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# Formulation and Characterization of Coconut-based Cream Cheese: Study of Influence of Starch and Hydrocolloids

*A thesis presented in partial fulfilment of the requirements for the degree of*

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## Abstract

Cream cheese analogue using plant-based ingredients requires the formation of a structurally stable matrix which can reproduce the viscosity and textural attributes similar to conventional cream cheese. Considering the functional properties and lipid content, coconut milk is a promising ingredient for plant-based cream cheese. But to achieve the properties associated with cream cheese, modifications using hydrocolloids and starch is necessary while using coconut milk. This study investigated the formulation and optimization of a coconut-based cream cheese analogue, while evaluating the effects of modified corn starch and xanthan-locust bean gum in product stability and functionality.

Nine formulations were prepared using three levels of modified starch (0,2,5% w/w), and xanthan-locust bean gum combinations at 1:1 ratio (0,0.1,0.5% w/w). Assessments on textural, rheological, colour, storage stability and microstructural characteristics were conducted on these samples on day 1,7 and day 14 while stored at 4°C. Consumer sensory evaluation was conducted to identify the most acceptable formulation.

The addition of starch and hydrocolloid to the coconut milk matrix during the production of vegan cream cheese helped to develop a firmer, adhesive, and spreadable cream cheese with a higher viscosity, relative to the control sample. The colour of the samples was comparatively unaffected by the hydrocolloid incorporations, with overall colour difference values ranging from 2.31-5.74. Microstructural observations of the samples supported the formation of a stable three-dimensional matrix while using starch and hydrocolloids in the formulations.

Sample CCC (Coconut cream cheese) was identified as the most acceptable formulation amongst the sample, to be a vegan cream cheese analogue developed using coconut milk. Although it had lower fat% (13.7%) similar to commercial reduced-fat cream cheeses, it had spreadibility (53.1 N.sec), firmness (9.07 N) and adhesiveness values (-19.2 N.sec) similar to commercial full fat cream cheese with lower viscosity compared to commercial cream cheeses at 20°C.

The results from this study can be used as an insight into starch-hydrocolloid structuring mechanisms in plat-based cream cheese alternative developments, and as a basis for further development of stable, sensory acceptable and commercially relevant products in this category.

## Acknowledgements

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I would like to dedicate this work to the memory of my uncle, who supported me from my childhood with his wisdom and cheerfulness. His absence has been deeply felt throughout this process, yet his influence remains as a guiding light in my academic journey.

To the friends who have helped me who have made this time of life amusing, and for assisting me with my work I would like to dedicate this work to you as well.

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**List of Abbreviation**

| | |
|---|---|
| PBDA | Plant-based dairy alternatives |
| PBM | Plant-based milks |
| MCT | Medium-chain triglycerides |
| MPI | Ministry for Primary Industries |
| GC-MS | Gas chromatography-mass spectrometry |
| GC-IMS | Gas chromatography-ion mobility spectrometry |
| GDL | Glucono-delta-lactone |
| LPSG | Lepidium perfoliatum seed gum |
| FG | flaxseed gum |
| WPC | Whey protein concentrate |
| WHO | World health organization |
| HDL | High-density lipoprotein |
| LDL | Low-density lipoprotein |
| UHT | Ultra-high temperature |
| MCFA | Medium-chain fatty acids |
| LBG | Locust bean gum |
| CLSM | Confocal lens scanning microscopy |
| SAOR | Small amplitude oscillatory rheology |
| TPA | Texture profile analysis |

# Chapter 1. Introduction

## 1.1 Background Information

Cheese is a category of fermented dairy products, and its market is a benchmark for the development of dairy market share (Wang et al., 2024b). There are numerous cheese varieties available on the market, which have different properties depending on their ingredients, production methods, and storage periods (Moatsou, 2019). Cream cheese is a type of fresh cheese that is widely consumed and has the capacity to incorporate different ingredients, such as herbs, fruits, and condiments, into its matrix (Hu, 2021). The acidification of milk, along with cream mixing, rennet addition, and whey removal, leads to the production of cream cheese, which has a characteristic semi-soft texture, a sour-creamy taste, and a smooth-shiny appearance (Lucey, 2011).

The popularity of plant-based alternatives to dairy products is rapidly increasing in the food industry. This trend is driven by several factors, including ethical concerns related to dairy farming, environmental issues, and rising health awareness among consumers. The use of plant-based milk and plant-based dairy alternatives (PBDA) reduce dependence on dairy products and addresses associated health concerns (Jaeger et al., 2024). Although plant-based milks are generally recognized as healthy, some, such as oat milk, have lower nutritional benefits, while others, like soy milk, contain allergenic compounds. However, plant-based milks (PBMs) like rice milk, coconut milk, and hemp milk have been part of human civilization for a long time and are promising ingredients for formulating PBDAs (Sethi et al., 2016).

Coconut milk is an allergen-free, widely used nut-based plant milk containing 36.84% fat and 3.81% protein. Even though the fat content is high, the lauric acid and medium chain triglycerides (MCTs) in the fats contribute to a positive health aspect for consumers. Coconut milk has high potential for developing plant-based cheese alternatives due to its creamy texture and high fat content (Halim et al., 2022).

Although coconut milk provides many key aspects for developing a vegan cream cheese, the lack of a strong protein network in coconut milk calls for the supplementation of ingredients to replicate the strong protein structure found in dairy cheese (Halim et al., 2022). The impact of starch and gums on the formulation of vegan cheese products has shown influence across a wide spectrum of product characteristics, ranging from textural to sensorial aspects. However, the use of gums and hydrocolloids in the production of vegan cream cheese using coconut milk has not been previously studied.

Hydrocolloids are used in manufacturing plant-based alternatives to dairy milk to impart texture, increase emulsion stability, and regulate moisture (Blok et al., 2023). Xanthan gum is a hydrocolloid produced by microbial species, which is used in liquid to alter viscosity and increase formulation stability (Kumar et al., 2022). Locust bean gum, extracted from the locust beans of the carob tree is used to promote colour development in samples. The synergic effect of these ingredients is used in the industry to develop samples with modified rheological and textural properties (Mandala et al., 2004).

Although most vegan cream cheese formulations use coconut oil, starch, and hydrocolloids (Michel et al., 2022), there have been no studies on cream cheese made using only coconut milk. The aim of this project was to produce a cream cheese formulation using coconut milk, starch, and hydrocolloids and to understand the consumer appeal towards the product. The principal areas of interest in the study were physicochemical characteristics such as colour, pH changes during storage, rheology, texture, and microstructure of coconut cream cheese, along with consumer sensory analysis. Factors like the influence of different concentrations of starch, hydrocolloids, and their combinations in cream cheese formulation were assessed. The coconut cream cheese sample was also evaluated against commercial and dairy-based samples to evaluate the key differences in textural, rheological, microstructural and colour attributes.

### 1.2 Overview of Thesis

The thesis is divided into the following chapters:

Chapter 1: A brief introduction to the background of the project and aspects of cream cheese. The chapter also briefly describes the research goal, the main objectives of the research and the rationale behind the project.

Chapter 2: The literature review of this thesis, which contains information on cream cheese, the history of cream cheese, vegan cream cheese mechanism, coconut milk and the hydrocolloid used in making cream cheese. It also encompasses the chemical composition of coconut milk, and cream cheese, along with the structure of traditional and vegan cream cheese.

Chapter 3: The experimental setup and methodology used for the preparation and analysis of cream cheese samples are detailed in this chapter. And it further discusses the results of the experiments conducted on coconut cream cheese formulations and the sensory evaluation of coconut cream cheese formulations.

Chapter 4: This chapter discusses the comparison of commercial cream cheese (dairy cream cheese) available in the market with the coconut cream cheese formulation selected based on sensory analysis.

Chapter 5: The conclusion and recommendation section, where the findings of the project are summarized. It also includes suggestions for future research in this field.

# Chapter 2: Literature Review

## 2.1 Introduction

Cream cheese is a dairy product that does not require ripening to develop a specific flavour and can be consumed after production and cooling (Coutouly et al., 2014). Cream cheese is a fresh soft, rindless, spreadable cheese with a loose protein matrix that entraps high moisture and fat content (Jeon et al., 2012). As a result, cream cheese has a creamy texture and a shiny appearance with a brittle to spreadable consistency. Cream cheese is defined by MPI as "unripen spreadable cheese with a mild creamy and/or acid flavour with minimum 25% milk fat, 65% moisture on a fat-free basis and 22% on a dry matter basis"(Ministry for Primary Industries).

The cream cheese invention could be traced back to the nineteenth century in the US, which was based on Neufchâtel cheese developed in Normandy, Northern France, which became popular due to the migration of the European population around the world(Pombo, 2021).

Cream cheese production involves the slow, inactive gelation of milk, which is achieved by the souring of cream, with or without the addition of rennet. This is followed by the removal of curd through draining and the addition of salt to impart the characteristic flavour (Guinee & Hickey, 2009). The use of cream cheese as a spread, dip, pastry and pie filling, and in cheesecakes is widespread, largely due to its sensorial properties, which provide softness and smoothness to the product (Brighenti et al., 2008).

The lower calorific value of cream cheese has made it a substitute for butter and margarine in food diets (Correia et al., 2022). Textural modification and flavour improvement of cream cheese can be done using the addition of herbs, vegetables, or fruits. For example, the production of flavoured cream cheese using strawberry-vanilla concentrate and cherry concentrate has been studied (Limanowski, 2016). Dairy cream cheese fortified with avocado puree and the implementation of different treatments on it have also been studied (Hu, 2021). The addition of tannin-sorghum flour to cream cheese formulation resulted in higher antioxidants and nutritional properties (Correia et al., 2022). Extension of cream cheese shelf life by the addition of microencapsulated basil extract has also been studied (Popescu et al., 2023). Cream cheese has proven to be an effective symbiotic product (probiotic and prebiotic career) in studies conducted using *Bifidobacterium* and *Lactobacillus* species (Alves et al., 2013; Barbara Speranza, 2018).

The nutritional and sensorial stability of cream cheese was maintained for 3 months when stored at 4°C (Coutouly et al., 2013). However, when stored at ambient conditions, the storage life of cream cheese was reported to come down to 28 days (Kahkashan et al., 2011). As a result of increased consumption of fast food along with rapid expansion of quick restaurant services, the market for cream cheese has crossed 7.23 billion in 2024, and is projected to continue its upward trajectory, reaching USD 11.45 billion by 2034 (Hernández-Figueroa et al., 2025).

Coconut milk is nut-based plant milk, which has tremendous potential to make low/lactose free cheese with similar sensory attributes to cow milk. Nutritionally, coconut milk has a very low content of proteins, but the amount of saturated fat in the milk is ten times higher than cow milk fat for the same amount high fat (Halim et al., 2022). The good digestibility of coconut milk and lack of antinutrients , non-allergic compounds, and unbalanced nutrition seen in other plant milks, makes coconut milk as an ideal choice for development of plant-based cream cheese alternative (Chetachukwu et al., 2019). But the coconut protein emulsifiability is very low, which makes it difficult for production of coconut based cheese by protein coagulation impossible (Pichler et al., 2017). Moreover, due to instability of coconut milk as an emulsion by creaming, flocculation, there exists an inconsistency in the products made only with coconut milk (Patil & Benjakul, 2018).

There is very little information on vegan cream cheese made using coconut milk. Even though there are many research papers based on soy-based cream cheese, very few research has been conducted to form a vegan cream cheese analogue using coconut milk. This literature review gives an overall review of cream cheese products, manufacturing methods, defects, and some benefits of coconut milk.

## 2.2 Cream cheese

### *2.2.1 The composition and history of cream cheese*

Cream cheese is a freshly consumed oil-in-water dairy emulsion produced by heat treatment, acidification and homogenization (Foguel et al., 2021). Depending on the fat content of the initial mixture, dairy cream cheese is classified into double cream cheese and single cream cheese with fat contents of 9-11% and 4.5-5%, respectively (Phadungath, 2005). According to the US Food and Drug Administration (FDA), cream cheese is defining as having a milk fat content of at least 33% by weight and up to 55% by weight when specified tests are performed on the finished food (*21 CFR 133.133 -- Cream Cheese*, n.d.). On the other hand, according to the Codex Alimentarius, cream cheese is defined as a white to yellow-coloured, spreadable

cheese with a smooth texture, high moisture content, and a fat content of 25% on a dry matter basis. Cream cheese is further categorized into reduced-fat, lite/light, and low-fat cream cheeses with fat contents ranging from 16.5 to 20 % for reduced-fat, and less than 16.5 % for lite/light and low-fat cream cheeses (Phadungath, 2005).

The invention of cream cheese can be traced back to the nineteenth century in the US. It was based on Neufchâtel cheese developed in Normandy, Northern France, which became popular due to the migration of the European population around the world(Pombo, 2021). The origins of traditional cream cheese come from "junket", a dish made from rennet-curdled pure cream, sweetened with sugar, and flavoured with rose water which was popular among the English upper class during the Tudor era. The popularity of cream cheese increased with the introduction of foil-wrapped cream cheese products, which became a huge success in New York markets after the introduction of refrigeration and transportation in the United States following 1920 (Marx, 2015).

The sensory perception and rheological properties of cream cheese have been found to be affected by pH, homogenization pressure, and heat treatment (Coutouly et al., 2014). In terms of taste, cream cheese has a moderately creamy, buttery flavour with no bitterness but a faint dairy sourness. In terms of texture, there should be no lumps or grittiness and no signs of whey separation or cracking. Studies using GC-MS (Gas Chromatography–Mass Spectrometry) and GC-IMS (Gas Chromatography–Ion Mobility Spectrometry) have reported that 2-nonanone and heptan-2-one are the compounds responsible for the sweetness of cream cheese, whereas 3-hydroxybutan-2-one, benzoic acid and δ-caprolactone contribute to the sour taste, while undecan-2-one has been reported to be responsible for the buttery flavour (Zheng et al., 2024). Research on cream cheese suggests that the quality of cream cheese depends on the quality of fat used in production. (Elkot & Khalil, 2018).

### *2.2.2 Manufacturing cream cheese*

The production of cream cheese was initially carried out using the cooked-curd method (P & S, 2017). Currently, the more frequently used methods are by hot-pack and cold-pack methods. The production steps include standardization, pasteurization, homogenization, coagulation, whey drainage, salting, packaging and storage (Pombo, 2021). The effects of hot-pack and cold pack methods on single and double cream cheeses were investigated by (Elkot & Khalil, 2018),

who suggested that hot-pack method is more resilient to product damage caused by microbial growth.

The various stages involved in double cream cheese manufacture are shown in Figure 2.1.

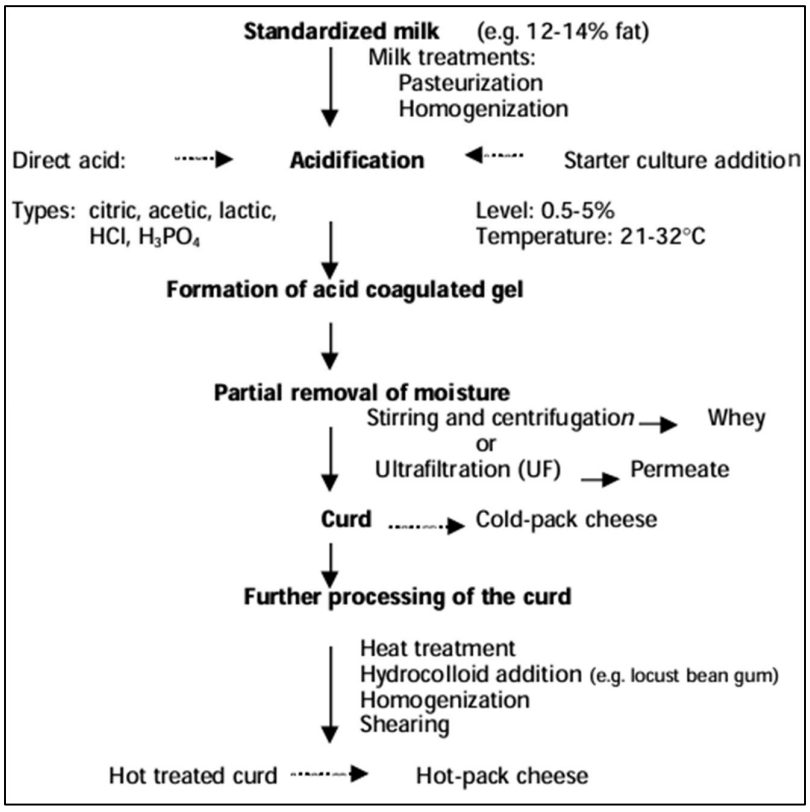



*Figure 2.1 Flowchart depicting the major steps in the preparation of dairy cream cheese (Lucey, 2011).*

Standardization of milk helps maintain consistency in milk composition, especially fat content, which can mitigate seasonal variations that affect the compositional and quality of the cheese produced (Soodam & Guinee, 2018). Milk with 8-14% fat content is used in the manufacture of double cream cheese, whereas 3-5% fat content is used in single cream cheese manufacture (Lucey, 2011).

After standardization, the milk and cream are pasteurized at 72-95℃ for 30-90 seconds to inactivate pathogenic microbes, and homogenization is conducted at 10-25 MPa to reduce the size of the milk fat globules (Guinee & Hickey, 2009). The milk is then cooled to 22-31℃ for either a long set (12-16 hours) or a short set (5 hours), followed by the addition of mesophilic lactic acid cultures for gel formation by acidification (Lucey, 2011).

Pasteurization of milk used in cheese-making was introduced to improve the quality of cheese rather than pathogen elimination and has been practiced in New Zealand since 1923. Pasteurization is used both as a regulatory tool and a safety measure in cheese manufacturing, as it can remove bacteria that could ferment the milk, ensuring better fermentation process control and higher cheese quality (Johnson, 2017).

Homogenization is conducted in liquids to improve their stability by reducing the size of fat globules and preventing fat separation. This technique uses high pressure to force the liquid through an orifice of 0.4 mm diameter at a speed of 2000-3000 cm/s (Shao et al., 2023). Homogenization of cheese milk used for the preparation of cream cheese results in firmer cream cheese with lower spreadability due to smaller fat globule size, which enhances casein-casein interactions. It was also noted that larger fat globules produce a less viscous cream cheese (Ningtyas et al., 2017a). Studies conducted by Coutouly et al. (2013) on the influence of pasteurization temperature and homogenization in cream cheese manufacture showed that homogenization pressure plays a vital role in influencing the rheology of cream cheese, while pasteurization temperature influences its stability.

Acidification is a crucial step in producing the characteristic taste and flavour of cream cheese. Cultures containing D-type *Streptococci* strains are responsible for the production of the specific aroma associated with acetate formation from citrate (Fox et al., 2017). Mesophilic cultures like *Lactococcus* and *Leuconostoc* are used in the long set process (22°C), while thermophilic microbes are used in the short set process (35°C) (Bot et al., 2007; Phadungath, 2005). The pH of cream cheese has an important role in cream cheese manufacture, as a higher pH contributes to softer cream cheeses, while lower pH results in firmer cream cheese with a denser microstructure and smaller corpuscular structures (Ong et al., 2020).

Renneting after acid coagulation results in a smoother cream cheese with moderate hardness and higher spread ability than acid-coagulated cream cheese alone (Chen et al., 2013).

The addition of stabilizers and hydrocolloid help increase the water-holding capacity of cream cheese during storage, preventing syneresis (Brighenti et al., 2020). Hydrocolloids are added at 70°C with stirring to improve the hydration of stabilizers and facilitate handling during pumping, mixing and packing (Lucey, 2011). According to Karan (2000) fat and salt content also influence the cream cheese properties, where salt can influence the yellow colour and contribute to bitterness in addition to saltiness.

The coagulation of milk is achieved by lowering the pH of milk toward its isoelectric point (pH 4.6-4.8). The reduction in pH due to acidification leads to the solubilization of colloidal calcium phosphate within casein micelles (Schulz-Collins & Senge, 2004). When the pH reaches 4.6, gel formation is induced due to a reduction in the negative surface charge, which can be further enhanced by the addition of rennet (Najera-Dominguez et al., 2022).

Some of the widely used coagulating agents include lemon juice, lime, alum, citric acid, lactic acid, and lactic acid bacteria cultures (e.g. *Lactobacillus* cultures). A recent study suggested using GDL (glucono-delta-lactone) acidulant and Silverleaf Nightshade extract for protein precipitation(Kim et al., 2022a; Kim et al., 2022b; Najera-Dominguez et al., 2022). The coagulation method and preparation parameters influence the texture and rheology of the cream cheese produced (Brighenti et al., 2008). After draining, the curd is cooked and cooled to 43°C to ensure proper whey removal (Johnson, 2017).

Packaging methods also affect the shelf-life of cream cheese. To improve the quality of cream cheese produced, both hot packing and cold packing methods have been used in cheese packaging. The key difference is that in hot packing, hydrocolloids are added, followed by homogenization and shearing. The curd is then heated at 80°C, packed hot and stored under refrigerated conditions (Lucey, 2003). In cold packing of cream cheese, the cream cheese procured after salting and is cooled to 4°C from 28-30°C in sterilized plastic cups (Elkot & Khalil, 2018).

### *2.2.3 Versatility of cream cheese*

Cream cheese is a versatile product that can be used as a base ingredient for the modification of other foods. The incorporation of fruits, herbs and spices into cream cheese to produce flavoured cream cheeses has been studied previously. The consumption of cream cheese is increasing due to its ability to blend with different ingredients and enhance its sensorial attributes. Table 2.1 shows some studies published on the inclusion of spices, fruits and herbs in cream cheese.

*Table 2.1 Studies on value-added cream cheese with the inclusion of fruits, herb and other plant-based ingredients.*

| Ingredients | Type | Content | Outcome | References |
|---|---|---|---|---|
| Oregano and rosemary oil | Essential oil | 0.2% | Higher oxidative and fermentative stability with low development of rancid and fermented flavour. | (Olmedo et al., 2013) |
| Cherry and strawberry vanilla | Concentrates | 21.2% | Produced flavoured-cream cheese with low viscosity | (Limanowski, 2016) |
| Lingonberries | Candied lingonberries | 10-25% | Increased antioxidant content and total polyphenol contents | (Raba et al., 2020) |
| Grumixameira | Pulp, seeds and leaves | 0.5, 1 and 2% each | Greater extraction of contents to cream cheese is from seeds. | (Graczyk de Souza et al., 2025) |
| Jujube | Jujube pulp | 0-20% | Reduced the hardness of the cream cheese and increased moisture content of the samples | (Wang et al., 2024a) |

In a study reported by Tipvarakarnkoon (2009), a combination of rehydrated coconut milk and fat-free skim-milk was used to produce a coconut cream cheese-like product using the renneting method.

### *2.2.4 Defects in cream cheese*

Cream cheese, being a milk-based emulsion gel with high moisture content, has a high probability of developing defects during manufacturing, handling, and storage. Grittiness in cream cheese arises due to the high protein content (Sainani et al., 2004). Rancid flavour development may occur due to excessive rennet or high starter culture usage. Whey separation in cream cheese occurs due to excess moisture in the samples. The texture of cream cheese becomes soft and lacks flavour when the pH is around 4.8 (Guinee & Hickey, 2009). Maintaining a fat content higher than 14 g per 100 g of cream cheese can reduce the likelihood of grainy texture formation.

The addition of gums as stabilizers can prolong the self-life of samples. Commercially, carrageenan, xanthan gum, and locust bean gum are the most used gums (Brighenti et al., 2020). These guys are added to cream cheese after the whey removal process, as they can absorb

moisture and prevent whey removal by increasing the viscosity of the cream cheese (Fox et al., 2017).

### 2.2 Cream cheese with reduced fat content

The low-fat cheese category is gaining popularity in society due to the impact of fat intake on increasing the risk of obesity, atherosclerosis, coronary heart disease, hypertension, and disorders that lead to tissue damage through lipid oxidation (Krishna & Ghosh, 2020).

Fat, being one of the main constituents in cream cheese, plays a key role in its sensorial qualities and overall quality (Sainani et al., 2004). In a study reported by Wendin et al. (2000), it was identified that the content of fat affects several factors, including appearance, flavour, taste, texture, and mouthfeel. A reduction in fat content in cream cheese results in lower spread-ability, graininess, reduced mouthfeel, and creamy textural faults.

Reduced-fat cream cheese was introduced in response to consumers' health concerns regarding fat consumption and to address the high cost of full-fat dairy products (Ningtyas et al., 2017b). Reduced-fat cream cheeses typically contain 16.55-20% fat, and the reduction in fat is compensated by increasing moisture content to 55-70% (Kim et al., 2022b). An alternative method for reducing fat in cream cheese is the use of fat mimetics or fat substitutes (Brighenti et al., 2020; K N & C Ghosh, 2020). Table 2.2 shows some studies conducted on the use of fat mimetics.

*Table 2.2 Some research involving the production of reduced-fat cream cheese.*

| Type | Fat mimetic | Procedure | Result | Reference |
|---|---|---|---|---|
| Low-fat whey less cream cheese | Inulin | Addition of 0,8,10 and 12% inulin. | The ideal concentration for low fat, cream cheese is 10%, while moisture content decreased with increasing inulin concentration. | (Fadaei et al., 2012) |
| Low-fat soft cheese with Arabic gum | Arabic gum | Addition of 2,4 and 6% Arabic gum | Addition of 4% Arabic gum produced cream cheese similar in sensory quality to full-fat cream cheese, with higher compressibility. | (Lafta et al., 2019) |
| Low-fat symbiotic cream cheese with herbal gum | Lepidium perfoliatum seed gum (LPSG) and flaxseed gum (FG) | Addition of 1% (w/w) LPSG and 1% FG containing *Bifidobacterium adolescentis* and *Lactobacillus rhamnosus* | Gums did not affect pH or acidity and improved texture comparable to full-fat cream cheese. | (Shahraki et al., 2023) |
| Reduced fat cream cheese | Inulin and whey protein concentrate (WPC) | Addition of 4% and 6% inulin and WPC | Samples with 4% WPC exhibited better sensory and textural properties than those with 6% WPC, while the sample containing 4% inulin showed better textural properties. | (K & Ghosh, 2019) |
| Fat-free cream cheese with flaxseed mucilage and probiotic bacteria | Flaxseed mucilage. | | The flaxseed mucilage improved the nutritional composition of cream cheese and reduced the pH. Its addition also helped with the survival of probiotic bacteria, improving both texture and sensory properties. | (Akl et al., 2020) |

## 2.3 Vegan cheese

Vegan cheese is a category of cheese produced from plant-based sources without the addition of animal-derived ingredients (Pm et al., 2024). This type of cheese has flourished in the markets by targeting vegans, vegetarians, those on plant-based diets and lactose-intolerant populations. (Thorning et al., 2016).

