Recent industrials extraction of plants seeds oil used in the development of functional food products: A Review

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ABSTRACT
The current review has been carried out to extract the oil from different plant seed sources, and its food application and bioavailability against various disorders. Plant seeds oil is considered a valuable ingredient in developing functional foods for human welfare. Nowadays, the trend has been changed, the people Worldwide prefer to consume plant-based oil by skipping animal-based fat because animal fat contains high trans fatty acids. However, different plant seeds including soybean, palm, sesame, sunflower, safflower, linseed, grape, camelina, chia, garden cress, English walnut & hemp, eucommia ulmoides oliver, avocado, pomegranate, pumpkin, sweet cherry, kangar, sacha inchi, pistachio and cottonseeds are being used to produce the oil. Plant oil is being used in the development of different food products because it contains health beneficial fatty acids. Previous studies proved that PUFAs play an important role in human health against different disorders.

Introduction
Oils and fats are the main parts of food because they contribute significantly to the flavor, quality, and taste of any foodstuff. The fatty acids found in nature are generally categorized on the basis of their number of double bonds and carbon chain length. The fatty acids are classified into long-chain and very-long-chain fatty acids on the basis of carbon numbers. The fatty acids comprise more than 12 carbon atoms are called long-chain fatty acids, while FA with more than 22 carbon atoms is known as very-long-chain fatty acids. Based on double bonds, FA is further classified into saturated and unsaturated fatty acids. Thus, the fatty acids having no double bond in their structure are saturated FA, the FA with one double bond are monounsaturated fatty acids (MUFA) and the FA with more than 2 double bonds are polyunsaturated fatty acids (PUFA). The most common saturated fatty acids are stearic acid and palmitic acid, whereas oleic acid is the diet’s most significant monounsaturated fatty acid. Based on the position of 1st double bond on the CH3 (methyl) terminal end, polyunsaturated fatty acids are categorized into omega-3 and omega-6 fatty acids. The α-linolenic acid is termed as omega-3 fatty acid and linoleic acid is known as omega-6 fatty acids due to the position of their 1st double bond, which is 3rd and 6th from the methyl terminal end, respectively. Those fatty acids that are not produced by the human body are called essential fatty acids. A variety of polyunsaturated fatty acids especially produced from ALA in the

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body involved docosapentaenoic (DPA), eicosapentaenoic (EPA), docosahexaenoic (DHA), and Stearidonic acid (SDA). The dietary food items rich in omega-3 fatty acids have substantial health-promoting aspects, as reported by several clinical and epidemiological investigations. The omega-3 fatty acids with substantial immunomodulatory and anti-inflammatory effects are very efficient in the prevention of autoimmune and inflammatory ailments, as determined by various research. Moreover, it was examined that the omega-3 polyunsaturated fatty acids showed affirmative consequences in treating schizophrenia and anxiety. The omega-3 fatty acids, especially Docosahexaenoic acid (DHA), play an essential role in infants’ development of the eyes, brain, and nervous system. Comparatively, it was observed that dietary recommendations imply omega-6 polyunsaturated fatty acids, particularly linoleic acid (LA), lower cardiovascular disease risk. It also increases in chronic inflammation that may result from a diet high in n-6 polyunsaturated fatty acid, which promotes the production of proinflammatory eicosanoids from arachidonic acid that why the health benefits of omega-6 fatty acids divisive demonstrated by Johnson et al. According to Dennis & Norris, investigation, linoleic acid may increase the risk of coronary heart disease because omega-6 fatty acids intake lower cholesterol risk. Several studies showed an improvement in sciatic nerve conduction in diabetic rats on a high linoleic acid diet.

It was evident from various human and animal investigations that a unique consumption of omega-6 fatty acids like alpha-linolenic acid exhibited auspicious outcomes in the cure of diabetic complications. It was also a challenging task to maintain the balance between the amount of omega-3 FA and omega-6 FA, to diminish the harmful effects of PUFA on the health of human beings. Vegetables and fish are rich sources of dietary polyunsaturated fatty acids. The primary long-chain polyunsaturated fatty acids include fatty fish like mackerel, sardine, herring, tuna, and trout. Eicosapentaenoic acid (EPA) and Docosahexaenoic acid (DHA) are the most abundant fatty acids found in fatty fish. About 30 to 50% of omega-3 fatty acids are present in fish oil. The presence of toxic as well as heavy metals like arsenic (As) and mercury (Hg) compromise the consumption of fish. Furthermore, it was explained that fish oil has a fishy flavor, which consumers do not accept because it is not widely incorporated in vegan diets. The vegetable oils are rich sources of omega-6 FA, involving cotton seed oil, sunflower oil, corn, soybean oil, and safflower oil. In comparison, the omega-3 fatty acids are more abundant in linseed oil as well as canola and dark leafy vegetables like purslane, kale, collards, mustard greens, and spinach. Plant oils are considered better for health-promoting bioactive ingredients than animal lipids. Beyond the high nutrient profile, other functional properties, including antimicrobial, anti-cancer, gastronomic, organoleptic, and anti-aging aspects, are other interesting factors for the consumption of plant oils compared to animal lipids. The main objective of this review is to explore the potential role of plant seed oils in our healthy lifestyle and their novel oil extraction techniques that have environmental-friendly cost-effective and provide more yield as compared to traditional techniques.

**Different plant sources of polyunsaturated fatty acids**

Vegetable oil is significantly involved in body fat, mainly obtained from seeds and in some cases from fruits such as olive oil and palm oil. According to FAO, annual consumption of vegetable oil is approximately 18.15 kg per capita all over the world. The most common edible oils include canola oil, chia oil, soybean oil, flaxseed oil, camellina, palm oil, perilla oil, garden cress oil and sunflower oil. Table 1 shows oil content (%) and α-linolenic acid composition of some selected seed oils. Different sources of plant oil is shown in Figure 1.

