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Conventional and Emerging Extraction Technologies for Vegetable Oils: A Comparative Review

Iuliana Ștefania BOLOLOI[1], Elena Gabriela STAN[1], Ionela Florentina TOMA[1] , Gratziela Victoria BAHACIU[1], Nela DRAGOMIR[1], Carmen Georgeta NICOLAE[1]

[1]*University of Agronomic Sciences and Veterinary Medicine of Bucharest, Faculty of Animal Production Engineering and Management*

ABSTRACT

Vegetable oils are among the most widely consumed lipid sources globally, playing a critical role in food technology, nutrition, and industrial applications. This review provides a comprehensive comparative analysis of conventional (mechanical pressing, hexane solvent extraction) and emerging ($SC\text{-}CO_2$, UAE, MAE, enzymatic) extraction technologies applied to vegetable oils, with emphasis on extraction yield, oil quality, bioactive compound preservation, and sustainability. Hexane extraction achieves the highest yields (95–99%) but raises serious environmental and safety concerns. Emerging technologies, particularly $SC\text{-}CO_2$ (85–95% yield), preserve 85–95% of tocopherols and polyphenols compared to only 20–30% with hexane. UAE reduces solvent consumption by 50–70% while maintaining yields of 80–90%. The findings indicate that while conventional methods remain dominant at industrial scale, emerging technologies offer significant advantages in terms of oil quality and sustainability.

Keywords: oil quality, supercritical fluids, ultrasound-assisted extraction, microwave-assisted extraction, solvent extraction, emerging technologies.

INTRODUCTION

Vegetable oils occupy a central place in human nutrition and the global economy, representing the primary source of essential fatty acids, fat-soluble vitamins, and bioactive compounds. Global production exceeded 220 million tons in 2023, with palm, soybean, rapeseed, and sunflower oils accounting for >80% of total output.

Oil quality is defined by fatty acid profile, tocopherol and polyphenol content, oxidative stability, and acid value — all strongly influenced by the extraction method. Inappropriate technology may lead to thermolabile compound degradation, solvent contamination, or significant bioactive losses.

This study performs a systematic comparative analysis of main extraction technologies, evaluating yield, quality, environmental implications, and economic feasibility.

MATERIALS AND METHODS

The research was conducted as a comparative analysis of the scientific literature (2010–2025), including studies on mechanical pressing, hexane extraction, $SC\text{-}CO_2$, UAE, MAE, and enzymatic extraction, selected for scientific relevance and data availability.

- **Parameters evaluated:**
  - Extraction yield (%)
  - Energy consumption
  - Fatty acid profile
  - Environmental impact
  - Tocopherol & polyphenol content
  - Regulatory compliance
  - Operational costs
  - Industrial scalability

Table 1. Main Regulatory Limits for Vegetable Oils

Parameter / Solvent	EU limit (mg/kg)	Codex limit(mg/kg)
Hexane residues in vegetable oils	≤ 1	≤ 1
Hexane residues in vegetable oils	≤ 1	≤ 1
Hexane residues in soybean meal	≤ 30	≤ 30
Free acidity (as oleic acid, %)	≤ 0,5 (extravg.)	≤ 1,0
Peroxide value (mEq O_2/kg)	≤ 20	≤ 15
Residual CO_2 ($SC\text{-}CO_2$)	GRAS / no limit	GRAS

