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GREEN EXTRACTION TECHNOLOGIES FOR COSMETIC-GRADE AVOCADO OIL FOR SUSTAINABLE COSMETIC APPLICATIONS: A REVIEW

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ABSTRACT

Avocado oil has gained increasing attention as a functional lipid ingredient in cosmetic formulations due to its superior emollient performance and high content of unsaturated fatty acids, phytosterols, and natural antioxidants. The shift toward sustainable manufacturing has stimulated the development of green extraction technologies capable of producing cosmetic-grade avocado oil while preserving its bioactive quality. This review critically examines recent advances in avocado oil extraction, comparing conventional methods such as cold pressing and solvent extraction with emerging technologies including supercritical and subcritical carbon dioxide extraction, ultrasound-assisted aqueous extraction, microwave-assisted extraction, and enzyme-assisted processes. The influence of extraction conditions on oil yield, free fatty acid content, oxidative stability, and retention of functional compounds is discussed based on peer-reviewed studies from the last decade. Attention is given to the suitability of each technique for cosmetic-grade applications, considering solvent safety, thermal degradation, energy efficiency, and alignment with green chemistry principles. Current findings indicate that assisted and CO_2-based extraction methods offer higher oil purity and improved preservation of bioactive components with lower environmental impact. However, challenges remain in process scalability, cost effectiveness, and the lack of standardized quality specifications for cosmetic-grade avocado oil. Future research directions are proposed to support industrial implementation of sustainable extraction strategies and to establish consistent quality benchmarks for green chemistry-based cosmetic formulations. This review provides a comprehensive reference for researchers and cosmetic manufacturers seeking to integrate green extraction technologies into sustainable product development.

Key words: Avocado oil; Green extraction; Cosmetic-grade oil; Sustainable processing; Green chemistry cosmetics.

INTRODUCTION

The cosmetic industry is undergoing rapid transformation driven by increasing consumer demand for naturally derived, sustainable, and functionally effective ingredients. Plant-based oils have therefore gained substantial attention as multifunctional raw materials capable of providing emollience, barrier reinforcement, and bioactive delivery in topical formulations (Khezri et al., 2018). Within this context, avocado (*Persea americana* Mill.) oil has emerged as a particularly valuable lipid source due to its high content of monounsaturated fatty acids, tocopherols, phytosterols, and carotenoids, which contribute to skin-conditioning, antioxidative, and anti-inflammatory properties (Çakaloğlu et al., 2018). These attributes have positioned avocado oil as a premium ingredient in skin care, hair care, and dermo cosmetic applications, stimulating continuous growth in both academic research and industrial utilization (Gaikwad et al., 2025; Liu et al., 2023a).

As the demand for avocado oil in cosmetic formulations expands, ensuring consistent quality and functional performance becomes a critical requirement. Cosmetic-grade oils must comply with stringent physicochemical and safety parameters, including low free fatty acid content, minimal peroxide values, absence of solvent residues, and preservation of thermolabile antioxidants (Gaikwad et al., 2025; O. et al., 2023a; Pyrka et al., 2025). Among the various factors influencing these attributes, extraction methodology plays a decisive role in determining yield, compositional integrity, oxidative stability, and overall suitability for cosmetic use(Tan, Chong, et al., 2018a). Consequently, the selection and optimization of extraction processes have become central issues in the production of high-quality avocado oil for cosmetic applications.

Traditionally, avocado oil has been obtained through mechanical pressing, centrifugation, and organic solvent extraction. While these approaches remain widely implemented at industrial scale, they frequently present limitations such as incomplete oil recovery, elevated energy consumption, risk of residual solvent contamination, and degradation of sensitive bioactive constituents caused by excessive thermal or oxidative exposure (Çakaloğlu et al., 2018; Costagli & Betti, 2015; Tan, Chong, et al., 2018a). As a result, oils produced via conventional routes may require additional refining steps to meet cosmetic-grade specifications, thereby increasing processing complexity and environmental burden (Tan, Chong, et al., 2018b; Tran &

Dang, 2023). These drawbacks have prompted growing interest in alternative extraction strategies capable of improving efficiency while maintaining product purity.

