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Oil Extraction Innovation: Strategies for a Sustainable Future

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Oil is a highly valued commodity with universal demand, and the potential income from its extraction often justifies the relatively high costs associated with establishing and operating a small-scale oil milling business. Global production of vegetable fats and oil in 2024 was about 228.3 million metric tons (The Hindu, 2025). Global oil production comprises 17 major commodity oils, including four of animal origin and the rest derived from vegetable sources. Of the total output of oils and fats, approximately 80% is utilized for food applications, 6% is incorporated into animal feed, and the remaining 14% serves as the foundation for the oleochemical industry. The method used for oil extraction is crucial, as it directly influences both the quality of the final product and its potential environmental impact. The involved oil extraction methods were briefly classified in two groups, viz. conventional and novel oil extraction methods. However, conventional oil extraction methods primarily mechanical expression and solvent extraction continue to dominate the industry (Tiwari, 2019). The demand for innovative techniques arises from the limitations of these traditional approaches, which often require more energy and time, deliver lower yields, and are less environmentally sustainable (Sharma *et al*., 2021). From the last decades many scientist and researchers have been taking effort to explore the novel area such as microwave assisted (MAE), ultrasound assisted (UAE), and ohmic assisted (OAE) extraction solicitations in oil extraction science. The advantages of these techniques over conventional methods stem from the enhanced quality of the extracted products. They are more time efficient, require less solvent, and are environmentally friendly. Additionally, they offer higher yields, are cost-effective, and allow the recovery of co-products without compromising their quality. The present article is focused on novel oil extraction technology viz. MAE, UAE and OAE mechanisms, advantages, disadvantages and industrial limitations.

Methodology

1. **Microwave Assisted Extraction (MAE):** Microwaves are electromagnetic fields having frequency in the range of 300 MHz to 300 GHz. Due to fast heating resulted in relevant short operation and processing time made a great interest in the microwave assisted technology. Microwave radiation interacts with dipoles in the sample matrix, causing them to oscillate in response to the alternating electromagnetic field. This oscillation generates heat at the material's surface, which then transfers inward through conduction. In addition to interacting with solvent dipoles, microwaves also act on the water molecules within the cells of the oil-bearing material, enabling rapid and uniform heat penetration into the target tissues (Senphan *et al*., 2024)

Advantages of MAE

- High extraction efficiency
- Fast extraction rate
- High retention of oil quality
- Reduced solvent utility

Disadvantages of MAE
- Limitation over depth penetration
- Higher initial investment cost
- Requires specialized equipment

Limitations of MAE
- Not suitable for all oilseed
- Scale up challenges

2. Ultrasound Assisted Extraction Technology (UAE)

Ultrasound-assisted extraction is an emerging and highly promising technology that has been successfully applied in the extraction field. Ultrasound is a form of energy produced by sound waves with frequencies ranging from 20 kHz and above the upper limit of human hearing. It is generally classified into power ultrasound (20–100 kHz), where cavitation is the dominant mechanism, and diagnostic ultrasound (5 MHz–GHz) used primarily for imaging applications. Ultrasound waves modify the physical and chemical properties of the plant material, and the cavitation they produce facilitates the release of extractable compounds. It consisting complex mechanism involved attributed to the production of cavitation bubbles, vibration, mixing and pulverization. Ultrasound improves xtraction by breaking down cell walls, increasing their permeability, and enhancing mass transfer. As ultrasound waves travel through a liquid, they induce cavitation tiny bubbles that form and collapse, producing intense shear forces and microjets that disrupt cellular structures (Chutia *et al*., 2021). These combined mechanical, thermal, and cavitation effects release intracellular compounds, reduce particle size, and accelerate chemical reactions, thereby greatly reducing extraction time while maintaining extract quality.

Advantages of UAE
- Enhanced oil yield
- Reduced extraction time
- Energy efficient
- Eco-Friendly

Disadvantages of UAE
- Equipment cost
- Noise and Operational challenges
- Heating issues

Limitation of UAE
- Difficult to scaling up
- Need for process optimization
- Safety consideration
- Dependence on material properties

3. Ohmic Assisted Extraction (OAE)

It is known by various names like Joule heating, electro conductive heating, electro-heating and electrical resistance heating. The basic principle of this method is very simple and based on the Ohm's law of electricity. The passage of alternating electric current through electricity conductive food material such as a liquid, liquid-particulates or pumpable foods obeys Ohm's law and heat is generated due to electrical resistance of the material (Bastias *et al*, 2022). The food materials which contain sufficient amount of water and electrolytes (mineral salts) can act as electric charge carriers and allows electric current to pass through them resulting generation of internal heat due to electrical resistance of food. In conventional methods of heating, heat transfer occurs from a heated surface to the food material by means of convection and conduction, while in case of ohmic heating it occurs volumetrically from inside the food. The rate of heat generation mainly depends on two factors in ohmic heating one is electric field strength and other is electrical conductivity. It avoids thermal damage to nutritional components of food material, such as vitamins and pigments and prevents overheating.

Advantages

- Rapid and Uniform heating
- Increased oil yield
- Environmental friendly
- Better oil retention quality

Disadvantages

- High initial investment
- Low conductivity materials are not suitable
- Electrochemical reactions

Limitations

- Dependence on electrical conductivity
- Scale up challenges
- Safety concerns

Conclusion

Extraction plays a vital role in the food, chemical, pharmaceutical, and cosmetic industries. In recent years, researchers have explored alternative technologies to improve the efficiency of oil and bioactive compound extraction. Modern approaches, especially non-thermal and green methods, provide faster processing, reduced energy consumption, and higher-quality products. Nevertheless, most techniques remain at the laboratory or pilot scale, highlighting the need for further research to enable industrial implementation. Integrating different methods and advancing sustainable, eco-friendly processes could improve efficiency, product quality, and yield while minimizing environmental impact.

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