# Development of camembert analogue from faba beans- a textural and structural analysis

Nariman Mousa

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Nariman Mousa

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| **Supervisor:** | Galia Zamaratskaia, SLU, Department of Molecular Sciences |
| **Assistant supervisor:** | Fredrik Fogelberg, Research Institute of Sweden (RISE) |
| **Examiner:** | Maud Langton, SLU, Department of Molecular Sciences |

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**Swedish University of Agricultural Sciences**
**Faculty of food science**
**Department of Molecular Sciences**

# Abstract

The faba camembert analogue is an innovative plant-based alternative to the traditional dairy camembert which could potentially be produced from Swedish-grown faba beans (Vicia faba L.). This project aimed to investigate the feasibility of the production of camembert cheese analogue from Swedish faba beans, accessing the possible final protocol of this production, and investigate the effect of two fat content and three various fat combinations on the textural properties of the final product. Faba bean milk prepared with a bean-water ratio of 1:6 (w/w) with addition of 0.05% ascorbic acid. Faba bean milk was mixed with one of three combinations of fat (40% coconut + 60% rapeseed oil), (50% coconut + 50% rapeseed oil), and (60% coconut + 40% rapeseed oil) to reach a total fat of either 15% or 30%. Then, lecithin (1%) and glucose (3%) were added to the prepared faba milk, mixed, and heated to 90 °C. The milk was held at this temperature for 5-10 min. Then, the mix was coagulated at 80°C using 0.6% (w/v) of calcium sulphate. The start culture and the white mould were added at 30°C. After the fermentation, the mixture was put in the camembert mold and stored in a fridge at 15°C for at least 10 days for a ripening time. The texture profile, dry matter content, and moisture content were analysed in the final faba camembert analogues. The data indicated that higher fat content generally had higher hardness, springness, chewiness, and lower moisture content. The effects of the ratio between coconut and rapeseed oil and the interaction between the ratios and fat content on these textural properties were generally not significant. Moreover, the adhesiveness, cohesiveness, and gumminess did not significantly differ in relation to fat content, fat ratio, or interaction between them. Nonetheless, the results indicated that there is potential to produce a camembert analogue from the Swedish faba bean with the desired textural properties by varying the fat content. Ultimately, further research and industrial adoption are required to solve the challenges in the production and optimise the textural and structural characteristics of this innovative product.


*Keywords: faba bean, Vicia faba L., camembert analogue, fat content, fat source, texture.*

# Contents

# List of tables

# List of figures

# 1. Introduction

Dietary paterns are one of the key factors to improve human health and environmental sustainability, yet current modern food paterns continue to threaten both human and planetary health. If current dietary practices will not changed, diet-related diseases will account for three-quarters of the global burden of disease and global temperatures will exceed 1.5°C due to greenhouse gas emissions that related to current dietary system (Carey et al. 2023).

The challenge of providing sufficient food for a growing world population, biodiversity loss, freshwater loss, and land-use changes poses a significant barrier in achieving sustainability and global food security. The challenges are expected to become more pronounced over the next 50 years (Carey et al. 2023), which require a rapid transition in the current food system toward more sustainable and healthy food systems. Thus, the exploration of innovative food sources are required to meet future demand.

The Intergovernmental Panel On Climate Change has warned that humanity has less than 15 years to make changes to address the current challenge of irreversible climate change (Carey et al. 2023). Therefore, the adoption of sustainable diets at the global level become urgently needed. Sustainable diets should predominantly consist of ecologically based, local, plant-based, and with a reduced intake of animal-based products. These diet not only support environmental sustainability but also offer nutritional benefits. Observational data from several studies suggest that individuals who follow vegetarian or vegan diets tend to have better cardiovascular outcomes, lower risk of developing type 2 diabetes metabolic syndrome, and some forms of cancers compared to individuals with omnivorous diets (Lynch et al., 2018).

The impact on health and the environment may also depend on the type of plant-based foods consumed. Legumes and legume-based foods have an important role in feeding and nourishing future generations (Semba et al. 2021). Faba bean (*Vicia faba L.*) is considered an important crop from the ecological, nutritional, and economic points of view (Xiao et al. 2021). Some studies indicate that the nutritional quality of faba beans including the contents of protein, dietary fibre, vitamins, and minerals relatively high which gives it a very important value in replacing the animals' protein in the plant-based diet (Erbersdobler et al. 2017). In addition to the positive impacts of the legumes on human health, legumes have a particularly positive soil fertility, not least because their roots fix nitrogen in the soil due to a symbiotic relationship with rhizobia, thus making the nitrogen available to other plants (Erbersdobler et al. 2017).

Sustainable food patterns which can be a part of the future solution include reducing the consumption of dairy and animal products and increasing the consumption of plant-based products. In addition, environmental and health awareness will encourage people to search for more sustainable and healthier alternatives. All of these factors will lead to high demand for plant-based food in the market which requires more innovative products to meet this high demand. Innovative products should be developed to mimic the properties of dairy products and meet the consumers' expectations regarding the sensory and quality properties as well as the sustainable and healthy ingredients. All these key points pushed us toward production and developing a new product from faba beans that can be a sustainable protein source and an innovative alternative to dairy products in the future human diet.

Faba beans are a cool climate crop that can be cultivated in Sweden. Therefore, this study aims to develop a camembert analogue from local faba beans. In this case, the beans can be utilised as human food directly instead of using them as animal feed.

## 1.1 Plant-based diet

Concerns about the increasing human disease are being voiced nationwide. Numerous studies suggested that these diseases can be related to the modern unhealthy lifestyles and dietary patterns that are adopted by people which depend on the high consumption of animal products. These dietary patterns contribute to the development of obesity, diabetes, and cardiovascular diseases (Tuso et al. 2013). Healthy and sustainable eating habits can be achieved with a plant-based diet, which is defined as dietary patterns based predominantly on foods derived from plants. This diet encourages the consumption of plant-based products such as cereals, preferably whole grains, legumes, fruits, and vegetables.

