OPTIMIZATION OF FLAXSEED OIL RECOVERY: SOXHLET EXTRACTION COMBINED WITH PEF TECHNOLOGY

M.S. Narziyev[1]
[1]*Doctor of Technical Sciences (DSc), Bukhara Technical University, Uzbekistan,*
Sh.N. Ismatova[2]
[2]*PhD, Associate Professor, Bukhara Technical University, Uzbekistan,*
Sh.J. Yuldasheva[3]
[3]*Senior teacher Bukhara Technical University, Uzbekistan,*
M.R.Bakayeva[4]
[4]*Senior teacher. ZARMED Universiteti. Republic of Uzbekistan,*
N.N. Ismatova[5]
[5]*PhD student, Bukhara Technical University, Republic of Uzbekistan,*
E-mail: ismatova.nafisa@inbox.ru

Abstract. Flaxseed (Linum usitatissimum L.) oil is a valuable source of polyunsaturated fatty acids, particularly α-linolenic acid (18:3n-3), which plays an important role in human health. Therefore, increasing the efficiency of oil extraction from flaxseed is of significant interest. In this study, the oil yield of different flaxseed varieties (“Bahorikor”, “Baxmalskiy”, and “Qo‘ng‘irotskiy”) was investigated using the Soxhlet extraction method. Two experimental conditions were compared: untreated flaxseeds and flaxseeds pretreated with pulsed electric field (PEF). The results showed that for “Bahorikor” flaxseed, the Soxhlet method extracted 29.5% oil from untreated seeds, leaving 11.5% residual oil in the cake. When PEF pretreatment was applied, the extraction yield increased to 35.0%, while residual oil content in the cake decreased to 6.0%. Similar trends were observed for “Baxmalskiy” and “Qo‘ng‘irotskiy” varieties. These findings indicate that PEF pretreatment significantly enhances oil extraction efficiency from flaxseeds and reduces residual oil in press cake, offering promising potential for industrial applications.

Keywords: Flaxseed (Linum usitatissimum), process optimization, seed oil extraction, Pulsed Electric Field (PEF), Soxhlet extraction

Annotatsiya. Zig'ir urug'i (Linum usitatissimum L.) yog'i ko'p to'yinmagan yog'li kislotalarning qimmatli manbai, xususan, inson salomatligida muhim rol o'ynaydigan linolenik kislota (18:3n-3). Shuning uchun zig'ir urug'idan yog ' olish samaradorligini oshirish katta qiziqish uyg'otadi. Ushbu tadqiqotda Soxlet ekstraksiya usuli yordamida zig'ir urug'ining turli navlari ("Bahorikor", "Baxmalskiy" va "qo'shtirotskiy") ning moy hosildorligi o'rganildi.avhum. Zig'ir urug'i (Linum usitatissimum L.) yog'i ko'p to'yinmagan yog'li kislotalarning

ISSN 3030-3907

qimmatli manbai, xususan, inson salomatligida muhim rol o'ynaydigan linolenik kislota (18:3n-3). Shuning uchun zig'ir urug'idan yog ' olish samaradorligini oshirish katta qiziqish uyg'otadi. Ushbu tadqiqotda Soxlet ekstraksiya usuli yordamida zig'ir urug'ining turli navlari ("Bahorikor", "Baxmalskiy" va "qo'shtirotskiy") ning moy hosildorligi o'rganildi. Ikkita eksperimental sharoit taqqoslandi: ishlov berilmagan zig'ir urug'lari va impulsli elektr maydoni (PEF) bilan oldindan ishlangan zig'ir urug'lari. Natijalar shuni ko'rsatdiki," Bahorikor "zig'ir urug'i uchun Soxhlet usuli ishlov berilmagan urug'lardan 29,5% yog' ajratib, tortda 11,5% qoldiq yog ' qoldirgan. PEF oldindan ishlov berilganda, ekstraktsiya rentabelligi 35,0% gacha oshdi, pirojnoe tarkibidagi qoldiq yog ' miqdori 6,0% gacha kamaydi. "Baxmalskiy" va "qo'shirotskiy" navlarida ham shunga o'xshash tendentsiyalar kuzatildi.atijalar shuni ko'rsatdiki," Bahorikor "zig'ir urug'i uchun Soxhlet usuli ishlov berilmagan urug'lardan 29,5% yog' ajratib, tortda 11,5% qoldiq yog ' qoldirgan. PEF oldindan ishlov berilganda, ekstraktsiya rentabelligi 35,0% gacha oshdi, pirojnoe tarkibidagi qoldiq yog ' miqdori 6,0% gacha kamaydi. "Baxmalskiy" va "qo'shirotskiy" navlarida ham shunga o'xshash tendentsiyalar kuzatildi. Ushbu topilmalar shuni ko'rsatadiki, PEF oldindan ishlov berish zig'ir urug'idan yog ' olish samaradorligini sezilarli darajada oshiradi va press kekidagi qoldiq yog'ni kamaytiradi va sanoat dasturlari uchun istiqbolli imkoniyatlarni taklif etadi.

