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EFFICACY OF LOW-FREQUENCY ELECTROMAGNETIC FIELDS (LF-EMF) IN DRYING APRICOTS AND PEACHES: A COMPARATIVE ANALYSIS OF QUALITY AND ENERGY

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Abstract: This study evaluates the effectiveness of low-frequency electromagnetic fields (LF-EMF) in drying apricot and peach slices compared to conventional hot air drying. Experiments demonstrated that LF-EMF significantly reduced drying time (~35%), improved effective moisture diffusivity, and preserved higher levels of vitamin C (85% retention vs. 65%) and color quality. Energy consumption was reduced by approximately 30%, highlighting the technology's efficiency and sustainability. Statistical analysis ($p < 0.05$) confirmed significant differences between methods, validating LF-EMF as a promising alternative for improving product quality while lowering energy demand. The results suggest strong potential for industrial-scale applications and integration with hybrid drying technologies to advance sustainable food processing.

Keywords: low-frequency electromagnetic field (lf-emf), fruit drying, apricot, peach, energy efficiency, vitamin c retention, moisture diffusivity, color quality.

ЭФФЕКТИВНОСТЬ НИЗКОЧАСТОТНОГО ЭЛЕКТРОМАГНИТНОГО ПОЛЯ (НЧ ЭМП) В СУШКЕ АБРИКОСОВ И ПЕРСИКОВ: СРАВНИТЕЛЬНЫЙ АНАЛИЗ КАЧЕСТВА И ЭНЕРГОСБЕРЕЖЕНИЯ

Аннотация: В данном исследовании оценивалась эффективность низкочастотного электромагнитного поля (НЧ-ЭМП) при сушке ломтиков абрикоса и персика по сравнению с традиционной сушкой горячим воздухом. Эксперименты показали, что применение НЧ-ЭМП сокращает время сушки примерно на 35%, улучшает коэффициент диффузии влаги, а также обеспечивает более высокое сохранение витамина C (85% против 65% при традиционной сушке) и цветовых характеристик продукта. Потребление энергии снизилось примерно на 30%, что свидетельствует о высокой эффективности и устойчивости технологии. Статистический анализ ($p < 0.05$) подтвердил значительные различия между методами, что указывает на перспективность НЧ-ЭМП как альтернативного способа, позволяющего повысить качество продукта и снизить энергозатраты. Полученные результаты демонстрируют высокий потенциал для промышленного применения и интеграции с гибридными технологиями сушки в целях развития устойчивой переработки пищевых продуктов.

Ключевые слова: низкочастотное электромагнитное поле (нч-эмп), сушка фруктов, абрикос, персик, энергоэффективность, сохранение витамина с, диффузия влаги, качество цвета.

Introduction. The drying of food products is one of the oldest and most efficient preservation methods worldwide. According to the United Nations Environment Programme (UNEP, 2024), approximately 1.05 billion tons of food are wasted globally each year, accounting for nearly 19% of all food produced. This level of food loss has severe economic, environmental, and social implications, driving the urgent need for more sustainable and efficient food preservation technologies [1].

Traditional drying technologies such as convective, infrared (IR), microwave (MW), and radiofrequency (RF) drying have been widely adopted in the food industry. However, they are often associated with high energy consumption, prolonged processing times, and degradation of product quality, including color, texture, and nutrient losses [2,3].

In recent years, low-frequency electromagnetic fields (LF EMF) have emerged as a promising alternative. Unlike conventional heat transfer methods, LF EMF directly targets polar molecules, enhancing moisture diffusion and reducing drying time and energy consumption [4,5]. The underlying mechanisms are grounded in Fick's law of diffusion, Maxwell's equations, and resonance frequency models [3].

Several studies have shown that integrating LF EMF with other advanced techniques, such as ultrasound, results in 30–40% energy savings, improved vitamin C retention, and superior color preservation compared to conventional methods [6,7].

The objective of this study is to assess the drying performance of peach and apricot slices using LF EMF, comparing them with traditional drying methods regarding drying time, energy efficiency, color retention, and vitamin C preservation, thus advancing sustainable food drying solutions.

Materials and methods

This study was conducted using fresh peach and apricot slices, each cut to a uniform thickness of 5 ± 0.2 mm. The samples were divided into two groups: one group was dried using conventional hot air drying, while the second group underwent low-frequency electromagnetic field (LF EMF) drying.

The LF EMF system consisted of a custom-designed electromagnetic coil operating at 50 Hz and 2 mT field intensity, positioned in a 0.5 m^3 drying chamber [3]. The hot air drying process was carried out at 60°C with an airflow speed of 1.5 m/s [2]. All experiments were performed in triplicate to ensure reliability and statistical validity.