Several recent studies indicate that individuals following a plant-based diet have lower risk factors for cardiovascular diseases, such as total cholesterol, low-density lipoprotein (LDL), and high-density lipoprotein (HDL) cholesterol compared with compared to individuals with omnivorous diets who are eating dairy and animal products every day (Huang et al. 2012). Additionally, the American Cancer Society, Diet, and Nutrition estimated that dairy factors account approximately 30% of all cancers in developed countries and 20% in developing countries while more than half of all cancer cases and deaths worldwide are potentially preventable by following more healthy diet (Tantamango-Bartley et al. 2013)

In addition to the benefits of the plant-based diet on human health, it can have a very important role in optimising planetary health (Tuso et al. 2013). Some studies indicate that high levels of greenhouse gas (GHG) emissions that influence climate change and global warming can be related to the current production and consumption of food systems. On the other hand, the transition to plant-based diets has the potential to reduce food-related greenhouse gas emissions by 49%. Additionally, it was suggested that the adoption of plant-based diets instead of the current omnivorous diets has the potential to lower food-related land use by 76%, and eutrophication by 49% ( Gibbs & Cappuccio, 2022).

## 1.2 Faba beans

Faba bean, also known as broad bean, is one of the oldest grown by man and was used as a source of protein in human diets and as fodder and a forage crop for animals. In recent years, interest has been growing in the health and sustainable benefits of faba beans and the development of different foods enriched with them and improved functionality, nutrition values, health benefits, and sensory proporities of this food (Dhull et al. 2020).

Cultivation of faba bean spread around the globe and is nowadays performed in almost all regions of the world. Faba bean is widely cultivated in cooler climates and enjoys broad global cultivation with China, Australia, Ethiopia, France, and the United Kingdom being the principal producers (Dhull et al. 2020).

According to FAO (Food and Agriculture Organisation of the United Nation) statistics, the global production of faba bean has bean increasing to meet the high demand for plant-based proteins. At present, the world's average of faba bean productivity is 1.5 t/ha, and Egypt ranked first with 2.96 t/ha (Dhull et al. 2020).

Mature seeds of faba bean are rich in protein (26.1%), carbohydrate, and dietary fibr. Faba bean also contains a variety of bioactive compounds, for example phenolics compounds particularly flavonoids with antioxidant activity (Dhull et al. 2020).

The seed of fab beans can be consumed dry, roaked, frozen, or canned. Faba beans though are less consumed in Western countries as human food, it is considered one of the main sources of cheap protein and energy in Africa, part of Asia and Latin America, where most people cannot afford animal sources of protein (Duc, 1997; Haciseferogullari et al. 2023). Similarly, faba bean in the Middle East is consumed mostly as dried seed while a little portion is consumed as fresh kernel. The crop is also becoming increasingly important in Saudi diets due to the high lysine content of the seed, which encourages the use of faba bean as a protein supplement for cereals (El-Fiel et al. 2002; Alghamdi, 2003). In contrast, the cultivation of faba beans is relatively limited in the United States and northern Europe, where they are primarily utilised for livestock feed (Singh et al.2013).

Faba bean contains different antinutritional factors such as lectins, saponins, trypsin inhibitors, vicine, convicine, phenolic content, oligosaccharides, and others that affect negatively its nutritional value (Labba et al. 2021). Therefore, for expanding the utilisation of faba beans in human nutrition, the removal of these antinutrients is necessary. Several methods are identified as methods to reduce the levels and activity of the antinutrient compounds in faba bean which involve thermal treatment (cooking, autoclaving, extrusions, microwaving, high-pressure processing, irradiation) and non-thermal treatments (soaking, germination, extraction, fermentation, and enzymatic treatment) (Badjona et al. 2023).

Camembert production includes soaking faba beans, heat processing, extraction, and fermentation which are efficient in reducing these antinutritional factors. In addition to the possibility of treating it in other ways in the future to be safe for human consumption all over the world.

## 1.3 Sustainable aspects of faba beans

Faba beans offer ecosystem services as faba beans are efficient in the symbiotic fixation of atmospheric nitrogen due to their ability to fix atmospheric nitrogen through symbiotic relationships with Rhizobium bacteria in the soil. This natural process can replace the need for nitrogen fertilizers and lead to reduce the environmental impacts of production and the addition of synthetic nitrogen fertilizers which can cause high (GHG) emissions. In addition to other environmental benefits such as reducing the pollution of groundwater that can be related to the addition of fertilizers and preventing soil degradation by increasing its fertility (Köpke & Nemecek, 2010).

On the other hand, whilst maintaining the health of the people and planet, there is also a need to find innovation toward more sustainable food systems that ensure meeting the high demand for food that is expected in the future due to the rapid increase in the population and meet the UN sustainable development goals to ensure the food security for the current and future generations. In addition to the adaptability of faba beans to different climates and farming systems makes them suitable for cultivation in diverse geographical regions that can ensure being a local food source for many countries (Augustin & Cole, 2022).

## 1.4 Aims

This project aims to investigate the feasibility of the production and development of camembert analogue from local Swedish faba beans, investigating the optimal fat content and different combinations of coconut and rapeseed oil of the final product.

First, processing conditions and ingredients for faba bean camembert were selected by visual inspection of camembert appearance, taste and stability at different fat content and combinations of different fat sources, the concentrations of coagulant, the proportion and effect of the emulsifier, the incorporation of fibre and decantation of starch, incorporation of ascorbic acid, and the effect of different types of start culture and white mold culture. This visual inspection was performed by the author of the study. Later, texture analyses of two different contents of fat and three ratios of coconut and rapeseed oils in the produced camembert analogue were performed.

# 2. Materials and methods

## 2.1 Materials

Faba beans (the “Tiffany” varity) and other ingredients were kindly supplied by the Research Institute of Sweden (RISE) in Uppsala, Sweden. Start culture and whilte mold culture were supplied by SACCO System Nordic AB company.

