12-linoleic acid (C18:2n6, 10.47%), γ-linolenic acid (C18:3n6, 0.14%), α- linolenic acid (C18:3n3[ALA], 0.75%), cis-11,14-eicosadienoic acid (C20:2, 0.64%), cis-8,11,14-eicosatrienoic acid (C20: 3n6, 0.71%) and cis-11,14,17-eicosatrienoic acid (C20:3n3, 0.08%). Polyunsaturated fat is a type of dietary fat. It is one of the healthy fats, along with monounsaturated fat. Polyunsaturated fat is found in plant and animal foods, such as fish, vegetable oils, nuts, and seeds. Polyunsaturated fat is different from saturated fat and trans fat. Polyunsaturated fats can help lower LDL cholesterol. Cholesterol is a soft, waxy substance that can cause clogged or blocked arteries (blood vessels). Having low LDL cholesterol reduces your risk of heart disease. Polyunsaturated fats include omega-3 and omega-6 fats. The body needs essential fatty acids for brain function and cell growth.

The unsaturated fatty acids composition of freshwater hybrid catfish oil is shown in Figure 4. The main portion of unsaturated fatty acids contained omega-3 (1.05±0.47%), omega-6 (11.72±0.81%), and omega-9 (43.52±1.73%). Calder (2017) verified that long-chain omega-3 polyunsaturated fatty acids such as eicosapentaenoic and docosahexaenoic acids are mainly extracted from fish and have numerous beneficial health effects on humans. Human bodies need dietary fats and oils and, while some are remarkably beneficial, other fats can be associated with poor health. omega-3 oils are a specific group of polyunsaturated fatty acids, the main building blocks of most fats and oils. Omega-3 oils are required for ongoing health and vitality and provide consumers with benefits across various areas, including heart disease, stroke, rheumatoid arthritis, some forms of cancer, and other disorders.

Omega-6 (n-6) is a polyunsaturated fatty acid precursor of potent lipid mediators, termed eicosanoids, essential in regulating inflammation. Eicosanoids derived from n-6 polyunsaturated fatty acids (e.g., arachidonic acid) have pro-inflammatory and immunoreactive functions (Wall et al., 2010). Polyunsaturated fatty acids contain two or more double bonds classified as omega-3 (n-3) and omega-6 (n-6) based on the last double bond's location relative to the molecule's terminal methyl end. PUFA is essential to all cell membranes and influences membrane fluidity, membrane-bound enzymes, and receptors' behavior. PUFAs regulate many body functions, including blood pressure, blood clotting, and correct development and functioning of the brain and nervous systems (Das 2006). Among the different natural polyunsaturated fatty acids sources, fish and purified fish oils are the primary source of omega-3 polyunsaturated fatty acids rather than seed oils or microalgae (Habib and Sarkar, 2016).

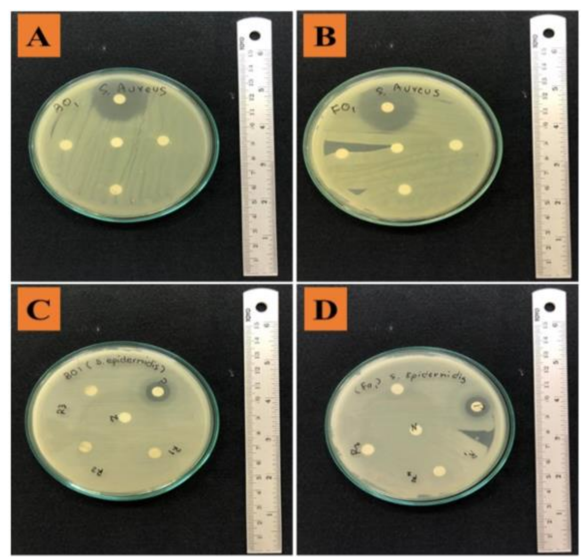

Figure 5. Antimicrobial activity and bacterial contamination test of freshwater fish oil (A-D)

