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Development of a vegan cooking cream prototype from faba beans with a high protein content

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Popular Science Summary

In response to the growing global demand for sustainable, nutritious, and plant-based food sources, this thesis explores the potential of faba beans (*Vicia faba* L.) as an alternative protein source. Faba beans are rich in protein, comprising 26 to 33 percent of their composition, and offer a well-balanced amino acid profile along with bioactive peptides that provide antioxidant, antidiabetic, and anti-inflammatory benefits. This positions faba beans as a viable substitute for animal-derived proteins, suitable for individuals with common allergies such as soy and nuts. This thesis, conducted in collaboration with The Green Dairy (TGD), a plant-based dairy company, aims to develop a plant-based cooking cream utilizing faba beans.

Membrane ultrafiltration was evaluated for concentrating proteins in the faba bean base, assessing the scaling up potential to industrial-sized membrane elements. A parameter study determined the optimal crossflow velocity of 0.12 m/s and transmembrane pressure of 0.65 bar for efficient protein retention (89-91 %) by the 5000 Da ultrafiltration membrane. A concentration study was then conducted, increasing the protein content of the faba base from 3.4 % to 7.6 % through removal of 30 litres of permeate from a starting volume of 45 litres.

Multiple sample recipes with varying faba base and fat contents were formulated for the plant-based cooking cream prototype. Proximate analysis revealed protein contents ranging from 3.4-4.8%. Oil droplet size measurements and stability tests indicated stable emulsions. The prototypes exhibited comparable characteristics to commercial cooking creams, offering a sustainable and nutritious alternative with the added benefit of a favourable plant-based protein profile.

The findings of this research highlight the nutritional and environmental advantages of faba beans, underscoring their potential to contribute significantly to the plant-based food industry and sustainable agriculture. The developed product aligns with TGD's mission to promote healthy, sustainable, and nutritious food alternatives, showcasing faba beans as a key component in future food systems.

Abstract

As interest in plant-based diets continues to grow, there is rising demand for tasty and nutritious alternatives to dairy products like cooking cream. This master's thesis explored creating a vegan cooking cream high in protein by utilizing faba beans (*Vicia faba* L.). Faba beans are an excellent source of plant protein, containing 26-33 % protein by weight with a favourable amino acid profile. They are also an environmentally sustainable crop, able to fix atmospheric nitrogen through symbiotic associations with nitrogen-fixing bacteria, reducing the need for synthetic nitrogen fertilizers and associated greenhouse gas emissions.

The research first concentrated the proteins from the faba bean base using membrane ultrafiltration. A parameter study determined the optimal crossflow velocity of 0.12 m/s and transmembrane pressure of 0.65 bar. The optimal settings retained 89-91 % of the proteins, increasing the protein content from 3.4 % to 7.6 %. This concentrated faba protein base was then used to formulate vegan cooking cream prototypes.

Multiple recipes were developed with varying amounts of the concentrated faba base and rapeseed oil. Proximate analysis revealed protein levels ranging from 3.4-4.8 % in the prototypes, with higher protein and fat content corresponding to increased viscosity. Oil droplet size measurements and stability tests indicated that the vegan cooking cream prototypes formed stable emulsions.

Overall, the faba bean-based cooking creams provided a good source of plant protein while avoiding the environmental impacts of dairy production. By harnessing faba beans' nutritional benefits and sustainable cultivation, this vegan alternative offers an appealing option for consumers seeking plant-based, eco-friendly products.

List of Abbreviations

UF	Ultra Filtration
TGD	The Green Dairy
TS	Total Solids or Dry Weight
CFV	Cross Flow Velocity
TMP	Trans Membrane Pressure
PWF	Pure Water Flux
MWCO	Molecular Weight Cut Off
VR	Volume Reduction
HPH	High Pressure Homogenisation

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1. Introduction

In recent years, the demand for sustainable, plant-based, and nutritious food sources has intensified, driven by a growing global population and heightened awareness of environmental and health issues [1]. This has led to a significant interest in plant-based diets and the exploration of alternative protein sources that can serve as viable substitutes for animal-derived products. Among these, faba beans (*Vicia faba* L.), also known as broad beans or fava beans, have emerged as a promising candidate due to their high protein content, nutritional benefits, and environmental sustainability [2].

Faba beans are recognized for their rich protein composition, containing 26 to 33 percent protein, which positions them as a valuable alternative to meat and dairy sources [2]. Their protein quality is further enhanced by a well-balanced amino acid profile and the presence of bioactive peptides with health-enhancing properties, including antioxidant, antidiabetic, and anti-inflammatory effects [2-5]. This makes faba beans not only a source of essential nutrients but also a potential functional food that can contribute to improved health outcomes [2, 6-8]. Moreover, the absence of common allergies such as soy and nuts make faba beans an attractive option for individuals with dietary restrictions or preferences.

Faba beans also provide substantial environmental benefits. As leguminous plants, they can fix atmospheric nitrogen through symbiotic relationships with nitrogen-fixing bacteria, reducing reliance on synthetic nitrogen fertilizers and lowering associated greenhouse gas emissions. [9]. Additionally, faba beans require relatively low inputs of water and energy compared to many other crops, making them a sustainable option for agricultural production in diverse ecosystems [9-11]. Furthermore, the cultivation of faba beans can contribute to soil health and biodiversity, as their deep root systems improve soil structure and nutrient cycling while providing habitat for beneficial soil organisms [9-11]. By harnessing the environmental benefits of faba beans, the development of the plant-based cooking cream aligns with the requirement to curate food systems that are both nourishing and regenerative for the planet.

The utilization of faba beans corresponds with the principles of the circular economy by potentially reducing food waste. They can be cultivated in a variety of soil types and climates, which minimizes the need for importing other less sustainable ingredients (field pea, dekeko and lentil) [9-11]. The entirety of the plant can be used, the beans for the cream base and the remaining biomass for animal feed or as a natural fertilizer, thus minimizing waste [9]. This approach maximizes the utilization of the agricultural product and contributes to a more sustainable food production system where resources are utilized efficiently and responsible.

As a collaborative effort with The Green Dairy (TGD), a plant-based dairy company, the aim for this project was to create a product that aligns with the company's mission to develop healthy, delicious, and sustainable food products [12]. The successful development of an improved plant-based cooking cream does not only contribute to a more palatable and eco-friendly option but has also direct benefits for The Green Dairy by expanding their product portfolio and meeting consumer demand for high-quality plant-based alternatives.

2. Objectives

This work aims to develop a vegan cooking cream (prototype) from faba beans with a high protein content.

The specific objectives:

- Evaluating membrane ultrafiltration for protein concentration in the faba base by assessing the scaling up of the process to industrial sized membrane elements.
- Develop multiple sample recipes with different faba base (ultra-filtrated) and fat contents for a plant-based cooking cream prototype, and conduct a proximate analysis, viscosity, and oil droplet size measurements on the sample recipes.
- Compare the characteristics of the sample recipes with commercially available cooking creams.

3. Theoretical background

3.1 Raw materials

The faba bean base serves as the primary material in all experimental work. The base was acquired in sealed five litre bags and stored under refrigeration conditions at 4 °C. Additional components utilized in the formulation process were rapeseed oil (100030309, oil AkoPlanet RSO 100-17 bulk), emulsifier E472e (97-100027403Panodan M2020 R), and stabilizer Xanthan E415 (97-100027352 Keltrol AP). They were also supplied by TGD and stored at room temperature. Lastly, tap water (Sweden, Lund, Lund University, Food department pilot hall) was added during the formulation process .

3.1.1 Faba bean

The faba bean (*Vicia faba* L.) is an ancient legume cultivated globally for its nutritional value and agronomic importance. Traditionally utilized as a primary protein source, it has a rich fibre content and high-quality protein with balanced essential amino acids. Faba beans aid agriculture through nitrogen fixation, reducing fertilizer use. However, they are sensitive to water scarcity and other abiotic stresses. Despite being Europe's third largest grain legume, global acreage has declined due to challenges like waterlogging, moisture stress, and poor cultural practices. The yearly production of faba beans, on average, is over 4.5 million tonnes [13].

Faba beans are highly nutritious, offering significant health benefits. They are an excellent source of plant-based proteins, providing 26-33% protein by dry weight [2]. The protein quality is high, containing all the essential amino acids, with particularly high levels of lysine (44.8-74.8 mg/g protein) and leucine (50.8-72.1 mg/g protein) [2]. In addition to proteins, faba beans are rich in complex carbohydrates, including starch and dietary fibre [3]. The fibre content promotes healthy digestion and may help reduce the risk of chronic diseases such as heart disease and type 2 diabetes [3, 4]. Faba beans are also a good source of several essential vitamins and minerals, including folate, iron, phosphorus, and magnesium [2, 3].

One of the key nutritional advantages of faba beans is their low glycaemic index [5]. This means they do not cause rapid spikes in blood sugar levels, making them a suitable choice for individuals with diabetes or those looking to maintain stable blood glucose levels [5]. Additionally, faba beans contain bioactive compounds such as phenolic acids and flavonoids, which have been associated with antioxidant and anti-inflammatory properties [5]. Despite their many nutritional benefits, faba beans also contain some antinutritional factors, such as tannins and lectins, which can interfere with nutrient uptake [14, 15]. However, these compounds can be reduced or eliminated through proper processing methods, such as soaking, cooking, or fermentation [4, 15].

Vicine and convicine are pyrimidine glycosidic alkaloids present in faba beans. These compounds are of particular concern as they can cause favism, a potentially life-threatening hemolytic condition, in individuals with glucose-6-phosphate dehydrogenase (G6PD) deficiency [16-18]. Favism is triggered by the hydrolysis of vicine and convicine, releasing their aglycones divicine and isouramil, which can lead to the breakdown of red blood cells in G6PD-deficient individuals [16-18]. G6PD deficiency is the most common enzymatic disorder worldwide, affecting over 400 million people, making vicine and convicine a significant antinutritional factor limiting the consumption of faba beans [16-18].

Faba beans have a long history of being use as a food crop, and their nutritional profile makes them a valuable ingredient in a variety of food products. One application is the processing of faba beans into flour, which can then be used as a gluten-free alternative to wheat flour in baked goods [15]. Studies have shown that faba bean flour can be successfully incorporated into breads and pasta, often improving the nutritional value and textural properties compared to wheat-based products [15, 19]. Additionally, the high protein and fibre content of faba bean flour makes it a suitable ingredient for developing functional foods and improving the nutritional profile of processed foods [15].

