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Review

Quality Standards and Pharmacological Interventions of Natural Oils: Current Scenario and Future Perspectives

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Shadab Ali,[○] Rustam Ekbbal,[○] Sapna Salar, Yasheshwar, Sayad Ahad Ali, Aakash Kumar Jaiswal, Mhaveer Singh, Dinesh Kumar Yadav, Santosh Kumar, and Gaurav*

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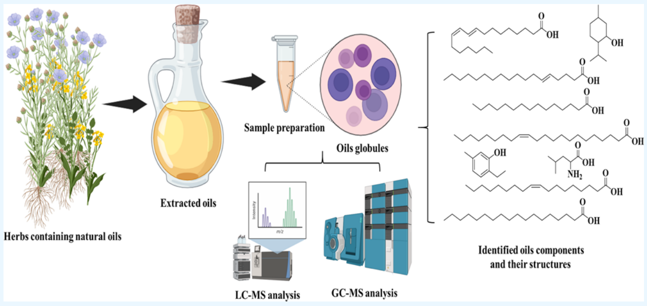
ABSTRACT: Medicinal plants are rich sources of natural oils such as essential and fixed oils used traditionally for nutritive as well as medicinal purposes. Most of the traditional formulations or phytopharmaceutical formulations contain oil as the main ingredient due to their own therapeutic applications and thus mitigating several pathogeneses such as fungal/bacterial/viral infection, gout, psoriasis, analgesic, antioxidant, skin infection, etc. Due to the lack of quality standards and progressive adulteration in the natural oils, their therapeutic efficacy is continuously deteriorated. To develop quality standards and validate scientific aspects on essential oils, several chromatographic and spectroscopic techniques such as HPTLC, HPLC, NMR, LC−MS, and GC−MS have been termed as the choices of techniques for better exploration of metabolites, hence sustaining the authenticity of the essential oils. In this review, chemical profiling and quality control aspects of essential or fixed oils have been explored from previously reported literature in reputed journals. Methods of chemical profiling, possible identified metabolites in essential oils, and their therapeutic applications have been described. The outcome of the review reveals that GC−MS/MS, LC-MS/MS, and NMR-based chromatographic and spectroscopic techniques are the most liable, economic, precise, and accurate techniques for determining the spuriousness or adulteration of oils based on their qualitative and quantitative chemical profiling studies. This review occupies the extensive information about the quality standards of several oils obtained from natural sources for their regulatory aspects via providing the detailed methods used in chemoprofiling techniques. Hence, this review helps researchers in further therapeutic exploration as well as quality-based standardization for their regulatory purpose.



1. INTRODUCTION

Medicinal plants are recognized as rich sources of diverse chemical compounds, each possessing unique therapeutic properties that can effectively address various acute and chronic illnesses. These plants contain a complex array of chemical constituents, including physiologically active metabolites from different molecular families, which exert a wide range of biological effects on humans. It is noteworthy that approximately a quarter of the pharmaceuticals currently in circulation are synthetic drugs derived from plant-derived chemicals. This transformation from indigenous and traditional medicine to modern pharmaceuticals has been facilitated by rigorous chemical and pharmaceutical testing.[1]

Essential oils are comprised of the hydrophobic liquid of volatile secondary metabolites produced by aromatic plants and exhibit strong fragrances. They are often obtained using steam or hydrodistillation, which was first invented by Arabs in the medieval centuries. They are employed in embalming, in food preservation, and as antibacterial, analgesic, sedative, anti-inflammatory, spasmolytic, and local anesthetics. They are also known for their antiseptic, i.e., bactericidal, virucidal, and fungicidal, and therapeutic effects as well as their odors. These traits have not altered much up to this point, with the exception that we now know more about some of their modes of action, especially at the antimicrobial level.[2]

Essential oils are mixtures of volatile lipophilic (i.e., fat-soluble) substances that are frequently derived from the leaf, twig, wood pulp, or bark tissue of a higher plant. They are also commonly found in bryophytes, such as liverworts. Although the fact that essential oils are rarely soluble in water, the

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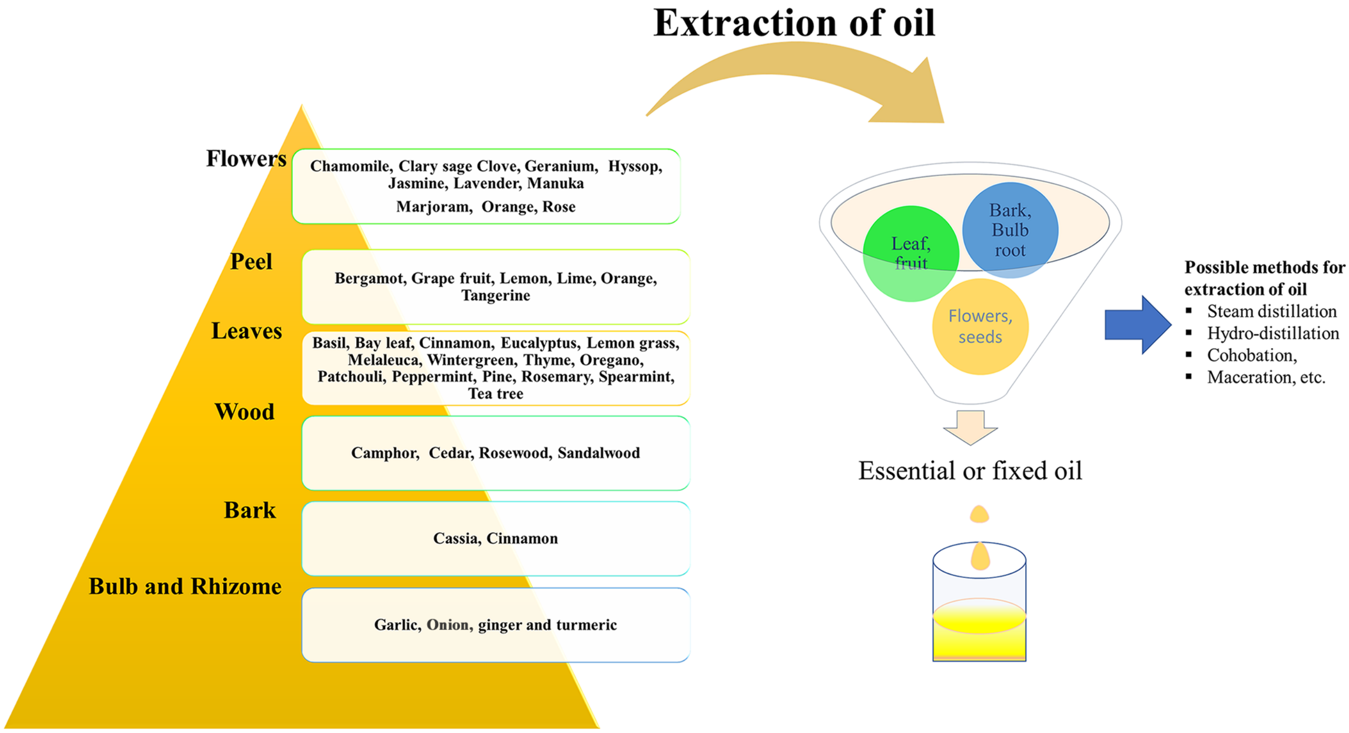

Figure 1. Sources of natural oils and abundantly used methods for their extraction.

polarity (magnetic activity) of the individual constituents influences how effectively they dissolve in water.[3] Recently, it has been shown that the essential oils and extracts of these species have significant biological capabilities, including activity against neurodegenerative disorders and antibacterial, antioxidant, hypoglycemic, anti-inflammatory, and cytotoxic actions.[4]

Due to the recognized antiviral properties of various volatile components present in essential oils, they hold potential as potential therapies for the 2019 coronavirus disease (COVID-19). Severe cases of COVID-19 have been linked to an elevated release of pro-inflammatory cytokines, but these treatments have demonstrated efficacy in managing this response.[5]

Plant essential oils have been shown to have effective contact and fumigant insecticidal effects against pests found in stored goods. The most lethal essential oils tested as fumigants against the bean weevil *Acanthoscelides obtectus* (Bruchidae) are those from *Thymus serpyllum* and *Origanum marjoram*, which are both high in the phenols thymol and carvacrol.[6]

Essential oils can be obtained through a range of extraction methods, including low- or high-pressure distillation using either boiling water or heated steam, as well as the utilization of liquid carbon dioxide or microwaves. The preferred methods for extraction often involve steam distillation or expression, especially in the case of citrus oils. Occasionally, supercritical carbon dioxide extraction is employed for aromatic purposes.[7] It is worth noting that chemically synthesized pharmaceuticals are increasingly replacing naturally derived products in various applications to maintain ecological balance, while still harnessing their therapeutic qualities.

As essential oils do not fall under the purview of the FDA in the United States, they are not subject to regulatory oversight regarding their composition. This regulatory gap can lead to instances of oils being diluted or adulterated in order to reduce manufacturing costs. This issue is particularly concerning as the commercial market for essential oils is rapidly expanding, with a projected increase in global market value from $17 billion to $27 billion by 2022. The growing popularity of these oils can be attributed, in part, to claims regarding the potential health benefits of their active ingredients, including antibacterial, anticancer, and anti-inflammatory properties. Additionally, essential oils are being explored as alternatives to conventional insect repellents, and some have even been studied for their ability to prevent food spoilage.[7]

Afterward, physical techniques are used to physically separate the essential oil from the aqueous phase.[8] A kind of distillation, such as hydrodistillation, steam distillation, or microwave-assisted dry distillation, is often used to create the essential oil, which is typically a combination of volatile organic components. It is incorrect to state that essential oils are found in aromatic plants, because they are really a byproduct of distillation. Although they are more commonly referred to as essential oil components, it is true that aromatic plants have the components and precursors needed to generate essential oils.[9] Different sources and parts of the medicinal plants that contain essential or fixed oils to be extracted are shown in a diagrammatic representation in Figure 1.[10]

2. REVIEW FINDINGS

2.1. Essential Oils. *2.1.1. Chemistry of Essential Oils.* Essential oils are very intricate natural compositions that can include 20−60 distinct components in vastly varied amounts. They have two or three main components that are present in relatively high quantities (20−70%) compared to other components that are only present in trace levels. The main ingredients of the essential oils of *Origanum compactum* are carvacrol (30%) and thymol (27%); that of *Coriandrum sativum* is linalool (68%); those of *Cinnamomum camphora* are α- and β-thujone (57%), camphor (24%), and 1,8-cineole

(50%); and those of *Mentha piperita* are menthol (59%) and menthone (19%). Typically, these key elements dictate the biological characteristics of the essential oils.[11] Moreover, agarwood is an essential aromatic plant that has been utilized for centuries in China and Southeast Asian nations as traditional medicine. Sesquiterpenes, 2-(2-phenylmethyl) chromone derivatives, and agarofurans are some of the volatile oils that make up the majority of agarwood's active ingredients. Studies have demonstrated the beneficial pharmacological benefits of agarwood essential oils (AEOs), which include antidepressant, sedative, and anti-inflammatory properties.[12] Major components of some essential oils isolated form different sources with typical percentage compositions of those components are described in Table 1.