The criteria for evaluating the quality of fish oil include the acidity index, peroxide value, iodine value, saponification value, the saturability and cis/trans configuration of fatty acids, and the unpleasant volatiles. Generally, crude fish oil has to undergo refining steps before being consumed or utilized as a food supplement (Song et al., 2018). The specific gravity of edible oil is lower than that of water and the difference in specific gravity of edible oils is relatively small, particularly amongst the common edible oils. Generally, the specific gravity of oil decreases with the increase in molecular weight and unsaturation level (Bako et al., 2017). The saponification value, peroxide value, viscosity, turbidity, specific gravity, melting point and smoke point of catfish oil were 196.30±0.63 mg KOH/g), 4.32±0.18 mEq/kg, 0.35±0.00 cSt, 4.48±0.26 NTU, 0.9027 g per cm², 33.0±1.5 °C and

192.3±8.5°C, respectively. The appearance of the untreated fish oil was reddish-brown, and the appearance of the treated fish oil was dark brown due to the prolonged heating period, which often oxidizes the oil and produces a dark color. This indicates that fish oil is only suitable in applications where bright color is not the primary consideration in its natural form. The oil color in a solid form at room temperature (30±5°C) estimated L*, a*, and b* were 82.66±3.10, 34.55±0.88 and 68.33±1.51, respectively, by a liquid form at 40°C L*, a*, b* were 58.29±0.03, -14.10±0.23, and -40.47±0.12, respectively.

Probiotic is the term as per WHO definition "live microbial feed supplement which beneficially affects the host animal by improving its intestinal microbial balance." As the definition indicates, most intestinal bacteria are essential to the digestive system. Earlier, probiotics were given to animals to improve their health, but later, much research has been put into developing probiotics for human health (Karmakar et al., 2012). The susceptibilities of isolates of Staphylococcus aureus (Figure 5A, B) and *Staphylococcus epidermidis* (Figure 5C, D) were determined against antimicrobial agents and two in combination using the oil.

Antimicrobial activity and bacterial contamination test of freshwater fish oil Figure 5 (A-D). The study results show that there is no effect of these gut microbes. Therefore, freshwater hybrid catfish oil is applicable and not harmful for human usage in daily life. Accordingly, probiotics and essential oils have great potential in terms of their beneficial effect against microbial gut infection. Since fish oil is edible, its extracts as food products do not have any side effects with low dosages. Therefore, these products may be very beneficial for human beings. However, much research must be put into these studies, as drug regulatory authorities still have strong regulations against using fish oil extracts as medicines.

In the context of the bio-circular-green economic model (BCG) (BCG) portfolio analysis, the oil extraction from freshwater hybrid catfish using a circular economy model could be classified as a 'Star' business. It possesses high growth potential due to the burgeoning interest in sustainable and renewable resources (Tongmee et al., 2020). Given its application across multiple sectors (food, pharmaceuticals, biofuels), the market demand is vast, making it a profitable venture. Additionally, innovations that make the extraction process more efficient add to its competitive advantage. The extracted fish oil's protein content can be analyzed for the Sodium Dodecyl Sulfate-Polyacrylamide Gel Electrophoresis (SDS-PAGE) application. This would be an essential aspect of quality control, ensuring that the oil meets the necessary standards for its intended uses, whether for food supplements, pharmaceuticals, or other applications. High-quality protein profiles can add to the product's market value. Also, SDS-PAGE can be employed in researching new, more efficient extraction techniques, possibly isolating enzymes or other catalysts that can further optimize the process. Therefore, the integration of sustainability innovation and circular economy principles into the oil extraction process from freshwater hybrid catfish shows significant potential for creating a business model that is financially robust, environmentally sustainable, and socially responsible.

4. Conclusion

Consumption of freshwater hybrid catfish (*Pangasius* sp.) oil catfish benefits human health and development. They provide essential nutrients to the human. Fish oil contains more polyunsaturated fatty acids, significantly affecting maintaining a healthy cardiac life. This study extracted fatty acid compositions of fish oil from the freshwater hybrid catfish adipose tissue. The amount of polyunsaturated fatty acids was 13.58±1.33%. The most significant amount of the ω-3, ω-6, and ω-9 fatty acids were found in the fish adipose tissue extracted oil content. Hybrid catfish are distinguished by having higher concentrations of unsaturated fatty acids than saturated fatty acids in the oil. Under the BCG economic model, oil extraction from freshwater hybrid catfish is a 'Star' business with high growth and profitability potential, particularly given its broad applications in food, pharmaceuticals, and biofuels. Innovative extraction methods enhance its competitive edge. This approach aligns financial gains with environmental sustainability and social responsibility.

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Conflict of Interest Declaration

The authors assert that no conflicts or personal affiliations might be construed as impacting the outcomes shared in this research.

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