Faba beans gained significant attention as a sustainable and environmentally friendly crop due to their unique attributes. They possess the ability to fix atmospheric nitrogen through symbiotic associations with rhizobia, reducing the need for synthetic nitrogen fertilizers and associated greenhouse gas emissions [9]. Additionally, faba beans exhibit a lower carbon footprint compared to animal-based protein sources, making them a viable alternative for sustainable food systems [10]. Research has demonstrated the ecological services provided by faba beans, including improved soil fertility, reduced soil erosion, and enhanced biodiversity [9].

Furthermore, the substitution of imported soybean with locally sourced faba bean in feed and food formulations can confer significant environmental benefits by reducing the carbon footprint associated with soybean transportation, mitigating the impacts of deforestation and habitat loss driven by soybean cultivation in ecologically sensitive regions like the Amazon rainforest and the biodiverse Cerrados in Brazil [9]. The cultivation of faba beans aligns with the principles of sustainable intensification, enabling increased food production while minimizing environmental impacts and promoting biodiversity conservation [11].

The faba bean base used during this research was of the variety Gloria and was provided by The Green Dairy (TGD) located in Karlshamn, Sweden [20]. TGD purchased the faba beans from a company called Kalmar-Ölands Trädgårdsprodukter [20]. Figure 1 shows the flowchart to produce the faba base, an extract obtained from faba beans.

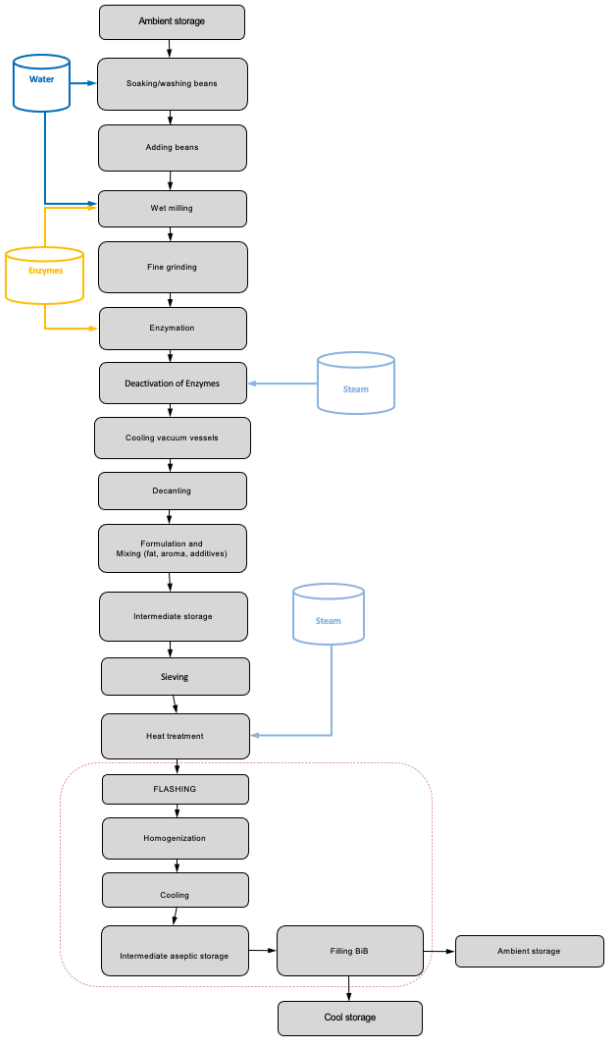

Figure 1. *The flowchart of the faba base production from The Green Dairy.*

3.1.2 Rapeseed oil

Rapeseed oil is one of the most widely produced and consumed vegetable oils globally. It ranks third in global vegetable oil consumption after palm oil and soybean oil . In 2017, the global rapeseed harvest reached 76.2 million tons [21]. It is rich in monounsaturated fatty acids, primarily oleic acid, which contributes to its oxidative stability and high smoke point, making it suitable for cooking applications [22]. Additionally, it contains a favourable amount of omega-6 fatty acids, known for their potential health benefits [22]. Studies show that the presence of phytosterols in rapeseed oil exhibit anti-inflammatory, anti-microbial, anti-carsinogenic, and cholesterol-lowering effects [23, 24]. Furthermore, the neutral flavour profile of rapeseed oil allows for versatility in flavouring and seasoning [25].

3.1.3 Emulsifier E472e

E472e, also known as DATEM (Diacetyl Tartaric Acid Esters of Mono- and Diglycerides), is a widely used emulsifier in the food industry. As an emulsifier, it plays a crucial role in stabilizing emulsions and improving the texture, appearance, and shelf-life of various food products [26]. DATEM is a mixed ester of glycerin, where one or more hydroxyl groups are esterified by diacetyl tartaric acid and fatty acids [26].

3.1.4 Stabilizer Xanthan E415

Xanthan gum (E415) is a widely used polysaccharide stabilizer and thickening agent in the food industry. It is an anionic hydrocolloid produced by aerobic fermentation of the bacteria *Xanthomonas campestris* [27]. Xanthan gum is highly stable both to salt and across a wide pH and temperature range [28]. When combined with other hydrocolloids like guar gum or locust bean gum, xanthan gum acts as an effective stabilizer in frozen desserts, sherbets, and milk shakes by preventing ice crystal growth [28]. Its ability to increase viscosity, elasticity, and create a smooth texture makes xanthan gum advantageous for various food formulations requiring thickening, stabilization, suspension, and emulsification [27].

3.2 Membrane filtration

Membrane filtration is a widely used separation technique that utilizes semi-permeable membranes to selectively remove components from liquid streams [29]. Its efficacy is determined by two key parameters: productivity, measured by flux, and selectivity, determined by retention or separation factor [29]. The process operates by applying a driving force (pressure) to facilitate the permeation of certain components through the membrane's pores, while retaining the rest of the components [30]. It offers several advantages, including low energy consumption, high selectivity, and gentle product treatment [31].

Membrane filtration encompasses various techniques that selectively separate components based on their size and molecular weight. The primary types include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO), each characterized by distinct pore sizes and separation capabilities [30]. This project utilized UF as its main method, so the focus will be on that type in particular. UF membranes consist of pore sizes ranging from 0.002 to 0.1 microns, enabling the retention of macromolecules (300–500,000 Daltons), while allowing smaller molecules to permeate (Figure 2) [30]. This process is driven by a pressure gradient across the membrane, known as the transmembrane pressure (TMP) [32, 33]. The selectivity and efficiency of UF membranes are influenced by factors such as pore size distribution and fouling [30]. UF has a wide range of applications in the food industry: dairy, beverage, fish and poultry processing, and gelatine industry [31].

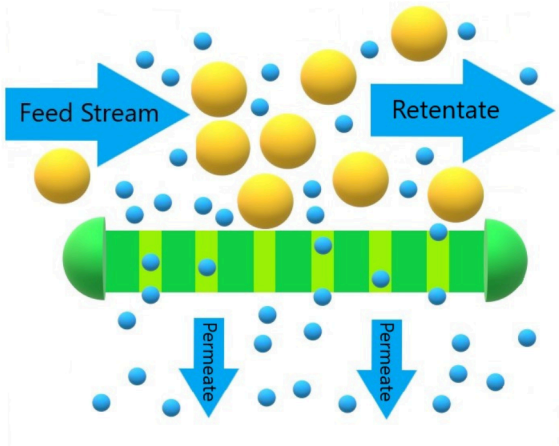

Figure 2. *Crossflow filtration [33].*

Spiral UF membrane modules are widely adopted in industrial applications due to their high packing density and efficient utilization of membrane area [34, 35]. These modules consist of flat sheet membranes enveloped around a perforated central collection tube, with alternating layers of membrane and spacers forming multiple leaf-like envelopes [34, 36]. The feed solution flows across the membrane surface, parallel to the envelopes, while the permeate spirals inward through the membrane envelope and is collected in the central tube [34, 36]. This design maximizes the membrane surface area per unit volume, resulting in compact and cost-effective systems [34, 35]. Additionally, the turbulent flow induced by the spacers reduces concentration polarization and fouling, thereby enhancing flux and overall performance [34, 35]. Spiral UF membrane models are extensively used in various industries, including food and beverage processing, pharmaceutical manufacturing, water treatment, and wastewater reclamation, owing to their versatility, scalability, and efficient separation capabilities [34].

Fouling is a major challenge in membrane processes, leading to a decline in flux and increased energy consumption. Particles present in feed solutions can cause fouling through various mechanisms, including pore blocking, cake layer formation, and adsorption onto the membrane surface [33, 37, 38]. The pure water flux (PWF) is a common parameter used to evaluate the performance of membranes. It is typically measured by filtering deionized water through a pristine membrane at a specific TMP and crossflow velocity. The pure water flux serves as a baseline for assessing the extent of membrane fouling during filtration experiments with feed solutions containing e.g. organic matter, particles, or macromolecules [38, 39].

Flux is a critical parameter in membrane filtration processes, quantifying the flow rate per unit membrane area (l/m^2h). However, membrane performance is often limited by the phenomena of critical flux, which is the point where the flux deviates from linearity. Critical flux is divided into the strong and weak form [33]. The strong form, the point where the flux deviates from the PWF, is primarily effected by reversible fouling [33]. The weak form represents the point at which the flux deviates from linearity as TMP increases, primarily effected by irreversible fouling [33]. These concepts are crucial for optimizing membrane operation and mitigating fouling.

Crossflow velocity (CFV) is a parameter that significantly influence the performance of membrane processes. CFV refers to the velocity of the feed stream flowing parallel to the membrane surface (Figure 2), typically expressed in m/s [40]. It is calculated by dividing the volumetric flow rate (Q) by the cross-sectional area of the flow channel. A higher CFV promotes turbulence and mitigates concentration polarization and fouling, thereby enhancing flux and overall membrane productivity. Conversely, low CFV can lead to the formation of a thick concentrated boundary layer, increasing fouling and flux decline [33, 40].

3.3 High pressure homogenisation (HPH)

High-pressure homogenization (HPH) is a mechanical process extensively employed in various scientific and industrial domains to achieve particle size reduction and uniform dispersion of components within a mixture [41]. This technique involves the application of extremely high pressures, typically ranging from 100 to 2000 bar, to force a liquid sample through a narrow gap, generating intense shear forces, turbulence, and cavitation [41]. These forces effectively disrupt cellular structures, emulsify immiscible phases, and reduce particle sizes, thereby enhancing the stability, bioavailability, and functional properties of the resultant product [41]. HPH is particularly valuable in the pharmaceutical, food, and biotechnology industries to produce stable emulsions, suspensions, and liposomal formulations. The process parameters, such as pressure, temperature, and the number of passes, are critical factors that influence the efficiency and outcome of homogenisation, necessitating precise control and optimization to achieve desired results [41].