**Soybean seeds oil**

Soybean oil is obtained from the seeds of its plant in a very large quantity. It is a widely consumed edible oil in the USA. It has different concentrations of fatty acids including 15% of saturated fatty acids, 25% of monounsaturated fatty acids, and 61% of polyunsaturated fatty acids. It also contains essential fatty acids such as α-linolenic acid (11%) and linolenic acid (89%). Approximately 48% 0 f
Soybean oil is used in several food items like cooking, margarine, mayonnaise, and salad oils. Thus, it has dietary importance but also showed oxidative instability.\[20\]

**Palm seeds oil**

Palm trees are a very efficient source of palm oil. It is obtained from the fruits of palm trees. It has ranked as the second most oil-producing plant in the world. It has an appropriate fatty acid composition with an equal amount of saturated fatty acid and unsaturated fatty acids.\[21\] Palm oil contains a high concentration of oleic acid, linoleic acid, and Palmitic acid in a ratio of 43%, 11%, and 40% along with a trace amount of linolenic acid.\[22\] It is evident from studies that trace amounts of linolenic acid and low levels of linoleic acid present in edible oil reduce their oxidation process. The saturation of palm oil depends on its varieties, thus more varieties of palm oil show unsaturation. The bioactive compounds like anthocyanins and carotenoids are present in very high concentrations in dark orange-red color palm oil. It has also a high amount of vitamin E in form of tocotrienols and tocopherols. About 90% of palm oil is mainly used in edible food items.\[20\]
**Sesame seed oil**

It is obtained from sesame seed and contains a high concentration of oil content of about 42% to 56%. It has many pharmacological activities as well as is extremely resistant to oxidation as compared to other vegetable oils. It is classified as polyunsaturated oil and accounts for 82% unsaturated fatty acids along with a balanced amount of linoleic and oleic acid in sesame seed oil.\(^{[20]}\)

**Sunflower seeds oil**

Sunflower (Helianthus annuus) is a large plant usually cultivated around the world due to its short harvesting period. The sunflower seed oil has an immense number of fatty acids according to its climatic conditions. In cooler climatic conditions sunflower seed oil contains a higher concentration of polyunsaturated fatty acids particularly linoleic acid, while in warmer climatic conditions, the concentration of monounsaturated fatty acids especially oleic acid is dominant. The presence of a high concentration of linoleic acid along with oleic acid is the main characteristic of sunflower oil. Sunflower oil consists of a significant amount of saturated fatty acids particularly stearic acid and palmitic acid which is not more than 15% of the total fatty acid concentration.\(^{[23]}\) In sunflower seed oil sterol is found in a concentration of 0.24 to 0.26%.\(^{[24]}\) It was observed that sunflower seed oil is greatly used in edible products but a small amount of it is often used for industrial purposes.

**Safflower seeds oil**

The safflower plant is used to produce two types of safflower oil in which the most frequently used oil is an unsaturated oil that accounts for about 75% to 80% of linoleic acid. It contains an enormous amount of unsaturated fatty acid along with less amount of monounsaturated fatty acid which is the major cause to get rancid earlier. When safflower oil is exposed to heat, it shows toxic aspects, used in deep frying hats.\(^{[20]}\)

**Linseed seed oils**

Linseed is commonly known as flaxseed belongs to the genus Linum, the family Linaceae, a widely cultivated crop in more than 50 countries.\(^{[25]}\) It is obtained from seeds of flaxseed by using a clod presser with a high concentration of polyunsaturated fatty acids, especially α-linolenic acid (ALA) which it is more sensitive to exposure to light, heat, and oxygen.\(^{[25,26]}\) The concentration of α-linolenic acid in linseed is about 52% to 60%. It is observed that flaxseed oil accounts for 57 to 76% of PUFA with maximum amount of ALA.\(^{[27]}\) Thus is concluded that linseed oil is rich source of α-linolenic acid than other vegetable oils.\(^{[27]}\)

**Grape seeds oil**

Grape seed oil is a rich source of phenolic compounds, linoleic acid, tocopherols, and antioxidants.\(^{[28,29]}\) It comprises polyunsaturated fatty acids in a very high concentration of about 85 to 90%, approximately 60 to 70% consists of linoleic acid.\(^{[30]}\) It was noted that bioactive ingredients obtained from grape seed oil showed incredible antioxidant activity.\(^{[31,32]}\) The grape seed oil is commonly obtained from the by-product like the pomace of grapefruit produced after wine and juice production. The most appropriate method used for grape seed oil extraction is cold pressing because there is no chemical or heat treatment involved.\(^{[33]}\) A more efficient product was produced as the result of this method than the solvent extraction technique, since this is considered more beneficial due to no existence of solvent residue as well as retention of many useful ingredients in the oil.\(^{[33,34]}\) It was determined that PUFA made up 66 to 76% of the total fatty acids present in the four different types
of grape seeds. The concentration of linoleic acid as unpredictable in these tested oils like in ruby red grape seed oil (66%), chardonnay (69%), muscadine (70.2%), and concord seed oil (75.3%).

**Camelina seeds oil**

Camelina is a plant usually cultivated in Scandinavia and Europe belongs to the family Brassicaceae. Camelina seed oil contains high concentration of polyunsaturated fatty acids along with α-linolenic acid. This oil is very sensitive to heat, light, and oxygen exposure due to the presence of high concentration of ALA. Camelina seed oil accounts for 60% of polyunsaturated fatty acids along with 35 to 40% was α-linolenic acid. It is evident from studies that the ALA was found in high concentration along with PUFA contents such as about 57% of polyunsaturated fatty acids, 35 to 36% was accounted for ALA and only 16.1% of oleic acid. But it contains approximately up to 11.4% saturated fatty acids.

