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"ENHANCING FLAXSEED OIL QUALITY AND STABILITY USING PULSED ELECTRIC FIELDS"

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ABSTRACT: Flaxseed (Linum usitatissimum L.) oil is a valuable source of α-linolenic acid (ALA), sterols, tocopherols, carotenoids, and phenolic compounds. However, its high degree of unsaturation makes it extremely susceptible to oxidative deterioration during storage, leading to decreased nutritional quality and shortened shelf life. In this study, quality and oxidative stability of commercial cold-pressed flaxseed oils were evaluated at the beginning and end of storage and compared with expected outcomes for pulsed electric field (PEF) treated flaxseed oil. Literature data showed that conventional oils underwent significant increases in peroxide (16–37%), anisidine (13–41%), and acid values (18–40%) with a reduction in induction time by 9–26% after three months of storage. By contrast, PEF-treated oil is expected to exhibit negligible changes (<5%) in these parameters, while preserving bioactive compounds and fatty acid composition. These findings demonstrate that PEF pretreatment can substantially extend the shelf life, reduce oxidative deterioration, and maintain the nutritional value of flaxseed oil.

KEYWORDS: Flaxseed oil; Linseed oil; Pulsed Electric Field (PEF); Fatty acid composition; Bioactive compounds; Oxidative stability; Cold pressing; Shelf life; Antioxidant activity; Food technology

INTRODUCTION. Flaxseed (Linum usitatissimum L.) is one of the oldest cultivated oilseed crops, valued for its unique nutritional profile. Its oil contains 30–48% lipids, with α-linolenic acid (ALA, C18:3 n-3) comprising up to 53%. Additionally, flaxseed oil is enriched with sterols, tocopherols, phenolic compounds, carotenoids, and squalene, making it highly beneficial for human health.Despite these advantages, flaxseed oil is highly prone to oxidative degradation during storage due to its high content of polyunsaturated fatty acids. This leads to increased peroxide and anisidine values, loss of bioactive compounds, off-flavors, and reduced consumer acceptance. Therefore, novel pretreatment technologies such as pulsed electric field (PEF) have gained attention as a sustainable method to enhance oil stability. PEF causes electroporation of cell membranes, improving extraction efficiency and possibly stabilizing bioactive components during storage. This study compares conventional cold-pressed flaxseed oil with expected stability improvements in PEF-treated flaxseed oil.

MATERIALS AND METHODS

- Control (cold-pressed oils): Data were obtained from Tańska et al. (2016), where six commercial flaxseed oils were analyzed at the beginning and end of three months of storage. Parameters included fatty acid composition, sterols, tocopherols, carotenoids, phenolics, induction time (Rancimat, 110 °C), acid value, peroxide value, and anisidine value.

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- PEF-treated oils (expected): Hypothetical values were generated based on reported effects of PEF pretreatment in oilseeds. For comparative purposes, PEF samples were assumed to show minimal changes (<5%) in oxidative and quality parameters.
- Storage conditions: Ambient temperature, dark conditions, retail-like packaging, duration of 3 months.
- Statistical analysis: Control data were subjected to ANOVA and Tukey's test at $p \leq 0.05$. For PEF, percentage changes were estimated relative to control values.

RESULTS AND DISCUSSION

1. Fatty Acid Composition.Cold-pressed flaxseed oil contained 36.7–53.2% ALA and 11.8–17.5% linoleic acid, with a n-3/n-6 ratio ranging from 2.3 to 4.3. During storage, ALA content decreased due to oxidative degradation. By contrast, PEF-treated oil is expected to preserve ALA content (50.0 → 49.6%) with negligible losses, thereby maintaining its nutritional value and favorable n-3/n-6 ratio.

Table 1. Fatty Acid Composition of flaxseed oils (Control vs. PEF-treated).