Table 1. Major Components of Six Essential Oils with Typical Percentage Compositions of Those Components

S. No.	Essential oil	Major components	Standard percentage of component (%)
1	eucalyptus	1,8-cineole (eucalyptol)	78
2	lavender	linalool	28−37
		linalyl acetate	4.6−4.7
		β-farnesene	0.9−7.1
		β-caryophyllene	0.6−6.3
		lavandulol acetate	0.8−4.8
3	lemongrass	citral	≥75
4	rose	geraniol	14−27
		citronellol	29−55
		nonadecane	2.6−19
5	sandalwood	*α*-santalol	≥43
		β-santalol	≥18
6	tea tree	terpinen-4-ol	30−48
		γ-terpinene	10−28
		α-terpinene	5.0−13
		α-pinene	1.0−6
		p-cymene	0.5−8

The mixture of pure essential oils comprises over 200 components. Typically, these mixtures consist of phenylpropanoid derivatives or terpenes, which share minimal structural and chemical differences. These components can be divided into two main categories. The first category is the volatile fraction, which constitutes 90−95% of the total oil weight. This fraction contains monoterpenes, sesquiterpenes, and their oxygenated derivatives. Additionally, aliphatic alcohols, esters, and aldehydes may be found within the volatile fraction. The second category is the nonvolatile residue, making up 1−10% of the essential oil's weight. This residue contains substances such as flavonoids, carotenoids, waxes, sterols, hydrocarbons, fatty acids, and hydrocarbons.[10] The chemical components of essential oils divide into two distinct categories: terpenoids and nonterpenoid hydrocarbons.

The nonterpenoid hydrocarbon short-chain alcohols and aldehydes that are found in essential oils are produced by the metabolic change or breakdown of oily substances and phospholipids. Methane (CH_4), which is an odorless, colorless, and extremely flammable gas, is the most basic hydrocarbon. Alkanes are homologous straight-chain structures that are saturated, while their unsaturated forms are called alkenes.[13] Isoprenoids, terpenes, and terpenoids are the products of the condensation of isoprene (2-methyl-1,3-butadiene), a pentacarbon unit with two unsaturated links. Moreover, different kinds of terpene constituents that are basically classified in several categories based on the number of isoprene units they contain, such as hemiterpenes, monoterpenes, sesquiterpenes, diterpenes, and so on are present in the wide category of essential oils.[14]

2.2. Fixed Oils. The term "fixed oils" refers to the oils that are nonvolatile in nature or a liquid mixture of nonvolatile components and are basically consumed in our day-to-day life in different forms. Fixed oils are liquids that are viscous, thick, and yellow in color. They also have a distinct smell. Due to their nonvolatility, they cannot be distilled. Due to the presence of free acidity, they become rancid when stored.[15] Technically comprehending, fixed oils are the portion of a nonvolatile oil that is mostly made up of lipophilic substances like fats, resins, and waxes and is typically soluble in organic solvents. Following the distillation of essential oils, fixed oils are drawn from the aroma-free spice matter.[16] Today's consumers are aware that eating healthily is essential to maintaining excellent health. Lipids are a crucial component of a healthy diet. As the main source of several crucial necessary elements, such as tocopherols, fatty acids, and phytosterols, seed oils play a key role in our diet. Omega-3 fatty acids, tocopherols, and sterols are among the nutrients found in oilseeds and oils that health-conscious people ingest. Omega-3 fatty acids, sterols, antioxidants, and linolenic acid are the most significant lipid components. Black cumin, dill, pomegranate, sesame, watermelon, pumpkin, chia, and flax seeds are abundant in the omega-3 fatty acid content of linolenic acid.[17] Different plant sources from which their fixed oils are extracted in major amounts include mustard, corn, flax, sunflowers, peanuts, coconuts, and olives.

Annual *Nigella sativa* (black seed), which is a member of the Ranunculaceae family, is a common crop in several nations. Although the chemical composition of black seed varies, alkaloids and fixed and volatile oils are among their main constituents.[18] According to reports, this oil possesses antitumor, anti-inflammatory, antibacterial, and anti-inflammatory properties as well as antioxidant and immune-system-stimulating properties. Black cumin seed oils have received a lot of attention, and as a result, more people are using them, particularly in Middle Eastern nations.[19] In many nations, the seeds are utilized for both culinary and medicinal reasons. They are typically tiny (1−5 mg), dark gray or black in color, and have an angular shape.[20]

Oils and fats are crucial for human nutrition for a number of reasons, and they also play a significant role in the food business. As sources of vitamins and vital unsaturated fatty acids, vegetable oils in particular are becoming more and more significant. As a result, it is crucial to look into the possibilities of utilizing some raw materials as sources of vegetable oils and vitamins.[21] Fixed oils, which may be found in both plants and animals (such as fish oils and nuts and seeds), are glycerol esters that come in a variety of viscosities; they are used as meals, as lubricants, and in the production of varnishes, paints, and soaps.[22]

Fixed oils are essential organic substances that play a crucial role in promoting human well-being. These oils serve as a significant lipid source for the human body, which is why people have historically cultivated crops with high oil content in their gardens. Plant-based fixed oils are known to occasionally demonstrate antibiotic properties and have the

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capacity to act against microorganisms.[23] Most of the vitamins, tocopherols, pigments, minerals, and phenolic compounds that offer health benefits to humans are derived from vegetable oils. Essential fatty acids like linoleic and α-linolenic acids, vital for proper growth, development, inflammation control, and reducing the risk factors associated with cardiovascular disease, cancer, and arthritis, are particularly significant.[24]

2.2.1. Sources of Fixed Oils. Fats and oils can be derived from various sources, including vegetables, animals, and marine life. Vegetable fats encompass solids like cocoa powder and oils such as maize, sunflower, soybean, and cottonseed. Animal fats include lard, tallow, and butterfat. Fish oils are sourced from fish bodies, primarily, although a small amount comes from krill, squid, marine mammals, marine and freshwater algae, and yeasts.[25]

Almost 80% of the food we eat contains fixed oils and fats (lipids). It is the sole substance found in vegetable oils and animal fats, and it plays a significant role in the composition of milk and milk-based products. Castor seed, olive, peanut, soybean, sesame, almond, cottonseed, maize, safflower, cocoa butter, linseed, sunflower, oil palm, and shea butter are only a few examples of plants that contain fixed oil and fat. Additionally, it is a part of animal fats, particularly those from milk, meat, and eggs.[26] Fruits are rich in bioactive chemicals and have significant antioxidant activity, both in their pulps and in the byproducts they create, including peels and seeds.[27] Both fixed and volatile substances are present in *Laurus nobilis* L. fruit's oils, mostly used in the production of soap; berry oil contains fatty acids (lauric, 54%; palmitic, 5%; oleic, 15%; and linoleic, 17%).[21]

2.2.2. Chemistry of Fixed Oils. Vegetable fixed oils (FOs), also known as non-essential oils, are often produced from a variety of plant parts, including seeds, pulp, leaves, stems, and flowers. They are typically a combination of fatty acid esters. Palmitic, steric, linoleic, and oleic acids are some of the most prevalent fatty acids found in plant oils. FOs can be removed mechanically or by using nonpolar organic solvents from vegetable matrixes.[28]

Almonds have a nutritional profile that makes them a good source of minerals (potassium, phosphorus, magnesium, calcium, iron, zinc, manganese, selenium, copper, etc.), macronutrients (proteins, carbohydrates, fibers, etc.), and fatty acids (saturated, monounsaturated, and polyunsaturated), which supports their industrial use.[29]

Coconut (*Cocos nucifera* L.) oil is one of the most well-studied edible oils in terms of clinical studies. Coconut oil contains a lot of saturated fatty acids, particularly lauric acid (48%) and myristic acid (19%).[30] Flaxseed (*Linum usitatissimum* L.) is a useful nutritional component, and its oil is used. In addition to omega-3 fatty acid, the GC−MS analysis of fixed oil revealed the presence of mono-, di-, and triterpenes including sesquiphellandrene, copaene, monoterpene, diethyl phthalate, hexadecanoic acid, squalene, and sitosterol as well as ascorbic acid and γ-tocopherol.[31]

Olive (*Olea europaea* L.) oil has elements that are known to be beneficial to health, including phenolic compounds (such as tyrosol, oleocanthal, oleuropein, hydroxytyrosol, and oleuropein aglycone) and the presence of highly bioactive carotenoids (provitamin A) like carotene and lutein.[32] Sunflower (*Helianthus annuus* L.) oil is one among the top five vegetable oil harvests in the world. Both linoleic acid (48.3−74.0%) and oleic acid (14.0−39.4%) are abundant in sunflower oil.[33]

2.3. Adulteration and Evaluation of Essential and Fixed Oils. "Adulteration" refers to the qualities of the essential oils being altered as a result of adulteration, decreasing their quality. There are four ways that essential oils might be tampered with by using more, less costly essential oils, including a component of natural chemistry, diluting with more carrier oils, and including elements that were created in a lab.[34−36]

We can detect falsified essential oils on the market in about 80% of cases. Essential oil contamination is an issue that is comparable to essential oil adulteration. Organoleptic testing, gas chromatography, and mass spectrometry are typically used to identify adulteration and contamination of essential oils. We can specifically mention gas chromatography−mass spectrometry and high-performance liquid chromatography as analytical techniques employed for detection. The previously mentioned tests come at a considerable price. New low-cost techniques must thus be created, tested, and implemented.[37]