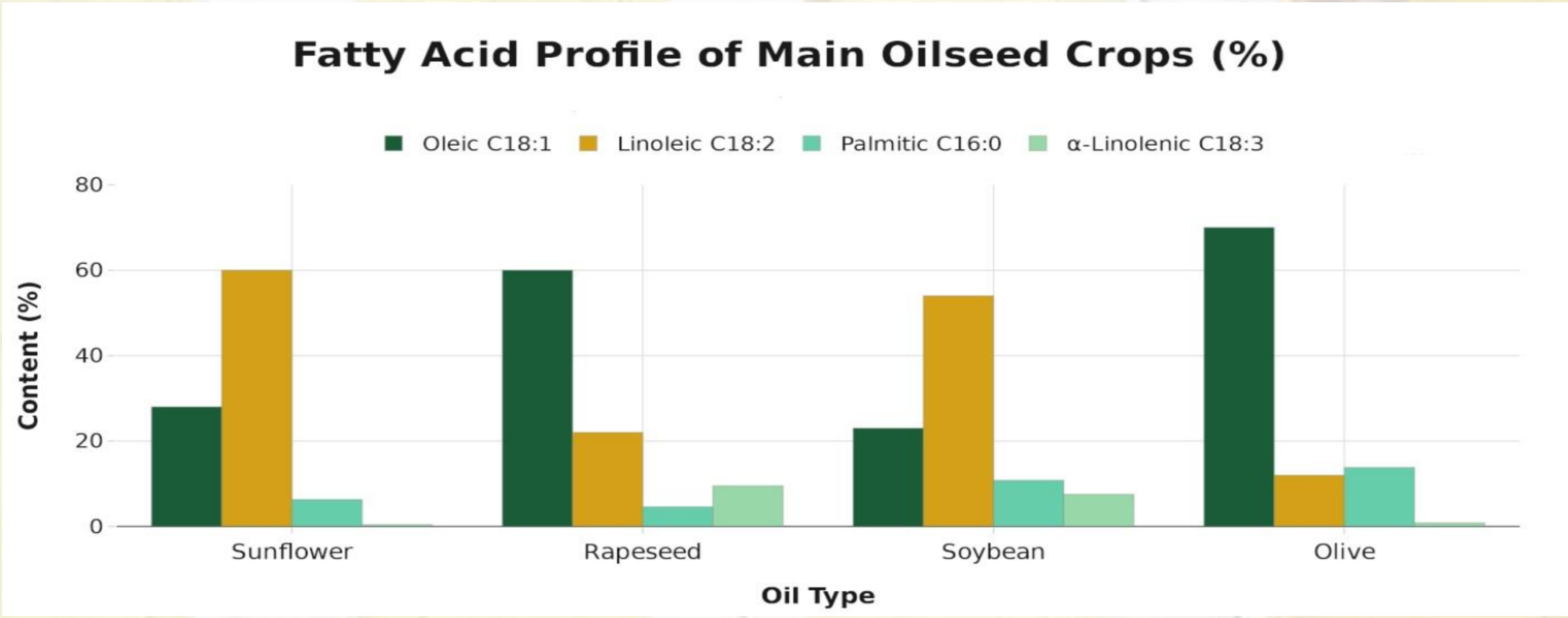
Key Findings

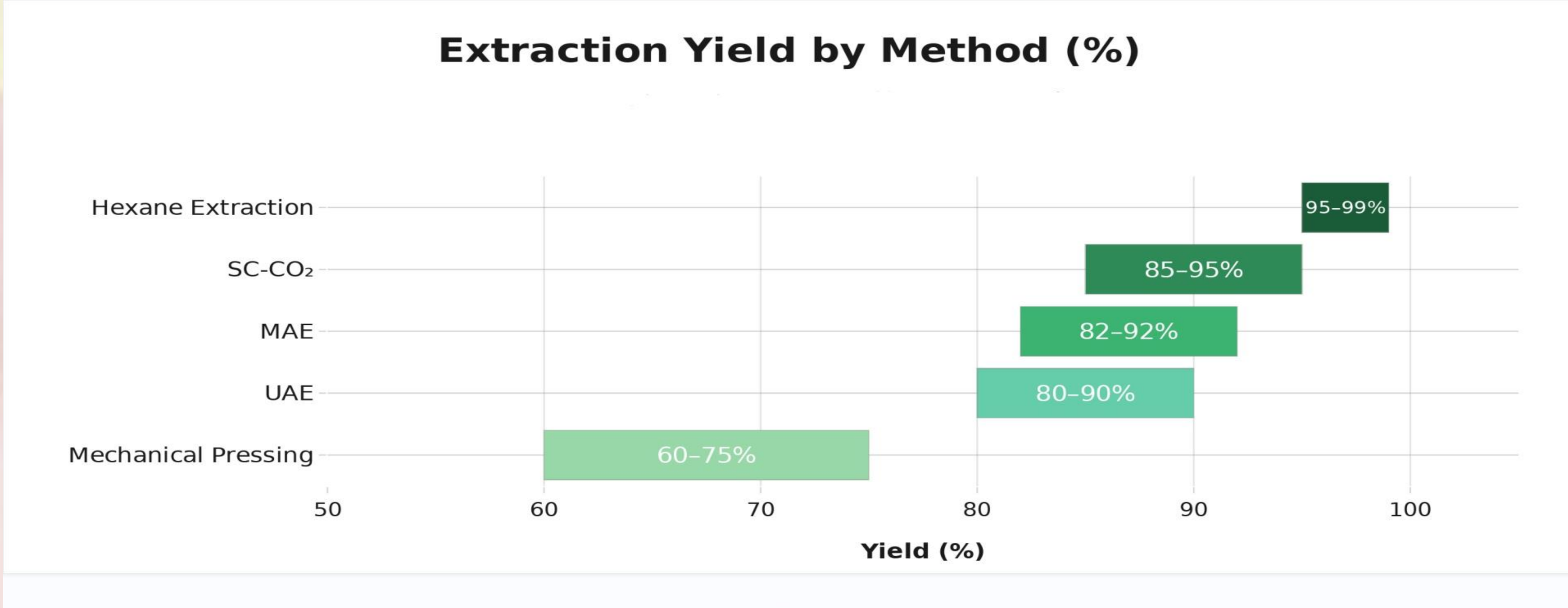
- Hexane: highest yield (95–99%) but degrades 70–80% of tocopherols; classified as hazardous VOC with fire/explosion risk.
- $SC\text{-}CO_2$: preserves 85–95% of tocopherols & polyphenols at 35–80°C, 100–500 bar using GRAS-certified CO_2; premium quality output.
- UAE: reduces solvent consumption by 50–70% and extraction time from hours to minutes via acoustic cavitation; yield 80–90%.
- EAE: increases yield by 10–15% via enzymatic cell wall degradation; requires 4–24 h contact time and incurs high enzyme costs.

RESULTS AND DISCUSSION

Table 2. Comparative Performance of Extraction Technologies

Parameter	Mechanical pressing	Hexane extraction	$SC\text{-}CO_2$	UAE
Extraction yield (%)	60–75	95–99	85–95	80–90
Oil quality	Medium	High*	Very high	High
Energy consumption	Low	High	High	Medium
Bioactive compounds	Partially preserved	Degraded	Preserved	Preserved
Environmental impact	Low	High	Reduced	Reduced
Operational cost	Low	Medium	High	Medium
Scalability	High	Very high	Limited	Medium
Solvent residue	Absent	Present	Absent	Absent





CONCLUSIONS

- The choice of the extraction method should be adapted to the type of raw material, quality objectives, and targeted market segment, as each technology presents specific advantages and limitations.
- Conventional methods (hexane) remain dominant at industrial scale due to high yields and technological maturity, but present significant limitations in product quality and environmental impact.
- Emerging technologies — particularly $SC\text{-}CO_2$ and UAE — offer clear advantages in bioactive compound preservation and sustainability, with $SC\text{-}CO_2$ preserving up to 95% of tocopherols vs. 20–30% with hexane.
- Future development indicates convergence between emerging technologies and circular economy principles: method hybridization (UAE+MAE, enzymatic pretreatment+$SC\text{-}CO_2$), process digitalization, and full biomass valorization.

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