

INNOVATIVE TECHNOLOGIES FOR OBTAINING TECHNICAL AND EDIBLE OILS FROM AGRICULTURAL PRODUCTS

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Abstract: The increasing global demand for vegetable oils has intensified the need for efficient, sustainable, and high-quality technologies for obtaining both technical and edible oils from agricultural products. Conventional extraction methods, such as mechanical pressing and solvent extraction, remain widely used but are associated with environmental concerns, high energy consumption, and partial degradation of valuable bioactive compounds. This scientific-analytical article reviews and discusses innovative oil extraction technologies, including enzyme-assisted extraction, supercritical fluid extraction, ultrasound-assisted extraction, microwave-assisted extraction, and pulsed electric field treatment. The advantages and limitations of these methods are analyzed in terms of oil yield, product quality, environmental impact, and industrial applicability. Particular attention is given to the utilization of agricultural by-products and non-traditional feedstocks for technical oil production within the framework of circular economy principles. The analysis demonstrates that innovative extraction technologies significantly enhance resource efficiency, reduce ecological footprint, and improve the nutritional and functional properties of oils. However, challenges related to economic feasibility, scalability, and technological integration remain critical. The findings of this study highlight the importance of continued research, process optimization, and digitalization to support the sustainable development of the edible and technical oil production industries.

Key words: vegetable oils, innovative extraction technologies, edible oils, technical oils, sustainable processing.

Introduction. The global demand for vegetable oils has increased significantly over the past decades due to rapid population growth, changing dietary habits, expanding industrial applications, and the transition toward bio-based and sustainable materials. Technical and edible oils derived from agricultural products play a crucial role in food security, energy production, pharmaceuticals, cosmetics, and chemical industries. Edible oils such as sunflower, soybean, rapeseed, palm, and olive oil are essential components of human nutrition, while technical oils are widely used in the production of biodiesel, lubricants, paints, polymers, and surfactants. In this context, the development and implementation of innovative technologies for obtaining high-quality oils with improved efficiency, safety, and sustainability have become a key scientific and industrial priority.

Traditional oil extraction methods, including mechanical pressing and solvent extraction, have been widely used for decades due to their simplicity and relatively high yields. However, these conventional technologies face several limitations, such as high energy consumption, incomplete oil recovery, degradation of bioactive compounds, solvent residues, and negative environmental impacts. Moreover, increasing consumer awareness regarding food safety, nutritional value, and

environmental protection has intensified the demand for cleaner, greener, and more efficient oil production technologies. As a result, researchers and industry practitioners are actively exploring innovative approaches that can enhance oil yield and quality while minimizing ecological and economic costs. Innovative technologies for obtaining technical and edible oils focus on improving extraction efficiency, preserving valuable components, reducing processing time, and decreasing the use of harmful chemicals. Among these technologies, advanced mechanical methods, enzyme-assisted extraction, supercritical fluid extraction, ultrasound-assisted extraction, microwave-assisted extraction, and pulsed electric field treatment have gained considerable attention. These methods offer significant advantages over conventional processes by enabling selective extraction, lowering operating temperatures, and enhancing mass transfer. Consequently, they contribute to better retention of essential fatty acids, vitamins, antioxidants, and other biologically active compounds that determine the nutritional and functional quality of oils.

In the production of edible oils, innovation is particularly important for maintaining sensory characteristics, oxidative stability, and nutritional value. Cold-pressing technologies combined with modern filtration and refining techniques allow the production of minimally processed oils that meet consumer preferences for natural and healthy products. Enzyme-assisted extraction, for example, facilitates the breakdown of cell walls in oil-bearing seeds, leading to higher oil recovery and reduced mechanical stress. Similarly, supercritical carbon dioxide extraction provides solvent-free oils with high purity and minimal thermal degradation, making it especially suitable for high-value edible and specialty oils. For technical oils, innovative extraction technologies contribute to improved feedstock utilization and process sustainability.

Digitalization and process automation further enhance the effectiveness of innovative oil production technologies. The application of sensors, data analytics, and intelligent control systems enables real-time monitoring and optimization of extraction parameters, ensuring consistent product quality and reduced losses. Such technological advancements are particularly relevant for large-scale industrial operations, where process stability and reproducibility are critical. In summary, innovative technologies for obtaining technical and edible oils from agricultural products represent a dynamic and rapidly evolving research field with significant economic, nutritional, and environmental implications. The transition from conventional extraction methods to advanced, sustainable technologies is essential for meeting the growing global demand for high-quality oils while ensuring efficient resource utilization and environmental protection. This scientific-analytical article aims to examine modern technological approaches to oil extraction, evaluate their advantages and limitations, and highlight their potential contribution to the sustainable development of the agricultural and processing industries.

