Chapter 8:

Advances in Lipid Processing and Utilization: Mechanisms, Applications, and Halalan Toyyiban Concept

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Lipid processing and utilization are complex yet fundamental processes involving both natural and engineered mechanisms. In this chapter, the mechanisms and technological advances in lipid extraction are discussed, illustrating their various roles across industries, from food to biodiesel production. The utilization of lipids in the food industry is explored, focusing on their role in enhancing texture, flavour, and nutrition, as well as innovations in functional foods and nutraceuticals. Recent advancements in lipid utilization focus on bioavailability and targeted delivery, especially in pharmaceutical and cosmetics sectors, where lipids are engineered into nanoparticles and other carriers which were also highlighted in the chapter. The role of lipids in biofuel production is covered, emphasizing conversion processes to biodiesel and the potential of microalgae as a lipid-rich source, along with discussions on environmental impacts. The chapter concludes by discussing the Halalan and Toyyiban principles, highlighting the importance of ensuring that lipid processing meets standards of permissibility and wholesomeness while also addressing issues in lipid processing and utilization.

1 Introduction

Lipids are a heterogeneous group of biological substances that are soluble in fats, hydrocarbons, and other fat-based solvents but nearly insoluble in water (Rios et al., 2020). They are important macromolecules vital to energy reserves, signalling, and the integrity and operation of cellular membranes (Kiran & Venkata Mohan, 2021). Lipids play a significant role across diverse industries, including food, cosmetics, pharmaceuticals, and biofuels, owing to their versatile properties and functional benefits. In the food industry, lipids serve as essential components for flavour enhancement, texture modification, and nutritional enrichment in various products. They contribute to the sensory attributes of foods, such as taste, aroma, and mouthfeel, while also providing a concentrated source of energy and essential fatty acids. In cosmetics, lipids act as emollients, moisturizers, and barrier enhancers, helping to hydrate and protect the skin, hair, and lips (Ahmad & Ahsan, 2020). Moreover, lipids also serve as carriers for active ingredients and enhance the stability and efficacy of cosmetic formulations. In the pharmaceutical sector, lipids are utilized for drug delivery systems, enabling the targeted and controlled release of therapeutic compounds, and improving drug solubility, bioavailability, and stability (Jaiswal et al., 2016). Additionally, lipids are vital constituents of biofuels, serving as feedstocks for biodiesel production and contributing to renewable energy solutions. Overall, the complex and unique nature of lipids makes them invincible across these industries, driving innovation and advancing product development to meet increasing consumer demands and sustainability goals. This chapter provides a comprehensive discussion of the advances in lipid processing and utilization, specifically focusing on their mechanisms, technologies, and applications as well as the halalan toyyiban concept.

2 Mechanism of Lipid Extraction

Lipid extraction is a crucial process in multiple industries, including food production, pharmaceuticals, cosmetics and biofuels. The objective is to isolate lipids from biological sources like plants, microorganisms or animal tissues. This process is intricate due to the variations in tissue structure, texture, sensitivities and lipid content. An ideal solvent for lipid extraction should selectively target lipids while minimizing the

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simultaneous extraction of non-lipid components, ensuring the purity of the extracted lipids (Hwang et al., 2021). To maximize yield, the solvent must effectively extract a wide range of lipids such as triglycerides, phospholipids, sterols and free fatty acids.

The isolation of lipids associated with the cell membrane requires a blend of polar and non-polar organic solvents. The procedure includes several key steps: the solvents penetrate the cell membrane, reach the cytoplasm and interact with the lipid complex. Non-polar solvents interact with neutral lipids through van der Waals forces, while polar solvents bond with the polar lipids via hydrogen bonds, forming an inorganic solvent-lipid complex. This complex then detaches from the membrane and diffuses through it to enter the bulk solvent. The introduction of a polar solvent to a non-polar one enhances the extraction of neutral lipid complexes but also results in the co-extraction of polar lipids. By disrupting membrane structures and selectively targeting a wide range variety of lipid polarities, this dual-solvent method efficiently releases the lipids. Therefore, careful optimization of solvent properties is required for effective and selective extraction (Amaro et al., 2015; Schuhmann et al., 2012).

The choice of solvent is critical and depends on the specific types targeted. Polar lipids such as glycolipids and phospholipids have high solubility in polar organic solvents like alcohols. The effectiveness of these solvents stems from their ability to interact with the polar head groups of the lipids through hydrogen bonding and the other polar interactions. Unlike polar lipids, non-polar lipids such as triacylglycerols exhibit greater solubility in non-polar solvents such as hexane. Non-polar solvents can engage with the hydrophobic tails of the lipids via van der Waals forces and other non-polar interactions (Hewavitharana et al., 2020). A common combination is non-polar chloroform and methanol, which have a high capacity to dissolve lipids with varying polarities. This solvent mixture can efficiently disrupt membranes and denature lipoproteins, therefore improving the overall efficiency of lipid extraction (Schreiner, 2006).

The Folch method and the Bligh and Dyer method are conventional techniques for extracting lipids, which include the use of a combination of chloroform and methanol. The Folch method calls for a 2:1 (v/v) mixture of chloroform and methanol, followed by the addition of water. The mixture separated into two different phases, with the lipids recovered from the chloroform-rich phase. Bligh and Dyer later improved on this approach, resulting in a rapid procedure for complete lipid extraction (Saini et al., 2021). Both methods are highly effective due to their ability to dissolve a wide range of lipid types, using the differential solubility properties of chloroform and methanol to achieve complete lipid extraction from varied biological matrices. Despite their limitations, the Folch and Bligh-Dyer methods have long been regarded as the "gold standards" for lipid recovery (Cossignani et al., 2019). Meanwhile, the Soxhlet extraction method is a long-standing approach for extracting lipids, particularly for non-polar lipids, from solid and semi-solid substances. However, extraction time and temperature are critical parameters that influence extraction efficiency and lipid recovery. Prolonged extraction time and high temperature may raise the risk of thermal degradation of the lipids being extracted (Zhang et al., 2018).

Cell wall disruption is a key component of all these lipid extraction techniques, particularly when working with biological sources like plants, algae and microorganism. Efficient disruption facilitates the release of lipids enclosed within cells, making them accessible for later extraction processes. Figure 8.1 shows several mechanisms and methods that are used to effectively disrupt the cell wall. This step is essential to ensure that the extraction methods can access the lipids effectively.

