Hovedoppgave

NTNU
Norges teknisk-naturvitenskapelige universitet
Fakultet for naturvitenskap
Institutt for bioteknologi og matvitenskap

Njål Berg Knudsen

Comparison of dairy mozzarella and plant-based alternatives under pizza baking conditions, with focus on sensorial-, nutritional-, and rheological properties

Hovedoppgave i Matvitenskap, Teknologi og Bærekraft
Veileder: Kari Helgetun Langfoss
Medveileder: Ida-Johanne Jensen
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Abstract

Cheese is one of the most commercially important food groups in the world, partially due to their use in popular dishes like pizza, which has gained global recognition and popularity due to its simple and distinct taste. Despite this growth, there is little available information concerning the alternatives of low-moisture mozzarella cheese (LMMC), particularly in terms of sensory properties.

The market for Plant-based alternatives to animal-based products is growing from a myriad of reasons. Consumers are getting increasingly concerned around ethical treatment for animals and show a greater desire to eat sustainably.

The primary goal of this thesis is to conduct a comprehensive comparison of LMMC and plant-based cheese alternatives (PBCA) which are produced to be used for pizza. To achieve this goal, a number of experiments to compare the nutritional composition, colour and rheological properties when heated in pizza-baking conditions, and important sensorial properties were conducted on a selection of PBCA-products purchased from Norway and the US.

Previous studies have scarcely begun to cover the unique sensory properties of PBCAs, partially because of their great variation and mouldability. A PBCA can be produced from many isolated ingredients in a manner which is meant to imitate the original product as closely as possible, or from simpler plant-based ingredients which embrace some of their inherent flavours. In this thesis, four PBCAs produced from ultra processed starch from various sources, and one product of PBCA made from cashew milk, were compared to typical LMMC intended for use on pizza.

From a chemical analysis, it was found that while most PBCA contain coconut oil as its only source of fat, there is potential for better properties of melting when using oils with more unsaturated fats. The little protein that is found in PBCAs has a significantly lower amount of essential amino acids but assists with meltability.

In the sensorical analyses it was found that consumers could easily distinguish between LMMC and PBCA and found that LMMC had a higher level of acceptance among non-vegan consumers, compared to PBCA, due to a number of sensory defects found in PBCA. Primary of which were low meltability, stickiness to touch, and stronger aroma and taste which was found distasteful.

In future experiments there should be a greater focus to identify the compounds that give flavour and aroma to LMMC, as well as more attention to PBCA produced from other sources than starch-and-oil.

Sammendrag

Det globale markedet for plante-baserte alternativer til animalske matprodukter har vokst enormt de siste årene, av diverse årsaker. Forbrukere har en økende bekymring og empati for behandling av dyr innen matindustrien. Det vestlige samdunnet blir stadig mer klar over de miljømessige konsekvensene som den globale matproduksjonen utgør, og ønsker et alternativ som tillater mer bærekraftig forbruk. Et eksempel på animalske matvarer som utgjør en stor del av den vestlige dietten er ost, hvor smelteost som mozzarella utgjør en kommersielt viktig del. Dette på grunn av dets rolle i populære matretter som Pizza, som har fått global anerkjennelse på grunn av sin enkle form og fornøyelige smak.

Hovedmålet med denne oppgaven er å gjennomføre en grundig sammenlikning av pizza-mozzarella og dets plantebasere alternativer. For å nå målet har det blitt gjennomført en rekke eksperimenters som sammenligner den næringsmessige sammensetningen, fargen, de reologiske egenskapene når varmet i pizza-baking tilstander, og de sensoriske egenskapene med spesielt fokus på de som gjelder fysiske sensasjoner. Et utvalg av fem plantebaserte oster; fire basert på stivelse fra ulike kilder, og en basert på cashew-nøtt melk, ble sammenlignet med pizza-mozzarella.

Mens plantebaserte alternativer er laget av stivt fett som finnes i kokosolje, er det mulighet for mer flytende olje til å bidra til forbedret smeltbarhet. Det ble funnet at plantebaserte alternativer hadde en lavere aksept blant ikke-veganske forbrukere, av grunner som klistrete konsistens, lav smeltbarhet, og uvanlig sterk smak. Fremtidige forsøk bør fokuseres på å bestemme akkurat hvilken effect smaken og lukten har for aksept av plantebaserte alternativer.

Preface

This master thesis was written as part of my master's degree in food science, Technology, and Sustainability at the Department of Biotechnology and Food Science at NTNU. Practical work was performed in the sensory laboratory, adjacent kitchen, Process-laboratory, and Chemical laboratory at Kalvskinnet Campus.

