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Recent Advances in the Extraction of Unsaturated Fatty Acids from Edible Plants: A Review

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Abstract: The recent global trend of fast food consumption due to the busy lifestyle has violated the dietary guidelines for the intake of saturated fat-related foods, causing multiple diseases. However, replacing saturated fats with unsaturated fats remains limited due to their chemical liabilities and the challenges associated with extraction techniques. The unsaturated fatty acids were usually extracted using conventional methods, which required substantial resources and were more complex. Besides, the efficiency of these techniques was limited, giving lower yields of the extracted materials from the raw materials. In contrast, industrial techniques, including low-temperature crystallization, distillation, urea complexation, supercritical fluid extraction, ultrasound-assisted extraction, etc., offer faster separations at lower, safer temperatures without the use of nontoxic solvents. This review critically examines developments in methods for the extraction of unsaturated fatty acids from edible sources over the last few years. It will provide valuable references to the scientific community on the established methods, advantages, and disadvantages of existing techniques across safety, economic, environmental, and commercial aspects.

Keywords: unsaturated fatty acids; extraction; edible source; health benefits.

1. Introduction

Unsaturated fats, which are in a liquid state at room temperature, are regarded as useful because they enhance cholesterol levels in the blood, stabilize heartbeats, alleviate inflammatory disorders, and fulfill various other beneficial functions. Based on the structural position, fatty acids are grouped as saturated, monounsaturated, or polyunsaturated. The hydrocarbon chains found in saturated fatty acids are primarily composed of single bonds, whereas unsaturated fatty acids (UFAs) are composed of single or multiple double bonds. UFAs that have a double bond between C-3 and C-4 or between C-6 and C-7 starting from the methyl end of the hydrocarbon chain (=ω-carbon) are also referred to as ω-3 and ω-6 fatty acids. These fatty acids play a crucial role in maintaining human health. The biological function of these fatty acids is influenced by the particular position of the double-bonded structure with respect to the methyl end. In the food industry, traditional oil extraction methods have several drawbacks, including labor-intensive, time-consuming processes, the use of toxic solvents in large quantities, and the need for specific operational procedures to remove solvent residues from the final product. Although much research has been conducted to develop alternative methods for extracting unsaturated acids and overcoming the drawbacks of conventional methods, no relevant review was found on the effective and efficient separation of monounsaturated or polyunsaturated fatty acids from edible sources. Also, the advantages and disadvantages of extracting these unsaturated fatty acids from saturated fatty acids, and the reaction parameters affecting their extraction, need further exploration. This review paper addressed, in a concise manner, emerging technologies for the extraction of unsaturated fatty acids from edible sources, including reaction conditions and other required parameters. It will help the researchers determine the most appropriate pathway to modify existing methods and identify favorable conditions for separating healthy fatty acids from edible plants, thereby improving mitigation techniques for 'bad' fatty acids.

2. Biological Importance of Unsaturated Fatty Acids (UFAs)

Plant sources are the major sources of polyunsaturated fatty acids. A comprehensive understanding of the various types of unsaturated fatty acids and their roles across molecular signaling pathways is helpful for developing diets that reduce inflammation and promote a long lifespan. A diet with more unsaturated fats is important as they are necessary for the body and also protect against illness. It was found that good therapeutic values can be obtained from unsaturated fatty acids, the prevention of oxidative stress, and cerebrovascular and cardiovascular diseases. Cardiovascular diseases, which involve the hardening and narrowing of blood vessels or the formation of blood clots, are the leading causes of mortality and morbidity worldwide. It is well understood that the type of dietary fats is highly responsible for an individual's disease risk, such as increased plasma low-density lipoprotein (LDL) cholesterol. It was observed that saturated fatty acids, when replaced with monounsaturated or polyunsaturated fatty acids, reduced LDL (the 'bad') cholesterol, thereby reducing the risk of developing the disease. Moreover, it was found that unsaturated fatty acids such as linoleic acid slightly raised the high-density lipoprotein (HDL, the 'good') cholesterol, assisting in the removal of triacylglycerols from the bloodstream. However, despite strong supportive evidence that these fatty acids protect against fatal heart disease, precise mechanisms and conclusive evidence are still lacking on how unsaturated fatty acids reduce cardiovascular disease risk.