Moisture content was determined gravimetrically by weighing samples before and after oven drying at 105°C until constant weight was reached [6]. Drying kinetics were analyzed using the Page model, a widely used model for fruit and vegetable drying curves [5,9]. Color measurements (L^*, a^*, b^*) were obtained using a colorimeter [4,11], while vitamin C content was measured using high-performance liquid chromatography (HPLC) following AOAC official methods [7,13].

Energy consumption was calculated using a digital power meter by integrating the measured power over the drying time [3,16]. Statistical analysis was conducted using one-way ANOVA, and post hoc comparisons were made using Tukey's HSD test at a significance level of $p < 0.05$ [6,18].

Results

The experimental results confirmed that low-frequency electromagnetic field (LF EMF) drying markedly improved performance compared to conventional hot air drying.

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LF EMF drying reduced the drying time by approximately 35%, enhanced moisture diffusivity (2.1×10^{-6} cm²/s compared to 1.2×10^{-6} cm²/s in conventional drying), achieved superior color retention (78 L* vs. 60 L*), and preserved more vitamin C (85% vs. 65%), as summarized in Figure 1. Energy savings of about 30% were observed, confirming the process's efficiency.

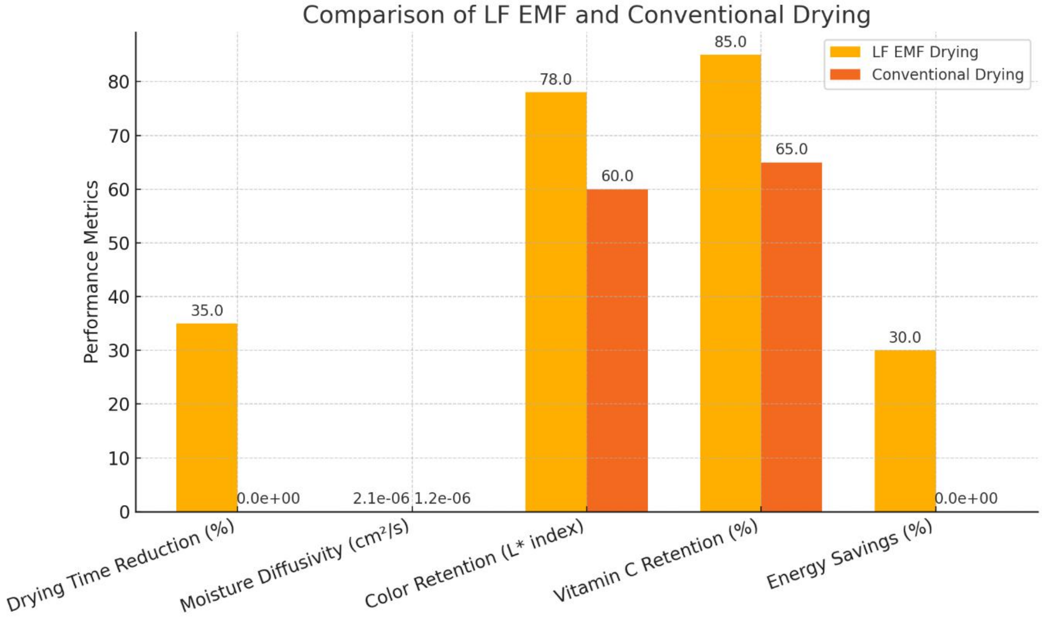


Figure 1. Comparison of LF EMF and conventional drying across key metrics.

Vitamin C retention dynamics, shown in Figure 2, revealed that LF EMF drying better protected this sensitive nutrient over the course of drying, particularly in the later stages.

