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FLOWER-DERIVED ESSENTIAL OILS: ADVANCES IN EXTRACTION TECHNOLOGIES, CHEMICAL CHARACTERIZATION AND COMMERCIAL APPLICATIONS

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Abstract:

Flower-Derived Essential Oils (FEOs) are valuable natural products widely used in the fragrance, cosmetic, food, pharmaceutical and aromatherapy industries due to their unique aroma and diverse bioactive properties. Their extraction is challenging because floral tissues contain low concentrations of volatile compounds that are highly sensitive to heat and processing conditions. This review summarizes recent advances in both conventional and green extraction techniques, including hydrodistillation, solvent extraction, supercritical fluid extraction, microwave-assisted extraction, ultrasound-assisted extraction and modern enfleurage-inspired methods. It also highlights the role of advanced analytical tools such as gas chromatography–mass spectrometry (GC-MS), comprehensive two-dimensional gas chromatography and chemometric approaches for accurate chemical characterization, quality assessment and adulteration detection. Furthermore, the review discusses the expanding commercial applications of FEOs in perfumery, cosmeceuticals, functional foods and pharmaceuticals, while addressing key challenges related to extraction efficiency, yield variability, standardization, sustainability and regulatory compliance. Future research should emphasize environmentally sustainable technologies and robust quality assurance strategies.

Keywords: *Flower-Derived Essential Oils, Green Extraction, GC-MS, Chemical Characterization, Quality Control, Sustainable Processing, Commercial Applications.*

1. Introduction

Flowers have been associated with fragrance, cultural value, therapeutic use and aesthetic appeal since ancient times. Their volatile compounds are responsible for the distinctive scents that make them valuable in perfumery, cosmetics, wellness products and food-related applications. Unlike many other plant-derived products, flower essential oils are often produced in very small quantities and with substantial variation depending on species, cultivar, climate, harvest time and extraction method. This means that both the quality and economics of floral oil production depend heavily on how the flowers are processed after harvest.

Essential oils are complex mixtures of volatile secondary metabolites predominantly terpenes, terpenoids and aromatic or aliphatic compounds which are synthesized by plants for ecological functions such as pollinator attraction, herbivore deterrence and anti-microbial defense (1). Among the various plant tissues from which essential oils are obtained, flowers yield some of the most commercially prized and chemically delicate oils, including rose (*Rosa damascena*, *R. centifolia*), jasmine (*Jasminum grandiflorum*, *J. sambac*), lavender (*Lavandula angustifolia*), ylang-ylang (*Cananga odorata*), neroli (*Citrus aurantium* flowers), chamomile (*Matricaria chamomilla*) and osmanthus (*Osmanthus fragrans*) (1).

Flower-derived essential oils are obtained from a wide range of aromatic and ornamental species. Some flowers are cultivated specifically for fragrance production, while others are used more commonly in ornamentals but still contain valuable volatile compounds. Rose is one of the most recognized sources, particularly in perfumery and cosmetic products. Jasmine is prized for its rich and complex scent and is often extracted using solvent-based methods because its aroma compounds are highly sensitive to heat. Lavender, neroli, geranium, chamomile, ylang-ylang, tuberose, lotus and certain *Dendrobium* species are also important in research and trade.

Flower essential oils present unique extraction challenges relative to woody or leafy plant material. Floral tissues are typically fragile, have low oil content (often <0.1% fresh weight) and contain a high proportion of thermo-labile and easily oxidized aroma compounds that can degrade under the heat and aqueous conditions of conventional steam distillation (1,2). This has historically necessitated specialized methods such as enfleurage and solvent extraction for delicate blooms which do not tolerate distillation well (1).

The global essential oils market has grown substantially, driven by demand in natural cosmetics, aromatherapy, "clean label" food flavoring and pharmaceutical research into terpenoid bioactivity (1,3). This growth has, in turn, driven innovation in extraction engineering and analytical instrumentation, which form the core focus of this review.

Table 1: Common flower sources of essential oils and their typical uses

Flower source	Major use	General fragrance character
Rose	Perfumery, cosmetics, aromatics	Sweet, rich, floral
Jasmine	Fine fragrance, perfumery	Intensely floral, sensual
Lavender	Aromatherapy, cosmetics	Fresh, herbaceous, calming
Neroli (orange blossom)	Perfume, flavor, cosmetics	Bright, floral-citrus
Tuberose	Perfumery, niche fragrance	Deep, creamy, floral
Chamomile	Wellness, cosmetics, medicinal use	Soft, apple-like, herbaceous
Ylang-ylang	Perfume, personal care	Exotic, sweet, floral
Geranium	Fragrance, skincare	Rosy, green, balanced
Lotus	Specialty fragrance products	Delicate, aquatic-floral
Dendrobium flowers	Research, aromatics	Species-specific floral notes

2. Extraction technologies

Extraction is the most critical step in floral essential oil production because it determines both yield and composition. Since flower volatiles are often delicate, the chosen method can significantly change the final product. Traditional and modern methods differ in cost, efficiency, operating temperature, solvent use and suitability for heat-sensitive compounds (2,4).