Essential oils (EOs) are often tainted through the inclusion of cheaper essential oils, for example, adding sweet orange to bitter orange, maize mint to peppermint, or synthetic linalyl acetate and/or linalool to lavender. They can also be adulterated with low-quality synthetic components, such as synthetic linalool and linalyl acetate added to bergamot EO. This kind of adulteration can be easily and swiftly detected by calculating the normalized percentage areas of specific markers. Another method of adulterating essential oils is by diluting them with vegetable oils, which reduces their fragrance. Vegetable oils are chosen for this purpose because they are cost-effective and share certain characteristics with essential oils, such as density and mouthfeel.[38]

As consumption has expanded, so has the need for inexpensive oils, increasing the temptation for producers to adulterate and/or dilute their oils to keep prices low, to enhance the oil's properties. Forms of adulteration include the addition of other, usually cheaper essential oils; the addition of nonessential oils; and the addition of natural or synthetic chemicals. The most popular method for the analysis of essential oils is GC−MS because such oils are composed primarily of volatile components, which GC−MS can reliably analyze.[7]

The market expansion led to the adulteration and falsification of EOs. In fact, the adulteration of these priceless items has become more common because of the rising demand for cheaper EOs from other natural sources or from vegetable oils, with higher profits as the main motivation.[39] Because of its excellent characteristic features, lemon oil is utilized as a component in body care products, cosmetics, and pharmaceuticals. Lemon essential oil is a high-value natural product that is very significant economically all over the world. Due to its relatively high cost, genuine lemon essential oil is more likely to be falsified for commercial gain.[40] When nonvolatile or high-boiling components like castor oil, polyethene glycol (PEG), or coconut oil are used, GC-FID and GC−MS cannot identify the substance, which is used to adulterate sandalwood or cedarwood oil. Vegetable oils are commonly utilized as adulterants in essential oils because they are widely available and reasonably priced.[41]

Adulteration, the practice of covertly combining one chemical with another, is what yields an adulterant. Food, cosmetics, medications, gasoline, and other chemicals are typical examples of contaminated compounds that jeopardize the safety or efficacy of the aforementioned material. The process of food quality management now includes food authenticity as a crucial component. It has become absolutely crucial to set up methods to check food quality at different points throughout manufacturing, processing, and distribution because the food industry is home to a variety of fraudulent practices.[42]

The qualities of fixed oils are altered by adulteration, which lowers their quality. Four methods of adulteration exist for fixed oils, such as including additional, less costly oils; incorporating a natural chemical; diluting with more carrier oils; and including components that were created in a lab.

Moreover, the issue of falsifying the compositions of oils, primarily virgin olive oil, with other cheap edible oils has been known for a very long time. This is the case with oils obtained from plant seeds, especially fruit seeds, which are often subjected to different kinds of adulteration.[43]

Vegetable oils come in a wide range and are an important part of the human diet. They provide taste to food and are popular because they offer nutritional and health advantages. They are used in cooking, frying, and salad dressing. In Europe, they are regarded as an important source of energy for people to consume. Selling adulterated goods to boost profits at the very least undermines customer confidence.[44]

Food quality and safety have become more of a worry for consumers, food producers, and governments as a result of the food supply chain's rising globalization, the presence of numerous stakeholders from "farm to fork", and the inherent vulnerability of such a system. A number of scandals, including the addition of melamine to infant formula in China in 2008, the horse meat scandal in Europe in 2013, and the discovery of peanuts and almonds in ground cumin and paprika in Europe and the United States in 2015, highlight the detrimental effects of food fraud, including both adulteration and authenticity.[45]

Moreover, some of the analytical parameters of essential and fixed oils for examination of their quality parameters have been defined for their authenticity, namely iodine value, saponification value, hydroxyl value, ester value, and acid value.[23]

Sunflower Oil. Because it is inexpensive, sunflower oil (SFO) has been utilized as a common edible oil and has been discovered as a common adulterant in olive oil. The SFO content of olive oil ranges from 5 to 100%. It is very difficult to determine whether olive oil has been adulterated.[46]

Sesame Oil. Lignans, tocopherols, and unsaturated fatty acids are only a few of the nutritious components found in sesame oil. These advantages make sesame oil more valuable than other vegetable oils, but it also makes it more expensive, making it a target for economically driven adulteration. Sesame oil adulteration is not only a financial scam; it also poses a risk to public health. There is an urgent need for a trustworthy adulteration detection technology to ensure the quality of sesame oil.[47]

Olive Oil. In Mediterranean nations, olive oil is a key economic component. It is the priciest kind of oil due to its excellent quality. It may occasionally be contaminated or mislabeled as a result. The addition of less expensive oils constitutes adulteration. Refined olive oil, OPO, seed oils (like sunflower, soy, corn, and rapeseed oils), and nut oils (like hazelnut and peanut oils) are the most typical adulterants discovered in virgin olive oil.[48] Evaluation of essential and fixed oils using various approaches such as sensory evaluation, physical analysis, and chemical and instrumental technique based analysis are represented in Figure 2.

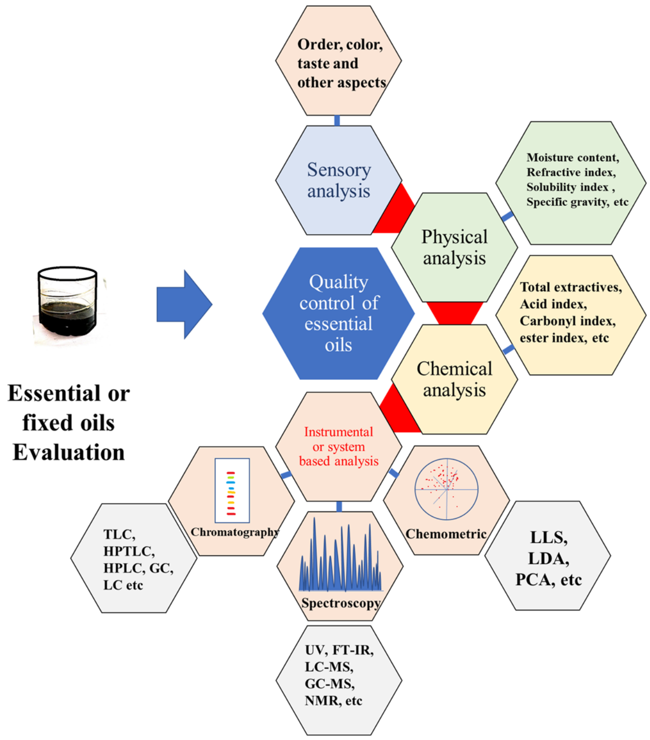

Figure 2. Evaluation of essential and fixed oils using various approaches such as sensory evaluation, physical analysis, chemical analysis, and instrumental technique based analysis.

2.4. Autoxidation of Oils.

Natural oils have long been valued for their culinary, cosmetic, medicinal, and industrial applications. These oils, often derived from plant sources, are rich in essential fatty acids, vitamins, and other bioactive compounds. However, their quality and shelf life can be compromised due to a complex chemical process known as autoxidation. Understanding the mechanisms and significance of autoxidation is essential for various industries and consumers who rely on these oils for a range of purposes.[49]

Autoxidation is a naturally occurring process that involves the reaction of oils with atmospheric oxygen. It is a complex chain reaction that initiates when oxygen molecules come into contact with unsaturated fatty acids present in natural oils. The process is accelerated by factors such as heat, light, and the presence of trace metals like iron and copper. Autoxidation can ultimately result in the deterioration of oil quality. The susceptibility of natural oils to autoxidation is closely linked to their fatty acid composition. Oils containing a high proportion of unsaturated fatty acids, especially polyunsaturated fatty acids (PUFAs) with multiple double bonds, are particularly prone to oxidation. Examples of such oils include flaxseed oil, soybean oil, and fish oil. The presence of double bonds in these fatty acids makes them highly reactive and vulnerable to attack by oxygen radicals.[50−54]

One of the most immediate consequences of autoxidation is the alteration of sensory properties, such as flavor and aroma. As the oil undergoes oxidative changes, it can develop off-flavors and off-odors. These sensory defects can render the oil unpalatable and unsuitable for culinary applications. Rancidity, a common result of autoxidation, is often described as a stale, musty, or cardboardlike taste and odor.[49]

Autoxidation also has nutritional implications. Natural oils are valuable sources of essential fatty acids, such as omega-3