Kalit so'zlar: zig'ir urug'i (Linum usitatissimum), jarayonni optimallashtirish, urug ' yog'ini olish, impulsli elektr maydon (PEF), Soxlet qazib

Аннотация. Льняное масло (Linum usitatissimum L.) является ценным источником полиненасыщенных жирных кислот, в частности альфа-линоленовой кислоты (18:3n-3), которая играет важную роль в поддержании здоровья человека. Поэтому повышение эффективности извлечения масла из льняного семени представляет значительный интерес. В данном исследовании был исследован выход масла из различных сортов льняного семени (“Бахорикор”, “Бахмальский” и “Кунгиротский”) с использованием метода экстракции Сокслета. Было проведено сравнение двух экспериментальных условий: необработанного льняного семени и льняного семени, предварительно обработанного импульсным электрическим полем (PEP). Результаты показали, что при производстве льняного семени Бахорикор по методу Сокслета из необработанных семян было извлечено 29,5% масла, в то время как в жмыхе оставалось 11,5% остаточного масла. При предварительной обработке жмыхом выход экстракта увеличился до 35,0%, а остаточное содержание масла в жмыхе снизилось до 6,0%. Аналогичные тенденции наблюдались для сортов “Бахмальский” и

ISSN 3030-3907

“Кунгироцкий". Эти результаты свидетельствуют о том, что предварительная обработка PEF значительно повышает эффективность извлечения масла из семян льна и снижает остаточное содержание масла в жмыхе, что открывает многообещающие перспективы для промышленного применения.

Ключевые слова: Льняное семя (Linum usitatissimum), оптимизация процесса, экстракция масла из семян, импульсное электрическое поле (PEP), экстракция Сокслета

Introduction

Although essential polyunsaturated fatty acids are abundantly found in fish oils, their sources are considered limited from an ecological perspective. Therefore, in recent years, the demand for sustainable and efficient plant-based sources of fatty acids has been steadily increasing in the food and pharmaceutical industries. In this regard, flaxseed oil has gained special attention. Flaxseed (*Linum usitatissimum* L.) is a unique plant source, distinguished by its high content of α-linolenic acid (ALA, 18:3n-3) and other ω-3 fatty acids [Reshetko, 2018; Sarochanu, 2020].

In Uzbekistan, several flax cultivars are cultivated, including “Bahorikor” (41% oil content), “Baxmalskiy” (38%), and “Qo‘ng‘irotskiy” (36%). Due to their relatively high oil yield, these cultivars are considered promising raw materials for the oil and fat industry.

To efficiently extract flaxseed oil, it is necessary to apply high-performance, cost-effective, and environmentally safe technological methods. Among advanced approaches, the use of pulsed electric field (PEF) treatment has emerged as a relevant technique. This technology enhances the permeability of seed cell membranes, accelerates oil release, and reduces energy and processing time requirements [Reshetko, 2018].

Moreover, bioactive compounds derived from flaxseed — including lignans, polyphenols, and ω-3 fatty acids — have been shown to exert beneficial effects on human health. Their regular consumption helps regulate hormonal balance and contributes to the prevention of cancer, diabetes, and cardiovascular diseases [Sarochanu, 2020]. Therefore, flaxseed oil is considered not only a valuable food product but also an important raw material for the production of biologically active supplements.

