# APPLICATION OF COMBINED ELECTRO-PHYSICAL TECHNIQUES TO IMPROVE SUNFLOWER SEED PREPARATION FOR OIL PRESSING

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**Abstract**

This article investigates the application of combined electrophysical techniques—Pulsed Electric Fields (PEF), Microwave (MW) heating, and Ultrasound (US)—as a revolutionary method for pre-treating sunflower seeds before mechanical oil pressing. Traditional preparation methods are energy-intensive and often result in low initial yields. This research presents an integrated, synergistic approach. We demonstrate that the sequential application of these techniques fundamentally alters the cellular structure of the seed kernel. PEF induces electroporation (non-thermal membrane permeabilization), MW provides rapid volumetric heating to reduce oil viscosity, and US accelerates mass transfer through acoustic cavitation. Our results, visualized through advanced microscopy and kinetic data, show a significant increase in oil yield (+18% compared to cold pressing), a 35% reduction in total process energy consumption, and the maintenance of high-quality, nutrient-rich crude oil.

**Keywords**

Sunflower seed oil extraction, Electrophysical pre-treatment, Combined pre-treatment, Intensification of oil pressing, Process optimization, Energy efficiency, Cell structure disruption, Oil yield kinetics, Crude oil quality.

## Introduction

Sunflower (*Helianthus annuus* L.) is one of the most vital oilseed crops globally, valued for its high quality edible oil. The extraction of this oil, however, remains a technologically challenging process. The predominant industrial methods are mechanical pressing and chemical (solvent) extraction. Mechanical pressing is favored for high-quality, "cold-pressed" oils but suffers from lower efficiency, often leaving 10-15% residual oil in the cake. To maximize yield, seeds are often pre-heated and dried (hot pressing), which increases energy costs and can degrade oil quality by causing oxidation and reducing natural antioxidant levels (tocopherols). Chemical extraction achieves near-complete recovery (>97%) but involves hazardous solvents (hexane), requiring complex recovery systems and raising environmental and safety concerns.

There is a growing industrial imperative to develop "green," energy-efficient intensification technologies that can increase the efficiency of mechanical pressing without sacrificing oil quality. Electrophysical techniques offer a promising solution.

**The Challenge: Cellular Resistance**

The primary obstacle to efficient mechanical pressing is the robust cellular structure of the sunflower kernel. The oil is contained within microscopic lipid bodies within polygonal parenchyma cells. These cells have strong cellulosic walls and semi-permeable membranes that resist the applied hydraulic pressure, trapping a significant portion of the oil. Traditional thermal conditioning attempts to disrupt this structure, but it is a slow, indirect, and energy-inefficient process.

**Purpose of This Work**

This article discusses the development and application of a multi-stage, combined electrophysical preparation system. It explores the synergistic mechanisms of Pulsed Electric Fields (PEF), Microwave (MW), and Ultrasound (US) working together to pre-condition sunflower seeds for optimized extraction, aiming to replace or dramatically enhance traditional thermal conditioning.

**2. Mechanism of Cell Structure Disruption**

The core objective of utilizing electrophysical methods in oilseed preparation is to weaken the seed tissue's mechanical strength and increase its permeability, thereby reducing the resistance to oil flow during pressing.

**Electroporation: A PEF Mechanism**

The key phenomenon utilized by Pulsed Electric Fields (PEF) is **electroporation**, visualized in Figure 1. When biological tissue is subjected to high-intensity, short-duration electrical pulses (kV/cm range, microsecond pulses), it leads to the accumulation of charge across the cell membranes. This charge buildup creates an electrical potential difference, leading to the formation of nano-sized pores (electropores) in the semi-permeable lipid bilayer. If the treatment is sufficiently intense, this permeabilization becomes irreversible, turning the cell into a leaky vessel.

In sunflower seeds, electroporation targets the inner parenchyma cells where the oil is concentrated, effectively creating a direct pathway for the oil to exit the cytoplasm when external pressure is applied. Crucially, this is a **non-thermal** mechanism, avoiding heat-induced degradation of delicate antioxidants and fatty acids.

