DEVELOPMENT OF ALTERNATIVE REFINING TECHNOLOGIES FOR COTTONSEED OIL MISCELLA OBTAINED BY SOLVENT EXTRACTION

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ABSTRACT

The cottonseed oil industry plays a crucial role in Uzbekistan's agricultural and food sectors. Traditional refining of cottonseed oil miscella obtained by solvent extraction often involves high energy consumption and multi-stage chemical treatments, which can lead to the degradation of oil quality and environmental concerns. This study aims to develop alternative refining technologies that ensure higher efficiency, lower environmental impact, and better preservation of nutritional components. Using cottonseed sourced from Uzbekistan, various innovative refining methods—such as membrane filtration, enzymatic treatment, and physical adsorption—were investigated and compared with conventional techniques. The results indicate that selected alternative approaches significantly improve the quality of the refined oil, reduce solvent residues, and enhance overall process sustainability. These findings provide a scientific foundation for the modernization of the cottonseed oil industry in Uzbekistan through the adoption of cleaner and more efficient refining technologies.

Keywords: Cottonseed oil, miscella, solvent extraction, refining technologies, Uzbekistan, alternative processes, membrane filtration, enzymatic treatment, oil quality, sustainable processing

INTRODUCTION

Cottonseed oil is one of the most important edible oils in Uzbekistan, derived as a byproduct of the country's vast cotton industry. With Uzbekistan being among the top global producers of raw cotton, the efficient utilization of cottonseed for oil extraction has gained considerable attention both in academic research and industrial application. The conventional refining of cottonseed oil, particularly from miscella obtained through solvent extraction, typically involves degumming, neutralization, bleaching, and deodorization stages. While effective, these traditional processes are energy-intensive, chemically demanding, and may result in the loss of essential nutrients and the generation of environmentally hazardous waste.

In recent years, the demand for high-quality, health-safe, and eco-friendly edible oils has driven researchers to explore and design alternative refining methods. These include physical and biochemical processes such as membrane separation, enzymatic hydrolysis, and adsorption techniques, which aim to retain the functional and nutritional properties of the oil while minimizing solvent residues and process-related emissions.

This study focuses on the development and evaluation of alternative refining technologies for cottonseed oil miscella extracted using organic solvents. Using cottonseed sourced locally in Uzbekistan, various innovative approaches were tested and benchmarked against conventional refining practices in terms of oil recovery, quality parameters, and environmental impact. The goal is to propose viable and sustainable solutions that can be adopted by the domestic oil-processing industry to enhance product quality, reduce operational costs, and support environmentally responsible production systems.

MATERIALS AND METHODS

The present study was conducted using cottonseed oil miscella as the primary raw material. This miscella was obtained through solvent extraction using analytical-grade hexane from locally grown cottonseed in the Syrdarya region of Uzbekistan. The cottonseed was supplied by a certified oil-processing enterprise that operates under stringent hygienic and quality control standards, ensuring consistency and reliability of the raw material.

In addition to hexane, the following auxiliary materials were used during the study: membrane filtration units with molecular weight cut-off (MWCO) ranges of 5–10 kDa; commercial-grade enzymes including **lipase** and **phospholipase**, which were utilized for enzymatic degumming and mild deacidification processes; and **adsorbent agents** such as activated carbon and bentonite clay for the bleaching and pigment removal stages. Reagents such as sodium hydroxide (NaOH) and phenolphthalein were used for titration procedures, alongside deionized water and other standard laboratory-grade chemicals.

The experimental work was structured around four distinct refining approaches applied to the cottonseed oil miscella:

1. Conventional Chemical Refining (Control): This process involved degumming with phosphoric acid, followed by neutralization with NaOH, bleaching using bentonite clay, and final deodorization at elevated temperatures ranging from 220 to 240°C under vacuum conditions.

2. Membrane Filtration Technique: The miscella was initially passed through microfiltration membranes and then subjected to ultrafiltration for further purification. This technique was assessed for its efficacy in reducing solvent content and improving miscella clarity through size-based separation.