4. Materials and methods

4.1 Membrane filtration

During the parameter and concentration study, a spiral UF membrane module (Alfa Laval GR90PP-3838/48) with a cross-sectional area of $2.8*10^{-3}$ m^2 was used to separate low molecular weight compounds like sugars and salts from proteins. The membrane consisted of three leafs with an active layer consisted of polyether sulphone and a support material of polypropylene. The molecular weight cut-off (MWCO) of the membrane was 5000 Daltons (Da), while the molecular weight of faba bean protein exceeds 5000 Da [42]. This characteristic indicated the high retention of proteins by the UF membrane. The filtration was carried out on pilot scale using a Alfa Laval Combi M39/3.8”membrane filtration system (Code no: 520337, manufactured 2007), see Figure 3.

Figure 3. *Membrane filtration system from Alfa Laval.*

4.1.1 Parameter study

A parameter study was performed to determine the optimal process conditions by varying trans membrane pressure (TMP) and crossflow velocity (CVF). The CFV was calculated from the volumetric flow and the cross-sectional area of the membrane. Before the parameter study was carried out the PWF of the pristine membrane was assessed by determining the permeability of the membrane. See section "4.1.3 Pure water flux" for details on the methodology employed in the initial evaluation of the pristine membrane's PWF.

Several CFV and the corresponding TMP were examined as part of the parameter study. The study started with the highest CFV of 0.12 m/s, followed by 0.09 m/s, and concluded with 0.06 m/s to avoid the appearance of fouling as much as possible. At the same time, various TMP were evaluated for each CFV, 0.25, 0.5, 0.75, 1.0, 1.5, and 2.0 bar. Each combination of CFV and TMP was kept constant for a duration of ten minutes. Throughout the entire study, both the retentate and permeate were continuously recirculated back into the feed tank. The temperature during the measurements was 50 °C. The flux was automatically logged.

Samples (see Appendix A.1) were collected at the start of the parameter study and for every combination of CFV and TMP, resulting in a total of 36 samples. The samples were stored in a cold room at a temperature of 4 °C. All samples underwent analysis for conductivity and brix. Furthermore, 18 samples were subjected to analysis for dry weight (total solids or TS), ash content, and protein content. These analyses were conducted on the retentate and permeate samples with a CFV of 0.12 m/s (TMP of 0.5, 1.0, and 2.0 bar), 0.09 m/s (TMP of 0.3, 1.0, and 2.0 bar), and 0.06 m/s (TMP of 0.25, 1.5, and 2.0 bar). After the parameter study, the PWF of the fouled membrane was evaluated. The methodology is outlined in section "4.1.3 Pure water flux".

4.1.2 Concentration study

Before the concentration study was carried out the PWF of the pristine membrane was assessed by determining the permeability of the membrane. See section "4.1.3 Pure water flux" for details on the methodology employed in the initial evaluation of the pristine membrane's PWF.

The concentration study was conducted to increase the protein content in the faba base. During the study the retentate was continuously recirculated back into the feed tank while the permeate was removed over time (see Appendix A.2). The study was carried out at a feed pressure of 6.5 bar, a CFV of 0.12 m/s, and a temperature of 50 °C. Throughout the measurements, the flux was automatically logged. The tank, containing 45 litres of faba base, was preheated to 50 °C prior to the start of the concentration study. Efforts were made to minimize evaporation by sealing the tank as much as possible. Over time 30 litres of permeate were removed resulting in15 litres of retentate. A preservative (0.1 % sodium benzoate) was added to both the retentate and the permeate at the end of the study to ensure stability over a prolonged period of time.

At the beginning of the study, samples were collected of both the retentate and permeate. They were taken of both retentate and permeate for every five litres of permeate that was removed, resulting in a total of 14 samples. The samples were stored in a cold room at a temperature of 4 °C. All 14 samples obtained from the concentration study underwent analysis for dry weight (TS), ash content, protein content, conductivity, and brix. Four samples were subjected to viscosity analysis: the retentate and permeate samples obtained before and after the study. Additionally, fat content and pH were determined for two samples, the retentate samples collected before and after the concentration study. After the concentration study, the PWF of the fouled membrane was evaluated. The methodology is outlined in section "4.1.3 Pure water flux".

4.1.3 Pure water flux (PWF)

Before both studies were carried out the pure water flux (PWF) of the pristine membrane was assessed by determining the permeability of the membrane. Deionized water served as the medium during the PWF measurement, and the temperature maintained during the measurements was set at 30 °C. By means of three different CFV, each associated with varying TMP, the membrane's permeability was determined. The first CFV was 0.17 m/s with a TMP of 0.9 bar, followed by a CFV of 0.18 m/s at a TMP of 1.5 bar, and lastly a CFV of 0.20 m/s with a TMP of 2.0 bar. Each round was kept constant for ten minutes at the parameters given above. The flux corresponding to CFV during measurement was then divided by the corresponding TMP to yield the permeability. Subsequently, the average permeability across the three conditions was determined, representing the PWF for the pristine membrane.

Following the concentration and parameter study, the PWF was re-evaluated using the same methodology as for the initial assessment of the pristine membrane's PWF. The difference between the permeability of the pristine membrane and the membrane post study represents the extent of fouling occurred. To mitigate fouling, an alkaline cleaning procedure was used on the membrane, 1 % Ultrasil 110 solution at a temperature of 50 °C. The cleaning agent was circulated over the membrane for a duration of one hour. After the cleaning process, another assessment of PWF was conducted, using the same methodology as during the initial assessment of the pristine membrane's PWF, to evaluate the effectiveness of the cleaning procedure. A membrane permeability recovery rate of 80 % or higher was considered satisfactory.

4.2 Formulation process

Literature search regarding vegan cooking creams was conducted. Furthermore, four dairy and five vegan cooking creams (Table 1), that were commercially available at the ICA Kvantum Malmborgs Tuna, were bought and analysed for pH, viscosity, and oil droplet size.

Table 1. *Fat content of the four dairy and the five vegan cooking creams..*

Dairy cooking creams	**Fat content (%)**
ICA Matlagnings Grädde [43]	13
Skånemejerier Matlagnings Grädde [44]	13
ICA Mellan Grädde [45]	27
Skånemejerier Mellan Grädde [46]	27
Vegan cooking creams	**Fat content (%)**
Oatly iMat Ruokaan [47]	13
Alpro cooking (soy) [48]	14
Planti (oats) [49]	15
Farmers and Chefs (oats) [50]	16
Oatly iMat Visp Ruokaan [51]	23

4.2.1 Recipes

The Green Dairy provided a recipe (Table 2) for a vegan cooking cream based on oats. This recipe was used for the development of a vegan cooking cream incorporating the faba bean base obtained from the concentration study. In the recipes developed during the formulation process, the oat base was substituted with the faba base.

Table 2. *Reference recipe of The Green Dairy.*

Reference recipe from The Green Dairy	Content (%)
Rapeseed oil	
Emulsifier E472e	
stabilizer Xanthan E415	
Oat base	
Water	

Based on the reference recipe, three formulations utilizing the faba base were selected for experiments (Table 3). The first recipe mirrored the composition of the reference recipe, while the second involved a decrease in faba bean base content together with an increase in water content. The third recipe consisted of an increase in oil content alongside a reduction in water content. All ingredients were supplied by The Green Dairy, maintaining consistency with those utilized in the reference recipe, excluding the oat base. The first recipe was prepared in triplicates and the second and third recipe was prepared in duplicate, resulting in seven sample recipes.

Table 3. *The formulations selected from the reference recipe.*

Ingredients	Recipe 1 (%)	Recipe 2 (%)	Recipe 3 (%)
Rapeseed oil		13	23
Emulsifier E472e		0.5	0.5
stabilizer Xanthan E415		0.4	0.4
Faba base		50	67
Water		36.1	9.1

4.2.2 Homogenizer

The homogenizer (Panda Plus, Homo GENIUS, GEA Niro Soavi) was activated to allow stabilization, achieved by circulating tap water through the system without applying any pressure. Simultaneously, a 400 ml sample recipe was prepared with each ingredient measured to ensure the correct composition according to the recipes (Table 3). The sample underwent pre-homogenization using a top-mounted stirrer (EUROSTAR, IKA LABORTECHNIK, power control-visc) for a duration of two minutes. Once the Panda reached stability, the tap water was drained from the system, and the prepared sample recipe was introduced. The sample recipe was circulated through the homogenizer for 20 minutes under conditions of 250 bar and a temperature of 43 °C.

This methodology was carried out seven times, with the initial sample using recipe one aimed at assessing the feasibility of emulsification within the homogenizer. Consequently, recipe one was evaluated in triplicates, while recipes two and three were evaluated in duplicates. All seven samples were analysed with regard to viscosity, oil droplet size, dry weight (TS), ash content, conductivity, brix, protein content, fat content, and pH. Furthermore, each sample recipe underwent a stability test where approximately 20 ml of each formulation was transferred into individual small containers and checked every week for oiling off. The containers were stored in a cold room at 4 °C.

4.3 Analysis of samples

The samples obtained from the parameter study, concentration study, the commercially available cooking creams, and the samples from the recipes underwent analysis on several characteristics. The methodologies of each analysis are explained below.

4.3.1 Viscosity

The rheometer (Anton Paar, Modular Compact Rheometer MCR 302) and pressure system were activated, allowing several minutes for stabilization. Concurrently, the computer was powered on, and the software (Anton Paar RheoCompass 1.25) utilized for the measurements was opened. Temperature adjustments were made to achieve the desired temperature, followed by modifications to viscosity curve settings: the number was adjusted to 50, and the final value was set to 1000. Subsequently, the sample was placed into the measuring cup (C-DG26.7/SS/AIR), which was then inserted into the rheometer. The bob (B-DG26.7 double gap) was mounted in the machine as well. Viscosity measurements were initiated automatically upon reaching the specified temperature. The measurements were carried out at temperatures of 25 ± 0.2 °C and 50 ± 0.2 °C, resulting in two viscosity curves for each sample. The measurements were conducted in duplicates.