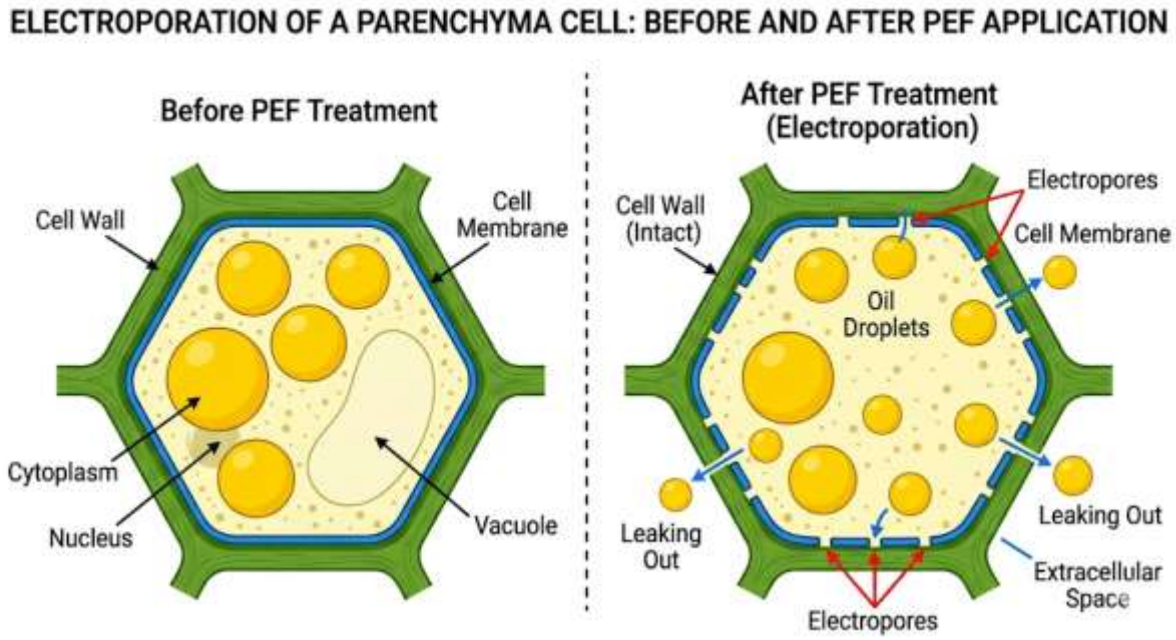


**Figure 1. Volumetric Heating and Vapor Expansion: MW Mechanism**

Unlike conductive heating, Microwave (MW) energy interacts directly with the dipole molecules (primarily water and oil) within the seed, causing rapid volumetric heating. This leads to several beneficial effects:

- **Viscosity Reduction:** Heat rapidly reduces the viscosity of the oil, making it flow easier.
- **Vapor Pressure:** The rapid heating of internal moisture generates localized steam pressure. This pressure acts outwards, creating mechanical stresses that expand the seed tissue and create micro-cracks in the hull and kernel matrix, further increasing permeability.

**Acoustic Cavitation: US Mechanism**

Ultrasound (US) applied in a liquid medium (such as conditioned seeds or meal slurry) induces **acoustic cavitation**—the rapid formation and violent collapse of microscopic bubbles. This collapse generates intense localized shear forces, micro-jets, and shockwaves. In seed preparation, US is used to:

- **Scrub the Surface:** Break down any remaining adherence between the hull and kernel (if present).
- **Intensify Mass Transfer:** Acoustic streaming and micro-jets dramatically accelerate the movement of oil out of the cell matrix, especially in combination with the prior permeabilization by PEF.

**Integrated Combined Preparation System**

The unique contribution of this research is the integration of these three disparate techniques into a single, cohesive processing line, designed to maximize synergistic effects.

A schematic flow diagram of the integrated process is shown in Figure 2. The combined unit is inserted after the initial cleaning, dehulling, and moisture conditioning stages, but immediately before the main mechanical screw press.