3. Recent Techniques of Extraction of UFAs from Edible Sources

At present, common methods for extracting unsaturated fatty acids include sorption separation, extraction with supercritical fluids, crystallization at lower temperatures, molecular distillation, urea encapsulation, *etc*. For example, Tarasevicˇiene *et al*.[1] studied the herbaceous species, stinging nettle, and extracted the roots and leaves by solid-liquid extraction using ethanol, methanol, and water, taking 96%, 70%, and 50%, respectively, as solvents, followed by phenol extraction with 96% methanol at 70°C. In roots, greater amounts of monounsaturated fatty acids (MUFAs) and polyunsaturated fatty acids (PUFAs) were identified, with α-linolenic acid and linoleic acid as the most dominant fatty acids. The structures of these acids are depicted in Figure 1 (Serra *et al*.) [2].

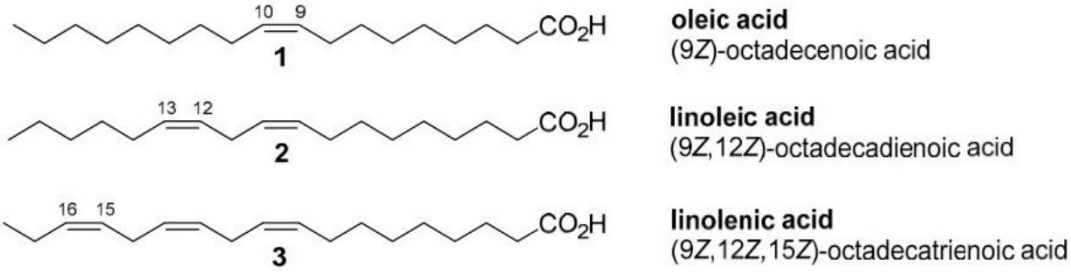

Figure 1. The most prevalent C 18 UFAs: **(a)** oleic; **(b)** linoleic; **(c)** linolenic acid. Serra *et al*. [2] .

3.1. Extraction of UFAs from edible oils.

In another experiment, Popović-Djordjević *et al*. [3] worked on the composition of fatty acids and bioactive species along with some other nutrients in rosehip seeds (Rosa canina L.), consisting of high amounts of *α*-linolenic acid, linoleic acid, and Z-octadec-9-enoic acid (Oleic acid). The seed oil was extracted using 0.5g of a blended sample with 5 mL n-hexane in an ultrasonic bath (1 h), followed by occasional shaking. Mohammadi *et al*.[4] studied *Pyrus glabra* for the extraction of seed oil using n-hexane under a dark environment, then evaporating the solvent using a vacuum evaporator. The total fatty acids in *P. glabra* were found to be 7, with a high level of USFAs, namely oleic acid followed by linoleic acid, and this seed oil can be used in the beauty, drag, and food industries. Karimzadeh *et al*. [5] analyzed *Gundelia tournefortii* L. to extract seed oil using the Soxhlet apparatus. The dominant fatty acid was oleic acid (OA), along with small amounts of linolenic acid (LnA) and linoleic acid (LA), as analyzed by gas chromatography with flame-ionization detection (GC-FID). The *G. tournefortii* L. seed was a valuable source of medicinal and nutritional industrial uses. Muhammad *et al*.[6] studied four species of *Cocos nucifera* nuts, *Canarium schweinfurthii* pulp, Sesamum indicum, and *Balanites aegyptiaca* seeds, for their fatty acid composition and physiochemical properties. The extraction was performed using a warm-press technique with n-hexane as the solvent. The analysis revealed that the four fruits contain PUFAs, followed by MUFAs, with oleic acid as the dominant fatty acid. Due to the presence of high levels of USFAs and low levels of SFAs, these compounds exhibit significant therapeutic benefits, including anticancer, wound-healing, improved skin permeation, antioxidant, and antidiabetic effects. Xu *et al*.[7] investigated the green plum seed for its nutritional benefits and fatty acid profile.