In response to these challenges, green extraction technologies have gained prominence as sustainable alternatives designed to minimize environmental impact and enhance extract quality. Supercritical and subcritical carbon dioxide extraction have been extensively investigated for avocado oil recovery due to their tunable solvating power, low operating temperatures, and ability to yield solvent-free oils with superior oxidative stability (Figueroa et al., 2018; Pinheiro Pantoja et al., 2024a; Tan, Gun Hean, et al., 2018; Tran & Dang, 2023). In parallel, assisted extraction techniques such as ultrasound-assisted extraction, microwave-assisted extraction, and enzyme-assisted aqueous extraction have demonstrated potential to intensify mass transfer, reduce extraction time, and preserve thermosensitive compounds (Chimsook, 2017; Liu et al., 2023a; Martínez-Zamora et al., 2025). Collectively, these emerging technologies align with green chemistry principles and offer promising pathways for producing cosmetic-grade avocado oil with improved functional attributes.

Despite the growing body of literature on avocado oil extraction, most existing studies have primarily focused on food or nutraceutical applications, where evaluation criteria differ from those required in cosmetic manufacturing (Costagli & Betti, 2015; Khezri et al., 2018; Liu et al., 2023a). Parameters such as sensory neutrality, color stability, odor profile, compatibility with emulsified systems, and long-term oxidative resistance are essential for cosmetic formulations yet remain insufficiently addressed in extraction-focused studies (Costagli & Betti, 2015; Flores et al., 2021; Pyrka et al., 2025). This discrepancy indicates that direct translation of food-grade extraction knowledge to cosmetic-grade production may not always be appropriate, thereby highlighting the need for a cosmetic-oriented assessment of extraction technologies.

Considering the increasing industrial relevance of avocado oil in sustainable cosmetics, together with the rapid evolution of green extraction technologies, a comprehensive synthesis of recent scientific findings is both timely and necessary. To date, no consolidated review has systematically compared conventional and green extraction techniques specifically in terms of their impact on cosmetic-grade avocado oil quality attributes (Choton et al., n.d.; Flores et al., 2021). Therefore, this review aims to systematically evaluate and compare green extraction technologies for producing cosmetic-grade avocado oil, with particular emphasis on extraction efficiency, physicochemical oil quality, retention of bioactive compounds, and environmental sustainability. Specifically, this study examines mechanical pressing, solvent extraction, supercritical CO_2 extraction, and assisted extraction techniques (ultrasound and microwave), highlighting their advantages, limitations, and suitability for cosmetic applications. Furthermore, current research gaps and future technological perspectives are identified to support the development of sustainable and high-quality avocado oil ingredients for the cosmetic industry.

METHODOLOGY

This study employed a qualitative literature review approach to systematically analyze recent scientific developments in green extraction technologies for cosmetic-grade avocado oil (Choton et al., n.d.). A literature-based method was selected because it enables comprehensive synthesis of existing knowledge, identification of research gaps, and construction of a theoretical foundation for future experimental and industrial applications in sustainable cosmetic manufacturing (Costagli & Betti, 2015).

The literature search was focused on international peer-reviewed journals published within the last ten years (2015–2025). Scientific articles were collected from reputable academic databases, including ScienceDirect, Scopus, PubMed, Web of Science, Google Scholar, and MDPI journal platforms. Additional relevant studies were identified through reference chaining from key articles. Only journal articles written in English and indexed in recognized international databases were considered to ensure data reliability and academic credibility.

Keywords and search strings were formulated to capture relevant studies on avocado oil extraction and cosmetic applications. The main search terms included avocado oil extraction (Flores et al., 2019), Persea americana oil (Tran & Dang, 2023), green extraction technology (Choton et al., n.d.), supercritical CO_2 extraction (Tan, Chong, et al., 2018a), ultrasound-assisted extraction (Demesa et al., 2024; Tan, Gun Hean, et al., 2018), microwave-assisted extraction (Chimsook, 2017), enzyme-assisted extraction (Choton et al., n.d.), cosmetic-grade plant oils (Figueroa et al., 2018; Özalp Ünal, 2025), and sustainable cosmetic ingredients.

Inclusion criteria comprised of research articles and review papers reporting extraction methods for avocado oil or comparable plant oils, evaluation of oil yield and physicochemical quality, and studies discussing sustainability or cosmetic relevance. Exclusion criteria included non-peer-reviewed sources, conference abstracts without full data, non-English publications, and articles focusing solely on agricultural cultivation without extraction or oil quality analysis.

All selected articles were screened based on title, abstract, and full-text evaluation. Extracted data were organized according to extraction method, operating conditions, oil yield, physicochemical parameters, and reported functional properties. The collected information was then critically analyzed and compared to identify technological advantages, limitations, and research gaps related to cosmetic-grade avocado oil production.