I want to thank many people who have helped me reach this point. First, I thank my main supervisor Kari, who encouraged me to create my own thesis from scratch, and for her constant help and impeccable knowledge of the dairy-technology. I also want to thank her Co-supervisor Ida-Johanne Jensen, for helping me find a thesis so late into the year and constant follow-up on writing, and Lene Waldenstrøm for her irreplacable help in understanding statistical and sensorical analyses.

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Njål Berg Knudsen

Njål B. Knudsen

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Abbreviasjons/symbols

LMMC	Low-moisture mozzarella cheese
NTNU	Norges teknisk-naturvitenskapelige universitet
MFA	Multiple-Factor analysis
PBCA	Plant-based cheese alternatives
PCA	Principal component analysis
UFP	Ultra flash profiling

1 Introduction

The market for plant-based alternatives to animal-based Food Products (PBFP) has been growing the last five years (Grasso, Roos et al. 2021, Grossmann and McClements 2021, Short, Kinchla and Nolden 2021, Lyu, Sala and Scholten 2023). According to the Good Food Institute, the sales value for plant-based cheese alternatives (PBCA) increased by 56% in the period of 2020-2022 (Pierce, Ignaszewski et al. 2023). The global market is expected to grow to 8,1 billion USD y 2032, from 3,3 billion USD in 2023 (Choudhury 2023).

In spite of the overall growth, the market for plant-based alternatives to animal food products is challenged today by different factors. From 2022 to 2023 the total units sold in the US decreased by 12,0% and dollar sales decreased by 9,0% (Pierce, Ignaszewski et al. 2023). The most important factors that influence someone's decision to purchase a PBFP is how tasty the product is, followed by how healthy it is perceived as, then how environmentally friendly the product is, and finally the degree to which the product is considered ethical regarding animal treatment (Ghaffari, Rodrigo et al. 2022). The primary barriers to whether people choose to purchase a plant-based product are the challenges of recreating a flavour found calorically dense animal-based food (Drake and Delahunty 2017), which most consumers find pleasurable, and the prejudice that plant-based alternatives are less tasty. Additionally, there are strong familiarities, traditions, and perceptions to non-vegetarians, which claim that a meal is not complete or "proper" without meat or dairy (Falkeisen, Gorman et al. 2022, Moss, Barker et al. 2022).

One of the animal-based products which is most difficult to replace with plant-based ingredients is cheese, both for its functional and nutritional purposes. One of the primary qualities of almost all types of cheeses as a product is its ability to melt when exposed to higher temperatures (exceptions are Halloumi and grilled cheeses). This produces a change in the cheese's texture and rheology which is considered more pleasurable for the consumer, and which fulfils technical purposes in a food dish, such as spreading over a surface or filling cavities in dishes (Fox et al. 2017). The various aspects of melted cheese, such as colour; ease of flowing; aroma; degree of rehardening, etc., depend on the cheese type. Cheese is a primary component of the traditional Italian dish Pizza, which has become one of the world's most recognizable and popular dishes, partly owing to the simplicity of the composition and flavour of cheese. The most popular and "conventional" type of pizza is Margharita, which consists of tomato, sliced mozzarella, and flatbread made from wheat, yeast, water, and salt (Di Vita et al. 2016 p. 60).

Producers of plant-based food alternatives are challenged with creating a product which can replace cheese as an ingredient in a satisfactory manner, as well as creating it in an economical and environmentally sustainable manner.

The overall purpose of this thesis was to compare dairy mozzarella and plant-based alternatives under pizza baking conditions, with focus on sensorial-, nutritional-, and rheological properties. The thesis can be divided into the following specific aims:

- Compare the chemical and nutritional composition in vegan mozzarella alternatives to that of dairy mozzarella.
- Investigate the rheological properties of cheese compared to cheese alternatives, when in conditions used for baking pizza.
- Investigate the sensorial properties and consumer acceptance of vegan mozzarella alternatives, compared to the properties of dairy mozzarella when melted in pizza conditions, elucidating prominent sensory properties important for acceptance.

2 Background

In this chapter there will be presented some basic information about cheese and milk, before going deeper into mozzarella, focusing on low-moisture mozzarella cheese (LMMC), which is the primary cheese used for pizza. Then there will be information about plant-based cheese alternatives (PBCA), with a focus on the relevant properties when used on pizza, and some of the main challenges for PBCA-producers who try to imitate the abilities of pizza cheese.

