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RESEARCH ARTICLE

Isolation for Omega 3 Omega 6 Fatty Acids and its Chemical Applications for Natural Resources

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Abstract: Omega-3 and omega-6 fatty acids are important classes of polyunsaturated fatty acids (PUFAs) It occurs in plant oils, marine organisms, microorganisms, and other biological resources. Their chemical structures, nutritional importance, oxidative behaviour, and functional properties have created interest in their isolation and purification for use in food chemistry, pharmaceuticals, cosmetics, biotechnology, and industrial formulations. However, the recovery of these fatty acids depends on the composition of the original material, the lipid class in which they occur, extraction conditions, and the stability of their multiple carbon–carbon double bonds. This review examines natural sources of omega-3 and omega-6 fatty acids and evaluates conventional and emerging methods for their extraction, separation, purification, and chemical characterization. Solvent extraction, mechanical pressing, enzymatic extraction, supercritical carbon dioxide extraction, chromatographic separation, and molecular distillation are discussed in relation to recovery efficiency, product quality, safety, and environmental performance. Gas chromatography coupled with flame ionization detection or mass spectrometry is considered for fatty-acid identification and quantification, following suitable derivatization. The review also examines chemical applications in functional food development, pharmaceutical and cosmetic formulations, biodegradable materials, oleochemicals, and biodiesel production. The literature indicates that no single isolation method is suitable for every natural resource or target fatty acid. Instead, an integrated process involving appropriate raw-material selection, controlled extraction, selective purification, oxidation prevention, and validated analytical measurement is required. Sustainable recovery from oilseed residues, fish-processing by-products, and microbial biomass offers opportunities to improve resource utilization.

Keywords: Omega-3 fatty acids, omega-6 fatty acids, polyunsaturated fatty acids, natural resources, extraction, isolation, supercritical carbon dioxide, chromatography, chemical applications, sustainable processing etc..

INTRODUCTION

Natural resources provide a wide variety of lipids that serve as sources of valuable fatty acids. Among these compounds, omega-3 and omega-6 fatty acids have received considerable attention because of their biological functions and potential applications in food science, pharmaceutical chemistry, cosmetics, and industrial biotechnology. They are classified as polyunsaturated fatty acids because their carbon chains contain two or more carbon–carbon double bonds [1], [2].

Omega-3 and omega-6 fatty acids differ in the position of the first double bond when counted from the methyl end of the carbon chain. In omega-3 fatty acids, the first double bond occurs at the third carbon, whereas in omega-6 fatty acids, it occurs at the sixth carbon. This structural difference influences their metabolic pathways, biological functions, and chemical properties.

Alpha-linolenic acid (ALA, 18:3, n-3) is an important omega-3 fatty acid, while linoleic acid (LA, 18:2, n-6) is an important omega-6 fatty acid. Humans are not synthesizing these two fatty acids from scratch and need to obtain them from dietary sources. ALA occurs in flaxseed, chia seed, soybean, and other plant oils. LA is present in several vegetable oils, including sunflower, safflower, soybean, and corn oils. Long-chain omega-3 fatty acids, eicosapentaenoic acid (EPA, 20:5, n-3) and docosahexaenoic acid (DHA, 22:6, n-3), are associated with marine organisms and certain microorganisms [1], [2].

Omega-6 fatty acids include gamma-linolenic acid (GLA, 18:3, n-6), dihomo-gamma-linolenic acid (DGLA, 20:3, n-6), and arachidonic acid (ARA, 20:4, n-6). These compounds participate in cell membrane structure and the formation of signalling molecules. Their physiological effects depend on the specific fatty acid, its metabolic conversion, the tissue involved, and the overall dietary context [2], [3].

The increasing demand for purified fatty acids has encouraged the development of improved extraction and separation techniques. Traditional solvent extraction remains useful because it recovers a broad range of lipids. However, solvent consumption, residual-solvent concerns, energy requirements, and possible oxidative degradation restrict its application. Alternative approaches, including supercritical fluid extraction, enzymatic treatment, membrane processing, and advanced chromatographic separation, offer different advantages and limitations [4], [5].

The isolation of omega-3 and omega-6 fatty acids is an important area of applied chemical research. A successful process must recover the target compounds, separate them from unwanted components, preserve their chemical structures, and demonstrate the identity and purity of the final product.

This review brings together the scientific principles of fatty-acid isolation and evaluates how these compounds are obtained from natural resources for chemical and industrial applications. The literature considered is restricted to work published on or before 31 December 2023.