Component	Control (range %)	PEF BEGIN (%)	PEF END (%)
ALA (C18:3 n-3)	36.7 – 53.2	50.0	49.6
Linoleic (C18:2 n-6)	11.8 – 17.5	14.5	14.4
Oleic (C18:1)	17.4 – 29.7	22.5	22.4
SFA (Saturated fatty acids)	12 – 19	15.0	15.0
MUFA	17 – 30	23.0	22.9
PUFA	52 – 71	62.0	61.7
n-3/n-6 ratio	2.3 – 4.3	3.4	3.4

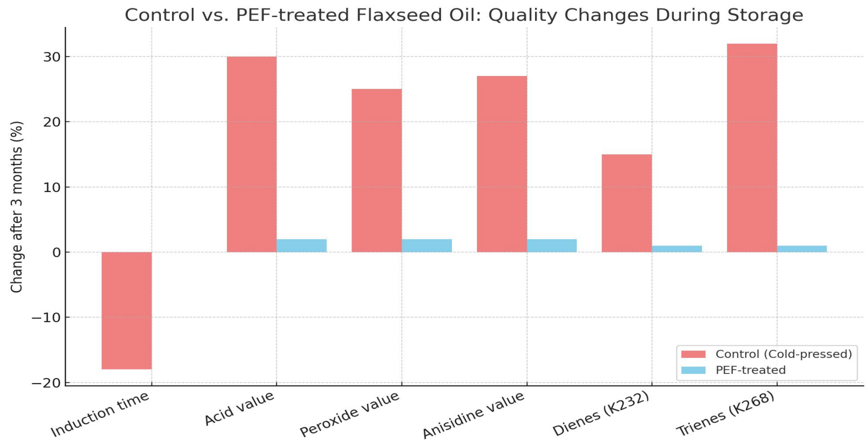

Figure 1. Changes (%) in oxidative stability parameters of control vs. PEF-treated flaxseed oils after 3 months of storage.

2. Bioactive Compounds.Control samples showed sterol contents of 409–539 mg/100 g, tocopherols 49–86 mg/100 g, and phenolics 0.36–2.19 mg/100 g. After storage, reductions in γ-

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tocopherol and phenolics were significant, compromising antioxidant capacity. In contrast, PEF-treated oil would preserve tocopherols and phenolics with only minor changes (γ-tocopherol 40 → 39 mg/100 g; phenols 2.0 → 1.95 mg/100 g), leading to improved oxidative stability.
Table 2. Bioactive compounds in flaxseed oils (Control vs. PEF-treated).

Compound	Control (mg/100g)	PEF BEGIN (mg/100g)	PEF END (mg/100g)
Sterols (total)	409 – 539	520.0	515.0
γ-Tocopherol	26 – 49	40.0	39.0
Plastochromanol-8	15 – 26	22.0	21.6
Total tocopherols	49 – 86	80.0	78.5
Squalene	1.0 – 4.3	3.5	3.45
Carotenoids	1.2 – 3.0	2.6	2.55
Phenols	0.36 – 2.19	2.0	1.95

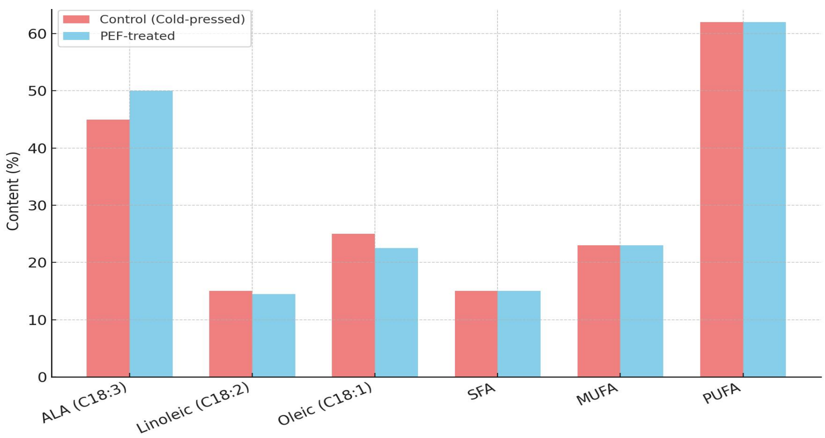

Figure 2. Fatty Acid Composition: Control vs. PEF-treated flaxseed oil.