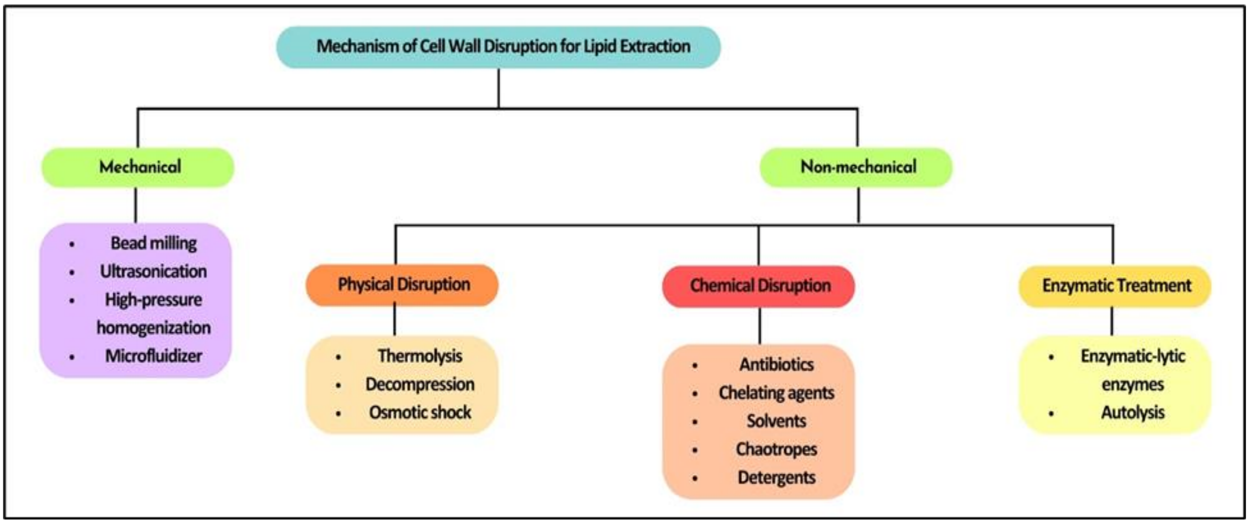

Figure 8.1: Methods used to disrupt cell walls for efficient extraction of lipids

Following cell wall disruption, the effectiveness of lipid extraction can be significantly enhanced. Mechanical lysis is a very efficient method for lysing a wide variety of cells. However, the use of this method gives rise to several problems such as heating of the sample volume, degradation of cellular products, accumulation of cell debris and higher operational cost (Islam et al., 2017). The high mechanical force used in mechanical lysis can generate heat, potentially causing the thermal degradation of sensitive cellular components, and affecting the quality and yield of retrieved lipid. Furthermore, cell disruption causes the release of cellular debris into the lysate, complicating subsequent downstream processing and purification steps. The presence of cell debris may require additional centrifugation of filtration steps to clarify the lysate and isolate the desired lipid fraction. Aside from mechanical lysis, non-mechanical methods of cell disruption offer alternate methods for lipid extraction. These procedures are gentler and more targeted, allowing for the preservation of lipid integrity and other cellular components. The selection of the extraction method is determined by the biological source and the specific requirement of the extraction process, with a focus on efficiency, cost-effectiveness and lipid integrity.

3 Technological Advances in Lipid Extraction

The efficient extraction of major and minor lipids is highly dependent on the selection of appropriate methods. The selection of these methods is determined by various parameters, including the source of the sample (plant or animal), its physical state (tissue or fluid), the moisture content, and the lipid composition (Saini et al., 2021). Moreover, the choice of extraction methods may also be influenced by the specific planned use of the extracted lipids. Consequently, the techniques used to extract lipids need to be tailored to match the particular traits of the microorganism being studied.

The efficiency, speed and sustainability of lipid extraction have been greatly improved by technological advancements. One of the notable advancements in this field is supercritical fluid extraction (SFE), which has attracted increasing attention in recent years as an alternative to conventional extraction techniques. This technique integrates the processes of extraction and separation into a single step by employing supercritical fluids such as carbon dioxide (CO2), to achieve highly pure and non-toxic products (Sivakumar et al., 2022). Arturo-Perdomo et al. (2021) conducted a study to extract the pure fraction of polar lipids from blackberry (Rubus glaucus) and passion fruit (Passiflora edulis) seeds using supercritical carbon dioxide under specific temperature and pressure conditions. It was highlighted that SFE is capable of preserving the bioactive compound present in the raw material. The study revealed that oleamides derived from oleic acid, particularly 9-octadecenamide were identified as the main compounds in both blackberry and passion fruit seed oils. The passion fruit seed oil was found to be rich in linoleic acid, whereas the extract from blackberry contained significant concentrations of vanillin. Another study by

Rodríguez-España et al. (2021) applied SFE to Schizochytrium algae biomass focusing on various pre-treatments and investigating the effects of pressure and temperature on lipid yields and docosahexaenoic acid (DHA) concentration. Pre-treatment, specifically grinding, increased extraction efficiency from 30% to 76%, resulting in 34.29 g of lipids/100 g of dry biomass and 17.51 g of DHA/100 g of dry biomass (51% DHA content). Compared to other solvent-based methods, SFE with pre-treatment allowed for higher lipids yield and DHA concentrations in shorter extraction times.

In addition to SFE, the incorporation of ultrasound-assisted extraction (UAE) has enhanced lipid extraction efficiency by enhancing mass transfer rates and disrupting cell structures (Deng et al., 2022). UAE was employed to extract lipids from papaya pulp and peel using soybean oil and sunflower oils as environmentally friendly solvents. According to the study, lycopene was identified as the most abundant carotenoid in the extracts, with high extraction yields of 94% and 95% from papaya pulp, and 81% and 82% from papaya peel using soybean oil and sunflower, respectively. The use of UAE with vegetable oils provides a sustainable and eco-friendly approach to lipid extraction from papaya pulp and peel. (Santos et al., 2024) investigated the lipid extracts from four different colours of peach palm (Bactris gasipaes Kunt) fruits – red, yellow, green and white – using a green method based on ethanolic UAE. The extracted lipids were of high quality based on Codex Alimentarius parameters. The extracts also exhibited fatty acid profile rich in unsaturated fatty acids, particularly omega-3, omega-6 and omega-9. The red peach palm lipid extract had the highest β-carotene content (748.36 μg/100 g of lipid extract) compared to other colours. The study highlighted the efficacy of the green extraction method in preserving the quality of the lipids.