II. Research Objectives

The principal objectives of this review are:

1. To identify important natural resources containing omega-3 and omega-6 fatty acids.
2. To explain the chemical characteristics relevant to their extraction, separation, and purification.
3. To compare conventional and emerging isolation methods.
4. To examine analytical techniques used for identification, characterization, and quantitative estimation.
5. To discuss applications in food chemistry, pharmaceutical formulations, cosmetics, oleochemicals, and renewable fuels.
6. To identify limitations, sustainability concerns, and research opportunities associated with fatty-acid recovery.

MATERIALS AND METHODS

This paper adopts a narrative literature-review approach. It synthesizes published scientific studies, review articles, and established analytical-method references concerning natural sources, extraction technologies, fatty-acid chemistry, purification, and industrial utilization.

The literature selection emphasizes research published up to 2023, including studies on plant oils, marine resources, microalgae, microbial oils, supercritical fluid extraction, chromatographic analysis, and oxidative stability. Specific attention is given to publications that explain the chemical principles or practical limitations of isolation and characterization.

The findings are organized thematically rather than presented as the results of a new laboratory experiment. No original extraction trials, numerical recovery measurements, or experimental purity results are claimed in this paper. The comparisons below are qualitative and is not interpreted as a quantitative ranking derived from newly collected data.

IV. Natural Resources of Omega-3 and Omega-6 Fatty Acids

Natural resources differ in their total lipid content and the relative proportions of individual fatty acids. Selecting the correct raw material is the first important step in designing an efficient isolation process.

A. Plant-Based Resources

Plant oils are important sources of essential fatty acids, sepecially ALA and LA. Flaxseed and chia seed are

D. Comparison of Major Natural Sources

widely recognized sources of ALA, while sunflower, safflower, soybean, and corn oils provide substantial amounts of LA. Rapeseed and soybean oils also supply ALA, although their fatty-acid compositions vary with cultivar, climate, agricultural conditions, and processing.

Plant oils generally contain fatty acids esterified in triacylglycerols. Minor quantities occur in phospholipids and other lipid fractions. Their composition is affected by seed maturity, storage conditions, moisture content, and extraction temperature [1], [4].

Plant-derived omega-3 oils offer an alternative to marine oils for applications requiring ALA. However, ALA is not treated as chemically or nutritionally identical to EPA or DHA. Its conversion into long-chain omega-3 fatty acids in humans is limited and variable [1], [2].

B. Marine Resources

Fish oils and certain marine by-products are important sources of EPA and DHA. These fatty acids occur in different lipid classes, including triacylglycerols, phospholipids, and, in some products, other lipid-associated forms.

Fish heads, frames, skin, viscera, and trimmings contain recoverable lipids, depending on species, processing history, and storage conditions. Recovery from these materials support waste reduction and improve the utilization of marine resources. However, raw-material quality must be controlled because microbial activity, hydrolysis, oxidation, and environmental contaminants affect the final product.

Krill and other marine organisms provide omega-3 fatty acids in phospholipid-rich fractions. Their lipid composition differs from that of many conventional fish oils, so extraction and purification conditions should be selected according to the lipid class and intended product specifications [1], [5].

C. Microalgae and Other Microorganisms

Microalgae and heterotrophic microorganisms are promising sources of long-chain PUFAs. Certain microalgae and thraustochytrid organisms accumulate DHA, while selected algal species are useful sources of EPA. Their lipid profiles depend on species, strain, nutrient availability, cultivation conditions, light exposure, temperature, and growth phase [5], [6].

Microbial production offers potential advantages because it is carried out under controlled conditions without relying exclusively on wild fish stocks. It also reduces some environmental pressures associated with marine harvesting. Nevertheless, large-scale production requires suitable cultivation systems, energy-efficient biomass recovery, cell disruption, and cost-effective oil extraction.

Table I. Representative natural resources and important considerations for fatty-acid recovery. The listed fatty acids are typical targets, guaranteed compositions for every sample.

Natural resource	Principal fatty acids of interest	Important isolation considerations
Flaxseed and chia seed	ALA, LA	Seed preparation, oil recovery, oxidation control
Soybean and rapeseed	LA, ALA	Oil refining, fatty-acid composition, solvent removal
Sunflower and safflower	LA	Selective recovery and purification of PUFA fractions
Fish oils and processing residues	EPA, DHA, other fatty acids	Raw-material freshness, oxidation, contaminant control
Krill and related marine resources	EPA, DHA, phospholipid-associated fatty acids	Lipid-class composition and selective separation
Microalgae and thraustochytrids	EPA or DHA, depending on species	Cell disruption, biomass processing, extraction selectivity

V. Chemical Characteristics of Omega-3 and Omega-6 Fatty Acids

A. Molecular Structure and Nomenclature

Fatty acids consist of a hydrocarbon chain and a terminal carboxyl group. The number of carbon atoms, the number of double bonds, and the position and geometry of those double bonds determine their chemical identity.