The extraction of volatile seed oil was performed by headspace gas chromatography-ion mobility spectrometry (HS-GC-IMS) using n-hexane. The fatty acids were determined by gas chromatography, and the extracted oil was found to contain high levels of oleic and linoleic acids. Recently, Sotelo-Méndez *et al*. [8] conducted an assessment of the fatty acid composition and dietary characteristics of six different varieties of lupine seed (*Lupinus mutabilis*) through the utilisation of Soxhlet extraction. The extract contained a large amount of MUFAs (specifically oleic acid), followed by PUFAs (specifically linoleic acid). Lupine seed oil was believed to have the potential to be a nutritious cooking oil. Liu *et al*. [9] developed a process for seed oil extraction from Cosmos sulphureus using supercritical CO2 assisted by ultrasound treatment at 55°C and 25 MPa. The USFAs, such as oleic acid and linoleic acid, were the dominant components of the extract, which is an important edible oil source with many nutritional properties. Andonova *et al*. [10]studied the biological functions, chemistry, fatty acid profile, and physical and chemical characteristics of the seed oil extracted from *Koelreuteria paniculata*. The extraction was performed using the Soxhlet apparatus with an organic solvent, such as hexane. A total of eleven fatty acids, including oleic acid and eicosenoic acid, were identified from the extracted seed oil. This extract has immense potential benefits for human health and is also used in pharmaceutical and cosmetic products. Singh *et al*.[11] investigated the oil extraction method for pumpkin seeds (*Cucurbita moschata Duch*.) and Kashi Harit seeds. There are three methods for extracting substances: Soxhlet extraction, mechanical shaking extraction, and cold-press extraction. The oil obtained contained significant amounts of linoleic acid, along with oleic acid, and a small quantity of a-linolenic acid. Martínez-Ramírez *et al*. [12] investigated edible mushrooms, which contain lipids, triacylglycerols, sterols, and phospholipids. The edible mushrooms incorporated fatty acid esters of hydroxy fatty acids (FAHFA) instead of fatty acid methyl esters, which have many properties, such as anti-inflammatory and antidiabetic effects. A total of 34 FAHFAs were found in edible mushrooms, including linoleic and oleic acids, which were extracted using biphasic extraction with water, methyl tert-butyl ether, and methanol as solvents.

He *et al*. [13] examined cottonseed (*Gossypium spp.)*, which was subjected to extraction using 80% EtOH and 100% n-hexane. The abundant USFAs in the seed oil were oleic and linolenic acid, as characterized by ^{1}H-NMR. The polar fraction of cottonseed contains bioactive substituents for medical, health, and nutritive applications. Kurdi *et al*. [14] considered two wild plants, *Prosopis farcta* and *Celtis toirnefortii* Lam, to analyze polyphenolic and fatty acids. The grinding sample was extracted with hexane in a Soxhlet chamber, followed by extraction with methanolic sulfuric and methanolic potassium hydroxide. Unsaturated fatty acids such as oleic acid, cis-11 eicosenoic, and cis-4,7,10,13,16,19-docosahexaenoic were dominant and can be used as flavor enhancers. Guici El Kouacheur *et al*. [15] evaluated Algerian *Prunus Amygdalus var. amara* (bitter almond) for its fatty acid profile, polyphenols, tocopherol, and flavonoid contents. A cold-press process was used to extract bitter almond seed, and the major components, oleic and linoleic acids, were identified. Elsorady *et al*.[16] extracted oil from *Moringa oleifera* via three different methods: supercritical fluid extraction, Soxhlet extraction, and solvent extraction. However, supercritical fluid extraction was more effective than solvent extraction. Due to its high oleic acid content, Moringa oil has become a desirable, nutritious, healthy cooking oil. Piseskul *et al*. [17] analyzed *Hodgsonia heteroclita* to extract seed oil using enzyme-assisted mechanical extraction, and the extracted oil consisted of omega-6 fatty acid, followed by linoleic acid, and omega-9 fatty acid associated with oleic acid, along with a small amount of linolenic acid. As seed oil contains high levels of USFAs, it has many health benefits against chronic diseases such as inflammation, diabetes, and cardiovascular disease. Grygier *et al*.[18] studied several legume species (*Samanea saman*, *Tamarindus indica*, *Enterolobium cyclocarpum*, *Pithecellobium dulce*, *Caesalpinia pulcherrima*, and *Sesbania grandiflora*). The legume seed oil was extracted by ultrasound-assisted extraction in an ultrasonic bath using n-hexane as the solvent. The most dominant fatty acid was linoleic acid, followed by oleic acid.