4.3.2 Oil droplet size

The oil droplet size was analysed with the MASTERSIZER 2000 where the Malvern Dispersion Unit Controller was used to set the speed of the sample dispersion unit (Malvern Small Volume Sample Dispersion Unit). The measurements were performed in duplicates. The computer was turned on and the software (Mastersizer 2000) was opened. The water dispersion unit was installed into the apparatus. The standard operating procedure (SOP) created by Jonas Börjesson, named "milkfat," was utilized. The refractive index of the product was 1.463 and of water was 1.33. The obscuration level was between 10 % and 20 %. The rotational speed of the dispersion unit was set to 850 revolutions per minute (rpm), and the background was allowed to stabilize before starting measurements. The forward laser intensity had to be approximately 75%, with detector one and detector two targeting laser intensities of 150 units or less and 20 units or less, respectively. The samples were introduced into the sample dispersion unit using a pipette until the desired obscuration level was achieved, initiating the measurement.

4.3.3 Dry matter (total solids or TS)

The samples, around 12 grams for each sample, were transferred into aluminium cups and placed in a 45 °C oven (Memmert, Type: UL 50, F-Nr 840 490, DIN 12880-Kl. 1, Schutzart DIN 40050 – IP 20) for a duration of 24 hours. Afterwards, the samples were allowed to cool down in a desiccator. The initial weight of the samples before drying, along with the weight of the aluminium cup and the sample weights after drying, were recorded. Dry matter content was calculated using Equation 1. The measurements were conducted in triplicate.

$$TS\ (\%) = \frac{sample\ after\ drying\ (g)}{sample\ before\ drying\ (g)} \times\ 100\ \% \quad (1)$$

4.3.4 Ash content

The samples were transferred into a ceramic cup and placed in a 45 °C oven for 24 hours. Following this, the samples were placed into an ashing furnace (Nabertherm, B 150, LE14/11/B150, SN 216202, LE140K1BN) and maintained at 700 °C for four hours and ten minutes. The first hour and ten minutes involved heating the oven with the sample inside at a rate of 10 °C per minute, followed by three hours at a constant temperature of 700 °C [52]. Afterwards, the oven was automatically cooled down and once the temperature fell below 150 °C, the cup containing the samples were then transferred into a desiccator and allowed to cool down before weighing. The initial weight of the samples before ashing (prior to exposure to the 45 °C oven), along with the weight of the ceramic cup and the sample post-ashing, were recorded. Ash content was calculated using Equation 2. The measurements were performed in duplicates.

$$Ash\ content\ (\%) = \frac{sample\ after\ ashing\ (g)}{sample\ before\ 45\ °C\ oven\ \ (g)} \times\ 100\ \% \quad (2)$$

4.3.5 Protein content

The protein content was determined using a N/Protein Analyzer (Thermo ELECTRON CORPORATION, FLASH EA 1112 Series). The samples were introduced into the instrument, where complete combustion occurred, enabling the detection of nitrogen present in the samples. The software (EagerSmart) used, calculated the nitrogen content by multiplying it by the Jones' factor of 6.25 [52]. Prior to starting the measurements, calibration factors were reset, and a leak test was performed. Additionally, the detector signal was required to be 1000 uV and remain stable. Calibration was conducted before sample analysis, utilizing aspartic acid as the standard and air as a blank. Each sample weighed approximately 25 mg, and the analysis was conducted in duplicate.

4.3.6 Fat content

The fat analysis had to be performed with a completely dried and fine powder. To achieve this, the sample underwent freeze-drying. It had to be frozen and covered with aluminium foil with perforations before it was placed inside the freeze drier (Termo Kyl, NORDIC CLIMATE GROUP, Heto DRYWINNER). The drying process comprised of two stages, the primary drying involved a temperature cycle of -25 °C for five hours, -5 °C for twelve hours, +5 °C for twelve hours, and +10 °C for 23 hours and ten minutes. This was followed by a secondary drying at +25 °C for 36 hours and 30 minutes, resulting in a total drying time of 88 hours and 40 minutes. The pressure for the primary drying stage was set to 1 mbar. No specific pressure was set for the secondary drying stage. The final pressure achieved was 0.6 mbar. Afterwards, the dried samples were placed in a desiccator.

The fat content analysis was performed using the Soxtec AVANTI, comprising of a manual extraction unit and a manual control unit (Tecator, 2055 SOXTEC). The aluminium cup, designated for fat collection, was prepared by adding five to seven glass beads and subjected to heating in an oven at 103 °C for 30 minutes. Afterwards, the cup was transferred to a desiccator for cooling, and its weight was noted down.

The samples, approximately three grams, were placed within a cellulose thimble, to which two teaspoons of sand had been added. The sand and sample were thoroughly mixed using a glass rod, which was cleaned afterwards with a small cotton swab dipped in acetone. The cotton swab was then inserted into the thimble to prevent any loss of samples. Additionally, a thin cotton flake was inserted into the centre of the thimble. This formed a cone extending slightly up the walls of the thimble, facilitating even distribution of the solvent and preventing channel formation in the sample.

The aluminium cup was filled with 80 ml of petroleum ether and together with the thimble placed into the extraction unit. Cold water was turned on at a rate of three litres per minute for cooling purposes. The control unit was activated, and the temperature (135 °C) and durations were set for various stages, including cooking (20 minutes), rinsing (40 minutes), evaporation (15 minutes), and drying (5 minutes). Upon completion of the measurements, both the control unit and the cooling water were turned off. The aluminium cup was removed and placed into the oven for two hours at 103 °C, afterwards the cup was transferred into a desiccator to cool down.

Lastly, the aluminium cup with the extracted fat was weighed, and the fat content was calculated using Equation 3. The measurements were conducted in duplicate.

$$Fat\ content\ (\%) = \frac{sample\ after\ extraction\ (g) - aluminium\ cup\ (g)}{sample\ before\ extraction\ \ (g)} \times\ 100\ \% \qquad (3)$$

4.3.7 Conductivity

Conductivity measurement involved immersing the probe of the conductivity meter (HANNA, HI 99301 EC/TDS meter) into the sample for a couple seconds until a stable value was obtained. The conductivity value in milli Siemens (mS) was recorded, along with the corresponding temperature. The measurements were conducted in triplicates.

4.3.8 Brix

The Brix analysis was conducted utilizing a refractometer (HANNA, HI 96801 Refractometer, 0-85 %Brix). A droplet of deionized water was applied to the refractometer, and the "zero" button was pressed to establish this as the baseline. Next, the sample was measured by adding a droplet to the refractometer and pressing the "read" button, yielding the value in °Bx. One degree Brix corresponds to one gram of sucrose per 100 grams. However, Brix represents the total soluble solids content which does not only include sugars but also other dissolved substances such as salts and proteins [53]. Additionally, the temperature was automatically recorded by the brix meter. The measurements were performed in triplicates.

4.3.9 pH

The measurements of the pH (Metrohm, 914 pH/Conductometer) involved immersing the probe into the sample until a stable value was obtained. The value was then noted down and the measurements were conducted in triplicates.

4.4 Statistical analysis

A statistical analysis using XLMiner Analysis ToolPak (Frontline Systems Inc.) in Excel was carried out to analyse the data, utilizing ANOVA . The test was performed with a significance level of 5% ($p < 0.05$), where a p-value lower than this threshold was considered of a significant difference. The null hypothesis (H0): “There is no significant difference in the means of the groups”.

5. Results and discussion

5.1 Membrane filtration

5.1.1 Parameter study

During the parameter study the CFV and TMP were varied to obtain the optimal values for these parameters. Observing the data seen in Figure 4, it shows that higher CFV corresponds to increased flux rates. This trend indicates that a higher CFV enhance the transport of components through and over the membrane. Appendix A.3 presents the calculations of the CFV from the corresponding volume flows. The data also shows that TMP plays a crucial role in determining the flux of the UF membrane. Initially, increasing the TMP led to a corresponding increase in flux. However, beyond a certain threshold as is seen in Figure 4, further increases in TMP showed levelling out of the graph or even a decrease in flux due to an increase of membrane resistance. This phenomena is called limiting flux [33].

A CFV of 0.12 m/s was chosen, for the concentration study, as it maximizes the flux and maintaining operational efficiency. At this CFV, the UF membrane showed relatively high fluxes (ranging from 5.22 to 6.45 l/m²h) across different TMP conditions, indicating efficient transport through the membrane. A TMP of 0.65 bar was selected to ensure an optimal flux while avoiding potential membrane damage or fouling.

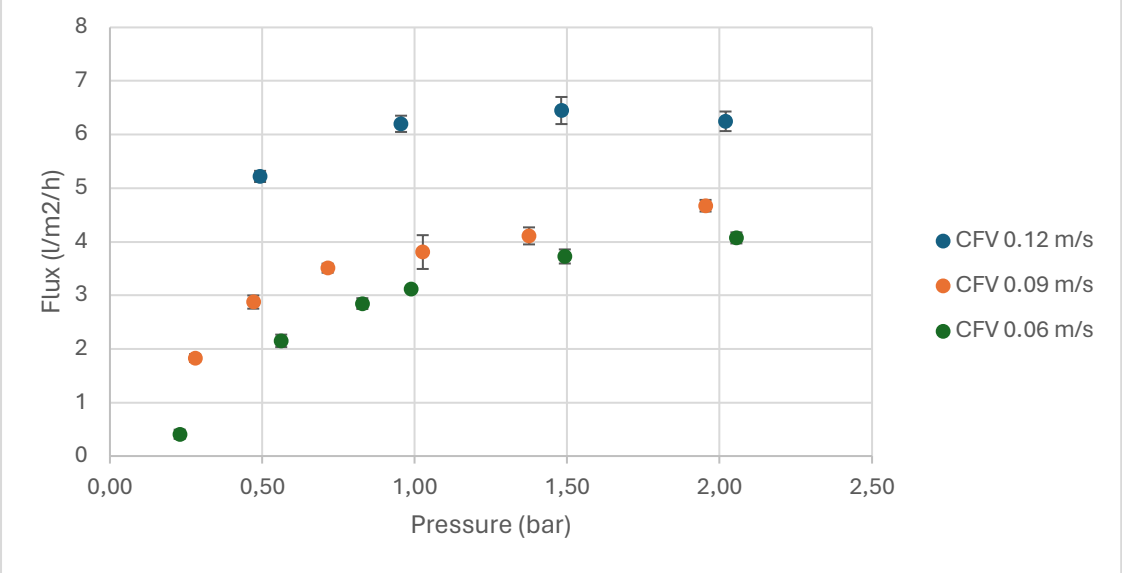

Figure 4. *Changes in filtration flux during the parameter study with various CFV and TMP.*

The high retention of proteins (Figure 5), ranging from 89 % to 91 %, across different volume flow rates and TMP indicates efficient separation by the UF membrane. With a MWCO of 5000 Da, the membrane effectively retained the proteins, which have molecular weights significantly higher than 5000 Da [42]. The ash retention (Figure 5) is ranging from 46 % to 52 %. The decrease in ash retention observed during UF membrane filtration of the faba base might be attributed to the presence of ash components with varying molecular sizes and solubilities, as well as potential interactions with other components within the faba base. Phytic acid is a naturally occurring compound found in plant-based materials, including legumes such as faba beans. It is known for its ability to form stable complexes with various metal ions, including calcium, magnesium, iron, zinc, and others [54, 55]. These metal-phytate complexes can have varying solubilities and molecular sizes, which could contribute to their retention or passage through the UF membrane [54, 55]. Changes in operating conditions and the possibility of membrane fouling or degradation could also contribute to the observed decrease in ash retention under different filtration conditions. The retention of total solids (Figure 5), ranging from 32% to 34%, indicates an average removal of all components present in the solution. This includes not only larger molecules and particles but also smaller substances such as salts and sugars. Therefore, a high retention of proteins suggests that there must be a correspondingly lower retention of other components, balancing the overall total solids retention.