The shorthand notation 18:3 n-3, for example, indicates a fatty acid with 18 carbon atoms and three double bonds belonging to the omega-3 family. Representative compounds include:

- ALA: 18:3 n-3, an essential fatty acid commonly found in plant oils.
- EPA: 20:5 n-3, a long-chain omega-3 fatty acid found in marine and selected microbial sources.
- DHA: 22:6 n-3, a long-chain omega-3 fatty acid found in marine organisms and selected microorganisms.
- LA: 18:2 n-6, an essential omega-6 fatty acid common in vegetable oils.
- GLA: 18:3 n-6, found in selected seed oils, including evening primrose and borage oils.
- ARA: 20:4 n-6, a long-chain omega-6 fatty acid occurring in animal tissues and selected microbial sources.

The exact composition of a natural oil should be established analytically rather than inferred solely from its source.

B. Solubility and Lipid Forms

Free fatty acids contain a carboxyl group, whereas fatty acids in natural oils are commonly esterified to glycerol or incorporated into phospholipids. This distinction affects their solubility, chemical reactivity, and response to extraction and purification.

Nonpolar organic solvents dissolve many neutral lipids, while more polar solvent systems are needed to recover phospholipids and other polar components. The choice of solvent depends on whether the objective is to obtain total lipids, a specific lipid class, or an isolated free fatty acid.

An additional distinction is necessary between oil extraction and individual fatty-acid isolation. Extracting oil from seeds or biomass does not automatically produce pure EPA, DHA, ALA, or LA. Individual fatty acids generally require further chemical conversion, fractionation, or separation.

C. Oxidative Stability

Polyunsaturated fatty acids contain multiple double bonds, making them susceptible to oxidation. Oxidation is promoted by oxygen, light, heat, transition metals, and prolonged storage. The resulting products include hydroperoxides and secondary oxidation compounds that reduce quality and alter the chemical composition of the product [7].

Highly unsaturated fatty acids, such as EPA and DHA, require specific care during processing. Suitable measures include limiting exposure to oxygen and light, controlling temperature, reducing unnecessary processing time, and using appropriately validated antioxidant protection where permitted.

Oxidative stability is important throughout the entire process, from raw-material storage to extraction, concentration, packaging, and final use. It should be assessed using appropriate analytical indicators rather than judged from colour or appearance alone.

VI. Isolation and Extraction Methods

Isolation generally involves several operations: raw-material preparation, lipid extraction, removal of unwanted components, concentration of the target fraction, and final purification. The sequence depends on the source and the required product.

A. Mechanical Pressing

Mechanical pressing is commonly used to recover oil from oilseeds. Prepared seeds are compressed so that oil is released from the cellular material.

The method has the advantage of avoiding or reducing organic-solvent use. It is suitable for producing crude flaxseed, chia, soybean, or other seed oils. However, the oil yield depends on seed composition, moisture, particle size, pressing pressure, and temperature.

Mechanical pressing normally produces a mixed oil rather than a pure fatty acid. The resulting oil requires filtration, degumming, removal of other impurities, and subsequent fatty-acid fractionation.

Cold pressing reduces thermal exposure, but the term does not by itself guarantee superior purity or oxidative stability. Raw-material quality and storage conditions remain important.

B. Conventional Solvent Extraction

Solvent extraction is widely used because many lipids dissolve readily in appropriate organic solvents. The solvent penetrates the prepared material and transfers extractable lipids into the liquid phase. The liquid is then separated from the solid residue, and the solvent is removed under controlled conditions.

Commonly used solvent systems include hexane-based systems for neutral oils and chloroform–methanol or other suitable mixtures for broader lipid extraction in analytical research. The solvent must be selected according to the source material, the lipid classes of interest, safety requirements, and intended use.

The main advantages of conventional solvent extraction are its established operating principles and ability to recover substantial quantities of lipids. Its limitations include solvent consumption, possible solvent residues, flammability or toxicity, energy requirements for solvent recovery, and the environmental burden of some solvent systems.

Food-grade and pharmaceutical applications require specific attention to solvent suitability, residual-solvent limits, and compliance with applicable regulations.

C. Soxhlet Extraction

Soxhlet extraction is a conventional laboratory technique in which heated solvent repeatedly passes through a solid sample. The solvent dissolves extractable components, and the collected solution is returned through a repeated extraction cycle.