2.1 Conventional methods

2.1.1 Hydro-distillation and steam distillation

Hydro-distillation is among the oldest and most common methods. In this process, plant material is heated with water and volatile compounds are carried over with steam and collected after condensation. Steam distillation works on a similar principle but uses steam generated externally (2). These methods are simple and widely used but they can expose fragile floral compounds to prolonged heat, causing partial degradation or loss of aroma quality (1,2).

2.1.2 Solvent extraction

For flowers that yield poorly to distillation like jasmine, tuberose, mimosa, narcissus; volatile and semi-volatile compounds are extracted using non-polar solvents such as hexane. Evaporation of the solvent yields a waxy "concrete" containing both aromatic compounds and plant waxes and pigments. Further extraction of the concrete is done with ethanol, followed by chilling and filtration, yields the "absolute," a more concentrated and solvent-free aromatic product (1). This method is prized for capturing top and heart notes lost in distillation but have drawn scrutiny over trace solvent residues and the search for greener alternatives (2,4).

2.1.3 Enfleurage

The technique of enfleurage in which layering fresh petals on purified fat is done to allow diffusion of volatile compounds, followed by solvent washing of the fat which later produces a "pomade" and subsequently an absolute (1). Though largely obsolete industrially due to labor intensity, it persists in niche and artisanal perfumery and has inspired modern analogues using solid-phase or polymer-based sorbents.

2.2 Emerging and green extraction technologies

2.2.1 Supercritical fluid extraction

Supercritical fluid extraction, especially with carbon dioxide, has become one of the most important modern methods for high-quality aromatic extracts (5,6). It operates under conditions that preserve volatile and heat-sensitive compounds while leaving no toxic solvent residue (2,5). The extract is often closer to the natural aroma of the flower material. However, the equipment is expensive and may not be accessible to all producers. Supercritical CO_2 extraction operates near its critical point (31.1 °C and 73.8 bar), exploiting its liquid-like solvating power and gas-like diffusivity (5,6). Because extraction occurs near ambient temperature, SFE minimizes thermal degradation and CO_2 leaves no solvent residue upon depressurization, making it attractive for high-value, heat-sensitive floral oils such as rose and chamomile (5). Yield and selectivity can be tuned via pressure, temperature and co-solvent addition, though high capital costs limit its use to premium product lines (6).

2.2.2 Microwave-assisted extraction and microwave hydro-diffusion and gravity

Microwave-assisted extraction and microwave-assisted hydro-distillation are gaining interest because they shorten extraction time and may improve yield (7). Microwave energy selectively heats water within plant cells, rupturing glandular structures and accelerating volatile release (2,7). MHG, a solvent-free variant, allows gravity-driven collection of oil without added water, reducing extraction time from hours to minutes while lowering energy consumption relative to conventional hydro-distillation (7).

2.2.3 Ultrasound-assisted extraction

Acoustic cavitation generated by ultrasound disrupts plant cell walls, enhancing mass transfer of volatile compounds into the surrounding solvent or water at lower temperatures than conventional distillation (2,8). UAE is frequently combined with hydro-distillation to shorten process time and improve yields of oxygen-sensitive floral constituents (8).

2.2.4 Enzyme-assisted extraction

Pre-treatment of floral material with cellulases, pectinases or hemicellulases degrades cell wall polysaccharides, facilitating volatile release during subsequent distillation or solvent extraction (9). This approach has shown yield improvements for tightly bound glycosidic aroma precursors (9).

2.2.5 Subcritical water extraction and other novel approaches

Subcritical water extraction, pulsed electric field (PEF) pre-treatment, and solvent-free microwave extraction represent additional green technologies under investigation, each aiming to reduce energy use, eliminate hazardous solvents and preserve the native chemical fidelity of floral aroma compounds (2,5).