Other than SFE and UAE, there are several other advanced techniques for lipid extraction. These include Microwave-Assisted Extraction (MAE), which uses microwave energy to enhance efficiency and reduce solvent consumption (Rezaei Motlagh et al., 2021; Zghaibi et al., 2020); Pulsed Electric Field Extraction (PEF), employing high voltage pulses to disrupt cell membranes and release lipids (Krishnegowda et al., 2023); Enzyme-Assisted Extraction (EAE), which uses enzyme to degrade cell walls and improve biomass extraction (Aitta et al., 2021; Rahmawati et al., 2019); Pressurized Liquid Extraction (PLE), applying high pressure and temperature to enhance lipid recovery (Ferreira de Mello et al., 2021; Piasecka et al., 2023; Señoráns et al., 2020); Subcritical Water Extraction (SWE), using water at sub-boiling temperature to extract lipids without organic solvents (Díaz-Reinoso et al., 2023; Hou et al., 2024; Krishnamoorthy et al., 2023) and Deep Eutectic Solvents (DES), employing environmentally friendly solvents for sustainable lipid dissolution (Lo et al., 2023, 2024).

4 Utilization of lipids in food industry

Lipids are condensed sources of energy and fat-soluble vitamins which are essential components of most biological systems and diet (Zheng et al., 2019). Lipids are important elements for human diets as they supply fatty acids and are also crucial for the development of flavour, off-flavour, and odour, as well as imparting energy, texture, and mouthfeel (da Silva Santos et al., 2019; Shahidi & Hossain, 2022). Lipids, whether simple, complex, or derived, can be used to make various foods. The lipid content of food is generally strongly correlated with its quality as food with lipids has a variety of appealing characteristics, such as mouthfeel, texture, structure, flavour and colour (Montesano et al., 2018). The lipid category encompasses not just fats and oils, which are esters formed from the trihydroxy alcohol glycerol and fatty acids, but also compounds that contain functional groups derived from phosphoric acid, carbohydrates, or amino alcohols, along with steroid compounds like cholesterol (Shamim et al., 2018).

Food lipids, whether innate or added as enhancers, act as a heat transfer medium during food processing, imparting an appropriate texture and flavour (Wang et al., 2023). According to (Suleman et al., 2020), intramuscular fat plays a significant role in the palatability of meat because of its unique contribution to the juiciness, flavour, and tenderness of the meat. In addition, fat also helps cakes, biscuits, and crackers last longer by imparting flavour and delaying the absorption of water by starch granules (Colla et al., 2018).

Healthy lipid sources and formulations are becoming more and more in demand from consumers. In response, the food industry is creating products that are lower in trans-fat, enhanced with omega-3, and have lower levels of saturated fat. Furthermore, because of their claimed health advantages and sustainability, plant-based oils and fats are becoming more and more popular. For example, products from rapeseed oil shown significant for human health as it has a low content of saturated fatty acid (SFA), a high level of monounsaturated fatty acid (MUFA) (oleic acid) and PUFA (omega-3 and omega-6) and high content of tocopherols and phytosterols. SFA are vital because they may boost blood lipid levels while unsaturated fatty acids can reduce blood lipid levels. Compared to SFA, unsaturated fatty acids may have a favourable impact on human blood lipid levels (Raboanatahiry et al., 2021). According to (Duhan et al., 2020), medium-chain fatty acids increase the expression of lipoprotein lipase and activate lipase, which increases the rate of lipolysis and reduces the buildup of fat. Therefore, obesity can be prevented and treated with medium-chain fatty acids. In addition, a diet high in medium-chain fatty acids lowers blood levels of LDL and LDL-cholesterol than traditional edible oils, which include long-chain, saturated triglycerides.

Nutraceuticals and functional foods are crucial in preventing and treating illnesses and disorders linked to specific lifestyles. Food can be classified as functional due to its nutritional components that support a healthy lifestyle and contribute significantly to health in ways that go beyond basic traditional nutrition and provide specific benefits, such as minimizing the risk or treating chronicle disease as well as positively affecting the body, additionally, they are less toxic than synthetic drugs (do Prado et al., 2018; Khalaf et al., 2021). Nutraceuticals are foods or parts of foods that originate from essential component-rich foods and have therapeutic effects to improve health, including illness prevention and treatment. Its advantageous elements can be separated and refined from marine, animal, or plant sources (Chandra et al., 2022; Khalaf et al., 2021). Functional foods are ingested daily, whereas nutraceuticals are typically taken as pills, capsules, and tablets, similar to prescription drugs (Chandra et al., 2022; Nieri et al., 2023). Although they can't take the place of pharmaceuticals, nutraceuticals can help prevent and treat some pathological disorders - (Chandra et al., 2022; Khalaf et al., 2021). However, the right interpretation of functional foods and nutraceuticals is still up for debate. In recent years, researchers and manufacturers have focused on the innovation of food and nutraceutical products. The primary focus is on substituting conventional components linked to inadequate diet and incorporating components that may confer supplementary health advantages to diet.

The use of lipids in edible coating and film application has gained popularity recently due to the hydrophobic materials that are typically used as a barrier against water-vapor transfer because of their polar characteristic. Lipid compounds' resistance to gas and vapour transfer during mass transfer is typically attributed to their hydrophobic nature and structure. Lipids are used as components of edible films and coatings that are designed to preserve grains, poultry, fish, fruits and vegetables. They have also been used to preserve candy, and complex and heterogeneous foods, including processed, frozen, cured, and fresh food items. Edible coatings and films that include lipids can be applied to a variety of foods and have been demonstrated to have a crucial role in their preservation. Appropriately composed edible coatings and films can be used by almost every segment of food manufacturing to address issues related to the processing and promotion of food products that are safe, nourishing, stable, affordable, and of high quality (Yousuf et al., 2022).