The method is useful for determining extractable lipid content in suitable solid materials. However, prolonged heating is undesirable for highly unsaturated fatty acids, specially if oxygen exposure and oxidation are not adequately controlled.

Soxhlet extraction is valuable for selected analytical and comparative purposes, but its suitability for producing oxidation-sensitive, high-purity fatty acids should be assessed against alternative methods.

D. Enzyme-Assisted Extraction

Enzyme-assisted extraction uses enzymes to weaken or degrade components of the biological matrix, facilitating the release of oil. Depending on the raw material, enzymes such as cellulases, hemicellulases, and proteases improve access to intracellular lipids.

This approach is useful for materials in which oil is trapped within plant cell walls, protein-rich tissues, or microbial cells. Its advantages include moderate operating temperatures and reduced reliance on harsh chemical conditions.

The efficiency depends on the enzyme type, substrate composition, pH, temperature, reaction time, and mixing conditions. Enzyme costs and the need for subsequent separation of water, proteins, and other impurities increase process complexity.

For microalgae and microbial biomass, enzymatic treatment is combined with mechanical disruption or another extraction technique.

E. Supercritical Carbon Dioxide Extraction

Supercritical carbon dioxide extraction uses CO_2 above its critical temperature and pressure, where it exhibits properties intermediate between those of a gas and a liquid. Under suitable conditions, supercritical CO_2 penetrate a matrix and dissolve lipid components. Pressure and temperature adjustments change its solvent behaviour and selectivity.

A major advantage is that carbon dioxide is separated from the extracted material by depressurization, reducing the likelihood of persistent solvent residues. It is also nonflammable under typical processing conditions and is recycled in appropriately designed systems.

Supercritical CO_2 has been investigated for recovering omega-3-rich oils from microbial biomass and fish-processing materials [5], [6]. Its effectiveness depends on pressure, temperature, flow rate, extraction duration, moisture content, particle size, and the chemical composition of the target lipids.

Because CO_2 is relatively nonpolar, its ability to extract polar lipid classes are limited under some conditions. Suitable co-solvents improve recovery, although they introduce additional separation and safety considerations.

The equipment investment, high-pressure operation, and energy requirements must also be considered when evaluating industrial feasibility.

F. Microwave-Assisted and Ultrasound-Assisted Extraction

Microwave-assisted extraction uses electromagnetic energy to facilitate heating and improve the release of extractable compounds from a biological matrix. Ultrasound-assisted extraction uses acoustic cavitation to enhance mixing, disrupt structures, and improve mass transfer.

Both techniques have shorten extraction time or reduce solvent requirements under appropriate conditions. Their performance depends on the material, solvent, power input, temperature, processing time, and equipment design.

Excessive energy input damage oxidation-sensitive compounds. Extraction conditions must be optimized to balance recovery, selectivity, product quality, and energy consumption.

G. Comparison of Extraction Techniques

Table II. Qualitative comparison of fatty-acid extraction methods. Actual recovery, purity, cost, and environmental performance depend on the process conditions and raw material.

Method	Principal advantage	Main limitation	Potential application
Mechanical pressing	Low solvent use	Residual oil remains in solid material	Oilseed processing
Conventional solvent extraction	Broad lipid recovery	Solvent safety and recovery	Seed oils and lipid-rich biomass
Soxhlet extraction	Repeated laboratory extraction	Prolonged thermal exposure	Analytical lipid determination
Enzyme-assisted extraction	Matrix-specific release under controlled conditions	Enzyme cost and process complexity	Plant tissues and microbial biomass
Supercritical CO_2	Reduced persistent solvent residues	High-pressure equipment cost	High-value oils and sensitive lipid fractions
Microwave-assisted extraction	Potentially faster extraction	Thermal control is essential	Selected plant and biomass matrices
Ultrasound-assisted extraction	Improved mass transfer	Scale-up and oxidation control	Oilseeds and selected biological residues

VII. Purification and Separation of Omega-3 and Omega-6 Fatty Acids

Extracted oils normally contain mixtures of fatty acids, glycerides, phospholipids, pigments, sterols, oxidation products, and other minor constituents. Additional separation is required when a specific fatty acid or a highly concentrated fraction is needed.

A. Hydrolysis and Transesterification

In natural oils, fatty acids are commonly bound in ester form. Hydrolysis release free fatty acids from glycerides by breaking ester bonds in the presence of water and suitable catalysts or enzymes.

Transesterification exchanges the alcohol component of an ester. In fatty-acid analysis, triglycerides are converted into fatty-acid methyl esters (FAMEs) using methanol and an appropriate catalyst. The FAMEs are more suitable for routine gas-chromatographic analysis because of their volatility and chromatographic behaviour [8], [9].