However, the efficiency of flaxseed oil extraction depends on several factors, including the biological and physicochemical properties of the seeds, the type of solvent used, temperature, treatment duration, and the applied technology (pressing, solvent extraction, PEF, etc.). Consequently, evaluating the application

ISSN 3030-3907

of PEF technology for flaxseed oil extraction, along with its efficiency and economic advantages, remains a highly relevant scientific task.

MATERIALS

In this study, three flaxseed varieties were used — “Bahorikor”, “Baxmalskiy” , and “Qo‘ng‘irotskiy” . All seed samples were purchased from local suppliers in Uzbekistan: AGRO BUSINESS LLC and BUKHORO LABSA LLC. The seeds were delivered to the laboratory in sealed polyethylene packages of 700 g and 900 g, with batch codes indicated by the manufacturing companies.

Upon arrival, each package was registered and labeled with individual codes. Before processing, the seeds were cleaned from mechanical impurities and stored under controlled conditions at 4 ± 1 °C in a dry, dark environment to prevent moisture uptake.

For extraction experiments, the samples were ground using a Bosch MKM 6000/6003 household grinder (power rating 180 W). The particle size was adjusted to approximately 0.5–1.0 mm, ensuring improved solvent penetration into the cellular structure and more efficient oil recovery.

From the ground flaxseed, 5-20 g of sample was weighed and placed into an extraction thimble made of filter paper, which was inserted into a Soxhlet extractor. Extraction was performed for 6 hours using ether or petroleum ether as a solvent. During the process, oil dissolved in the solvent and was collected in the extraction flask.

After completion, the solvent was evaporated, and the flask containing the extracted oil was dried in an oven at 100–105 °C for 30 minutes. The flask was then cooled to room temperature in a desiccator and weighed.

The oil yield was calculated according to the following equation:

$$X(\%) = \frac{(m - m_1) \cdot 100}{m_2}$$

where:

- m – weight of the extraction thimble (g),
- m_1 – weight of the thimble with oil (g),
- m_2 – weight of the seed sample (g).

Oil Extraction

In this study, oil was extracted from flaxseed samples using the Soxhlet method. Three different solvents – petroleum ether, diethyl ether, and n-hexane – were employed for the extraction process. After extraction, the solvent was removed using a rotary evaporator, and the obtained oil was prepared for further analysis. The extracted oil was stored in amber-colored bottles and kept frozen until analysis. The oil obtained after Soxhlet extraction showed a pale yellow color.

ISSN 3030-3907

Soxhlet Extraction Method

The Soxhlet extraction technique was employed to obtain oil from flaxseed samples. This method involves a solid–liquid extraction process, where the sample is kept in continuous contact with the solvent, enhancing the transfer of oil into the solvent phase. Although simple and efficient, Soxhlet extraction requires long processing times and relatively large volumes of solvent, and prolonged heating at the solvent's boiling point may lead to thermal degradation of sensitive oil components.

In this study, the Soxhlet apparatus was used. Since stirring was not possible, the extraction process relied solely on continuous solvent cycling. After extraction, the solvents were removed by means of a rotary evaporator under reduced pressure (100 mbar) at 40 °C, and the obtained oils were stored in amber bottles at low temperature until analysis.

Oil Extraction with Pulsed Electric Field (PEF) Pre-Treatment

Samples of 3 flaxseed brands were subjected to oil extraction. Extraction was carried out using Soxhlet methodology with three different solvents (petroleum ether, diethyl ether, and n-hexane). Prior to extraction, seed portions were treated with a Pulsed Electric Field (PEF) pre-treatment in order to enhance cell membrane permeabilization and facilitate lipid release. The PEF parameters were as follows: seed portions were arranged in a 1 cm layer between parallel plate electrodes, and a voltage of U = 8 kV was applied across a d = 1 cm gap, corresponding to an electric field strength of E = 8 kV/cm. Each portion received n = 25 square pulses (τ = 20 μs pulse duration) at a repetition frequency of 1 Hz. Following treatment, samples were allowed to equilibrate at laboratory temperature for 10 min to minimize transient heating before grinding and Soxhlet extraction. Thermal effects were monitored during treatment using an infrared thermometer. The bulk temperature of the treated seeds did not increase by more than 2–3 °C under the applied conditions, confirming that the process operated in a non-thermal regime. After extraction, the obtained oil exhibited a pale yellow color. All extracts were concentrated on a rotary evaporator and stored in amber jars under freezing conditions until further analysis.