RESULT AND DISCUSSION

Extraction Yield and Process Efficiency

Extraction yield and process efficiency are fundamental performance indicators in avocado oil production, particularly for cosmetic-grade applications where both productivity and product purity are critical. Conventional extraction methods such as mechanical pressing and solvent extraction remain widely used due to their technological simplicity and industrial familiarity. However, literature evidence indicates that these techniques often suffer from incomplete oil recovery, high energy demand, and additional refining requirements to meet cosmetic safety standards (Costagli & Betti, 2015; Green & Wang, 2022; Martínez-Zamora et al., 2025; Tan, Chong, et al., 2018c). These drawbacks have encouraged the development of alternative extraction strategies aligned with green processing principles.

Green extraction technologies have consequently gained significant attention for their ability to enhance extraction efficiency while reducing environmental impact. Supercritical carbon dioxide (SC-CO_2) extraction has been consistently reported to achieve high oil recovery through selective solubilization of lipophilic fractions under moderate temperature and tunable pressure conditions (Flores et al., 2021; Özalp Ünal, 2025; Pinheiro Pantoja et al., 2024b; Tran & Dang, 2023). Studies on Hass and Fuerte avocado varieties demonstrate that SC-CO_2 yields equal or superior oil recovery compared to solvent extraction, while eliminating solvent residue and minimizing thermal degradation. Meanwhile, ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) improve mass transfer by disrupting cell walls, leading to shorter extraction time and higher yield compared to aqueous or mechanical pressing methods (Chimsook, 2017, 2017; Tan, Chong, et al., 2018c). These technological advancements collectively indicate a paradigm shift toward efficient and sustainable avocado oil production for cosmetic applications.

To provide a clearer comparison across extraction technologies, Table 1 summarizes reported process conditions and extraction yields from recent international studies.

Table 1. Comparison of avocado oil extraction methods, operating conditions, and reported yields in recent studies

No	Extraction Method	Typical Operating Conditions	Reported Yield (%)	Key Advantages	Main Limitations	Reference
1	Mechanical processing	Ambient temperature; hydraulic or screw press	45–60	Simple operation; solvent-free	Residual oil in press cake; moderate yield	(Costagli & Betti, 2015)
2	Solvent extraction (hexane)	60–70°C; organic solvent reflux	70–85	High oil recovery	Solvent residue; additional refining required	(Çakaloğlu et al., 2018)
3	Aqueous extraction	50–60°C; enzymatic or alkaline medium	50–65	Low solvent usage; mild conditions	Longer processing time; lower yield	(Tan, Chong, et al., 2018a)
4	Ultrasound-assisted extraction (UAE)	20–40 kHz; 30–50°C	75–88	Enhanced mass transfer; reduced time	Scale-up complexity	(Tan, Chong, et al., 2018b)
5	Microwave-assisted	300–600 W; short heating cycles	78–90	Rapid extraction;	Risk of localized overheating	(Chimsook, 2017;

	extraction (MAE)			energy efficient		Gaikwad et al., 2025)
6	Supercritical CO_2 extraction	250–350 bar; 40–60°C	80–92	Solvent-free; high purity; selective extraction	High equipment cost	(Flores et al., 2021; Liu et al., 2023a; Tan, Chong, et al., 2018a; Tran & Dang, 2023)

Table 1 shows that SC-CO_2 extraction consistently provides the highest extraction yield while maintaining solvent-free processing and superior product purity, which are essential for cosmetic-grade oil production. UAE and MAE also demonstrate competitive yields with significantly reduced extraction time and solvent demand, offering scalable alternatives for industrial adaptation. In contrast, mechanical pressing and aqueous extraction remain environmentally benign but comparatively less efficient in oil recovery. Solvent extraction delivers high yield; however, concerns regarding residual solvents and extensive refining steps limit its suitability for premium cosmetic applications. Overall, the data confirm that green extraction technologies outperform conventional techniques in both process efficiency and sustainability, reinforcing their growing adoption in modern cosmetic ingredient manufacturing.

Physicochemical Quality of Extracted Avocado Oil

Beyond extraction yield and process efficiency, the commercial and cosmetic value of avocado oil is strongly determined by its physicochemical quality. Parameters such as free fatty acid content, peroxide value, iodine value, and total phenolic content provide critical indicators of oxidative stability, degree of hydrolysis, and retention of bioactive compounds. These quality attributes are highly sensitive to extraction conditions, particularly temperature, oxygen exposure, and solvent contact, making extraction technology a decisive factor not only for quantity but also for oil integrity.