Hydrolysis and transesterification are not interchangeable in every application. The choice depends on whether the objective is to manufacture free fatty acids, produce esters for an industrial application, or prepare a representative analytical sample.
Reaction conditions should be controlled to avoid incomplete conversion, unwanted side reactions, and degradation of highly unsaturated compounds.

B. Molecular Distillation

Molecular distillation is a high-vacuum separation technique that exploits differences in volatility and molecular behaviour under reduced pressure. It has been used in the processing and concentration of marine oils and other lipid mixtures.

Reduced operating pressure permit separation at lower temperatures than would be required under atmospheric conditions. This is beneficial for certain heat-sensitive materials, although temperature and residence time must still be carefully controlled.
Molecular distillation helps remove selected volatile or lower-molecular-weight components and concentrate specific fractions. However, it does not necessarily separate every fatty acid with sufficient selectivity to yield a chemically pure compound. Further processing is needed.

C. Urea Complexation

Urea complexation is a fractionation technique based on differences in the ability of fatty-acid chains to form inclusion complexes with urea under suitable conditions. Straight-chain saturated and certain monounsaturated fatty acids can preferentially enter these complexes, while highly unsaturated fatty acids enriched in the non-complexed fraction.

The method has been explored for concentrating long-chain PUFAs from mixed fatty-acid preparations. Its selectivity depends on the composition of the starting material, solvent, temperature, urea-to-fatty-acid ratio, and crystallization conditions.

Urea complexation is generally a fractionation method rather than a guarantee of complete separation of EPA, DHA, or individual omega-6 fatty acids. Additional purification and compositional analysis remain necessary.

D. Chromatographic Separation

Chromatography separates compounds according to differences in their interactions with a stationary phase and a mobile phase. Depending on the method, separation is influenced by polarity, molecular structure, chain length, degree of unsaturation, or other chemical properties.

Gas chromatography is widely used to determine fatty-acid composition after suitable derivatization. Preparative chromatography and selected liquid-chromatographic methods are used when physical separation or concentration of specific compounds is required.

High-performance liquid chromatography, silver-ion chromatography, and other specialized chromatographic techniques are useful for separation objectives. The choice should depend on the chemical form of the fatty acids and the required selectivity, purity, recovery, and throughput.

E. Purification Strategy

An integrated process involves as the following sequence:

- Natural raw material
- Seeds, marine by-products, algae, or microbial biomass
- Preparation and lipid extraction
- Pressing, solvent extraction, enzymatic treatment, or supercritical CO_2
- Crude oil or lipid fraction
- Removal of solids, water, and unwanted components
- Chemical conversion and fractionation
- Hydrolysis, transesterification, distillation, or complexation where appropriate
- Selective purification
- Chromatography or other suitable separation technology
- Characterized fatty-acid product
- Identity, composition, purity, oxidation status, and intended-use quality

The sequence is illustrative rather than universal. Some processes require fewer steps, while others require additional purification to achieve pharmaceutical, analytical, or specialty-chemical specifications.

VIII. Analytical Characterization of Isolated Fatty Acids

Reliable characterization is essential for confirming that the isolated material contains the intended fatty acids. The analytical strategy should distinguish between total oil content, fatty-acid composition, individual fatty-acid concentration, chemical purity, and oxidative quality.

A. Gas Chromatography–Flame Ionization Detection

Gas chromatography with flame ionization detection (GC-FID) is widely used to quantify fatty-acid profiles. In a common approach, fatty acids are converted to FAMEs before injection. The chromatographic system separates the derivatives, and the detector generates signals related to the amount of organic material reaching it.

Individual fatty acids are identified by comparing retention times with suitable reference standards. Quantification requires appropriate calibration, internal standards, and consideration of response factors where necessary.

GC-FID is suitable for routine fatty-acid profiling, but its reliability depends on sample preparation, derivatization efficiency, chromatographic resolution, calibration, and quality control. Reporting only relative percentages are misleading when the absolute number of fatty acids in the original sample is required [8], [9].

B. Gas Chromatography–Mass Spectrometry

Gas chromatography–mass spectrometry (GC-MS) combines chromatographic separation with mass-based detection. It supports compound identification by comparing mass spectra and retention behaviour with reference data.

GC-MS is valuable when identifying fatty-acid derivatives in complex natural mixtures. However, mass spectra alone not resolves every positional or geometric isomer. Suitable standards and appropriate chromatographic conditions are needed when exact double-bond location or configuration must be established.