## 2.2 Faba bean milk preparation

Dry peeled faba beans (500g) were soaked in water for 10-12 hours at room temperature, swelling to about twice their original size and weight. Soaked peeled beans were then washed and mixed with an appropriate amount of water (tap water) to reach a “total weight of 3000g. This resulted in a faba bean-water ratio (BWR) of 1:6 (W/W) on a dry bean weight basis. Subsequently, 0.05% of ascorbic acid was added to the mixture. The faba beans and water were blended using a kitchen blender until a homogenous structure was achieved. The mixture was then filtered through a muslin cloth and manually pressed to extract the filtrate, resulting in faba beans milk.

## 2.3 Faba beans camembert analogue production

This study was considered the first exploration into the feasibility of producing and developing the appearance and textural properties of camembert analogue from local Swedish faba beans. Therefore, the production processes detailed in the study were derived through experimental works, exploring a lot of processing conditions and plant-based ingredients, and visual inspections of the appearance and sensory properties of the final product by the authors. This exploration ended in reaching a foundational protocol which provided a basis protocol production for this innovative product that can be developed by further research to optimise the taste of the final product.

Bean milk produced as previously described was mixed with an appropriate amount of one of the three combinations of fat (40% coconut + 60% rapeseed oil), (50% coconut + 50% rapeseed oil), (60% coconut + 40% rapeseed oil) fat to reach a total fat of either 15% or 30%. Then, an appropriate amount of lecithin (1%) and glocus (3%) were added to ensure the binding of the oil with the water in the next stages and have the appropriate amount of glucose which is necessary for the start culture activity in the fermentation stage. The milk, oil, emulsifier (lecithin), and glucose (syrup) were mixed by a large kitchen mixer to ensure the distribution of all ingredients in the faba bean milk and help in the binding of the water with oil to have a milky and creamy texture that ensured not separate the oil in the next stages. Then, the mix was transferred to a stainless-steel pot and heated until reached a boiling temperature (90°C). The milk was then held at this temperature for 5-10 min, with stirring to prevent sticking. The mix was transferred into a water bath (80°C) and waited until reaching the mix to this temperature. After this stage, a suspension of calcium sulphate dihydrate (gypsum) in 100 mL of water was added to the milk. The amount of coagulant added corresponded to the concentration of 0.6% (w/v). the mix was stirred manually for 20-30 seconds to distribute the coagulant evenly and then left for 40-50 min to allow the coagulation.

After the completion of the coagulation, the curd was cut and cooled by using a cold-water bath until it reached to the temperature of 30°C which is the optimal temperature for the activity of the start culture and white mold culture. Then, the start culture (1g) and white mold culture (1g) was mixed with (10ml) of water 30°C added to the curd and gently stirred to not destroy the curd. The mix was put in the camembert molds and stored in a fridge room at 15°C and left for two days. After two days, they have put out the molds and left for at least 10 days with some flipping for the completion of fermentation and penicillium growth.

## 2.4 Pilot study. Optimization of appearance and texture of the analogues from faba bean

The development of the camembert analogue involves a complex process that aims to mimic the texture and appearance of traditional dairy camembert cheese using plant-based alternative ingredients. This protocol of production highlights key steps, challenges, and the main considerations in producing camembert analogue from Swedish faba beans, focusing on the ingredients selection and incorporation.

### 2.4.1 Bean-water ratio (BWR)

The bean-water ratio is a crucial factor that affects the faba beans milk and the final camembert analogue texture. Two bean-water ratios were investigated in this study 1:6 (w/w) and 1:3 (w/w) to optimize the final texture of the camembert analogue. It was observed that the result of the BWR 1:6 (w/w) was described as bright, very soft, and creamy which was evaluated by the visual inspection followed by dividing the product into two parts and leaving it at room temperature for 2-3 hours, then trying to divide it again with a kitchen knife.

Some studies indicate that the high water ratio can result in more efficient extraction and solubilization of proteins from the beans into the milk (Stone et al., 2024) which can affect the textural properties of the final product making it creamy, spreadable, and possibly mimic the texture of the dairy camembert. The result of BWR 1:3 (w/w) was a product that was described as gry, hard, and firmer. This texture was due to the low moisture content in the final camembert analogue.

Therefore, the bean-water ratio 1:6 (w/w) was chosen to prepare faba bean milk which was used in the production of faba bean camembert analogue.

### 2.4.2 Fat content

There are a lot of plant-based sources that can be integrated into this production. In this study, rapeseed oil and coconut oil were selected depending on their physical properties and nutritional values of these fat sources. The fat content in traditional dairy camembert is typically approximately 24-30 % fat by weight (Adamska et al., 2017). In the present study, the fat contents of 15%, 30%, and 50% were investigated to mimic the fat content in the traditional dairy camembert and investigate the feasibility of increasing or decreasing this fat content.

### 2.4.3 Fat Combinations

Exploration of the effect of the different fat combinations on the final texture of the product is very crucial to optimise the texture of the product. Therefore, different fat ratios of rapeseed oil and coconut oil should be tested to determine the optimal ratio of fat sources that offer the best texture of camembert analogue that can mimic the properties of traditional dairy camembert. This exploration aims to assess the effect of fat ratios on the texture and stability of the final product. All the fat ratios were investigated in fat content 30% which is similar to the fat content on the traditional dairy camembert.

Three fat ratios were investigated in fat content 30% (100 % rapeseed oil), (50% coconut + 50% rapeseed oil), and (100 % coconut). It was observed that the samples with 100% rapeseed oil were unable to be pressed or formed (Figure 1). While in the samples with 100% coconut oil, the curd was very soft at the coagulation temperature of 80°C which was the optimal temperature of the coagulant activity. Therefore, after coagulation, the curd was left for more than 1 hour to cool down with cold bath water to solidify the coconut oil. This process helped stabilize the curd, making it easier to press and form but it was melted quickly at room temperature. In samples with 50% coconut oil and 50% rapeseed oil, the final camembert analogue was more able to be formed than the samples of 100% rapeseed oil and more stable at room temperature than the samples with 100 % coconut oil, this ratio was achieved the balance between the two other fat ratios.