2.1 Cheese

The modern definition of cheese depends on geographical location. In general terms, it is considered as a group of fermented milk-based food products with a great diversity of flavour, textures, and forms.

The legal definition of cheese in Norway is in accordance with the description in the Codex Alimentarius "General Standard for Cheese" CXS 283-1978 (WHO/FAO 2013), which begins as follows:

> *"Cheese is the ripened or unripened soft, semi-hard, hard, or extra-hard product, which may be coated, and in which the whey/casein protein ration does not exceed that of milk, obtained by:*
>
> a) *Coagulating wholly or partly the protein of milk, skimmed milk, partly skimmed milk, cream, whey cream or buttermilk, or any combination of these materials, through the action of rennet or other suitable coagulating agents, and by partially draining the whey resulting from the coagulation, while respecting the principle that cheese-making results in a concentration of milk protein (in particular, the casein portion), and that consequently, the protein content of the cheese will be distinctly higher than the protein level of the blend of the above milk materials from which the cheese was made; and/or*
> b) *processing techniques involving coagulation of the protein of milk and/or products obtained from milk which give an end-product with similar physical, chemical and organoleptic characteristics as the product defined under (a)."*

The essential, and occasionally only, ingredient of cheese is milk or products obtained from milk. Other ingredients that are permitted for making cheese are starter-cultures of lactic-acid bacteria, bacteria that provide flavour, safe enzymes (such as rennet), salt, and water (Fox, Guinee et al. 2017).

Cheese is considered one of the oldest food items in the world, traces of which has been discovered in the fertile crescent from some 8000 years ago, from the milk of goats and sheep who were the first dairy-livestock to be domesticated. It is an enormously varied group of products with over 1000 different marketable cheese "types", who are separated by factors such as the degree of ripening, moisture level, and the type of animal that provided the milk (Fox, Guinee et al. 2017). Today it is one of the most prominent livestock-products in the world and can be consumed in a myriad of ways, including as a ready-for-consumption food product, as an ingredient in other dishes, and as flavour enhancer. Cheese is a hallmark of culinary culture, with different types originating from different countries, towns, and companies, such as Brie from France, Gouda from the Netherlands, and Mozzarella from Italy. According to the FAO the global production of cheese is estimated to be 25 million tonnes in 2023, and global exports were pegged to be 3,5 million tonnes (FAO 2024). The global production of milk was estimated to be around 911 million tonnes, of which an estimated 451 million tonnes were used for producing hard products (cheese, butter, powder) (FAO 2023).

2.2 Composition of milk

Milk is a complex fluid secreted by female members of all mammal species, for the purpose of feeding the youngest members, or neonates, of their species (Weaver, Wijesinha-Bettoni et al. 2013). Because young mammals from many species can only subsist from milk in their earliest years milk is nutritious and rich in calories, containing a balanced composition of proteins, fats, carbohydrates, as well as hundreds of minor constituents such as vitamins, ions, and flavour compounds (Weaver, Wijesinha-Bettoni et al. 2013). Milk is a variable biological fluid, which has different compositions and physiochemical properties based on which species of mammal it comes from, as well as the individuality of the animal. Common species who produce milk fit for human consumption are cows, goats, sheep, and buffalo, which are also the best studied in terms of nutritional information, physiochemical properties, and possible applications as ingredients. The composition of milk depends on several factors. Milk can be produced at any time of year for many species, including cows, but the nutritional composition of the milk depends on the breed of cattle; its health and how well fed it is; stage of lactation; age, etc. Some of the qualities of milk are more easily adjusted than others. For example, the cow's diet can be changed to achieve an optimal fatty-acid profile. This applies to other milk-producing species as well. (Svensson 2015)

Physiochemically, milk is a complex liquid. It is primarily a water-based solution with an emulsion of lipids. The aqueous phase contains lactose, organic and inorganic salts, water-soluble vitamins, and its various proteins. The proteins exist on two different levels: whey protein exists on the molecular level, and casein protein that are made up of colloidal aggregates ranging in size from 50 to 600 nm (Dalgleish 2011). The lipids in milk exist as an emulsion of fat-globules in the aqueous phase. The average nutritional composition of cow's milk can be seen in Table 1.

Table 1. Overview of the mean macronutrients in cow's milk from both early and late lactation-stages, for the most popular cattle breeds for milk in Norway and the US: Norwegian Red Cattle (Devold, Brovold et al. 2000, Inglingstad, Devold et al. 2024) and Holsteins (Bondan, Folchini et al. 2018, Neves, Leno et al. 2018) respectively.