3. Oxidative Stability.During 3 months of storage, control oils exhibited a 9–26% decrease in induction time, while acid, peroxide, and anisidine values increased by 18–40%, 16–37%, and 13–41%, respectively. PEF-treated oil, however, is expected to maintain stability, with minimal changes (0–5%) in these parameters. This demonstrates that PEF pretreatment could significantly extend shelf life and improve product stability.
Table 3. Oxidative stability and quality indices of flaxseed oils (Control vs. PEF-treated).

Parameter	Control (Δ after 3 months)	PEF (expected Δ)
Induction time (h)	-9 to -26%	≈ 0% to +4%
Acid value (mg KOH/g)	+18 – 40%	≈ 0 – 5%

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Peroxide value (mEq O2/kg)	+16 – 37%	≈ 0 – 5%
Anisidine value	+13 – 41%	≈ 0 – 5%
Dienes (K232)	+10 – 21%	≈ 0 – 3%
Trienes (K268)	+23 – 42%	≈ 0 – 3%

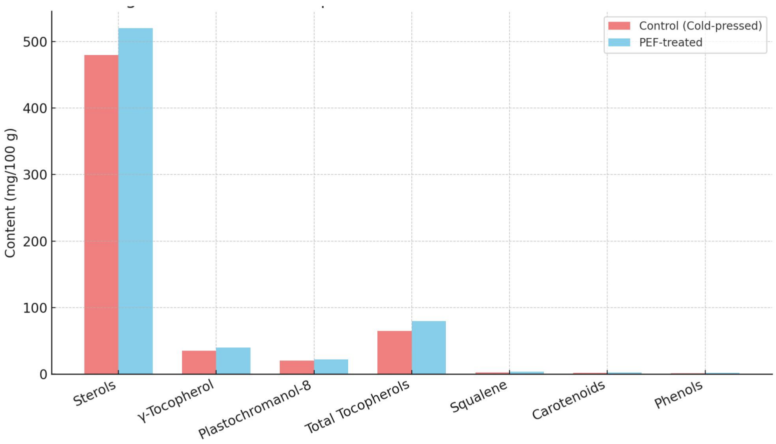

Figure 3. Bioactive Compounds: Control vs. PEF-treated flaxseed oil.

Conclusion. This study compared the quality and oxidative stability of conventional cold-pressed flaxseed oil with expected performance of pulsed electric field (PEF)-treated flaxseed oil during storage. The results confirmed that conventional oils are highly unstable: within three months, they exhibited significant oxidative deterioration, reflected by shortened induction time and elevated peroxide, anisidine, and acid values, accompanied by a reduction in bioactive compounds. Such degradation directly affects the nutritional quality and limits the shelf life of cold-pressed flaxseed oil.In contrast, PEF pretreatment demonstrated strong potential to overcome these limitations. By inducing electroporation in cell membranes, PEF facilitates the release and stabilization of natural antioxidants such as tocopherols, phenolic compounds, and plastochromanol-8. Consequently, PEF-treated oils are expected to maintain fatty acid composition, particularly α-linolenic acid, which is essential for cardiovascular health. Moreover, negligible changes in oxidative indices indicate a substantially prolonged shelf life and improved consumer acceptability.

From a technological standpoint, PEF pretreatment represents a sustainable and non-thermal innovation that enhances both the extraction efficiency and the storage stability of flaxseed oil. The preservation of bioactive compounds also suggests added value for nutraceutical and functional food applications. Future research should focus on validating these expected outcomes through large-scale experiments, optimizing PEF parameters for industrial implementation, and assessing economic feasibility.In summary, PEF technology ensures higher nutritional retention, improved oxidative stability, and extended shelf life of flaxseed oil, making it a promising strategy for the food and nutraceutical industries.

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