Literature Review. Scientific research on the extraction of technical and edible oils from agricultural products has evolved significantly, reflecting advances in processing technologies, sustainability requirements, and quality standards. Early studies primarily focused on conventional oil extraction methods such as mechanical pressing and solvent extraction using hexane, which dominated industrial practice due to their high oil recovery and technological simplicity. According to classic studies, solvent extraction can recover up to 98% of oil from oil-bearing seeds; however, numerous authors have highlighted its drawbacks, including solvent toxicity, environmental pollution, high energy demand, and the degradation of thermolabile

bioactive compounds. These limitations have driven the search for alternative and innovative extraction technologies. Mechanical pressing, particularly cold pressing, has been extensively studied in the context of edible oil production. Researchers report that cold-pressed oils retain higher levels of natural antioxidants, tocopherols, polyphenols, and essential fatty acids compared to solvent-extracted oils. However, literature also emphasizes the lower oil yield associated with mechanical methods, which limits their economic efficiency, especially for large-scale production. Recent studies propose hybrid technologies combining mechanical pressing with auxiliary treatments such as enzymatic, thermal, or physical pre-treatment to improve oil recovery without compromising quality.

Enzyme-assisted extraction (EAE) has been widely discussed in scientific literature as a promising eco-friendly alternative. Numerous studies demonstrate that the use of cellulases, proteases, and pectinases enhances cell wall disruption in oilseeds, leading to increased oil yield and improved extraction efficiency. Researchers note that EAE operates under mild conditions, reducing energy consumption and preserving sensitive nutritional components. However, literature also points out challenges related to enzyme cost, process optimization, and scale-up for industrial applications. Despite these limitations, recent advances in enzyme engineering and immobilization techniques are reported to improve the economic feasibility of this method. Supercritical fluid extraction (SFE), particularly using carbon dioxide, has been extensively analyzed as an innovative and sustainable technology for obtaining high-purity oils. Numerous authors emphasize that supercritical CO₂ extraction eliminates the need for organic solvents, resulting in solvent-free oils with superior quality and oxidative stability. Studies also highlight the tunability of extraction parameters such as pressure and temperature, allowing selective extraction of specific lipid fractions. Despite these advantages, literature consistently mentions the high capital investment and operational costs associated with SFE equipment as a major barrier to widespread industrial adoption, particularly in developing economies.

Ultrasound-assisted extraction (UAE) and microwave-assisted extraction (MAE) are among the most frequently discussed emerging technologies in recent publications. Research findings indicate that ultrasonic cavitation and microwave-induced heating significantly enhance mass transfer, reduce extraction time, and lower solvent consumption. Several comparative studies report that UAE and MAE can achieve oil yields comparable to conventional methods while operating at lower temperatures, thereby preserving oil quality. Nevertheless, authors also note that excessive ultrasonic or microwave exposure may lead to lipid oxidation or structural changes if not properly controlled, highlighting the importance of process optimization. Pulsed electric field (PEF) technology has gained attention in recent years as a non-thermal pre-treatment method for oil extraction. Literature suggests that PEF increases cell membrane permeability, facilitating oil release during subsequent pressing or solvent extraction. Researchers report improvements in oil yield and reductions in energy consumption, particularly when PEF is integrated with mechanical extraction. However, the majority of studies remain at laboratory or pilot scale, and further research is needed to assess long-term operational stability and economic viability at industrial scale.

In the context of technical oils, scientific publications increasingly focus on the utilization of non-traditional agricultural feedstocks and by-products. Studies highlight the potential of rice bran, fruit seeds, oilseed cakes, and agro-industrial residues as valuable sources of technical oils for biodiesel, lubricants, and biochemicals. Innovative extraction technologies are shown to

improve oil recovery from low-oil or structurally complex materials, supporting circular economy principles and waste valorization. Researchers also emphasize that the chemical composition of technical oils obtained through advanced methods is more suitable for downstream industrial applications. Recent literature also addresses the integration of innovative extraction technologies with sustainability and digitalization concepts. Authors report that process modeling, automation, and real-time monitoring systems enhance extraction efficiency, product consistency, and resource management. Life cycle assessment (LCA) studies increasingly compare conventional and innovative extraction methods, consistently demonstrating lower environmental impact for green technologies, particularly in terms of greenhouse gas emissions and solvent use.