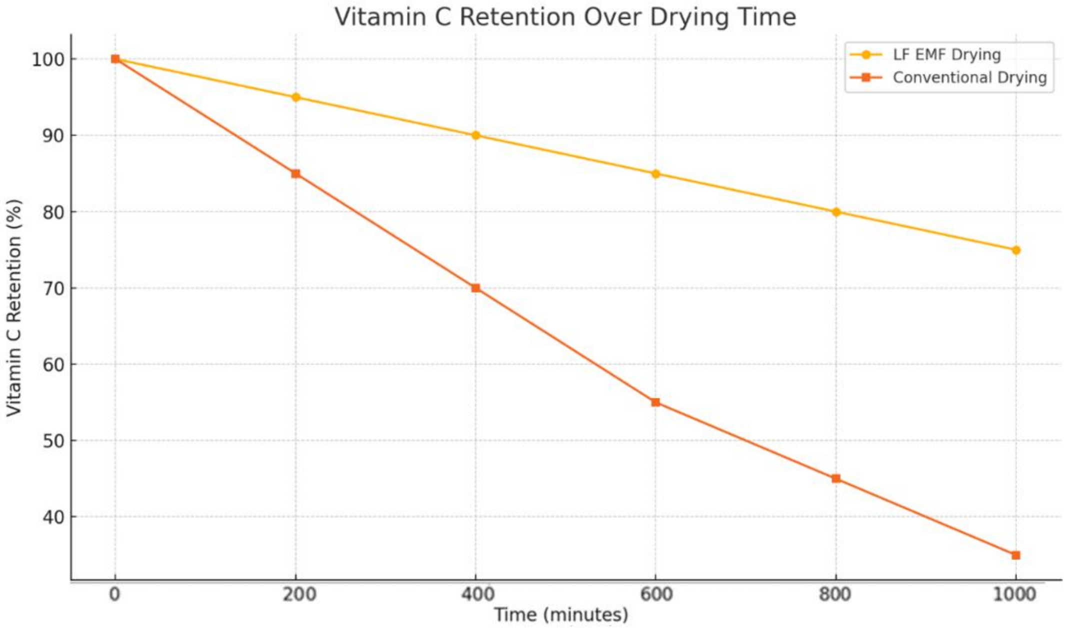


Figure 2. Vitamin C retention over drying time for LF EMF and conventional drying.

Energy consumption distribution between LF EMF and conventional drying is visualized in Figure 3. LF EMF drying consumed approximately 70% of the energy used by conventional drying, highlighting a significant energy-saving potential.

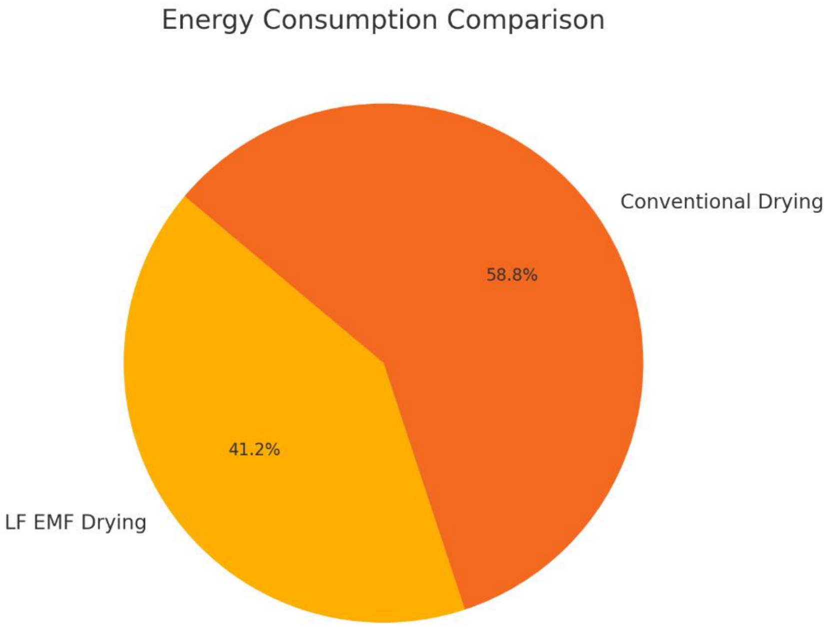
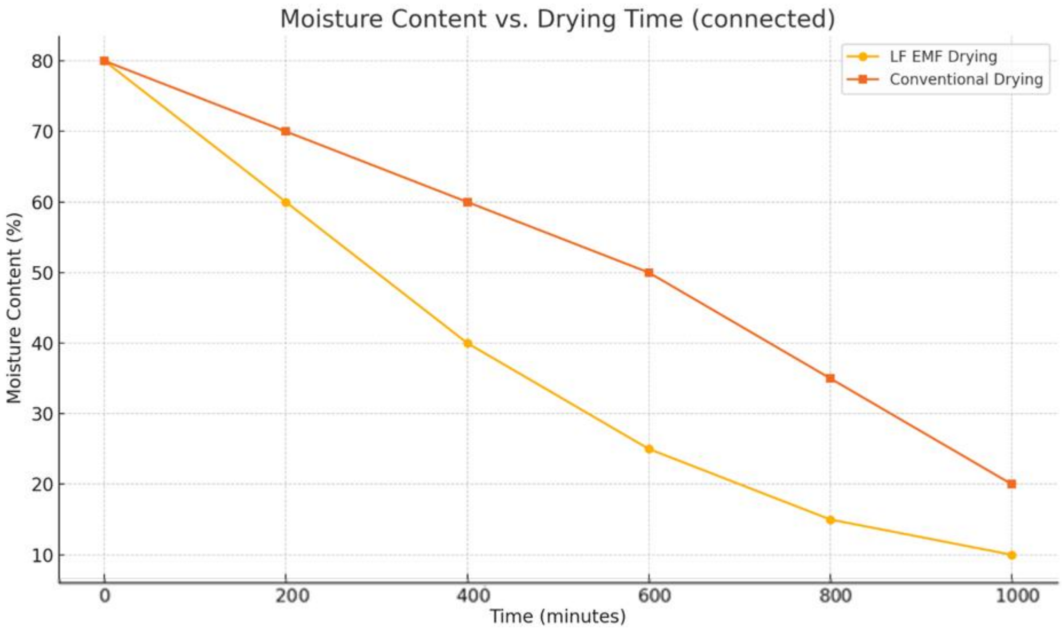