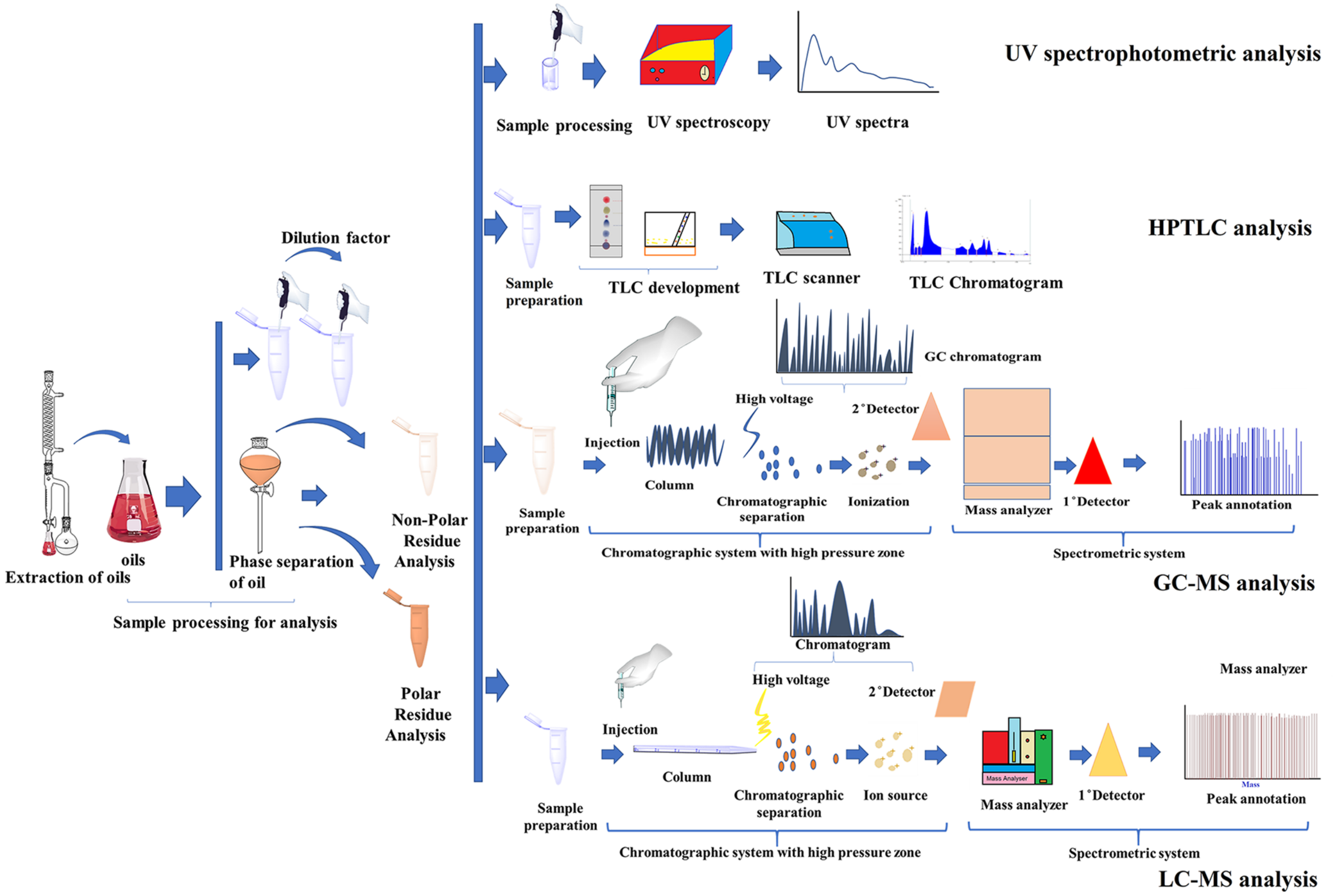

Figure 3. Systematic approach for quality-based evaluation of oils using different modern analytical techniques. Representation of various analytical techniques such as UV spectrophotometric analysis, HPTLC analysis, GC−MS analysis, and LC−MS for qualitative and quantitative evaluations of phytochemicals in natural oils.

and omega-6, which are vital for human health. However, the oxidative breakdown of these fatty acids during autoxidation can lead to the formation of harmful compounds, including peroxides and aldehydes. These compounds not only compromise the nutritional value of the oil but may also have adverse health effects when consumed. Understanding autoxidation and its implications for natural oils is of significant importance in various domains such as the food industry, manufacturing, pharmaceuticals, etc.[51,54,55]

In the food industry, preserving the stability of oils is crucial to ensure product quality and safety. Manufacturers employ various strategies, such as adding antioxidants, using proper packaging, and optimizing storage conditions, to prevent or delay autoxidation. Chefs and home cooks need to be aware of the susceptibility of cooking oils to autoxidation. Factors like prolonged exposure to air, high temperatures, and light can accelerate this process, leading to unwanted changes in the flavors and textures of dishes. Oils are frequently used as carriers for pharmaceutical compounds in medications. Ensuring the stability of these oils is essential to maintain the efficacy and safety of the drugs. Natural oils are common ingredients in cosmetics, skincare products, and haircare formulations. Autoxidation can result in changes in product texture, color, and scent, impacting both shelf life and user satisfaction.[49,56−59]

Moreover, to prevent autoxidation, to mitigate the effects of autoxidation, and to extend the shelf life of natural oils, several preventive measures can be employed: adding antioxidants, such as tocopherols (vitamin E), ascorbic acid, and rosemary extract, can inhibit the formation of free radicals and delay the onset of autoxidation; utilizing opaque, airtight containers can protect oils from oxygen exposure and light, reducing the rate of oxidation; storing oils in a cool, dark place and minimizing exposure to air can help maintain their stability; choosing oils with a higher saturation level or lower polyunsaturated fatty acid content can increase their resistance to autoxidation. However, critical consideration of autoxidation deals with understanding its mechanisms, and implementing preventive measures is essential to ensure the stability, quality, and safety of these valuable commodities.[49−52,60]

2.5. Current Research Paradigm in Quality-Based Standardization of Essential and Fixed Oils. The many techniques often employed for determining the compositions of EOs and fixed oils include UV spectroscopy, gas chromatography (GC), high-performance liquid chromatography (HPLC), mass spectrometry (MS), and nuclear magnetic resonance (NMR) spectroscopy.[14]

2.5.1. Chromatographic Characterization of Essential Oils. For the analysis of the compositions of essential oils and fixed oils, it is customary to use chromatographic techniques together with a variety of detection modalities. These techniques provide information about the identification of the oils as well as any potential impurities or fabrications, as well as any possible degradation reactions the oils may have gone through. Although more modern separation techniques have grown significantly in relevance for scent research, thin-

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Table 2. Quality-Based Standardization of Natural Oils Isolated from Medicinal Plants Using Modern Analytical Techniques

no.	essential oil/fixed oil, biological source, family (plant part)	techniques	method/type of analysis	identified metabolites (major)	pharmacological activity	ref
1	essential oil, *Eucalyptus globulus*, Myrtaceae (leaves)	GC–MS	column: OV-101 (0.31 mm i.d. × 25 m); medium: electron ionization, ion source 200 °C, at 35 eV	monoterpenoids, terpinolene, 3-methylbutanal, linalool, *trans*-pinocarveol, α-thujene, α-pinene, γ-terpinene, citronellal, borneol, *p*-cymene, terpinen-4-ol, β-terpineol, α-terpineol, cuminal, carvone, neral, verbenone, β-caryophyllene, terpinyl acetate, aromadendrene, globulol	gastrointestinal effects, anti-inflammatory, analgesic effect, antioxidant effect, cytotoxic effect, insecticidal repellent effects, antiparasitic, antidiabetic effect, dermatological effects	19, 68
2	essential oil, *Lavandula angustifolia*, Lamiaceae (flowers)	GC–MS	column: BPX5 (30 m × 0.25 mm i.d., 0.25 μm SGE, Australia); medium: He (99.999%), as carrier gas, flow rate 0.5 mL/min	linalool, 1,8-cineole, camphene, linalyl acetate, borneol, β-ocimene, α-terpineol, terpinen-4-ol, camphor	neurological such as epilepsy, psychiatric disorders, sustained-seizure damage, parkinsonism, etc.	69, 70
3	essential oil, *Cymbopogon citratus*, Poaceae (leaves)	HPLC	column: C18 (2.1 × 100 mm i.d., 3 μm); medium: water–methanol as carrier, flow rate 0.8 mL/min	geranial (55.2%) and geraniol (20.8%), neral (44.7%), citronellal (41.7%), piperitone (59.8%)	antimicrobial activity, antiprotozoan activity, antifungal activity, antioxidant activity, antidiarrheal activity, anti-inflammatory activity, mutagenic activity, antimalarial activity	71, 72
4	essential oil, *Rosa damascena* Mill., Rosaceae (flower)	HPLC–MS	column: RP18 (5 μm, 250 mm × 4.6 mm); medium: flavonoids—0.1% formic acid mobile, flow rate 1.0 mL/min, phenolic acid—water/acetonitrile/glacial acetic acid (980/20/5, v/v/v) and acetonitrile/glacial acetic acid (1000/5, v/v) as carrier, flow rate 0.8 mL/min, alkaloids—0.2% diethylamine, 0.16% formic acid (solvent A), and 0.2% diethylamine, 0.16% formic acid (solvent B) as carrier, flow rate 1.0 mL/min	chrysoeriol, quercetin apigenin, luteolin, catechol, resorcinol phloroglucinol, boldine	antimicrobial effect, antioxidant effects, antidiabetic activity, hepatoprotective activity, antilipase effect, anti-HIV effects, effect on Alzheimer's disease, anti-inflammation, anticonvulsant effect, hypnotic effect, analgesic effect, effect on constipation	73, 74
5	essential oil, *Santalum album* Linn., Santalaceae (stems and roots)	GC–MS (qualitative)	column: RTX-WAX (30 m × 0.25 mm i.d), 0.25 mm); medium: He as carrier gas, flow rate 1.40 mL/min	*trans-Z*-α-bergamotol 1.41–3.45%, α-santalol 55%, *trans*-β-santalol 30%, *E-cis-epi*-β-santalol 4%	antiseptic, dysuria, urinary infection, antipyretic, antiscabietic, expectorant, bronchitis, gonorrhea, antibacterial and antifungal properties	75, 76
6	essential oil, *Melaleuca alternifolia*, Myrtaceae (leaves and terminal branches)	GC-17A with FID	column: ZB-5MS (30 m × 0.25 mm i.d.; 0.25 μm); medium: He as carrier gas, flow rate 1.2 mL/min	terpinen-4-ol 56.80%, γ-terpinene 19.30%, *p*-cymene 9.84%; for *Melaleuca quinquenervia* α-pinene 61.37%, linalool 22.08%, citral 91.19%, γ-terpinene, 1,8-cineole	antimicrobial, antiparasitic, acetylcholinesterase inhibition, antioxidant, anti-inflammatory, neuroprotective, molluscicidal, anticancer, antihistaminic, cardiovascular and hepatoprotective, antisecretory, antiulcerogenic activities	77, 78
7	essential oil, *Boswellia serrata*, Burseraceae (tree)	GC–MS	column: 50 m × 0.32 mm i.d. × 0.52 m; medium: He as carrier gas, flow rate 1.3 mL/min	myrcene, *p*-cymene, pinene, camphene, sabinene, limonene	anti-inflammatory, antiasthmatic, antifungal, antimicrobial, antiarthritic, anticonvulsant, and as cardiotonic, bronchitis, asthma, cough, bad throat, and treatment of various intestinal problems	79, 80
8	essential oil, *Citrus bergamia*, Rutaceae (citrus fruit)	GC–MS	column: HP-35MS 35% diphenylsiloxane (20 m × 0.25 mm × 0.25 μm); medium: He as carrier gas, flow rate 1 mL/min	acyclic oxygenated hydrocarbon monoterpenes: linalool, linalyl acetate, neral, geranial, octyl acetate, cyclic hydrocarbon monoterpenes of α-phellandrene, limonene, pinene, β-pinene, *p*-cimene, γ-terpinene, terpinolene; acyclic hydrocarbon monoterpenes of mircene, α-terpineol, ocimene, β-caryophyllene	antiviral, antimicrobial, antifungal, antitumoral, cardioprotective, and anticancer activities	81, 82
9	essential oil, *Matricaria chamomilla* L., Asteraceae (flower head and leaves)	GC–MS	column: SH-RX-5Si/MS (30 m × 0.25 mm × 0.25 μm); medium: N_2 as carrier gas, flow rate 1 mL/min	β-farnesene, germacrene D, eucalyptol (1,8-cineole), artemisia ketone, camphor, bicyclogermacrene, *epi*-α-cadinol, chamazulene, naphthalenedione, 2-hydroxy-3-(1-propenyl), bisabolol oxide A, en-in-dicycloether, 1,4-bisabolol oxide, phloroacetophenone, 4-dimethyl ether	astringent, bactericide, stomachic, antimalaria, carminative, anti-inflammatory	83, 84
10	essential oil, *Jasminun officinale*, Oleaceae (flower)	GC–MS	column: 30 m × 0.25 mm, 0.25 mm; medium: He as carrier gas; transfer temp 180 °C, source temp 160 °C, scan 40–400 Da; solvent delay fixed at 4.00 min	benzyl acetate, α-pinene, *cis*-linalol oxide, *trans*-linalool oxide, caryophyllene, α-hexylcinnamaldehyde, benzyl benzoate, linalool, benzyl acetate, *cis*-jasmone,	antispasmodic, antidiarrheal, cardioprotective, antiulcer, dermatological and ophthalmic disorders	85, 86