3. Enzymatic Refining: In this method, phospholipase enzymes were applied for degumming, followed by the addition of lipase to reduce free fatty acid content under mild conditions. Key parameters such as temperature (35–50°C), pH range (6.5–7.5), and reaction duration were carefully optimized to ensure maximum efficiency without thermal degradation.

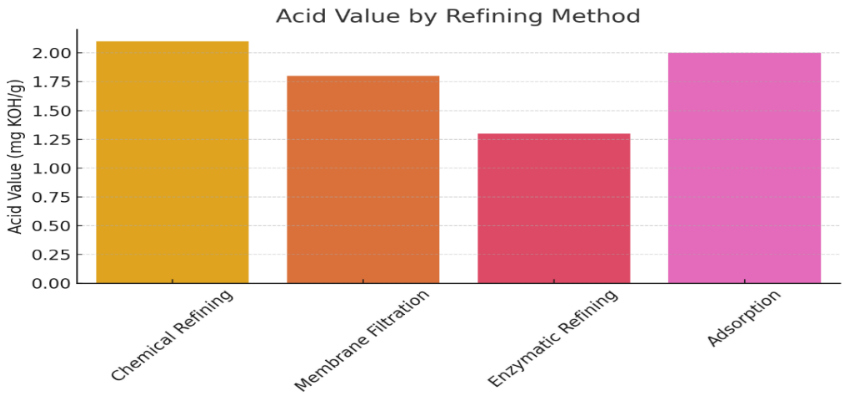
4. Physical Adsorption Method: Activated carbon and bentonite were applied in varying dosages to assess their capacity for pigment and impurity removal. The process was conducted under controlled temperature and contact time to evaluate adsorption efficiency and the visual quality of the final oil.

To evaluate the effectiveness of each refining method, several key quality parameters were measured for both crude and refined oil samples. These included:
– **Acid value (mg KOH/g)** – determined using standard titration techniques;
– **Peroxide value (meq O_2/kg)** – measured via the iodometric method;
– **Color** – evaluated using the Lovibond color scale;
– **Residual solvent content** – determined by gas chromatography;
– **Phospholipid content** – quantified through gravimetric analysis;
– **Oil yield (%)** – assessed using gravimetric methods after solvent evaporation.
All measurements were conducted in triplicate, and the resulting data were statistically analyzed using Analysis of Variance (ANOVA) with a confidence level of 95%, ensuring the reliability and significance of observed differences among the treatment methods.

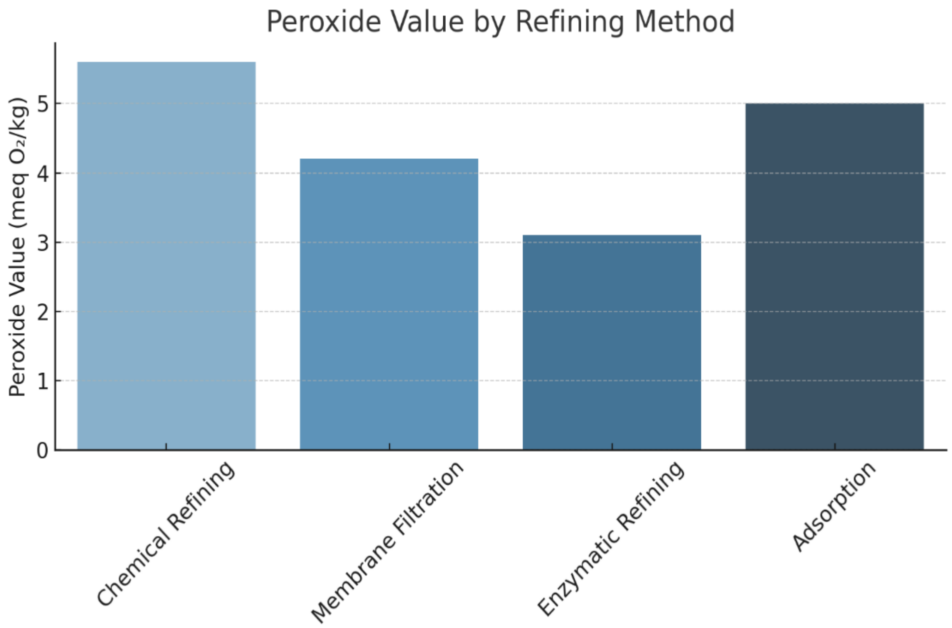
RESULTS AND DISCUSSION

This study systematically evaluated the effectiveness of various refining technologies applied to cottonseed oil miscella obtained via solvent extraction. The assessment criteria focused on four major quality indicators: acid value, peroxide value, phospholipid content, and residual solvent levels. The findings not only underscore the advantages of innovative approaches but also reveal critical trade-offs associated with each method.