Nebolisa *et al*.[19] extracted seed oil using microwave-induced extraction and Soxhlet extraction techniques. High levels of MUSAs, such as oleic acid, cis-9-octadecenoic acid, palmitoleic acid, 11-eicosenoic acid, and cis-6-octadecenoic acid, were detected during the above-mentioned extraction acid. Norazlina *et al*. [20] analyzed dabai seed (*Canarium odontophyllum*) extracted using semi-continuous Soxhlet extraction. In the extract, oleic acid was the most dominant unsaturated fatty acid, and linoleic acid was a major component. Konadu *et al*. [21] studied *Allanblackia floribunda* seeds using several methods, including solvent extraction, cold-press extraction, and traditional hot-water extraction. The extraction using hexane yielded a substantial amount of fatty acids viz., oleic, linolenic, and linoleic acids.

Santinoni *et al*. [22] examined the baru almond (*Dipteryx alata*), which is rich in fibers, lipids, proteins, and bioactive compounds. The extraction of baru seed oil was performed using a Soxhlet apparatus and a hydraulic press, with eco-friendly EtOH, d-limonene, and 2-methyltetrahydrofuran as solvents, under microwave and ultrasound conditions. Among the USFAs, oleic and linoleic acids were the major components. Kostrzewa *et al*. [23] evaluated *Paprika (Capsicum annuum L.), which contains PUFA and carotenoids and has* high health benefits. Three methods were used to extract paprika seed oil: supercritical CO_2 (SC-CO_2), SC-CO_2 with a co-extractant, and a Soxhlet apparatus. The principal USFAs were linoleic acid, followed by oleic acid, along with linolenic acid.

Albakry *et al*. [24] studied *Nigella sativa* L. (black cumin), which is of high pharmaceutical importance due to its unsaturated fatty acids. The black cumin seeds were extracted using solvent extraction, cold press, and supercritical fluid extraction. The extracted oil contained a high amount of linoleic acid (PUFA). Yusuff *et al*. [25] analyzed green microalgae (*Chlorophyta* species) and performed Soxhlet extraction at 61.31°C. A total of 5 fatty acids were identified in the algal extract, and gas chromatography showed high levels of linoleic acid, oleic acid, and palmitoleic acid. Symoniuk *et al*. [26] studied mullein flowers (chia seed, hempseed, rapeseed, and linseed). These flower seeds were extracted using the cold-press method, and the extracted oil contained a high level of PUFA. Rapeseed had high levels of MUFA, whereas linseed and chia seeds had PUFA. Chia and linseed seeds contained a-linolenic acid 69% and 65%, respectively. Hempseed possesses gamma-linolenic acid, linoleic acid, and MUFA. Grygier *et al*. [27] investigated 14 leguminous plants for their medicinal and food supplements. The seed oils were extracted with the organic solvent n-hexane using ultrasound treatment. The main fatty acid components were linoleic acid, followed by oleic acid (USFA). Ghosh *et al*.[28] examined tomato seeds to investigate fatty acid profile, along with antioxidant activity and oxidative stability. The tomato seeds were extracted with n-hexane and aqueous solvents using a Soxhlet apparatus. PUFAs and MUFAs were the major fatty acid components, with high levels of linoleic acid, followed by oleic acid and linolenic acid. Makrygiannis *et al*. [29] assessed the multifunctional uses of apricot kernels, a bioactive species, in the food and cosmetic sectors. Apricot kernel extraction was carried out employing hexane as a solvent, and the fatty acids were analyzed using GC-FID. The primary fatty acids identified were oleic acid, linoleic acid, and a lesser amount of palmitoleic acid. Izadi-Darbandi *et al*. [30] examined Foeniculum vulgare Mill. Var. vulgare (Iranian Fennel Landraces) for evaluation of their fatty acid composition. The fatty acids were extracted using a Soxhlet apparatus with hexane, and the major fatty acids were identified as oleic acid, linoleic acid, and linolenic acid. The omega-3 to omega-6 fatty acid ratio was very low in the seed oil. Pham *et al*. [31] investigated *Terminalia catappa* trees and treated their seeds with a hydraulic compressor. The seed oil was collected at low (~40°C) and high (~165°C) temperatures using cold-pressed and hot-press techniques. The oil extracted contained significant levels of UFAs, including oleic and linoleic acids, indicating its potential as an alternative source of antioxidants and valuable fatty acids for use in the pharmaceutical and food industries. Cruz

Reina *et al*. [32] studied cashew nut shells from Colombia for use in cosmetic applications. The same supercritical fluid extraction method could extract fatty acids from cashew nuts. The principal fatty acids in cashew extract were C16 and C18 fatty acids. The conjugated structure of linoleic acid could be produced by the trans-vaccenic acid (C18