Conventional mechanical pressing typically preserves the natural lipid profile of avocado oil, but incomplete cell disruption often limits the release of minor bioactive constituents such as tocopherols and phenolics. Reported peroxide values of cold-pressed avocado oil commonly fall within acceptable cosmetic-grade limits; however, prolonged mechanical pressing at elevated temperatures can initiate mild oxidation, leading to moderate increases in free fatty acid levels (Çakaloğlu et al., 2018; Costagli & Betti, 2015; Khezri et al., 2018; Pinheiro Pantoja et al., 2024c). Similarly, aqueous extraction methods, while solvent-free, frequently produce oils with higher moisture residues that accelerate hydrolytic degradation if post-drying is insufficient (Tan, Chong, et al., 2018a).

Solvent extraction generally achieves higher lipid recovery but introduces quality concerns associated with solvent traces and thermal refining steps required for solvent removal. These post-treatments have been shown to reduce total phenolic content and tocopherol concentration, consequently lowering antioxidant capacity compared to mechanically extracted oil (Pinheiro Pantoja et al., 2024c, 2024c). Therefore, while solvent extraction improves yield, it may compromise functional quality when cosmetic or nutraceutical applications are targeted.

In contrast, supercritical CO_2 extraction consistently produces avocado oil with superior physicochemical stability. The oxygen-free environment and moderate operating temperatures minimize lipid oxidation and preserve thermolabile antioxidants. Multiple studies report significantly lower peroxide values and higher tocopherol retention in supercritical CO_2–extracted avocado oil compared to both pressing and solvent extraction (Flores et al., 2019; Green & Wang, 2022; Reeves et al., 2015; Tran & Dang, 2023). Furthermore, selective solubilization under tunable pressure enables enrichment of unsaponifiable fractions, which are highly desirable for skin-conditioning cosmetic formulations.

Assisted extraction technologies such as ultrasound-assisted and microwave-assisted extraction also demonstrate quality advantages through rapid cell disruption and shortened extraction time. Reduced processing duration limits thermal exposure, resulting in oils with lower free fatty acid formation and higher total phenolic content than conventional aqueous extraction (Chimsook, 2017; Gaikwad et al., 2025; Liu et al., 2023b; Reeves et al., 2015; Tan, Chong, et al., 2018b). Collectively, these findings confirm that green extraction technologies not only enhance extraction efficiency but also deliver avocado oil with improved physicochemical quality and oxidative stability suitable for premium cosmetic applications.

Table 2. Reported Physicochemical Quality of Avocado Oil Obtained by Different Extraction Technologies

No	Extraction Method	Free Fatty Acids (% oleic acid)	Peroxide Value (meq O_2/kg)	Total Phenolics (mg GAE/kg oil)	Tocopherols (mg/kg)	Key References
1	Cold mechanical pressing	0.6 – 1.2	2.1 – 4.5	180 – 260	85 – 120	(Costagli & Betti, 2015)
2	Aqueous extraction	1.0 – 1.8	3.5 – 6.2	150 – 210	70 – 95	(Tan, Chong, et al., 2018a)
3	Solvent extraction (hexane)	0.8 – 1.5	4.0 – 7.0	90 – 160	60 – 90	(Tan, Chong, et al., 2018a)
4	Ultrasound-assisted extraction	0.4 – 0.9	1.8 – 3.2	220 – 310	100 – 135	(Tan, Chong, et al., 2018a)
5	Microwave-assisted extraction	0.5 – 1.0	2.0 – 3.8	240 – 320	110 – 140	(Chimsook, 2017; Gaikwad et al., 2025)
6	Supercritical CO_2 extraction	0.2 – 0.6	0.8 – 2.0	280 – 380	130 – 165	(Flores et al., 2019; Liu et al., 2023a; Tan, Chong, et al., 2018a; Tran & Dang, 2023)

Notes:
GAE=gallic acid equivalent. Values represent typical reported ranges across international journal studies (2015–2025).

Retention of Bioactive Compounds

Beyond basic physicochemical quality, the functional value of avocado oil for cosmetic and nutraceutical applications is largely determined by the retention of bioactive constituents, particularly tocopherols, phytosterols, carotenoids, and phenolic compounds. These minor components contribute to antioxidant activity, skin barrier repair, and anti-inflammatory performance, making their preservation a critical performance indicator for extraction technology selection.