Several lipid bio-based components derived from plant and marine sources are used to reformulate meat products. Adding a healthy oil directly to the emulsified batter, either with or without an emulsifier such as sodium caseinate, is the easiest method to enhance the nutritional value of meat products. Encapsulating oil is widely used for frankfurter making as it has various advantages over direct emulsification, including the ability to mitigate lipid oxidation and conceal unusual or unpleasant odours (Domínguez et al., 2021). The functional properties make lipids a promising source in the food and nutraceutical industry. Some lipophilic bioactive components of nutraceuticals, such as fatty acids, carotenoids, and Co-enzyme Q10 have gained attention for their incorporation into food formulations and the production of functional products because of their notable health advantage. However, it is not possible to add these nutraceutical substances straight to food and beverage because some of the issues impeding the application and lowering the effectiveness of these compounds in preventing diseases include poor water solubility and bioavailability, a high melting point, chemical instability and sensitivity to deterioration during processing, storage, and digestion, as well as undesirable sensory attributes (Soleimanian et al., 2020).

The utilization of phospholipid vesicles, or liposomes, is one encapsulation technique that has drawn a lot of interest in the food and pharmaceutical industries. According to scientific definitions, liposomes are closed, continuous, bilayer structures mainly composed of phospholipid molecules. Encapsulation technology is a technique used in the nutraceutical and food industries to preserve delicate components, regulate the dissolution of core material, physically divide reactive or incompatible materials, and prolong product shelf life (Zarrabi et al., 2020). A recent area of interest in the food sector is nanotechnology. Consequently, because of the encouraging outcomes linked to the possible application of functional qualities in food products, such as physical and chemical stability, protection and controlled release of bioactive compounds, and enhanced solubility of lipophilic compounds (da Silva Santos et al., 2019).

Novel food ingredients were developed based on low-energy by-products with health advantages. One of the most popular techniques for lowering or swapping out the unhealthful and controversial fats in food products is oleo gelation. Innovative oleo gels were created using fermentation processes that utilized by-products from the food industry, specifically sugarcane molasses and soybean processing residues. These by-products were fermented by the oleaginous yeast Rhodosporidium toruloides to generate microbial oil. Oleo gels have been used to produce a wide range of food products, such as spreads, baked goods, candies, dairy products, and meat products. In addition to replacing trans and saturated fats, they are utilized for other important reasons, including binding oils, stabilizing products without the need for emulsifiers, transporting water-insoluble bioactive chemicals, and giving the products heat resistance (Puscas et al., 2020).

5 Lipid Utilization in Cosmetics and Pharmaceuticals

Lipid utilization in pharmaceuticals and cosmetics is a rapidly growing field, driven by the unique properties of lipids that enhance product efficacy and safety. Since the early twentieth century, products like fish oils, shark cartilage, shark liver oil, and vitamins have been marketed. However, many of their health claims were initially anecdotal and lacked rigorous scientific validation. Today, there is a more comprehensive understanding of the biological properties of lipids, leading to their expanded application in pharmaceuticals and cosmetics. This includes their roles in disease prevention and treatment, as excipients and co-adjuvants, transdermal carriers, and skin emollient agents.

Lipids are a diverse and distinct group of natural organic compounds found in plants, animals, and microorganisms, playing several critical roles in biological systems. Derived from the Greek word “lipos,” meaning fat, lipids include a broad range of molecules including fatty acids, triglycerides, phospholipids, and sterols such as cholesterol. Different types of lipids serve various functions in cosmetic formulations through multiple mechanisms. Table 8.1 lists different functions and types of lipids commonly used in cosmetic products. Lipids and their derivatives in cosmetic formulations perform various functions, including forming a protective barrier on the skin to keep out external elements and maintain hydration by reducing water loss through mechanisms like occlusion, which involves creating a waterproof film on the skin (Duprat-De-Paule et al., 2018). Substances typically used for these aims are fatty acids, hydrocarbons, fatty alcohols, sterols, phospholipids, and vegetable waxes. Deficiencies in cutaneous lipids cause significant discomfort, which may develop into serious skin diseases. In the cosmetics industry, lipids contribute to the formulation of moisturisers, emulsifiers, and other skin care products, providing essential hydration and barrier protection (Ahmad & Ahsan, 2020). Acting as emollients, lipids moisturize and soften the skin by forming a protective barrier that reduces water loss, ensuring sustained hydration and a smooth texture. Skin softness and smoothness are due to the capacity of thin oily substances to temporarily deposit between corneocytes making their edges smoother. Additionally, lipids contribute to the skin's defence system, protecting it from environmental aggressors and potential irritants, while also aiding in repair and restoration processes (Franco et al., 2021). Other than that, lipid-based carriers have gained prominence for delivering active ingredients, mainly due to their ability to load different compounds with hydrophobic or hydrophilic nature. Different types of lipid-based delivery systems, like microemulsions, liposomes, solid lipid nanoparticles (SLN), and nanostructured lipid carriers (NLC) are being explored (Garcês et al., 2018). Lipid nanocarriers are preferred over polymeric nanoparticles because they can resolve the challenges associated with polymeric nanoparticles, such as cytotoxicity and lack of suitable methods for large-scale production (Haider et al., 2020). Another use of lipids in cosmetics is being used as surfactants and emulsifiers in cosmetic products to reduce surface tension between the skin and the product and to maintain the mixture of water and oil. Surfactants, owing to their chemical structure with both hydrophobic and hydrophilic components, lower surface tension and enable the formation of stable emulsions between liquids of differing polarities. In cosmetics, polyethylene glycol ethers have traditionally been the most commonly used commercial surfactants. However, there is a growing trend towards the use of biosurfactants, such as glycolipids, lipopeptides, phospholipids, fatty acids, and polymeric compounds. Glycolipids are the most frequently used biosurfactants in cosmetics and personal care products due to their excellent physicochemical properties, biological activities, biocompatibility, and biodegradability. These attributes make glycolipids become multifunctional ingredients in cosmetic formulations (Ahmad & Ahsan, 2020).