*Table 1. The texture of camembert analogue in relation to fat proportions.*

| Sample ID | Rapeseed oil | Coconut oil | Texture, visual inspection |
|---|---|---|---|
| 1 | 100% | - | Not stable, soft, and unable to form |
| 2 | 50% | 50% | Fairly stable texture and able to form |
| 3 | - | 100% | Hard in the fridge and melts at room temperature |

100 % rapeseed oil    50% rapeseed oil+50%coconut oil    100% coconut oil

*Figure 1. The texture of the camembert analogue depends on fat proportions.*

### 2.4.4 The concentration of coagulant

Different concentrations of coagulant calcium sulphate dehydrate were investigated in this study 0.4% (w/v), 0.6% (w/v), 0.8% (w/v). It was observed that the coagulation was not stable at the concentration 0.4% (w/v), while the fat content was lost more with the whey of coagulation, which was the liquid that remained after milk coagulation where it included whey proteins and some of the soluble nutrients left after coagulation, by testing the concentration 0.8% (w/v). The stability of coagulation and trapping of the fat inside the curd was better with the concentration of coagulant at 0.6% (w/v). The pH of the faba bean milk was 6.1 ± 0.3 which was suitable for the coagulant activity, while the pH of the curd after coagulation was between 4.6 and 4.8.

This result explains that the low concentration may not provide enough coagulant to intact with all the protein fat and form a stable protein network during the coagulation. The high loss of fat in the concentration 0.8% (w/v) was perhaps due to the coagulation occurring rapidly which made it difficult to entrap the fat inside the curd.

### 2.4.5 The fibre incorporation

Fibre can improve the structural and textural properties of food products. A type of food texture improvement fibre (citrus fibre) was investigated in two different concentrations 5% and 10% to optimise the texture of the final camembert analogue. It was observed that the addition of 5% fibre made the texture of the curd stable and soft, but it was as one mass that made the separation of the curd from the whey after coagulation became very hard while the curd with 10 % fibre unable to be press due to the high softness of the curd. After 10 days, the final texture of the camembert analogue with the addition of fibre was very soft and crumbly compared with the sample with no fibre addition (Figure 2).

This result can be explained by the high water-holding capacity of fibres, allowing them to bind and retain moisture in food products (Chen & Rosenthal, 2015). Therefore, the addition of fibre to the camembert analogue can lead to more absorption and retaining of moisture which can increase the overall moisture content in the final product. While some moisture is desirable to avoid a dry, firm texture, excessive moisture can make the cheese too soft, crumbly, and lack stability.

Without fibre 5% fibre 10% fibre

*Figure2. The incorporation of different concentrations of fibre on the visual appearance of camembert analogue.*

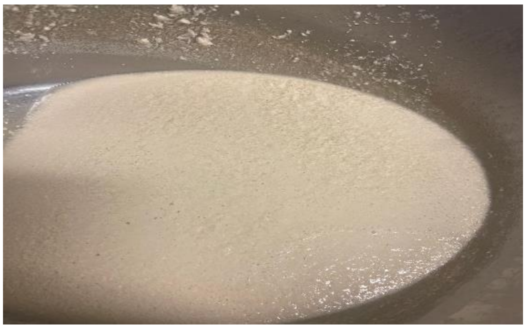
### 2.4.6 The decantation incorporation

Decantation is a physical common process used to separate mixtures, the separation is based on the difference in the density of substances, which allows the heavier substance to settle at the bottom and the lighter one to remain on top. It is particularly effective for separation of solid from liquid in which it is not soluble, such as starch from water (Damodarna et al. 2007).

The filtered faba bean milk was left undisturbed at room temperature for 2- 3 hours which allowed the starch granules to settle at the bottom due to the gravity. After 2-3 hours, the milk on top was carefully transferred without disturbing the starch at the bottom.

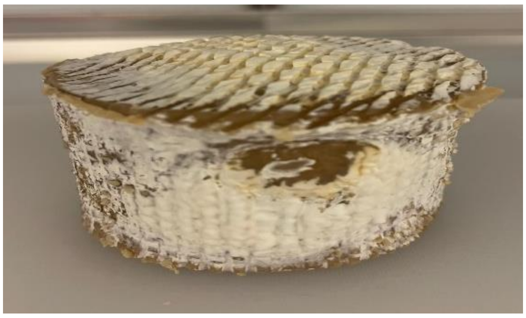
Visual inspection showed that the coagulation process resulted in an unstable, granular texture after the decantation process. Conversely, in the samples which were not subjected to the decantation process., the curd was stable as one cohesive mass that could be cut effectively to separate the whey which mimics the curd in the production of dairy camembert

Furthermore, in the absence of decantation, the colour was brighter white and more similar to the traditional dairy curd. The variation between the appearance of the curd and the final product with and in the absence of decantation is illustrated in Figure 3.



The curd after decantation

The curd without decantation



The final product after decantation, without ascorbic acid

The final product without decantation, without ascorbic acid

*Figure3. The effect of decantation of starch in the appearance of curd and the final product.*

### 2.4.7 The ascorbic acid incorporation

Two different concentrations of ascorbic acid 0.05% and 0.1% were investigated to optimise the colour of the final camembert analogue. The colour of the curd and the final faba camembert analogue were brighter white and the stability of the colour after cutting was higher than the samples without ascorbic acid. In the sample with

1% ascorbic acid, the colour was brighter, but the coagulation was very slow and not completed because of the low pH of milk which was not suitable for coagulant activity.

The final product after adding ascorbic acid 0.05%

The final product after adding ascorbic acid 0.05%

*Figure4. The effect of ascorbic acid on the colour of the final product..*

### 2.4.8 The start culture and white mold culture incorporation

The start culture that was used to ferment the milk was a type of freeze-dried culture. It has medium-slow citrate fermentation. It can be used in the production of fresh cheese, semi-hard cheese, and quark cheese. Four types of start culture type 1,2,3, and 4 which are a combination of different kinds of start culture which are supplied by SACCO to improve the taste and texture of plant-based products. The samples with type 2 of start culture were observed with the best texture.
The white mould cheese culture that was used in this processing was penicillium candidum. This white mould culture played a critical role in the development of the flavour, texture, and distinctive white rind mould of the product.