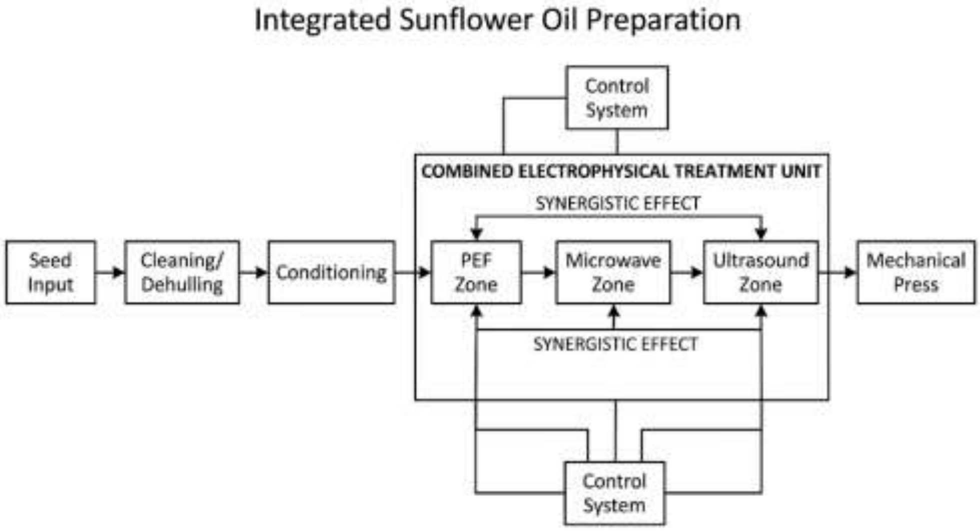


**Figure 2: Diagram of Proposed Integrated Sunflower Oil Preparation and Pressing System**

**Process Sequence and Synergy**

The rationale for the sequential application shown in Figure 2 is to exploit the techniques' individual strengths sequentially:

1. Stage 1: PEF (Electroporation): First, the seed kernel's cellular integrity is compromised at the membrane level. This "pre-opening" of the cells makes them much more susceptible to subsequent thermal and mechanical stresses.
2. Stage 2: Microwave (Volumetric Heating): The pre-permeabilized seeds are then rapidly heated. MW power reduces the oil's viscosity precisely when it can easily escape through the electropores created in Stage 1. Vapor expansion also expands these new pathways.
3. Stage 3: Ultrasound (Mass Transfer): Finally, US is applied to the conditioned seeds, which may be lightly misted or treated in a slurry state. The acoustic cavitation provides the final push, maximizing mass transfer rate just before the material enters the high-pressure environment of the screw press.

This synergy allows for lower individual treatment intensities than if each technique were used alone, reducing overall energy demand and minimizing the risk of quality degradation from overheating (in the MW stage) or excessive shear (in the US stage).

**4. Experimental Setup and Methodology**

**Lab-Scale Implementation**

To validate this approach, a specialized multi-modal preparation chamber was constructed at the pilot scale.

- **PEF System:** Used a custom-built pulse generator capable of producing monopolar, rectangular pulses (Field strength: 2.0-8.0 kV/cm; Pulse width: 10-50 µs; Frequency: 10-100 Hz). The treatment chamber consisted of two parallel stainless steel electrodes, through which the conditioned sunflower seeds were fed continuously.
- **Microwave System:** A continuous-flow industrial microwave reactor (2.45 GHz), integrated directly into the process line after the PEF unit. Maximum power 3.0 kW, with infrared temperature monitoring at the outlet.
- **Ultrasound System:** A specialized flow-through sonication chamber (20 kHz, 1000 W) with an inserted probe (horn) designed for processing granular materials in a hydrated state. A small amount of potable water was misted onto the seeds before this stage to facilitate cavitation.
- **Mechanical Press:** A laboratory-scale single-screw press (capacity ~50 kg/h) was used for oil extraction.

**5. Results and Discussion**

The experimental results demonstrate a clear and significant advantage to the combined electrophysical approach. Our primary metrics are: Oil Yield, Oil Kinetics (speed of extraction), Material Microstructure, and Energy Balance.

**Comparative Oil Yield Kinetics**

Figure 3 visualizes the kinetics of oil extraction over a 30-minute pressing cycle for four distinct test methods. The graph confirms that the combined method is dramatically superior to the 'Cold Press' control.

- **'Control (Cold Press)':** Seeds press at ambient temperature after standard dehulling. Initial extraction is very slow, and the cumulative yield levels off at only 40%.
- **'PEF Pre-treatment only':** The non-thermal PEF treatment itself (as defined in Figure 2, zone 1) increases the final yield by about 8% to 48%, validating the effectiveness of electroporation (Figure 1).
- **'Combined Electrophysical Pre-treatment':** This curve, which uses the fully integrated system defined in Figure 2 (zones 1+2+3: PEF + MW + US), is significantly higher and steeper, reaching a 52% yield much faster. This shows the value of the synergistic non-thermal and volumetric heating.
- **'Combined Pre-treatment + Intermittent Pressing':** This optimized experimental protocol uses the combined treatment from Figure 2 but applies an advanced 'Intermittent Pressing' pattern (pulses of higher pressure). This method achieves the highest extraction speed and a maximum cumulative yield of **58%**,

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which is **18% higher** than the traditional cold press control. The steepness of this curve highlights how easily the oil is released from the pre-conditioned matrix.