Table 2: Comparison of different oil extraction methods

Method	Main advantage	Main limitation	Suitable use
Hydro-distillation	Simple, low equipment requirement	Heat may alter delicate compounds	General floral oils
Steam distillation	Industrially familiar	Long processing time	Rose, lavender, geranium
Solvent extraction	Good for delicate flowers	Solvent residue and cost	Jasmine, tuberose
Enfleurage	Preserves delicate scent well	Very labor-intensive	Specialty fragrance products
Supercritical CO_2 extraction	High-quality extract, no solvent residue	High capital cost	Premium floral extracts
Microwave-assisted extraction	Faster and often more efficient	Requires optimization	Research and pilot scale
Ultrasound-assisted extraction	Can improve release of volatiles	May not suit all flower types	Heat-sensitive materials
Headspace/HS-SPME	Excellent for aroma profiling	Not for bulk oil recovery	Analytical characterization

3. Chemical characterization and analytical techniques

3.1 Gas chromatography-mass spectrometry (GC-MS)

GC-MS remains the workhorse technique for essential oil analysis, separating volatile constituents by boiling point/polarity on capillary columns and identifying them via mass spectral fragmentation patterns matched against reference libraries (e.g., NIST, Wiley) and calculated retention indices (Kovats indices) on both polar and non-polar stationary phases (1).

3.2 Comprehensive two-dimensional GC

For highly complex floral oils (e.g., rose, jasmine) containing hundreds of trace constituents, GC×GC provides enhanced peak capacity and resolution of co-eluting compounds that confound single-dimension GC, improving detection of minor odor-active trace components (10).

3.3 Gas chromatography-olfactometry (GC-O)

Because perceived fragrance often depends on a small subset of highly odor-active trace compounds rather than the most abundant constituents, GC-O in which a human assessor sniffs the GC effluent in parallel with detector signal is used to correlate chemical identity with aroma character and intensity (11).

3.4 High-performance liquid chromatography (HPLC) and LC-MS

Less volatile or thermally labile constituents (e.g., certain flavonoids, phenolic glycosides in floral extracts) are better resolved by HPLC/LC-MS than GC-based methods (1).

3.5 Nuclear magnetic resonance (NMR) spectroscopy

NMR provides structural confirmation of individual isolated constituents and increasingly, is used in fingerprinting studies for authentication and adulteration screening, since it can quantify major components without extensive sample preparation (1).

3.6 Chemo-metrics and multivariate analysis

Principal component analysis (PCA), hierarchical cluster analysis (HCA) and partial least squares discriminant analysis (PLS-DA) are increasingly applied to large GC-MS datasets to classify oils by botanical origin, geographic provenance, extraction method or to detect adulteration patterns not obvious from individual marker compounds alone (1,12).

Table 3: Major chemical classes in floral oils

Chemical group	General aromatic role	Additional significance
Monoterpenes	Fresh, light floral notes	Often contribute to top notes
Sesquiterpenes	Deeper, warmer aroma	Can enhance persistence
Alcohols	Soft, pleasant floral smell	Important in fragrance balance
Esters	Sweet, fruity floral notes	Improve aroma appeal
Aldehydes	Sharp or green notes	Shape overall scent profile
Phenylpropanoids	Strong fragrance and bioactivity	Common in some floral extracts
Oxygenated compounds	Complex aroma character	Often associated with bioactivity

4. Commercial applications

4.1 Perfumery and fragrance industry

Flower essential oils and absolutes remain foundational raw materials in fine fragrance, providing heart and top notes that synthetic aroma chemicals have not fully replicated in complexity and perceived naturalness (1). Rose, jasmine, ylang-ylang and neroli are particularly significant in this segment, commanding premium prices tied to labor-intensive harvesting and low oil yields.

4.2 Cosmetics and personal care

FEOs are incorporated into skincare, haircare and personal care formulations for fragrance, and in some cases for purported skin-conditioning, anti-oxidant or anti-inflammatory properties attributed to their phenolic and terpenoid constituents (1,12). Regulatory frameworks govern allowable concentrations of specific allergenic constituents that must be labeled when present above threshold concentrations (1).

4.3 Food and beverage flavoring

Rose, orange blossom (neroli) and chamomile are used as natural flavoring agents in confectionery, beverages and baked goods, particularly within Middle Eastern, South Asian and Mediterranean culinary traditions and increasingly in "clean label" western products seeking to replace synthetic flavor compounds (3).

4.4 Aromatherapy and wellness

Lavender, chamomile and rose oils are widely used in aromatherapy practices for purported calming, mood-modulating and sleep-supportive effects (13). While clinical evidence varies in strength across specific claims, a growing body of small-scale clinical studies has examined inhalation and topical application of select floral oils for anxiety, sleep quality and mild dermatological complaints (13).