To provide vegan cheese with functional qualities comparable to those of dairy cheese, it should form an emulsion-filled gel or a multiple emulsion gel (Mefleh et al., 2022). The two common methods for producing vegan cheese, based on the main polysaccharide used, are illustrated in Figure 2.2.

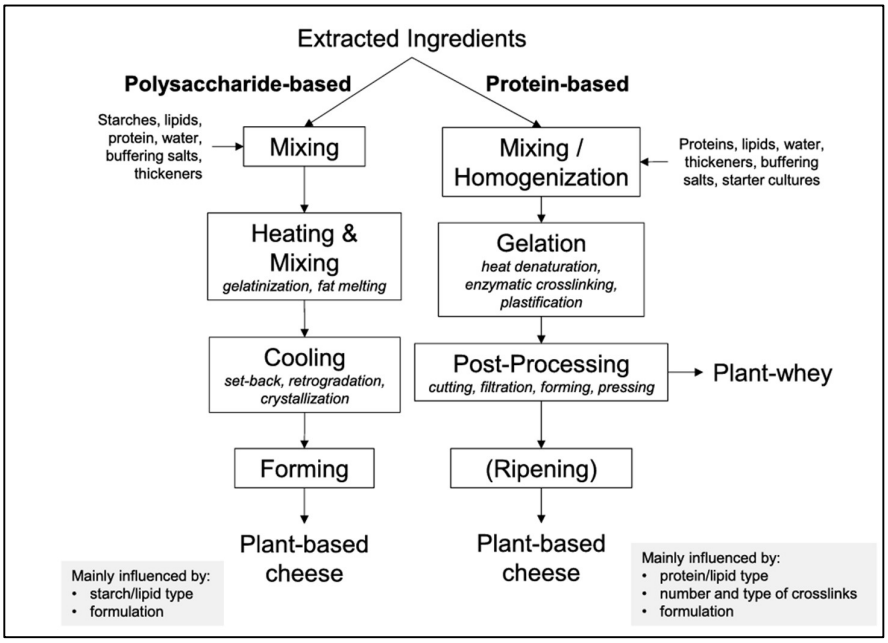



*Figure 2.2 Two mechanisms of vegan cheese production based on the materials used (Grossmann & McClements, 2021).*

The formation of a semi-solid curd at high temperatures results in water absorption by starch granules. Upon cooling, these granules become entangled, trapping oils and water, and leading to partial coalescence of fats, which gives the characteristic consistency of cheese (Grossmann & McClements, 2021). In protein-based vegan cheese manufacturing, plant protein colloids approximately 200 nm in size, similar to casein micelles, are formed under heating, specific pH and ionic strength conditions. However, these protein aggregates exhibit different properties

than casein due to their distinct surface chemistry and composition, resulting in alternative gelation behaviour and aggregation properties (Grossmann & McClements, 2021).

### *2.3.1 Vegan cream cheese analogue*

Vegan cream cheese can be defined as a high-moisture cheese analogue with a spreadable nature (Michel et al., 2022). The growing consumer demand for plant-based diets and dairy-free alternatives has been a key driver in the innovation of vegan cream cheese (Michel et al., 2022). Several studies have been conducted on the production of cream cheese analogue products, some of which are listed in Table 2.3.

*Table 2.3 Some studies on vegan-cream cheese analogue products*

| Type | Ingredients | Result | Reference |
|---|---|---|---|
| Citrus fibre-enriched vegan cream cheese | Citrus fibre, lactic acid, potassium sorbate, gellan gum, cheese flavour, coconut oil | Sample with 1.4% citrus fibre had higher acceptability compared to commercial vegan cream cheese. | (Gurbuz et al., 2024) |
| Soy-based cream cheese with hydrocolloids and maltodextrin | Soya milk, calcium sulphate (coagulant), palm oil, carrageenan, pectin, maltodextrin | The product had lower elasticity. Maltodextrin provided bulk; carrageenan and salt added firmness, while pectin increased viscosity and spreadability. | (Zulkurnain et al., 2008) |
| Soy-coconut milk combined with cream cheese | Soy milk, coconut milk, cocoa powder, lemon juice, sucralose, oil | The colour of the cream cheese was highly affected by the presence of cocoa powder. | (Sakpal & Jaisinghani, 2025) |

Bemer et al. (2016) used vegetable oleo gels made from rice bran wax or ethyl cellulose as organogelators in combination with vegetable oils and other non-fat ingredients to reduce the fat level by up to 25% in comparison to commercial full-fat cream cheese. In another study reported by Brighenti et al. (2020), it was suggested that vegetable organogels could be used to replace between 4.08 and 6.43% fat in cream cheese, though the impact may vary depending on the type of organogel used.

Another study investigated the blending of soy milk with coconut milk to produce cream cheese with better acceptability than soy milk-based cream cheese alone (Halim et al., 2022; Zulkurnain et al., 2008). Although many studies have been conducted on using coconut milk in combination with other milks to produce vegan cream cheese, only a limited number have

focused on the use of hydrocolloids to produce vegan cream cheese solely from coconut milk (Mazalana et al., 2024).

### 2.4 Coconut milk

Coconut milk is a plant-based milk extracted from the kernel of the coconut palm (*Cocos nucifera*). It has a unique taste, high nutritional value, and is widely used in beverages and ice cream (Chen et al., 2024a). According to WHO standards, commercial coconut milk should contain 87.3% moisture, 10% fat and 2.7% protein, with a pH of 5.9 (CODEX, 2003). The protein content in coconut milk is similar to that in dairy milk, but the fat content is ten times higher than that found in dairy milk (Nadeeshani et al., 2015).

The presence of medium-chain triglycerides (MCTs) in coconut milk helps promote good cholesterol levels, improve insulin sensitivity, and support weight management (Hewlings, 2020). Consumption of coconut milk has shown to increase HDL (good) cholesterol levels and reduce LDL (bad) cholesterol levels, benefiting heart health, while serum lipid levels remain unaffected (Fernando et al., 2015). The absence of lactose in coconut milk makes it an ideal substitute for developing dairy-free or analogue products for people who are lactose intolerant (Tulashie et al., 2022).

Commercially available coconut milk is categorized into four types based on fat content: light coconut milk (fat ≥ 5%), coconut milk (fat ≥ 10%), coconut cream (fat ≥ 20%), and coconut cream concentrate (fat ≥ 29%) (Pak, 2023). Table 2.4 presents the standards for the composition of commercial coconut milk and coconut cream. Codex defines the quality criteria for coconut milk and coconut cream to include normal colour, flavour, and odour characteristics, and permits the addition of coconut water, maltodextrin and sodium caseinate (CODEX, 2003).

Coconut milk is available in various forms, including canned milk, powder, and aseptically packed products in pouches or Tetra Paks (Karunasiri et al., 2020). Canned coconut milk is produced using fat-adjusted pasteurized coconut milk to which stabilizers may be added, followed by homogenization. The mixture is then canned and retorted before storage (Chiewchan et al., 2006). Coconut milk powder is a dehydrated form of coconut milk that can be reconstituted with water to create a stable emulsion (Zafisah et al., 2017). It is commercially produced by spray drying, often with the addition of maltodextrin, casein, skim milk or corn syrup powder as encapsulating agents (Yulistiani et al., 2023). Studies on the comparison freeze drying with spray drying for coconut milk powder production have shown that freeze drying is a lengthier process that yields a free-flowing dried powder with low moisture content than

spray drying (Zafisah et al., 2017). Another effective method for coconut milk powder production is foam-mat drying assisted with infrared and convective hot-air drying, particularly when operated at 65°C (Pandiselvam et al., 2025).

*Table 2.4 Composition of fresh coconut milk in tropical countries*

| | Canned products [a] | | | | Spray-dried products [a] | Raw coconut milk [b] |
|---|---|---|---|---|---|---|
| **Constituent (wt%)** | **Thailand** | **Malaysia** | **Singapore** | **West Somalia** | | |
| Moisture | 76.2 | 78.8 | 84.4 | 75.8 | 2.2 | 67.3 |
| Fat | 15 | 14 | 11 | 18.4 | 63.6 | 23.8 |
| Solids non-fat | 9 | 7.2 | ND | ND | ND | 8.9 |
| - Protein (N x 6.25) | 0.3 | 0.3 | 0.5 | 0.9 | 4.5 | 2.9 |
| - Ash | ND | ND | ND | ND | ND | 0.7 |
| - Carbohydrates* | 8.1 | 6.2 | 3.5 | 4.5 | 28.7 | 5.5 |
| - Minerals | 0.4 | 0.7 | 0.6 | 0.7 | ND | 0.7 |
| - Free fatty acid | 0.2 | ND | 0.3 | 0.5 | ND | ND |
| - Crude fibre | ND | ND | ND | ND | ND | 2.2 |
| pH | 6.2 | ND | 6 | 6.3 | ND | ND |

*ND = Not Determined
*Carbohydrates calculated by difference
Adopted from [b] (Tulashie et al., 2022) and [a] (Chalermnon, 2013)

### *2.4.1 Extraction of coconut milk*

Green or young coconuts, with a maturity of 12-14 months and tender meat, are commonly used for coconut milk extraction. Coconut milk is obtained from grated coconut kernel meat with or without the addition of water (Ephraim Edem & Isaac Elijah, 2016). The extraction method generally involves size reduction and compression of the coconut meat to extract the coconut milk (Babatunde Victor et al., 2023). The characteristics of the coconut milk produced, such as pH, viscosity, and total solids, as well as the yield of milk, are highly dependent on factors like extraction time, extraction temperature and particle size of the coconut meat (Ephraim Edem & Isaac Elijah, 2016). Domestically, fresh coconut milk is prepared by blending scraped coconut milk with water and using a strainer to collect the coconut milk (Karunasiri et al., 2020). The commercial extraction process of coconut milk has been described by (Seow & Gwee, 2003) where the steps include husking, removal of the testa, washing, draining and machine grating. In industrial settings. screw presses or hydraulic presses are used for extraction, followed by centrifugation, cloth filtration or micro fluidization to produce a stable emulsion with fine coconut particles (Deng et al., 2022). Commercially available coconut milk may also contain added stabilizers or emulsifiers to enhance shelf-life.

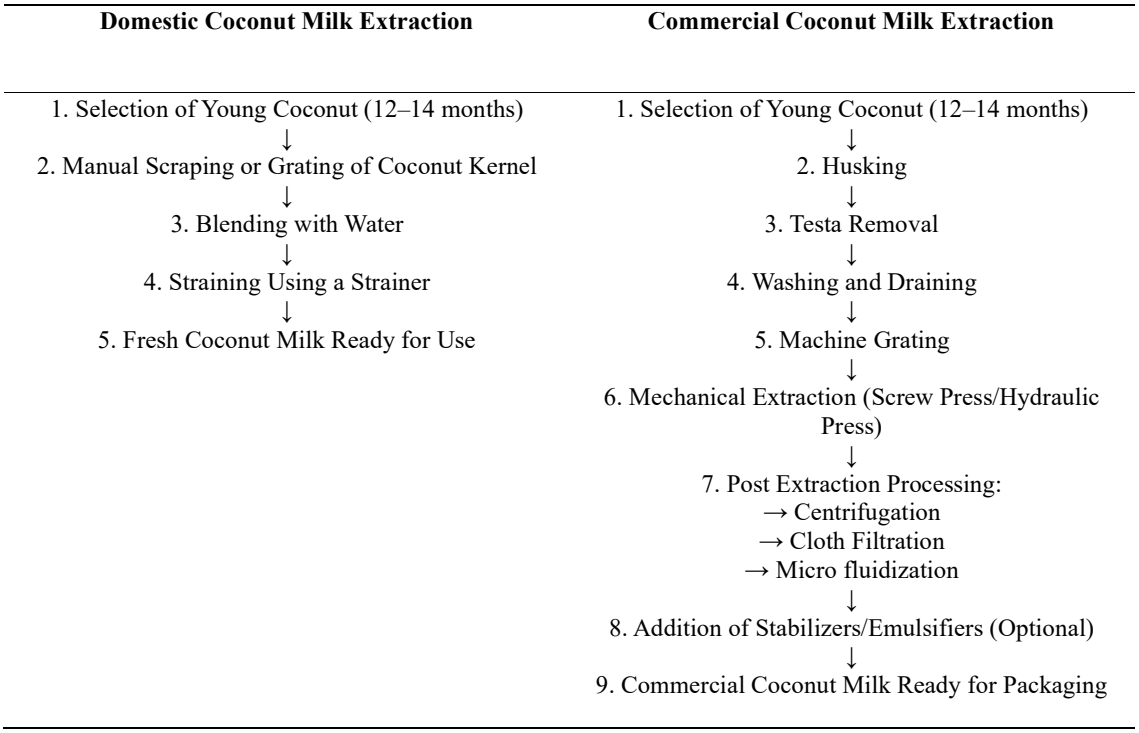



*Figure 2.3 Flow chart of coconut milk extraction.*

Compounds such as peroxidase and polyphenol oxidase in coconut milk can lead to discolouration and off-flavour development if not treated properly (Deng et al., 2024). Blanching and freezing of coconut kernel before milk extraction have been shown to result in more uniform milk yield and a reduction in lipase and peroxidase activity (Waisundara et al., 2007). Although pasteurized coconut milk (72°C for 20 minutes) packed in laminated pouches made of nylon polyethylene and aluminium polyethylene can be stored at 4°C for 4 weeks, better flavour compound retention in coconut milk is achieved with UHT treatment (130°C for 5 s), which may preserves the quality of coconut milk (Ambigaipalan et al., 2008; Deng et al., 2024).

### *2.4.2 Chemical composition and physical properties of coconut milk*

Coconut milk is an oil-in-water emulsion of coconut oil, stabilized by phospholipids and proteins (Patil & Benjakul, 2018). Its composition is highly dependent on the raw material, maturity of the coconut, geographical origin, and the extraction method used during production(Chalermnon, 2013). The oil droplets in coconut milk carry a surface charge of approximately -16 mV at the normal pH range of 6.1-6.3. These droplets typically have an average diameter of 10μm, with a volume-weighted mean diameter ($d_{43}$) of 11-12 μm, exhibiting a bimodal size distribution (Chalermnon, 2013; Tangsuphoom & Coupland, 2008).

Coconut milk tends to undergo stratification and instability due to its limited emulsifying properties, leading to the separation of the emulsion into two layers under gravity: a lighter cream layer and a heavier aqueous phase (Sun et al., 2022). Occasionally, grey precipitate, serum, cream, and oil can be observed after storage (Jiang et al., 2016).

Coconut milk exhibits non-Newtonian flow behaviour characterized by pseudoplasticity (Chiewchan et al., 2006; Tangsuphoom & Coupland, 2006). Heat-treated and homogenized coconut milk exhibits a non-Newtonian flow pattern, with a flow behaviour index of 0.719 to 0.971, lower than 1.0, which is typical for Newtonian fluids (Chalermnon, 2013). Micro-fluidization can induce higher viscosity and stability by enhancing droplet interactions and reducing droplet size (Thirukumaran et al., 2023). Abdullah et al. (2018) reported that ultrasonication, used as a method for homogenization with added sodium caseinate as an emulsifier, resulted in phase separation within 24 hours when lower concentrations of emulsifier were used.

*2.4.3 Coconut oil and coconut protein*

Coconut oil contains 40-50% lauric acid in its fatty acid composition, earning it an alternate name “lauric oil” (Deen et al., 2020). The main fatty acids found in coconut milk are lauric, palmitic and stearic acids, as shown in Table 2.5, which are saturated, along with the unsaturated oleic acid (Waisundara et al., 2007). These fatty acids are called medium-chain fatty acids (MCFAs) and have nutraceutical benefits similar to those found in human milk (S & Raghavarao, 2010). The saturated fatty acid concentration of coconut oil is around 92%, which is the highest among vegetable oils. In addition to triglycerides, coconut oil also contains phospholipids, sterols, tocopherols and volatile substances (Deen et al., 2020).

*Table 2.5 Fatty acid composition of coconut oil*

| Type | Fatty acid | Content (%) |
|---|---|---|
| Saturated fatty acids | Lauric acid | 52-45 |
| | Myristic acid | 21-16 |
| | Palmitic acid | 10-7 |
| | Caprylic acid | 10-5 |
| | Capric acid | 8-4 |
| | Stearic acid | 4-2 |
| | Caproic acid | 1-0.5 |
| | Palmitoleic acid | Trace |
| Unsaturated fatty acids | | |
| | Oleic acid | 8-5 |
| | Linoleic acid | 3-1 |
| | Linolenic acid | 0.2 |

Globulins (61.9%), albumins (30.6%), glutenin (4.1%) and prolamins (1.1%) are the protein fractions found in coconut milk (Chen et al., 2024b). Cocosin, an 11S globulin, is identified as the predominant globulin protein (86%) in coconut endosperm. It contributes to the emulsifying properties of coconut milk through electrostatic repulsion and steric hindrance, preventing droplet aggregation by surface adsorption at oil-water interfaces (Tangsuphoom & Coupland, 2009). In addition to cocosin, a 7S globulin present in coconut milk is structurally similar to the 7S globulin found in other plant proteins (Chen et al., 2024b). The isoelectric point of coconut protein is approximately pH 4, at which protein solubility is at its lowest and protein aggregation is most favoured. The solubility of coconut proteins increases under strong acidic or alkaline conditions (Meenmanee et al., 2022).

*2.4.4 Stability of coconut milk*

The stability of coconut milk is governed by intrinsic factors, such as pH and protein content (Patil & Benjakul, 2018). An emulsion of coconut oil as the dispersed phase is created when coconut meat is ground with or without the addition of water, to produce coconut milk. These oil particles become destabilized, even in the presence of aqueous-phase albumin and globulin proteins, due to creaming, flocculation and coalescence (Thirukumaran et al., 2023). The separation of coconut milk into two phases creates ideal conditions for microbial spoilage.

UHT and retort processing are the most common methods for extending the shelf-life of coconut milk (Tiravibulsin et al., 2021). Studies have shown that flavours in canned coconut milk are affected during storage by compounds including alcohols, 3-methyl-2-(5H)-furanone, lactones and acids (Tinchan et al., 2015). Homogenization of coconut milk at 5000 psi using a single-stage homogenizer produces a more stable product than homogenization at 1000 psi. However, greater stability is achieved when two-stage homogenization is applied on the coconut milk with an initial pressure of 1000 psi followed by 2000 psi, as reported by (Chiewchan et al., 2006). Studies on processing temperature by Simuang et al. (2004) suggested that coconut milk exhibits pseudoplastic behaviour at higher temperatures, which is also influenced by the fat concentrations of the coconut milk.

**2.5 Coconut-based cheese**

Coconut milk has been used in combination with several other plant-based milks to produce cheese and cream cheese analogues. Some of these studies are presented in Table 2.6.

*Table 2.6 Some studies on coconut-based cheese production*

| Type | Ingredient | Coagulant | Result | Reference |
|---|---|---|---|---|
| Coconut milk cheese | Coconut milk and soy milk (80:20; 70:30; 60:40) | Lemon extract | Yield and spreadability decreased with the addition of soymilk. | (Halim et al., 2022) |
| Cheese from coconut milk | Coconut milk and full cream milk (ratios from 80:20 to 20:80) | | Protein content decreased, while ash, fibre, moisture and fat content increased with more coconut milk. | |
| Non- dairy cheese analogue | Soy milk and coconut milk-blended (90:10; 80:20; 70:30; 60:40; 50:50) | Heat treatment at 63°C for 30 minutes and renneting at 31°C with 0.1% rennet. | The 50:50 blend had the highest sensory scores, especially for colour, but scored lower for taste. | (V et al., 2019) |
| Traditional cheese (Warankash) | Cow's milk partially substituted with coconut milk (5:95; 10:90; 15:85; 20:80; 25:75; 30:70 v/v) | Addition of *Calotropis procera* leaves at 50°C and cooling to 40°C | Fat and protein levels increased with coconut milk addition. 5-10% substitution was most preferred. | (Balogun et al., 2016) |
| Cheddar-like cheese analogue | Coconut cream, agar powder, tapioca starch, salt, water | ND | Acceptability was similar to dairy-based cheddar cheese, except for the colour difference. | (Ismail et al., 2021) |

The key reasons for using coconut milk in these studies were its ability to produce vegan cheeses with texture profiles raging from sliceable to meltable characteristics (Tangsuphoom & Coupland, 2008).

**2.6 Factors influencing cream cheese rheology.**

The rheological properties of cream cheese are directly dependent on fat concentration and production methods (Bot et al., 2007). These properties are also highly influenced by the dispersed phased (fats) in the cream cheese matrix, including fat type, concentration, and the distance between fat globules.

A pH higher than 4.7 results in a softer texture, while a pH lower than 4.6 produces a grainy texture (Ong et al., 2020). Although the rheology of these gels is affected by both the dispersed phase and dispersion medium, the properties of emulsion gels primarily depend on the network that holds the emulsion droplet aggregates (Geremias-Andrade et al., 2016). As an emulsion gel, the dispersed phase (fat) is bound within a gel network and stabilized by emulsifiers.

**2.7 Emulsion stability**

Emulsion stability can be defined as the ability to preserve its original physicochemical properties over time (Hu et al., 2017). The inherent tendency of a liquid/liquid mixture to diminish its interfacial interactions (and/or interfacial energies) makes an emulsion an unstable system (Goodarzi & Zendehboudi, 2018). The compositional components and processing conditions of emulsions affect their stability, which is determined by the properties of the droplets they contain. Concentration, size, charge, interaction and rheological behaviour of the droplets are all significant properties in an emulsion (Hu et al., 2017). This natural thermodynamic instability of emulsions can cause oil-in-water emulsions to separate into their original aqueous and oil phases. The interactions responsible for emulsion stability are generally classified as steric interactions and electrostatic interactions. The mechanisms causing emulsion destabilization are illustrated in Figure 2.3 and include creaming, sedimentation, flocculation, coalescence, phase separation, and Ostwald ripening.

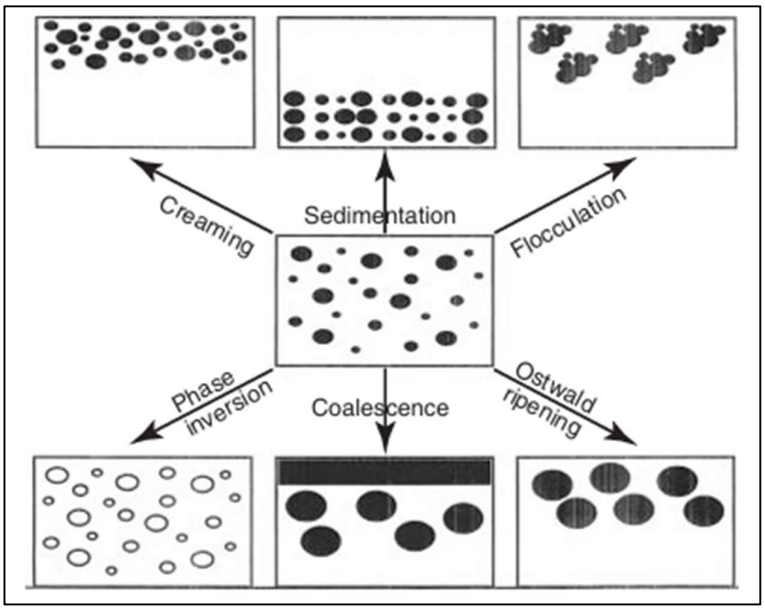



*Figure 2.4 Representation of breakdown processes observed in emulsions (Tadros, 2013).*

### *2.7.1 Creaming and sedimentation*

The particles in emulsions (continuous phase and dispersed phase) may have distinct densities. The influence of gravity or centrifugal force on these systems can cause lighter droplets to ascend and denser droplets to descend. This separation can lead to phase separation. The rise of the lighter droplets is called creaming, while sedimentation refers to the sinking of the heavier particles.

In an oil-in-water emulsion, the oil droplets usually have a lower density than the water, causing creaming of the oil droplets and sedimentation of the water. The rate of separation can be theoretically calculated using the Stoke's law as shown in Equation 2.1.

*Equation 2-1*

$$\nu = \frac{2r^2\Delta\rho}{9\eta}$$

The parameters involved in the calculation are $v$ (creaming rate), $g$ (acceleration due to gravity), $r$ (droplet radius), $\rho$ (density difference between particle and fluid) and $\eta$ (viscosity). As indicated, Stoke's law shows that the creaming velocity can be regulated by several approaches, such as reducing droplet diameter, enhancing the viscosity of the continuous medium, and minimizing the density difference between the continuous and dispersed phases.

### *2.7.2 Flocculation*

Flocculation is a type of aggregation that occurs in oil-in-water emulsions, in which dispersed phase droplets come into close proximity and form clusters known as flocs. The primary reason for flocculation is the reduced steric repulsion experienced at intermediate distances, dominated by van der Waal forces (Dickinson, 2019).

### *2.7.3 Coalescence*

Coalescence is the formation of a single large droplet by the merging of two or more liquid droplets under collision (Liao & Lucas, 2010; Ravera et al., 2021). The susceptibility of droplets to coalescence depends on physical mechanisms affecting the droplets (Brownian motion, gravity, shear force, and turbulence), interactions between droplets (colloidal and hydrodynamic forces), and the mechanical stability of the inter-droplet film (McClements, 2015).

### *2.7.4 Ostwald ripening*

Ostwald ripening occurs due to diffusive fluxes between droplets, leading to the dissolution of the dispersed phase and the growth of larger droplets at the expense of smaller ones (Ravera et al., 2021; Zwicker et al., 2015). The solubility of dispersed droplets increases with decreasing droplet size, thus influencing the overall droplet size distribution in the emulsion. The rate of this process depends on the interfacial surfactants and the rheological properties of the emulsion (Ravera et al., 2021). The application of shear can be used to suppress Ostwald ripening (Zwicker et al., 2015). Ostwald ripening is prevalent in emulsions containing long-chain triglycerides with alcohol as the aqueous phase, whereas is negligible in emulsions with long-chain triacylglycerols as the oil phase (McClements, 2015).

### *2.7.5 Phase Inversion*

Phase inversion refers to a change in emulsion morphology, where the continuous and dispersed phases switch roles (Jiang et al., 2022). These inversions are influenced by the physical properties of the system, including particle size, particle size distribution, volume fraction, phase chemical composition and mixing speed (Maffi et al., 2020). Phase inversions do not occur in gel emulsions (Jiang et al., 2022).