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Table 2. continued

no.	essential oil/fixed oil, biological source, family (plant part)	techniques	method/type of analysis	identified metabolites (major)	pharmacological activity	ref
				cis-n-hexadecanoic acid, oleic acid, linalyl acetate, α-cubebene, 8-dodecenol, benzyl cinnamate		
11	essential oil, *Mentha piperita*, Labiatae (stem, leaves, and flowers)	HPLC	column: ChromGate HPLC with Eurospher 100, C18 column (4.6 mm i.d. × 250 mm, 5 mm); medium: rosmarinic acid as mobile phase, flow rate 1 mL/min	alkaloids, phenols, terpenoids, tannins	anti-inflammatory, antibacterial, antiviral, antitumor, neuroprotective, antifatigue, and antioxidant activities, hypolipidemic effects	87, 88
12	essential oil, *Matricaria chamomilla*, Asteraceae (flower)	GC−MS	column: Agilent 7890B (*l* 30 m × *d* 0.25 mm, 0.25 μm); medium: He (99.999%) as carrier gas, flow rate 1 mL/min	β-farnesene 52.73%, (*E*)-β-farnesene 42.59%, β-cubebene 27.8%, spathulenol 12.50%, α-bisabolol oxide A 7.9−62.1%, α-bisabolol oxide B 25.56%, *trans*-β-farnesene, chamazulene 27.8−31.2%, and α-bisabolol 56.9%	antifungal, antioxidant, antibacterial, and anti-inflammatory properties	89, 90
13	essential oil, *Citrus aurantium* Linn., Rutaceae (rind/peel)	GC−MS	column: Clarus 600 (*l* 30 m × *d* 0.25 mm × 0.25 mm); medium: He (99.9999%) as carrier gas, flow rate 1.0 mL/min	α-pinene, D-limonene, *trans*-β-ocimene, sabinene, β-pinene, β-ocimene, β-thujene, limonene oxide, isoterpinolene, linalool, *trans*-limonene oxide, citronellal, terpinen-4-ol, *cis*-verbenol, L-α-terpineol, *Z*-citral, geraniol, *E*-citral, neryl acetate, 3,7-dimethyl-2,6-octadien-1-ol, geranyl acetate, β-elemene, *trans*-caryophyllene, α-springene, caryophyllene oxide, γ-elemene, α-bisabolol, spathulenol	anti-inflammatory, hypolipidemic, antityphoid, hepatoprotective, antifertility activity, antibacterial activity, cardiovascular activity, antiobesity activity, anticancer/cytotoxic activity, antifungal, antioxidant property	91, 92
14	essential oil, *Cananga odorata*, Annonaceae (flower)	HPLC	column: C18 (250 mm × 4.6 mm, 5 μm in particle size); medium: acetonitrile and water (1:1, v/v) as mobile phase, flow rate 1 mL/min	linalool 29.15%, thymol 8.45%, limonene 6.40%, germacrene D 11.82%, α-phellandrene 3.62%, 1,8-cineole 4.87%	antioxidant, anticancer antimalaria, analgesic, gout, rheumatism, ophthalmitis, ulcers, fevers	93, 94
15	essential oil, *Pogostemon cablin* Benth, Lamiaceae (leaves)	GC−MS	column: DB-5HT (length 30 m, diameter 0.32 mm, film thickness 0.10 μm); medium: N_2 as carrier gas, flow rate 1.0 mL/min	β-patchoulene, β-elemene, cycloseychellene, (*E*)-seychellene, α-humulene, caryophyllene, α-guaiene, α-patchoulene, *epi*-(*E*)-caryophyllene, β-chamigrene, β-celinene	antiulcer, antimicrobial, antioxidative, anti-inflammatory, antitumor, analgesic, antidiarrheal activity	95, 96
16	essential oil, *Rosmarinus officinalis* L., Lamiaceae (branches and leaves)	HPLC	column: C18 (250 mm × 4.6 mm, 5 μm i.d.; Agilent); medium: 2% formic acid in water (solvent A) and 2% formic acid in acetonitrile (solvent B), flow rate 1 mL/min	α-pinene, camphor, eucalyptol, verbenone, borneol, camphor, bornyl acetate	antibacterial, anti-inflammatory, analgesic activities, antitumor, antioxidant	97, 98
17	essential oil, *Zingiber officinale*, Zingiberaceae (root and rhizomes)	HPLC−MS/MS	column: C18 gravity (125 × 2 mm i.d., 5 μm particle size); medium: A (0.5% formic acid) and B (0.5% formic acid), flow rate 300 μL/min	curcumin, *p*-coumaric acid, α-tocopherol	anticancer, anticoagulant, antiemetic, anti-inflammatory, antinociceptive, antioxidant, cardiovascular, gastrointestinal, and immunomodulatory effects	99, 100
18	essential oil, *Zingiber officinale*, Zingiberaceae (root and rhizomes)	HPLC	column: C18 gravity (125 × 2 mm i.d., 5 μm particle size); medium: A, 0.5% formic acid, and B, 0.5% formic acid, flow rate 300 μL/min	curcumin, pyrogallol, *p*-hydroxybenzoic acid, α-tocopherol	anticancer, anticoagulant, antiemetic, anti-inflammatory, antinociceptive, antioxidant, cardiovascular, gastrointestinal, and immunomodulatory effects	99, 100
19	essential oil, *Citrus aurantifolia*, Rutaceae (fruit)	HPLC-UV-QDa	column: XBridge BEH C18 (2.5 μm, 4.6 × 10067 mm), guard column (2.5 μm, 3.9 × 5 mm); medium: A (water + 5 mM $(NH_4)_2CO_3$ + 0.2% NH_4OH) and B (acetonitrile +5 mM $(NH_4)_2CO_3$+ 0.2% NH_4OH), flow rate 0.8 mL/min	limonene, D-limonene, α-terpineol, terpinen-4-ol, 1,4-cineole, 1,8-cineole, β-pinene, *p*-cymene, β-bisabolene, citral, γ-terpinene, linalool, linalyl acetate, geranyl acetate, terpinolene	antibacterial, antiobesity, and anticancer/cytotoxic activities, antifungal, antioxidant property, cardiovascular and antifertility activities	91, 101
20	essential oil, *Syzygium aromaticum*, Mirtaceae (flower buds)	LC−MS	column: Supelco C18 (15 mm × 2.1 mm × 3 μm); medium: MS carried out in negative ionization mode, flow rate 0.2 mL/min	eugenol, caryophyllene, acetyleugenol, chavicol, copaene, humulene, cadinenes, methyl eugenol, (−)-germacrene D, isoeugenol, (−)-α-cubebene, 2-nonanone, (−)-α-gurjunene, heptyl acetate	antifungal, aphrodisiac, antipyretic, appetizer, hypnotic, anxiolytic, antiemetic, analgesic, decongestant, antimicrobial, antiepileptic, myorelaxant, anti-inflammatory, and expectorant properties	102, 103
21	essential oil, *Rosa rubiginosa*, Rosaceae (seed)	HPLC−DAD−MS	column: G1315B (150 × 3.0 mm, 5 μm); medium: MeOH:H_2O (10:90; v:v) as carrier, flow rate 1−100 μg/mL	carotenoids (2.92 μg/g) and ascorbic acid (1798 μg/g); furthermore, polyunsaturated fatty acids, linoleic acid (54.05%), linolenic acid (19.37%), and phytosterols, mainly β-sitosterol (82.1%)	antidepressant effects, psychological relaxation, improvement of sexual dysfunction, antioxidant, antimicrobial, antifungal, probiotic and antipyretic effects, smooth muscle	104, 105