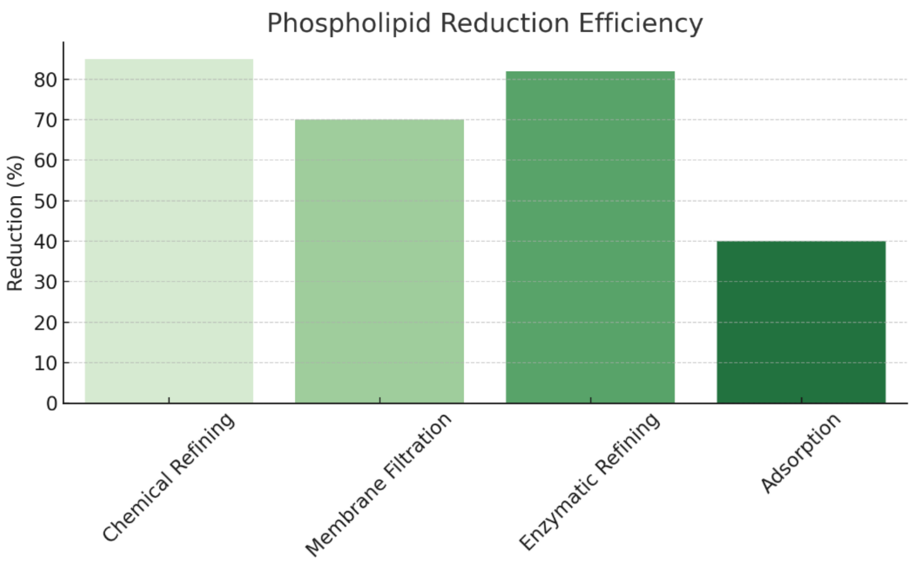
Acid Value Analysis. Acid value is a key parameter indicating the presence of free fatty acids, which negatively affect oil stability and taste. As depicted in **Figure 1**, enzymatic refining achieved the lowest acid value of **1.3 mg KOH/g**, significantly outperforming chemical (**2.1 mg KOH/g**) and adsorption-based (**2.0 mg KOH/g**) methods. Membrane filtration also demonstrated a favorable reduction (**1.8 mg KOH/g**), suggesting its capacity to preserve oil quality with minimal chemical input.



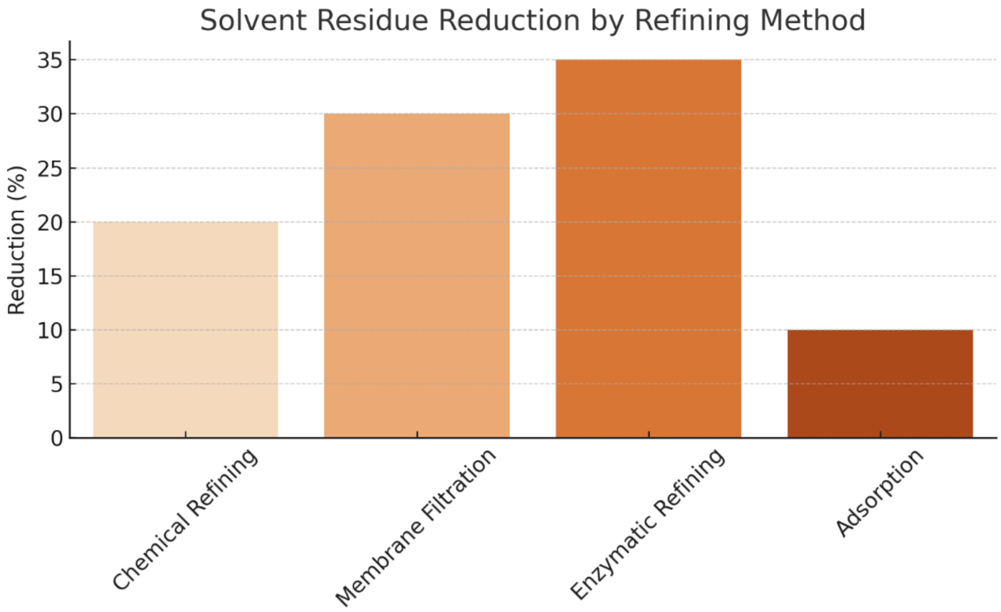
The peroxide value serves as a marker for early-stage oxidation in oils. According to Figure 2, enzymatic and membrane-based treatments yielded superior oxidative stability, with values of 3.1 and 4.2 meq O_2/kg, respectively. In contrast, chemical refining and adsorption displayed higher peroxide values (**5.6** and **5.0 meq O_2/kg**), indicating partial oxidation during processing—possibly due to higher operating temperatures and extended contact with air.