## 2.8 Food hydrocolloids

Hydrocolloids include polysaccharides and some proteins that have a plant-based or microbial origin, or are modified biopolymers produced by chemical or enzymatic modification of starch

or cellulose (Dickinson, 2003). These are universally used for their functions as thickening and gelling agents, stabilizers of food dispersions, and encapsulation and delivery carriers for functional ingredients and their controlled release (Fang et al., 2021).

The selection of hydrocolloids is driven by the required functional properties, although price and supply security invariably also play a role (Williams & Phillips, 2021). In addition to textural and rheological enhancements, hydrocolloids also act as dietary fibres and gut health modulators (Hollingworth, 2010). The application of hydrocolloids in low-fat, low-sugar, and gluten-free foods has been well studied over the last few decades. The market demand for food hydrocolloids is expected to grow to $14.07 billion in 2025, compared to $12.08 billion in 2024, with a CAGR (compound annual growth rate) of 8.4% (The Business Research Company, 2023).

Ions are present in foods as minerals in relatively low concentrations. These ions, for example $H^+$, $Na^+$, $K^+$ and $I^-$, form specific or non-specific bonds with hydrocolloids, which can generate an "ion atmosphere" if constantly presence. This ion atmosphere can influence the solubility and rheological properties of hydrocolloids through hydration effects or electrostatic interactions.

*2.8.1 Waxy corn starch*

Corn starch is composed of amylose and amylopectin, along with protein (0.35%) and lipid (0.08%), with starch granules ranging in size from 2 to 30 μm (BeMiller, 2019). Waxy corn starch is used in this thesis, and more details are reviewed as follows.

The highly branched, amylopectin-rich starch from corn is classified as waxy corn starch, and it has a high affinity for water (Li et al., 2025). The high rapidly digestible starch (RDS) content in waxy corn starch can elevate blood glucose levels due to its fast digestion process (Zheng et al., 2021). The unique functional properties provided by its high amylopectin content include clarity, mix stability and improved viscosity, which largely depend on the distribution of *A, B1, B2* and *B3* chains in the starch structure (Yang et al., 2019).

*2.8.2 Non-starch hydrocolloids*

Several commercial formulations of dairy cream cheese use starch and other gums in combination to enhance the stability, texture and rheology of cream cheese. In this study, a combination of xanthan gum and locust bean gum was used in the formulation of coconut cream cheese as a stabilizer. Therefore, it is important to discuss the characteristics of these hydrocolloids in general and their synergistic effects in the following sections.

2.8.2.1 Xanthan gum

Xanthan gum is produced due to the fermentation of glucose or saccharose media by *Xanthomonas spp* as an heteropolysaccharide having an anionic charge. The structure of xanthan consists of D-glucose, D-mannose, and D-glucuronic acid with a molar ratio of 2:2:1, where the backbone is arranged similar to cellulose with (1 → 4)-linked β-D-glucose with every second glucose residue having a trisaccharide side linked (Brunchi et al., 2023; Kang et al., 2023).

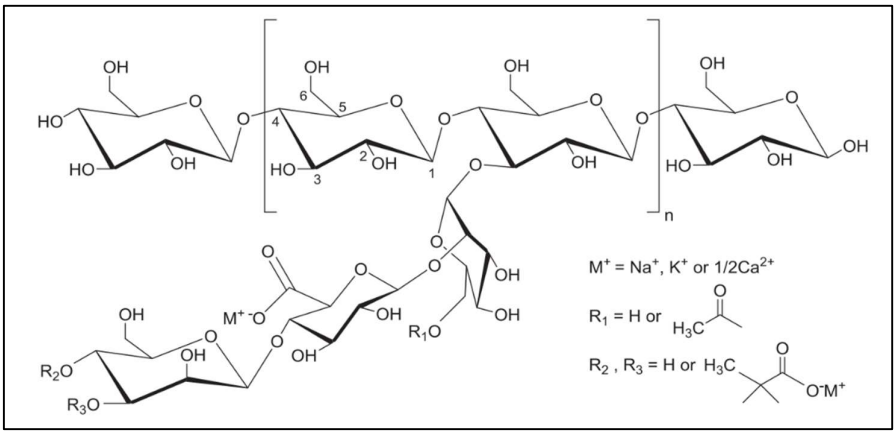



*Figure 2.5 Chemical structure of xanthan gum (Ong et al., 2018).*

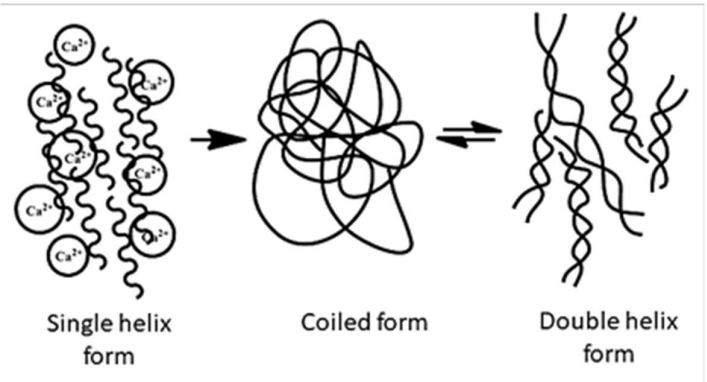



*Figure 2.6 Conformational changes in xanthan gum structure (Jadav et al., 2023).*

Its trisaccharide side chains and helical organization under normal temperatures enable them exceptional stability in different foods with acidic and basic pH conditions (from pH 2.5 to11)

(Kashaudhan et al., 2023).The xanthan gum exists as a coaxial double helix in an ordered condition below 40℃ and attains a disordered random coil structure at higher temperatures (Ong et al., 2018)

Xanthan forms a non-Newtonian fluid and extreme pseudoplastic solutions when mixed with aqueous media in hot or cold conditions. The effect of temperature and polymer concentration of xanthan in aqueous media have been investigated by (Brunchi et al., 2023) and identified that xanthan gum solutions follow pseudoplastic behaviour regardless of concentrations and temperatures. Xanthan is observed to produce low viscosity at 20℃ and 40℃ dissolution temperature, whereas at 40℃ to 60℃ they have higher thickener behaviour due to their disordered structures (Casas & Garcia-Ochoa, 1999). Its large molecular weight and unusual chemical structure are responsible for its pseudoplasticity, thickening and rheological qualities, as well as its resistance to alkali, acid, and heat (Hu et al., 2019).

The significance of xanthan gum alone in the production of vegan cream cheese is vast due to its ability to improve the textural and rheological properties of a solution. Xanthan have been linked to low fat dairy products with reducing syneresis and maintaining stable gel networks (Portaghi et al., 2023). Xanthan has proved its ability to replicate the creamy mouthfeel of higher fat content in stringy cheeses, thus providing a rich and indulgent sensory experience (Oberg et al., 2015).

2.8.2.2 Locust bean gum

Locust bean gum (LBG), also known as Carob gum (E410), is a polysaccharide of non-ionic galactomannan or is made up with a β-(1-4)-mannose backbone with irregularly branched α-(1-6)-galactose units at a ratio of 4:1 respectively, making a high weighted molecule (Petitjean & Isasi, 2022). The gum is extracted from the kernel endosperm of the seed. Generally, locust bean gum solutions do not exhibit gelling properties under normal conditions; the presence of borate or a large amount of saccharose and freeze-thaw treatments induce gelling of locust bean gum. LBG is slightly soluble in cold water due to the low degree of galactose substitution on mannose chain and requires a temperature of up to 80°C to achieve maximal dissolving and viscosity (Nasrallah et al., 2024; Barak & Mudgil, 2014). Locust bean gums are non-ionic hydrocolloids, which make them tolerant against pH, salts and heat treatments (Barak & Mudgil, 2014). Locust bean is seen to have smooth region or free radicals without galactose linkages or hairy zones with a large number of galactose regions depending on the dissolution temperature (Casas & Garcia-Ochoa, 1999).

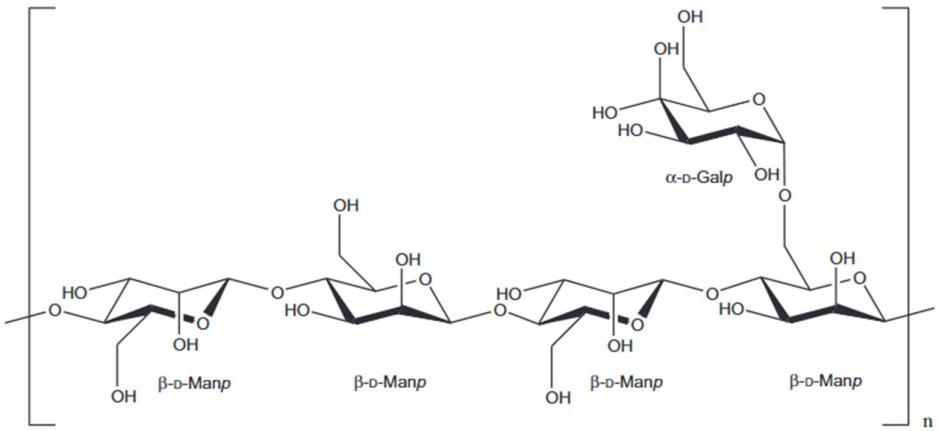



*Figure 2.7 Locust bean gum representation(Food) et al., 2017).*

Brighenti et al. (2020), in their study on the incorporation of vegetable organogels into cream cheese, reported that LBG alone produced an entangled polymer solution when used in the ice cream formulation, whereas a combination of xanthan and LBG formed a gel. LBG is extensively used in the yoghurt industry to influence the textural properties that give more emphasis on consistency and viscosity (Macit et al., 2019).

**2.9 Hydrocolloid-hydrocolloid interactions**

These non-covalent interactions between starch, polysaccharides and proteins in food matrix contribute to achieving desired properties and consistency in food formulations (Gao et al., 2017). Phase separation occurs more frequently than compatible mixture formation due to the low entropy gain produced during mixing.

Phase separation is categorized as segregative or associative, depending on the nature of the interactions between hydrocolloids. Segregative phase separation occurs between two similarly charged hydrocolloids, two neutral hydrocolloids, or one charged and one neutral hydrocolloid. This can be explained by the fact that the enthalpy of heterotypic interaction is less favourable than that of homotypic interaction. Associative separation occurs between oppositely charged molecules or when the enthalpy of heterotypic interaction is more favourable than that of homotypic interactions.

*2.9.1 Xanthan and locust bean interaction*

The interactions between xanthan gum and galactomannans have been widely studied and remain a topic of debate. Mannion et al. (1992)reported that the solid-like behaviour of xanthan-LBG mixtures above 70°C was primarily dependent on LBG, whereas at room

temperature, it was mainly governed by the xanthan gum helix. Studies have suggested that the mass of xanthan gum and LBG has an evident effect on the synergistic interaction. Xanthan at low concentration with LBG gives maximum viscosity under the same operational conditions, which was also notified in their studies with gels made of xanthan and locust bean gum (Garcia-Ochoa & Casas, 1992; Tako et al., 1984). Previous research also derived that the interaction between the gums also dependent on the gum ratio in the mixture. According to Zhang et al. (2023), 3:7 mixture ratio of xanthan to locust bean gum was the ideal mix for strong interaction and gel strength, showing dense gel network formation. While other studies suggest that dynamic moduli are higher with 1:2 mixing ratio of xanthan to locust bean gum, 6:4 ratio of xanthan and locust bean gum offered flexible and stronger attraction. However, Tako et al. (1984)suggested the possibility of xanthan gum side chain interacting with locust bean gum backbone while Garcia-Ochoa and Casas (1992) suggested the high temperature treatments of xanthan leads the confirmation to a disordered structure which has minimal interaction which causes the low viscosity and the interaction of double helicoidal structure of xanthan with unsubstituted mannosyl residue of locust bean gum forms an association. Xanthan and galactomannan interactions have a maximum viscosity at 60°C when combined, and to achieve this the mixture should be dissolved at 80°C (Casas & Garcia-Ochoa, 1999).

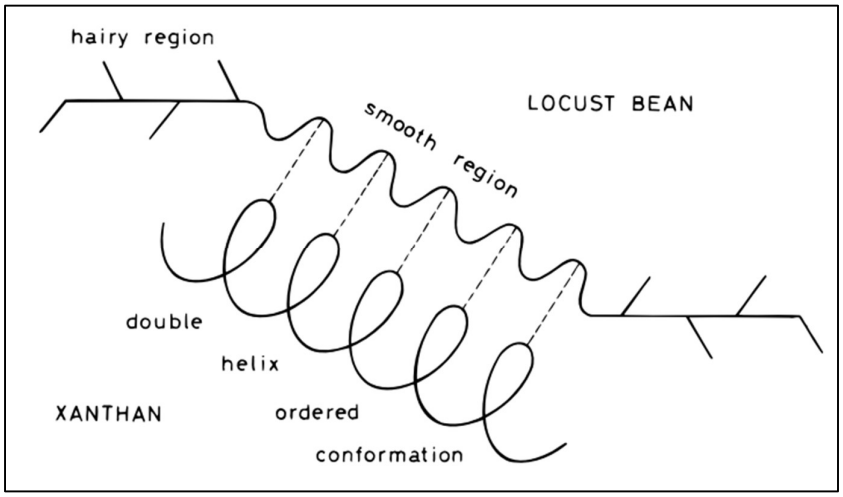



*Figure 2.8 Xanthan and locust bean molecule interactions in solution (Casas & Garcia-Ochoa, 1999).*

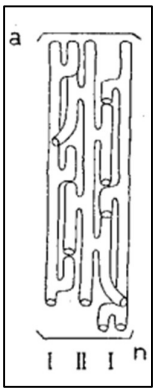



*Figure 2.9 Representation of xanthan locust bean interaction model predicted by(Tako et al., 1984).*

The recent studies conducted by (Wang et al., 2023) have identified different structures for different confirmations exists for xanthan and locust bean gum combined where, xanthan side chain interaction happens in ordered helix confirmation due to electrostatic interactions and backbone interaction is promoted in disordered conformation via hydrogen bonding.

The impact of locust bean gum and xanthan combination is by interaction with surfactants or by increasing viscosity of the water layer to stabilize emulsions rather than acting like emulsifiers which bind to the hydrophobic and lipophobic groups.

## 2.10 Microstructural analysis

Microstructural analysis can be used in foods for direct visualization of their three-dimensional arrangements. Knowledge of these arrangements can be correlated with the texture, rheological and organoleptic attribute data to understand the behaviour of different foods (Rao, 2007).

Confocal laser scanning microscopy (CLSM) is an optical imaging technique used in microstructural analysis of food by overlaying two-dimensional micrographs to generate a three-dimensional structure using computerized image analysis (Everett & Auty, 2008). This technique is different from widefield microscopy as image capture is restricted to the focal plane, with the laser scanning initiated only when the laser is triggered (Canette et al., 2025). CLSM uses fluorescent dyes that selectively bind to specific molecules in food samples to examine interactions and their relative positions in the matrix (Everett & Auty, 2008).

CLSM has been implemented in many studies related to cream cheese and has effectively compared imaging results with texture, rheological, and composition data. For example, CLSM

has been used to study the effects of freezing and thawing on the structure of cream cheese, identifying fat destabilization and protein clustering in the post-thaw stage (Alinovi et al., 2020).

## 2.11 Rheological properties

Rheology is used to understand the texture of foods and correlate it with sensory analysis, significantly impacting food product development. Changes in formulation, equipment used, and manufacturing procedures for emulsions are greatly affected by rheological measurements (Taslikh et al., 2021). Strain or stress tests conducted on cream cheeses can be used to understand the rheological properties of cream cheese. The influence of fat, protein interaction, and moisture distribution in cream cheese can be assessed through viscosity, elasticity, and rheological data.

Furthermore, the flow curve evaluations of food can be used to assess the complex models. It has been noted in previous studies that Herschel Bulkley model is most appropriate rheological model with yield stress and shear thinning characteristics.

*Equation 2-2*

$$T = \Upsilon nKH + T0$$

The T0 value (measured in Pa) being the minimum value required to initiate the flow within material, while $K_H$ (also called consistency index, measured in $Pa.s^{n)}$ represents the thickness of the system, and n value denotes the deviation from Newtonian fluid behaviour. Y denotes the shear rate of the system at stresses above yield stress. If n<1, they have a shear thinning nature, while n>1 shows a shear thickening behaviour. Non-linear regression is performed with sensible estimated values for the initial parameters to understand true nature of the sample (Akmal, 2017).

### *2.11.1 Measurement of rheological properties*

Rheological measurements of complex fluid systems can be characterized using small amplitude oscillatory rheology (SAOR), which is the most widely used method for analysing cream cheese. This method is highly reliable for evaluating emulsion gels. The measurement of G' (storage modulus) and G" (loss modulus) can be carried out to understand the linear viscoelasticity of cream cheese. G' represents the solid-like behaviour of a material, indicating the energy stored and recovered per cycle, whereas G'' indicates the liquid-like behaviour, representing energy dissipated as heat. A sample exhibiting a solid-like behaviour has a higher

G' value than G" when measured at the same frequency. The comparison of these values over different storage periods can be used in a way to monitor sample stability.

Stress or strain sweeps, carried out on the samples by changing the amplitude of input signal at a constant frequency, are used to study the rigidity and structural integrity of materials (Geremias-Andrade et al., 2016; Kavanagh & Ross-Murphy, 1995).

Apparent viscosity can also be measured in relation to shear using a dynamic shear rheometer under controlled shear rate and temperature to understand the flow behaviour of samples. This method is widely used in cream cheese studies (Bayarri et al., 2012; Geng et al., 2008).

### 2.12 Texture measurements

Texture is a combination of sensory experiences perceived through touch, vision, and hearing (Bourne, 1982). The International Organization for Standardization defines texture as "all the mechanical, geometrical and surface attributes of a food product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors". Texture plays a vital role in consumer acceptance of food products. In cream cheese, texture is influenced by several factors, including the raw materials used, fat content, the use of stabilizers, and production conditions. Common texture parameters assessed in cream cheese include firmness, spreadability, and adhesiveness (Bayarri et al., 2012).

Textural parameters of cream cheese are assessed using a Texture Profile Analysis (TPA), as shown in Figure 2.10. The most common method used in TPA for cream cheese is double compression, which is used to measure firmness, spreadability, adhesiveness, cohesiveness and gumminess. TPA has been applied in numerous cream cheese studies. For example, to analyse cream cheese samples with different fat contents (Ningtyas et al., 2017b) and in low-fat cream cheese produced using Lepidium perfoliatum seed gum and flaxseed gum (Shahraki et al., 2023).

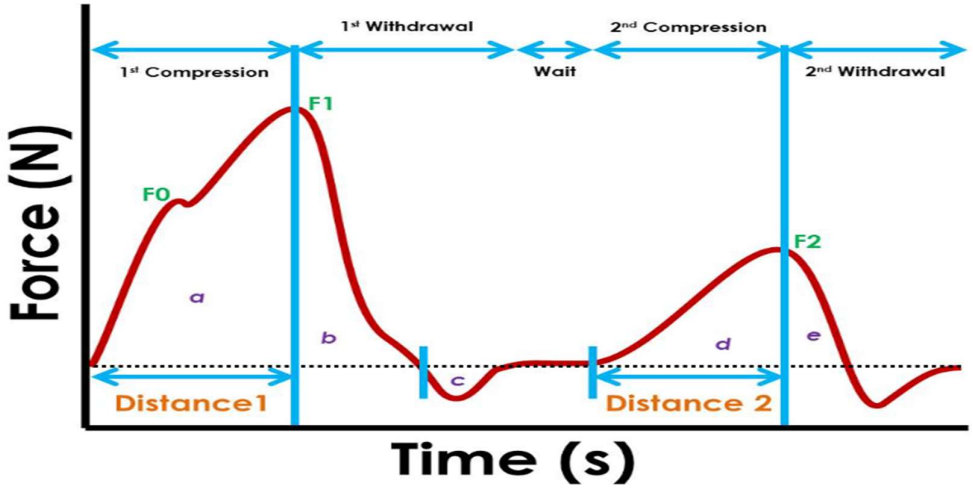



*Figure 2.10 Texture analysis and texture profile analysis (TPA) (rheology, 2020).*

a= area between time and force graph during first compression until reaching F1 point.
b= area under graph during first decompression from F1 point until the decompression reaches the time axis or horizontal.
c= Area of the TPA occurring under time axis after first compression also called adhesiveness.
d= Area under the second compression cycle until the graph reaches F2.
e= Area under the second decompression cycle after point F2.
$F_0$= Fractur ability or the first force at which a small peak is obtained while running TPA.
$F_1$= Highest peak point value during first compression cycle, hardness (N).
$F_2$=second peak in double penetration.

### *2.12.1 Hardness/Firmness*

Firmness is the resistance to force during sample penetration. It refers to the force required to bite through the sample using molars or incisors (Allen Foegeding et al., 2003). Softer samples exhibit lower firmness (Silva et al., 2024).The firmness or hardness is measured as the peak force during the first compression. The firmness of water or liquid samples is generally "0" (Peleg, 2019). The values are represented in Newtons (N).

### *2.12.2 Spreadability*

Spreadability refers to the ease with which a sample can be uniformly spread across a surface (Lučan et al., 2020). Spreadability is calculated as the area under the curve of the first compression cycle. It is defined as the force required to spread the sample over a specific time interval. The values are represented in Newton-seconds (N*s) (Silva et al., 2024).

### *2.12.3 Adhesiveness*

Adhesiveness is a measure of physical attraction between two surfaces (Peleg, 2019). It measures the force required to overcome the attraction between the food products and a contact

surface. In TPA, it is represented by the negative force-time area during the first compression (Chandra & Shamasundar, 2014). Studies have shown that using gums in low-fat cream cheese affects its adhesiveness (Shahraki et al., 2023).

*2.12.4 Cohesiveness*

Cohesiveness is a measure of internal bonding strength of food, and defined as the extent to which a sample can be deformed before rupturing (Chandra & Shamasundar, 2014). It is calculated as the ratio of the positive force-time area of the second compression to that of the first (Salari et al., 2017).

*2.12.5 Gumminess*

Gumminess is the energy required to disintegrate a semi-solid food to a state suitable for swallowing. It is calculated as the product of firmness and cohesiveness in TPA and is expressed as gumminess (Mahat et al., 2020).

## 2.13 Conclusions

The literature review examines key information about cream cheese products, production methods, vegan cream cheeses, and the use of coconut milk and hydrocolloids in vegan cream cheese production. This review also discusses the potential benefits of low-fat cream cheeses and the application of coconut milk in vegan cream cheese production.

A vegan cream cheese analogue made from coconut milk has a higher potential of producing a product comparable to dairy cream cheese. To improve vegan alternatives to dairy products, additional varieties could be developed, such as flavoured versions or probiotic-enriched vegan cream cheese.

The coconut-based cream cheese analogues can be formulated using coconut milk combined with additives like starch and gum. This type of cream cheese analogue is novel and may offer the health benefits of coconut milk, including its medium-chain triglycerides (MCTs). Although numerous studies have been conducted on soy-based vegan cream cheese, the effects of a coconut-based vegan cream cheese analogue, particularly one made with different concentrations of waxy corn starch and gums, on the formation and physicochemical properties have not been previously investigated. Therefore, this study aims to address these research gaps.

# Chapter 3. Coconut Cream Cheese Analogue Production

## 3.1 Abstract

The production of coconut-based cream cheese analogue has become a topic of interest due to increasing consumer demand for healthier and food products. The aim of this study was to develop a coconut cream cheese formulation with a composition and colour similar to coconut milk, while having textural and rheological properties comparable to dairy cream cheese using hydrocolloids (xanthan and locust bean gums) and starch in the formulation. In this study, various concentrations of starch and gum were used alone or in combination to achieve this. The moisture, fat and ash contents of the selected formulations had similar or negligible differences between samples on chemical analysis, while each sample had a different textural, rheological and stability characteristic based on the formulation. The Confocal laser scanning microscopy (CLSM) revealed a significant influence on the size and distribution of fat globules in the sample matrix. The addition of gums and starch into the formulation did not cause significant change in colour and pH of the formulation on storage. In overall, the results resonated in a coconut cream cheese formulation with ideal textural and rheological characteristic with higher stability, requires a combination of gums and starch than individual use of these ingredients.

## 3.2 Introduction

Cream cheese is a popular product known for its freshness, delicate taste characterized by its sweet, creamy, soft, and tangy flavour, and nutritional value (Hernández-Figueroa et al., 2025). However, growing awareness of the health risks associated with high-fat foods like cheese has negatively affected the cream cheese market. As a result, research has been conducted to develop a variety of cream cheese products that can reduce these health risks, such as reduced-fat and low-fat cream cheeses.

Coconut milk is a plant-based milk made from grated coconut meat with or without added water (Chen et al., 2024a). This milk is an unstable emulsion that can separate into two layers under gravity due to flocculation (Deng et al., 2022). Coconut milk contains minerals such as phosphorus, calcium and potassium, along with vitamin B, ascorbic acid, sucrose, and starch (Seow & Gwee, 2003). Recent studies comparing butter and coconut oil suggest that while coconut oil increases LDL cholesterol levels it also generates higher HDL cholesterol levels

compared to butter, indicating better cardiovascular health outcomes with coconut oil consumption (Khaw et al., 2018). Therefore, cream cheese made with coconut milk may replicate dairy cream cheese while potentially improving its nutritional value.

Although coconut milk has a similar fat content to dairy milk, its protein content is comparatively low, and the protein network formed during coagulation is not as strong as that formed by casein proteins in dairy milk (Halim et al., 2022). As a result, coconut-based cream cheese analogues require additional ingredients such as starch and hydrocolloids to achieve the desired texture and rheological properties.

It is important to understand how these additions affect the sensory and physicochemical properties of coconut-based cream cheese analogues. Therefore, this study was carried out to investigate the effects of storage at refrigeration temperature (4°C) for 14 days on coconut-based cream cheese analogues, and to determine the optimal levels of starch and hydrocolloids. By comparing samples with different ratios of starch and hydrocolloids, their effects on the textural and rheological properties of the coconut-based cream cheese analogues were assessed.

The specific objectives of this study were to determine changes in colour, texture, rheology, and sensory properties. This study aims to fill existing gaps in the development of a vegan cream cheese product with safe and acceptable properties.