Table 8.1: *Different functions and types of lipids commonly used in cosmetic products (De Luca et al., 2021)*

Function	**Commonly used lipids**
Moisturizing and softening properties	Hydrocarbons, fatty acids, fatty alcohols, triacylglycerols, waxes, phospholipids, sterols
Surfactant and emulsifier agents	Phospholipids, glycolipids, lipopeptides, fatty acids
Texturizer agents	Waxes, alkenones, triacylglycerols
Colour carriers	Isoprenoids
Fragrance carriers	Essential oils, triacylglycerols
Preservative agents	Glycerolipids, sphingolipids
Active ingredients	Glycerolipids, sphingolipids, sterols, isoprenoids, flavonoids
Molecule delivery	Phospholipids

One of the uses of lipids in cosmetics products was evident in a study by (Manca et al., 2016) which studied the combination of two lipids consisting of argan oil and phospholipids for the development of an effective liposome-like formulation able to improve skin hydration and allantoin dermal delivery. The formulations, particularly those enriched with argan oil, significantly enhanced allantoin accumulation in the skin. The effectiveness of the vesicles as skin delivery systems was compared to that of allantoin in water dispersion and a commercial gel, Sameplast®. It is shown that the use of argan oil-enriched liposomes helps to soften and relax the skin, thereby facilitating drug accumulation and penetration. Likewise, lipids from green microalgae were also studied for their ability to be used in cosmetic products. These microalgae contain many active pigments such as carotenoids which have strong antioxidant and protective activity on human cells. The biological activity of an ethanol/water extract of the marine green microalga Tetraselmis suecica containing high levels of carotenoids such as the xanthophylls lutein, violaxanthin, neoxanthin, antheraxanthin and loroxanthin esters were investigated. This extract has a strong antioxidant and has tissue-repairing effects on reconstructed human epidermal tissue cells (EpiDermTM) indicating a potential cosmeceutical activity of this microalgal species (Sansone et al., 2017). Lipid-based drug delivery was also extensively studied as a cosmetic product. Virgin coconut oil and glyceryl monostearate were formulated as nanostructured lipid carriers for skin barrier improvement. In the study, when compared with the positive controls, which are Trolox and ascorbic acid, the nanocarrier shows the highest antioxidant value. Cell proliferation activity study indicates that the nanocarrier is not toxic to cells, and could potentially treat damage by ultraviolet B (UVB) irradiation (Azmi et al., 2020). alginate beads encapsulated with olive oil were integrated into semi-solid vehicles to create cosmetic products designed for elderly skin, serving as moisturizers and photo-protectants. The findings revealed that the specific type of olive oil used influences the antioxidant activity and polyphenol content. In vitro tests demonstrated UV protection, while in vivo tests showed a moisturizing effect (Mota et al., 2018).

Lipids play a crucial role in pharmaceuticals, enhancing the efficacy, stability, bioavailability, and delivery of various medications. Their versatile functions as carriers, stabilizers, and penetration enhancers are critical in producing effective pharmaceutical products. Lipids have long been fundamental components of pharmaceutical dosage forms. Even in early civilizations, the preparation of pills and ointments often included various lipids, such as oils and waxes, in their medicinal formulations (Siepmann et al., 2019). Today, the use of controlled release for drugs and bioactive substances is expanding rapidly, with lipids playing a significant role in developing new pharmaceutical products. Controlled-release delivery systems enable pharmacologists to enhance drug efficacy and better assess patient tolerance. Applications include delivery systems for cancer treatments, bacterial and fungal infections, and respiratory diseases. Drugs are delivered primarily intravenously, orally, and transdermally, with transdermal and oral applications rapidly advancing due to the important role of lipids (Neupane et al., 2021). A significant role of lipids in pharmaceuticals is enhancing drug delivery. One of the most promising carriers for this purpose is liposomes, small artificial vesicles made from amphiphilic molecules, including lipids such as cholesterol and natural phospholipids, which influence their rigidity or fluidity. Widely used in the cosmetic and pharmaceutical industries, liposomes can encapsulate both hydrophobic and hydrophilic compounds, protecting unstable molecules like antibiotics, antioxidants, and biomolecules, and releasing them to targeted areas (Ahmad & Ahsan, 2020). However, liposomes have some drawbacks, such as burst release of active compounds, solubility limitations, high production costs, and susceptibility to oxidation and hydrolytic reactions of phospholipids. To address these issues, lipid-based particulate systems were introduced in the early 90s and have significantly evolved. The advancements have led from preliminary liposomal formulations to more advanced nanosystems like solid lipid nanoparticles (SLNs) and nanostructured lipid carriers (NLCs), which effectively overcome many of the limitations associated with conventional liposomes (Antunes et al., 2017). Lipid nanoparticles can significantly enhance the solubility, bioavailability, pharmacokinetic parameters, intestinal absorption, skin penetration, and ocular residence time of drugs. This improvement aids in crossing physiological barriers and reducing side effects. Consequently, these drug delivery carriers show considerable promise in pharmaceutical and medical applications (Dhiman et al., 2021). The present study by Mancini et al., (2021) explores the use of SLNs, prepared using a fusion-emulsification method, to increase skin permeation and in vivo activity of two relevant NSAIDs: Etofenamate, a liquid molecule and ibuprofen, a solid one, formulated in a 2% hydroxypropyl methylcellulose gel through the gelation of SLN suspensions. Formulated SLNs possessed high encapsulation efficiency (>90%), a mean particle size of <250 nm, a polydispersity index <0.2, and were stable for 12 months. In vitro permeation, using human skin in Franz diffusion cells, showed increased permeation and similar cell viability in Df and HaCaT cell lines for SLN formulations when compared to commercial formulations of etofenamate (Reumon® Gel 5%) and ibuprofen (Ozonol® 5%). In vivo activity in the rat paw oedema inflammation model showed that SLN hydrogels containing lower doses of etofenamate (8.3 times lower) and ibuprofen (16.6 times lower) produced similar effects compared to the commercial formulations while decreasing oedema and inflammatory cell infiltration, and causing no histological changes in the epidermis. These studies demonstrate that encapsulation in SLNs associated with a suitable hydrogel is a promising advancement in the pharmaceutical field. A recent study from Ahmadi et al., (2020) utilized gelatin/hyaluronic acid (HA) scaffolds containing different amounts of atorvastatin-loaded nanostructured lipid carriers (NLCs) coated entirely with polycaprolactone (PCL) film were fabricated for skin regeneration. Results revealed that the novel gelatin/HA/PCL nanocomposite scaffold containing 54.1 wt% atorvastatin-loaded NLCs can be a good candidate for skin regeneration. Other than that, nanostructured lipid carriers (NLCs) were also developed as an oral delivery system for Tilmicosin where the results indicate that NLCs are a potential delivery carrier for improving the solubility, permeability and oral bioavailability of Tilmicosin (Zhang et al., 2020). Lipids are essential in pharmaceuticals, offering diverse benefits that enhance the efficacy, stability, and delivery of medications, with advanced lipid-based systems like lipid nanoparticles showing significant promise for future pharmaceutical applications.