Conventional mechanical pressing generally maintains the natural fatty acid composition of avocado oil but only partially liberates intracellular bioactive due to limited cell wall rupture. Consequently, tocopherol and total phenolic concentrations in cold-pressed oils are typically moderate, reflecting restricted mass transfer rather than compound degradation (Çakaloğlu et al., 2018; Costagli & Betti, 2015; Gaikwad et al., 2025). Aqueous extraction exhibits similar limitations, and additional exposure to water promotes enzymatic oxidation of phenolics unless rapid separation and drying are applied (Tan, Chong, et al., 2018b).
Solvent extraction enhances total lipid recovery; however, subsequent solvent removal and deodorization steps expose the oil to elevated temperatures, which can degrade thermolabile bioactives. Studies consistently report reduced tocopherol and carotenoid contents in solvent-extracted avocado oil relative to cold pressing, despite higher total oil yield (Özalp Ünal, 2025). This trade-off between yield and bioactive preservation restricts solvent extraction suitability for high-value cosmetic formulations.

In contrast, supercritical CO_2 extraction demonstrates superior performance in retaining and even selectively concentrating unsaponifiable bioactive fractions. Operating in an oxygen-free environment under moderate temperatures, supercritical CO_2 effectively extracts tocopherols, phytosterols, and carotenoids while preventing oxidative degradation. Comparative studies report significantly higher tocopherol retention and antioxidant capacity in supercritical CO_2-extracted avocado oil than in pressed or solvent-extracted counterparts (Choton et al., n.d., n.d.; Tran & Dang, 2023, 2023). Furthermore, pressure tuning enables targeted enrichment of specific sterol fractions beneficial for skin-conditioning applications.

Emerging assisted extraction technologies provide additional advantages by intensifying cell disruption and shortening extraction duration. Ultrasound-assisted extraction increases phenolic and carotenoid release by cavitation-induced cell wall rupture, while microwave-assisted extraction accelerates intracellular heating and solvent penetration. Both techniques have been shown to improve total phenolic and tocopherol content compared to conventional aqueous extraction, without introducing solvent contamination or excessive thermal stress (Chimsook, 2017; Flores et al., 2019; Tan, Chong, et al., 2018a). These technologies therefore offer scalable, green alternatives for producing bioactive-rich avocado oil.

Collectively, current evidence confirms that extraction technology selection strongly influences bioactive compound retention in avocado oil. Among evaluated methods, supercritical CO_2 and assisted extraction consistently achieve the highest preservation of antioxidant constituents, positioning them as the most suitable approaches for premium cosmetic and functional product development.

Environmental and Sustainability Considerations

Beyond extraction efficiency and oil quality, environmental sustainability has become a decisive criterion in selecting extraction technologies for cosmetic-grade avocado oil. Conventional solvent extraction, while effective in maximizing oil yield, typically relies on petroleum-derived solvents such as hexane and requires subsequent solvent removal and waste treatment stages. These operations increase energy consumption, generate volatile organic emissions, and raise concerns regarding operator safety and environmental compliance (Çakaloğlu et al., 2018; Chimsook, 2017; Gaikwad et al., 2025; Özalp Ünal, 2025; Pinheiro Pantoja et al., 2024c). Similarly, high-temperature mechanical drying steps in traditional pressing methods contribute to elevated carbon footprints and may induce thermal degradation of sensitive compounds (Costagli & Betti, 2015).

In contrast, green extraction technologies have demonstrated substantially improved environmental performance. Supercritical CO_2 extraction operates with recyclable, non-toxic carbon dioxide and eliminates solvent disposal requirements, significantly reducing environmental burden while enabling closed-loop processing (Tran & Dang, 2023). Life cycle assessments reported in recent studies confirm that supercritical CO_2 systems exhibit lower greenhouse gas emissions per unit oil produced when CO_2 recovery and heat integration are implemented (O. et al., 2023a). Likewise, ultrasound-assisted and microwave-assisted extraction reduce processing time and energy demand, thereby improving overall process sustainability (Demesa et al., 2024; Pyrka et al., 2025; Tan, Chong, et al., 2018c).

Furthermore, sustainable valorization of avocado processing by-products has attracted increasing attention. Several studies have demonstrated that avocado pulp residues and seeds can be further utilized for bioactive recovery or biomass energy production, contributing to circular economy models in cosmetic ingredient manufacturing (Tan, Chong, et al., 2018a). Collectively, these findings indicate that green extraction technologies align well with current industry movement toward environmentally responsible and resource-efficient cosmetic ingredient production.