## 3.3 Materials and Methods

### *3.3.1 Materials*

The coconut cream cheese was produced using the following ingredients: Organic coconut milk (Ceres Organics, Sri Lanka) was procured from a local supermarket (Pak'nSave, New Zealand), which contained 1.4% protein, 18% fat, and 2.3% carbohydrate. The nutritional information for coconut milk is provided in the Appendix A. Table salt (Pams iodized table salt) was also purchased from the local supermarket (Pak'nSave, New Zealand). Xanthan gum (Xanthan 80), locust bean gum (Locust Bean Seed Gum A-200), modified corn starch (Ultra-Tex 4), and citric acid anhydride (Citric acid Anhydrous F6000 Powder) were obtained from Hawkins Watts (Auckland, New Zealand). The nutritional information for both the coconut milk and Ultra-Tex 4 used is provided in Appendix B.

*3.3.2 Preparation of coconut cream cheese*

The procedure used for preparation of the coconut cream cheese analogue with different hydrocolloids was adopted from Michel et al. (2022), with slight modifications and is illustrated in the flow diagram as shown in Figure 3.1.

Coconut milk was extracted from the cans and poured into a 2-liter mixing bucket. It was thoroughly mixed using a ladle before beginning the experiment. Each sample was prepared using 400 g of the coconut milk, measured using a weighing balance. The weighed samples were transferred into a Thermomix TM6-1 (Vorwerk Elektrowerke GmbH & Co. KG, Muhlenweg, Wuppertal, Germany).

Initially, coconut milk was heated in a water bath set at 55°C and stirred until the temperature of the coconut milk attained 35°C prior to the start of the experiment. This was done to uniformly mix the fat in coconut milk. The coconut milk was then heated at 50°C for 5 minutes and mixed at a speed setting of 4.5 using the Thermomix for the preparation of each sample. The sample was then removed and homogenized using a high shear mixer (Silverson L4RT, Silverson Machine Ltd., Waterside, England) for 3 minutes at 3000 rpm. The homogenized coconut milk was reweighed while being transferred back to the Thermomix. At this point, the other ingredients, such as salt, citric acid anhydride, xanthan gum (XG)-locust bean gum (LBG) mixture, and Ultra-Tex 4, were added in precise proportions as specified in Table 3.1. The mixture was then initially mixed for 2 minutes at 50°C to incorporate the ingredients into the coconut milk, followed by mixing and heating at 85°C for 7 minutes and 30 seconds at speed setting 4 for pasteurization. This temperature selection was based on gel activation temperature and proper hydration of gums at 85°C, and based on destabilization of protein in coconut milk at 80°C(Copetti et al., 1997; S & Raghavarao, 2010). After processing, the samples were transferred into storage containers (polypropylene containers of 100 mL capacity) using a rubber spatula and stored at 4°C for 14 hours before further analyses were conducted.

The concentrations of starch and hydrocolloid used were based on the results of the preliminary trials conducted.

*Table 3.1 Sample codes of coconut-based cream cheese analogues prepared using coconut milk, starch. and hydrocolloids at different ratios (w/w). Xanthan-locust bean gum (XG-LBG, 1:1 ratio).*

| No | Sample Code | Coconut milk % | Starch % | Hydrocolloid % (XG + LBG, 1:1 ratio) | Salt % | Citric acid Anhydrous F6000 Powder % |
|---|---|---|---|---|---|---|
| **1** | 0SH0 | 98.8 | - | - | 1 | 0.2 |
| **2** | 0SH.1 | 98.7 | - | 0.1 | 1 | 0.2 |
| **3** | 0SH.5 | 98.3 | - | 0.5 | 1 | 0.2 |
| **4** | 2SH0 | 96.8 | 2 | - | 1 | 0.2 |
| **5** | 2SH.1 | 96.7 | 2 | 0.1 | 1 | 0.2 |
| **6** | 2SH.5 | 96.3 | 2 | 0.5 | 1 | 0.2 |
| **7** | 5SH0 | 93.8 | 5 | - | 1 | 0.2 |
| **8** | 5SH.1 | 93.7 | 5 | 0.1 | 1 | 0.2 |
| **9** | 5SH.5 | 93.3 | 5 | 0.5 | 1 | 0.2 |

A total of nine samples were prepared in this study (Table 3.1) to investigate the effects of starch and xanthan-locust bean gum (XG-LBG, 1:1 ratio) interactions on the rheological and textural properties of coconut-based cream cheese analogues. The base ingredients for all samples included coconut milk, citric acid anhydride (0.2%) and salt (1%).

The control sample (0SHO) consisted of coconut milk acidified with citric acid anhydride (0.2%) and salt (1%), with no added starch or hydrocolloids. Two starch-only formulations (2SH0 and 5SH0) were prepared by mixing the base ingredients with starch at concentrations of 2% and 5%, respectively. Two hydrocolloid-only formulations (0SH.1 and 0SH.5) contained the base ingredients with a combination of hydrocolloids (XG-LBG) at 0.1% and 0.5%, respectively, in a 1:1 ratio. The remaining four formulations were prepared using combinations of starch (2% and 5%) and hydrocolloids (0.1% and 0.5% XG-LBG) to develop the cream cheese analogues.

### *3.3.3 Analysis of samples*

#### 3.3.3.1 pH measurement

The pH of the samples was measured using a pH meter at ambient temperature. Ten g sample was weighed and transferred into a centrifuge tube into which a probe was immersed into the

solid gel to measure the pH of the sample. The pH probe was calibrated using standard buffer solutions of pH 4.0 and pH 7.0 before analysis. Samples were measured in triplicate on days 1, 7 and 14 of storage at 4°C.

3.3.3.2 Colour analysis

Colour analysis was performed using a Minolta Chroma Meter (CR-300) calibrated with a white reference plate. Samples were placed in transparent Petri dishes (55 mm diameter) and measured under a black cover to minimize ambient light interference. Each sample was measured in duplicate during storage at 20°C on days 1, 7 and 14.

CIE L*, a*, and b* values were measured to determine the colour of the samples. The L* value represents lightness, which ranges from 0 (black) to 100 (white), indicating how bright the colour is. The a* value indicates red (+a) and green (-a). The b* value represents yellow (+b) and blue (-b). Colour difference (ΔE*) between samples was calculated using the formula.

*Equation 3-1*

$$\Delta E = \sqrt{[(L-L_1)^2 + (a-a_1)^2 + (b^*-b_1)^2]}$$

where L, a, and b are the reference sample values, and $L_1$, $a_1$, $b_1$ represent the values for the sample being compared (Lucey, 2003; Marx, 2015). Higher ΔE* values indicate greater colour differences.

3.3.3.3 Textural analysis

Texture profile analysis (TPA) was performed using a TA-XT Plus Texture Analyzer (Stable Micro Systems, UK) with a 5 kg load cell. A 35 mm cylindrical probe was used to measure the texture of samples, based on a modified method from (Brighenti et al., 2018). Samples were loaded into plastic containers (40 mm diameter, 60 mm height) using a piping bag, tapped to remove air bubbles, levelled with a spatula, and stored at 5°C for 14 hours prior to analysis. The following test conditions were carried out on each sample with a double compression test: pre-test speed at 1.00 mm/sec, test speed 1.00 mm/sec, post-test speed 1.00 mm/sec, target mode at 20% strain, hold time 3 seconds, and trigger force 1 mN.

Parameters measured included firmness, spreadability, adhesiveness, cohesiveness and gumminess, calculated from force-time curves using Exponent Software (Version 6.1.18.0). All samples were measured in quadruplicate on days 1, 7 and 14 during storage.

3.3.3.4 Microstructural analysis

Confocal laser scanning microscopy (CLSM) was conducted using a Zeiss LSM900 microscope with Airyscan 2 resolution. Samples were stained with 0.0001% (w/v) Nile Red

for lipid visualization and 0.1% Acridine Orange in 0.1M phosphate buffer (pH 7) to visualize starch and proteinaceous materials. FCF Green was also used for protein identification. Imaging was performed at 40 x magnification under the excitation wavelengths of 543 nm for Nile Red and 488 nm for Acridine Orange. The images were processed using ImageJ software.

3.3.3.5 Stability analysis of coconut-based cream cheese analogue

For stability analysis, 40 g of each sample was weighed into 50 mL centrifuge tubes, sealed with plastic caps, and centrifuged using a Multifuge X Pro Series centrifuge (Thermo Scientific, GmbH, Germany) at 4000 g for 20 minutes at 4°C. After the centrifugation, the emulsion samples were visually inspected for phase separation, free oil, aggregation, and creaming.

3.3.3.6 Rheological analysis

Rheological measurements were performed using an MCR 301 Rheometer (Anton Paar Physica, Germany) equipped with a P-PTD 200/56 system and PP25/P2 profiled parallel plate geometry with a 1 mm gap. Analyses were conducted at 20°C, and data were analysed using Rheometer Plus software (Version 3.62, RHEOPLUS/32).

Strain sweep tests were performed at a constant oscillation frequency of 1 Hz, recording G' and G" as functions of logarithmically increasing strain (0.01-100%). Shear viscosity was calculated in 40 steps (10 s per data point) as a function of logarithmically increasing shear rate. Samples were pre-sheared for one minute at 100 $s^{-1}$ and allowed to rest for 2 minutes to allow structural relaxation.

Viscosity measurements were performed by gradually increasing the shear rate from 0.1 $s^{-1}$ to 100 $s^{-1}$, over 31 points with data recorded every 10 seconds. A 2-minute rest period was provided to the sample after the strain sweep test to allow internal structural adjustments before beginning viscosity testing. All tests were performed at 20°C.

Each sample was analysed on days 1, 7 and 14 of storage, at least in duplicate.

*3.3.4 Sensory evaluation*

Four samples were selected based on their composition, rheological and textural attributes for sensory evaluation (2SH.1,2SH.5,5SH.1 and 5SH.5) and compared with the 0SH0 sample (the acidified coconut milk sample). The sensory panel consisted of 30 individuals aged between 18 and 55, all of whom had previously consumed cream cheese in their daily lives. A 9-point

hedonic scale was used for the evaluation, with 9 indicating like extremely and 1 indicating dislike extremely. Samples (10 g) were measured and stored at 5°C for one day before the sensory evaluation was conducted. The sensory evaluation was conducted two days after the preparation of the samples. Each sample was coded with three-digit random numbers and presented in random order to the panellists. The attributes ranked by the panellists included colour, aroma, texture, mouthfeel, and overall product scores.

The sensory test has received low-risk classification approval from the Human Ethics Committee at Massey University (notification No. 4000028912).

*3.3.5 Proximate analysis of coconut cream cheese formulation*

Proximate analysis of the samples selected from sensory analysis and the coconut milk was conducted at the Nutrition Laboratory at Massey University, Palmerston North, New Zealand. Fat, crude protein, and crude fibre were analysed in the Nutrition Laboratory, while moisture content, and ash were analysed separately in the Food Chemistry Laboratory. Carbohydrates content was calculated as difference from the total percentage. The Dumas method was carried out according to the AOAC 968.06 protocol using an N-P factor of 6.25 for protein content measurement. The AOAC method 922.06 (Mojonnier) was used for fat analysis. The crude fibre measurement was carried out using the AOAC 991.43 protocol using Megazyme kits. All AOAC methods were adapted from Latimer, (2023).

Moisture content analysis method was adopted from Kim et al., (2022), which was based on AOAC 930.15 (2005. Moisture content was calculated by measuring the variation in weight before and after the samples had after drying. Ten grams of samples were weighed into aluminium dishes and weights were measured. The samples were then placed into a hot air oven for 2 hours which was set at 135°C. After drying, the samples were removed and placed in a desiccator for cooling over 2 hours before the weight of the dried sample was measured.

*Equation 3-2*

$$Moisture\ content\% = \frac{(Wet\ weight\ (g) - Dri\quad wei\quad (g)) * 100}{Wet\ weight\ (g)}$$

The ash content of the samples was measured using the method AOAC method 935.42. Briefly, 5 g of sample was weighed into a pre-weighed metal crucible and heated until all moisture evaporated and the samples was charred in the crucible. The crucible was placed in a muffle

furnace set at 550°C for over 6 hours until complete ashing of the samples was achieved. The crucible was transferred into a desiccator and kept for cooling for 30 minutes after which the samples were reweighed.

*Equation 3-3*

$$Ash\% = (Mass\ of\ ash\ residue\ (g)) * 100/(Initial\ mass\ of\ sample\ (g))$$

*3.3.6 Data analysis*

All sample preparations and measurements were conducted at least in duplicate. The data are expressed as mean ± standard deviation. The data obtained were analysed using Minitab Statistical Software. One-way analysis of variance (ANOVA) and Tukey's multiple range test were applied to determine the significant differences between mean values at a significance level of $p < 0.05$.

## 3.4 Results and discussion

*3.4.1 pH analysis of coconut cream cheese*

The pH of coconut cream cheese samples with different concentrations of hydrocolloids was measured and recorded from day 1 to day 14 of storage at 4°C (day 1 refers to 24 hours after the production of the samples). The pH of the reference sample (0SH0) was measured to be 4.20 on day 1 after sample preparation and showed a minor reduction in pH to 4.11 on day 14 of storage. On day 1, the highest pH value recorded was 4.22 for the 5SH0 sample, while the least recorded was 4.13 for the 2SH0 sample. On day 14 of storage, the reference sample (0SH0) and 5SH0 showed a similar pH of 4.11 and the highest pH recorded on that day was 4.21 for sample 0SH0.1. A small trend in pH reduction of the reference sample (0SH0) was identified, which might have arisen due to the absence of starch and hydrocolloids in the formulation. This might have developed due to the small charges on gums and starch molecules which can alter the pH of the samples. Another trend observed was that samples containing hydrocolloids consistently retained a pH above 4.14. The 0SH0 sample reported a pH 4.11 on day 14 of storage while the other samples, except 5SH0, had a slightly higher pH.

The pH of the samples did not show much variation on storage from day 1 to day 14 of storge. The pH of all cream cheese samples was similar to the pH of the samples of soft cheese made from coconut milk (Yunita et al., 2022). Similar results were reported by Kratochvilova et al. (2022)where hydrocolloids did not affect pH variations in processed cheese during storage.

Also, studies on effect of starch on pH changes during storage by Vitheejongjaroen et al. (2024), suggested that pH of the samples are not influenced by the starch during storage.

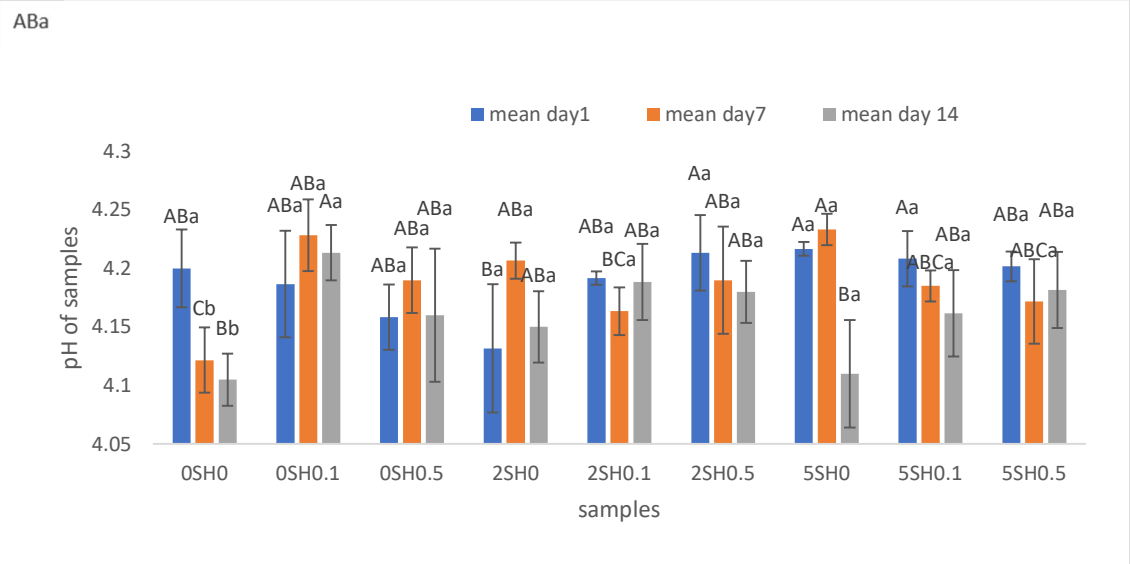



*Figure 3.1 Changes in pH of coconut cream cheese formulations during 1, 7, and 14 days of storage at 4°C (n=4).*

[A, B, C] Within the column, different uppercase superscript denotes significant differences ($p<0.05$) different days of storage for each formulation.

[a, b, c] Within a row, different lowercase superscripts represent significant differences ($p<0.05$) between different types of coconut cream cheese formulations on the same day of storage.

### *3.4.2 Colour of coconut cream cheese analogues*

Colour measurements of all coconut cream cheese formulations were recorded during the storage period of 2 weeks. The colour attributes of the coconut cream cheese analogues were represented using CIE L*, a* and b* values, which numerically depict lightness/darkness, redness/greenness, yellowness/ blueness, respectively. Figure 3.2 shows the comparison of L*, a* and b* values. Visually, all the samples had a whitish appearance with a smooth or glossy nature, as shown in Figure 3.3.

The measurement of L* values showed a distinct pattern depending on the use of starch and hydrocolloids. The L values were in the range between 75.22 to 84.84 throughout the storage period, which was in a bright region of the darkness - lightness index. On day 1, the highest value for L values was observed for2SH.5 sample (84.50) and least observed for 2SH0 (77.03). Samples without starch (0SH0,0SH0.1 and 0SH0.5) retained high L* values throughout the storage period, while starch-rich samples without hydrocolloids (2SH0 and 5SH0) had lower

values measured for L* on day 1. Samples having both starch and higher concentration of hydrocolloids added (2SH0.5 and 5SH0.5) showed initially high L* values, which declined after day 7. On day 14, a general decline in the L values compared to day 1 was observed for most solutions. 2SH0 is the only sample that retained their l value without drastic changes in the value throughout the storage while, 0SH.5 is the only sample that increased its L value on storage from 79.13 on day 1 to 81.55 on day 14.

The a* values measured for all the samples were negative throughout the study and ranged between, suggesting a green hue in the colour. The values were near the zero by day 14, suggesting a reduction in the green colour of the samples, observed mainly in samples with starch and higher hydrocolloid concentrations (2SH0.5 and 5SH0.5). The control sample (0SH0) and 0SH0.1 maintained consistent values near -1.1, showing a higher colour stability throughout the experiment. A common trend observed in the samples with hydrocolloids and starch was the decline in a* values over the storage period.

The b* values for all samples was positive, indicating a yellow dominance. The highest b* values were recorded for samples with high hydrocolloid concentrations (0SH0.5 and 2SH0.5). Conversely, the control sample (0SH0) showed a reduction in yellow colour. The general trend observed in the study was that the intensity of yellow colour increased as the solids contents increased.

The ΔE values of each sample were evaluated using control sample (0SH0) day 1 value as reference. All the values were higher than 1 which suggested the colour changes were perceptible, but not obvious colour difference could be observed (except for sample 5SH0.1 on day perceptible. Samples showed a colour difference of 2.31-5.74 units compared to control sample on day 1, suggesting influence of formulation in colour of the samples. The highest deviation was observed for 5SH0.1 sample, while the lowest was seen in 5SH.5 sample.

The samples showed variations for the ΔE values on storage. On Day 7, the E value change was observed the highest for 0SH.1 (5.49), while the 0SH0 sample had the least deviation. By day 14, the control sample had a higher deviation compared to day 1 (4.34), and sample 2SH.5 (4.53) had the highest recorded deviation from control sample on day 1. However, sample 2SH0 was the only sample that showed a consistent deviation from the control sample across all days of observation, with deviations of (4.15) on day 1, (4.6) on day 7, and (4.34) on day 14. Although some samples showed deviations greater than 5 units compared with the control sample (0SH0) on day 1, these changes were not visually prominent.

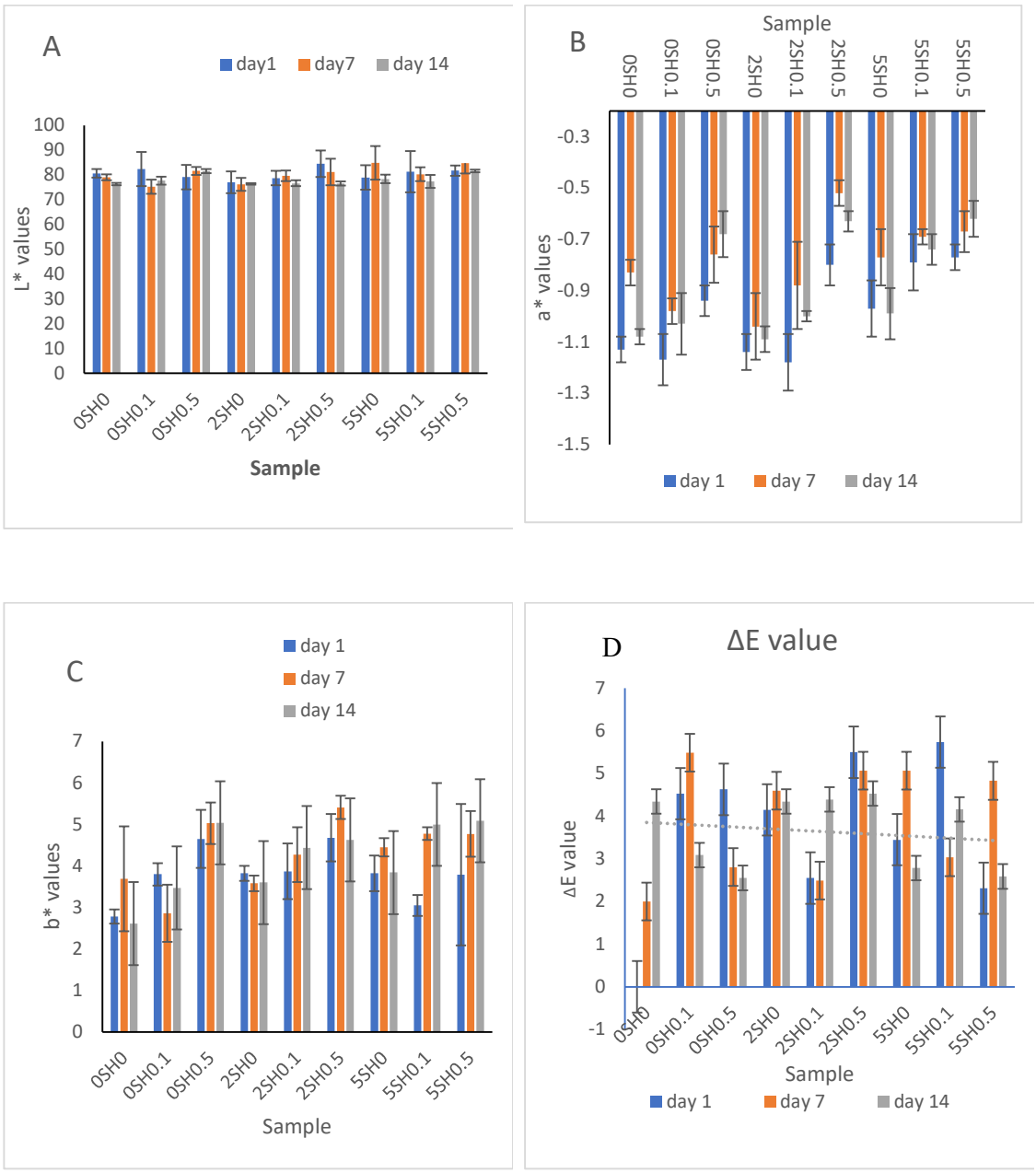



*Figure 3.2 Changes in attributes of colour of coconut cream cheese formulations containing different concentrations of starch and hydrocolloids (xanthan: locust bean gum at 1:1ratio) during storage of 2 weeks at 4°C. A) L* values B) a* values and C) b* values and D) ΔE values (n=6).*

From the results, the colour of the product was influenced by the added starch and hydrocolloid contents in the formulations. Only sample 0SH0.1 retained the colour scheme similar to the control sample (0SH0), suggesting the addition of starch and hydrocolloids might produce deviation to the colour during storage of the product.

The values of this analysis were similar to the results reported in the study of rheology of coconut emulsions stabilized by maize kernels and starch by Lu et al. (2019), where E values

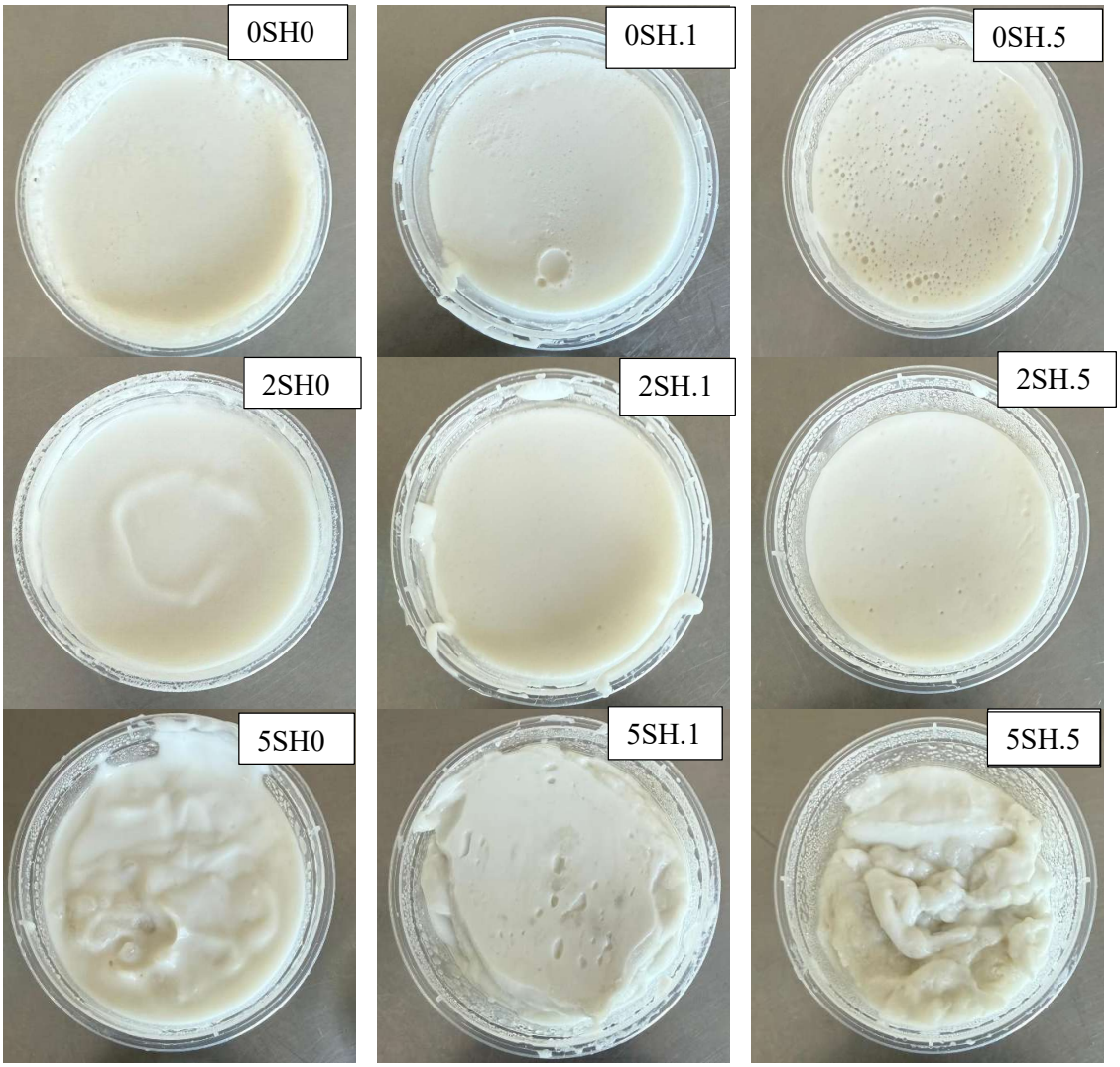



*Figure 3.3 Visual appearance of coconut cream cheese formulations 0SH0 (control sample), Sample codes indicate first number =starch content (0%,2%, or 5%), SH= starch and hydrocolloid, and the last number represents the hydrocolloid content (0%,0.1%, or 0.5%.)*

were in a range between 2.46 (coconut milk +maize kernel) and 5.4 (high amylose maize starch+ coconut milk).