## 2.5 Effect of fat content and ratios of coconut and rapeseed oils on dry matter content and texture of the camembert analogues

Different models of camembert analogue were produced which differed in the fat content and ratios regarding Table 1 to study the effect of these two factors on the appearance, textural parameters, and dry matter content of the final product.

*Table 1. Experimental design to study total fat and ratios between two plant fat sources.*

| Sample ID | Coconut | Rapeseed | Total fat |
|---|---|---|---|
| C15:40 | 40% | 60% | **15%** |
| C15:50 | 50% | 50% | **15%** |
| C15:60 | 60% | 40% | **15%** |
| C30:40 | 40% | 60% | **30%** |
| C30:50 | 50% | 50% | **30%** |
| C30:60 | 60% | 40% | **30%** |

### 2.5.1 Dry matter content

The dry matter content refers to the portion of the material that remains after all the content of water has been removed. It is a very crucial parameter due to its effect on the texture, stability, and shelf-life of the final product.
The dry matter content of the faba bean camembert analogue was analysed following the method described by Nielsen (1994).
The representative samples of the final camembert analogue samples were prepared by mixing and blending to be analysed. The mixing ensures that the moisture of the analysed sample represents the moisture content of all layers due to the differences in moisture content between the surface and inside of the camembert analogue.
Briefly, 5.0 g from the prepared sample was weighed (the recorded weight represents the weight of the wet sample). Then, the weighed samples were placed in small aluminium containers and were put in an oven at 105°C for 18-24 h. The samples were weighted after drying ( the recorded weight was represented as the weight of the dry sample).

The dry matter content (DM) was calculated using the formula:
DM%= (Weight of dry sample) / (Weight of wet sample) × 100

### 2.5.2 Texture analysis

Texture profile analysis (TPA) is a common double compression test for determining the textural properties of different types of food. The textural analysis involves the instrumental measurements and evaluations of the textural parameters of food products in assessing food quality and consumer acceptance of food, including hardness, cohesiveness, adhesiveness, springiness, chewiness, and guminess.

The TPA test was often called the Two Bite Test because during this test the samples are compressed twice using a texture analyser TA-XT plus (model TA-HDi, Stable Micro System Ltd., Surrey, UK) to mimic the mouth's biting action and evaluate how samples behave when chewed by consumers.

This analysis detailed by Bourne (2002) involves compressing food twice and measuring the force and time deformation characteristics during these compressions to determine the textural properties. Hardness is a measure of firmness, springiness determines elasticity, cohesiveness measures the strength of the bonds between the different ingredients, and chewiness indicates the sensory profile and prediction of consumer satisfaction.

### 2.5.3 Statistical analysis

Data were analysed with SAS Version 9.4 (SAS Institute Inc., Cary, NC, USA). The effect of fat content, fat ratios between coconut and rapeseed oil, and interactions between fat content and ratios on texture parameters, dry matter and moisture content were evaluated using a general linear model. The level of statistical significance was set at $p < 0.05$. Data are presented as least squares mean (LSmeans) ± standard errors.

# 3. Results and discussions

Nowadays, plant-based diets are increasingly popular in many countries because it can help reduce environmental impact and improve the overall human health and well-being. The development of planet-based analogues that closely mimic the taste based diet. The increase in the number of consumers choosing plant-based analogues increases the demands for plant-based cheese analogues are often from soy, pea, nuts and corn (Grossmann & McClements, 2021). The selection of the protein source is important in determining the structure , texture, sensory attributes, and nutritional composition of the analogues, A recent consumer survey in Sweden showed that 87% of study participants were interested in the consumption of plant-based dairy analogues (Östlund et al. 2024). In the same study, the participants were positive about faba bean as an ingredient in a plant-based dairy analogue.

In the present study, an analogue to camembert cheese for the first time was prepared using locally grown faba beans. First, several steps were undertaken to optimise the appearance and texture of the analogues, based on visual inspection by the author of the study, and then instrumental measurement of texture parameters were performed on six models of cheese analogues which were differed on the fat content and ratios.

## 3.1 Pilot study. Optimisation of appearance and texture of the camembert analogues

The selection of a combination of coconut and rapeseed oil was based on their physical properties and possible health effects. The melting point of coconut oil is around 24°C but the coconut oil is solid at temperatures below this degree which can optimise the textural properties of camembert analogue due to increasing the firmness and stability of the final product at fridge temperature and reducing the oil separation (Wen et al. 2023).

However, coconut oil has a relatively high content of saturated fatty acids which might negatively affect human health due to increased total cholesterol and low-density lipoprotein-cholesterol levels (Jeyakumar et al. 2023). In contrast, rapeseed oil has a high content of unsaturated fatty acids (Shen et al. 2023), which tend to be liquid at room temperature which can improve the desirable soft and creamy texture of camembert analogue. In addition to the healthier fatty acid profile of rapeseed oil and its neutral flavour that ensures the desirable taste of the camembert without the interference of any strong oil flavour. Therefore, a combination of these oils can strike a balance between taste, texture, product stability and nutritional value.

After exploring different combinations of coconut oil and rapeseed oil to optimise the appearance and texture of the camembert analogue, it was observed that all the samples with 100% rapeseed oil had a very soft and oily texture, it was also very hard to press or form. This observation can be explained by the high content of unsaturated fatty acids, which tend to be liquid at high temperatures as the coagulation temperature of 80°C. Some studies indicate that the dynamic viscosity of rapeseed oil decreases exponentially with increasing temperatures of 40-90°C, it was found to be very low at 90°C which is very close to the optimal temperature of coagulation which can explain the softness of the curd after coagulation and it remained soft even after cooling.