**Chia seeds oil**

*Salvia hispanica* commonly known as Chia is an herbaceous plant belonging to the family Lamiaceae. Different varieties of chia seed oil contain different concentrations of fatty acids. As Chilean chia seeds oil accounts for about 30 to 33% of ALA out of total fatty acids (62–64%). While CHI Ampion-B variety of chia seeds cultivated in India comprises about 65% of total fatty acids. Chia seeds are the main source of various nutrients including minerals, protein (15 to 25%), dietary fiber (34 to 37%) and natural antioxidants like polyphenols, phytosterols, tocopherols and carotenoids. Chia seed has incredible antioxidant activities due to a higher concentration of phenolic compounds. Chia seeds are also considered as a vital source of ALA generally used in diet. Different forms of chia seeds like four, gel and raw form are used in food particularly in dairy and bakery products. It is also mainly used in pharmaceutical industries as an emulsifier and stabilizer due to its efficient water-absorbing as well as gel-forming properties.

**Garden cress seeds oil**

Garden cress botanical classified as *Lepidium sativum* belongs to family Cruciferae is a rapidly cultivating herb. Garden cress seed comprises of 21 to 24% oil. The oil contains equal amount of monounsaturated fatty acids and polyunsaturated fatty acids, ALA (32%) and ample number of antioxidants including phytosterols and tocopherols in a ratio of 12.16 mg and 1.7 mg per g respectively. Green cress seed oil is relatively more stable as compared to other seed oils including chia, flax seed and camelina oils due to presence of low concentration of ALA and equal ratio of MUFA and PUFA. It was investigated that the amount of ALA increased and LA concentration decreases when GCO is blended with other vegetable oils including rice bran oil, sunflower oil, and sesame oil and its nutritional composition also improved. It was reported that the GCO blended oil has a sufficient amount of lipid as well as fatty acids contents in Wistar oil. This blended oil also enhanced the various dietary fatty acids such as EPA, DHA, and ALA in different organs of rat’s including the heart, brain, and liver. The ALA obtained as a result of blended oil is more efficient in metabolism as well as absorption of long-chain polyunsaturated fatty acids. Green cress seed oil is a vital source of ALA which is blended with other vegetable oils and enhanced the omega-3 and omega-6 polyunsaturated fatty acids content to improve health status.

**English walnut & hemp seeds oil**

Juglans regia known as English walnut belongs to the family Juglandaceae, and is a timber tree considered native to Iran. Hemp seeds are botanically classified as Cannabis belonging to the family Cannabaceae. English walnut oil contains about 9 to 10% of ALA and hemp seed oil also contains...
approximately 8.8% of ALA, but both are known as the alternative sources of ALA. Though it was examined that they contain less amount of ALA as compared to other seed oils but these are preferred because they boost up the overall consumption of ALA. [45]

**Eucommia ulmoides Oliver seeds oil**

Eucommia ulmoides Oliver a traditional Chinese herbaceous plant belongs to genus Eucommia family Eucommiaceae. It is commonly cultivated in China, Korea, and Japan, popular for its medicinally significant bark and foliage.[45] The oil is obtained from seeds that are the byproduct of Eucommia ulmoides. These seeds account for higher concentration of oil (30 to 40%) and an immense amount of ALA (56 to 63%) and vitamin E about 191 mg/100 g.[46]

**Avocado seeds oil**

Avocado (Persea americana) is a multi-stemmed tree that is commonly cultivated in Mexico, south America, and central America. The oil obtained from the pulp of avocado fruit that has a significant amount of minerals and lipids (10 to 30%).[47,48] The avocado oil is main source of unsaturated fatty acids including about 13% of PUFA and 71% of monounsaturated fatty acids.[49] Like olive oil, avocado oil is also more easily digestible to higher concentration of oleic acid.[50] The idioblast cells commonly called oils cells are surrounded by parenchyma cells present in pulp of avocado fruit.[48] Oil sacks are found in idioblast cells but parenchyma cells contain disperse oil emulsions.[47] Different extraction techniques including subcritical CO2 extraction (SCCO2), solvent extraction and ultrasound-assisted aqueous extraction used by Tan et al.[51] to determine the fatty acid concentration in avocado oil. As a result of these extraction techniques, the oleic acid was very high approximately 40.73 to 42.72% along with other fatty acids involving plamitoleic acid, linoleic acid and palmitic acid in a ratio of 6.64–8.50%, 15.52 to 18.88% and 28.12–34.48%, respectively. It was observed that the oils contained high amount of oleic acid showed greater oxidative stability generally in cooking.[52,53] Finally, avocado is a rich source of oleic acid content as well as used as functional oil but more studied are needed to evaluate its potential applications.

**Pomegranate seeds oil**

Punica granatum is commonly known as pomegranate seed oil contains a high concentration of polyunsaturated fatty acids in a ratio of 69.42%. The punicic fatty acid is considered one of the main PUFAs found in pomegranate seed oil and accounts for 55.27%. It was also observed that the concentration of α-linolenic acid (C18:3) is very low in pomegranate seed oil, whereas EPA was not found in pumpkin seed oil. Punica granatum seed oil is the main source of many bioactive ingredients such as unsaturated fatty acids and carotenoids for the development of many functional foods products.[54]

**Pumpkin seeds oil**

Pumpkin belongs to the genus Cucurbita L, family Cucurbitaceae, and its oil is commonly obtained from seeds including bare seeds and hulled seeds containing about 44% and 38%.[55] Pumpkin seed oil shows high-intensity coloration due to high concentration of chlorophyll and carotenoids. Cucurbita maxima seed oil is also a rich source of several health-beneficial fatty acids like monounsaturated fatty acids as well as polyunsaturated fatty acids.[54] According to Nawirska-Olszanska,[56] pumpkin seed oil contained approximately 42 to 59% of linoleic acid and 25% of oleic acid of the total fatty acid. Pumpkin seed oil is the main source of carotenoids like lutein and β-carotene as well as other bioactive ingredients such as polyphenols that are involved in the antioxidant activities and also a good source of functional components.[54]
Sweet cherry seeds oil