Main constituent	**Norwegian red cattle**	**Holstein**
Total solids (%)	12,6	12,1
Fat (%)	4,0	3,4
Proteins (%)	3,3	3,2
Lactose (%)	4,5	4,5
Calcium (mmol/l)	2,8	2,3

2.2.1 Carbohydrates

The main carbohydrate-component of milk is lactose. Milk is the only natural source of lactose in the world. Carbohydrates are the most potent source of energy in our diet, and lactose is the same in dairy products. In the process of making fermented dairy products (cheese, yoghurt, skyr, etc.) lactic acid bacteria transport the lactose into their cells, where it is split into the two monosaccharides glucose and galactose, and further split into smaller components, the largest part of which is lactic acid. Lactose is also the source of all browning in milk and milk-products, due to Maillard-reaction.

2.2.2 Protein

Proteins are an essential part of human diets, as they get broken down in digestion to form the building blocks of the body's own protein. All proteins are large molecules that are made from a chain of 20 different smaller molecules called amino acids. An amino acid always consists of a fundamental amino group (NH_2-), one carboxyl-group (-COOH), and side chain which gives the amino acid its identifying function (commonly identified as –R). Amino acids readily bond with each other via condensation of a carboxyl- and amino-group, resulting in a peptide bond. Both amino acids and proteins are polar and hydrophilic. Side chains contain polar functional groups like hydroxyl, carboxyl, amines or non-polar alkenes. A polar side chain combined with the polar nature of the amino acid itself makes a molecule which is completely water-soluble, while a non-polar side chain only makes the amino acid hydrophobic to a lesser extent.

The 20 amino acids are commonly separated into essential and non-essential amino acids, where non-essential amino acids are ones that the human body can synthesize on its own, while essential amino acids must be supplied through diet. A protein can contain as many as 17 000 units of amino acids but are more commonly made up of 100-200 units, and a protein consisting of all the amino acid-types are considered full. Proteins in food are graded on their quality depending on the concentration of essential amino acids and how evenly they are distributed.

Milk proteins are the main component of dairy products and have the largest impact on their technological suitability and nutritional value. As mentioned previously, milk protein is a heterogenous group consisting of colloidal complexes of casein protein in the insoluble fraction, and whey protein in the aqueous fraction the milk (Pereira 2014). There are hundreds of different proteins in milk, but most of them can be classified as either casein or whey. There are other proteins, but these are negligible. Casein is the most prominent protein in milk, making up between two-thirds and four-fifths of the total protein mass. Casein is likewise heterogenous when compared to whey, since it is divided into four categories: α_{s1}-, α_{s2}-, β-, and κ-casein, the mean ratio of which is respectively 4 : 1 : 3,5 : 1,5 (Dalgleish 2011). Each of these categories contain several genetic variants that differ by a few amino acids. It is this hydrophobic fraction of protein along with lipids that are trapped in the micelles which makes up the body of conventional rennet-curd cheese (Pereira 2014). The composition the casein proteins are significant to how effective the milk is for cheesemaking, with regards to rennet-coagulation time, fat-retention, firmness of curds, and other factors (see 2.3.3).

The casein micelle is constructed as a globule which incorporates all the casein subgroups. The surface of the micelle is made from κ-casein, and the centre is made up of a colloidal aggregate of phosphorylated β- and α_{s1}-casein which interacts with calcium-phosphate. The average size of a micelle depends on the total concentration of κ-casein in the milk to form the surface and depends to a smaller degree on the amount of β-casein (Figure 1). The cell-size does not depend on other caseins to the same degree since they can be filled with pockets of water. The average size of a casein-micelle in bovine milk is 200 nm which contains over 20 000 individual proteins, but the total size range is between 50 and 600 nm. The molecular weight of a micelle lies between 19 and 27 kDa (Dalgleish 2011)

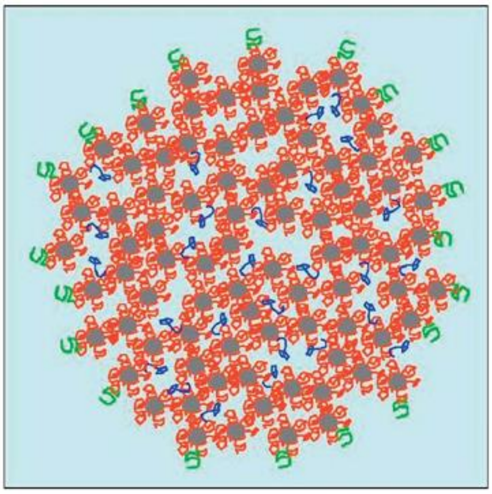

Figure 1. Schematic structure of a Casein micelle, with calcium-phosphate nanoclusters (grey); attached caseins (red), κ-casein on the surface (green), and water-bound β-casein forming aqueous pockets and channels (blue). Not to scale. (Dalgleish 2011)