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Table 2. continued

no.	essential oil/fixed oil, biological source, family (plant part)	techniques	method/type of analysis	identified metabolites (major)	pharmacological activity	ref
					relaxation, lipid-lowering content, antiulcerogenic effects	
22	essential oil, *Citrus paradisi* Macfad, Rutaceae (fruit)	LC–MS	column: Agilent Zorbax C18 (100 mm × 2.1 mm, 1.8 μm); medium: water/formic acid (solvent A) and acetonitrile/formic acid (solvent B), flow rate 0.28 mL/min	meranzin, isomeranzin, tangeretin, nobiletin, epoxybergamottin, auraptene monoterpenes (96.93%), limonene (93.33%), β-myrcene (2.16%), α-pinene (0.76%), and sabinene (0.60%)	antibacterial, antiviral, antifungal, insecticide, antioxidant, astringent, cell regenerator and detoxifier	106, 107
23	essential oil, *Citrus paradisi* Macfad, Rutaceae (fruit)	GC–MS	column: GCMS-TQ8030 (30 m × 0.25 mm i.d. × 0.25 μm); medium: He as carrier gas, flow rate 30 cm/s	meranzin, isomeranzin, tangeretin, nobiletin, epoxybergamottin, and auraptene	antibacterial, antiviral, antifungal, insecticide, antioxidant, astringent, cell regenerator and detoxifier	106, 107
24	essential oil, *Cannabis sativa*, Cannabaceae (seed)	HPLC–Q Exactive Orbitrap MS analysis	column: Synergi Hydro RP (150 × 2 mm i.d., 4 m) with (4 × 3 mm i.d.) C18 guard column; medium: mobile phase A (0.1% aqueous formic acid) and B (acetonitrile), flow rate 0.3 mL/min	β-myrcene, β-pinene, D-limonene, α-terpinene, α-terpinolene, δ-3-carene, β-ocimene, caryophyllene	used in inflammation and various cancers, like liver, bladder, breast, and lung; also used in treatment of epilepsy, gastrointestinal disorders	108, 109
25	essential oil, *Cannabis sativa*, Cannabaceae (seed)	GC–MS	column: Trace GC Ultra coupled to Trace DSQII quadrupole (MS) equipped with Rtx-Wax column (30 m × 0.25 mm i.d., 0.25 m); medium: He as carrier gas, flow rate 1 mL/min	β-myrcene, α-terpinene, α-terpinolene, β-pinene, D-limonene, δ-3-carene, β-ocimene, caryophyllene	anti-inflammation, anticancer activity such as breast cancer, lung cancer, bladder cancer; also used in treatment of epilepsy, gastrointestinal disorders, Parkinson's disease	108, 109
26	essential oil, *Helichrysum italicum*, Asteraceae (flower)	GC–MS	column: Hewlett-Packard GC–MS (model 5890 series II) with mass selective detector (model 5971A) HP-101 column (25 m × 0.2 mm i.d., 0.2 μm) and HP-20M column (50 m × 0.2 mm i.d., 0.2 μm); medium: He as carrier gas, flow rate 1 mL/min	1,8-cineole, *trans*-2-methyl-2-butenoic acid, nerol oxide, *cis*-3-hexen-1-ol, 6-methyl-3-heptanone, linalool, fenchol, *trans*-pinocarveol, α-terpineol, neryl acetate, geraniol, 2-methylcyclohexyl pentanoate, geranyl acetate, 2-methylcyclohexyl octanoate, *trans*-nerolidol, torreiol, α-bisabolol, β-eudesmol, decanoic acid, undecanoic acid, guaiol, phenylethyl tiglate, thymol, dodecanoic acid	antioxidant, anti-inflammatory, and antimicrobial activities; allergies; liver, gallbladder, and urinary disorders; infections, colds, cough, skin diseases, burns, snake bites, inflammation, sciatica hernias, sleeplessness, hysteria	110, 111
27	fixed oil, *Cocos nucifera* (L.), Arecaceae (fruit)	GC–MS	column: 5977A Agilent Tech with HP-5MS (Agilent) (30 m × 0.25 mm i.d., 0.25 mm); medium: He as carrier gas, flow rate 1 mL/min	fatty acids, capric acid (7%), caprylic acid (8%), lauric acid (49%), myristic acid (8%), stearic acid (2%), palmitic acid (8%), oleic acid (6%), and 2% of linoleic acid, elaidic acid	anti-inflammatory, antimicrobial activity	112, 113
28	fixed oil, *Olea europoea* Linn., Oleaceae (ripe fruit)	GC–MS	column: Zebron ZB-5HT (30 m × 0.25 mm i.d., 0.25 μm); medium: (5% phenyl)-dimethylpolysiloxane high temperature phase, at 5 °C/min rate	glycerides of oleic acid (56–85%), palmitic (7–20%), linoleic (3–20%), palmitoleic (3%), linolenic, stearic (1–5%), arachidic (0.9%), eicosenoic, gadoleic, qualene 0.7%, phytosterol and tocopherols, lignoceric acids, about 0.2%	antidiabetic potential, anticancer effect, antimicrobial potential, enzyme inhibition effect, antioxidant, antihypertensive, cardioprotective, antinociceptive, anti-inflammatory gastroprotective effect, neuroprotective potential	114, 115
			and column: HP-5 (30 m × 0.32 mm i.d., 0.25 μm); medium: (5%-phenyl)-methylpolysiloxane phase, at 5 °C/min rate			
29	fixed oil, *Argania spinosa* L., Sapotaceae (fruit)	GC–MS	column: 30 m × 0.32 mm, DI 0.25 μm; medium: N_2 as carrier gas, flow rate 1 mL/min	vitamins; fatty acids present are myristic acid (0.10–0.15%), palmitic (11–13%), and stearic (5–7%); 80% unsaturated fatty acids, oleic–linoleic 29–35% of essential fatty acids, linoleic acid (29–34%), myristic, palmitic, palmitoleic, oleic, arachidic, heneicosanoic, 11-eicosenoic, tricosanoic, and nervonic acids	skin treatment, antioxidant, anti-inflammatory, antibacterial, antifungal, antidiabetic, and anticancer activities	116, 117
30	fixed oil, *Simmondsia chinensis*, Simmondsiaceae (fruit capsules)	GC–MS	column: Rtx-5MS (30 m × 0.25 mm, 0.25 μm); medium: He as carrier gas, flow rate 1.2 mL/min	simmondsin, 11-eicosenoic acid, erucic acid	antimicrobial, anticancer, antioxidant, antiacne, antipsoriasis, anti-inflammatory, antifungal, antipyretic, analgesic, antimicrobial, antihyperglycemia activities	118, 119
31	fixed oil, *Zea mays* L., Gramineae (grain)	HPLC	column: Rtx-5MS WCOT (30 m × 0.25 mm; 0.25 mm); medium: He as carrier gas, flow rate 1 mL/min	99% triacylglycerols with polyunsaturated fatty acid, linoleic acid, and linolenic acid	anti-inflammatory, antioxidant, antimicrobial, antiarrhythmic, anti-ischemic, anticancer, antidiabetic	120, 121

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Table 2. continued

no.	essential oil/fixed oil, biological source, family (plant part)	techniques	method/type of analysis	identified metabolites (major)	pharmacological activity	ref
32	fixed oil, *Prunus amygdalus*, Rosaceae (kernels)	HPLC	column: 100-5 NH2 (4.6 × 250 mm, 5 mm); medium: mobile phase acetonitrile/deionized water, 7:3 (v/v), flow rate 1 mL/min	68% oleic acid, 25% linoleic acid, 4.6−4.8% palmitic acid, palmitoleic acid, stearic acid, arachidic acid	antiradical, antioxidant, antifungal, anxiolytic, hyperlipidemia, nootropic, anti-Parkinsonian and antidepressant activity	122, 123
33	fixed oil, *Helianthus annuus*, Asteraceae (flower)	LC−MS	column: RP-C18 (150 × 210 mm, 1.8 μm); medium: 0.1% formic acid (A) and 0.1% formic acid acetonitrile (B) as mobile phase, flow rate 0.3 mL/min	oleic acid, linoleic acid, myristic acid, palmitic acid, palmitoleic acid, behenic acid, erucic acid, stearic acid, arachidic acid	anti-inflammatory, antiasthmatic, antipyretic, antioxidant, antitumor, astringent, cathartic, antihypoglycemic effect, diuretic, stimulant, vermifuge, antimicrobial activities	124, 125
34	fixed oil, *Linum usitatissimum*, Linaceae (seed)	LC−MS	column: Agilent Poroshell 120 EC-C8 (150 mm × 2.1 mm i.d., 1.9 μm); medium: 5 mM ammonium formate in water and methanol (1/4, v/v) (A) and 2-propanol (B), flow rate 0.3 mL/min	α-linolenic acid (ALA), 30−48% oil, which includes ∼55% to ∼14% linoleic acid, ∼18% oleic acid, ∼5% palmitic acid, and ∼3% stearic acid, α-linolenic acid, arachidic acid, palmitoleic acid, stearidonic acid	antioxidant, antimicrobial, immunomodulatory, analgesic, antihypertensive, antihypercholesterolemia, antihyperlipidemic, bactericidal, antineoplastic, wound healer, antiulcerative, moisturizer, hair follicle cycle regulator	126, 127
35	fixed oil, *Sesamum indicum* L., Pedaliaceae (seed)	HPLC-PDA	column: Thermo Finnigan HPLC-PDA and Supelco RP18 Discovery HS-C18 (250 mm × 4.6 mm, 5 μm); medium: 0.1% formic acid in water (solvent A) and methanol (solvent B) as mobile phase, flow rate 1 mL/min	sesamolin, sesamin, arachidic acid, α-linolenic acid, sesamol, 11-eicosenoic acid, linolenic acid, palmitic acid, palmitoleic acid, oleic acid, linoleic acid, myristic acid, stearic acid	anticancer activity, anti-inflammatory activity, cardioprotective activity, neuroprotective potential, hepatoprotective activity, wound healing, nephroprotective	128, 129
36	fixed oil, *Gossypium hirsutum*, Malvaceae (seed)	U-HPLC	column: Agilent Zorbax Eclipse XDBC18 (150 × 4.6 mm, 5.0 μm); medium: solvent A, water:trifluoroacetic acid 1%, and solvent B, acetonitrile:solvent A, flow rate 1.3 mL/min	gallic acid, caffeoyl D-glucose, catechin, gossypetin, gentisic acid, 3-*p*-coumaroylquinic acid, monoglucosyl-3 cyanidine, ferulic acid	anticancer effect, antiepileptic effect, antioxidant effects, antidepressant effect, antidiabetic and hypolipidemic effects, protective effect	130, 131
37	fixed oil, *Adansoina digitata* L., Malvaceae (seed)	GC−MS	column: GCMS-QP2010-Ultra (Rtx-5MS; 30 m × 0.25 mm, 0.25 μm); medium: He as carrier gas, flow rate 1.61 mL/min	methyl ester, 5-octadecenoic acid, methyl ester, methyl tetradecanoate *cis*-5-dodecenoic acid, pentadecanoic acid, methyl ester 7,10-hexadecadienoic acid, methyl ester, 7-hexadecenoic acid	antioxidant activity, diuretic, antiviral, antidiarrheal, antibacterial, anti-inflammatory, antitrypanosomal, antimicrobial, and antidiabetic activities	132, 133
38	fixed oil, *Glycine max*, Fabaceae (seed)	GC−MS	column: Shimadzu 8040 GC−MS/MS (30 m × 0.25 mm, 0.25 μm); medium: He as carrier gas, flow rate 1.69 mL/min	leucine, oleic acid, phenylalanine, lipoxygenase, lipid, 2-methoxy-4-vinylphenol, genistein	anticancer activity, antimicrobial activity, prevention of hot flashes that occur with menopause, and osteoporosis	134, 135
39	fixed oil, *Vitis vinifera*, Vitaceae (seed)	HPLC	column: TSK gel ODS-100 V (250 × 3.0 mm, 3 μm); medium: mobile phase water/formic acid (99.9:0.1, v/v; solvent A) and acetonitrile/formic acid (99.9:0.1, v/v; solvent B), flow rate 0.5 mL/min	caftaric acid, oenin, isoquercetin, viniferal, petunidin-3-*O*-glucoside, ϵ-viniferin	antioxidant, antifungal, antibacterial, anti-inflammatory, antidiabetic, antihypertension, antiviral activities	136, 137
40	fixed oil, *Cucurbita pepo* L., Cucurbitaceae (seed)	GC−MS	column: GC/MS-QP2010 (30 m × 0.25 mm, 0.25 μm); medium: He as carrier gas, flow rate 1.12 mL/min, and linear velocity 39 cm/s	octen-3-ol, hexane, cyclohexene-1-carboxaldehyde, 2,6,6-trimethyl-, 4-ethyl-2-methyl, nonanal, 1-*trans*-β-ionone, phytol, *trans*-farnesol, squalene	antioxidant activity, anti-inflammation, antiaging activity, antityrosinase activity, antiangiogenesis activity	138, 139