MUFA), which was an anti-carcinogenic component. 9Z,12Z-octadecadienoate, also called cis-linoleic acid, is an important compound that serves as a precursor for human prostaglandins and exhibits various biological activities that could be used in dermatological treatments. Sarikurkcu *et al*. [33] evaluated the fatty acid composition, antioxidant capacity, and enzyme activity of some edible plants (*Rumex patientia L.*, *R. acetosella L.*, *Mentha piperita L.*, *Eruca sativa Mill.*, *E. sativa*, *R. patientia*, *E. cicutarium (L.) L'*, and *Cardaria draba (L.) Desv.)*) in the Aegean. Extraction of these wild edible plants was done using ethanol as a solvent. C. draba E. sativa contained high levels of oleic acid, while M. piperita was enriched in various monounsaturated fatty acids, such as palmitoleic, pentadecanoic, and myristoleic acids, along with some polyunsaturated fatty acids, such as gamma-linolenic acid, linoleic acid, and alpha-linolenic acid. Ünver *et al*. [34] examined tropical fruits found in Turkey (Hylocereus undatus and Hylocereus polyrhizus) and investigated their fatty acid profiles alongside other parameters. Fatty acids were extracted using petroleum ether to obtain the final fatty acids. Due to its high PUFA content, it offers significant health benefits and promising future prospects.

Ahmadou *et al*.[35] studied techniques of extraction of *Moringa oleifera* seed for their massive importance in health using cold press, ultrasonic, and Soxhlet methods. The principal fatty acid was oleic acid, along with linoleic and linolenic acids. Qi *et al*. [36] extracted both monounsaturated and polyunsaturated fatty acids from *Acer truncatum* bundles using ethanol and water as solvents. Hashem *et al*. [37] studied seven oleaginous fungal strains using a $CHCl_3$-MeOH solution and a temperature range of 5-35°C. The PUFAs were dominant fatty acids, and linoleic acids with oleic acids were obtained from the extract. The presence of a high amount of USFAs in M. racemosus has various applications in pharmaceuticals and biodiesel production. Abdessalem Mrabet *et al*. [38] examined both seeds and fruits of Phoenix dactylifera L. Species and analyzed them for their therapeutic health benefits. Oil extraction was performed using solvent extraction with n-hexane, and fatty acids were determined by GC-FID. Due to the presence of MUFAs and PUFAs, these plants have promising applications in the food, medicinal, and cosmetic industries. Baskar *et al*. [39] evaluated the extraction of Annona squamosa (custard apple seed) using the solvent-assisted ultrasonic method with various solvents, including diethyl ether, chloroform, isopropanol, hexane, and methanol, at 50°C. The dominant fatty acid was oleic acid. In their study, Hagos *et al*. [40] focused on Cucurbita maxima, commonly known as pumpkin, and its seed oil extraction. They employed the Soxhlet extraction method with petroleum ether and reported that linoleic acid was the most significant product, followed by oleic acid.Fifty percent of the extracted seed oil consisted of linoleic acid (omega-6), a potential source of nutrient-rich oil used in the food, medicine, and cosmetic industries. Kong *et al*. [41] extracted Sacha inchi seed oil using several methods. The hydraulic cold-press technique was an extremely effective extraction method at approximately 25°C, with varying pressing times. The ultrasound-assisted and solvent extraction methods were also very useful for extracting Sacha ichi oil, which contained omega-3, omega-6, and omega-9 fatty acids. Badawy *et al*. [42] examined *Opuntia ficus indica* (L.) to recover seed oil, using ultrasound-assisted extraction rather than the conventional Soxhlet method. The major USFAs were linoleic and oleic acids. O. ficus indica seed oil could heal wounds, support immune responses, and be used as an edible oil. Narziyev M.S. *et al*. [43] studied the impact of ancient industrial crop flax on human health. The extraction of flaxseed was performed using the most effective mechanical pressing method available, compared to solvent extraction. Flaxseed oil was a fantastic source of omega-3 fatty acid (a-linolenic acid) and small amounts of oleic acid. Three-phase partitioning (organic, intermediate, and aqueous phases) was a very effective bioseparation technique for flaxseed oil extraction. Brahmi *et al*. [44] studied the extraction of fruits (Apricot, watermelon, and melon) using a cold-press method for effective extraction. Linoleic and oleic acids were the dominant fatty acids in the extract. Abdolshahi *et al*. [45] studied *Pistacia vera* L. (pistachio) nuts for high levels of fatty acids and vital nutrients. They extracted pistachios using maceration and Soxhlet techniques with four solvents: ethyl acetate, dichloromethane, ethanol, and n-hexane. Unsaturated fatty acids were predominantly obtained from the extracted oil. The principal fatty acids in the pistacia extract were identified by GC-FID, which revealed the presence of linolenic acid and oleic acid. Due to the presence of USFAs, pistachio nuts have many health benefits. Dong *et al*. [46] analyzed *Firmiana simplex* L. (phoenix) for oil extraction from phoenix seed to evaluate fatty acid profile and physicochemical properties. Soxhlet and ultrasound-assisted techniques were used for extraction, and Soxhlet was found to be more acceptable than ultrasound-assisted. Oleic and linoleic acids were the main USFAs detected in phoenix seed oil by GC-MS. Abdalla El-Hadary *et al*.[47] studied *Curcubita pepo* L. pumpkin seed varieties (Chinese and Egyptian). HPLC was performed to obtain water- and ethanolic extracts from pumpkin seeds, which contained high levels of USFAs, including oleic and linoleic acids. The water and ethanolic extracts contained several bioactive compounds with potent antioxidant activity. Wickramasinghe *et al*. [48] examined the hybrid and traditional coconut varieties and extracted oil from them using cold-press techniques. The extracted oil contained both oleic and linoleic acids, but linolenic acid was the component present in higher amounts in traditional coconut species. Coconut oil extract offers many important health benefits and can be used as an edible oil to support a healthier lifestyle. Jaski *et al*. [49] studied *Olea europaea* L. leaves along with sesame and chia seeds and used the pressurized propane method for extraction. Chia and sesame oils were en