While the ability to form and press the curd of a 100% coconut sample was higher, the texture of the final product was harder and more stable. This result can be explained by the differences in the fatty acid composition between rapeseed oil and coconut oil. This is not surprising because coconut oil has a relatively high viscosity compared to other vegetable oils due to its high saturated fat content (Usman et al. 2023). After a few days in the fridge, the samples were stable and had bright colour, However, because the melting point of coconut oil is 24 °C, these samples melted rapidly at room temperature (after 2-3 hours). Additionally, the coconut taste in the samples was very pronounced and overpowering. Consequently, despite coconut oil providing beneficial textural properties after cooling and in the refrigerator, it can melt quickly at room temperature and this big difference in the textural stability and solidity between the fridge and room temperature can affect the quality of the final product.

In the samples with a proportion of 50% rapeseed oil and 50% coconut, it was observed that the curd was also soft, but it was able to be formed after cooling. The samples were more stable than other samples and achieved the balance of the physical properties of two different oils. These findings highlight the impact of the fat combination on the final appearance and texture of the product.

On the other hand, understanding how fat content influences the appearance and textural properties of the product is crucial for optimising the formulation of products, such as the production of faba camembert analogue, where the appearance, texture, and stability are key factors. Therefore, three fat content was investigated in this study (15%, 30% and 50%) to understand the effect of fat content on the textural properties of the final product and optimise the best fat content that can be adopted in the production of the product that can mimic the traditional camembert cheese. All this fat content was investigated in the combination of fat oil 50:50.

The curd with a high content of fat 50% was observed very soft due to the low cohesiveness of the protein network because of the high content of fat. This soft texture due to the higher oil content in the system which leads to increased instability of the emulsion, likely due to a higher frequency of droplet-droplet encounters, providing more opportunities for droplet merging which can hinder the formation of the protein network during the coagulation (Wen et al. 2023).

On the other hand, it was observed that the samples with low fat content 15% tend to be very soft and unstable. In addition to the clear crumbly texture of the final product due to low-fat content. Several studies indicate that plant-based cheese analogues tend to be soft solids that exhibit both elastic and viscous properties, the textural properties of these plant-based products depend on the ingredients, especially protein and fat content (McClements & Grossmann 2022).
Therefore, depending on the fact that the plant-based protein network naturally lacks strength and stability, increasing fat content can to some extent increase the stability of the textural (McClements & Grossmann 2022).

Conversely, the sample with 30% fat content exhibited characteristics that might be more desirable for certain applications. The curd was more stable and remained relatively consistent between the fridge and room temperature. This stability of the texture at room temperature is very crucial for this product which is needed during marketing, consumption, and storage.

Emulsifiers are necessary to stabilise the fat and protein components in plant-based cheese, as the plant-based proteins cannot form a coherent network like casein in dairy cheese. Emulsifiers, such as lecithin, have amphiphilic properties, meaning they contain both hydrophilic (water-attracting) and lipophilic (fat-attracting) segments (Norn, 2014). It was observed that the low concentration of lecithin 0.5% was insufficient to bind all the fat content with water and trap it inside the curd, leading to a high rate of fat loss in the whey. Conversely, a higher lecithin concentration (1.5%) led to incomplete and unstable coagulation due to an excess amount of emulsifier that can hinder the protein-protein interaction that is essential for forming a stable protein network (Kim et al. 2020). Upon thorough investigation, it was determined that the optimal lecithin concentration was 1% which led to the optimal binding of water with fat effectively and reduced the loss of fat with the whey without affecting the protein network and the water content of the product.

Ascorbic acid plays a critical role in the colour stabilisation of faba bean milk by interacting directly with the phenolic compounds and metals that are naturally present in faba beans. It can prevent the oxidation of these compounds and prevent the formation the grey or brown colour. Therefore, the concentration of 0.05% of ascorbic acid led to a brighter white colour due to its effect on preventing the oxidation of the ingredients. While higher concentration of ascorbic acid (1%) can affect the coagulation due to its effect on the pH and perhaps on the coagulant's activity. Some studies indicate that pH is one of the most important factors that affect the stability of the plant-based protein network (McClements & Grossmann 2022).

The texture of the samples without decantation of the starch was better and more stable. One possible explanation for this phenomenon is the starch that is naturally present in faba bean can have a role as a thickening agent. Thus, during heating, starch absorbed water, granules swelled and gelatinised which led to forming a gel network that integrated the other ingredients and contributed to an increase in firmness and stability of the texture. In addition, legume proteins used in plant-based cheeses cannot form a stable protein network as the casein matrix in dairy cheese and non-protein ingredients like starch are often used to stabilize the fat and meet the structural properties of dairy products (El Soudi, 2023).

## 3.2 Effect of fat content and ratios of coconut and rapeseed oils on dry matter content and texture of the camembert analogues

The variation in the appearance of the samples that differ in the fat content and fat ratios are illustrated in Figure 5. The LS mean values of the TPA parameters of all samples are given in Table 3.

C15:40

C15:50

C15:60

C30:40

C30:50

C30:60

*Figure 5, The appearance of the samples which were involved in the TPA test and dry matter content.*

*Table 3. TPA parameters of faba camembert analogue and dry matter content. Data are presented as Lsmeans ± standard errors.*