RESULTS AND DISCUSSION

Oil extraction from flaxseed samples primarily involves a mass transfer process, with efficiency strongly influenced by several key factors, including the choice of extraction method, the type of solvent employed, and the intrinsic characteristics of the sample. The selection of solvents is mainly determined by their polarity and their affinity for lipid components. One limitation of solvent-based extraction methods is the regulatory restrictions on residual solvent levels in

ISSN 3030-3907

oils, particularly when the extracted oil is intended as raw material for food or nutraceutical products. These limits are established by current legislation and may be further reduced in the future to ensure consumer safety. Additionally, prolonged exposure of flaxseed samples to solvents may lead to the oxidation of fatty acids, potentially affecting oil quality

Tables 3 present the oil yield obtained from samples of different flaxseed brands and trademarks. Each table summarizes the results for each trial and its replicate, indicating the extraction method used, the flaxseed sample, and whether a Pulsed Electric Field (PEF) pre-treatment was applied. Additionally, the charts provide key statistical parameters, including the mean value, standard deviation, and the minimum and maximum values obtained in each test, allowing for a comprehensive analysis and comparison across different brands.

Table 1.

Oil yield measured following extraction by the Soxhlet method with petroleum ether.

Flaxseed	Oil content (%)	Replicates	Soxhlet method		Difference (PEF – Soxhlet, %)
			Oil content (%)	PEF Oil (%)	
Bahorikor	41.3	1	29.60	35.0	+5.40
Baxmalskiy	38.1	2	26.60	30.48	+3.88
Qo‘ng‘irotskiy	36.2	3	24.97	28.6	+3.63
Mean	38.53	—	27.06	31.36	+4.30
SD	2.56	—	1.96	2.66	0.96
Upper range	41.3	—	29.60	35.0	+5.40
Lower range	36.2	—	24.97	28.6	+3.63

Table 2.

Oil yield (%) after Soxhlet extraction with diethyl ether.

Flaxseed	Oil content (%)	Replicates	Soxhlet method		Difference (PEF – Soxhlet, %)
			Oil content (%)	PEF Oil (%)	
Bahorikor	41.3	1	30.5	36.3	+5.8
Baxmalskiy	38.1	2	27.9	31.8	+3.9
Qo‘ng‘irotskiy	36.2	3	25.1	29.4	+4.3
Mean	38.53	—	27.83	32.5	+4.67
SD	2.55	—	2.71	3.47	0.96

ISSN 3030-3907

Upper range	41.3	—	30.5	36.3	+5.8
Lower range	36.2	—	25.1	29.4	+3.9

Table 3.

Oil yield (%) obtained through Soxhlet extraction with n-hexane.

Flaxseed	Oil content (%)	Replicates	Soxhlet method		Difference (PEF − Soxhlet, %)
			Oil content (%)	PEF Oil (%)	
Bahorikor	41.3	1	28.7	34.1	+5.4
Baxmalskiy	38.1	2	25.9	29.1	+3.2
Qo‘ng‘irotskiy	36.2	3	24.2	27.0	+2.8
Mean	38.53	—	26.27	30.07	+3.8
SD	2.55	—	2.25	3.63	1.37
Upper range	41.3	—	28.7	34.1	+5.4
Lower range	36.2	—	24.2	27.0	+2.8

The efficiency of oil extraction from flaxseed depends on the intrinsic oil content of the seeds and the extraction process. In this study, all samples were subjected to **Soxhlet extraction**, while the difference in oil yield was assessed based on **PEF (pulsed electric field) pre-treatment**.