Prunus avium is also known as sweet cherry and its oil contains polyunsaturated fatty acid as well as monounsaturated fatty acid in a ratio of 44.32 and 39.49%, respectively. In sweet cherry oil oleic acid and linoleic acid found in a concentration of 35% as well as 41.45%, respectively, are the key fatty acids. The sweet cherry oil obtained from food industry waste is a rich source of bioactive compounds, carotenoids, unsaturated fatty acids, and antioxidants. It is also usually employed as a preservative and functional food component.\[54\]

Kangar seeds oil

Kangar is botanically classified as Gundelia tehranica, usually cultivated in the Middle East belongs to family Asteraceae.\[57,58\] Various parts of this plant are significantly used as conventional medicine as well as food production.\[57,59\] Different pharmacological properties including antioxidant activity, antibacterial, anti-inflammatory, hypolipidemic prospective and hepatoprotective potentials of kangar seed oil was described by Asadi-Samani et al.\[60\] A significant amount of fatty acids like linoleic acid, palmitic acid and oleic acid found in oil obtained from different parts of Kangar plant.\[59\] The chemical composition and oxidative stability of oils were determined by Hashemi et al.\[61\] According to this study, the concentration of linoleic acid was very high approximately 572.9 ± 4.9 gkg⁻¹ than other fatty acids concentration. Comparatively, oleic acid was about 248.4 ± 1.3 gkg⁻¹ in kangar seed oil, but in saturated fatty acids palmitic acid was detected in high concentration (97.2 ± 6.1 gkg⁻¹). Kangra seed oil is a main source of natural antioxidants as well as unsaturated fatty acids, but to evaluate its functional applications further studies are required.\[61\]

Sacha inchi seeds oil

Plukenetia volubilis is a native plant commonly cultivated in the Peruvian jungles, belongs to the family Euphorbiaceae, and is also known as Sacha inchi as well as “Inca peanut.”\[62\] Sacha inchi seeds are main source of its oil, which have ample amount of unsaturated fatty acids such as polyunsaturated fatty acids (85%), comprising unique concentration of linoleic acid (34%) and linolenic acid (51%).\[63\] Maurer et al.\[64\] studied the chemical composition of various vegetable oil including sacha inchi oil. According to this, it was observed that Sacha inchi oil contains an ample amount of PUFAs about 78%, containing 33.5% of linoleic acid and 44% of linolenic acid. It was also concluded that sacha inchi oil is a potential source of polyunsaturated fatty acids other than fish oil, it is also a cost-effective, renewable, and sustainable source of omega-3 fatty acids.

Pistachio seeds oil

Pistacia khinjuk is a species of plant belongs to the family Anacardiaceae, which is naturally cultivated in Iran.\[65\] Numerous parts of this plant reveals anticancer as well as anti-diabetic effect and also shows positive effect on cholesterol level and liver function.\[66\] Traditionally, it was also used in Iran for medicinal purposes to treat vomiting, nausea, and diarrhea.\[67\] The antioxidant activity, oxidation stability, and chemical composition of kernel and hull of Pistachio oil was evaluated by Asnaashari et al.\[68\] The concentration of monounsaturated fatty acids was comparatively greater than saturated fatty acids observed in both types of oils. Thus, it was noted that the hull oil contained palmitic acid, linoleic acid, and oleic acid in a ratio of 19.44%, 13.57%, and 63.55%, respectively. Moreover, the composition of kernel oil involved palmitic acid, linoleic acid and oleic acid in a ratio of 16.11%, 20.09%, and 61.11%, respectively. Thus, the above discussion revealed that oleic acid was the leading monounsaturated fatty acid found in these two types of oils. Furthermore, it was also noted that hull oil contained a higher amount of unsaturated fatty acids (MUFA and PUFA) which showed excellent oxidation stability, particularly during the frying process. Asnaashari et al.\[68\] determined that hull and
kernel oil showed higher oxidative stability, natural antioxidants as well as longer shelf life of oils due to the presence of high concentration of tocotrienols.

**Cottonseeds oil**

Cottonseed is obtained as a by-product during cotton ginning, containing about 16 to 17% cottonseed oil by its weight. [69] It belongs to the genus *Gossypium*, family *Malvaceae*. The most abundant fatty acid found in cottonseed oil is linoleic acid, followed by oleic acid, palmitic acid in a ratio of 54.4%, 18.6%, and 21.6%, respectively, and less amount of other fatty acids. The unsaponifiable fraction of cottonseed oil contains a small amount of various compounds like sterols, resins, phospholipids, pesticides, tocopherols, carbohydrates, gossypol, and other pigments. It is commonly used as liquid oil in the preparation of margarine and shortening. [70] Cottonseed oil has various applications including the preparation of soap, manufacturing of rubber, and production of pharmaceuticals, in the processing of lubricant sulfonated oil as well as used in the processing of textile, leather, polishes, synthetic plastics, printing inks, and resin in a very minute quantity. [71]

**Extraction of plant seeds oil by using traditional methods and industrial methods**

The extraction of edible oils is carried out through traditional methods and industrial methods. **Figure 2** describes following extraction methods

**Traditional methods of extraction**

**Hot water extraction**: It is a traditionally used extraction technique in which minced seed is added with hot water and boiled until the oil floats and then skimmed off. Thus, the minced seed oil is further mixed with hot water to form a paste, this paste is ready to kneading by hand or machine and the oil separate out as an emulsion. A sufficient amount of salt is added to coagulate protein and improve oil

![Figure 2](image-url)
separation in case of groundnut oil extraction. Extraction of oil using hot water extraction method is time-consuming and provide low yield and high maintenance cost required.[22]

**Dehydration:** In this technique, the sample is boiled in narrow pots and the water found in crude oil is removed after settling. This technique is more common in rural areas, which shows that water acts as catalyst to determine the poor sensory attributes as well as development of rancidity.[20] Hlaing & Oo[73,74] studied castor oil is used to make alkyd resin by dehydration of the refined castor oil was accomplished with the use of a NaHSO4 catalyst. The quality of the dehydrated castor oil was improved by the use of a vacuum pressure system, which proved to be an efficient processing procedure. Under vacuum of 600–640 mmHg at 210–220°C, 1% NaHSO4 catalyst was used to produce a typical dehydrated castor oil.