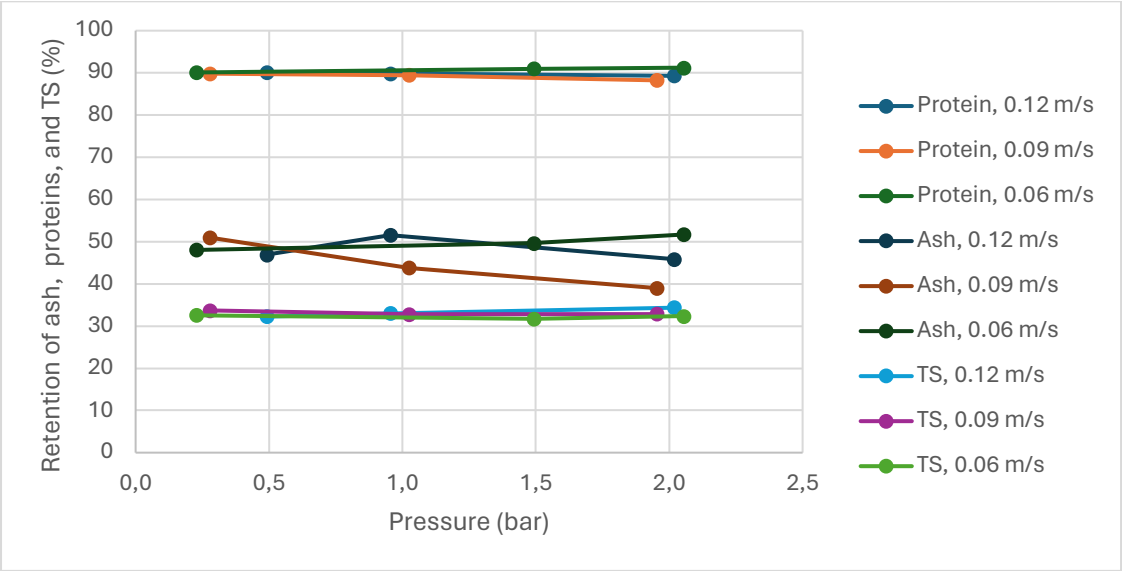

Figure 5. *Retention of protein, ash, and total solids (TS) during the parameter study.*

The significant variation in brix retention (Figure 6), ranging from 2 % to 15 %, underscores the complex nature of dissolved solids in the faba base. While larger molecules (proteins) were retained by the membrane, smaller molecules (sugars and salts) with molecular weights below 5000 Da might have passed through the membrane, leading to lower retention percentages. The retention of conductivity (Figure 6), remaining at 0 % across all conditions, indicates minimal retention of ions and small charged molecules by the UF membrane. With a MWCO of 5000 Da, the membrane primarily targets larger molecules, allowing smaller molecules and ions to pass through freely, as reflected in the conductivity results.

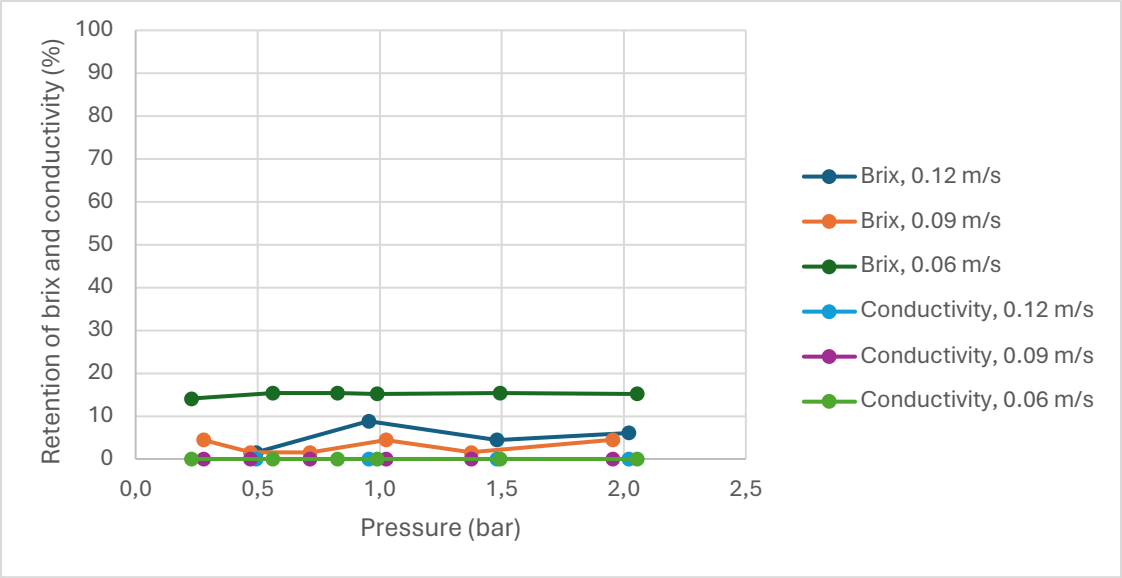

Figure 6. *Retention of brix and conductivity during the parameter study.*

Permeabilities were calculated from the PWF measurements (Figure 7). The pristine membrane gave a permeability of 48 l/m²/h/bar. After the parameter study, a decrease in permeability to 21 l/m²/h/bar was observed, indicating fouling, and thus reduced membrane capacity. Following alkaline cleaning, the calculated permeability was 42 l/m²/h/bar, obtaining a recovery of the membrane performance of 87 %, exceeding the target 80 % recovery threshold considered sufficient for effective cleaning.

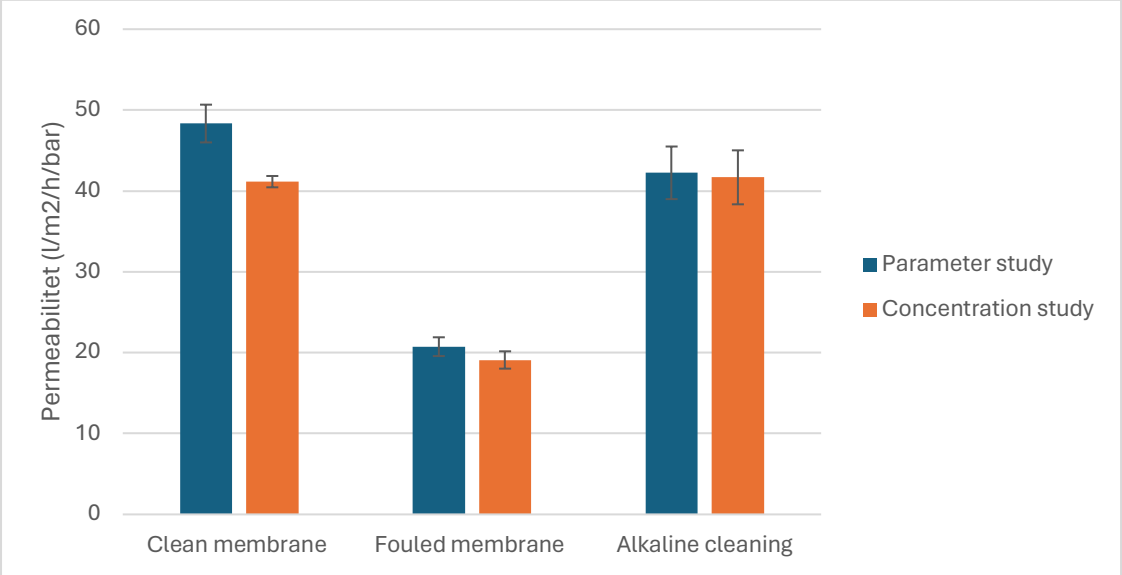

Figure 7. *Permeabilities of the pristine, fouled, and clean membrane in the parameter and concentration study.*

5.1.2 Concentration study

The aim of the concentration study was to increase the protein content in the faba base. The concentration study was conducted at a CFV of 0.12 m/s and a pressure of 0.65 bar. The volume reduction (VR) increased from 0 % to 67 % as the volume of the retentate decreased from 45 litres to 15 litres. As expected, the flux decreased gradually (Figure 8) with increasing VR. Due to the VR, the concentration of certain components in the retentate (proteins) increased, leading to several factors that can decrease flux, such as concentration polarization, increased viscosity, cake layer formation, and membrane fouling.