In conclusion, lipid utilization in pharmaceuticals and cosmetics represents a rapidly growing field, owing to the unique properties of lipids that enhance product efficacy and safety. Lipids play diverse roles in cosmetic formulations, from serving as moisturizing agents to acting as carriers and penetration enhancers, contributing to their effectiveness. Moreover, the advancements in lipid-based drug delivery systems, such as liposomes and lipid nanoparticles, have addressed various limitations associated with conventional formulations, increasing the potential for enhanced drug delivery and therapeutic outcomes.

6 Lipid Processing in Biofuel Production

Energy security, environmental concerns, concerns, and climate change issues are driving a global search for renewable energy sources (Ehsanullah et al., 2021; Kumar, 2019). The global energy landscape is shifting due to the urgent need for renewable and environmentally friendly alternatives to fossil fuels. Multiple countries, including Malaysia, Indonesia, Argentina, the United States, Brazil, and the Philippines, together with countries in the European Union (UN) are practising and utilizing biodiesel as a sustainable renewable source and biodegradable energy option (Ibrahim, 2019; Pratiwi and Juerges, 2020). Biodiesel is a fuel derived from lipids found in plants and animals (Elgharbawy et al., 2021; Venkateswaran et al., 2022). It is an alternative fuel obtained from fats and oils and offers a promising solution to conventional diesel fuel. This renewable option offers a significant advantage. However, despite its environmental benefits, there are drawbacks which remain significant challenges in the production. To address this economic barrier, researchers are actively exploring alternative feedstock options with lower costs.

6.1 Conversion of Lipids to Biodiesel

Used cooking oils, non-edible plant oils, and even lipid-rich microalgae are being investigated as potentially viable sources (Elgharbawy et al., 2021; Bender et al., 2022). This shift towards utilizing non-edible feedstocks represents significant steps towards ensuring the long-term sustainability of biofuel production. In parallel with the exploration of alternative feedstocks, the ongoing research into optimizing biodiesel production methodologies holds considerable promise for the widespread adoption of biofuels. Using edible oils as a primary source of biodiesel poses ethical and environmental issues. The contemporary approach focuses on producing biodiesel from waste oils, waste fats, and non-edible oil sources such as jatropha and castor oils (Fasanya et al., 2022; Vilas Bôas and Mendes, 2022). The use of low-quality raw materials necessitates the development of more efficient processes, such as renewable diesel technologies and the application of solid catalysts in the transesterification process to yield higher-quality fatty acid esters (FAME) biodiesel (Gardy et al., 2019; Wang et al., 2023).

The physical state of fats and oils, solid versus liquid at room temperature, offers a glue to their chemical makeup (Zahiri et al., 2020). Both fats and oils are categorized as lipids, and their primary building block is a molecule called triglyceride (TG) (Elgharbawy et al., 2021; Pereira et al., 2020). This triglyceride consists of a glycerol molecule bonded to three long-chain fatty acids (Karmakar and Halder, 2019; Razzak et al., 2022). Unfortunately, the high viscosity and lower volatility of these lipids (de Lima et al., 2019; Gamayel et al., 2022), regardless of their physical state, make them unsuitable for direct use as fuel in standard diesel engines. They added more vegetable oils that can be improved through various methods; transesterification appears as the most effective approach for biodiesel production. This chemical reaction transforms TGs (the main component of vegetable oils) into fatty acid methyl ester (FAMEs), the main ingredient in biodiesel (Alvarez et al., 2019; de Lima et al., 2019; Gamayel et al., 2022). The process essentially involves replacing the glycerol backbone in TGs with an alcohol molecule, typically methanol (MeOH) (Wang et al., 2023; Park et al., 2024). To convert TGs into biodiesel, it must undergo a chemical reaction called transesterification that occurs in a series of three consecutive reactions, with intermediate products like diglycerides and monoglycerides forming along the way (Shrivastava et al., 2020). The most crucial aspect of transesterification is the catalyst, typically a base like sodium hydroxide (Maleki et al., 2022). The type and amount of catalyst significantly influence the reaction rate and yield. Compared to hydrolysis, which uses water, transesterification utilizes alcohol, leading to the term "alcoholysis" (Wang et al., 2023). While methanol is the most common alcohol used, other options like ethanol are also being explored. The primary advantage of transesterification lies in its ability to significantly reduce the viscosity of vegetable oils (de Lima et al., 2019; Gamayel et al., 2022). This lower viscosity makes the resulting biodiesel more compatible with engines, enabling easier combustion. Additionally, the properties of biodiesel produced through transesterification closely resemble those of conventional diesel fuel, further enhancing its usability (Ghosh and Halder, 2022). In short, vegetable oils which are enriched with TGs are subjected to a transesterification process to become FAME, which is the primary component of biodiesel, a renewable fuel that can be used in diesel engines confirmed by several studies.