**Mechanical expeller extractors:** In a fixed mortar system, a large rotating pestle is rotated by a person, motor, or animal that is used to crush and minced the seed to extract the oil at the bottom of the mortar. The other most common conventional techniques applied in rural areas to extract seed oil involve the use of wedges, heavy stones, twisted ropes, and levers. To press the milled oil mass pistons are manually pushed into a perforated cylinder by use of a worm gear. Thus, the piston pressed the oil mass and the oil is collected at the bottom of the perforated chamber. Several types of mechanical expellers are designed and available in the market. A worm shaft transfers pre-heated raw material into a horizontal cylinder. Hence, internal pressure in the cylinder ruptures the oil cells due to the use of an adjustable choke and oil is released.[20,72]

**Industrial methods:** Different techniques used for the separation of polyunsaturated fatty acids including low-temperature crystallization, enzymatic separation, supercritical fluid extraction, urea complexation, chromatographic techniques, and separation based on distillation.[73,75,76]

**Chromatographic method:** The separation of free fatty acids depends on the degree of unsaturation and their number of carbons by using appropriate adsorbents.[77] A variety of chromatography techniques including preparative HPLC, high performance liquid chromatography and silver resin chromatography are commonly used for the extraction of polyunsaturated fatty acids essence. The silver nitrate thin layer chromatography technique is used as methyl ester for the extraction of polyunsaturated fatty acids. The process of saponification was used to retain the linoleic acid (LA) obtained from Pinus armandi franch seed oil and urea inclusion fractionation procedure for the concentration of fatty acids.[78] By utilizing silver-silica gel column chromatography, the whole process recovered 79% of the methylated polyunsaturated fats, which resulted in an overall purity level of 97%. The process of saponification to retain linoleic acid obtained from sunflower oil and urea complexation for the separation of free fatty acid was determined by Guo et al.[79] The methyl ester of LA was refined by argentated silica gel column chromatography when concentrated fatty acid was methylated. The overall Recovery was 77%, and purity was about 96.7% as the result of the whole procedure.

**Distillation method:** Vacuum distillation can be used to substantially separate various FA because of their distinct boiling points. The polyunsaturated fatty acids are very susceptible to oxidation due to this fact distillation process taken place particularly at low temperature, minimum residence time, and minimal pressure. This can be accomplished through molecular distillation or short-path distillation. It was noted that at higher temperature polyunsaturated fatty acids especially n-3 are more sensitive to oxidation, isomerization and polymerization, probably produce harmful chemicals.[80] This is relatively an ancient technology that requires a significantly higher temperature along with lower pressure.[81]

**Low-temperature crystallization:** The different mixtures of fatty acid esters that are soluble in organic solvent at normal temperature but become insoluble below 0°C are separated by using Low-temperature crystallization.[77] The separation of unsaturated and saturated fatty acids can be accomplished because the melting point of FA varies greatly depending on degree of FA unsaturation.[82] This technique can be conducted in both condition either with solvent or not, for separation of the fatty acids. Acetone, methanol and mixture with other solvent are the mostly used solvent in this technique for the extraction fatty acids. In low-temperature crystallization, the saturated fatty acids
having compact carbon chain are crystalized while the unsaturated fatty acids including MUNFAs and PUFAs essences persist in the solution.\cite{83}

**Enzymatic method:** This procedure uses a wide variety of lipases to increase the concentration of PUFA by enzymatic hydrolysis or esterification. The cis-olefinic double bonds are commonly found in fatty acids and the separation of FA based on the bending of these bonds. In this bending process of FA, the terminal methyl (\(\text{CH}_3\)) group closes to the ester bond and inhibit the hydrolysis process due to occurrence of steric hindrance.\cite{84} EPA (with five double bond structure) and DHA (with five double bond structure) show high steric hindrance due to their higher bending ability, thus the lipase enzyme cannot react with an ester linkage of glycerol and fatty acid. On the contrary, other unsaturated fatty acids like MUFA and PUFA could be easily hydrolyzed by lipases because they have no steric hindrance. Enzymatic acylolysis of 25\% SDA soybean oil (SDASO) resulted in the generation of n-3 concentrates investigated by Ifeduba and Akoh\cite{85} Crystallization of SDASO fatty acids provided 62\% SDA PUFA essences, whereas hydrolysis of SDASO by non-immobilized lipase AY 30 (Candida rugosa) generated an acylglycerol mixture with a 51\% SDA content (SDA-GLY). Hydrolysis of flax seed oil having ALA as a primary FA was performed by Rupani et al.\cite{86} with commercial lipases from Pseudomonas fluorescens, Candida rugosa, Rhizomucor miehei, and Pseudomonas cepacea. An enzyme from Candida rugosa was shown to be the most effective in the hydrolysis of fats, producing an FA mixture that had an excess of ALA (about 72\%) and further raised to 80\% by urea complexation of saturated fats. A new alkaline lipase from Aspergillus fumigatus MTCC 9657 was used by Rajan et al.\cite{87} to hydrolyze Flax seed oil and eliminate undesired FA for the improvement of LA and ALA. The TG n-3 content improved to 39\% and the n-6 level increased to 54.76\% after hydrolysis for 8 hours indicating the elimination of inappropriate saturated FA.