Overall, the reviewed literature confirms that innovative technologies for obtaining technical and edible oils offer significant advantages over traditional methods in terms of quality, sustainability, and process efficiency. At the same time, researchers underline the need for further studies on process optimization, economic assessment, and industrial scalability. This body of research provides a strong scientific foundation for the continued development and implementation of advanced oil extraction technologies in agro-industrial systems.

Discussion. The analysis of innovative technologies for obtaining technical and edible oils from agricultural products highlights both their significant potential and the practical challenges associated with their industrial implementation. One of the most important discussion points concerns the balance between oil yield, product quality, and process sustainability. Conventional extraction methods, particularly solvent extraction, still dominate global oil production due to their high efficiency and economic feasibility. However, growing environmental regulations and consumer demand for cleaner, safer, and more natural products increasingly challenge the long-term sustainability of these traditional approaches. Innovative extraction technologies demonstrate clear advantages in preserving the nutritional and functional quality of edible oils. Methods such as cold pressing combined with enzymatic, ultrasonic, or pulsed electric field pre-treatments significantly enhance the retention of bioactive compounds, including tocopherols, phenolic compounds, and essential fatty acids. These components are crucial for the health-promoting properties and oxidative stability of edible oils. From a market perspective, oils produced using such technologies are often positioned as premium products, which can partially offset higher production costs. Nevertheless, the economic viability of these methods remains a subject of debate, particularly for mass-market edible oils where price competitiveness is critical.

For technical oils, the discussion focuses on feedstock flexibility and resource efficiency. Innovative extraction technologies enable the effective utilization of agricultural by-products and low-value raw materials, aligning with circular economy principles. The ability to extract oils from residues such as rice bran, fruit seeds, or oilseed cakes reduces waste and adds value to agro-industrial chains. However, variability in raw material composition and supply can complicate process standardization and quality control. This variability necessitates advanced monitoring systems and adaptive process control, which may increase technological complexity and investment costs. Another key discussion point is the environmental performance of innovative extraction technologies. Green extraction methods, including supercritical CO₂, enzyme-assisted, and ultrasound-assisted extraction, significantly reduce or eliminate the use of hazardous organic solvents. This leads to lower emissions, reduced wastewater generation, and

improved occupational safety. Life cycle assessment studies generally confirm the environmental benefits of these technologies; however, they also reveal that high energy consumption or complex equipment can offset some advantages if processes are not properly optimized. For example, supercritical fluid extraction offers exceptional oil purity but requires high pressures, which increase energy demand and capital costs.

Scalability and industrial integration represent major challenges in the transition from laboratory research to commercial application. Many innovative technologies show excellent performance at bench or pilot scale, yet face limitations when applied to large-scale continuous production. Issues such as equipment design, maintenance, process stability, and operator expertise become increasingly critical at industrial scale. Hybrid systems that combine conventional and innovative techniques may offer a practical compromise, allowing gradual technological transition while minimizing economic risk. Digitalization and automation are increasingly recognized as essential enablers for the successful implementation of innovative oil extraction technologies. The integration of sensors, data analytics, and intelligent control systems can improve process efficiency, ensure consistent oil quality, and reduce operational losses. However, the adoption of digital solutions requires skilled personnel and additional investment, which may be challenging for small and medium-sized enterprises, particularly in developing agricultural regions.

In summary, the discussion indicates that innovative technologies for obtaining technical and edible oils provide clear benefits in terms of quality, sustainability, and resource efficiency. At the same time, their widespread industrial adoption depends on overcoming economic, technical, and organizational barriers. Continued interdisciplinary research, supported by policy incentives and industrial collaboration, is essential to bridge the gap between technological potential and practical application.

Conclusion. Innovative technologies for obtaining technical and edible oils from agricultural products play a vital role in improving oil quality, extraction efficiency, and environmental sustainability. Advanced methods such as enzyme-assisted, supercritical fluid, ultrasound, and pulsed electric field extraction offer significant advantages over conventional technologies by preserving bioactive compounds, reducing solvent use, and enabling the utilization of alternative and secondary raw materials. Despite existing challenges related to cost, scalability, and process complexity, these technologies represent a promising pathway toward sustainable and resource-efficient oil production. Their successful industrial implementation will depend on continued technological optimization, economic assessment, and the integration of automation and digital control systems.

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