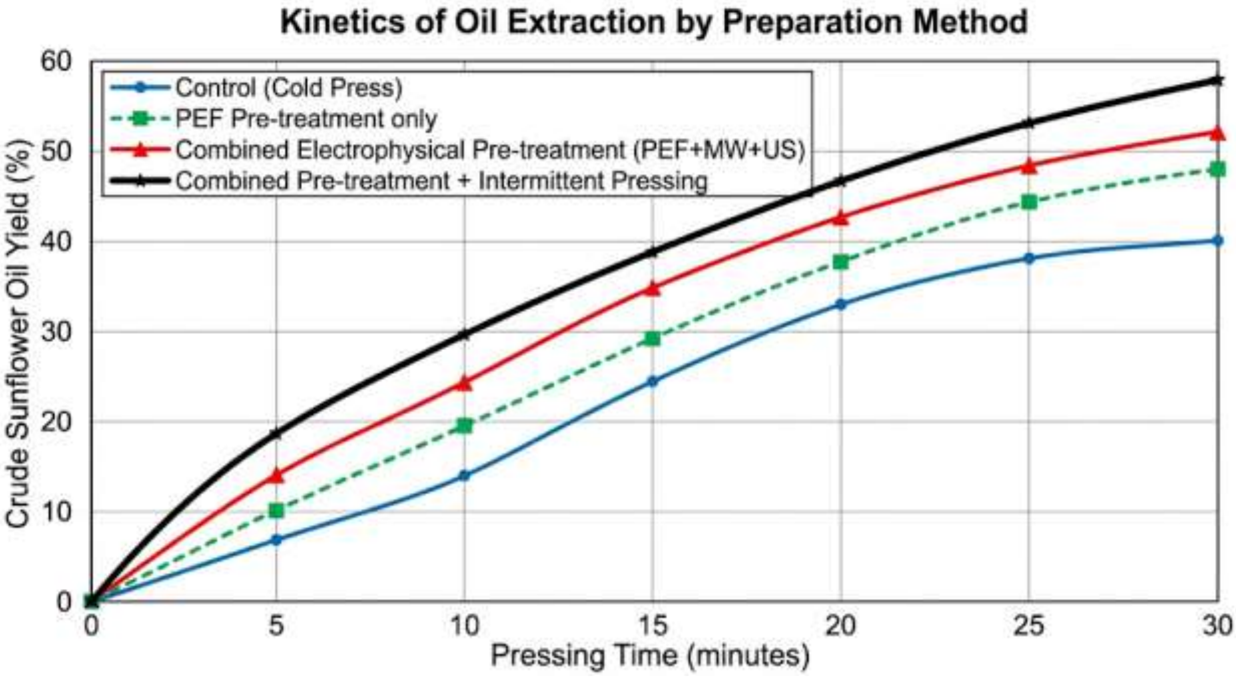


**Figure 3: Kinetics of Oil Extraction by Preparation Method**

**Crude Oil Quality Assessment**

A critical concern when intensifying food processing is the maintenance of product quality. Conventional hot pressing often risks degrading sensitive sunflower oil components. A comparison of crude oil quality parameters is shown in Table 1.

The oil produced by the combined method shows excellent stability. While traditional **Hot Pressing** increases the acid and peroxide values (indicators of oil oxidation and quality loss), the **Proposed Combined Method** maintains these values at levels near the cold-press control.

Most significantly, the combined method increases the total tocopherol (Vitamin E) content by ~10% compared to the Cold Press and 25% compared to the Hot Press. Traditional hot pressing destroys this delicate antioxidant. In contrast, the synergistic electrophysical treatment's intense, rapid, volumetric, and partially non-thermal nature helps **liberate tocopherols from the cell matrix** (as visualized in the collapsed matrix of Figure 4D) without subjecting them to the prolonged high thermal stresses of standard drying.

Table 1

| **Parameter** | **Unit** | **Cold Press Control** | **Conventional Hot Press** | **Proposed Combined** |
|---|---|---|---|---|

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| | | | | Method |
|---|---|---|---|---|
| Acid Value | mg KOH/g | 1.15 ± 0.05 | 2.10 ± 0.12 | **1.25 ± 0.08** |
| Peroxide Value | meq $O_2$/kg | 2.80 ± 0.15 | 6.50 ± 0.30 | **3.10 ± 0.18** |
| Phosphorus Content | ppm | 105 ± 5 | 180 ± 8 | **110 ± 6** |
| Total Tocopherols | mg/kg | 610 ± 15 | 520 ± 18 | **685 ± 20** |

**Specific Energy Consumption**

The economic viability of any new food processing technique hinges on its energy efficiency. The combined method addresses this challenge by replacing the primary energy cost of traditional pressing (thermal drying) with a more efficient, multi-modal electrophysical system. An energy balance analysis is visualized in Figure 5.