6.2 Microalgae and Other Lipid-Rich Sources for Biofuel

Microalgae have garnered significant interest from environmentalists and biologists as a promising feedstock for biodiesel production. Among lipid-producing organisms, they are recognized as an efficient candidate due to their ability to thrive in brackish or saline water (Sirajunnisa and Surendhiran, 2016). Their photosynthetic nature, capacity to absorb industrial flue gas, growth in wastewater, high oil yield, and minimal impact on the food chain further enhance their suitability for biodiesel production (Peng et al., 2020; Amit et al., 2021). Zhang et al., (2020) highlighted that third-generation biodiesel can be produced by cultivating microalgae with high lipid content. An emerging fourth generation of biofuels aims to genetically engineer specific algal species to enhance biomass growth and lipid yield. Microalgae, diverse autotrophic organisms, synthesize food using light, water, carbon dioxide, and essential nutrients (Dolganyuk et al., 2020). Due to their high CO2-fixing abilities, lipid-rich algae are an appealing biodiesel feedstock (Almomani et al., 2023). During their growth, microalgae absorb around 183 gigatons of CO2 and generate about 100 gigatons of algal-cell biomass (Singh et al., 2018; Wood, 2021). Their photosynthesis rate is notably higher than that of traditional crops (Musa et al., 2019). Wood et al., (2021) reported that when compared to other terrestrial crops with microalgae, the potential for microalgae to produce is ten times more biodiesel per unit area. Among the species that were utilized and reached high concentrations of targeted biofuels such as Chlorella protothecoides, Scenedesmus obliques, Nannochloropsis salina and Acutodesmus obliquus (Grobler et al., 2021; Rahul et al., 2021; Wood et al., 2021). Along with this, the current cost of cultivating microalgae is higher than conventional crops.

Another significant factor affecting biodiesel production is availability and the types of sources (non-edible, edible, or waste). According to studies by Elgharbawy et al., (2021) and Bender et al., (2022), vegetable oils are broadly categorized into edible oils (such as palmitic oil, sunflower oil and soybean oil) and non-edible oils (such as karanja, jatropha oil and rubber seed oil) can be modified into more engine-friendly forms through processes like microemulsion, pyrolysis and transesterification (Aktas et al., 2021; Khan et al., 2023). Pyrolysis of vegetable oils yields low-viscosity products with high cetane numbers (Irawan and Hasan, 2021) and acceptable sulphur, water, and sediment levels (Thangaraj and Solomon, 2020). However, these products have high ash content, carbon residues and pour points, making them less desirable. Gebremariam and Marchetti (2021) explained that micro-emulsions lower the viscosity of vegetable oils but can cause issues such as irregular injector needle sticking heavy carbon deposits, and incomplete combustion. The use of vegetable oils in diesel engines traces its roots in 1895 when Dr Rudolf Diesel developed the first diesel engine designed to run on vegetable oil. He demonstrated his engine at the World Exhibition in Paris in 1900 using peanut oil (Long et al., 2021). The beginning of low-cost petroleum products eventually replaced vegetable oils in engines. However, the energy crises of the 1970s saw urgency in the use of vegetable oils and alcohol as engine fuels. Today, rising crude oil prices and growing environmental concerns have renewed interest in vegetable oils and their derivatives for engine applications (Erdogan et al., 2020). The high viscosity of vegetable oil can lead to poor atomization, incomplete combustion, injector clogging, ring carbonization, and the accumulation of fuel in lubricating oils (Igbax, 2023). To address these issues and enhance performance, it is crucial to reduce the viscosity of vegetable oil. This can be achieved by diluting vegetable oils with materials like diesel fuel, solvents, or ethanol. Blending vegetable oil with diesel fuel has shown significant advantages, requiring minimal processing and engine modifications (Wu and Choi, 2020). Because of these properties, vegetable oils are viable for short-term use in diesel engines. Tripathi and Poluri (2021) found high CO2-fixing capabilities of lipid-rich algae, another promising biodiesel feedstock, highlighting the on-going interest in finding sustainable alternatives to petroleum-based fuels. For example, third-generation biofuels can be produced by cultivating microalgae with high lipid content. Furthermore, they mentioned that fourth-generation biofuels aim to genetically engineer algal species to enhance biomass growth and lipid yield.

Conversely, waste fats from animals such as chicken oil, chicken fat and fish oils are characterized by lower saturated fatty acids (this condition occurs after a pre-treatment before the process of transesterification) Hasan and Ratnam (2022), oxidative stability (Hazrat et al., 2021), good calorific value (Ganesha et al., 2023), higher heating value (Fassinou et al., 2010), zero corrosivity (Ganesha et al., 2023) and rapid ignition (Hasan and Ratnam, 2022) made them as an interesting option into biodiesel. In addition, their cost is much lower in comparison to vegetable oils. Another significant source of biodiesel feedstock is waste cooking oil, which encompasses yellow and brown grease and does not compete directly with food security. Another potential source to produce biodiesel is yellow grease, which has fatty acids (FFA) maximum or less than 15% and proves to be a low-cost material for biodiesel production compared to brown grease (Mićić et al., 2019). It is because the brown grease has exceeded the 15% FFA and poses challenges to biodiesel production (Bangar et al., 2024).

6.3 Environmental and Economic Impacts of Lipid-Based Biofuels

Biodiesel has caught the attention of conventional fossil fuels because of relevant technologies and its environmental benefits as well as economic opportunities. The US DOE (Department of Energy) reported biodiesel potentially significantly reduces greenhouse gas emissions (GHG) compared to fossil fuels as the released CO2 is absorbed by the feedstock during the biodiesel growth phase (Aljaafari et al., 2022). This is also showing positive energy saving and balance in the production cycle (Kularathne et al., 2019). Furthermore, biodiesel also promotes a green environment since the production itself derived from biomass natural sources or waste crop material aids in maintaining sustainability (x). Leite et al., (2019) mentioned that soy biodiesel reduces carbon dioxide by 78% on a life cycle basis (Leite et al., 2019). They also sharply reduce pollution because of lower gas emissions such as carbon monoxide (CO), particulate matter (PM), nitrogen oxides (NOx), sulfur dioxide (SO2), and unburned hydrocarbons (HC) (O'Malley and Searle, 2021). Combustion of biodiesel typically results to the production of fewer pollutants compared to fossil fuels. In the year 2018, the National Biodiesel Board of USEPA (USEPA, 2020) reported the combustion of biodiesel (B100) as a transportation fuel decreased total HC by 67%, polycyclic aromatic hydrocarbon (PAH) by 80%, carbon emissions by 48%, and 100% deduction in sulphur emission, (Ogunkunle and Ahmed, 2019). These reductions lead to better air quality and minimize road transport pollutants. Converting used cooking oils and animal fats mitigates disposal issues while reducing waste. This is due to waste cooking oil (WCO) production causing serious discharge issues into water bodies in most situations (Singh et al., 2021; Yaqoob et al., 2021). Along with this, it degrades the water quality. Hence, the utilization of WCO as biodiesel feedstock will help to mitigate water pollution issues, clogging of sewer networks which need additional cleaning and also damaging the properties (De Feo et al., 2023; Foo et al., 2022). Studies by Ali et al. (2019) and Rehman et al., (2022) highlighted soil health degradation like soil erosion, nutrient depletion and soil fertility could decrease soil's productivity. Large-scale intensive agriculture for biofuels could be among the causes that affect soil health. Supported by Tabriz et al., (2021) and Haruna et al. (2020), several practices that can be done in biofuel production like crop rotation, cover cropping and nutrient management will help keep the soil healthy, and moisture, contribute to soil quality and prevent degradation.