*3.4.3 Texture profile analysis*

The samples were analysed for textural properties using a double penetration method for the characteristics of firmness, spreadability, adhesiveness, cohesiveness, and gumminess. The results are presented in Table 3.2. Cream cheese texture is primarily determined by its spreadability, which is defined as the measure of the prime force required to spread the sample (Brighenti et al., 2008).

The firmness of the samples differed significantly with both storage time and formulation. The 0SH0 and 0SH0.1 samples exhibited the least firmness across all time points of observation, showing consistent values below 0.05 N throughout storage. However, samples with higher concentration of starch and hydrocolloids (i.e., 5SH0.5) demonstrated higher firmness on day 1 peaking at 12.62 N, while other samples, like 5SH0 displayed a reduction in firmness. From these findings, we can understand that hydrocolloids alone can increase the firmness due to their gelling and water-binding capacity, as observed with 0SH.5 sample. The starch used alone had a milder impact on the firmness of coconut cream cheese produced, as can be observed in the 2SH0 sample. However, the firmness data from 2SH0.1, 2SH0.5, 5SH0.1 and 5SH0.5 samples suggests that starch and hydrocolloid combinations resulted in the enhanced firmness of the sample.

Spreadability of the samples improved with starch and hydrocolloid in the formulations. The 0SH0 sample exhibited the least spreadability value throughout the storage period, while the 5SH0.5 sample had the highest spreadability observed on day 14. Starch in the formulations alone provided a strong and consistent increase in spreadability over time, likely due to gelatinization and retrogradation process induced during the processing step. Comparatively, the influence of gum alone on enhancing the spreadability of coconut cream cheese was low, which could be due to gel formation and water immobilization. Combining both starch and hydrocolloids in the formulation produced samples with higher spreadability, producing a cohesive but spreadable formulation.

The control sample (0SH0) had the least value when measured for adhesiveness, ranging from -0.089 to -0.122 throughout storage. Samples containing hydrocolloid alone showed an increase in the adhesiveness values over the storage period, which can arise due to the interaction between in coconut milk fat and the gums, as well as water absorption by the gums. The starch in the formulations alone showed a substantial increase in adhesiveness with an increase in concentration. Formulations containing 0.5**%** hydrocolloid, combined with starch

showed the highest adhesiveness values, suggesting a product developed with more adhesiveness.

The cohesiveness of the samples increased with higher starch concentrations. The highest value was measured for 5SH0.5 sample (0.699) on day 1, which decreased slightly during storage. The addition of hydrocolloids improved water retention in the samples, thus water loss due to the retrogradation of starch throughout storage was limited to a level because of the presence of gums in the formulations.

The lowest gumminess was exhibited in the 0SH0 and 0SH0.1 samples measured, following a trend like the firmness and cohesiveness. Samples with higher gum and starch concentrations had higher gumminess values, providing them a denser texture. The higher gumminess values of 2SH0 and 2SH0.1 samples suggested a synergistic interaction between hydrocolloids and starch, where starch creates the structural bulk in the samples while integrity of the formulation was conserved by the hydrocolloids (xanthan combined with locust bean gum at 1:1 ratio) used (Lu et al., 2025). The highest value of gumminess was recorded for the 5SH0.5 sample (4.873) on day 7.

Based on these observations, it can be concluded that starch and hydrocolloids play a vital role in the texture development of coconut cream cheese analogues, influencing firmness, spreadability, and adhesiveness of the formulations. Similar trends in texture analysis of cream cheese were established in previous studies by Shahraki et al. (2023) in which, usage of gums in low-fat probiotic cream cheese production have made similar impacts on cream cheese texture during storage periods.

*Table 3.2 Textural attributes of coconut cream cheese formulations containing starch (0%,2%,5%) and hydrocolloids (0%,0.1%,0.5%) measured on day 1, 7 and 14 of storage at 4C (n=4).*

| Parameter | Storage days | 0SH0 | 0SH.1 | 0SH.5 | 2SH0 | 2SH.1 | 2SH.5 | 5SH0 | 5SH.1 | 5SH.5 |
|---|---|---|---|---|---|---|---|---|---|---|
| **FIRMNESS (N)** | DAY1 | 0.033 ± 0.005$^{Ae}$ | 0.023 ± 0.010$^{Be}$ | 13.943 ± 0.668$^{Aa}$ | 0.703 ± 0.005$^{Ae}$ | 2.733 ± 0.096$^{Bd}$ | 11.890 ± 0.862$^{Bb}$ | 4.883 ± 0.120$^{Ac}$ | 5.663 ± 0.067$^{Ac}$ | 12.628 ± 0.339Bb |
| | DAY7 | 0.028 ± 0.005Ae | 0.038 ± 0.005Ae | 13.705 ± 0.105Aa | 0.735 ± 0.024Ad | 3.040 ± 0.262Bc | 13.453 ± 0.066Aa | 4.508 ± 0.042Bb | 4.408 ± 0.293Bb | 13.918 ± 0.762Aa |
| | DAY 14 | 0.033 ± 0.005Ad | 0.040 ± 0.000Ad | 12.853 ± 0.877Aa | 0.703 ± 0.021Ad | 3.710 ± 0.153Ac | 11.938 ± 0.259Ba | 4.533 ± 0.285ABbc | 4.278 ± 0.275Bc | 5.323 ± 0.707Cb |
| **SPREAD ABILITY (N.sec)** | DAY1 | 2.215 ± 0.066Ae | 2.380 ± 0.054Ae | 57.615 ± 0.436Aa | 2.890 ± 0.072Ae | 14.058 ± 0.217Ad | 59.935 ± 1.266Ab | 20.980 ± 2.070Ac | 27.733 ± 0.546Ac | 35.153 ± 1.160Cb |
| | DAY7 | 2.285 ± 0.013Ae | 2.370 ± 0.036Ae | 58.248 ± 0.830Aa | 2.775 ± 0.079Ad | 13.130 ± 10.430Ac | 60.630 ± 0.266Aa | 22.173 ± 0.715Ab | 23.425 ± 0.963Bb | 54.965 ± 0.992Aa |
| | DAY 14 | 1.683 ± 0.076Bd | 1.768 ± 0.264Bd | 53.463 ± 1.863Ba | 3.085 ± 0.505Ad | 18.220 ± 0.715Ac | 60.310 ± 2.330Aa | 17.168 ± 1.593Bbc | 17.598 ± 0.943Cc | 41.680 ± 3.670Bb |
| **ADHESIVE NESS (N.sec)** | DAY1 | -0.085 ± 0.006Ae | -0.103 ± 0.005Ae | -1.470 ± 0.022ABa | -1.210 ± 0.027Ae | -4.438 ± 0.246Bd | -2.760 ± 0.089Ab | -16.070 ± 0.432Bc | -12.710 ± 0.664Bc | -10.603 ± 0.334Ab |
| | DAY7 | -0.120 ± 0.008Be | -0.103 ± 0.010Ae | -1.295 ± 0.243Aa | -1.700 ± 0.022Cd | -2.740 ± 1.536ABc | -4.590 ± 0.186Ba | -9.278 ± 0.563Ab | -12.993 ± 0.552Bb | -16.998 ± 1.603Ba |
| | DAY 14 | -0.105 ± 0.013Bd | -0.113 ± 0.010Ad | -1.713 ± 0.127Ba | -1.445 ± 0.091Bd | -2.500 ± 0.099Ac | -4.515 ± 1.558Aba | -15.875 ± 0.521Bbc | -7.715 ± 0.950Ac | -9.085 ± 0.866Ab |
| **COHESIVE NESS** | DAY1 | 0.968 ± 0.028Be | 0.898 ± 0.013Ae | 0.123 ± 0.005Ba | 0.760 ± 0.008Be | 1.300 ± 0.008Ad | 0.278 ± 0.005Ab | 0.778 ± 0.102Ac | 0.528 ± 0.017Ac | 0.363 ± 0.015Ab |
| | DAY7 | 0.525 ± 0.006Ce | 0.875 ± 0.021Ae | 0.123 ± 0.005Ba | 0.813 ± 0.042ABd | 0.363 ± 0.280Bc | 0.175 ± 0.006Ca | 0.528 ± 0.013Bb | 0.538 ± 0.030Ab | 0.370 ± 0.014Aa |
| | DAY 14 | 1.033 ± 0.049Ad | 0.870 ± 0.014Ad | 0.160 ± 0.008Aa | 0.895 ± 0.089Ad | 0.358 ± 0.010Bc | 0.208 ± 0.013Ba | 0.543 ± 0.064Bbc | 0.523 ± 0.120Ac | 0.343 ± 0.068Ab |
| **GUMINESS (N)** | DAY1 | 0.033 ± 0.005Ae | 0.028 ± 0.010Ae | 1.938 ± 0.094Aa | 0.478 ± 0.010Be | 3.570 ± 0.046Ad | 2.168 ± 0.053Ab | 3.490 ± 0.348Ac | 2.445 ± 0.114Ac | 4.135 ± 0.120Bb |
| | DAY7 | 0.010 ± 0.000Be | 0.035 ± 0.006Ae | 1.603 ± 0.091Ba | 0.600 ± 0.036Ad | 0.683 ± 0.670Bc | 1.363 ± 0.028Ca | 2.188 ± 0.071Bb | 2.400 ± 0.293Ab | 4.873 ± 0.516Aa |
| | DAY 14 | 0.035 ± 0.006Ad | 0.030 ± 0.000Ad | 0.968 ± 0.209Ca | 0.623 ± 0.088Ad | 0.960 ± 0.065Bc | 1.515 ± 0.096Ba | 2.308 ± 0.296Bbc | 1.885 ± 0.417Ac | 1.460 ± 0.278Cb |

$^{A, B, C}$ Within a column, different uppercase superscript letters denote significant differences ($p<0.05$) between different days of storage for each formulation.

$^{a, b, c, d, e, f}$ Within a row, different lowercase superscripts letters represent significant differences ($p<0.05$) between formulations on the same day of storage.

*3.4.4 Rheological properties*

The rheological characteristics of all coconut cream cheese formulations were conducted using the procedure described in Section 3.3.3.6. The viscosity flow curves for each coconut milk-based vegan cream cheese analogue were assessed as a function of shear rate and are presented in Figure 3.4. All samples showed a pseudoplastic flow behaviour, as the viscosity of samples decreased with increasing shearing rates (Arora et al., 2016).

Referring to Figure 3.4 and Table 3.3, the viscosity of the samples increased with the addition of starch and hydrocolloids into the formulations, showing an increase from 0.251 Pa. s (0SH0) to 53.050 Pa. s (5SH.5). The highest viscosity values throughout the storage were observed in samples containing combination of starch and hydrocolloids, particularly 5SH.5,5SH.1,2SH.5. However, the samples with low levels of starch or hydrocolloids alone (2SH0 and 0SH.1), along with 0SH0 samples were measured with the lowest levels of viscosity throughout the storage period.

Although no significant differences were observed across different days of storage for the same sample, there was a significant difference observed in the viscosity of different formulations (0SH0,5SH0) on same day of storage. This means that the addition of gums has an impact on the viscosity of samples during storage. The results of the viscosity measurement revealed that the viscosity of the cream cheese increased with hydrocolloid and starch incorporation into the vegan cream cheese formulations. In a study reported by Biglarian et al. (2022), use of stabilizers in cream increases viscosity by attaching to water molecules, increasing flow resistance of creams.

*Table 3.3 Apparent viscosity (Pa. s) measured at a shear rate of 50s-1 for all coconut cream cheese samples with different levels of starch and hydrocolloids at different storage days measured at 20°C.*

| STORAGE DAYS | 0SH0 | 0SH.1 | 0SH.5 | 2SH0 | 2SH.1 | 2SH.5 | 5SH0 | 5SH.1 | 5SH.5 |
|---|---|---|---|---|---|---|---|---|---|
| **1** | 0.251 ± 0.038 $^{Ade}$ | 0.487 ± 0.025$^{Af}$ | 11.750 ± 2.330$^{Af}$ | 4.940 ± 1.650$^{Acd}$ | 8.740 ± 0.042$^{Aef}$ | 24.450 ± 0.919$^{Ab}$ | 37.350 ± 0.778$^{Ac}$ | 20.600 ± 2.550$^{Aef}$ | 53.050 ± 6.720$^{Aa}$ |
| **7** | 0.429 ± 0.026 $^{Bd}$ | 0.542 ± 0.039$^{Af}$ | 11.390 ± 3.550$^{Af}$ | 4.320 ± 0.099Ac | 7.565 ± 0.912$^{Aef}$ | 25.600 ± 1.840$^{Ab}$ | 31.650 ± 1.344$^{Bb}$ | 18.950 ± 0.212$^{Ade}$ | 51.400 ± 2.400$^{Aa}$ |
| **14** | 0.370 ± 0.021 $^{ABd}$ | 0.656 ± 0.103$^{Af}$ | 11.400 ± 0.707$^{Af}$ | 4.920 ± 0.354$^{Ac}$ | 7.195 ± 0.247$^{Aef}$ | 23.050 ± 1.344$^{Ab}$ | 26.650 ± 1.202$^{Cbc}$ | 18.900 ± 3.820$^{Ade}$ | 48.300 ± 1.840$^{Aa}$ |

$^{A, B, C}$ Within a column, different uppercase superscript letters denote significant differences ($p<0.05$) between different days of storage for each formulation.

$^{a, b, c, d, e, f\ Within}$ a row, different lowercase superscripts letters represent significant differences ($p<0.05$) between different formulations on the same day of storage.

The long-time storage of coconut cream cheese samples at 4°C, did not result in significant changes in the sample viscosity. The viscosity of coconut cream cheese formulations and control samples was higher at low shear rates, i.e., below 20 $s^{-1}$. A shear rate of 50 $s^{-1}$ was used as a reference to simulate the oral shear condition and to understand the behaviour of coconut vegan cream cheese during the oral-phase (Bolivar-Prados et al., 2022) as shown in Table 3.3. The viscosity of samples decreased over the storage period compared to day 1 measurements. The apparent viscosity measurements were in agreement with the firmness results of cream cheese during the storage period, which also showed a decreasing trend during storage.

The irregularity in viscosity readings for samples with 5% starch agreed with the previous study reported by Liete et al. (2012). Their results showed that a higher concentration of tapioca starch (8%) reached a viscosity (154 RVU) in the absence of hydrocolloid, while a lower viscosity (145 RVU) was reported when 0.15% xanthan was added, which further increased (168 RVU) at 0.45% xanthan concentration when measured at 25°C. In contrast, formulations containing lower starch concentrations exhibited more predictable behaviour, consistent with previous reports. Supporting this, Li (2020) observed a clear increase in the apparent viscosity for a starch system containing 4% UltraTex starch, with apparent viscosity values of 0.26, 3.32, and 6.77 Pa.s at 0, 0.1 and 0.8% gum concentrations, respectively.

*Table 3.4 Herschel Bulkley parameter for each coconut cream cheese formulation.*

| STORAGE DAYS | **Sample** | **T0** | **$K_H$** | **N** | **$R^2$** |
|---|---|---|---|---|---|
| 1 | 0SH0 | 0.672 | 0.237 | 0.343 | 99.9 |
| | 0SH.1 | 2.033 | 0.144 | 0.5774 | 99.99 |
| | 0SH.5 | 5 | 2.444 | 0.425 | 99.24 |
| | 2SH0 | 5 | 2.028 | 0.542 | 99.98 |
| | 2SH.1 | 5 | 1.154 | 0.731 | 99.98 |
| | 2SH.5 | 5 | 16.245 | 0.51 | 99.99 |
| | 5SH0 | 5 | 3.265 | 0.352 | 95.83 |
| | 5SH.1 | 5 | 3.593 | 0.309 | 95.65 |
| | 5SH.5 | 5 | 3.878 | 0.318 | 98.05 |
| 7 | 0SH.0 | 1.217 | 0.496 | 0.457 | 99.99 |
| | 0SH.1 | 2.193 | 0.211 | 0.522 | 99.99 |
| | 0SH.5 | 5 | 3.191 | 0.366 | 94.82 |
| | 2SH0 | 5 | 2.43 | 0.49 | 99.99 |
| | 2SH.1 | 5 | 16.336 | 0.163 | 95.78 |
| | 2SH.5 | 5 | 3.532 | 0.342 | 94.19 |
| | 5SH0 | 5 | 3.522 | 0.342 | 89.03 |
| | 5SH.1 | 5 | 2.842 | 0.39 | 86.11 |
| | 5SH.5 | 5 | 0.132 | 0.704 | 98.47 |
| 14 | 0SH0 | 1.04 | 0.49 | 0.393 | 99.99 |
| | 0SH.1 | 2.617 | 0.114 | 0.603 | 99.98 |
| | 0SH.5 | 5 | 3.127 | 0.357 | 94.9 |
| | 2SH0 | 5 | 2.369 | 0.427 | 99.93 |
| | 2SH.1 | 5 | 1.113 | 0.651 | 99.61 |
| | 2SH.5 | 5 | 20 | 0.373 | 99.86 |
| | 5SH0 | 5 | 4.23 | 0.293 | 95.39 |
| | 5SH.1 | 5 | 2.748 | 0.392 | 84.55 |
| | 5SH.5 | 5 | 0.322 | 0.358 | 89.59 |

The T0, $K_{H,}$ n values for the Herschel-Bulkley model were attained through non-linear regression method in Minitab software. All the initial values were based on preliminary examination of the experimental data and values suggested from previous studies (Rao, 2014). The bounds were refined through fitting trials for convergence and attaining meaningful parameter estimates. The correlation coefficients were ranging between 84.55-99.99 for model, which suggests that the flow behaviour can be explained using these parameters. Coconut cream cheese formulations show shear thinning nature; thus, the flow behaviour index (n) of all the values were below 1. The flow behaviour index ranged between 0.293 to 0.731, while the consistency coefficient ($K_H$) varied between 0.114 to 20 $Pa.s^n$. The yield stress (T0) for the coconut cream cheese varied between 0.672-5 Pa on different days of storage.

The control sample (0SH0) exhibited low T0 value on day 1 which increased to 0.672 Pa on storage until day 14. This suggests that the control sample requires only a small stress to initiate flow. The consistency index ($K_H$) suggests the tendency to resist flow (Rao, 2014). Samples 2SH.5 on day 14 showed the highest $K_H$ value among the samples followed by 2SH.1 on day 7 and 2SH.5 on day 1. On the contrary, the least values were exhibited by 0SH.1 sample on day 1.

The storage moduli (G') and loss modulus (G") of all the coconut cream cheese formulations were analysed as a function of frequency at 20°C to determine the internal structure of coconut cream cheese. As shown in Figure 3.5, most samples with a mixture of gums and starch had a weak gel behaviour where G'>G" when measured on different days of storage.

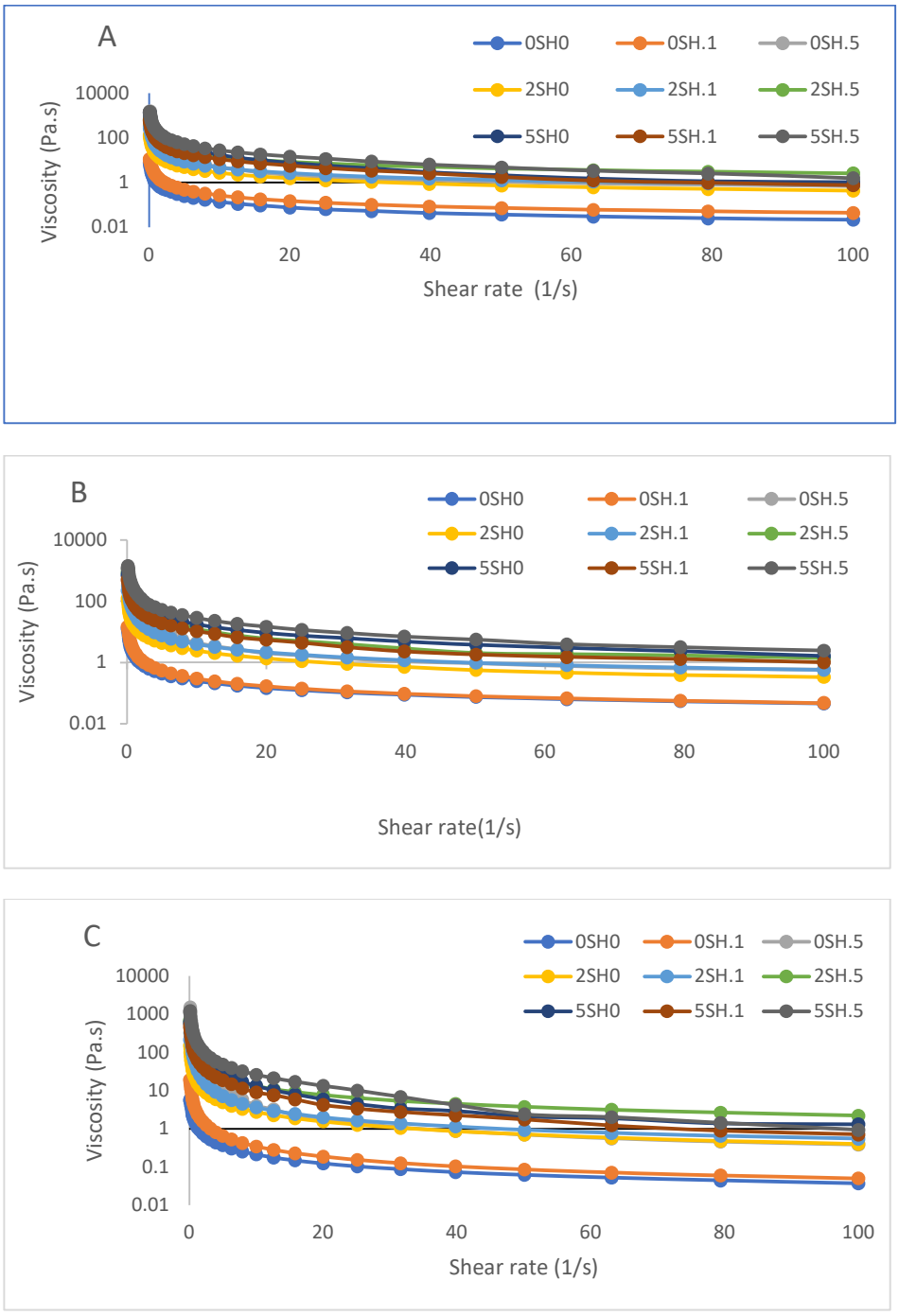



*Figure 3.4 Apparent viscosity of coconut cream cheese formulations measured on day 1 (A), day 7 (B) and day 14 (C) measured at 20°C.*

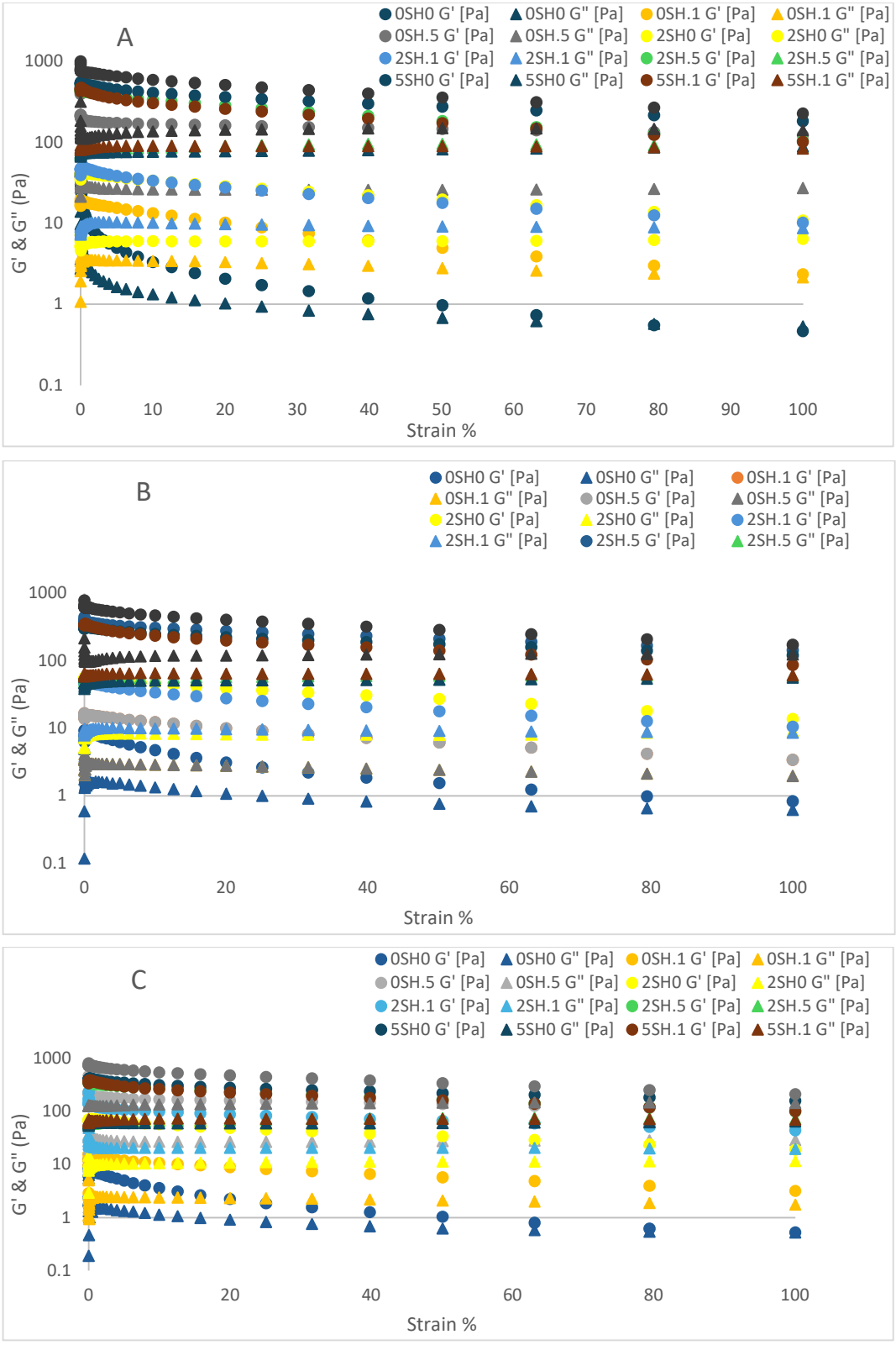



*Figure 3.5 Rheological properties (storage modulus G' and loss modulus G") values of coconut cream cheese formulations containing different concentrations of starch and hydrocolloids measured at 20°C on (A) day 1, B) day 7 and C) day 14 of storage (4°C).*

Samples (5SH.5, 5SH.1 and 2SH.5) had significantly higher G' and G" values compared to the control sample (0SH0). This might be due to the higher starch and gum contents in the formulations. A slight decrease in the G' and G" of all the samples were observed throughout the storage, which denotes a lowering in gel strength during storage.