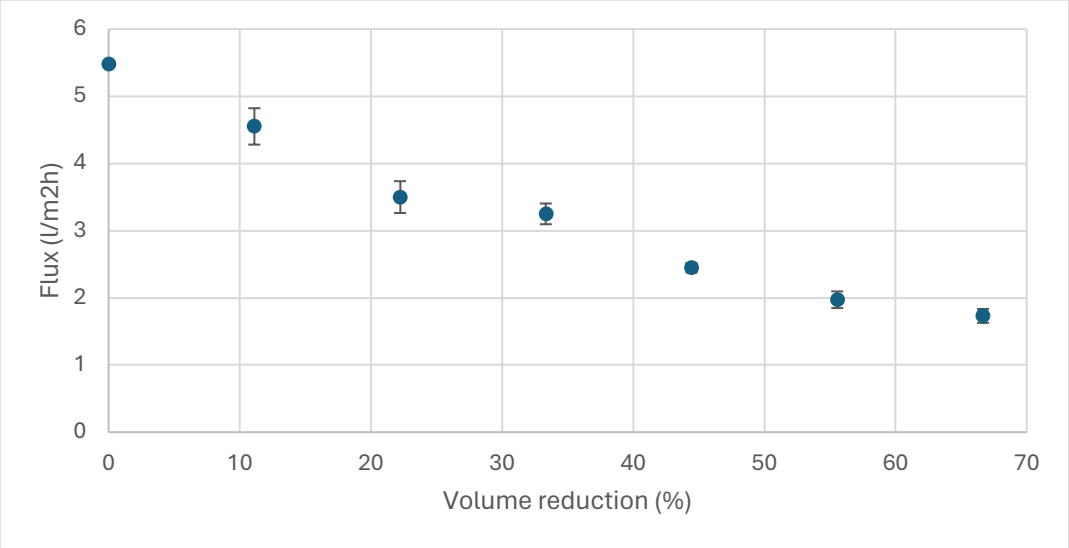

Figure 8. *Influence of the volume reduction (VR) on the flux during the concentration study.*

The retention of several components during the concentration study are shown in Figure 9. Protein retention remained consistently high throughout the concentration study, with retention percentages ranging from 88 % to 94 % across different volume reductions. This indicates effective retention of proteins by the UF membrane, ensuring a high protein content in the retentate. The retention of TS showed a slight increase with increasing volume reduction, with retention percentages ranging from 40 % to 55 %. Ash and brix retention also demonstrated an increasing trend with higher volume reductions, ranging from 55 % to 74 % and 36 % to 49 % respectively. The increase in TS, ash, and brix retention observed might be attributed to the presence of components with varying molecular sizes and solubilities, as well as potential interactions with other solutes. Additionally, concentration polarization and potential membrane fouling could have contributed to the enhanced retention of ash components. Conductivity retention remained consistently low across all volume reductions, with retention percentages at 0 %. This suggests that the UF membrane efficiently removed ions and small molecules responsible for conductivity, regardless of volume reduction.

The higher retention of TS, ash, and degrees Brix during the concentration study compared to the parameter study might be attributed to increased concentration of components, leading to more effective retention by the membrane. Additionally, differences in membrane fouling between the two studies could have influenced the observed retention percentages.

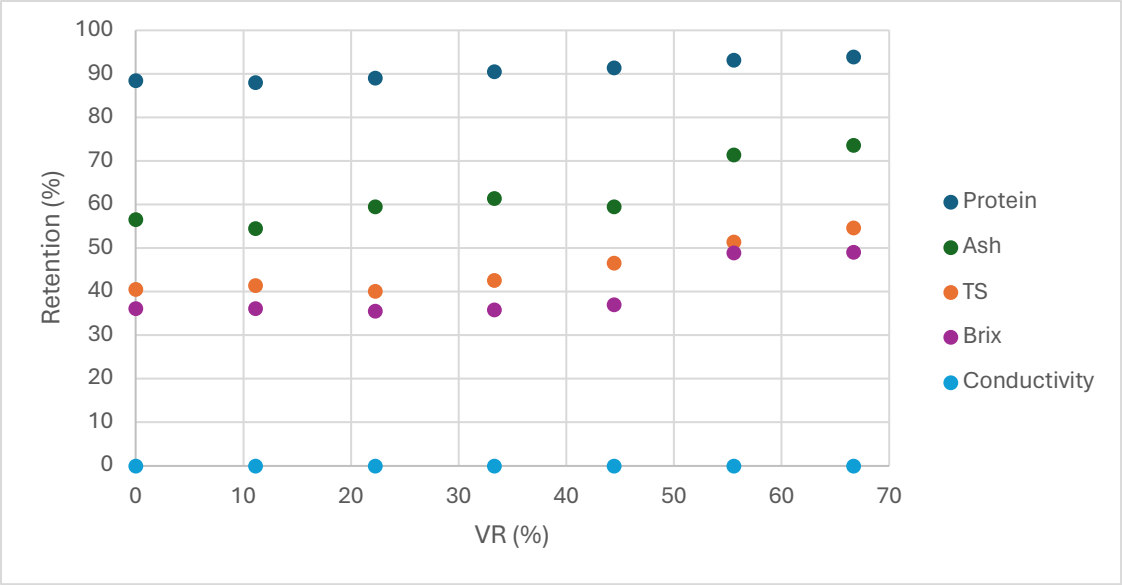

Figure 9. *Retention of protein, ash, total solids (TS), brix, and conductivity during the concentration study.*

Permeabilities were calculated again but this time for the concentration study (Figure 7). The pristine membrane gave a permeability of 41 l/m²/h/bar. After the study, a decrease in permeability occurred due to fouling. Following the alkaline cleaning a successful recovery of the membrane performance was obtained, exceeding the 80 % recovery threshold which is considered sufficient for effective cleaning.

5.2 Formulation process

5.2.1 Commercially available cooking creams

At the start of the formulation process, an assessment was conducted on commercially available cooking creams, both dairy and vegan categories. Appendix B.1 presents the nutritional compositions of these creams, while Appendix B.2 shows the ingredients in the vegan cooking creams. Unfortunately, quantitative information regarding ingredient proportions was unavailable.

The nutritional values of the commercially available cooking creams vary significantly, reflecting differences in their formulations and intended uses. The dairy-based creams contain higher amounts of fat and protein compared to their vegan counterparts, which rely on plant-based sources such as oats, soy, and rapeseed oil. Nevertheless, one variant of the Oatly vegan cooking creams contained 23 % of oil, which was still lower compared to the 27 % found in dairy-based cooking creams.

In terms of ingredients, the vegan creams featured a diverse range of components, including emulsifiers, stabilizers, and thickeners to mimic the texture and functionality of traditional dairy creams. Notably, the presence of specific additives like gellan gum and xanthan gum might have contributed to the creamy texture and mouthfeel of these products. Comparing the nutritional profiles and ingredients of the sample recipes with the commercial vegan creams

can provide insights into potential formulations for plant-based cooking creams, allowing for the development of products that meet consumer preferences for taste, texture, and nutritional content.

5.2.2 Recipes

As stated in the Materials and Method section, the reference recipe was provided by The Green Dairy (Table 2). This recipe was very similar in ingredients to the recipes of the commercially available cooking creams, excluding the Oatly cream with a 23 % fat content. The reference recipe provided detailed quantitative information for each ingredient, information that was absent in the commercially available cooking creams. Therefore, the decision was made to adopt the recipe supplied by The Green Dairy for formulation purposes. Preferably the permeate from the concentration study should have been added instead of water, but unfortunately the permeate had mould growth and was not possible to repeat the test due to time constraints.

Two oil contents, [redacted], were evaluated for the sample recipes, with the decision to adjust the faba base content, if needed, rather than oil content to achieve a desired viscosity reduction. [redacted] The resulting emulsion gave higher viscosity values compared to the commercially available cooking creams. Consequently, an adjustment was made to formulate a recipe with reduced faba base content, thereby increasing the water content while maintaining the oil content [redacted]. In the formulation of the third recipe, the faba base content was maintained while oil content was increased to [redacted], resulting in a decrease in water content.

5.2.3 Homogenizer

The temperature of the sample inside the homogenizer was unchangeable and measured at 43 °C. A pressure of 250 bar was applied to facilitate efficient homogenization of the faba bean base. The pressure was selected based on prior research findings indicating its efficacy in achieving the desired emulsion properties [56]. Additionally, the choice of this pressure setting was discussed with Andreas Håkansson, lecturer of the course “Food Engineering” at Lund University [57]. Moreover, the duration of circulation of the faba bean base within the homogenizer was 20 minutes, ensuring adequate exposure to the homogenization process for the desired emulsion characteristics. The time was selected based on prior research findings [56] together with the consultations of Klara Sjölin [58].

The faba base, after UF and before any other ingredients were added, displayed a darker colour compared to the sample recipes after the homogenizer (Figure 10). Adding ingredients such as oil, emulsifier, stabilizer, and water into the faba base resulted in dilution. Additionally, the homogenization process involved subjecting the mixture to high shear forces, which can impact the dispersion of oil droplets and other components. Homogenization can lead to finer oil droplets that are better dispersed throughout the mixture, potentially resulting in a more uniform appearance and lighter colour [59]. Due to the fact that smaller oil droplets scatter light more symmetrically compared to larger droplets, an effect perceived as an increase in lightness [60].

Figure 10. *Colour change in the sample recipes after the homogenizer.*

5.2.4 Stability of the emulsions

There was no oiling off visible after four weeks of storage in the cold room. All three recipes are stable for at least four weeks at 4 °C. Appendix B.3 shows the small containers after four weeks in the cold room.

5.3 Analysis of cooking creams

5.3.1 Viscosity

The shear rate (1/s) was calculated to be 108.56, derived from an average of shear rates, specifically 72, 86.8, 105, 126, and 153. Subsequently, the viscosity was determined by averaging the viscosity values corresponding to these shear rates. Viscosity measurements were conducted at 25 °C and 50 °C, as these temperatures were anticipated to be relevant for the end consumer and during the processing stages of the cooking cream, respectively. The viscosity values for the faba base, the commercially available cooking creams and the sample recipes are show in Table 4, the percentages provided in brackets are the oil content in the cooking creams.

The faba base showed a significant increase in viscosity after UF treatment, both at 25 °C and 50 °C. This increase in viscosity can be attributed to several factors. Firstly, the removal of water through the UF process results in a higher concentration of components, leading to increased viscosity. Additionally, the retention of macromolecules and colloidal particles by the UF membrane contributed to the elevated viscosity, as these components can significantly influence the flow properties.

The viscosity values of the faba base, the commercially available cooking creams, and the sample recipes showed notable differences. For instance, the Planti cooking cream exhibited remarkably higher viscosity compared to the faba base after UF treatment. This difference could stem from variations in composition, such as the presence of stabilizers, emulsifiers, or thickeners. The sample recipes had a higher viscosity compared to the faba base and the commercially available cooking creams, this was probably due to the high amount of emulsifier and stabilizer added in the sample recipes.

Recipes 2.1 and 2.2 had a lower viscosity compared to the other sample recipes, due to the lower amount of faba base and the increase of water content present in recipes 2.1 and 2.2. Recipe 3.1 and Recipe 3.2 exhibited substantially higher viscosities compared to other recipes, this was due to an increased amount of oil present in these recipes.

The ANOVA results for the viscosity at 25 °C gave a p-value < 0.05 for all the recipes, suggesting statistically significant differences in viscosity among them. This outcome is consistent with the formulation of the recipes, as each recipe has a unique combination of fat and faba base content, both of which influence viscosity. The ANOVA results for the viscosity at 50 °C gave a p-value > 0.05 for the comparison between recipe one and recipe two, suggesting no significant difference in viscosity between these two recipes at this temperature. In contrast, the comparisons between recipe one and recipe three, as well as between recipe two and recipe three, yielded p-values < 0.05, indicating significant differences in viscosity at 50 °C.