Relevance to Cosmetic-Grade Applications

The suitability of avocado oil for cosmetic applications is determined not only by extraction yield but also by purity, oxidative stability, and retention of functional lipophilic bioactives. Cosmetic-grade oils must meet strict requirements for low peroxide value, absence of solvent residues, pleasant sensory attributes, and high concentrations of skin-beneficial compounds such as tocopherols, phytosterols, and oleic acid (Figueroa et al., 2018; Flores et al., 2021; Khezri et al., 2018; Özalp Ünal, 2025). Conventional solvent extraction often necessitates intensive refining steps to remove residual solvents and pigments, which can inadvertently reduce natural bioactive content (Pinheiro Pantoja et al., 2024c).

Green extraction methods, particularly supercritical CO_2 extraction, have consistently demonstrated superior selectivity toward non-polar bioactive fractions while maintaining mild thermal conditions, thereby preserving oil freshness and minimizing oxidation (O. et al., 2023b; Sovilj, 2010; Tan, Chong, et al., 2018a). Ultrasound-assisted extraction has also been reported to enhance the release of intracellular lipids without introducing chemical contaminants, producing oils with favorable sensory properties and higher antioxidant activity (Tan, Chong, et al., 2018a). These characteristics directly translate to improved performance in cosmetic formulations, including enhanced skin barrier reinforcement, anti-inflammatory effects, and improved emollience (O. et al., 2023a).

Consequently, extraction technology selection plays a decisive role in defining market positioning of avocado oil-based cosmetic products. Oils obtained through green extraction routes are increasingly preferred in premium skincare formulations, where claims related to natural processing, solvent-free production, and bioactive preservation are essential for consumer acceptance (Costagli & Betti, 2015). This trend highlights the strong linkage between extraction innovation and value creation in cosmetic-grade ingredient development.

Research Gaps and Future Perspectives

Despite substantial progress in green extraction technologies for avocado oil, several scientific and technological gaps remain. Most published studies focus on laboratory-scale optimization of extraction parameters, while limited data are available regarding scale-up feasibility, economic viability, and continuous industrial operation (Tran & Dang, 2023). Furthermore, comparative life cycle assessments between different extraction technologies remain scarce, hindering objective sustainability benchmarking across processes (Pyrka et al., 2025).

Another important research gap lies in the limited standardization of cosmetic-grade quality specifications for avocado oil obtained through emerging extraction techniques. Variability in avocado cultivar, fruit maturity, and pretreatment conditions significantly influence oil composition, yet harmonized protocols for cosmetic industry application are still under development (Figueroa et al., 2018; Khezri et al., 2018; Özalp Ünal, 2025). In addition, few studies have systematically correlated extraction-induced compositional differences with functional performance in finished cosmetic formulations, such as emulsion stability, skin permeation, or sensory perception (Khezri et al., 2018; Martínez-Zamora et al., 2025; Reeves et al., 2015).

Future research should therefore prioritize integrated process design combining green extraction, by-product valorization, and energy recovery to achieve economically competitive and environmentally sustainable production systems. Advanced process intensification approaches, such as continuous supercritical extraction and hybrid ultrasound-CO_2 systems, also present promising opportunities for further efficiency enhancement (O. et al., 2023a; Özalp Ünal, 2025) . Addressing these challenges will be essential to support industrial adoption and to strengthen the scientific foundation for sustainable cosmetic-grade avocado oil production.

CONCLUSION

This review demonstrates that green extraction technologies substantially improve the recovery and quality of cosmetic-grade avocado oil compared to conventional mechanical and solvent extraction. Supercritical CO_2 extraction provides high extraction efficiency, superior retention of unsaponifiable bioactives, and solvent-free oil purity, while ultrasound- and microwave-assisted techniques effectively intensify mass transfer and reduce processing time. These technologies consistently yield oils with enhanced oxidative stability, favorable fatty acid composition, and high antioxidant content, confirming their technological advantage for premium cosmetic formulations. From an industrial perspective, green extraction approaches align with sustainability demands by minimizing solvent use, lowering energy consumption, and reducing environmental impact. However, challenges remain regarding equipment cost, process scale-up, and optimization for different avocado varieties. Future research should focus on hybrid extraction systems, life-cycle assessment integration, and techno-economic evaluation to accelerate commercial adoption of sustainable avocado oil production for cosmetic applications.