riched with high levels of USFAs. Linolenic acid was dominant in chia seed oil, while oleic and linoleic acids were found in sesame seed oil. OMEH *et al*. [50] studied breadfruit to evaluate the extracted oil. Breadfruit seed oil was extracted using Soxhlet and cold maceration, and six fatty acids were detected by GC/MS. The two PUFAs were oleic and linoleic acids, and that is why breadfruit had a potential future in the pharmaceutical industry. Jethro *et al.* [51] studied *Mangifera indica* L. for the extraction of mango kernel oil using conventional Soxhlet methods with n-hexane. Linoleic acid was the major fatty acid, followed by oleic acid.

3.2. Advances in extraction methods of UFAs.

The fatty acid compositions of soybean, oilseed radish, niger, and crambe seed oils were studied by Rocha et al. [52] using a Soxhlet apparatus with hexane solvent at 65°C. Linoleic acid was the major fatty acid in soybean and niger seeds, while erucic acid was the primary fatty acid in oilseed radish and crambe. Wang *et al*. [53] examined *Camellia sinensis* L. (tea plant) seeds, where extraction was performed using supercritical carbon dioxide and Soxhlet extraction, using response surface methodology at 35 to 45°C and 50 to 90 MPa of pressure. The extracted edible oil contained 80% oleic and linoleic acids, as determined by gas chromatography. Pereira *et al*. [54] examined *Passiflora edulis* var. *flavicarpa* (yellow passion fruit) for its physicochemical properties, fatty acids, and organic components. Passion fruit was extracted using various methods, including Soxhlet extraction with n-hexane and EtOH, ultrasound-assisted extraction with EtOH, and subcritical fluid extraction with compressed propane (30 to 60°C and 2-8 MPa). Subcritical fluid extraction with compressed propane yielded high levels of USFAs, primarily linoleic acid, followed by oleic and alpha-linolenic acids; therefore, passion fruit became a potential source of essential USFAs, which are good for human health. Mestour *et al*. [55] extracted onion seed oil by supercritical fluid extraction without using organic solvents. The four fatty acids obtained were predominantly 9,12-octadecadienoic acid, its methyl ester, 9-octadecadienoic acid, its methyl ester, 9,12-octadecadienoic acid (known as omega-6), its methyl ester, and hexadecanoic acid with its methyl ester as analyzed by the GC-MS technique. Due to its high content of beneficial fatty acids, onion seed oil offers various health benefits and can be used in cosmetics, pharmaceuticals, and the food industry. Atalay *et al.* [56] investigated the fatty acid profile of Capsicum Annuum L. (red pepper). Green methods, such as ultrasound-assisted extraction and cold-pressing with EtOH as the solvent, were used to extract seed oil from red pepper, in which linoleic and oleic acids were identified as the major components. From these studies, it can be concluded that red pepper may be a potential food source.