C. Fourier-Transform Infrared Spectroscopy

Fourier-transform infrared spectroscopy (FTIR) provides information about functional groups and chemical bonds. It helps identify characteristic absorptions associated with carboxyl groups, ester bonds, and unsaturated structures.

FTIR is useful for rapid screening and process monitoring. It does not generally provide an unambiguous, complete fatty-acid profile in a complex oil without additional validated analytical methods.

D. Nuclear Magnetic Resonance Spectroscopy
Nuclear magnetic resonance (NMR) spectroscopy provides information about molecular environments and chemical structure. It is used to characterize lipid classes, monitor chemical conversion, and examine the presence of unsaturated structures.

NMR support quantitative analysis under suitable conditions, but sensitivity, sample complexity, overlapping signals, and the need for appropriate reference procedures must be considered.

E. Oxidation and Quality Assessment
PUFA-rich products require quality tests that address both composition and degradation. Relevant measurements include peroxide value, secondary oxidation indicators such as p-anisidine value, and other validated tests appropriate to the product.

No single measurement provides a complete assessment of oxidation. Peroxide value, for example, measures primary oxidation products and decline when hydroperoxides decompose. Therefore, several complementary measurements are needed. A complete analytical report should ideally include:

- Identity of the raw material and extraction method.
- Fatty-acid composition and the basis used for reporting.
- Absolute concentration when quantitative claims are made.
- Reference standards, calibration, and internal-standard details.
- Replicate measurements and appropriate uncertainty estimates.
- Oxidation indicators and residual-solvent information where relevant.
- Validation data for selectivity, recovery, precision, and detection limits, as applicable.

IX. Chemical Applications of Omega-3 and Omega-6 Fatty Acids

A. Food Chemistry and Functional Foods
Omega-3 and omega-6 fatty acids are used in edible oils, fortified foods, dietary supplements, and formulated food products. ALA and LA are important dietary fatty acids, while EPA and DHA are incorporated into selected foods and nutritional formulations.

Their use in food chemistry requires careful control of taste, odour, oxidative stability, and compatibility with the food matrix. Highly unsaturated oils develop undesirable flavours when oxidized. Encapsulation, suitable packaging, antioxidant systems, and controlled processing helps protect the fatty acids.

The incorporation of purified fatty acids into a product should be based on the intended nutritional purpose, food safety requirements, and validated product specifications. Potential nutritional benefits are not assumed to be identical across all omega-3 or omega-6 compounds [1], [2].

B. Pharmaceutical and Nutraceutical Formulations
Purified fatty acids and their derivatives are used in selected pharmaceutical and nutraceutical products. EPA- and DHA-containing preparations have received attention because of their physiological roles and applications in specific clinical contexts.

In pharmaceutical formulation, chemical identity and purity are especially important. Relevant requirements include control of oxidation products, residual solvents, contaminants, concentration, stability, and batch-to-batch consistency.
The pharmaceutical usefulness of a fatty acid depends on its formulation and intended indication. Findings relating to one compound or preparation is not automatically be generalized to all products containing omega-3 or omega-6 fatty acids.

C. Cosmetic and Personal-Care Products
Vegetable oils and selected fatty-acid derivatives are used in skin-care products, creams, lotions, emollients, and cleansing formulations. Their properties depend on the fatty-acid profile, chemical form, formulation composition, and stability.

Fatty acids are converted into esters, soaps, and other oleochemical ingredients. These products influence texture, spreading behaviour, lubrication, and interactions between oil and water phases.

The suitability of a fatty acid for cosmetic use depends on formulation performance, stability, safety assessment, and regulatory requirements. A fatty acid's presence in a natural oil does not by itself establish that a concentrated or chemically modified product is suitable for every cosmetic application.

D. Surfactants, Soaps, and Oleochemicals
Fatty acids are important feedstocks for oleochemical manufacture. Their carboxyl groups undergo esterification, neutralization, and other chemical reactions, while their hydrocarbon chains contribute hydrophobic properties.

Depending on the starting fatty acid and the reaction pathway, derivatives used in soaps, emulsifiers, lubricants, surfactants, and specialty chemical formulations. The industrial value of a specific feedstock depends on its composition, availability, purity, and conversion cost.

Omega-3-rich fractions are investigated as specialty chemical feedstocks. However, their high degree of unsaturation makes them more susceptible to oxidation during processing and storage than less unsaturated feedstocks.

E. Biodiesel and Renewable Fuels

Fatty-acid-containing oils are converted into fatty-acid alkyl esters through transesterification. These esters are commonly associated with biodiesel production.