Milk protein is frequently considered the most biologically valuable in the world (Pereira 2014, O'Brien and O'Connor 2017). Casein protein contains all essential amino acids in moderate amounts, and high amounts of particularly histidine, methionine, and phenylalanine. Casein proteins also fulfil the technical purpose of carrying minerals such as calcium and phosphorous. Whey protein contain high amounts of branched and sulfur-containing essential amino acids such as leucine, isoleucine, valine, and lysine (Pereira 2014). All milk proteins are highly digestible (for non-atopic people) and contain bioactive peptides with antibacterial, antiviral, antioxidant, and antihypertensive properties among others (Pereira 2014).

2.2.3 Lipids

Fats have a large influence on the rheological characteristics and nutritional profile of any food group. Both factors are influenced by the length of the fatty acid chain and the degree of saturation (lack of double bonds in the chain) (MacGibbon 2020). The melting point of fat typically increases with the length of the fatty acid chain but is more strongly influenced by non-saturation, where unsaturated fatty acids show a much lower melting point than saturated.

Milk and cream are the most prominent examples of naturally occurring fat-in-water emulsions, whose fat is considered one of the most complex in nature with over 400 different fatty acids (Muehlhoff, Bennett and McMahon 2013, Pereira 2014). The fat in milk consists of droplets and small globules dispersed in the aqueous fraction, with diameters between 0,1-20,0 µm and an average concentration of 10.000 globules per ml of milk, depending on the animal and other factors. The globules' structure is made up of a core and a membrane, which stabilizes the emulsion by rebuffing other globules' membranes throughout the serum. The core is made of roughly 98% Triacylglycerol, <2% diacylglycerol, cholesterol, free fatty acids, sterols, carotenoids, vitamins, and several other minor constituents (Pereira 2014). The membrane mainly consists of phospholipids, lipoproteins, and cerebrosides. Membrane-width varies from globule to globule and depends on the components in the milk serum surrounding the globule, which in turn depends on the animal and feed (Pereira 2014).

Table 2. Composition of fatty acids (%) in cow's milk with variation (MacGibbon 2020), and melting point in triglycerides (°C). RT = room temperature.

Saturated	**Fatty acid**	**Minimum – Maximum (%)**	**Melting point (°C)**
4:0	Butyric acid	2,6 – 3,6	1,0
6:0	Caproic acid	1,7 – 2,2	-4,0
8:0	Caprylic acid	1,0 – 1,4	16,0
10:0	Capric acid	2,3 - 3,5	31,0
12:0	Lauric acid	3,1 – 5,5	44,0
14:0	Myristic acid	2,6 – 4,2	54,0
16:0	Palmitic acid	9,1 – 11,9	63,0
18:0	Stearic acid	23,6 – 31,4	70,0
Unsaturated			
18:1	Oleic acid	14,9 – 22,0	16,0
18:2	Linoleic acid	1,2 – 1,7	-5,0
18:3	Linolenic acid	0,9 – 1,2	-12,0

Cow's milk fat contains roughly 70% saturated fatty acids and 30% unsaturated (MacGibbon 2020) (Table 2). The fatty acid-composition determines the melting point of the fat, which affects its suitability for cheesemaking (see 2.3.3).

2.3 Mozzarella

Mozzarella (Italian for "slice of cheese" or "cut-off piece") is a *Pasta-Filata* soft mediterranean cheese made from buffalo milk or whole cow's milk, which owes its unique melting- and stretching-ability to the process of kneading and pulling on the coagulated curds in hot water. The term *pasta-filata* literally means "spun paste" or "stretched curd". The earliest version of mozzarella cheese was created from the milk of Italian buffalo, and it is this type that has the original claim to the name "Mozzarella". This cheese is sold and consumed without any ripening-period, either for melting in dishes such as Napolitan Pizza, or in cold dishes such as Caprese salad. Due to its popularity, a great number of varieties and analogues are produced and sold globally. Today, versions of this cheese produced from cow's milk are the most common. The first version was created in Italy with the name "Fior di Latte", meaning "flower of the milk", which simply substitutes buffalo milk for cow's milk, and changes nothing else. In countries where Italian dishes are popular besides Italy, Fior di Latte is sold under the name mozzarella.