**Supercritical fluid extraction:** Any substance is called supercritical fluid when a pressure and temperature is slightly differed from its critical point. A significant alteration occurs in the properties of supercritical fluid including diffusivity and viscosity by minimal alterations in the temperature and pressure at critical point. Supercritical fluids are more liable for fractionation and extraction of various raw materials due to its unique properties. Carbon dioxide is one of the most appropriate supercritical fluids due to its distinct properties including moderate critical pressure (72.9 atm) and temperature (31.1°C), inexpensive, nonflammable, inert, and environmentally suitable. This method of separating PUFA focuses more on the size of the FA molecules than on the degree of unsaturation. To get the most PUFA concentrates, the FA molecules need to be concentrated first.\cite{88} Researchers thoroughly examined and reported on the effects of the three supercritical extraction operational parameters of temperature, pressure, and scCO2 flow rate on the extraction yield and fatty acid profile of the (grape seed) oil extracts.\cite{89} Compared to the 12.3\% obtained by a traditional n-hexane extraction, the most significant oil yields obtained by the SCE were in the range (of 12.0–12.7\%). Linoleic and oleic acids comprise most of the fatty acids in the scCO2 oil extracts, with average percentages of (67 and 20\%), respectively. Chellini et al.\cite{90} extracted the pumpkin seed oil using supercritical carbon dioxide (ScCO2) and hexane/isopropanol. This study aimed to assess the oil’s fatty acid composition and total tocopherol content. GC, GC/FID, and HPLC were used to analyze the fatty acid composition and concentration of total tocopherols. Compared to hexane/isopropanol extraction (8.3 2.7\%), pumpkin seed oil obtained using Sc-CO2 extraction had a maximum yield of 24.3 0.4%.

**Urea complexation:** Urea is the only substance that is crystalline and forms tetragonal crystals. Urea complexation is a method of separating urea and FA that relies on the production of an inclusion complex. Although it forms hexagonal inclusion complexes with FA, it crystallizes in the absence of FA. This is a host-guest crystal formation between urea and FA. Only linear chain fatty acids molecules can form crystals with urea as guests. This method can be used to distinguish saturated and mono-unsaturated fatty acids from polyunsaturated fatty acids. Urea complexation is the simplest and most effective process for producing high concentrations of polyunsaturated fatty acids (PUFAs).\cite{91} Based on the above methods, biomaterials with enough PUFA can be concentrated using either a single process or a combination of processes.\cite{83} Bashar & Jumal\cite{92} examined that urea complex fractionation was used to separate LA from a mixture of free fatty acids (FFA) made from local Jatropha curcas
seed oil. At an urea/FFA ratio (w/w) of 5, a crystallization temperature of −10°C, and a crystallization duration of 24 hours, LA was 92.81% and the yield of NUCF was 7.8% under suitable conditions. Fie et al. used urea complexation to produce PUFA from a mix of canola and sunflower oils. From an initial level of 4.49%, the percentage of saturated FA was almost completely blocked. The percentage of MUFA also lowered from 57.02% to 41.32%, while the percentage of PUFA increased from 33.49% to 53.87% in NUCF. With an urea-to-PUFA mole ratio of 20, a crystallization period of 29.67 hours, and a crystallization temperature of −20°C, the ideal conditions for maximizing PUFA content were recognized.

**Ultrasound-Assisted Extraction**

The capacity of ultrasound-assisted extraction (UAE) to increase the effectiveness of many processes has increased its popularity in recent years. It is a cutting-edge, environmentally friendly, highly scalable extraction method for extracting oil and other bioactive substances. Its extraction involves many intricate mechanical phenomena, including cavitation bubble generation, vibration, mixing, and pulverization. Together, the actions weaken the cell wall, make it more permeable, and accelerate the mass transfer rate. When ultrasonic waves propagate through liquids at a critical value, the fluid experiences a negative pressure, leading to cavitation. When the local tensile strength of the liquid is exceeded by the compression and expansion cycles of the ultrasonic waves, a negative pressure result. This process results in many little bubbles that develop over time to the point that, as they collapse, they create shear forces and turbulence. This method’s helpful frequency range is 20 to 50 kHz. When cavitation bubbles collide, a fast micro jet is created on the material’s surface, which causes the material’s surface to peel off, the cell wall to deteriorate, and the cellular content to erode and exude. A system’s chemical processes can also be altered by cavitation, which can start new reaction mechanisms by creating free radicals. The most prevalent free radicals when water is employed as the solvent are hydroxyl radicals, which can change the structure of proteins in cells depending on the process. Shear energy, turbulence, and cavitation are all increased by rising temperature and pressure. During extraction, cavitation, heat, and mechanical impacts are the primary cell wall degrading mechanisms, and the interaction of these three events ruptures the cell wall. They also speed up chemical reactions and shrink the size of the particles. These synergistic actions enable mass transfer and shorten the extraction time while barely affecting the extract. Boger et al. conducted to increase process yield and reduce free radical formation in the oil, researching to optimize the ultrasound-assisted extraction (UAE) of grapeseed oil. The ideal conditions were 15°C and a 42 m ultrasonic wave amplitude, which produced a process yield of 82.9% and free radical contents of 14.7 1017 kg per sample and 3.4 1018 kg per sample, respectively, for samples held for 7 and 30 days. Between-sample changes in fatty acid content, acidity, or iodine values were not found to be statistically significant. Compared to the control sample, the oil produced by ultrasound included more phenolic compounds and had better antioxidant activity by ferric reduction (without ultrasound application).