The results indicate that PEF-treated seeds consistently showed higher oil yields compared to untreated seeds, even though the extraction method remained the same. For instance, using petroleum ether (Table 1), the Bahorikor variety yielded 29.60% oil without PEF and 35.0% after PEF treatment (+5.4%). Similarly, diethyl ether (Table 2) yielded 30.5% for untreated Bahorikor seeds and 36.3% for PEF-treated seeds (+5.8%), while n-hexane (Table 3) resulted in 28.7% without PEF and 34.1% with PEF (+5.4%).

Average values across all varieties confirm this trend: PEF treatment increased the mean oil yield by +3.8% to +4.67%, depending on the solvent used. This increase is attributed to the enhanced permeability of cell membranes caused by PEF, which facilitates solvent penetration and improves mass transfer, leading to higher oil recovery.

The data also highlight differences among flaxseed varieties. The Bahorikor variety consistently provided the highest oil yield, whereas Qo‘ng‘irotskiy produced the lowest. These differences reflect the intrinsic oil content of the seeds, varietal characteristics, and the environmental conditions where they were cultivated.

ISSN 3030-3907

In conclusion, Soxhlet extraction remains a highly efficient method for flaxseed oil recovery. The application of PEF pre-treatment further enhances oil yield by improving cell membrane permeability and mass transfer, optimizing the extraction process.

Conclusion

This study demonstrates that the efficiency of flaxseed oil extraction can be significantly enhanced through the application of Pulsed Electric Field (PEF) pre-treatment in combination with Soxhlet extraction. Across all tested varieties ("Bahorikor", "Baxmalskiy", and "Qo'ng'irotskiy"), PEF-treated seeds consistently yielded higher oil content compared to untreated seeds, regardless of the solvent used (petroleum ether, diethyl ether, or n-hexane). The increase in oil yield ranged from +3.8% to +4.67% on average, highlighting the effectiveness of PEF in enhancing cell membrane permeability and facilitating mass transfer.

Among the tested flaxseed varieties, Bahorikor consistently exhibited the highest oil yield, whereas Qo'ng'irotskiy yielded the lowest, reflecting intrinsic differences in seed oil content and varietal characteristics. In addition, diethyl ether showed slightly higher extraction efficiency in Soxhlet experiments compared to the other solvents, indicating the importance of solvent selection for optimal recovery.

Overall, Soxhlet extraction remains a reliable and efficient method for flaxseed oil recovery, while PEF pre-treatment provides a clear advantage in maximizing oil yield. These findings suggest that the combined use of Soxhlet extraction and PEF treatment offers promising potential for industrial-scale flaxseed oil production, ensuring higher efficiency and reduced residual oil in the press cake.

REFERENCES:

1. Ahsan, H., Ahad, A., & Siddiqui, W. A. (2015). A review of characterization of tocotrienols from plant oils and foods. Journal of Chemical Biology, 84 (2), 45- 59. http://dx.doi.org/10.1007/s12154-014-0127-8

2. Ismatova S.N. Prospects of the use of quinoa and amaranth for expanding of food reserve of poultry farming //Isabayev I.B., Ergasheva Kh.B.,Yuldasheva S.J. // Austrian Journal of Technical and Natural Sciences, 2020, Vol. 7-8, pp. 26-30.

4. Ismatova Sh.N. Prospects of the use of quinoa and amaranth for expanding of food reserve of poultry farming / Ismatova Sh.N., Isabaev I.B., Ergasheva X.B., Yuldasheva Sh.J.// Austrian journal of technical and natural sciences.Austria, No. 7-8. 2020. pp. 26-30

ISSN 3030-3907

5. Ismatova Sh.N. Alternative sources of raw materials for the production of feed products / Ismatova Sh.N., Isabaev I.B., Ergasheva H.B.// Universum: Technical sciences: scientific journal 2019. – No. 12(69). – pp.18-23.
6. Sharipov N.Z., Narziyev M.S., Yuldasheva Sh.J., Ismatova N.N., Functional Properties of the Processing Soybeans Products, Eurasian Research Bulletin, Volume 12|September, 2022, ISSN: 2795-7365, 50-54 pages, https://geniusjournals.org/index.php/erb/article/view/2222

ISSN 3030-3907