The most popular version is Low-Moisture Mozzarella Cheese (LMMC), which is considered the most produced and economically important pasta-filata cheese in the world, due to its use as melting cheese on pizza, improved shreddability, and longer shelf-life. In a similar manner to Fior di Latte, countries where pizza is popular besides Italy, LMMC is referred to simply as mozzarella without designators as low-moisture or part-skim. Most versions of mozzarella are considered purely as ingredients to other dishes and are referred to as "ingredient cheeses". Ingredient cheese is manufactured to optimise particular functionalities which make it more attractive for a specific application, such as pizza. Attractive functions in pizza cheese include melting temperature, ease of flowing once melted, degree of browning, and stringiness. The market of ingredient cheese has grown greatly since the 1970s due to growth of the food service and prepared consumer food sectors, a significant portion of which is pizza, both through the food service-sector and the retail sector for frozen pizza ([i])

The national production of mozzarella cheese in the US was 2,0 million tonnes in 2021 (McMahon and Oberg 2017), which makes USA-produced mozzarella alone close to one tenth of global production of cheese in general. Much of this is produced on an industrial scale in plants that can produce up to 1 million kg a day with cheesemaking vats capable of holding 40 000 litres of milk. By 2023 the market for mozzarella grew to a total value of 39,6 billion USD and is expected to grow into 64.1 billion USD by 2031, according to Skyquest Technology. In the US alone, shredded mozzarella as a pizza topping made up 4,2 billion USD in the market by 2013.

2.3.1 Production

The following is the complete process of creating LMMC:

(1) Most large-scale producers of LMMC in the US and other countries use vats that can contain up to 40 000 litres of milk. Cow's milk is standardized to approximately 4% fat-content. Depending on the preferences of the target consumers, the casein-to-fat ratio of the milk can be made higher by adding skim-milk powder. Increased casein increases the total yield of the cheesemaking, but higher fat-content is preferred by many quick-service pizza restaurants due to greater ease of melting and more released fat during heating. The milk is subjected to low-grade pasteurization at 72 °C for 15 seconds, or 61 °C for 30 minutes, and cooled down to 31 °C.

(2) The lactic-acid starter-culture and the rennet is added to the milk. LMMC is almost always produced with Termophilic lactic acid bacteria (LAB), although some use mesophilic cultures which produce a different taste. The purpose of the starter-cultures is to convert lactose into lactic acid so that the cheese can be plasticized and stretched, which happens by reducing the amount of calcium bound to the casein at the time of stretching. Additionally, it reduces the rennet coagulation time (see Selection and treatment of milk). The mass gets stirred while at 33-35 °C, until all the casein has coagulated into curds and the firmness is at the optimal stage.

(3) The curds are then cut into cubes whilst still in the vat to initiate whey syneresis.

(4) The mix is then heated to a higher temperature, ranging from 40-50 degrees °C depending on the starter culture cooked and stirred until the consistency of the curds is at a desirable level, whereupon the mix is drained of the whey solution. This is typically around pH 5,2. LMMC gets cooked at 50 °C for reduced moisture.

(5) The whey is drained at around pH 6,0-6,2 and remaining curds are "matted" by being stacked onto itself to dry. Once pH is at 5,2-5,3 the curd mass is cut into pieces.

(6) Once the mass has reached an optimum calcium content, the mass is taken to hot water (65-70 °C) to be stretched, also known as "plasticizing". In modern production of mozzarella, the stretching is achieved by mixing the curd mass in a large container with the warm water, and lowering a large screw which hooks into the mass and drags and stretches the mass along.

(7) The mass is taken out of the stretching-vat with a temperature to be pre-cooled in a chilled container, which helps the mass retain its shape when cooled properly in brine.

(8) Once cooled to 6 °C the cheese is taken out of the brine to be stored for a short period of 1 month at 4 °C. After a few weeks in aging, the cheese can be shredded for remaining aging. Mozzarella cheese is then sold as soon as possible to retain its baking-properties.

The process for making traditional high-moisture buffalo mozzarella and Fior di Latte is similar. The differences lie in that high moisture cheese preferably uses milk with a lower casein-to-fat ratio (1); the milk can be pre-acidified using acetic acid or citric acid (2); and there is little to no cooking (4) (Arora and -Khetra 2017).