*3.4.5 Stability of coconut cream cheese formulations*

The stability of coconut cream cheese formulations was analysed by centrifugation at low speed (4000g for 20 minutes at 20°C) in terms of free oil separation, creaming, phase separation, and sedimentation. The pictures of the coconut cream cheese after centrifugation are presented in Figure 3.6.

An oil rich layer was observed on the top layer of all the samples after centrifugation in samples 0SH0, 0SH.1, 2SH0. This separation could have arisen from the instability of coconut milk under gravity forcing separation of coconut milk into different layers. From the stability analysis, it is evident that at lower concentration of starch and hydrocolloid alone, the stability of the coconut cream cheese formulation is very low. However, at higher concentration of starch and hydrocolloid alone or in combination with each other, samples have shown comparatively higher stability by displaying a uniform bulkiness throughout the sample. Samples with hydrocolloids alone showed a thickened oil layer with the water layer precipitated at the bottom possibly with some carbohydrates present in it. In contrast the formulation with 2% starch alone showed comparatively a lower level than 0.1% hydrocolloid sample.

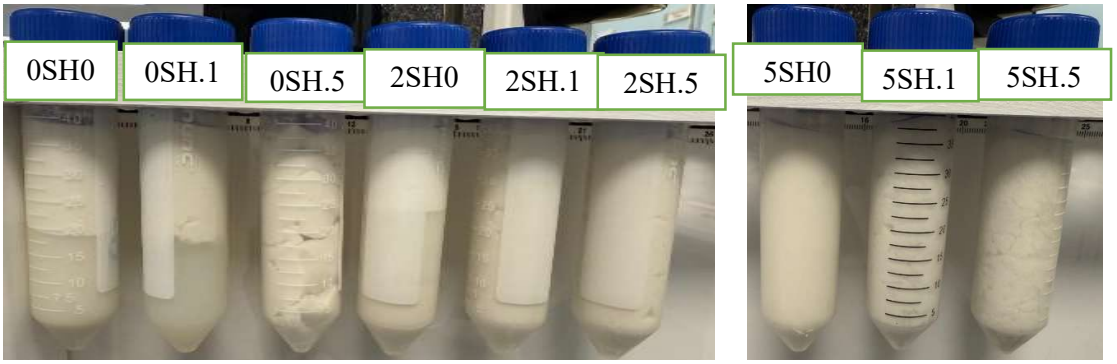



*Figure 3.6 Stability of coconut cream cheese formulation by centrifugation at 4000 g at 20°C for 20 minutes.*

*3.4.6 Microstructural analysis of coconut cream cheeses*

The microstructural characteristics of the different formulations of the coconut cream cheese analogue were examined using CLSM (Figure 3.7). The green regions represent the protein network, while the red regions correspond to the oil droplets present in the samples. The black regions represent the serum phase, which contains water, starch and gums. All samples were analysed after two days of storage at 4°C.

The CLSM images of the nine formulations used in the study are presented in Figure 3.7. Some variation in fat droplet size and the distribution of the protein network was observed among the formulations. These differences in microstructural organisation may be attributed to the incorporation of starch and gums into the formulations. The absence of starch appeared to be associated with larger fat globules, whereas the samples containing starch showed a reduction in fat globule size with increasing starch concentration. However, the effects of gums, either alone or in combination with starch, on the structural arrangement and size of the fat droplets were not clearly evident from the CLSM images.

A more extensive protein network was observed in samples containing either gums or starch. This may be attributed to the presence of starch and gums, which could contribute to the formation of a more stable continuous matrix and thereby support the incorporation and stabilisation of the protein network.

The CLSM observations in this study were similar to the results of microstructural sample study previously reported by Michel et al. (2022) for a vegan cream cheese formulated with coconut oil. Michel et al. (2022) reported coconut oil fat droplets ranging from approximately 10 µm to 50 µm in diameter, which was also observed in the present study.

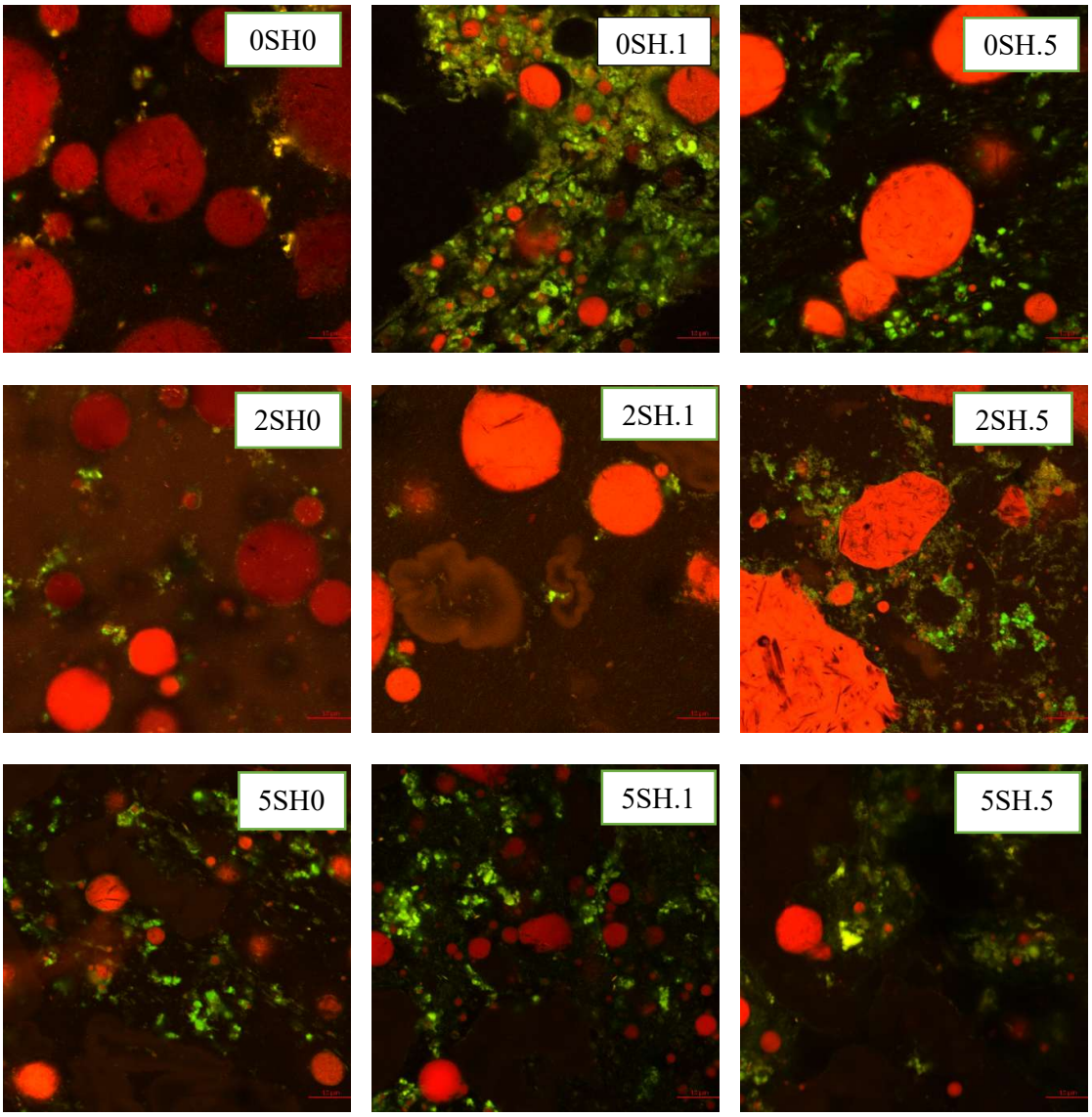



*Figure 3.7 CLSM images of coconut cream cheese at different concentrations of starch (0,2 and 5% w/w) and gum concentrations (0,0.1 and 0.5% w/w) measured at 10-20 µ Green depicts the protein region, whereas red depicts the lipids in the cream cheese matrix.*

### *3.5 Sensory evaluation of the reduced- fat vegan cream cheese analogue*

The sensory evaluation of samples dedicated to six attributes of consumer appeal (flavour, colour, taste, texture, mouthfeel, and overall acceptability) was conducted are presented in the Figure 3.8. The average rating of each attribute was in a range between 3.5 and 8, which is considered acceptable for a new formulation developed. Considering all the samples tested, formulation 5SH.1 attained the highest scores with higher ratings particularly in mouthfeel (7.93), texture (6.97) and overall acceptability (6.9).

The control sample scored the lowest in several categories, especially texture (3.84), mouthfeel (4.42) and overall acceptability (4.65), as the control sample lacked the firmness usually seen in other coconut cream cheese samples. The relevance of adding texture modifiers in a vegan cream cheese sample can be observed from these results, which can contribute to improving the consumer preferences for the samples. However, the highest consumer appeal for colour (7) was attained for control sample (0SH0) from this sensory analysis.

The samples containing 2% starch, namely 2SH.1 and 2SH.5, received mixed to intermediate ratings from the consumers. Between the two formulations, 2SH.1 sample showed better consumer acceptance than 2SH.5 in terms of mouthfeel, texture, taste, and overall acceptability.

The sample with higher starch and hydrocolloid concentrations, 5SH.5, received a similar rating in colour to the control sample (0SH0) but scored 6.42 for taste and attained an overall acceptability of 6, suggesting a higher selectiveness over samples with texture modifiers in the sample for cream cheese formulations using plant-based milks.

Although 2SH.5 formulation showed a similar trend to the control sample (0SH0), throughout the experiment, the sample most liked by the consumer panel was 5SH.1, based on the overall consumer acceptability scores. The overall trend in consumer acceptability followed a trend in which samples with higher starch-based formulations received higher consumer acceptability. The formulations with 0.1% hydrocolloids received higher acceptability, in which with the samples had higher acceptability than the control sample (0SH0) sample used in the sensory analysis.

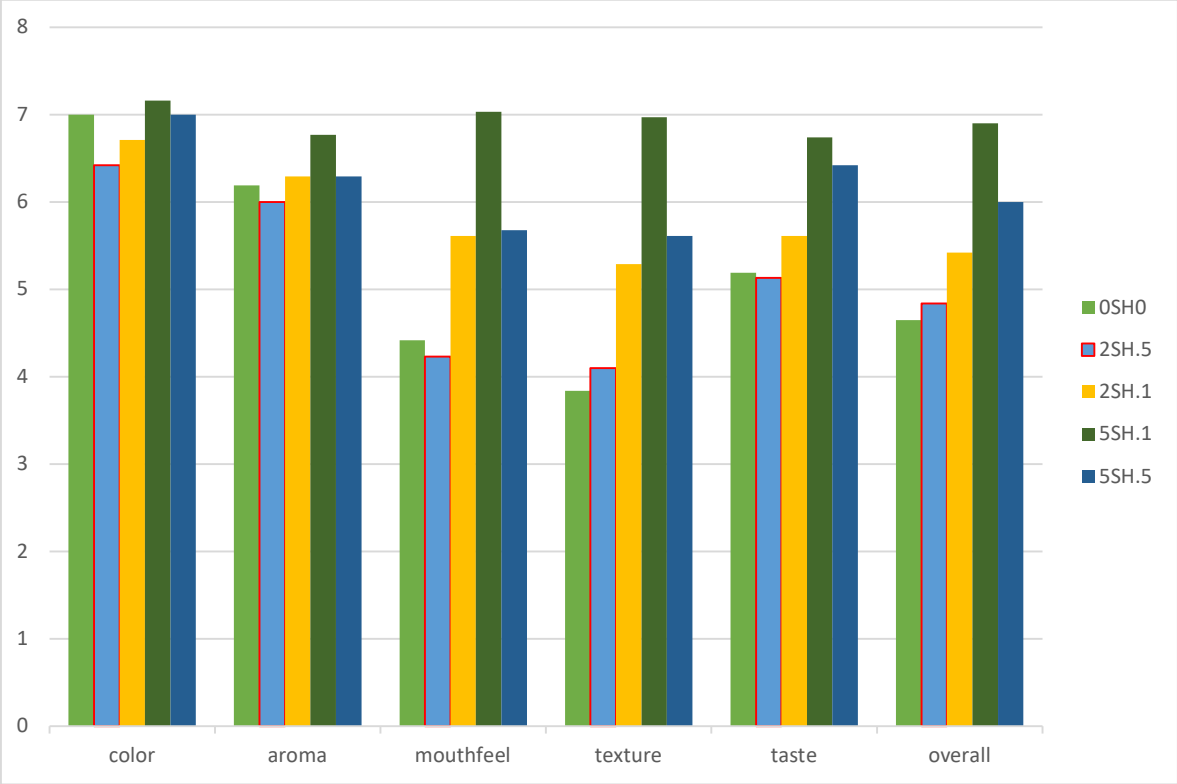



*Figure 3.8 Sensory evaluation of four coconut cream cheese formulations (2SH.1,2SH.5,5SH.1, and 5SH.5) with control sample (0SH0) after 48 hours of storage at 4°C.*

### *3.6 Proximate analysis of selected cream cheese*

The results of the proximate analysis of the coconut cream cheese formulation selected from the sensory analysis are detailed in Appendix B and Appendix C and summarized in Table 3.5. The coconut milk or control sample (0SH0) and coconut cream cheese formulation (5SH.1) were mainly composed of water, which was around 80.2% and 79.1% of their total composition, respectively. This was followed by fat content of 14.8%in the 0SH0 sample, and 13.7% in the 5SH.1 sample. The total dietary fibre content of 5SH.1 sample increased to 0.3% of total weight compared to 0.1% in the 0SH0 sample. Crude protein accounts for 1.2% of 5SH.1 sample and 1.1 % in the control sample. Total carbohydrate was estimated by calculation and was found to be 7.7% in the vegan cream cheese sample (5SH.1) and 3.8% control sample (0SH0).

The increase in crude protein, total dietary fibre content and carbohydrate in the 5SH.1 sample is due to the addition of ingredients (starch, xanthan and locust bean gum) in the formulation, while the reduction in moisture content maybe also be influenced by these ingredients.

*Table 3.5 Proximate analysis of coconut cream cheese*

| Proximate Contents | Control sample (0SH0) or coconut milk acidified | Vegan cream cheese sample selected (5SH.1) |
|---|---|---|
| **Moisture** | 80.2 | 79.1 |
| **Fat** | 14.8 | 13.7 |
| **Total dietary fibre** | 0.1 | 0.3 |
| **Crude protein** | 1.1 | 1.2 |
| **Ash** | 0.3 | 0.5 |
| **Carbohydrate by difference** | 3.5 | 5.2 |

## 3.7 Conclusions

The coconut cream cheese formulations containing different ratios of gums and starch showed some significant changes in stability and physicochemical attributes during storage. The incorporation of gums and starch caused an increase in viscosity and textural attributes. The introduction of starch and gums has also changed the nature of the product from a liquid to a low-viscosity gel which shows non-Newtonian behaviour depending on the ratio of ingredients used.

Based on the scores from the sensory evaluation and stability analysis of the coconut cream cheese formulations, sample 5SH.1 was selected as the most ideal sample to be compared with commercial cream cheese samples in the next chapter. Starch below 5% or with gums alone at a concentration below 0.5% were not considered ideal because of lower stability of samples. In contrast, the sample with a higher concentration of starch and gums in combination received lower consumer acceptability score which made them unsuitable for further studies.

This study identified that gums and starches can be used effectively as bulking agent in production of cream cheese alternatives using non-dairy milk.

# Chapter 4. Comparison of Commercial Cream Cheese Samples with a Coconut-based Cream Cheese Analogue

## 4.1 Abstract

The consumer demand for vegan alternatives to dairy products is paving a way for novel product development in the food sector. This study aims to compare the coconut cream cheese formulation selected after sensory analysis in the previous chapter with both commercial dairy and non-dairy samples to understand the product's properties and overall quality attributes. Two samples each of full-fat dairy cream cheese, reduced-fat dairy cream cheese, and vegan cream cheese formulations available commercially in New Zealand were selected in the study, respectively, to be compared with the coconut cream cheese formulated. The coconut cream cheese formulation demonstrated the lowest viscosity among all samples analysed at 20°C, while texture measurements suggested that coconut cream cheese formulation exhibited better characteristics in firmness, spreadability and adhesiveness than commercial reduced-fat cream cheese samples. The stability of the coconut cream cheese formulation was similar to vegan cream cheese available commercially, which showed no phase separation upon centrifugation. In terms of colour, even though lightness value (L) of the coconut cream cheese was identical to all the commercially available cream cheese samples, these samples had lower a* and b* values resulting in a characteristic more whiteish appearance.

## 4.2 Introduction

Cream cheese is a fat-in-protein emulsion particle gel, whose properties differ based on the components (carbohydrates, protein, fat, and moisture), the spatial arrangement of particles, and strength of different interaction among the components (Kim et al., 2022b). In 2023, the cream cheese export market in New Zealand recorded a 38.77% increase over five years (*Australia and New Zealand cheese market outlook report - market size, share analysis and forecast (2025-2034)*, 2024). Due to dietary restrictions brought on by vegetarianism, lactose intolerance religious, and cultural convictions, many consumers are opting for alternatives for high-fat diary-based cream cheese.

The high demand for reduced-fat and low-fat cream cheese varieties suggests that the consumer population prefers premium healthier products with lower fat content. To accommodate the vegan consumers, plant-based cream cheese alternatives are now widely available.

The objective of this research is to explore the differences in the physicochemical characteristics of the selected cream cheeses available in the markets of New Zealand, and to compare their characteristics with the cream cheese formulation selected previously by the consumer panellist through the sensory analysis conducted. The commercial dairy and non-dairy cream cheese samples were procured from the local markets and tested for appearance, textural and rheological properties, and stability.

## 4.3 Materials and Methods

### *4.3.1 Materials*

Commercial dairy cream cheese, commercial vegan cream cheese, and commercial reduced-fat cream cheese were purchased from the local market (New World, Palmerston North). Here, DA, and DP (commercial full-fat dairy cream cheese), SA, and SP (reduced-fat commercial cream cheese), NDA, and NDN (commercial vegan cream cheese), and CCC is a coconut cream cheese formulation formulated in the lab; refer Appendix E through Appendix J for the sample manufacturer information. The raw materials for coconut cream cheese manufacturing were the same as described in Section 3.2 in Chapter 3.

### *4.3.2 Sample preparation*

The coconut cream cheese formulation prepared as per Section 3.2, along with other samples in this study, was collected and transferred into 100 mL polypropylene containers a day prior to the start of the experiments.

*Table 4.1 Proximate composition and ingredients information for each cream cheese variety used in this study. * Moisture is calculated as (100-Carbohydrate+Fat+Protein) for all samples other than CCC.*

| **Cheese Variety** | Brand | Fat | Protein | Moisture* | Carbohydrate | Ingredients |
|---|---|---|---|---|---|---|
| **CCC** | Lab made sample* | 13.7 | 1.2 | 77.1 | 7.7 | coconut milk, xanthan gum, locust bean gum, salt, citric acid anhydride |
| **DA** | Anchor<br>Full fat cream cheese, Fonterra Brands NZ Ltd | 35.7 | 4.1 | 53.6 | 5.4 | cream, skim milk, milk solids, mineral salts (450, 452, 451, 339), salt, acid (lactic acid), stabiliser (401), flavour. contains milk. |
| **DP** | Philadelphia Full fat cream cheese, Philadelphia and Mondelez Australia (Foods) Ltd | 29.3 | 6.6 | 61.5 | 2.6 | pasteurized milk and cream, salt, carob bean gum, cheese culture |
| **NDN** | NuDairy Dairy-Free Cream Cheese, AlternaFoods Northland Ltd | 30.1 | 1 | 55.6 | 12.4 | water, coconut oil, modified starch (1404, 1420, 1450), sugar, emulsifier (341, 450), salt, acids (270,330), acid regulator (331), flavour, thickener (415), preservative (202), colour (160a). |
| **NDA** | Angel dairy free cream cheese alternative, Angel Food Ltd | 30.8 | 1 | 55 | 13.2 | water, coconut oil, modified starch (1420, 1450), sugar, salt, vegetable gum (carrageenan, xanthan gum), mineral salt (calcium phosphates), acidity regulator (lactic acid, citric acid), emulsifier (450), antioxidant (331), natural flavour, preservative (potassium sorbate), colour (carotene). |
| **SP** | Philadelphia light dairy cream cheese, Philadelphia and Mondelez Australia (Foods) Ltd | 13.7 | 7.9 | 71 | 4 | milk, cream (from milk), water, milk solids, salt, vegetable gums (412, 410), starter culture, processing aids (contain milk). |
| **SA** | Anchor lite dairy cream cheese, Fonterra Brands NZ Ltd | 16.5 | 5 | 64 | 14.5 | skim milk, cream, maltodextrin, milk solids, stabilisers (460, 466,401), acid (lactic acid), mineral salts (450, 452, 451, 339), salt, flavour. contains milk. |

*4.3.3 Analysis of Samples*

Cream cheese samples were analysed in different aspects such as colour change, textural properties, microstructural arrangements as mentioned in Sections 3.4 of chapter 3. All the samples were measured at room temperature.

4.3.3. 1 Colour

The colour of the samples was determined using Minolta Chroma colourimeter as described by the method. Using the equation for calculating Whiteness Index (WI) (Lapcikova et al., 2024), the results were compared and recorded.

*Equation 4-1*

$$WI = 100 - \sqrt{(100 - L)^2 + a^2 + b^2} \quad ----------$$

4.3.3.2 Rheological analysis

The rheological analysis of cream cheese samples was conducted at 20°C using a MCR 301 Rheometer (Anton Paar Physica, Germany). The system setup used P-PTD 200/56 with profiled parallel plate geometry (PP25/P2) with a gap of 1mm. The samples were analysed at 20°C. The data generated was analysed using Rheometer plus software (Version 3.62, RHEOPLUS/32).

The storage modulus (G') and loss modulus (G") analysis was conducted on the samples under a constant oscillation frequency of (1 Hz) under a strain sweep at 20°C as a function of logarithmically rising shear strain ($0.1s^{-1}$ to $100\ s^{-1}$). To allow for structural relaxation, samples were pre-shared for one minute at $100\ s^{-1}$ and then rested for two minutes.

Viscosity was measured as a function of shear rate, which was measured by gradually increasing the shear rate from 0.01-10%, with data recorded at equally spaced 31 points by every 10 seconds. A 2-minute waiting time was provided to the sample after the strain sweep test to allow internal structural adjustments. All the tests were performed at 20°C. Each sample was analysed in triplicate.

4.3.3.3 Stability analysis of cream cheese

A 50 g of each sample was weighed and transferred into a 50 mL centrifuge tube (Thermo Fisher Scientific, New Zealand). The tubes were tightly capped and centrifuged under two conditions: 4000g for 20 minutes at 4°C and 4000g for 50 minutes at 20°C, using a Multifuge X Pro Series Centrifuge (Thermo Scientific, GmbH, Germany) to analyse the stability of the

samples. This method was adopted from Yuxan Hu (2021) but modified to suit the characteristics of the coconut cream cheese and commercial samples. After centrifugation, the stability of the samples was visually evaluated for phase separation. The centrifugation method for observing phase separation and analysis of stability was adopted from and modified to observe the separation.

4.4 Data Analysis

All measurements were conducted at least twice for each sample with a minimum of duplicate experiments. The data obtained were analysed using a Minitab statistical software. One-way analysis of variance (ANOVA) and Tukey's honestly significant difference (HSD) test were applied to examine the significant differences between the mean values at a significance level ($p<0.05$).

## 4.5 Results and discussion

### *4.5.1 Texture analysis*

Texture analysis of the commercial dairy cream cheese (DA, DP), commercial vegan cream cheese (NDA, NDN), commercial reduced fat cream cheese (SA, SP), and coconut cream cheese formulated (CCC) was measured and compared. The textural characteristics are explained using firmness, spreadability, adhesiveness, cohesiveness and gumminess as shown in Figure 4.1.

For firmness the CCC, SA, SP and DP samples had significantly different values ($p<0.05$) from all other samples, while the DA, NDA and NDN samples did not show any significant differences among themselves. The lowest firmness was measured for the SP sample (1.69 N), while the highest was recorded for DA sample (21.55 N). According to the results, the cream cheese with higher fat contents had higher firmness, while reduced-fat cream cheese showed a softer texture.

The similar firmness values observed for the DA, NDA and NDN samples may be attributed to their relatively high fat contents. The lower firmness observed for the DP sample, despite its higher fat content, may be due to the absence of E401(sodium alginate), which can contribute to sample thickness and is present in the DA formulation. The lower fat content of the SP sample may explain its reduced firmness. Although the CCC samples contained the same amount of fat as the SP samples, they exhibited higher firmness, which may be attributed to the presence of fat replacers in their formulations. These findings are consistent with previous

studies on low-fat cream cheese and cream cheese, which reported that fat is an important component in determining cream cheese firmness (Brighenti et al., 2008).