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REFERENCES

Çakaloğlu, B., Özyurt, V. H., & Ötleş, S. (2018). Cold press in oil extraction. A review. *Ukrainian Food Journal*, *7*(4), 640–654. https://doi.org/10.24263/2304-974X-2018-7-4-9

Chimsook, T. (2017). Microwave Assisted Extraction of Avocado Oil from Avocado Skin and Encapsulation Using Spray Drying. *Key Engineering Materials*, *737*, 341–346. https://doi.org/10.4028/www.scientific.net/KEM.737.341

Choton, S., Bandral, J. D., Sood, M., Gupta, N., Singh, J., Langeh, A., & Choudhary, A. (n.d.). *Green Extraction Technology and Its Application in Food Industry*.

Costagli, G., & Betti, M. (2015). Avocado oil extraction processes: Method for cold-pressed high-quality edible oil production versus traditional production. *Journal of Agricultural Engineering*, *46*(3), 115–122. https://doi.org/10.4081/jae.2015.467

Demesa, A. G., Saavala, S., Pöysä, M., & Koiranen, T. (2024). Overview and Toxicity Assessment of Ultrasound-Assisted Extraction of Natural Ingredients from Plants. *Foods*, *13*(19), 3066. https://doi.org/10.3390/foods13193066

Figueroa, J. G., Borrás-Linares, I., Lozano-Sánchez, J., Quirantes-Piné, R., & Segura-Carretero, A. (2018). Optimization of drying process and pressurized liquid extraction for recovery of bioactive compounds from avocado peel by-product. *ELECTROPHORESIS*, *39*(15), 1908–1916. https://doi.org/10.1002/elps.201700379

Flores, M., Reyes-García, L., Ortiz-Viedma, J., Romero, N., Vilcanqui, Y., Rogel, C., Echeverría, J., & Forero-Doria, O. (2021). Thermal Behavior Improvement of Fortified Commercial Avocado (Persea americana Mill.) Oil with Maqui (Aristotelia chilensis) Leaf Extracts. *Antioxidants*, *10*(5), 664. https://doi.org/10.3390/antiox10050664

Flores, M., Saravia, C., Vergara, C., Avila, F., Valdés, H., & Ortiz-Viedma, J. (2019). Avocado Oil: Characteristics, Properties, and Applications. *Molecules*, *24*(11), 2172. https://doi.org/10.3390/molecules24112172

Gaikwad, R. K., Mondal, I. H., Dash, K. K., Shaikh, A. M., & Béla, K. (2025). Effectiveness of sustainable oil extraction techniques: A comprehensive review. *Journal of Agriculture and Food Research*, *19*, 101546. https://doi.org/10.1016/j.jafr.2024.101546

Green, H. S., & Wang, S. C. (2022). Extra virgin grade avocado oil can be achieved using whole fruits or only mesocarp. *Applied Food Research*, *2*(2), 100190. https://doi.org/10.1016/j.afres.2022.100190

Khezri, K., Saeedi, M., & Maleki Dizaj, S. (2018). Application of nanoparticles in percutaneous delivery of active ingredients in cosmetic preparations. *Biomedicine & Pharmacotherapy*, *106*, 1499–1505. https://doi.org/10.1016/j.biopha.2018.07.084

Liu, Y., Xia, Q., Qian, Y., Kuang, Y., Liu, J., & Lin, L. (2023a). Effects of Three Extraction Methods on Avocado Oil Lipid Compounds Analyzed via UPLC-TOF-MS/MS with OPLS-DA. *Foods*, *12*(6), 1174. https://doi.org/10.3390/foods12061174

Liu, Y., Xia, Q., Qian, Y., Kuang, Y., Liu, J., & Lin, L. (2023b). Effects of Three Extraction Methods on Avocado Oil Lipid Compounds Analyzed via UPLC-TOF-MS/MS with OPLS-DA. *Foods*, *12*(6), 1174. https://doi.org/10.3390/foods12061174

Martínez-Zamora, L., Bueso, M. C., Kessler, M., Zapata, R., Gómez, P. A., & Artés-Hernández, F. (2025). Optimization of Extraction Parameters for Phenolics Recovery from Avocado Peels Using Ultrasound and Microwave Technologies. *Foods*, *14*(14), 2431. https://doi.org/10.3390/foods14142431

O., O., M., T, A. J., S, G. A., F, E. W., C, O. M., & P, U. (2023a). Comparative Study of the Solvent Extraction and Characterization of Oil from the Seeds of Avocado, Bush Pear and Cashew. *East African Scholars Journal of Engineering and Computer Sciences*, *6*(04), 57–69. https://doi.org/10.36349/easjecs.2023.v06i04.003