2.3.2 Selection and treatment of milk of LMMC

The abilities that influence a milk's suitability for cheese production include rennet-coagulation time (RCT); total cheese yield; final composition; and ripening time. RCT is the total time it takes for milk with a given temperature to fully separate into curds and whey. For large-scale producers of LMMC a shorter RCT is desirable due to shorter production time, and so is one of the most sough-after qualities in milk (Panthi, Jordan et al. 2017). The total cheese yield is the total amount of usable curds that can be extracted from milk, which producers prefer to be as high as possible while still producing sufficient quality for their target-groups. The final composition and ripening profile determine which type of cheese is produced. For LMMC and other mozzarella types the ripening-period is none or shorter than for most other cheeses.

Higher levels of milk solids improve the rennet-coagulation properties via reduced RCT, higher curd firmness, and improved total yield. (Joudu, Henno et al. 2008) discovered that the composition of casein-proteins also significantly affects the rennet-coagulation properties of milk. Lower proportions of β- and α_{s1}-casein in the total protein content, or higher proportion of κ-casein, makes firmer curds during coagulation.

2.3.3 Characteristics of LMMC

LMMC is almost exclusively used as a pizza-topping in the food service- and retail sector, and so the quality of LMMC as a product is dependent on a few factors.

Nutritional value and flavour

Cheese of any type is widely regarded as a nutritious and versatile food group. It is characterized by high concentrations of essential nutrients relative to its energy-content, particularly of fat and protein, as well as several micronutrients, foremost of which is calcium and vitamins A, B_{12} and riboflavin. An overall nutritional composition in LMMC in comparison with other cheeses can be found in Table 3.

Table 3. Mean nutritional composition of four cheeses, assessed in laboratory tests by Guinee et al. (2017). Samples are commercial LMMC from 8 Irish sources, Cheddar from 8 Irish sources, Gruyère from 1 retailer in Switzerland, and Jarlsberg from Norway (Holland, Unwin and Buss 1989, Fox, Guinee et al. 2017). LMMC = low-moisture mozzarella cheese, FDM = Fat-in-dry matter, MNFS = Moisture in non-fat-substance, Ca = Calcium, P = Phosphor

Type of cheese	**Moisture (%)**	**Protein (%)**	**Fat (%)**	**FDM (%)**	**MNFS (%)**	**Lactose (%)**	**Ca (mg/ 100 g)**	**Choles-terol (mg/ 100 g)**
LMMC	46,4	26,0	23,2	44,6	60,4	Tr	1046,0	65
Cheddar	37,2	25,4	33,1	52,6	55,6	Tr	1102,0	100
Gruyère	34,1	27,7	36,8	55,8	54,0	Tr	1011,0	100
Jarlsberg	40,4	27,7	31,3	52,4	58,7	N/a	770,0	N/a

Fat contains twice as many calories as protein and most carbohydrates (Fox, Guinee et al. 2017, Hjartåker, Pedersen et al. 2020) and cheese has a significant amount compared to the typical intake of fat in western countries. Approximately 60-70% of this fat is saturated, 25-30% is monounsaturated, while 4-5% is polyunsaturated (see Table 4). Lauric (12:0) -, Myristic (14:0) -, and Palmitic (16:0) acid have the ability to raise blood cholesterol levels and contribute to cardiovascular disease (Gu and Yin 2020), which is problematic because these represent the majority of fatty acids in cheese fat. LMMC has a lower ratio of fat-in-dry-matter and total fat percentage than many other types (Table 3).

Fat contributes greatly to the aroma of mozzarella (Kilcawley 2017). Short-chain fatty acids in milk go through chemical reactions during the cheesemaking process to form many odour-active compounds, such as esters when reacting with alcohol groups; lactones when fatty acids are hydroxylated; and methyl-ketones which are created through oxidization and subsequent decarboxylation (Kilcawley 2017).

Table 4. Fatty-acid profile of fat from cow's milk cheese (Paszczyk and Łuczyńska 2020).