Adhesiveness is an important textural attribute in characterizing cream cheese. The higher the negative value of adhesiveness, higher stickiness of the sample (Wong et al., 2023). The CCC sample had the highest adhesiveness, followed by DP sample, which has significantly higher adhesiveness than all other samples used in this study. The least stickiness was shown by the NDA, NDN and SP samples.

According to the TPA results, cohesiveness measurement for the samples did not produce any significant difference between NDA, NDN, SA and SP samples, or between the CCC, DA and DP samples. The maximum cohesiveness was reported for the SP sample, while the least was reported for the CCC samples. The low value for the CCC samples might be due to a lack of protein network and a high amount of moisture in the sample.

Spreadability is defined as the ease with which a sample is spread over a surface. Figure 4.1B shows that the commercial vegan cream cheese samples (NDA, and NDN), and coconut cream cheese analogue sample shows higher spread ability, followed by the DA and DP samples. The reduced-fat cream cheese samples (SA, and SP) showed the least spread ability, in which SP sample having the least value. These findings were in accordance with the results of Brighenti.et.al (2008), where cream cheese with lower fat contents provided lower spreadibility.

Gumminess was highest in commercial vegan cream cheese samples (NDA, and NDN), while the lowest were seen in the commercial reduced fat dairy samples (SA, and SP). The coconut cream cheese analogue (CCC) had higher gumminess than reduced-fat dairy cream cheese sample (SP) but lower gumminess than commercial full- fat dairy samples (DA, and DP).

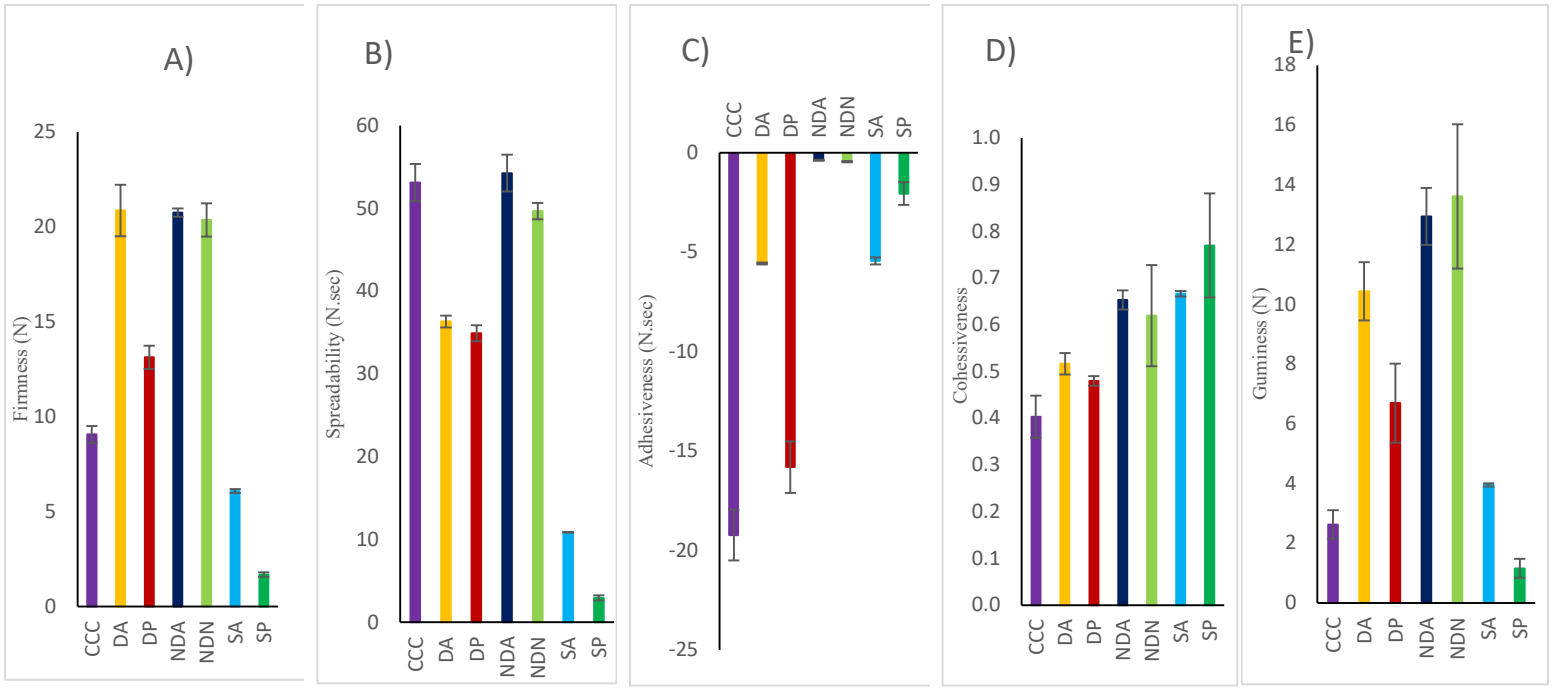



*Figure 4.1 Changes in texture attributes: firmness (A), spreadability (B), adhesiveness (C), cohesiveness (D), gumminess (E), of different commercial dairy (DA, DP, SA, and SP), and non-dairy cream cheese (NDA, NDN) with coconut cream cheese formulation (CCC) on day 1.*

*4.5.2 Rheological measurements*

The rheological properties of all cream cheese samples were determined using the procedure described in Section 4.5. The apparent viscosity of different samples of cream cheeses measured at 20°C at increasing shear rate is illustrated in Figure 4.2. The reduction in viscosity with an increase in shear rate suggests that all the samples have a shear thinning or non-Newtonian behaviour which was like previous studies on cream cheese (Ningtyas et al., 2017b). The samples were measured in the range between 0.01-10$s^{-1}$ shear rate as the NDA and NDN samples were experiencing breaking of samples above 10$s^{-1}$ shear rate. The CCC sample measured the lowest viscosity in the given shear rate, while the NDA and NDN samples had the highest viscosity. The dairy-based samples had lower viscosity than commercial vegan cream cheese samples which could be due to the presence of starch acting as bulking agents in the vegan cream cheese. This can be understood by comparing the firmness of cream cheese with viscosity, as DA sample shows the higher firmness comparable to that of NDA and NDN sample, it shows a lower viscosity due to the higher milk-fat content in DA sample. The lower viscosity of CCC samples, even though starch being in their formulation could be due to variety of starch and concentration of starch in the formulation.

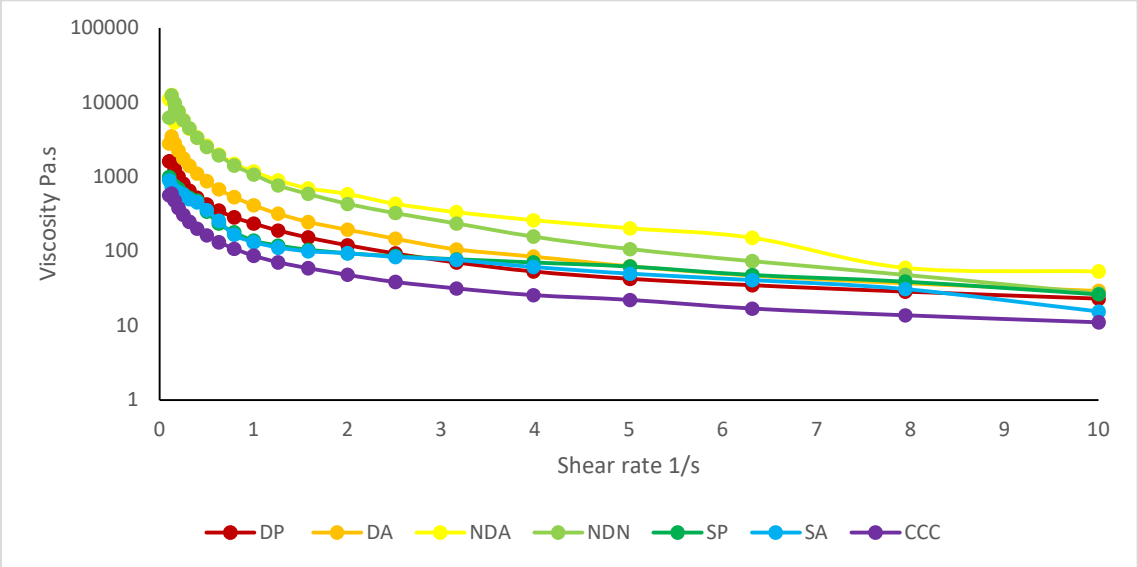



*Figure 4.2 Apparent viscosity of cream cheese samples measured at 20°C.*

Commercial vegan cream cheese samples (NDA, NDN) had the highest G' and G" values measured through the strain range. However, the commercial full fat cream cheese samples (DA and DP) had the initial high G' value indicating a solid behaviour at low strain% which reduced significantly after the strain of 40%. Among all the samples, coconut cream cheese formulation (CCC) had the lowest G'and G" values. However, the smaller variation between G' and G" value of CCC sample suggests that these samples possess higher gel nature compared to other samples in the analysis.

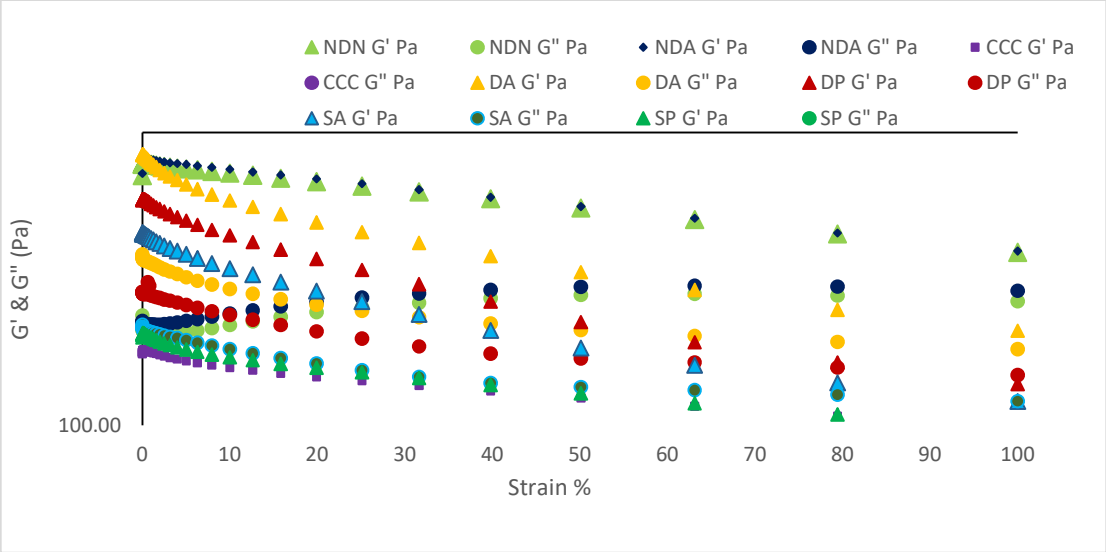



*Figure 4.3 G' and G" of dairy and non-dairy cream cheese samples measured at 20°C.*

### *4.5.3 Colour*

The colour of commercial cream cheese, commercial vegan cream cheese and coconut cream cheese made was assessed using CIE L*, a*, b* values, which denote lightness, redness-greenness, and yellowness-blueness respectively. Comparison of L*, a* and b* values of coconut cream cheese (CCC) with commercial dairy and non-dairy samples showed a significant difference ($p<0.05$). All the results are presented in Figure 4.5.

The commercial dairy cream cheese had a glossy surface appearance, which is typically seen in dairy cream cheese. The vegan cream cheese, however, had a light, glossy appearance. The coconut cream cheese (CCC) had a glossy appearance, almost similar to commercial dairy cream cheese (Figure 4.4). The difference in colour intensities seen in the samples could be described between white and pale yellow. Dairy based cream cheese samples had a pale yellowish colour which is due to the colour of dairy cream, whereas the commercial vegan

cream cheeses had colourants (carotene, also called E 160a) added to them to replicate the colour of dairy cream cheese. The coconut cream cheese had a white colour, which is a result of coconut milk, and this colour was not deteriorated by the ingredients used in the formulation.

Comparison of L* values suggest the influence of fat and starch in the formulations on the lightness of the product. The samples exhibited L* values in the range between 83.24 and 87.71. The coconut cream cheese (CCC) had lower lightness compared to all other samples except SA, while SP was measured with the highest L* value. Even though differences between the L* values were observed, the variation in darkness intensity was not pronounced within the samples.

The a* values which represent the redness for positive values and green for negative values suggested that the NDA sample had more greenish colour compared to all the other samples, while the CCC had a more neutral colour, tending toward white.

All samples denoted positive b* values, which suggested all samples had a yellow colour. The NDN, SA and SP samples had a similar b* values, while the NDA sample had the highest value for b* value of 17.59 among all samples. The DA sample had a comparatively lower b* value of 12.71 while measured and CCC sample measured the least value of 4.14 for b* value. The reason for the low b* value of CCC sample is the use of coconut milk, while the similarity in b* values recorded for SA and SP samples could be because of the reduced fat content present. The low b* value of DA sample can be associated with use of lactic acid instead of the fermentation process used for the DP sample.

The whiteness index (WI) is a measure of the deviation of a product's colour from an ideal white colour. The comparison of WI values is presented in Figure 4.5D. No significant differences in WI were observed among most of the samples. However, the CCC sample exhibited the lowest WI value, which was significantly different from those of all other samples. In contrast, the highest WI value was observed for the NDA sample. The WI values of the full-fat dairy cream cheese samples (DA and DP) were higher than those of the low-fat dairy cream cheese samples (SA and SP). This difference may be attributed to the greater light-scattering effect of fat in the full-fat cream cheese samples. In contrast, the lower fat content of the low-fat cream cheese samples may have resulted in reduced light scattering and, consequently, lower whiteness. These results suggest that fat content is an important factor influencing the WI of cream cheese. In addition to fat, the water content and protein network structure may also contribute to the whiteness of the product. The CCC sample had the lowest

protein and fat contents and a relatively high-water content, which may explain its lowest WI among the samples tested.

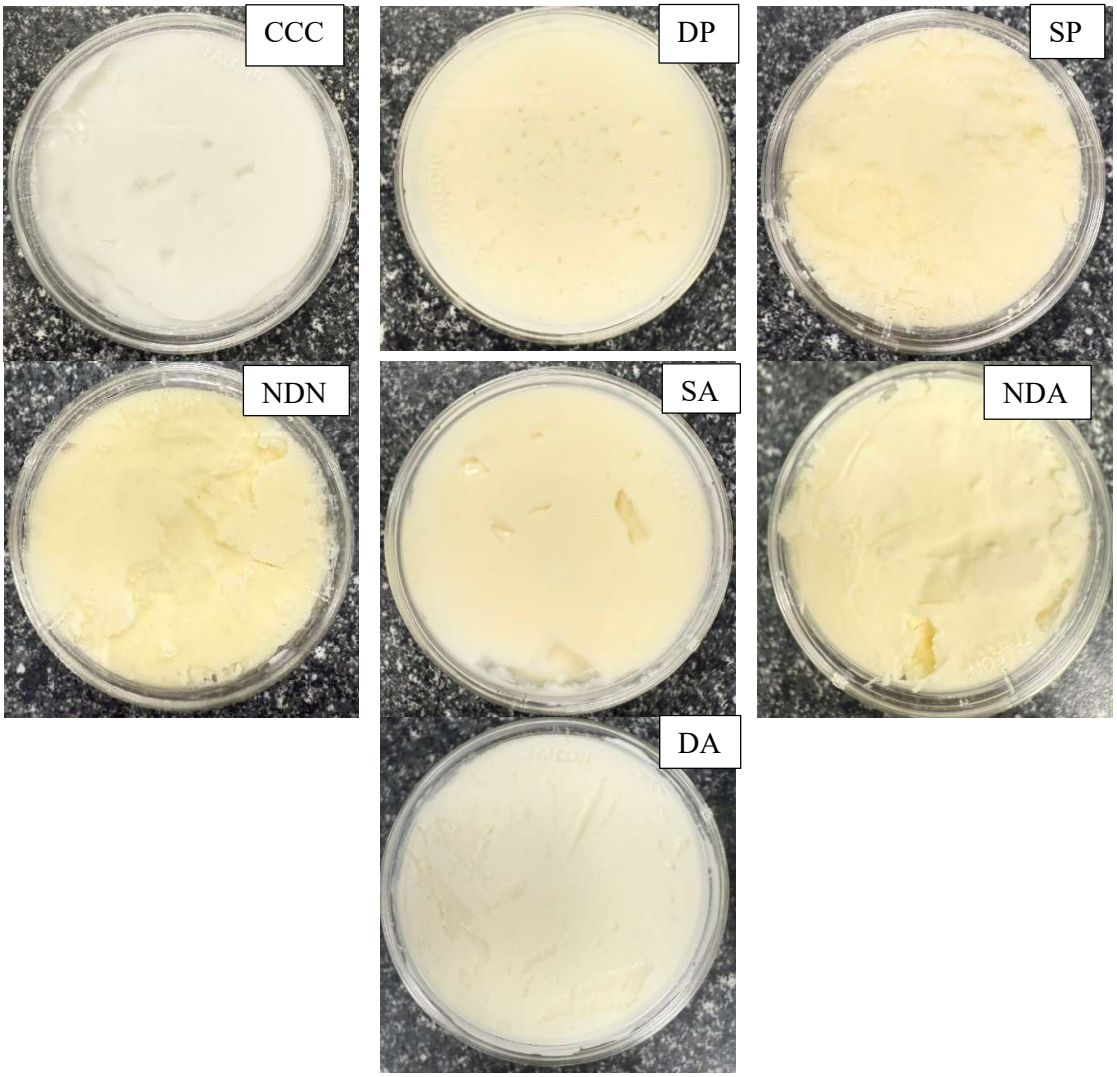



*Figure 4.4 Photographs of cream cheese samples: DA, and DP (commercial full-fat dairy cream cheese), SA, and SP (reduced-fat commercial cream cheese), NDA, and NDN (commercial vegan cream cheese), and CCC is a coconut cream cheese formulation formulated.*

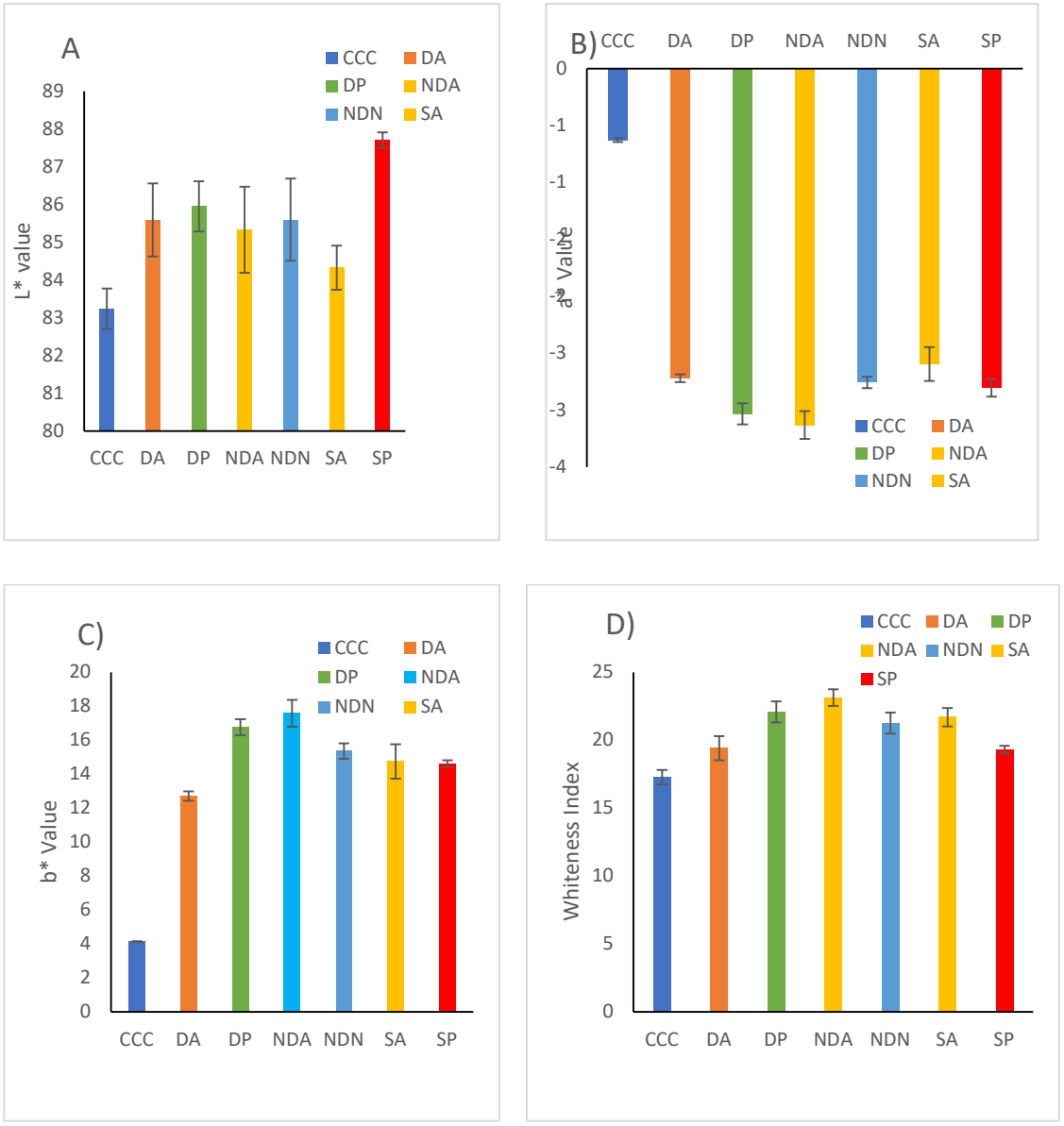



*Figure 4.5 Changes in colour (CIE L*, a* and b* values) of cream cheese samples stored at 5°C, A, B C respectively. D) whiteness index comparison of different cream cheese samples.*

***Dairy full-fat (DA, DP), dairy reduced-fat (SA, SP), commercial vegan cream cheese (NDA, NDN) and coconut cream cheese (CCC) formulated in lab measured.***

*4.5.4 Microstructure of cream cheese*

The microstructural analysis of the cream cheese samples was conducted using confocal laser scanning microscopy (CLSM). The images are displayed in Figure 4.6, which represent the arrangement of fat, protein and starch within the matrix of commercial dairy cream cheese, commercial vegan cheese and the coconut cream cheese sample formulated. All samples evince polydisperse condition with oil droplet sizes ranging from 10 μm to 20 μm.

The oil droplets are represented by the red globules, and the yellow colour represents the presence of starch and protein in the cheese matrix. Being an emulsion-gel, dairy cream cheese (DA, DP), has an oil-in-water type emulsion, entrapped between the protein network formed by casein. In reduced fat cream cheese (SA, SP), the reduction of fat is attained by the substitution of fat with fat mimetics, like starch and gums. In vegan cream cheeses, gel formation is achieved using a starch matrix as a substitute for the weak protein network formation. Samples DA and DP are full-fat cream cheeses and have their oil- droplets adhered to the protein network, whereas SA and SP are reduced fat cream cheese samples, which could mean a higher presence of starch or gums and protein in the matrix. The unstained area in the matrix denotes the serum phase with a part of starch and hydrocolloids, which includes water, various solutes and stabilizers in the cheese matrix.

The commercial vegan cream cheese (NDA, and NDN), however, has a matrix with starch present throughout, reducing the unstained are in the matrix. This suggests that starch has a crucial role in the texture and stability of cream cheese samples. The microstructure analysis of the coconut cream cheese sample (CCC) also shows a comparable result to the commercial vegan cream cheese sample in this aspect, where the starch in the sample is present throughout the matrix, which could be the reason for the texture and stability of the sample

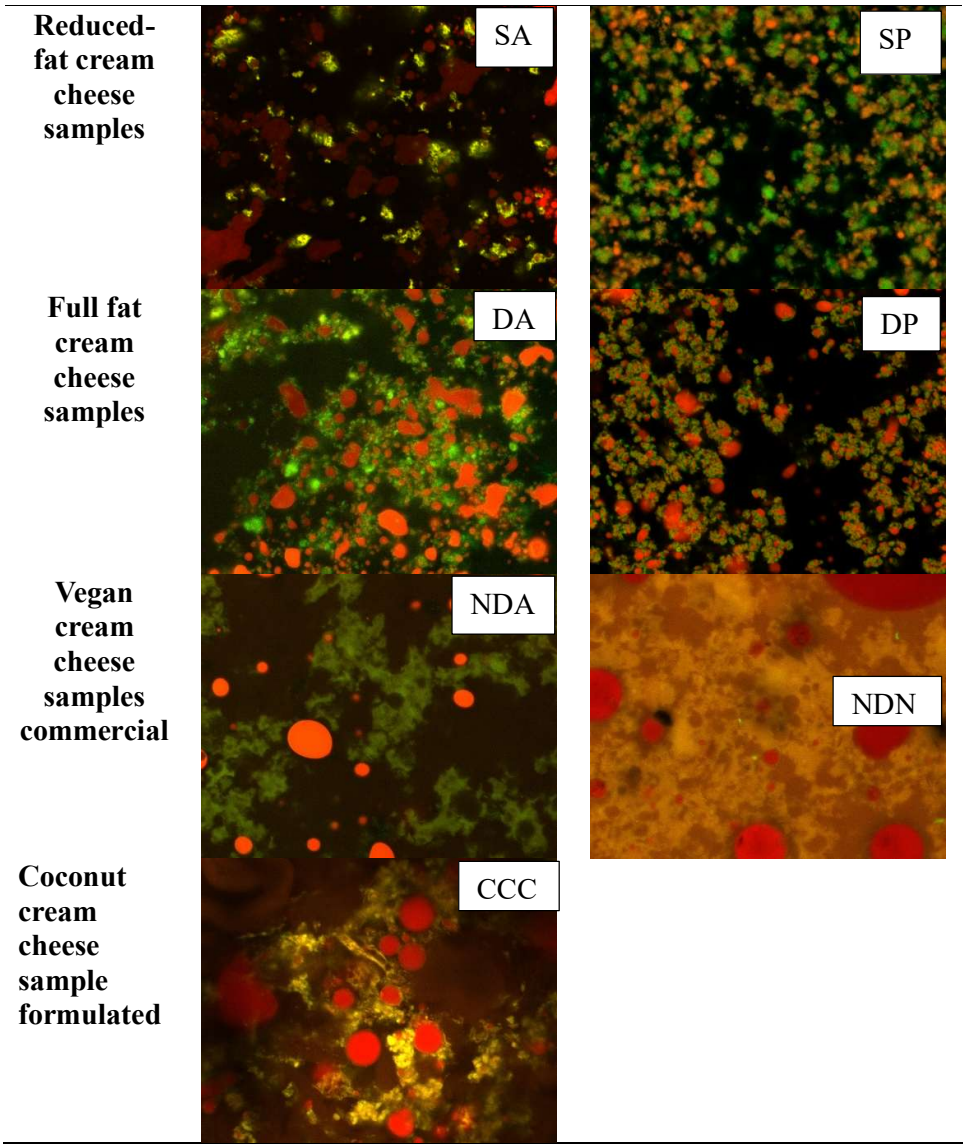



*Figure 4.6 Microstructural images of different cream cheese samples. (Scale observed at 10 µm).*

*4.5.5 Stability of cream cheese*

The stability of commercial dairy cream cheese (DP, DA, SP, and SA), commercial vegan cream cheese (NDA and NDN) and the formulated coconut cream cheese sample (CCC) was assessed at 4°C and 20°C by centrifuging the samples at 4000 x g for 20 minutes and 50 minutes, respectively. The results of the centrifugation test are presented in Figure 4.7.