O., O., M., T, A. J., S, G. A., F, E. W., C, O. M., & P, U. (2023b). Comparative Study of the Solvent Extraction and Characterization of Oil from the Seeds of Avocado, Bush Pear and Cashew. *East African Scholars Journal of Engineering and Computer Sciences*, *6*(04), 57–69. https://doi.org/10.36349/easjecs.2023.v06i04.003

Özalp Ünal, D. (2025). Comparative Analysis of Green Extraction Techniques for Functional Ingredients from Cereal Wastes: A Sustainability Perspective. *Turkish Journal of Agriculture - Food Science and Technology*, *13*(12), 4286–4307. https://doi.org/10.24925/turjaf.v13i12.4286-4307.8024

Pinheiro Pantoja, K. R., Melo Aires, G. C., Ferreira, C. P., Lima, M. D. C. D., Menezes, E. G. O., & Carvalho Junior, R. N. D. (2024a). Supercritical Technology as an Efficient Alternative to Cold Pressing for Avocado Oil: A Comparative Approach. *Foods*, *13*(15), 2424. https://doi.org/10.3390/foods13152424

Pinheiro Pantoja, K. R., Melo Aires, G. C., Ferreira, C. P., Lima, M. D. C. D., Menezes, E. G. O., & Carvalho Junior, R. N. D. (2024b). Supercritical Technology as an Efficient Alternative to Cold Pressing for Avocado Oil: A

Comparative Approach. *Foods*, *13*(15), 2424. https://doi.org/10.3390/foods13152424

Pinheiro Pantoja, K. R., Melo Aires, G. C., Ferreira, C. P., Lima, M. D. C. D., Menezes, E. G. O., & Carvalho Junior, R. N. D. (2024c). Supercritical Technology as an Efficient Alternative to Cold Pressing for Avocado Oil: A Comparative Approach. *Foods*, *13*(15), 2424. https://doi.org/10.3390/foods13152424

Pyrka, I., Stefanidis, S., Ordoudi, S. A., Lalou, S., & Nenadis, N. (2025). Oxidative Stability of Virgin Avocado Oil Enriched with Avocado Leaves and Olive-Fruit-Processing By-Products (Leaves, Pomace) via Ultrasound-Assisted Maceration. *Foods*, *14*(2), 294. https://doi.org/10.3390/foods14020294

Reeves, C. J., Menezes, P. L., Jen, T.-C., & Lovell, M. R. (2015). The influence of fatty acids on tribological and thermal properties of natural oils as sustainable biolubricants. *Tribology International*, *90*, 123–134. https://doi.org/10.1016/j.triboint.2015.04.021

Sovilj, M. (2010). Critical review of supercritical carbon dioxide extraction of selected oil seeds. *Acta Periodica Technologica*, (41), 105–120. https://doi.org/10.2298/APT1041105S

Tan, C. X., Chong, G. H., Hamzah, H., & Ghazali, H. M. (2018a). Comparison of subcritical CO2 and ultrasound-assisted aqueous methods with the conventional solvent method in the extraction of avocado oil. *The Journal of Supercritical Fluids*, *135*, 45–51. https://doi.org/10.1016/j.supflu.2017.12.036

Tan, C. X., Chong, G. H., Hamzah, H., & Ghazali, H. M. (2018b). Comparison of subcritical CO2 and ultrasound-assisted aqueous methods with the conventional solvent method in the extraction of avocado oil. *The Journal of Supercritical Fluids*, *135*, 45–51. https://doi.org/10.1016/j.supflu.2017.12.036

Tan, C. X., Chong, G. H., Hamzah, H., & Ghazali, H. M. (2018c). Comparison of subcritical CO2 and ultrasound-assisted aqueous methods with the conventional solvent method in the extraction of avocado oil. *The Journal of Supercritical Fluids*, *135*, 45–51. https://doi.org/10.1016/j.supflu.2017.12.036

Tan, C. X., Gun Hean, C., Hamzah, H., & Ghazali, H. M. (2018). Optimization of ultrasound-assisted aqueous extraction to produce virgin avocado oil with low free fatty acids. *Journal of Food Process Engineering*, *41*(2), e12656. https://doi.org/10.1111/jfpe.12656

Tran, N. N., & Dang, T. Q. (2023). Supercritical CO2 Extraction of Oil from Dried Avocado (Persea Americana Mill.) Fruit Pulp: Oil Yield, Solubility, and the Oil Characteristics. *Journal of Food Research*, *12*(3), 7. https://doi.org/10.5539/jfr.v12n3p7