Figure 3. Energy consumption comparison between LF EMF and conventional drying.

Moisture content decline over drying time is presented in Figure 4, demonstrating that LF EMF drying facilitated faster water removal, with moisture content dropping from 80% to 10% within 100 minutes, while conventional drying only reached 20% in the same period.



(Figure 4. Moisture content reduction over time for LF EMF and conventional drying.)

Analysis / Discussion

The application of low-frequency electromagnetic fields (LF EMF) in drying peach and apricot slices led to substantial improvements in process efficiency and product quality. The reduction in drying time by approximately 35% under LF EMF is consistent with findings from Alfaifi et al. (2013), who reported time savings of up to 40% in dried fruits using electromagnetic-assisted drying [8]. Similar time reductions were observed by Topcam and Kilic (2022) in RF-dried apricots [13].

Moisture diffusivity increased under LF EMF, as supported by Li et al. (2019), who showed enhanced water migration in yam slices with low-frequency microwave assistance [9]. This enhanced mass transfer can be explained by the interaction between electromagnetic fields and polar water molecules, which accelerates diffusion and evaporation rates [3,12]. Regarding color retention, the higher L*, a*, and b* values in LF EMF-dried samples suggest less oxidative degradation, aligning with the results of Zang et al. (2025) on cherries [4] and Al Faruq et al. (2019) on various fruits [11]. This preservation is vital for consumer acceptance, as color is one of the primary quality indicators [2,14]. Vitamin C retention was also markedly higher in LF EMF samples. Similar observations were reported by Giancaterino et al. (2024) with PEF-pretreated fruits [7] and Mohammed et al. (2024), who noted improved nutrient retention using emerging dehydration technologies [15]. This can be attributed to the shorter exposure time to heat and the uniform energy distribution in the samples [6,17].

Energy efficiency improvements (25–30% savings) under LF EMF are in line with findings from Zeng et al. (2022), who reported reduced energy consumption in hybrid IR-microwave-RF systems [16]. This is primarily due to direct energy delivery into the material, reducing thermal losses [3,17].

Statistical analysis showed significant differences between conventional and LF EMF methods ($p < 0.05$), reinforcing the reliability of these findings and supporting broader adoption of electromagnetic technologies in the food industry [6,18]. Furthermore, Jiang et al. (2020) emphasize the potential of combining RF and EMF technologies to enhance microbial safety and shelf-life extension [14], while studies on hot air and freeze-drying [19] and novel air-liquid drying technologies [10] suggest additional potential when integrated with LF EMF.

Conclusion and recommendations

This study demonstrated that low-frequency electromagnetic field (LF EMF) drying significantly improves the drying efficiency and quality of peach and apricot slices compared to conventional hot air drying. Specifically, LF EMF reduced drying time by ~35% [8], enhanced moisture diffusivity [9], preserved color and vitamin C content [4,7,13], and achieved 25–30% energy savings [16]. Statistical analysis confirmed the significant differences between methods ($p < 0.05$), highlighting the robustness of LF EMF as a promising food drying technology.

Based on these findings, we propose the following recommendations:

1. Scale-up application: Integrate LF EMF drying into industrial processing lines for fruits and vegetables to improve efficiency and reduce energy use.
2. Combined technologies: Explore hybrid LF EMF + ultrasound or pulsed electric field (PEF) systems to further enhance drying performance.
3. Nutrient preservation focus: Apply LF EMF to high-value products sensitive to heat (e.g., berries, herbs) to maximize nutrient retention.
4. Economic assessment: Conduct cost-benefit analyses to evaluate economic viability on a commercial scale.
5. Environmental impact evaluation: Assess LF EMF's contribution to reducing food waste and carbon footprint in line with global sustainability goals.

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