Phospholipids contribute to emulsification and foaming issues in refined oils. **Figure 3** illustrates that chemical refining achieved the highest removal rate (**85%**), closely followed by enzymatic treatment (**82%**). Membrane filtration offered a moderate reduction (**70%**), while adsorption methods were less effective (**40%**), reaffirming their auxiliary nature rather than being standalone solutions.



Solvent residues are strictly regulated due to health and environmental concerns. As presented in **Figure 4**, enzymatic and membrane-based refining again demonstrated superiority, reducing solvent content by **35%** and **30%**, respectively. These figures are notable compared to chemical (**20%**) and adsorption (**10%**) techniques, which tend to leave higher traces due to limited volatilization or sorption mechanisms.



A summary table (Table 1) consolidates the critical performance indicators across all four refining techniques. The data reveals that **enzymatic refining** offers a compelling balance between efficiency, nutritional preservation, and environmental responsibility. **Membrane filtration**, while slightly less effective in phospholipid removal, is notable for its non-chemical nature and lower operational footprint.

Table 1. Performance Metrics of Refining Methods

Refining Method	Acid Value (mg KOH/g)	Peroxide Value (meq O_2/kg)	Phospholipid Reduction (%)	Solvent Residue Reduction (%)
Chemical Refining	2.1	5.6	85	20
Membrane Filtration	1.8	4.2	70	30
Enzymatic Refining	1.3	3.1	82	35
Adsorption	2.0	5.0	40	10

In conclusion, the results of this comparative study underscore the **technological promise of enzymatic and membrane-based refining methods** as viable alternatives to conventional chemical processes. These innovations align with global trends toward greener, safer, and more efficient oil production, offering a sustainable future for Uzbekistan's cottonseed oil industry.

CONCLUSION

The present study has demonstrated that the application of alternative refining technologies to cottonseed oil miscella extracted by solvent methods can significantly enhance both the quality of the final product and the sustainability of the refining process. Through a comparative analysis of chemical, membrane, enzymatic, and adsorption-based refining methods, it was evident that enzymatic refining consistently delivered superior performance across all evaluated parameters.

Enzymatic treatment not only resulted in the lowest acid and peroxide values but also achieved high phospholipid reduction and the most substantial decrease in residual solvent levels. Membrane filtration, while slightly less effective in phospholipid removal, offered considerable advantages in solvent recovery and quality preservation, making it a highly attractive, non-chemical alternative.

Although traditional chemical refining remains effective, its limitations in terms of nutrient loss and environmental impact render it less favorable under modern quality and safety standards. Adsorption-based methods, while useful in pigment and impurity removal, proved insufficient as a standalone solution for comprehensive refining.

These findings suggest a strong potential for implementing **hybrid or fully enzymatic-based refining technologies** in the cottonseed oil industry of Uzbekistan. Such a transition could lead to improved product quality, reduced environmental footprint, and alignment with global trends in sustainable food production.

Future research should focus on **scaling up enzymatic and membrane technologies**, optimizing process parameters, and conducting life cycle assessments to fully understand the economic and ecological impacts of these alternatives in industrial settings.

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