Table 4. *The values of viscosity (at different temperatures), oil droplet size, and pH of various products.*

Faba base	**Viscosity (mPa·s) at 25 °C**	**Viscosity (mPa·s) at 50 °C**	**Oil droplet size (D[4, 3]-Volume weighted mean)**	**pH***
Before UF	24 ± 1.6	11 ± 1.8		6.1 ± 0.1
After UF	58 ± 2.3	27 ± 2.7		4.7 ± 0.0
Commercially available cooking creams				
ICA mat (13%)	49 ± 0.3	12 ± 0.7	29 ± 8.5	6.7 ± 0.1
Skåne mat (13%)	49 ± 0.0	13 ± 1.7	31 ± 14.4	6.6 ± 0.1
ICA mel (27%)	8 ± 0.1	4 ± 0.5	4 ± 0.2	6.8 ± 0.1
Skåne mel (27%)	13 ± 0.0	4 ± 0.3	8 ± 1.4	6.8 ± 0.0
Oatly (13%)	60 ± 3.4	36 ± 0.2	16 ± 11.2	6.1 ± 0.1
Alpro cooking (14%)	100 ± 0.1	75 ± 1.3	9 ± 1.8	7.6 ± 0.0
Planti (15%)	235 ± 17.0	161 ± 2.2	29 ± 12.4	5.7 ± 0.0
Farmers and chefs (16%)	29 ± 0.5		25 ± 4.9	6.1 ± 0.1
Oatly (23%)	78 ± 2.3	26 ± 0.1	7 ± 2.1	7.0 ± 0.0
Sample recipes				
Recipe 1.1	191 ± 0.2	83 ± 0.0	15 ± 0.5	4.8 ± 0.0
Recipe 1.2	181 ± 0.1	74 ± 0.2	25 ± 0.2	4.7 ± 0.0
Recipe 1.3	204 ± 0.4	97 ± 0.6	23 ± 0.6	4.4 ± 0.4
Recipe 2.1	154 ± 0.3	82 ± 0.3	22 ± 0.5	4.4 ± 0.1
Recipe 2.2	135 ± 1.1	72 ± 0.1	32 ± 0.3	3.9 ± 0.0
Recipe 3.1	346 ± 0.6	173 ± 0.7	49 ± 0.7	4.4 ± 0.1
Recipe 3.2	320 ± 0.4	156 ± 0.9	47 ± 0.9	4.0 ± 0.0

*Microbial growth and an acidic odour were present, during the measurements of the pH, for the sample recipes and the faba base after UF.

5.3.2 Oil droplet size

Due to the absence of fat in the faba bean base, oil droplet size measurements were not conducted before or after UF. For the commercially available cooking creams, the oil droplet size measurements (Table 4) indicated a range of values, suggesting variability in the emulsion structures among different products. These differences could result from variations in formulation, processing methods, or ingredients used in each product. For instance, creams with larger oil droplet sizes might have undergone less intensive processing or might contain stabilizers or emulsifiers with different functionalities, leading to distinct emulsion structures.

Comparing the oil droplet sizes of the commercially available cooking creams with those of the sample recipes revealed that they fell within a similar range. However, there are some variations in the values that are possible due to different formulations, ingredients, or processing techniques. Recipes 3.1 and 3.2 exhibited larger oil droplet sizes compared to the other sample recipes, likely due to their higher oil content. Due to emulsification being conducted under identical pressure and duration as the other recipes, the increased oil quantity in recipes 3.1 and 3.2 might have resulted in less uniform oil distribution and larger oil droplets. It may also be indicative that a higher concentration of emulsifiers is required to enhance the stabilization of the droplets.

The ANOVA results for the oil droplet size shows a p-value > 0.05 for the comparison between recipe one and recipe two, suggesting no significant difference in oil droplet size between these two recipes. This is expected, as both recipes contain the same amount of added oil. In contrast, the comparisons between recipe one and recipe three, as well as between recipe two and recipe three, yielded p-values < 0.05, indicating a significant difference in oil droplet size. This result is logical, given that recipe three has a higher oil content compared to recipes one and two.

5.3.3 pH

The pH assessments (Table 4) of both the sample recipes and the faba base post-ultrafiltration occurred under conditions characterized by the presence of mould and an acidic odour. These circumstances introduced a high degree of uncertainty into the reliability of the obtained results, making it difficult to conduct accurate comparisons between the sample recipes and commercially available cooking creams. Additionally, the comparison of pH values between the faba base pre- and post-UF treatment was more difficult as well since they were not measured on the same day. The pH of the faba base before UF was assessed on the day of the concentration study and the pH after UF evaluated over a month later. Consequently, the observed decrease in pH post-UF is due to microbial growth. Investigating the quantity of preservative added is needed, and it may be necessary to consider increasing the amount of sodium benzoate. The ANOVA was not performed due to the microbial spoilage.

5.3.4 Dry matter (TS)

The results, shown in Table 5, indicate a significant increase in total solids content following ultrafiltration of the faba bean base, with the TS increasing from 11 % to 16 %. This increase can be attributed to the removal of water and smaller molecules during the ultrafiltration process, resulting in a concentration of solids in the retentate. During the formulation of the recipes, oil was added, contributing to the high TS content observed in the sample recipes. Recipes 1.1, 1.2, 1.3, 3.1, and 3.2 had a faba base content of 67 % which should give a TS in the recipe (without fat) of 11 %. Recipes 2.1 and 2.2 had a faba base content of 50 %, which should give a TS of 8 %. Removing the percentages of the fat content from the percentages of the TS shows that these theoretical values were reached.

The ANOVA results gave a p-value < 0.05 for the total solids (TS) across all recipes when the fat content was included in the TS, signifying a statistically significant difference among the recipes. However, upon removing the fat content from the TS, the ANOVA results revealed a p-value > 0.05 for comparisons between recipe one and recipe three, while comparisons between recipe one and recipe two, as well as between recipe two and recipe three, yielded a p-value < 0.05. This outcome is consistent with the composition of the recipes, as recipe one and recipe three contain the same amount of faba base content, whereas recipe two has a lower amount of faba base content.

Table 5. *The values of TS, ash content, protein content, fat content, conductivity, and brix of the faba base and the sample recipes.*

Faba base	TS (%)	Ash (%)	Protein (%)	Fat (%)	Conductivity (mS)	Brix (°Bx)
Before UF	11 ± 0.5	0.36 ± 0.02	3.4 ± 0.5	0	2.00 ± 0.01	10.5 ± 0.1
After UF	16 ± 0.5	0.61 ± 0.01	7.6 ± 0.3	0	1.68 ± 0.01	14.7 ± 0.2
Sample recipes						
Recipe 1.1						
Recipe 1.2						
Recipe 1.3						
Recipe 2.1	21 ± 0.1	0.30 ± 0.01	3.4 ± 0.2	12 ± 0.2	3.00 ± 0.01	4.7 ± 0.8
Recipe 2.2	21 ± 0.1	0.31 ± 0.02	3.4 ± 0.1	12 ± 0.1	3.25 ± 0.05	4.7 ± 0.3
Recipe 3.1	34 ± 0.1	0.38 ± 0.01	4.6 ± 0.2	23 ± 0.4	2.92 ± 0.01	9.5 ± 0.5
Recipe 3.2	33 ± 0.1	0.39 ± 0.02	4.3 ± 0.1	22 ± 0.8	3.16 ± 0.01	9.5 ± 0.5

5.3.5 Ash content

The ash content (Table 5) of the faba bean base significantly increased from 0.36 % before UF to 0.61 % after UF. This increase can be attributed to the removal of water and smaller molecules during the ultrafiltration process, leading to a concentration of ash components in the retentate. The metals present in the faba bean base are likely connected to organic molecules in larger complexes, rather than existing as free ions, which would allow them to pass through the membrane during the ultrafiltration process. Recipes 1.1, 1.2, 1.3, 3.1, and 3.2 had a faba

base content of [redacted] which should give an ash content of [redacted]. Recipes 2.1 and 2.2 had a faba base content of [redacted], which should give an ash content of [redacted]. Recipes 1.1, 1.2, 1.3, 3.1, and 3.2 had a slightly lower ash content compared to the theoretical value. Interactions between ingredients in the formulation process can influence the distribution and availability of ash components in the final product. As mentioned before phytic acid is a naturally occurring compound found in faba beans. It is known for its ability to form stable complexes with various metal ions, including calcium, magnesium, iron, zinc, and others [54, 55].

The ANOVA results for the ash content yielded a p-value < 0.05 for the comparisons between recipe one and recipe two, as well as between recipe two and recipe three, suggesting significant differences in ash content among these pairs. This outcome aligns with the fact that recipe two has a lower faba base content compared to recipes one and three. The ANOVA results for the comparison between recipe one and recipe three gave a p-value > 0.05, indicating no significant difference in ash content. This is expected, as both recipes have the same faba base content.

5.3.6 Protein content

The protein content of the faba bean base before and after UF, as well as the protein content of the sample recipes, are presented in Table 5. Similarly to the TS and ash content, the protein content of the faba base significantly increased. This substantial increase in protein content post-ultrafiltration can be attributed to the removal of water and smaller molecules, resulting in a higher concentration of protein in the retentate.

Recipes 1.1, 1.2, 1.3, 3.1, and 3.2 had a faba base content of [redacted] which should give a protein content of [redacted]. Recipes 2.1 and 2.2 had a faba base content of [redacted], which should give a protein content of [redacted]. The measured values are within expected range of the theoretical values. Comparison of the protein content in the sample recipes with the protein content of the commercially available cooking creams (Appendix B.1) showed that the sample recipes had a higher protein content even compared to the dairy based cooking creams.

The elevated protein content observed in the sample recipes relative to commercially available cooking creams, including those of dairy origin, underscores a potential advantage in terms of nutritional value. This finding shows that the sample recipes offer a higher content of protein, which may align with dietary preferences or requirements emphasizing protein intake. Thus, the higher protein content could be considered favorable from a nutritional standpoint, particularly for individuals seeking products with enhanced protein profiles.

The ANOVA results for the protein content gave a p-value > 0.05 for the comparison between recipe one and recipe three, suggesting no statistically significant difference. Conversely, the comparisons between recipe one and recipe two, as well as between recipe two and recipe three, yielded p-values < 0.05, indicating statistically significant differences. These results align with the composition of the recipes, as recipe one and recipe three have the same amount of faba base content, whereas recipe two contains a lower amount of faba base content, resulting in a lower protein content.

