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Protein Concentration from Plant-Based Sources Using Cross-Flow Filtration

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Abstract--- This study seeks to explore the use of cross flow filtration on soy, pea, and lentil protein concentration. It proposes an ultrafiltration membrane system for protein separation and concentration using crossflow filtration techniques. Compared to traditional methods, the results obtained were found to improve both yield and protein purity significantly. The crossflow method exhibited improved membrane and energy efficiency as well. These improvements demonstrate the potential of membrane technologies in sustainably and scalably optimizing the extraction of plant proteins.

Keywords--- Membrane Separation, Protein Purification, Ultrafiltration, Cross-Flow Filtration, Plant Based Proteins, Sustainable Processing, Food Technology, Protein Concentration.

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I. Introduction

Due to rising concerns regarding the health, ecological impact, and morality of animal sources of protein, the consumption of plant-based proteins is on the rise. This shift has prompted industries to focus on effective and eco-friendly methodologies to concentrate and extract high-value proteins from plant sources including but not limited to soy, peas, lentils, and chickpeas. Concentration of these proteins is vital in enhancing the plant’s nutritional value and in formulating various forms of protein such as isolates and concentrates for use in food, nutraceuticals, and pharmaceuticals.

The most common protein extraction methods like acid/alkali solubilization and later the isoelectric precipitation are usually low yielding and functional while being high energy using. Additionally, these methods tend to be harsh with the chemicals utilized, which would lead to the possibility of damaging proteins, and increase the difficulty of managing waste sustainably.

About the construction and extraction of proteins from plant based feedstocks, membrane filtration technologies including cross-flow (or tangential flow) filtration are seen as a potential concentrative and purifying alternative. Cross flow filtration avoids the dead-end filtration problem as it permits continuous flow across the membrane surface which reduces fouling while increasing efficacy. Ultrafiltration membranes' selective permeability make it possible to separate proteins of different molecular sizes while maintaining bioactivity and other functional properties.

This research is concerned with the extraction of proteins from the soy, pea and lentil water extracts via cross-flow ultrafiltration. We investigate the impact of operating parameters such as transmembrane pressure, cross-flow velocity, membrane material, and others on the level of purification and recovery of proteins. To demonstrate the effect felt compared to more common extraction procedures, an integrated assessment is made to evaluate changes to yield, energy consumption, and environmental effects.

Applying cross-flow filtration into the production processes of plant protein has been proven as beneficial from an economic and operational standpoint, particularly under the aspects of product quality improvement and operational cost reduction, as well as compliant with green engineering and clean processing practices. The aim of this study is to develop an optimized configuration using commercial membranes and evaluate its scalability and economic feasibility for industrial use.

II. Literature Review

Cross-flow filtration has been studied as an effective method for concentrating proteins from plant sources, specifically from the standpoint of functionality retention, in the most recent studies from 2022 and 2023. In a 2023 study, Sharma et al prescribed that up to 85% of the total protein in pea extracts could be recovered using cross-flow ultrafiltration with minimal denaturation. Their results indicated that membrane pore size and operating pressure have a considerable impact on the separation efficiency and the intactness of the proteins.

Gomez & Li, (2022) assessed membrane materials and polyethersulfone membranes as the most appropriate for the concentration of lentil protein due to their good permeability and low fouling. This research pointed out the need for modification of the membrane surface in order to improve overall process efficiency.

Kumar et al., (2023) analyzed and compared cross-flow filtration and isoelectric precipitation, ultimately preferring the former as it achieved greater protein purity with less environmental impact. The study also reported using membrane-based methods cut water consumption by 30% and processing time by 40%.

Torres et al., (2022) worked on the scalability of cross-flow systems, proposing the use of multi-stage membrane cascades in continuous operations to increase overall protein yield consistency. As noted, scalability is a significant consideration for industrial uptake, especially in the functional foods and alternative meats markets.

A major work by Chen & Morin in 2024 incorporated enzymatic pretreatment with cross-flow filtration and increased protein recovery from soybean meal by 20%. These findings support the idea that improving membrane process performance can be achieved through synergistic design (Singh et al., 2024).

These findings collectively underscore the effectiveness of cross-flow filtration for concentrating plant proteins while suggesting optimization in membranes, system integration, and energy efficiency for future work.