Ben-Othman *et al*. [57] investigated the extraction of *Chaenomeles japonica* (Japanese quince) by the SC-CO_2 extraction technique with EtOH as a co-solvent. Fatty acids were extracted using a $CHCl_2$/MeOH mixture, and methylation of fatty acids was done using acyl chloride and methanol. Among PUFAs, linoleic and a-linolenic acids were predominant, and oleic and palmitoleic acids were major as MUFAs. JQ fruit extract could be used in wine, and its by-products were used in the cosmetics and food industries. Roy *et al*. [58] examined the Eastern Himalayan regional plant *Tupistra nutans* wall. Ex Lindl. It was readily available in Sikkim's local market between September and November. T. nutans were extracted using methanolic extraction. Linoleic and palmitoleic acids were common fatty acids found, and T. nutans was used as an anticancer and skin care treatment. Chin *et al*. [59] investigated six Malaysian seaweeds (brown: Sargassum binderi, Padina australis; red: Gracilaria changgi; green: Caulerpa sertularioides, Caulerpa racemosa) to evaluate their chemical and antioxidant properties. The composition of fatty acids was determined by using the GC-FID technique of extracting seaweed samples with 300 mL n-hexane. All seaweeds consisted of small amounts of PUFAs and MUFAs. Brown seaweeds contained higher levels of MUFAs than green seaweeds. All brown seaweeds except S. binderi had high PUFA amounts. Except for red seaweeds, all the seaweeds consisted of omega-6 and omega-3 fatty acids. Fatty acid amounts in seaweeds were determined using high-performance liquid chromatography (HPLC), GC, and atomic absorption spectroscopy. Irshad *et al*. [60] studied four types of mushrooms *(Pleurotus sajor-caju*, *Pleurotus sapidus*, *Pleurotus columbinus*, and *Pleurotus ostreatus*) to determine their nutrient content. These species were extracted using ethanol followed by ethyl acetate, water, n-hexane, and dichloromethane. The fatty acid composition was determined by GC-MS. Linoleic, a-linolenic, oleic, and palmitoleic acids were detected, and the seaweeds could be good sources of biochemical and nutritional compounds. Li *et al*. [61] studied samara oil (Elaeagnus mollis Diels kernels seed oil) to evaluate fatty acid profile, antioxidant activities, and chemical composition. These were extracted using solvent extraction, mechanical extraction, cold-pressing, and hot-pressing techniques. A total of seven types of fatty acids were found. Linoleic acid was the major among them, followed by oleic acid.

4. Conclusions and Future Perspectives

There is strong scientific evidence that unsaturated fatty acids play an important role in all life forms, and their presence is associated with the etiology of many diseases. Hence, the extraction of these unsaturated fatty acids from edible sources has received significant attention from the scientific community. However, due to the complex composition of fatty acids, there are significant challenges in their extraction, including poor separation of unsaturated from saturated fatty acids. This review provides a critical evaluation of methods for extracting unsaturated fatty acids from edible plant sources, which are of great interest to human health. It also emphasized the challenges associated with analyzing the fatty acid profile and optimizing the parameters required for their extraction.

It is now well known that fatty acids are the major constituents of living organisms; they play essential structural roles in cell biology and are essential for preventing chronic diseases and maintaining good human health. However, the biggest problem so far is obtaining sufficient levels of unsaturated fatty acids to meet the increasing global demand. To address the modern world's challenge of finding renewable, sustainable, and cost-effective sources, the scientific community needs to develop advanced biotechnological methods for extracting unsaturated fatty acids from microalgae, yeast, fungi, bacteria, and plants. With the advent of climate change and the protection of the environment, as well as the development of green chemistry and the bioeconomy, scientists are continually seeking alternative ways to obtain unsaturated fatty acids in large quantities without harming the marine ecosystem or vegetation. To achieve this goal, significant efforts are required to achieve widespread applicability of the newer methodology, which can eventually enter industrial production and, ultimately, commercialization.

Author Contributions

Conceptualization, T.S., M.R., and M.S.; methodology, T.S., M.R., and M.S.; writing—original draft preparation, T.S., M.R., and M.S.; writing—review and editing, T.S., M.R., and M.S. All authors have read and agreed to the published version of the manuscript.

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Conflicts of Interest

The authors declare no conflict of interest.

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