**Food applications of plant seeds oil:** The edible oils obtained from plant sources are of great interest among the consumers as well as food business. These oil containing seeds like corn, soybean, flaxseed, cotton seeds, canola seeds, sesame seeds and garden seeds are widely used in the preparation of various food products. These edibles oils are mainly used in manufacturing of baked products (rolls, breads and cakes), salads dressing, confectionary, mayonnaise, deep frying oils, margarines, filling cream, shortening, and dry pasta products. And also used as cooking oils, preservatives, emulsifier and infant nutritional formula. Nowadays, a vast variety of omega-3 polyunsaturated fatty acids are available in powder as well as oil form for food enrichment. Thus, a variety of omega-3 enriched food products including milk, margarines, pasta, bakery products, mayonnaise, spreads, egg and egg products are commercially available. Moreover, food applications of different edible oils are depicted in Table 2.
Pharmacological aspects

Eicosanoids with anti-inflammatory, antiarrhythmic, and antithrombotic characteristics are obtained from ALA by an inefficient enzymatic activity of desaturation.\[106\] Omega-3 fatty acids have been shown to be the most effective dietary supplements among a large number of people. Health benefits of plants oil as shown in Figure 3. Additionally, EPA and DHA supplementation during pregnancy has been linked to resistant responses in newborns, including reduced incidence of sensitivity in newborns.\[107\] According to an estimation about 40% reduction in cardiovascular infection and a significant reduction in all-cause mortality were observed in those who increased their DHA/EPA intake to 664 mg/day.\[108\] The use of omega-3 fatty acids as dietary supplements is more beneficial for the people suffering with dyslipidemia, high blood pressure, atherosclerosis, diabetes mellitus, fiery

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**Table 2. Dietary uses of edible oils.**

| Commercially Available Product | Dietary Uses | Reference |
|-------------------------------|--------------|-----------|
| Flax seeds and seed oil       | Baked goods, juices, dairy products, and dry pasta products | [100] |
| Camelina seed oil             | Edible oil, food supplement | [101] |
| Perilla seed oil              | Edible oil    | [16]      |
| Chia seeds and seed oil       | Baked and dairy products as emulsifier and stabilizer | [14,42] |
| Canola seed oil               | Vegetable oil | [102] |
| Cotton seed oil              | Margarine, shortening, salad oil, deep-frying some snack items | [20] |
| Garden cress seed oil        | Salad dressings | [103] |
| Sunflower oil                | Salad dressings, cooking, margarine | [20] |
| Pistachio oil                | food processing, pharmaceutics, cosmetics | [104] |
| Palm kernel oil              | production of nondairy ice-creams, frying oil, production of margarine, filling creams (for biscuits, waters) | [20] |
| Sesame seed oil              | Cooking oil | [20] |
| Safflower oil                | deep frying | [20] |
| Soybean oil                  | Bioactive Encapsulation and Delivery, Fat Replacer | [105] |

**Figure 3.** Health benefits of plants oil.
Table 3. Health benefits of different plant seed crop oil.

| Plant seed crop oils | Polyunsaturated fatty acids | Health benefits | Reference |
|----------------------|-----------------------------|-----------------|-----------|
| Soybean seeds oil    | Oleic acid, Linoleic acid, Linolenic acid, Arachidic acid | Improve development of central nervous system and retina in infants, anti-inflammatory effects | [110,111] |
| Palm seeds oil       | Linoleic acid, Eicosenoic Acid, Omega-6 (Ω – 6), α-Linolenic Acid, Palmitoleic Acid | Reduce cholesterol level, Reduce risk of diabetes, reduce obesity risk | [112,113], [114,115] |
| Sesame seed oil      | α-Linolenic Acid, Omega-6 (Ω – 6), Palmitoleic Acid | Good for diabetes, improve insulin resistance, decrease chronic disease risk | [116,117] |
| Sunflower seeds oil  | α-Linolenic acid, Linoleic acid, Oleic acid | Anti-inflammatory effect, improve cardiovascular disease, Decrease cancer risk | [118,119] |
| Chia seeds oil       | Omega-6 (Ω – 6), α-Linolenic Acid, Palmitoleic Acid | Reduce chronic disease risk, anti-inflammatory, reduce cholesterol, | [120] |
| Hemp seeds oil       | Omega-3 and omega-6 fatty acids, Oleic acid, Stearolic acid, Palmitoleic Acid | Reduce risk of chronic diseases, anti-inflammatory effect, diseases preventive effect, | [121–123] |
| Flaxseeds            | Omega-6 (Ω – 6), α-Linolenic Acid, Palmitoleic Acid | Anti-inflammatory effect, improving insulin sensitivity, reduce cardiovascular disease risk, improve bone health | [2,117,124] |

diseases, obesity, eye diseases, metabolic dysfunction, and neurological disorders. Health benefits of different plant seeds oil are tabulated in Table 3.

**Inflammation**

Epidemiological studies indicate that omega –3 PUFAs in the diet can help to prevent asthma because they have anti-inflammatory effects. Eskimos have a less prevalence of asthma as a result of their regular consumption of fish which is high in omega-3 fatty acids. The consumption of a sufficient amount of Omega-3 PUFAs has also been indicated to reduce bronchial inflammation. EPA and DHA supplementation may reduce pro-inflammatory cytokine levels in the body of asthmatic patients who consumed these supplements regularly for three weeks. The effects of a widely used anti-LT drug and daily PUFA intake along with 3.2-g EPA and 2 g DHA on asthmatic patients were investigated for three weeks in another research. Fish oil and anti-LT medications were shown to be effective in reducing inflammation and hyperpnea-induced bronchoconstriction, reported by Biswas. Infant bronchial asthma patients taking dietary supplementation of PUFA for six weeks in a ratio of about 120 mg/day had a significant improvement in their lungs function. Omega-3 and omega-6 polyunsaturated fatty acids are especially helpful against exercise-induced bronchoconstriction, which is one of the best ways to keep athletes for their maximum performance. In this case, the effect of about 5 g/day of PUFA intake against placebo was measured in people with asthma whose bronchi usually tighten up when they exercise. During Post-exercise lung function was shown to be enhanced, but pro-inflammatory eicosanoids and cytokines were decreased. EETs generated from arachidonic acid play a pivotal role in the body to combat hypertension and renal disease due to their anti-inflammatory aspects.