The chemical principle involves reacting triglycerides with an alcohol, generally methanol, in the presence of an appropriate catalyst to form fatty-acid methyl esters and glycerol. The final fuel properties depend on the feedstock's fatty-acid composition and the conversion and purification process.

Highly unsaturated feedstocks present a challenge because double bonds increase susceptibility to oxidation. This affects storage stability and influence the suitability of a specific oil for fuel applications. Accordingly, PUFA-rich oils are not automatically be considered ideal biodiesel feedstocks without evaluating fuel-quality requirements.

In a resource-efficiency context, lower-value lipid residues is considered for fuel production while higher-value fractions are directed toward more selective applications, provided the overall process is technically and economically justified.

F. Biodegradable Materials and Polymer Chemistry

Unsaturated fatty acids serve as starting materials for selected chemical modifications. Their double bonds and carboxyl groups provide reaction sites for producing functionalized lipids and, under suitable conditions, polymer-related intermediates.

Possible applications include modified oils, coating ingredients, plasticizing components, and selected biodegradable material systems. The properties of the resulting materials depend on molecular structure, reaction conditions, crosslinking behaviour, and the presence of other formulation components.

Omega-3 and omega-6 fatty acids should be considered potential specialty feedstocks rather than universally interchangeable raw materials for polymer production. Their suitability depends on the intended chemical transformation and the stability requirements of the resulting material.

G. Agricultural and Biotechnological Applications

Selected fatty acids and their derivatives are investigated in agricultural formulations, microbial systems, and biotechnological processes. Their effects depend on concentration, chemical form, target organism, and the surrounding environment.

Microbial oils provide opportunities for integrated bioprocessing in which biomass is cultivated, lipids are recovered, and residual biomass is evaluated for other suitable uses. Such processes is improving resource utilization, although the feasibility of each downstream use requires separate assessment.

H. Summary of Chemical Applications

Table III. Representative chemical applications and their main technical requirements.

Application area	Relevant fatty-acid property	Principal technical consideration
Functional foods	Nutritional role and lipid composition	Oxidative stability and sensory quality
Pharmaceuticals and nutraceuticals	Defined chemical composition	Purity, stability, and product-specific standards
Cosmetics	Emollient and formulation properties	Safety, compatibility, and oxidation control
Soaps and surfactants	Carboxyl-group reactivity and hydrophobic chains	Reaction selectivity and product performance
Biodiesel	Conversion of glycerides to alkyl esters	Fuel properties and oxidation stability
Modified oils and polymer-related materials	Reactive double bonds and carboxyl groups	Controlled modification and final material properties
Biotechnology	Potential for microbial production and recovery	Cultivation cost and process integration

X. Environmental Sustainability and Resource Utilization

The sustainable isolation of omega-3 and omega-6 fatty acids requires consideration of the complete process rather than extraction yield alone.

A. Use of Processing By-Products

Fish-processing residues and oilseed press cakes contain recoverable lipids. Their use improves resource efficiency and reduces the amount of organic material requiring disposal.

However, by-products vary substantially in composition and quality. Their suitability depends on storage history, contamination risks, lipid content, and the specifications of the intended product.

B. Solvent Reduction and Recovery

Reducing solvent consumption and recovering solvents lower operating costs and environmental impacts. Solvent choice should consider toxicity, flammability, recyclability, extraction selectivity, and regulatory requirements.

Supercritical CO_2 reduces reliance on some organic solvents, but the energy used for compression, refrigeration, and pressure management must be included in environmental comparisons.

C. Microbial Production

Microbial production offers an alternative route for obtaining selected PUFAs. Controlled cultivation reduces dependence on certain wild marine resources, but its sustainability depends on electricity use, nutrient sources, water demand, biomass recovery, and downstream purification.

A microbial process should be evaluated using realistic production-scale data rather than assuming that biological production is automatically more sustainable.

D. Process Integration

An integrated biorefinery approach could combine the recovery of high-value fatty acids with appropriate utilization of remaining biomass and processing streams. Potential co-products must be assessed for quality and market suitability.

The most suitable configuration depends on the resource, target compounds, local infrastructure, energy sources, and market demand.

XI. Challenges:

Several technical and scientific challenges remain in the isolation of omega-3 and omega-6 fatty acids.

First, natural-source variability makes it difficult to predict product composition from the raw material alone. Cultivar, species, growing conditions, season, storage, and processing influence fatty-acid profiles.

Second, extraction yield does not equal target-compound recovery. A process recovers substantial total oil while obtaining only a modest concentration of the desired fatty acid. Future studies should report both total lipid yield and the recovery of individual target compounds.