Through the lens of economics, local production of biodiesel enhances energy security by utilizing various natural sources like non-food crops and waste oils which led to the dependence on imported fossil fuels and mitigating supply disruptions. Datta (2022), Chia et al., (2022) and Majid (2020) agreed the renewable diesel industry also creates employment opportunities in agriculture, biodiesel production facilities, and research and development technologies, as well as for rural development where they can improve socio-economic and incomes. Incentives provided by the government, like subsidies, tax benefits and permission to mix biodiesel with normal fuel at certain percentages or requirements (Ebadian et al., 2020). All of these incentives help balance the higher production costs in biodiesel processing lines which are influenced by a few factors like feedstock prices (cost of raw materials), the technology used and the scale of production (Che Hamzah et al., 2020). With government support, the competitiveness of biodiesel and economic feasibility could be enhanced. Advances in technology, such as better catalysts, process improvements, and genetically engineered feedstock, can enhance efficiency, cut costs, and boost yields even more. Biodiesel indeed offers and proves its potential for economic and long-term benefits in the environment, which allows the utilization of current fuel distribution networks and secured demands in production facilities. These advantages led to the reduction in distribution costs, advocating for sustainable energy solutions, and positioning biodiesel in increasing energy security since they are less combustible than fossil fuels and petroleum.

In summary, lipid-derived biofuels offer a positive substitute for fossil fuels which benefit the environment and economy. Nevertheless, it is important to tackle challenges like land use consequences, water usage, manufacturing expenses, and competitiveness with food availability. Utilizing sustainable methods, technological advancements, and supportive regulations is essential for optimizing the advantages and reducing the limitations of biodiesel manufacturing.

7 Halalan and Toyyiban concept in lipid processing and utilization

The concept of Halal goes far beyond mere dietary restrictions, and various aspects of consumables and services, including lipid processing and utilization. In the context of lipids, adherence to Halal principles involves ensuring that all stages of processing, from sourcing raw materials to the final product, comply with Islamic Shariah law. This involves not only excluding prohibited substances such as pork and alcohol but also extends to ethical sourcing practices, including humane treatment of animals and environmentally sustainable production methods. Moreover, the concept of "toyyib," meaning good or desirable, emphasizes the importance of quality and wholesomeness in lipid products. Four verses in the Qur'an contain the integration of the words halal and toyyib, resulting in a halalan toyyiban phrase. The Qur'anic verses are in Al-Baqarah 2: 168, Al-Maidah 5: 88, Al-Anfal 8: 69 and An-Nahl 16: 114. A standard of quality is reflected when the word 'toyyib' is merged with the word halal (Hanapi & Khairuldin, 2017). The concept of toyyiban denotes the importance of quality and wholesomeness in the extracted lipids, emphasizing purity, nutritional integrity, and ethical sourcing practices. Ethical considerations extend to sourcing from suppliers that uphold animal welfare, environmental sustainability, and fair labour practices. Rigorous quality assurance protocols, including monitoring of extraction conditions and adherence to Halal-certified standards, ensure the integrity and safety of the extracted lipids. Most importantly, applying Halalan toyyiban principles in lipid extraction not only guarantees the permissibility of the final products for Muslim consumers but also upholds ethical and quality standards for all consumers, building trust and confidence in the product's integrity. Therefore, lipid processing and utilization must adhere to Halal standards to ensure product safety, efficacy, and ethical integrity, aligning with Islamic principles and meeting the needs of Muslim consumers.

While there has been a significant focus on ensuring that lipid processing and utilization adhere to Halalan Toyyiban principles, some challenges and issues need to be addressed. First of all, the usage of haram ingredients including any constituents derived from human body parts, blood, forbidden animal parts and insects, and prohibited or restricted chemicals that are harmful or injurious to consumers. For example, there are already studies that show that lipids from insects are a suitable replacement for personal care product formulations. To date, different lipids extraction methods from insects are exploited at a laboratory scale (Franco et al., 2021). Other than that, serious attention should be paid to food colouring from insects such as cochineal (E120), particularly in red velvet cake and crab sticks. Islam prohibits animals such as caterpillars, ants, cockroaches, scorpions, mosquitoes, flies, bees, and spiders. According to a fatwa given by the State Mufti of Brunei in June 2015, cochineal is prohibited in food because the insect is regarded as impure or najs. Even if only an extract or very small amounts of the insect are used to produce the colouring, it is still considered haram because the food colouring is still derived from the insect (Md Zainia et al., 2023). Additionally, the use of certain processing aids or additives may raise concerns regarding the lipids' Halal status, requiring thorough investigation and verification. For example, the usage of hexane which is considered harmful in the extraction of oil should be restricted (Cravotto et al., 2022). Other than that, critical ingredients in any products if they originated from sources (e.g., unspecified animals, halal animals slaughtered in an unspecified manner) and process of synthesis (incorporation of haram processing aids, contamination with haram or filth) nonconforming to the halal system. However, the use of alternatively sourced ingredients classified as "critical" may still be allowed to be part of a halal product after the manufacturer has secured halal certification for its origin and production, at the same time, uncontaminated with filth (Sugibayashi et al., 2019). The development of halalan toyyiban in lipid processing covers the concept of critically sourcing halal ingredients, applying halal practices in every step of the manufacturing process, and ensuring conformance of product performance to Islamic rituals. The halalan toyyiban concept should be applied in a suitable context while progressing with technology and time development.

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