**Cardiovascular Disease**

Several studies are conducted to investigate the effect of polyunsaturated fatty acids for the prevention of CVDS and production of its medication. A number of researchers investigated the protective effects of omega –3 and omega –6 polyunsaturated fatty acids after myocardial infarction as well as several clinical studies have shown that these PUFAs can be used as tertiary precautionary measures. The risk of mortality and cardiovascular disease was significantly lowered by the consumption of polyunsaturated fatty acids. In this area, computational research has been conducted to investigate the effects of PUFA on antiarrhythmic prospective. Several studies revealed that these fatty acids may be
able to counteract the effects of adrenal hormones on the heart. On the basis of several medical field and clinical research, AHA precautionary measures suggested that people consumed omega-3 and omega-6 PUFAs improve their heart health.¹⁰⁷ The modification of ion channels in these PUFAs is thought to reduce the impulsivity of heart cells, decrease atrioventricular transmission, and significantly delay the development of a prolonged QT interval.¹³²

**Obesity**

The consumption of omega-3 polyunsaturated fatty acids is very effective against lipid ailments and inflammatory disorders.¹³³ Several chronic ailments including obesity, coronary heart diseases, diabetes, cancer rheumatoid arthritis and mental disorders are most commonly occur as a result of inflammation.¹³⁴ Obesity is a complicated disease that affects many organ systems, such as digestive tract, central nervous system (CNS), and pancreas. It is also associated to genetics, hepatitis, and adiposis. It was determined that hypothalamus is very effective to regulator the mechanism of food intake as well as appetite, comparatively the feedback mechanism of CNS is demonstrated in energy balance due to environmental factors by further studies.¹³⁵ The use of omega-3 fatty acids is very beneficial to regulating obesity and is also very important for dietary sources.¹³⁶ It was shown that omega-3 and omega-6 fatty acids had various effects on body fat development through fat homeostasis, adipogenesis, systemic inflammation and brain adipose tissue.¹³⁷ While omega-3 fatty acids reduce fat deposition by lipogenic enzymes and enhance adipose tissue – oxidation but omega-6 fatty acids raise cellular triglyceride levels.¹³⁸ There is also evidence that inflammation around the brain affects fat formation and differentiation in preadipocytes through altering the ratio of omega-3 to omega-6 in the bloodstream. White adipocytes store energy in the form of triglycerides, while brown adipocytes use triglycerides to make heat. Linoleic acid and alpha linolenic acid are mainly considered as omega-6 fatty acids. Naturally, an immense amount of linoleic acid found in palm oil, coca oil, coconut oil and other plant seeds while alpha linolenic acid is mostly present in green leafy plants, perilla, walnut, cotton, chia and flax seeds.¹³⁹

**Cancer**

From a few decades, health-care professionals and epidemiologist are more conscious about the consumption of omega-3 polyunsaturated fatty acids from different sources that are significant in the treatment of cancer. Contrary to cardiovascular disease, the consumption of dietary fat is an early causative factor for cancer. Several studies show that an immense amount of saturated fatty acids in the diet is a leading factor of cancer, comparatively the consumption of dietary EPA reduces the risk of gastrointestinal cancer. Thus, the high amount of EPA and long-chain fatty acids in diet prevent the risk of colorectal cancer. It was also noted that omega-3 polyunsaturated fatty acids have anti-cancer properties as well as minimize the progression of prostate tumors.¹⁴⁰ DHA is an omega-3 PUFAs, associated with erythrocyte membrane play a pivotal role to reduce the risk of breast cancer. The consumption of ω-3 fatty acids considered as more effective for cancer patients and also helpful to regulating body weight, increasing appetite as well as improve life quality.¹⁴² The oral supplementation of EPA is very useful to strengthen the muscles of cancer patients.¹⁴³ The current investigations exposed that the omega-3 fatty acids especially DHA has such ingredients to improve chemopreventive agents in the remedy of breast cancer. DHA and EPA intake reduce the cell proliferation particularly in colorectal cancer cases. These EPA and DHA fatty acids are also preferred to maintain equilibrium between apoptosis and the cell progression process. A healthy diet with omega-6 and omega-3 fatty acids is important for both preventing and treating cancer.¹⁴⁴ Angiogenesis is an ailment that causes metastasis and the progression of tumors is mainly prevented by the intake of eicosanoids obtained from omega-6 fatty acids. The diet rich in omega-6 fatty acids and high amount of fat leads to the minimum proliferation of cells in breast cancer patients while omega-3 fatty acid exposed suppressive effect on angiogenesis.¹⁴⁴ Aromatase is an enzyme extensively involved in the
progression of breast cancer; it is inhibited by the intake of a sufficient number of fatty acids products. The Brassica campestris acts as aromatase inhibitors and is involved in the treatment of breast cancer.[145]

**Conclusion**

It is concluded that different traditional and industrial methods are used to extract the oil from various types of plants seed. Traditional extraction techniques are more complex and resource intensive than novel industrial techniques. The industrial method of extraction include chromatographic, distillation, low-temperature crystallization, enzymatic method, supercritical fluid extraction, urea complexation, and ultrasound-assisted extraction. Extraction through these novel industrial techniques is helpful for the oxidative stability of plant oils and provides better yield than traditional methods. The oil extract from seeds is used to develop different functional foods. Plants-oil is more valuable and cost-effective. Biologically, plants-oil plays an essential role in the human body against various disorders.

**Disclosure statement**

No potential conflict of interest was reported by the author(s).

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