5.3.7 Fat content

The fat content measurements (Table 5) of the faba base before and after UF yielded in 0 %, indicating that all the oil present in the vegan cooking cream formulations was added during the formulation process. Analysis of the fat content in the various sample recipes revealed variability, however, the value for fat content is still similar to what has been added. Recipes 1.2 to 2.2, with [redacted] oil added, showed a fat content ranging from [redacted]. Similarly, recipes 3.1 and 3.2, which had 23 % oil added, display fat contents ranging from 22 % to 23 %.

Recipe 1.1 is the only recipe that had somewhat of a bigger difference between the measured value compared to theoretical value. This recipe served as a trial formulation, primarily aimed at evaluating the compatibility of the formulation with the homogenizer and assessing the ability of the ingredients to form a cohesive and homogeneous emulsion. It is acknowledged that the precision of ingredient measurements in this sample recipe might have been comparatively lower than that of the other recipes.

The ANOVA results for the fat content gave a p-value > 0.05 for the comparison between recipe one and recipe two, suggesting no significant difference in fat content between these two recipes. This is expected, as both recipes contain the same amount of added oil. In contrast, the comparisons between recipe one and recipe three, as well as between recipe two and recipe three, yielded p-values < 0.05, indicating significant differences in fat content. This result is logical, given that recipe three has a higher oil content compared to recipes one and two.

5.3.8 Conductivity

The observed increase in conductivity in the sample recipes compared to the faba base before and after UF), seen in Table 5, deviated from the expected trend. The addition of rapeseed oil and water typically lead to lower conductivity. This unexpected result might be influenced by several factors. Firstly, it is noteworthy that the conductivity measurements of the faba base before and after UF were conducted at a temperature of 22 °C, while the sample recipes were measured at a lower temperature of 18 °C. Temperature can affect conductivity measurements, with higher temperatures generally resulting in higher conductivity due to increased ion mobility [61]. This, however, does not explain the increase in conductivity since the temperatures of the sample recipes were lower.

Additionally, it is important to consider the conditions under which the conductivity measurements for the sample recipes were taken. The presence of an acidic odour and mould suggests potential microbial activity or spoilage in the sample recipes. Microbial growth can lead to the production of organic acids and other metabolites, which might increase the ionic strength and conductivity of the solution [62]. There is a possibility that due to this the pH of the sample recipes were considerably lower compared to the pH of the faba base before UF (Table 4). In acidic conditions, hydrogen ions are abundant, contributing to increased ionic concentration and thus higher conductivity [62].

Furthermore, the pH of the sample recipes was between 4 and 5, which is above the pKa of 3.1 for Xanthan gum [63]. The carboxyl groups on the xanthan gum molecules will predominantly be in their deprotonated form. This results in an increased presence of negatively charged carboxylate ions, which can enhance the solution's conductivity [63]. The ANOVA was not performed due to the microbial spoilage.

5.3.9 Brix

The Brix measurements for the faba base before and after UF and the sample recipes were measured at a temperature of around 22 °C. The Brix value of the faba bean base increased significantly from 10.5 % before UF to 14.7 % after UF (Table 5). This increase suggests a higher concentration of soluble solids in the faba bean base after UF. The removal of water and smaller molecules during UF contributed to the concentration of proteins in the solution and thus an increase in Brix.

The Brix measurements for the sample recipes were taken when the recipes had an acidic odour and showed mould growth. Similarly, the Brix measurement of the faba base (after UF) conducted on April 19th, also characterized by mould and an acidic odour, yielded a value of 9.5 ± 0.3 °Bx. This is lower compared to the Brix measurement obtained during the concentration study conducted on March 5th, when the Brix value for the faba base (after UF) was recorded at 14.7 ± 0.2 °Bx. Consequently, the Brix of the faba base (after UF) decreased from 14.7 to 9.5 °Bx over time. It is plausible that the observed decrease in Brix is due to potential spoilage, potentially because of the breakdown of sugars during spoilage within the solution.

Recipes 1.1, 1.2, 1.3, 3.1, and 3.2 contain [redacted] faba base, theoretically corresponding to a Brix value of approximately [redacted] when calculated from the measured Brix of 14.7 ± 0.2 °Bx. However, recalculating based on a Brix value of 9.5 °Bx it yields in a value of approximately [redacted], aligning it more closely with the measured values. Similarly, recipes 2.1 and 2.2, with a faba base content of [redacted], would theoretically yield in a Brix value of approximately [redacted] when calculated from 14.7 ± 0.2 °Bx. Yet, when recalculated from 9.5 °Bx, the value is approximately [redacted], again closer to the measured values. Notably, the measured values of recipes 3.1 and 3.2 differ, being closer when calculated from 14.7 ± 0.2 °Bx. This divergence come from the higher oil content and lower water content in these recipes, contributing to a higher Brix value. The ANOVA was not performed due to the microbial spoilage.

6. Conclusion and future research

In conclusion, this work successfully addressed the objectives to develop a vegan cooking cream prototype from faba beans with high protein content. Through membrane ultra-filtration (UF), the faba base achieved efficient protein concentration, demonstrating high flux rates and protein retention while undergoing parameter and concentration studies. The subsequent formulation of sample recipes showcased variations in viscosity, oil droplet size, pH, dry matter, ash, protein, fat content, conductivity, and Brix, providing insights into the emulsion properties and overall quality of the cooking creams.

The membrane filtration process, optimized through parameter studies, underscored the significance of factors such as crossflow velocity (CFV) and transmembrane pressure (TMP) in maximizing flux rates and protein retention while managing membrane fouling. The concentration study further highlighted the effectiveness of UF in increasing protein content and overall solids concentration in the faba base, essential for developing a protein-rich cooking cream.

Additionally, the homogenization process played a crucial role in enhancing emulsion properties, evident in the improved appearance and lighter colour of the faba base after homogenization. A lighter colour is generally more appealing to consumers and can be associated with a higher quality product, potentially influencing positive consumer perception and preference. Furthermore, all three recipes are stable for at least four weeks at 4 °C, which is advantageous as it ensures a longer shelf life and maintains product quality during storage and distribution.

Analysis of the cooking creams revealed significant differences in viscosity, oil droplet size, and composition compared to commercially available products, with notable variations attributed to formulation differences and processing techniques. Despite challenges in pH measurements due to spoilage, the overall increase in protein content and the absence of fat in the faba base post-ultrafiltration demonstrate the potential of this plant-based alternative in meeting consumer demand for nutritious and sustainable food options.

In comparing the samples to commercially available products, the protein content in the sample recipes was higher, even surpassing that of dairy-based cooking creams. Additionally, while the fat content in the samples matched the range of vegan commercial products, the highest fat content tested in the sample recipes was 23%, compared to 27% in some dairy cooking creams. This suggests that the sample recipes may provide a balanced nutritional profile with higher protein and slightly lower fat content compared to some commercial alternatives.

In summary, this study represents a significant step forward in the development of vegan cooking cream alternatives, providing valuable insights into the optimization of membrane filtration processes and formulation strategies to achieve desirable product characteristics. Further research and refinement in stability and sensory attributes are warranted to fully realize the potential of faba bean-based cooking creams in the market.

6.1 Future research

6.1.1 Membrane filtration

To enhance the membrane filtration process, a comprehensive study to further optimize key parameters such as temperature could be conducted. By systematically investigating and optimization, future research might aim to improve efficiency, enhance protein concentration, and elevate overall product quality.

6.1.2 Formulation process

To optimize the formulation and performance of cooking cream, future research should focus on a series of systematic investigations across multiple variables and processing techniques. A detailed exploration of varying ratios and types of ingredients, such as emulsifiers, stabilizers, and thickeners, is essential. These components play a crucial role in defining the texture, mouthfeel, and stability of the final product. By adjusting these ingredients, researchers can pinpoint optimal combinations that enhance the overall quality and consumer acceptance of cooking cream.

The homogenization process, a critical step in cream production, requires careful examination of pressure, time, and temperature settings. This process directly influences the emulsion properties, including oil droplet size distribution and creaminess. Identifying the ideal parameters will help achieve a desirable and consistent emulsion, which is key to maintaining the cream's quality during storage and use.

Investigating the impact of different fat content levels is another crucial aspect. This research will reveal how varying fat levels affect the texture and mouthfeel of cooking cream, providing insights into formulations for different applications, including whipped cream alternatives. Such studies will inform the development of products that meet diverse consumer preferences and dietary needs.

Even though during this research it was favourable to remove salts and sugars from the faba base during the concentration study, it would be interesting to look at the effects of these components. The addition of salt and sugar, even in small amounts, can significantly influence the texture, stability, and sensory attributes of cooking cream. Research in this area aims to understand how these additives enhance or detract from the product's overall quality. The goal is to determine optimal inclusion levels that improve taste and functional properties without compromising stability.

A specific focus on faba bean content within the formulation is essential to understand its effects on nutritional composition, texture, and sensory characteristics. Given the rising interest in plant-based ingredients, varying the faba bean content can offer valuable insights into how this component can enhance or detract from the desired qualities of the cooking cream.

Viscosity measurements at 4°C are crucial, as this temperature likely reflects the conditions under which consumers will purchase the product in supermarkets.

Improving the colour of the cooking cream is another area that can enhance consumer appeal. Research should explore the use of natural food colorants or processing techniques that can achieve a visually appealing product without compromising its quality or nutritional value.

Comprehensive carbohydrate analysis is necessary to accurately assess the nutritional profile of the cooking cream. This analysis will provide crucial information for evaluating the product's suitability for specific dietary preferences or restrictions, ensuring that the cream meets diverse consumer needs.

For the development of a vegan cooking cream, it is important to investigate methods for formulating a product directly from the faba base before UF. This research should explore alternative processing techniques and ingredient combinations that can achieve the desired texture and functionality, ensuring that the vegan cream meets high standards of quality.

Sensory evaluation is a pivotal component of this research, involving both trained sensory panels and consumer taste tests. This analysis will assess the overall acceptability, taste, aroma, texture, and appearance of the vegan cooking cream. Feedback on attributes such as creaminess, mouthfeel, and flavour profile will provide valuable insights into consumer preferences, guiding formulation adjustments to optimize sensory appeal.

Additionally, for end-products, an allergen profile needs to be provided to guarantee consumer safety and meet the demand for transparency in food labelling.

Finally, conducting cooking trials with the vegan cooking cream prototypes in various culinary applications, such as sauces, soups, desserts, and baked goods, is essential. These trials will evaluate the performance of the cooking creams in terms of stability, emulsion properties, heat resistance, and flavour retention during cooking processes. Additionally, assessing the final dishes' sensory attributes, including taste, texture, and appearance, will ensure the compatibility and versatility of the cooking cream in different recipes.

7. References

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