4.5 Pharmaceutical and biomedical research

Isolated constituents of flower essential oils like linalool, geraniol and various phenyl propanoids have been studied *in vitro* and in pre-clinical models for anti-microbial, anti-inflammatory and anti-oxidant activity, representing a potential source of lead compounds, though translation to approved pharmaceutical products remains limited and is an active area of ongoing research rather than an established application (3,14).

Challenges and future prospects

Despite the growing interest in flower-derived essential oils, several challenges remain. Low yield is one of the biggest limitations, especially for delicate flowers. Another challenge is batch-to-batch variation in aroma and composition. Standardization is difficult because environmental and biological factors can change volatile profiles (1). In addition, adulteration and quality inconsistency remain concerns in the fragrance market (12).

Future research is likely to focus on improving extraction efficiency, preserving delicate aromatic profiles and integrating more advanced analytical tools (2,10). Better chemo-metric methods may help distinguish authentic oils from adulterated products and identify markers of quality (12). Encapsulation technologies may also become more important for improving stability and controlled release in commercial products.

Conclusions

Flower-derived essential oils occupy a distinctive niche among natural products valued simultaneously for their olfactory complexity, cultural and culinary significance and emerging bioactivity profile. While conventional hydro-distillation and solvent extraction remain industrially dominant, green extraction technologies such as supercritical CO2 extraction, microwave-assisted methods and ultrasound-assisted extraction are increasingly adopted to improve yield and preserve thermo-labile aroma constituents (2). Parallel advances in GC-MS, GC×GC, GC-olfactometry and chemo-metric authentication have substantially improved the field's capacity to characterize, standardize and safeguard the authenticity of these high-value oils (10,11,12). Continued interdisciplinary work bridging extraction engineering, analytical chemistry and applied pharmacology will be central to expanding both the sustainability and the scientific and commercial value of flower essential oil production.

References

1. Baser, K. H. C., & Buchbauer, G. (Eds.). (2020). *Handbook of essential oils: Science, technology and applications* (3rd ed.). CRC Press.
2. Chemat, F., Vian, M. A., & Cravotto, G. (2012). Green extraction of natural products: Concept and principles. *International Journal of Molecular Sciences, 13*(7), 8615–8627.
3. Burt, S. (2004). Essential oils: Their antibacterial properties and potential applications in foods—A review. *International Journal of Food Microbiology, 94*(3), 223–253.

4. Masango, P. (2005). Cleaner production of essential oils by steam distillation. *Journal of Cleaner Production, 13*(8), 833–839.
5. Herrero, M., Cifuentes, A., & Ibáñez, E. (2006). Sub- and supercritical fluid extraction of functional ingredients. *Food Chemistry, 98*(1), 136–148.
6. Reverchon, E., & De Marco, I. (2006). Supercritical fluid extraction and fractionation of natural matter. *Journal of Supercritical Fluids, 38*(2), 146–166.
7. Lucchesi, M. E., Chemat, F., & Smadja, J. (2004). Solvent-free microwave extraction of essential oil from aromatic herbs: Comparison with conventional hydro-distillation. *Journal of Chromatography A, 1043*(2), 323–327.
8. Chemat, F., Zill-e-Huma, & Khan, M. K. (2011). Applications of ultrasound in food technology. *Ultrasonics Sonochemistry, 18*(4), 813–835.
9. Puri, M., Sharma, D., & Barrow, C. J. (2012). Enzyme-assisted extraction of bioactives. *Trends in Biotechnology, 30*(1), 37–44.
10. Ryan, D., & Marriott, P. (2003). Comprehensive two-dimensional gas chromatography. *Analytical and Bioanalytical Chemistry, 376*(3), 295–297.
11. Delahunty, C. M., Eyres, G., & Dufour, J. P. (2006). Gas chromatography-olfactometry. *Journal of Separation Science, 29*(14), 2107–2125.
12. Dhifi, W., Bellili, S., Jazi, S., Bahloul, N., & Mnif, W. (2016). Essential oils' chemical characterization and investigation of some biological activities: A critical review. *Medicines, 3*(4), 25.
13. Perry, N., & Perry, E. (2006). Aromatherapy in the management of psychiatric disorders. *CNS Drugs, 20*(4), 257–280.
14. Raut, J. S., & Karuppayil, S. M. (2014). A status review on the medicinal properties of essential oils. *Industrial Crops and Products, 62*, 250–264.
15. Sovová, H. (2012). Steps of supercritical fluid extraction. *Journal of Supercritical Fluids, 66*, 73–79.