None of the samples exhibited visible phase separation after centrifugation at 4°C, suggesting that the cream cheese samples were relatively stable under refrigerated conditions. This stability may be attributed, at least in part, to the presence of gums in the formulations, which can enhance water binding and contribute to the stability of the product structure. Previous studies have reported phase separation in cream cheese formulations without gums, supporting the potential role of hydrocolloids in maintaining structural stability.

At 20°C, the DP, SP, and SA samples showed lower stability than the other cream cheese samples, as visible phase separation was observed after centrifugation for 50 minutes. The observed separation may have been associated with the effect of temperature on fat melting and oil release, as well as the relatively high moisture contents of these samples (55%, 71%, and 70%, respectively) and their comparatively weaker gel networks. In contrast, the NDA, NDN, and CCC samples exhibited greater stability under these conditions. The higher stability of CCC may be related to the presence of coconut fat, which remains relatively solid at 20°C, together with the starch incorporated into the formulation, which may contribute to the formation of a more stable structural network.

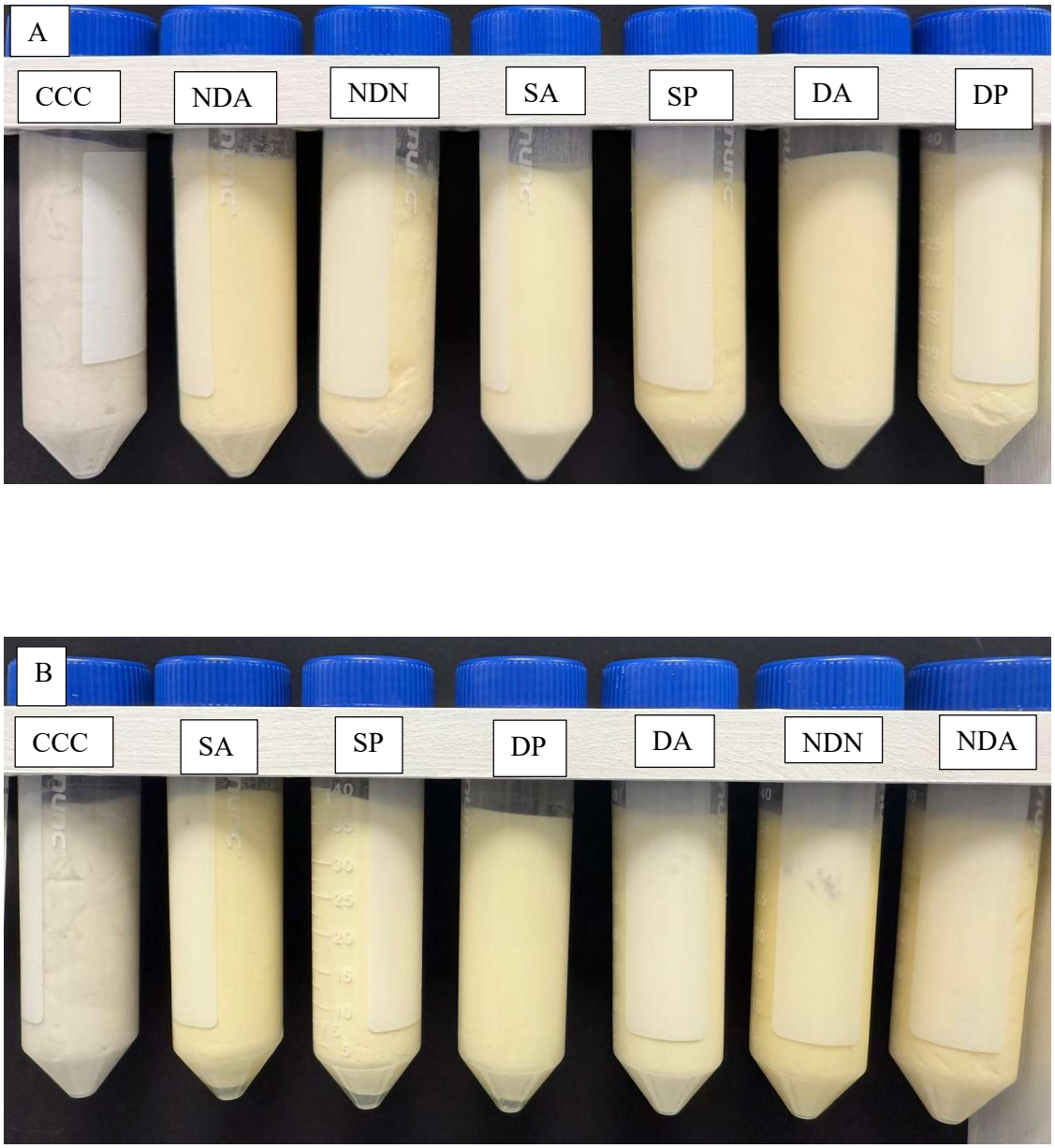



*Figure 4.7 Stability of cream cheese samples observed at different temperatures after centrifugation.*

**A) after centrifugation at 4°C for 20 minutes. B) after centrifugation at 20°C for 50 minutes.**

**Dairy full-fat (DA, DP), dairy reduced-fat (SA, SP), commercial vegan cream cheese (NDA, NDN) and coconut cream cheese (CCC) formulated in lab measured.**

## 4.6 Conclusions

Six commercial cream cheese samples, including full-fat (DP, and DA), and reduced-fat dairy (SP, and SA), and non-dairy (NDA, and NDN) were compared with a coconut cream cheese sample formulated (CCC) in this study. Significant differences in all parameters were observed among the samples, suggesting an individuality in the characteristics of the product based on their ingredients and method of manufacture. The formulated coconut cream cheese (CCC) had lower viscosity than reduced-fat cream cheese samples (SP, and SA) but had higher firmness than all commercial reduced-fat cream cheese samples (DP, DA, SP, SA, NDA, and NDN). This suggests that the starch-hydrocolloids inclusion helped in development of a firmer matrix in the CCC sample but only could provide significant improvement in the viscosity of the sample.

In terms of stability, the coconut cream cheese formulation exhibited a higher stability than its commercial dairy- free samples (NDA, and NDN), as defined by the absence of phase separation after centrifugation at 20°C. This indicates that the starch-hydrocolloid combination in the CCC sample was effective in stabilising the coconut cream cheese matrix and maintain the integrity of the product under the applied conditions.

Overall, these findings indicate that coconut cream cheese formulated can be used as alternative to commercial cream cheese in terms of texture and stability. However, more optimisations might be required to enhance the viscosity of the CCC sample. Thus, these results provide evidence for starch-hydrocolloid structuring can enhance the functional properties of coconut-based cream cheese and can be used as an approach for production of vegan cream cheese commercially.

# Chapter 5. Conclusion and Recommendations

## 5.1 Research outcome

The study focused on developing a vegan cream cheese alternative using coconut milk and hydrocolloids and investigating their effects on the physicochemical characteristics and sensory attributes of the product. Nine formulations, including a control, were prepared by incorporating varying ratios of gums (at a 1:1 concentration) and starch into coconut milk to produce cream cheese alternatives and evaluate their effects on product properties. In addition to the coconut cream cheese formulations, the selected formulation was subsequently compared with commercial dairy and non-dairy cream cheese products. This research provides useful information on the development of a vegan cream cheese alternative using non-dairy milk and contributes to addressing gaps in the availability of plant-based cream cheese products.

According to the results, the formulated coconut cream cheese exhibited lower viscosity than the commercial samples but relatively higher firmness. Different concentrations of starch and gums significantly affected the stability and quality characteristics of the formulated vegan cream cheese. Although the samples had relatively similar moisture and fat contents, the addition of starch and gums improved their viscosity and textural properties. All formulations exhibited pseudoplastic behaviour under shear, which became more pronounced with increasing concentrations of gums and starch. The addition of starch and gums had little effect on the colour of the formulations, and no significant differences in colour were observed among the samples during storage.

In general, formulations containing 0.1% (w/w) hydrocolloids individually, and those containing less than 2% (w/w) starch, were unable to provide sufficient functional and textural characteristics for use as a cream cheese alternative. In contrast, formulations containing higher concentrations of starch (5%) and gums (0.5%), either individually or in combination, exhibited characteristics more suitable for a vegan cream cheese analogue. Considering the potential health benefits of coconut milk, the selected coconut milk-based cream cheese formulation was compared with commercial cream cheese products to further evaluate its physicochemical and quality characteristics.

The comparison of commercial dairy and non-dairy cream cheese samples with the formulated coconut cream cheese provided further insights into their rheological and textural characteristics.

For the sensory evaluation, a 9-point hedonic scale was used to assess the consumer acceptability of the coconut cream cheese formulations containing starch and hydrocolloids. The formulations were compared with the 0SH0 sample, consisting of acidified coconut milk without starch or gums, to evaluate the effect of these hydrocolloids and starch on consumer acceptability relative to the base coconut milk formulation. The formulation receiving the highest overall acceptability score was selected for comparison with commercial cream cheese samples in the second study. Among the formulations tested, the 5SH.1 sample, containing 5% starch and 0.1% gum mixture, received the highest overall acceptability from the consumer panellists.

**5.2 Recommendations**

The aim of this research was to develop a reduced-fat, coconut-based vegan cream cheese using coconut milk in combination with hydrocolloids and starch. The study investigated different concentrations of a hydrocolloid mixture consisting of xanthan gum and locust bean gum at a 1:1 ratio (w/w), together with varying starch concentrations (0%, 2%, and 5%), to achieve desirable textural and sensory properties in a cream cheese analogue with reduced fat content. The effects of hydrocolloid and starch concentrations on the sensory, textural, and rheological properties of the vegan cream cheese analogue were evaluated.

Based on the findings of this study, further research could focus on optimising the concentrations and combinations of starch and hydrocolloids to improve the texture, stability, and sensory acceptability of the product. Further investigation of the interactions between starch, xanthan gum, and locust bean gum could provide a better understanding of their contribution to the structure and rheological behaviour of the product. Further studies could also investigate the storage stability of the selected formulation over an extended period and under different storage conditions. In addition, optimisation of the formulation could be undertaken to further improve its similarity to commercial cream cheese in terms of colour, texture, rheological properties, and sensory acceptability.

Different coagulation methods, such as the application of glucono-delta-lactone (GDL), could be investigated to determine their effects on the structure, texture, and sensory properties of the reduced-fat vegan cream cheese analogue. The incorporation of probiotic cultures into the product could also be explored to enhance its potential functional properties. Further research is required to evaluate the potential health benefits of the product and to better understand its effects on consumers.

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# Appendices

## Appendix A.

**The composition of coconut milk (Organic coconut milk, Ceres Organics Ltd., Sri Lanka) used in this study to produce coconut cream cheese analogue.**

| Component | Average quantity per 100 g |
|---|---|
| Protein | 1.4 g |
| Fat | 18 g |
| Carbohydrate | 2.3 g |
| Sodium | 18 mg |
| Dietary fibre | 1.1 g |

## Appendix B.

**Nutritional information on Ultra-Tex 4 starch**

| **Nutritional information** | |
|---|---|
| **Nutrients** | **Avg. Qty per 100g** |
| Energy | 1556 kJ |
| Calories | 372 kcal |
| Protein | 0.1 g |
| Fat Total | 0 g |
| Saturated | 0 g |
| Carbohydrates | 92.9 g |
| Sugar | 0 g |
| Fibre | 0 g |
| Salt | 0.42 g |

## Appendix C.



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| | | | | |
|---|---|---|---|---|
| TO: | Lara Matia-Merino | AT: | SF&AT | |
| SUBJECT: | Final Report | DATE: | 1/07/24 | ON: NP963121222PRADE |
| TRIAL: | TN24-385 | SAMPLES RECEIVED: | 15/05/24 | |

Number of pages in this report: 1
Client Reference: Dr Sung Jee Lee, Dr Lara Matia Merino
Testing initiated: 29/05/24
Testing completed: 1/07/24

TN24-385 Cream cheese & Coconut milk Results are on an as received basis

| NutLab ID | Sample Name | Crude Protein % | Fat % | TDF % |
|---|---|---|---|---|
| TN24-385-01 | Vegan Cream Cheese | 1.2 | 13.7 | 0.3 |
| TN24-385-02 | Coconut Milk Acidified | 1.1 | 14.8 | 0.1 |

*Methodology*

*Crude protein : AOAC 968.06 (Dumas method). N-P = 6.25*

*Fat : (Majonnier) Acid, (Flour, Baked, extruded products) AOAC 922.06*

*Total Dietary fibre : Megazyme, AOAC 991.43*

Wibha Desai
IANZ Key Technical Person

Karl Dale
IANZ Key Technical Person

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***Samples will be discarded one month from date of this report unless otherwise requested by client.***

**Fliss Jackson**
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All tests reported herein have been performed in accordance with the laboratory's scope of accreditation

**Appendix D.**

**Moisture content and ash% of vegan cream cheese and coconut milk**

| Component | Coconut milk | Vegan cream cheese |
|---|---|---|
| Moisture content | 80.2 | 79.1 |
| Ash | 0.3 | 0.5 |

**Appendix E.**

**The composition of Anchor dairy cream cheese (Anchor cream cheese, Fonterra Brands NZ Ltd., New Zealand) used as DA sample in the study.**

| Component | Average quantity per 100 g |
|---|---|
| Protein | 4.1 g |
| Fat | 35.7 g |
| Carbohydrate | 5.4 g |
| Sodium | 688 mg |

**Appendix F.**

**The composition of Philadelphia dairy cream cheese (Philadelphia cream cheese, Philadelphia and Mondelez Australia (Foods) Ltd., Australia) used as DP sample in the study.**

| Component | Average quantity per 100 g |
|---|---|
| Protein | 4.9 g |
| Fat | 21.8 g |
| Carbohydrate | 2.9 g |
| Sodium | 350 mg |

**Appendix G.**

**The composition of Philadelphia light dairy cream cheese (Philadelphia light cream cheese, Philadelphia and Mondelez Australia (Foods) Ltd., Australia) used as SP sample in the study.**

| Component | Average quantity per 100 g |
|---|---|
| Protein | 6.1 g |
| Fat | 21.9 g |
| Carbohydrate | 2.9 g |
| Sodium | 379 mg |

**Appendix H.**

**The composition of Anchor lite dairy cream cheese (Anchor cream cheese lite, Fonterra Brands NZ Ltd., New Zealand) as SA sample in the study**

| Component | Average quantity per 100 g |
|---|---|
| Protein | 5 g |
| Fat | 16.5 g |
| Carbohydrate | 14.5 g |
| Sodium | 694 mg |

**Appendix I.**

**The composition of Angel dairy free cream cheese alternative (Angel dairy free cream cheese alternative, Angel Food Ltd., New Zealand) as NDA sample in the study**

| Component | Average quantity per 100 g |
|---|---|
| Protein | <1 g |
| Fat | 30.8 g |
| Carbohydrate | 13.2 g |
| Sodium | 855 mg |

**Appendix J.**

**The composition of Nudairy dairy-free cream cheese (Nudairy dairy-free cream cheese, AlternaFoods Northland Ltd., New Zealand) NDN sample**

| Component | Average quantity per 100 g |
|---|---|
| Protein | <0.1 g |
| Fat | 30.1 g |
| Carbohydrate | 212.4 g |
| Sodium | 855 mg |

## Appendix K.

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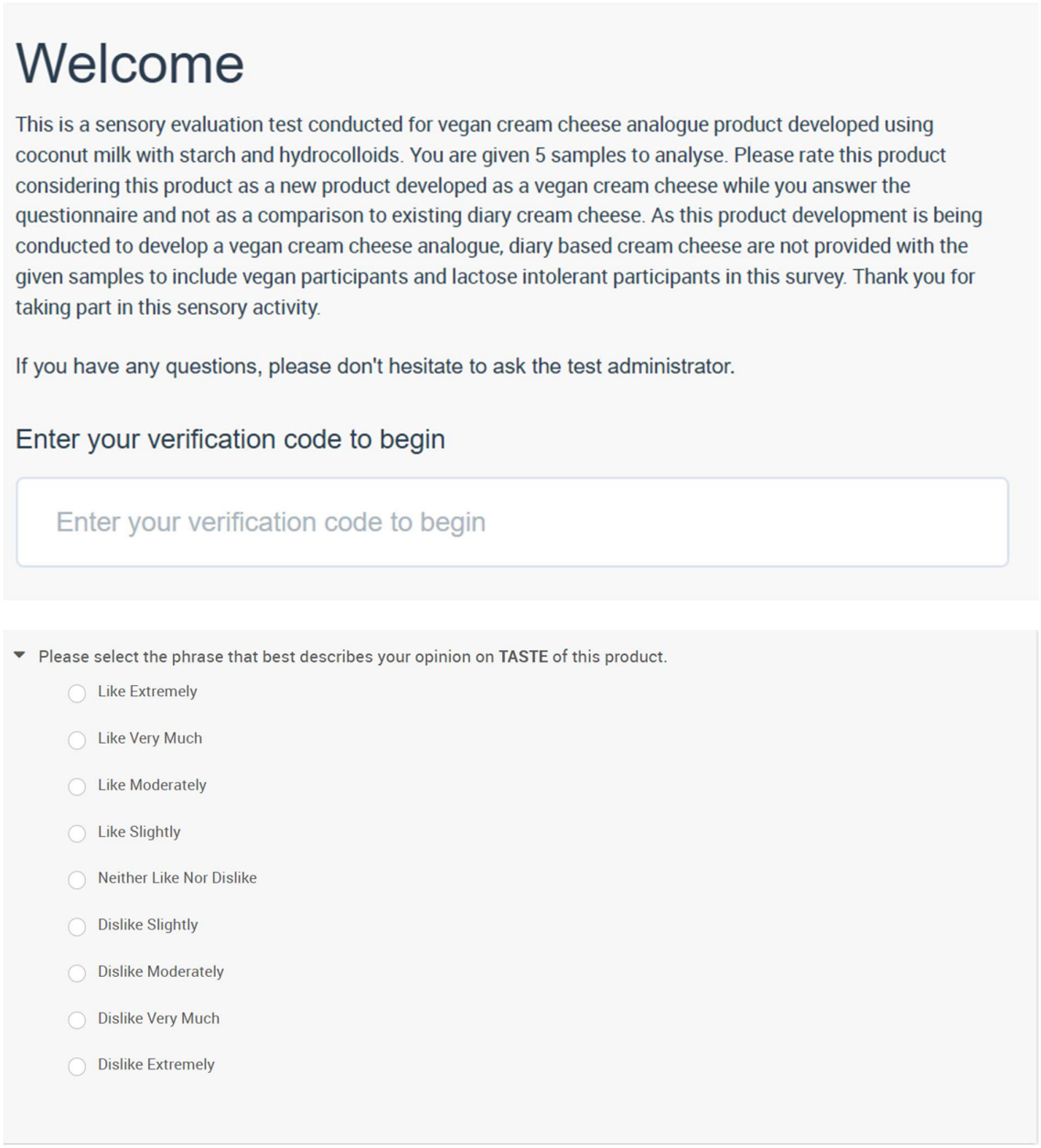
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**Appendix L.**

**The sensory questionnaires in the sensory test**



# Welcome

This is a sensory evaluation test conducted for vegan cream cheese analogue product developed using coconut milk with starch and hydrocolloids. You are given 5 samples to analyse. Please rate this product considering this product as a new product developed as a vegan cream cheese while you answer the questionnaire and not as a comparison to existing diary cream cheese. As this product development is being conducted to develop a vegan cream cheese analogue, diary based cream cheese are not provided with the given samples to include vegan participants and lactose intolerant participants in this survey. Thank you for taking part in this sensory activity.

If you have any questions, please don't hesitate to ask the test administrator.

Enter your verification code to begin

Enter your verification code to begin

Please select the phrase that best describes your opinion on **TASTE** of this product.

- Like Extremely
- Like Very Much
- Like Moderately
- Like Slightly
- Neither Like Nor Dislike
- Dislike Slightly
- Dislike Moderately
- Dislike Very Much
- Dislike Extremely

Please select the phrase that best describes your opinion on **TEXTURE** of this product.

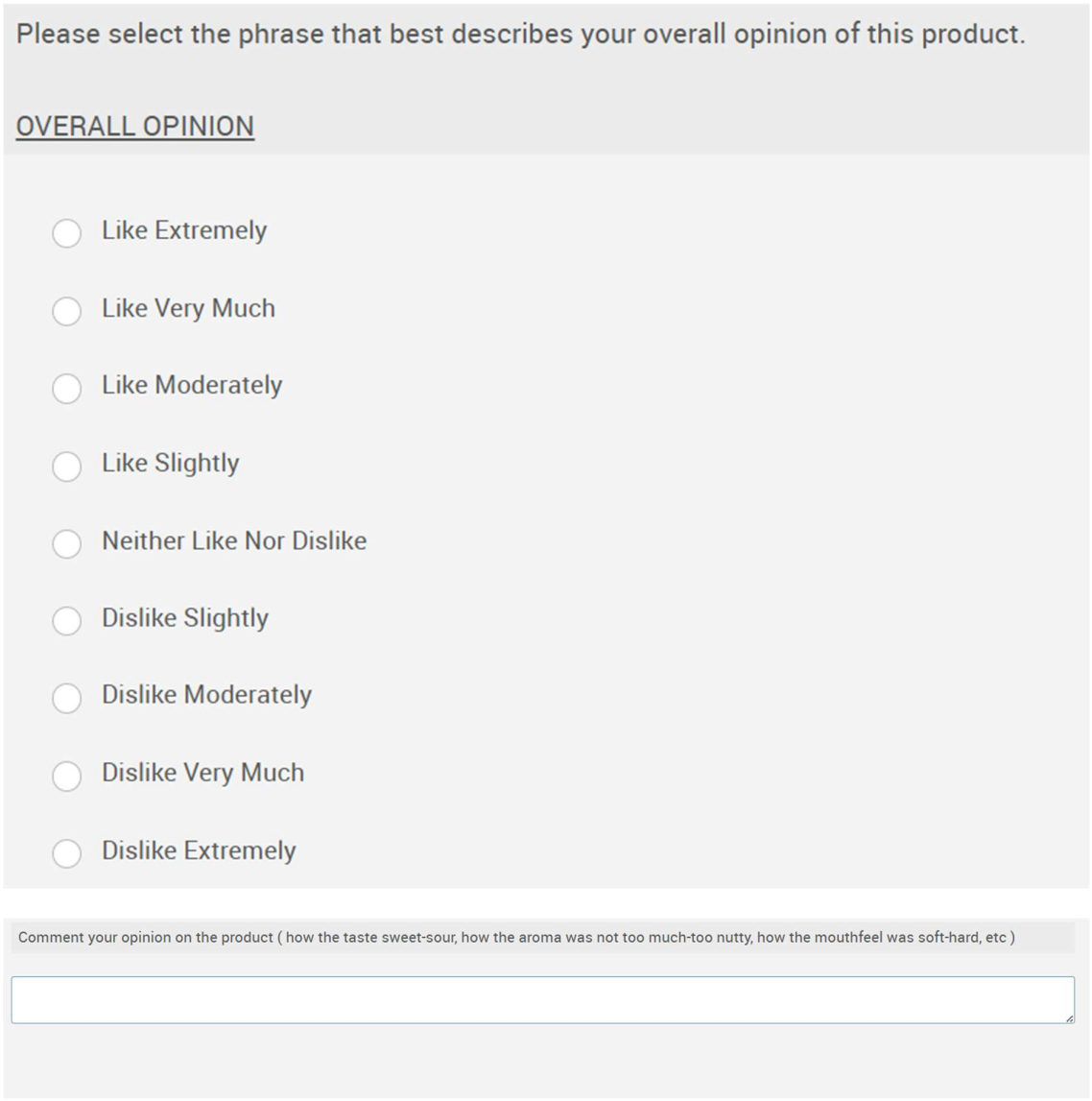
- ○ Like Extremely
- ○ Like Very Much
- ○ Like Moderately
- ○ Like Slightly
- ○ Neither Like Nor Dislike
- ○ Dislike Slightly
- ○ Dislike Moderately
- ○ Dislike Very Much
- ○ Dislike Extremely

Please select the phrase that best describes your opinion on **AROMA** of this product.

- ○ Like Extremely
- ○ Like Very Much
- ○ Like Moderately
- ○ Like Slightly
- ○ Neither Like Nor Dislike
- ○ Dislike Slightly
- ○ Dislike Moderately
- ○ Dislike Very Much
- ○ Dislike Extremely

Please select the phrase that best describes your opinion on Color of this product.

- ○ Like Extremely
- ○ Like Very Much
- ○ Like Moderately
- ○ Like Slightly
- ○ Neither Like Nor Dislike
- ○ Dislike Slightly
- ○ Dislike Moderately
- ○ Dislike Very Much
- ○ Dislike Extremely




**Appendix M.**

**Declaration of use of AI software throughout the thesis**

I have used AI software's like ChatGPT and Grammarly to support various sections of my thesis, ensuring AI-assisted outputs are critically reviewed and ethically integrated into my thesis. As a responsible researcher, I acknowledge that the use of AI in my thesis was only to overcome the writer's block and identify grammar or vocabulary errors to distinctly explain the contents that was originally written by myself.

## Appendix N

## Combined Texture analysis plots