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layer chromatography, which is simple to use, formerly played a crucial role in regulating the quality of essential oils.[61]

UV spectroscopy is one of the most conventional, affordable, or economical analytical techniques for qualitative and quantitative evaluation of phytochemicals in the analysis of oils. It works based on the Beer−Lambert law that states the absorbance of the light is proportional to the sample path length as well as the concentration of the sample. It works in different ranges of wavelength, 200−400 nm wavelength (λ_{max}) range works for analysis of the colorless components, while 400−800 nm wavelength (λ_{max}) range works for analysis of colored components. Herewith, calibration of the standard sample with respect to the drug sample deals with the quantification of chemical compounds.[62,63]

Furthermore, a popular analytical platform used for volatile profiling is gas chromatography linked to mass spectrometry (GC−MS) using a capillary column. Peak capacity and selectivity, as well as the volatility of the sample components, are two key characteristics that govern how gas chromatography with a single capillary column operates in theory. However, due to its limited elution range, the peak identification and component assignments of GC−MS spectrum data may be impaired, especially in the case of complex substances like EOs.[64]

These days, the method of choice for examining the intricate compositions of essential oils is gas chromatography (GC). Due to their high volatilities, perfumes are ideally suited for investigation by gas chromatographs, which have large numbers of theoretical plates and exceptional separation capacity.[61]

One of the most popular analytical methods used for research and lab measurements is high-performance liquid chromatography (HPLC). Its natural capacity to analyze, separate, and purify a range of chemical samples, including but not limited to acidic, basic, and neutral analytes, makes it widely utilized in the chemical, pharmaceutical, and biological analysis as well as in drug treatment monitoring. Size exclusion (SEC), ion exchange (IC), normal phase (NP-HPLC), and reversed phase (RP-HPLC) are a few different types of HPLC columns that may be categorized according to how they separate their constituents. The majority of HPLC separations (more than 90%) use RP-HPLC columns. High-performance liquid chromatography (HPLC) has proved to be adaptable and sensitive for locating essential oils.[65]

Despite its well-known durability and adaptability, liquid chromatography's ability to effectively separate multicomponent mixtures is constrained by a number of fundamental technological issues, including limited peak capacity (at tolerable run durations), resolving power, and selectivity. As a logical technical progression of the common one-dimensional (1D) equipment, two-dimensional liquid chromatography (2D-LC) has arisen to address these issues.[66] In the last 10 years, the importance of 2D-LC in the biopharmaceutical business has been clear, and the efforts of several research organizations have made it easier to put this technology into practice. The development of 2D-LC techniques to overcome the limitations of peak capacity with the 1D-LC method and MS concerning solvent compatibility has been sped up due to the complexity of big molecules being higher than that of tiny ones.[67] There are various approaches that have been used in quality-based standardization of medicinal plants. A systematic approach for the quality-based evaluation of oils using different modern analytical techniques is represented in Figure 3, while the quality control approaches and the recent research advancement on natural oils isolated from medicinal plants using modern analytical techniques have been summarized in Table 2.

2.6. Pharmacological Activities.

2.6.1. Anti-inflammatory Activity. The body's reaction to unpleasant stimuli like infection or tissue damage is inflammation, which is influenced by biological, chemical, and mechanical factors.[140] Numerous disorders, including skin inflammation, and autoimmune disorders including diabetes and arthritis, Alzheimer's disease, and cancer, are linked to the inflammatory process. Various plants' biological properties have been utilized for centuries in ethnomedicine to treat inflammatory illnesses. These biological qualities are frequently brought about by the essential oils found in plants, which are employed in traditional medicine as herbal remedies.[141] Plasma and leukocyte infiltration to the site of injury or infection triggers the acute inflammatory response. Localized mast cells and macrophages release inflammatory mediators during the early stages of infection, including cytokines, tumor necrosis factors, eicosanoids, and vasoactive amines (such as histamine). To return tissue homeostasis during inflammation, these mediators play intricate regulatory roles.[142]

Due to the oxidative burst that happens in a variety of cells (monocytes, neutrophils, eosinophils, and macrophages), including those involved in inflammation, essential oils have anti-inflammatory properties. During inflammation, bacteria undergo a process called phagocytosis which is followed by a sharp rise in oxygen consumption. This causes the production of a radical called superoxide anion, which is swiftly transformed into hydrogen peroxide.[143] A single 0.1 mL injection of carrageenan (200 g/paw), which contains prostaglandin I2 (PGI2, 200 ng/paw), caused paw edema. Edematous inflammation is a reported effect of carrageenan. Using a plethysmograph, the volume of the rat paw was measured prior to the irritant injection and at predetermined intervals (1, 2, 3, and 4 h) following the injection of each of the *Eucalyptus* essential oils (10 or 100 mg/kg). After subtraction of the baseline paw volume before the irritant injection, the increase in paw volume (in milliliters) was calculated.[144]

2.6.2. Antioxidant Activity. Antioxidants are substances that can inhibit or delay the oxidation of an oxidizable material, even when employed in very little amounts. Due to their strong reactivity with peroxyl radicals, which are eliminated via formal hydrogen atom transfer, phenolic compounds, both natural and synthetic, generally serve as antioxidants.[145] Antioxidants can be either natural or man-made compounds that counteract the negative consequences of oxidative stress. Natural antioxidants may be found in plants and various plant parts like flowers, stems, and roots. The antioxidant capabilities of the oregano EO were discovered utilizing carotene bleaching, 2,2-diphenyl-1-picrylhydrazyl radical scavenging, and thiobarbituric acid reactive species assays. The EOs of these plants display antioxidant activity.[146]

However, there are several in vitro chemical based assays for the determination of antioxidant activities of medicinal plants and their derived products. With DPPH radical scavenging and ABTS radical cation decolorization assays, the antioxidant capabilities of the EOs were evaluated.[147] The stable free radical DPPH (1,1-diphenyl-2-picrylhydrazyl) is employed to mimic the antioxidant action of the chemical components of EOs. When the DPPH and antioxidant molecules in the EO interact, 1-diphenyl-2-picryl hydrazine is produced. Then, a

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spectrophotometer is used to evaluate the antioxidant activity at 517 nm and calculate the percentage of radical scavenging activity.[148]

Superoxide dismutase (SOD) activity was assessed using the nitroblue tetrazolium (NBT) photochemical technique. The control (1 mL) was made of 50 mM potassium phosphate buffer, pH 6.5, 0.1 mM EDTA, 50 M NBT, 13 mM methionine, 4 mM riboflavin, and 100 L of SOD. At room temperature and with a UV light on for 15 min, the absorbance was measured at zero time and up. SOD concentrations of 0.5, 1.0, and 1.5 mg/mL were employed to measure the inhibition brought on by the *Jacquinia macrocarpa* antifungal fraction (JmAF). The amount of enzyme needed to prevent a 50% fall in NBT was referred to as one unit of SOD.[149]

The liver is a vital component of an organism's physiological metabolism and has larger quantities of antioxidant enzymes than other tissues, which produce more reactive oxygen species (ROS) and other byproducts of lipid peroxidation. Recent research has shown that GPx is expressed differently in different tissues, with the liver exhibiting the highest levels of activity. The outcome demonstrates that the coconut oil groups' (CO-1, CO-2, and VCO-4) liver GPx levels were substantially greater than those of the C group's (p 0.05), with increased rates of, respectively, 57.68, 96.33, and 169.62%.[150]

Malondialdehyde (MDA) levels in the liver were significantly lower in fish receiving meals containing CO; the lowest levels were observed in fish getting food containing 50% coconut oil (P 0.05; 57.68, 96.33, and 169.62%, respectively).[151]

A decrease in the optical density (OD) at 240 nm for 1 min next to the breakdown of H_2O_2 was used to assess the catalase activity. The reaction mixture (1.5 mL) contained an enzyme aliquot, 10 mM H_2O_2, and 50 mM potassium phosphate buffer. With the help of the H_2O_2 extinction coefficient (40 mM^{-1} cm^{-1}), the catalase activity (unit per milligram of protein) was calculated. One unit equals 1 mM H_2O_2 decline/min.[152]