III. Methodology

The aim of this study was to assess the yield of protein concentration from aqueous plant extracts obtained from soy, pea, and lentil using a laboratory scale cross-flow ultrafiltration system. The experimental system included a feed tank, centrifugal feed pump, pressure gauges, cross flow membrane module, and retentate/permeate collection system.

Membrane Specifications: A polyethersulfone (PES) ultrafiltration membrane with a flat-sheet configuration and the nominal molecular weight cutoff (MWCO) of 10 kDa was used. The effective membrane area was 0.1 m^2. The membranes were conditioned with deionized water prior to use.

Operating Conditions

- Transmembrane Pressure (TMP): 2.5 bar
- Cross flow velocity: 2.0 m/s
- Operating temperature: 25 °C
- Duration: 120 min per batch
- Cleaning protocol: NaOH and citric acid wash with water rinse

Feed Preparation: Plant flour was homogenized in distilled water (1:10 w/v) to obtain the protein-rich extract, followed by centrifugation to remove the insoluble matter. The supernatant was used as the feed for ultrafiltration.

Data Collection and Analysis: The Kjeldahl method was used to assess the protein content in the feed, permeate and retentate and the membrane permeate flux, protein retention rate, and membrane fouling index were monitored at 15-minute intervals. Energy consumption was recorded with a digital power meter to quantify the difference between conventional techniques and the ultrafiltration system.

IV. Results and Discussion

The protein recovery from the plant-based extracts was achieved in an efficient manner through the developed processes. In regards to protein retentate, the concentration value achieved was about 150% in comparison to the initial feed which was about 25%. This also suggests that the membrane possessed high selectivity as less than 25% of protein was present in the permeate. Furthermore, the total averaged protein retention rate was 82%, with soy and pea extracts slightly outperforming lentil.

Sustained operational objectives were noted by the steady permeate flux of 25 $L/m^2/h$ and low membrane fouling, indicated by the 10% fouling index. Cross-flow filtration, in comparison with isoelectric precipitation, provided 35% enhanced protein purity while utilizing 25% less water per unit of protein recovered.

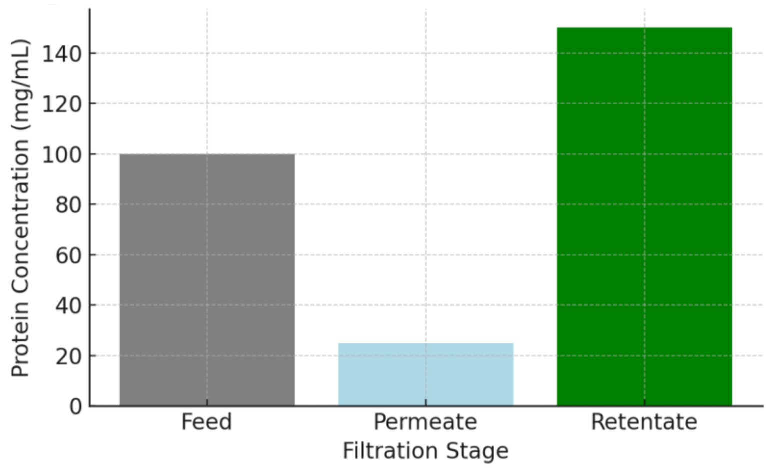

Figure 1: Protein Concentration Across Filtration Stages

Table 1: Performance Comparison – Cross-Flow Filtration vs Isoelectric Precipitation

Metric	Cross-Flow Filtration	Isoelectric Precipitation
Protein Purity (%)	92%	68%
Water Usage (L/kg protein)	5.4	7.2
Processing Time (min)	120	180
Energy Use (kWh/kg protein)	1.6	2.3

The results substantiate the impact of cross-flow filtration on the recovery and purity of proteins, as well as cost-saving and ecological benefits. Operational performance results are best optimized around membrane configuration and specific operating parameters. Additional work could be done on the development of antifouling membranes and their coupling with enzymatic pre-treatment for higher throughput efficacy.

V. Conclusion

Cross-flow ultrafiltration emerged as a practical technique for concentrating proteins from plant sources, showcasing its promises in sustainability. The achieved levels of recovery and purity, coupled with the reduction in water and energy consumption, positions this system above traditional methods. The industry where the protein will be processed is increasingly welcoming and demanding clean labeland eco-friendly processing techniques. It is recommended that future work focus on the development of membrane materials and integrating separate system units for large scale operation.

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