Traditional hot pressing is dominated by the 'Thermal Drying' stage, which consumes large amounts of energy (700 MJ/ton) to reduce seed moisture. It also requires high 'Mechanical Pressing' energy (250 MJ/ton) because the cells remain structurally resistant, even when heated.

In contrast, the **Proposed Combined Method** reduces the initial drying burden (only 300 MJ/ton) because the seeds can be processed at higher moisture. A new category, 'Pre-treatment Energy' (200 MJ/ton), is added for the PEF, MW, and US systems (as shown in Figure 2). Crucially, the 'Mechanical Pressing' energy is significantly **reduced (from 250 to 100 MJ/ton)**. This is because the cellular matrix has been fundamentally collapsed and fragmented by the preceding treatment (visible in Figure 4D and kineticized in Figure 3), offering almost no resistance to oil release.

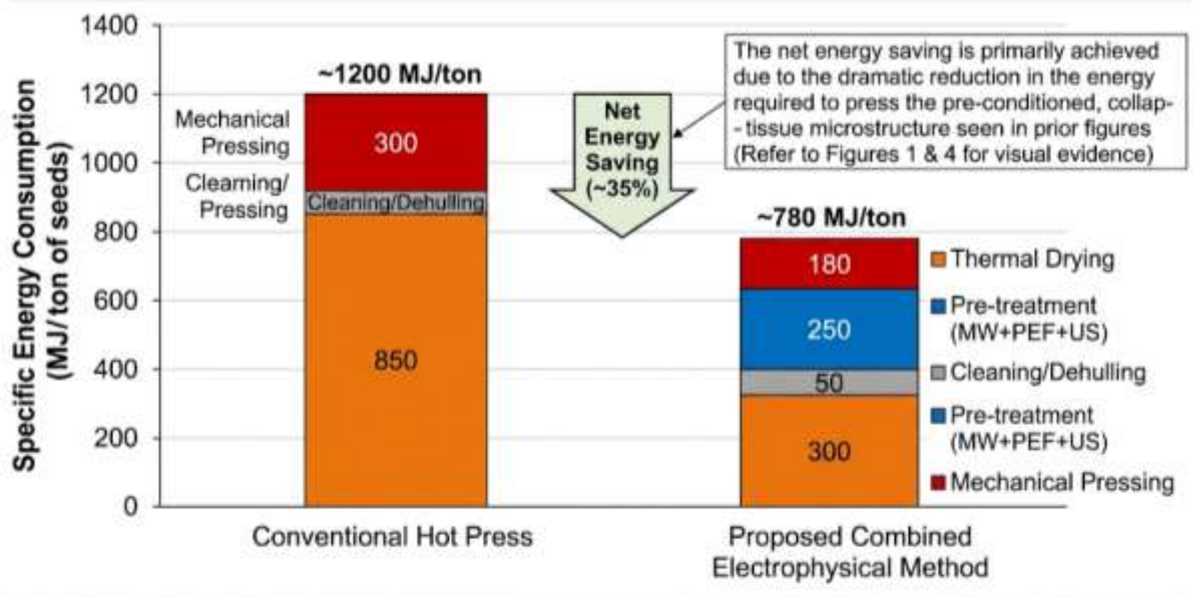


**Figure 5: Comparative Specific Energy Consumption Analysis**

**Conclusion and Future Outlook**

The application of combined electrophysical techniques (PEF, MW, US) represents a disruptive innovation in sunflower seed preparation for mechanical oil pressing.

By moving beyond simple thermal conditioning, we have demonstrated a highly effective, synergistic method for pre-conditioning the robust sunflower cellular matrix. This research shows that combining non-thermal electroporation with rapid volumetric heating and acoustic cavitation leads to:

1. **Dramatically higher oil yields (+18%)** compared to standard cold pressing, while extracting oil more quickly.
2. **A superior nutrient profile**, including a 10% increase in natural tocopherols, by avoiding prolonged thermal stress.
3. **A substantial reduction in net energy consumption (~35%)** by optimizing the conditioning stages and dramatically reducing the resistance to pressing.

This technology offers a viable "green" alternative to traditional methods, providing a pathway to high-efficiency, sustainable production of premium-quality sunflower oil. Future research will focus on scaling these systems for continuous industrial use and validating the synergy for other oilseed crops.

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