2.6.3. Antimicrobial Activities. Strong antioxidant, antibacterial, antifungal, antiviral, and anti-inflammatory activities can be found in essential oils. Tumors have been treated using certain essential oils in the past. To combat the growing threat of antibiotic resistance, new research has urged the use of plant-based extracts, such as essential oils, for the treatment of infectious disorders.[153] Traditional uses for essential oils in natural medicine include antibacterial and antifungal properties. Essential oils extracted from the leaves or flowers of *Hydrangea* were tested for their antibacterial and antifungal properties. *Bacillus subtilis*, *Staphylococcus epidermidis*, and *Staphylococcus aureus* are among the Gram-positive bacteria that are most susceptible to the essential oils from *Hydrangea*.[154]

To assess the essential oils' prospective applications, the antibacterial and antifungal properties of the oils were tested. When *Thymus daenensis* essential oil was used to treat *S. aureus*, the highest inhibition halo diameter was produced; it was even higher than the inhibition halo diameter produced by rifampin and gentamicin.[155]

2.6.4. Antiarthritis Activity. One of the most prevalent long-term medical conditions and a key contributor to disability is arthritis. Osteoarthritis (OA), rheumatoid arthritis (RA), psoriatic arthritis, gout, and fibromyalgia are the most prevalent kinds of the more than 100 distinct illnesses that make up arthritis. During the last 10 years, a lot of research has been done on the antiarthritic potential of several plant species and extracts.[156]

Rats with adjuvant arthritis are inhibited by the essential oils from Zingiberaceae plants. Ibuprofen, a commonly available anti-inflammatory drug, is helpful in lowering joint swelling in rats with arthritis when compared to the model group. The same is true for essential oils' ability to prevent arthritis.[157] The potential usefulness of *Foeniculum vulgare* in the treatment of inflammatory illnesses has been suggested by many investigators. The synthesis of the pro-inflammatory mediator nitric oxide was effectively inhibited in vitro by all essential oils in a concentration-dependent manner.[158]

2.6.5. Antigout Activity. Due to a deficiency in the uricase enzyme, uric acid builds up in the blood, which leads to gout. Kidney malfunction may induce an abnormal rise in uric acid levels in body fluids like blood, which can then precipitate in internal organs like the viscera and cause gout symptoms.[159] It is a long-lasting metabolic condition marked by the accumulation of monosodium urate (MSU) crystals in tissues, especially joints. These crystals trigger an immediate inflammatory response and can result in persistent tissue damage, which manifests as geodic and erosive lesions, chronic synovial membrane inflammation, ulceration of the joint cartilage, and marginal osteophytosis.[160]

In diabetic rats, extracts from celery seeds have been shown to reduce lipid peroxidation through antioxidation. Rats' blood levels of uric acid were decreased by methanol and celery seed petroleum extracts.[161] By reducing inflammation brought on by MSU crystals, the powerful antioxidant and anti-inflammatory compound (6)-shogaol has shown considerable promise in the treatment of gouty arthritis.[162]

2.6.6. Activity on Atopic Dermatitis (AD). The stratum corneum's moisture content declines and transepidermal water loss rises in the presence of dermatitis. Dry skin is moreover frequently linked to poor barrier performance. Emollient usage has been demonstrated to enhance barrier function in eczematous dermatitis, including atopic dermatitis, by rehydrating the stratum corneum and lowering transepidermal water loss.[163] Itching, dryness, and dysfunctional skin are signs of AD, which is brought on by an aberrant immunological response involving immune cells that have been activated. Itching reduction has been proposed as an AD therapy. The mint plant *Mentha arvensis* belongs to the Lamiaceae family of flowering plants. Until now, the molecular processes behind the anti-inflammatory and antiatopic properties of *M. arvensis* oil have not been thoroughly understood. Using the 2,4-dinitrochlorobenzene-induced mouse model of AD, the antiatopic dermatitis activity of *M. arvensis* oil was examined.[164]

2.6.7. Antipsoriatic Activity. Psoriasis is an autoimmune, persistent inflammatory skin condition with a significant hereditary propensity. It is distinguished by persistent inflammation that causes unchecked keratinocyte proliferation and differentiation. The scalp, trunk, and extensor surfaces of the limbs are all affected. 90% of the body's surface erythematizes and becomes inflamed with erythrodermic psoriasis.[165] Despite the fact that the pathophysiology of psoriasis is yet understood, it is believed to be a T-cell-triggered illness due to the presence of T-helper cells in the psoriatic state. The clinical categories of psoriasis are chronic plaque psoriasis (psoriasis vulgaris), inverse psoriasis, guttate psoriasis, pustular psoriasis, and erythrodermic psoriasis.[166] Some drugs, including lithium, beta-blockers, and antimalarials,

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might alter normal cell proliferation and differentiation, which can lead to psoriasis. Psoriasis is thought to be a multifactorial disease that is brought on by abnormally abundant pro-inflammatory mediators such as interleukins, endothelin, and vascular endothelial growth factors as well as hyperproliferation of keratinocytes, angiogenesis, and unbalanced cell differentiation.[167] Simple to find herbal remedies are used to diagnose illnesses. Changes in nutrition, lifestyle, fasting, low-energy diets, and vegetarian diets have all been shown to improve psoriasis and reduce its symptoms. Some supplements including fish oil (omega-3 fatty acids), vitamin E, and other ingredients can be utilized in the treatment of psoriasis.[168]

2.6.8. Analgesic Activity. Controlling pain is one of the most crucial treatment goals since it is a debilitating companion to many medical illnesses. One of the most common medications used to treat pain in a variety of conditions is analgesic medication.[169] The hunt for novel analgesic compounds has been a top priority for pharmacologists and the pharmaceutical industry due to the vast variety of adverse effects and excessive potency or weakness of the currently available synthetic analgesic medications. Due to their analgesic properties, certain plant species have attracted scientific attention.[170] Notably, mice that were given a combination, at a dose of 150 mg/kg, dramatically reduced the number of abdominal contractions better than the control group, which received the painkiller Tramadol as the standard treatment. The 150 mg/kg dosage of *Thymus algeriensis* and *Artemisia herba-alba*'s essential oils exhibited a little less potent analgesic effect than Tramadol and the combination.[171] At given dosages of 100, 200, and 400 mg/kg in the acetic acid induced writhing reflex test, we saw a substantial decrease in the number of writhes compared to both the control and negative groups.[172] The tail-flick technique is used to determine the analgesic activity of the methanol extract of *Smilax ornata* Lem. The analgesic effect of the methanol extract (200 mg/kg) was substantial (P 0.05), with a 60 min onset and a 2 h duration. At the 60 min mark, the methanol extract's maximal analgesic efficacy (200 mg/kg) was attained.[173]

3. FUTURE PERSPECTIVES

We are aware of the complexity of the chemical constituents in medicinal plants, and each chemical exhibits its own therapeutic effect to alleviate various acute and chronic ailments. Essential oils as well as fixed oils isolated from medicinal plants significantly contribute to the development of therapeutically active pharmaceutical formulations. Exponential spuriousness or adulteration of oils significantly reduces their efficacy, hence deteriorating human health. To investigate the adulteration or development of quality standards for essential or fixed oils, there are several chromatographic and spectroscopic techniques that have significantly contributed to quality based evaluation via exploring the marker constituents of oils, qualitative and quantitative phytochemical acquisition, as well as revealing the chemistry of each metabolite existing in the oils. Nevertheless, these techniques are not only devoted to determining the chemistry of oils but also determining the quality standard of the oils to evade spuriousness or adulteration. Moreover, it has been determined that single technique-based evaluation of oils has not sufficiently contributed to exploration of the complete chemoprofile. Techniques such as GC−MS/MS, LC-MS/MS, and NMR are the most precise and economical techniques to explore the chemistry and reveal the chemoprofiles of the oils. Hence, these techniques would be the better selections of the techniques to scientifically validate therapeutically active oils and thus establish the scientific data for their regulatory purpose.

4. CONCLUSION

In this review, information about the different sources, spuriousness or adulteration, and possible phytopharmacological investigation of essential or fixed oils has been comprehensively summarized. The outcome of the review found that spuriousness or adulteration of oils is being exponentially upheld and thus deteriorating the health of humans. GC−MS/MS and NMR-based chromatographic and spectroscopic techniques are the most liable, economical, precise, and accurate techniques for determining the spuriousness or adulteration of oils based on their chemical profiling using qualitative and quantitative studies. This review presented extensive information about the quality standard of several oils for their regulatory purpose via providing the detailed methods used in techniques for chemoprofiling. Hence, this review helps researchers in further therapeutic as well as quality-based standardization.

■ AUTHOR INFORMATION

Corresponding Author

Gaurav − *IIMT College of Medical Sciences, IIMT University, Meerut, Uttar Pradesh 250001, India;* orcid.org/0000-0002-0530-0788; Email: gautamgaurav878@gmail.com

Authors

Shadab Ali − *IIMT College of Medical Sciences, IIMT University, Meerut, Uttar Pradesh 250001, India*

Rustam Ekbbal − *IIMT College of Medical Sciences, IIMT University, Meerut, Uttar Pradesh 250001, India*

Sapna Salar − *BBDIT College of Pharmacy, Ghaziabad, Uttar Pradesh 201206, India*

Yasheshwar − *Department of Botany, Acharya Narendra Dev College (University of Delhi), New Delhi 110019, India*

Sayad Ahad Ali − *IIMT College of Medical Sciences, IIMT University, Meerut, Uttar Pradesh 250001, India*

Aakash Kumar Jaiswal − *School of Pharmaceutical Sciences, IIMT University, Meerut, Uttar Pradesh 250001, India*

Mhaveer Singh − *Pharmacy Academy, IFTM University, Moradabad, Uttar Pradesh 244102, India*

Dinesh Kumar Yadav − *Department of Pharmacognosy, SGT College of Pharmacy, SGT University, Gurugram, Haryana 122505, India*

Santosh Kumar − *Department of Botany, Maharaja Bijli Paasi Government Post Graduate College, Lucknow, Uttar Pradesh 226012, India*

Complete contact information is available at:
https://pubs.acs.org/10.1021/acsomega.3c05241

Author Contributions

○These authors have made equal contributions.

Notes

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