Third, oxidative degradation affects product quality. Extraction, heating, concentration, purification, and storage should be evaluated for their effects on the target fatty acids and their oxidation products.

Fourth, analytical comparability remains important. Differences in derivatization procedures, reference standards, detector response, and reporting conventions complicate comparisons between studies. Validated quantitative methods should distinguish relative fatty-acid composition from absolute concentration [8], [9].

Fifth, selective purification is costly. Producing an individual high-purity fatty acid requires several processing stages. Future research should compare overall recovery, purity, energy consumption, solvent use, and operating cost.

Sixth, scale-up requires further evaluation. A laboratory method that performs well with a small sample behave differently in a large extraction system because of mass-transfer limitations, heat distribution, solvent circulation, or biomass-handling requirements.

Seventh, sustainability claims require quantitative evidence. Life-cycle assessment, process economics, and realistic waste-management data should be used to compare conventional extraction with newer technologies.

Future research would benefit from standardized experimental reporting, validated mass-balance calculations, improved oxidation monitoring, and systematic evaluation of natural resources that are currently underutilized.

DISCUSSION

The literature reviewed in this paper indicates that the isolation of omega-3 and omega-6 fatty acids is a multistage chemical process in which raw-material selection, extraction, purification, and analytical validation are closely connected.

Plant oils provide accessible sources of ALA and LA, while marine organisms and selected microorganisms are important sources of EPA and DHA. The choice of extraction method reflects the chemical form of the target fatty acid and the composition of the biological matrix.

Conventional solvent extraction remains useful for recovering total lipids, in laboratory research and established industrial processes. Mechanical pressing reduces solvent use for suitable oilseeds. Enzyme-assisted and ultrasound-assisted methods improve the release of lipids from selected matrices, while supercritical CO_2 offers opportunities for processing sensitive lipid fractions with reduced persistent solvent residues.

However, extraction alone is not guaranteeing the required concentration or purity. Further fractionation is needed to obtain a specific fatty acid. Hydrolysis, transesterification, molecular distillation, urea complexation, and chromatography serve different purposes and should be selected according to the intended product.

Analytical characterization is equally important. GC-FID and GC-MS are valuable for determining fatty-acid composition, while FTIR and NMR provide complementary information about chemical structures and lipid transformations. The reliability of the final result depends on suitable standards, validated sample preparation, accurate quantification, and appropriate quality-control procedures.

The industrial applications of these compounds extend beyond nutritional products. Their chemical functionality makes them useful in selected cosmetic formulations, oleochemicals, modified oils, and renewable-fuel processes. The suitability of a specific fatty acid depends on the intended application, its oxidation stability, and the required material specifications.

A central finding of this review is that the best isolation process is the one that achieves an appropriate balance between target-fatty-acid recovery, purity, stability, safety, environmental performance, and production cost. A method that produces a high total oil yield is unsuitable when a highly purified individual fatty acid is required.

Future studies should move beyond reporting total extraction yield and provide reproducible data on individual fatty-acid recovery, absolute concentration, purity, oxidation, energy use, and solvent consumption. Such information would support meaningful comparisons among extraction technologies and facilitate the development of commercially viable processes..

CONCLUSION

Omega-3 and omega-6 fatty acids are valuable natural compounds with applications in food chemistry, pharmaceutical and nutraceutical formulations, cosmetics, oleochemical production, and selected renewable-material processes. Their recovery from plant oils, marine resources, fish-processing residues, and microbial biomass provides opportunities for both industrial development and improved resource utilization.

Conventional solvent extraction and mechanical pressing remain important approaches for obtaining crude oils. Enzyme-assisted extraction, ultrasound-assisted extraction, and supercritical CO_2 provide alternative methods for selected materials and processing objectives. Further purification involves hydrolysis, transesterification, molecular distillation, urea complexation, and chromatographic separation.

The chemical sensitivity of polyunsaturated fatty acids requires careful control of oxygen exposure, temperature, light, and storage conditions. Analytical techniques such as GC-FID and GC-MS are essential for verifying fatty-acid identity and composition, while complementary spectroscopic and oxidation tests help establish product quality.

No single technique is recommended universally for all natural sources and target fatty acids. Process selection should be based on the characteristics of the starting material, the required product specification, quantitative recovery, environmental considerations, and economic feasibility.

Future research should focus on efficient recovery from underutilized natural resources, reduced-solvent processing, validated quantitative analysis, improved oxidative stability, and integrated biorefinery approaches. These developments could improve the sustainable utilization of omega-3 and omega-6 fatty acids and strengthen their role as important feedstocks for food, pharmaceutical, cosmetic, and chemical industries.

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