| **Parameter** | **Fat 15%** | | | **Fat 30%** | | |
|---|---|---|---|---|---|---|
| | **Ratio 40:60** | **Ratio 50:50** | **Ratio 60:40** | **Ratio 40:60** | **Ratio 50:50** | **Ratio 60:40** |
| **Hardness** (N) | 1.7 ± 0.19 | | | 2.4 ± 0.16 | | |
| | 1.6 ± 0.35 | 1.4 ± 0.29 | 2.1 ± 0.35 | 2.2 ± 0.29 | 2.1 ± 0.29 | 2.7 ± 0.25 |
| **Adhesiveness** (N·s) | -1.4 ± 0.19 | | | -1.47 ± 0.15 | | |
| | -1.24 ± 0.32 | -1.44 ± 0.26 | -1.65 ±0.32 | -1.56 ± 0.26 | -1.07 ±0.26 | -1.78 ± 0.23 |
| **Springiness** (%) | 13.84 ±0.88 | | | 18.86 ± 0.73 | | |
| | 13.79 ± 1.61 | 13.75 ± 1.32 | 13.99 ± 1.62 | 18.34 ± 1.32 | 16.09 ± 1.32 | 22.16 ± 1.14 |
| **Cohesiveness** | 0.14 ± 0.01 | | | 0.13 ± 0.01 | | |
| | 0.16 ± 0.01 | 0.14 ±0.01 | 0.12 ± 0.01 | 0.14 ±0.01 | 0.11 ±0.01 | 0.15 ±0.01 |
| **Chewiness** (N) | 3.25 ± 0.68 | | | 6.16 ± 0.56 | | |
| | 3.61 ± 1.25 | 2.6 ± 1.01 | 3.56 ±1.25 | 5.66 ±1.018 | 3.97 ±1.02 | 8.86 ± 0.88 |
| **Gumminess** (N) | 0.23 ±0.03 | | | 0.32 ± 0.03 | | |
| | 0.26 ± 0.06 | 0.19 ± 0.05 | 0.25 ±0.06 | 0.31 ±0.05 | 0.24 ± 0.05 | 0.4 ± 0.04 |
| | 33.04 ± 3.79 | | | 57.1 ± 3.14 | | |

| | | | | | | |
|---|---|---|---|---|---|---|
| **Dry matter content (%)** | 39.23 ± 6.95 | 37.51 ± 5.68 | 22.36 ± 6.95 | 59.13 ± 5.68 | 59.05 ± 5.68 | 53.11 ± 4.91 |
| **Moisture content (%)** | 66.97 ± 3.79 | | | 42.9 ± 3.14 | | |
| | 60.77 ± 6.95 | 62.48 ± 5.68 | 77.64 ± 6.95 | 40.86 ± 5.68 | 40.95 ± 5.68 | 46.89 ± 4.91 |

Statistical analysis was conducted to determine the impact of fat content and fat ratio on the faba camembert analogue texture. The Statistical Analysis System SAS outputs were used to evaluate the main effects of fat content, fat ratio, and interactions between them (Table 4).

*Table 4. TPA parameters of faba camembert analogue, the P-value of SAS outputs.*

| Parameter | P-value, fat content | P-value, the ratio between fat sources | P-value, Interactions between fat content and fat ratio |
|---|---|---|---|
| **Hardness** | 0.016 | 0.126 | 0.985 |
| **Adhesiveness** | 0.902 | 0.267 | 0.460 |
| **Springiness** | 0.001 | 0.109 | 0.144 |
| **Cohesiveness** | 0.501 | 0.207 | 0.115 |
| **Chewiness** | 0.007 | 0.053 | 0.19 |
| **Gumminess** | 0.07 | 0.136 | 0.567 |

The texture of faba camembert analogue was found to be influenced by multiple factors, the most influential factors are the fat content and fat ratio. Regarding the Texture Profile Analysis (TPA) data in the context of total fat content reveals a pronounced relation between the fat content and textural properties such as hardness, springiness, cohesiveness, chewiness, and gumminess.

Hardness reflects the mechanical strength of the food. A significant difference in hardness was detected between the samples with different fat contents (Table 4; $p < 0.05$). It is known that fat content contributes to a more firm texture in plant-based products primarily due to the solid nature of fats especially the saturated type of fat at room temperature (Kilcast & Clegg, 2002). It can also be related to the low moisture content in the samples with higher fat content. Different ratios of coconut and rapeseed oil had similar hardness ($p > 0.05$). No interactions between fat content and different fat ratios were observed. This suggests that modifying the fat content in the final product is a viable strategy for increasing the hardness of the texture where a firmer texture is desirable. In contrast, the hardness of traditional dairy cheese was highest with the lowest fat content (7% fat vs 25% fat), due to its high protein content and the nature of dairy protein which forms a very stable and firm network (Koca & Metin, 2004). In addition, fat disrupts the protein structure and acts as a lubricant, resulting in a smoother, softer texture of dairy cheese (Romeih et al. 2002).

Adhesiveness represents the stickiness or adhesive force of the camembert analogue. Adhesiveness does not seem to be significantly affected by either fat content or fat ratio under the conditions tested. (Table 4; $p > 0.005$). No interactions between fat content and different fat ratios were observed. This might suggest that other factors, possibly ingredients or processing conditions, could play a more critical role in influencing this property. The type and ratio of plant proteins used in the cheese formulation can influence adhesiveness (Mattice et al. 2020). Additionally, high values of adhesiveness contribute to the stickiness perceived in the mouth during consumption of plant-based cheese which refers to the importance of controlling this parameter which can be by further searchers on the effect of other ingredients, especially the effect of the type and content of the protein on this parameter.

On the other hand, the springiness which can be called the elasticity of faba camembert analogue was influenced more by the fat content than fat ratio. This result can be observed in the samples C15:50 and C30:50 (Table 4) which are produced by the same fat ratio with the variation in fat content, where the value of springiness slightly decreases in sample C15:50 compared to C30:50. Fat can affect the matrix of the product by modifying the interaction between protein-protein networks affecting its ability to return after deformation which makes the product more elastic and increases the springiness. In addition, the moisture content was higher in the samples with less fat content which can contribute to less elasticity in the structure (Fox et al. 2017). Significant increases in springiness occurred with a higher fat content of 30% compared with a lower fat content of 15% ($P = 0.001$). Consequently, there is no significant effect of fat ratio ($P > 0.05$, Table 4) or interaction between fat content and fat ratio ($P > 0.05$, Table 4) on the springiness. This suggests that the elasticity of the product can be influenced by the fat content that can be applied during production.

The cohesiveness did not vary significantly between samples with different fat content which can be explained by the integrity of the protein matrix is not largely affected by the variations in fat type and content. This explanation depends on the fact that cohesiveness is predominantly influenced by protein-protein interactions and the continuity of the protein network (Lucey & Singh, 1997). The values of cohesiveness range between 0.11 and 0.16 without any clear increase or decrease in the values related to the different fat content and fat ratios. This suggests that variations of fat content and ratio do not dramatically affect cohesiveness. The statistical data indicate that no significant effects on cohesiveness were observed from fat content (P =0.501), fat ratio (P = 0.207), or interaction (P= 0.115).

Increasing the total fat content generally leads to an increase in chewiness. This was also observed in data (Table 4) where samples with 30% fat consistently exhibited higher chewiness values across all oil proportions compared to samples with 15% fat content. A significant effect of fat content in chewiness (P= 0.007) can be related to a significant increase in hardness and springiness in the samples with the high-fat content of 30% compared with the low-fat content of 15%. A marginal effect of fat ratio (p = 0.053) and no significant interaction (p = 0.19) on chewiness was observed due to no significant effect of fat ratio or interaction between the fat content and fat ratio on both hardness and springiness (Bourne, 2002).

Table 4 indicates that increasing the total fat content generally leads to an increase in the values of the gumminess, which can be related to the increase in hardness, given that gumminess is a derivative measure of hardness and cohesiveness (Bourne, 2002). On the other hand, Table 5 indicates that there were no significant effects of fat content (p= 0.07), fat ratio (p= 0.136), or no interaction between them ( P= 0.567) on the gumminess of faba camembert analogue.

## 3.3 Dry matter content

Dry matter content was determined for each of six faba bean camembert analogues, differentiated by two fat content 15% and 30%. For each fat content, three ratios of fat were analysed as detailed in Table 2. Data were analysed with SAS Version 9.4 and presented as least squares mean (LSmeans) Standard ± errors (Table5).

*Table 5. Mean dry matter content and moisture content.*

| Parameter | Fat 15% | | | Fat 30% | | |
|---|---|---|---|---|---|---|
| | Ratio 40:60 | Ratio 50:50 | Ratio 60:40 | Ratio 40:60 | Ratio 50:50 | Ratio 60:40 |
| Dry matter content | 33.04 ± 3.79 | | | 57.1 ± 3.14 | | |
| | 39.23 ± 6.95 | 37.51 ± 5.68 | 22.36 ± 6.95 | 59.13 ±5.68 | 59.05 ±5.68 | 53.11 ± 4.91 |
| Moisture content | 66.97 ± 3.79 | | | 42.9 ± 3.14 | | |
| | 60.77 ± 6.95 | 62.48 ± 5.68 | 77.64 ± 6.95 | 40.86 ± 5.68 | 40.95 ± 5.68 | 46.89 ± 4.91 |

*Table 6. Mean dry matter content and moisture content, P-value of the SAS outputs.*

| Parameter | P-value, fat content | P-value, the ratio between fat sources | P-value, Interactions between fat content and fat ratio |
|---|---|---|---|
| **Dry matter content** | 0.0005 | 0.155 | 0.640 |
| **Moisture content** | 0.0005 | 0.155 | 0.640 |

The moisture and dry matter content in faba bean camembert analogue is an issue that needs to be addressed. Generally, it was observed that the samples with the higher total fat content of 30% tended to have higher dry matter content and lower moisture content compared with samples with the lower fat content of 15% (Table 5) which affected the texture and stability of the faba camembert analogues. This was not a surprising result because when the fat content in cheese increases, it takes the place of moisture, leading to lower moisture content in higher fat samples. The statistical data indicates a highly significant effect of fat content ( $p= 0.0005$) with no significant effect from fat ratio ( $p= 0.155$) or interaction ($p= 0.640$) on dry matter or moisture content.

# 4. Conclusions and recommendations for further research

The results of the study indicate the potential for producing and developing a camembert analogue from Swedish-grown faba beans. Indeed, faba bean milk colour can be improved by ascorbic acid and be coagulated using calcium sulphate to produce a curd with textural characteristics that to some extent mimic the traditional dairy camembert. Nonetheless, it is essential to modify the fat content to improve the taste and the texture. For this purpose, different fat content can be investigated to modify the fat content to mimic the traditional dairy camembert. In addition, a lot of fat resources can be investigated to improve the texture, two of them are investigated in this study, coconut oil and rapeseed oil. Texture profile analysis TPA data indicates that increasing fat content generally increases hardness, springiness, chewiness, and dry matter content while decreasing moisture content. The generally insignificant effect of fat ratio or interaction between fat ratio and fat content on these textural parameters. Moreover, it appears that the adhesiveness, cohesiveness, and gumminess are not significantly different in connection to fat content, fat ratio, or interaction between them. These suggest that control of these properties can be achieved by modification of the fat content of the final product regardless of the source of this fat content. Ultimately, there is still much work to be done, more experimental work is required to improve the taste and the texture of the product which can mimic the dairy traditional cheese and the expectation of the consumer. In addition, fat content and proportion should be undertaken to determine the effect and interaction between the fat content and proportion on the texture of the faba camembert analogue.

# Popular science summary

Concerns about climate change, global warming, and food security are growing every day and the scientific studies indicate that many of these negative impact on the environment can be caused by food production and consumption. Additionally, as the worlds population increases, the global demand for food will increase in the future and more food production will be needed to meet this high demand which can lead to worse environmental impacts. Therefore, nowadays, we are responsing to explore new innovative food source that can meet the high demand of food in the future and have lower environmental impact as faba bean. Faba bean is a type of lygume which has high nutritional value and environmental benefits but used as animal feed in Sweden and a lot of other European countries rather than human consumption. This study aim to produce and develop a new product "vegan cheese" from Swedish faba bean as a base to shift its consumption directly to human nutrition. In addition to study the viability to develop the sensory and textural proporities of this product to mimic the dairy cheese which can encourage people to switch to the vegan alternative. The resault of the study indicate the potential for production vegan cheese from Swedish faba bean accessing to an initial protocol for this production which can be improved by further researchers. The study also includes analysing the final product to explore how can the different ingredients and processing conditions affect the proporities of the final product especially the effect of fat content and fat sources. Nonetheless, ther is still much work to be done to improve the taste and the appearance of this product.

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