Saturated	**Fatty acid**	**Min-Max (%)**	**Melting point (°C)**
4:0	Butyric acid	2,2 – 3,34	1,0
6:0	Caproic acid	1,8 – 2,3	-4,0
8:0	Caprylic acid	1,0 – 1,4	16,0
10:0	Capric acid	2,8 - 3,2	31,0
12:0	Lauric acid	1,9 – 3,6	44,0
14:0	Myristic acid	11,0 – 11,7	54,0
16:0	Palmitic acid	27,7 – 31,0	63,0
18:0	Stearic acid	9,7 – 11,5	70,0
Unsaturated			
10:1	Caproleic acid	0,27 – 0,32	26,5
12:1	Lauroleic acid	0,04 – 0,05	n/a
14:1	Myristoleic acid	0,9 – 1,1	n/a
16:1	Palmitoleic acid	1,4 – 2,0	-0,1
18:1	Oleic acid	14,9 – 22,0	16,0
18:2	Linoleic acid	1,9 – 2,5	-5,0
18:3	Linolenic acid	0,9 – 1,2	-12,0

Cheese protein is, like with milk, some of the most bioavailable and valuable in the world (O'Brien and O'Connor 2017). Most of the whey protein in milk is passed in the moisture during curd-formation, and roughly 2% of the protein in cheese is whey while the rest is casein, which reduces the total digestibility to between 91 and 97 percent that of total milk protein. In conventional cheese production the ripening phase assists in breaking the casein into water-soluble peptides and free amino acids. Since mozzarella and pasta-filata cheese in general uses a much shorter ripening time, the overall digestibility is reduced a bit further compared to other cheeses (O'Brien and O'Connor 2017).

Because mozzarella, and especially LMMC, is primarily characterized as an ingredient-cheese, one must consider the flavour profile in both its unheated and its melted state. Henneberry, O'Sullivan et al. (2016) report that in tasting different brands of mozzarella cheese, certain tastes like saltiness would disappear when melted, due to the emergence of a different flavour like creamy and fatty. There is comparatively little information available on the sensory properties of heated cheeses because of the sensitivity of the melting process and how briefly cheese stays in its melted phase (Henneberry, O'Sullivan et al. 2016). Additionally, mozzarella is considered as having quite a mild flavour in comparison with other cheeses. The primary descriptors of flavour used in sensory analyses for mozzarella are fattiness, saltiness, and creaminess. Cheese is considered to be a unique enough food product that "cheese flavour" is also used for evaluation, though the definition is unclear.

Meltability

The meltability of cheese is critical to its performance as a food product, especially when it is used as a topping or otherwise ingredient in prepared foods. Inducing heat to almost all cheeses, except for halloumi and others intended for grilling, will cause the cheese to soften, turn stretchable, and flow as a viscous liquid, i.e. melt, which is considered a pleasurable texture for consumers (Fox, Guinee et al. 2017). Melting occurs due to structural changes when energy is transferred via heating. The hydrophobic linkages between and outside proteins become stronger, while other interactions, such as hydrogen-bonding, are reduced (Atik and Huppertz 2023).

Pasta-filata cheeses are exceptional compared to other cheese types when melted, due to superior stretchability, stringiness, high viscosity, good flowability, and shorter melting-time, which makes it perfect for pizza (Fox, Guinee et al. 2017). The proteolysis of casein in LMMC, within a certain limit, leads to increased meltability, viscosity-to-elasticity rate, and stretchability, while exaggerated proteolysis leads to LMMC becoming overly soft and liquid when melted (Kindstedt and Fox 1993). The stringiness and stretchability of LMMC is attributed to the plasticization-process, which forms para-casein fibres with high tensile strength (McMahon and Oberg 2017). In LMMC it is also necessary to have a minor degree of flow resistance, which is the term for preserving the shape of the cheese even once it is softened through melting, in order to prevent it from overflowing the pizza crust or dripping (Fox, Guinee et al. 2017).

Rheological sensorial properties

Each of the quality-factors relating to the melting of LMMC can be explained through rheology, which in turn depends on the cheese’s nutritional and chemical composition (Fox, Guinee et al. 2017).

The rheology of LMMC when heated is greatly influenced by the fat content. Fat and protein do not have chemical interactions, so fat globules are physical impediments for the connective protein-network and are trapped within during coagulation. A higher content of lipids leads to more openness in the microstructure and softer texture. Before melting, the fat-globules entrapped in the casein-network are still mostly solid and contribute to make the LMMC elastic at low temperatures (<5 °C). At room temperature (~20°C) more than half of the milk fat becomes liquid and contribute to making the cheese act like a viscous fluid (Fox, Guinee et al. 2017).

LMMC's rheological functions are greatly influenced by the type of casein, where increased levels of calcium promotes more protein-protein interactions, causing lower meltability and greater stretch (O'Brien and O'Connor 2017). Increased calcium in in κ-casein correlates with decreased moisture as well as a firmer, chewier and less meltable LMMC cheese (Ren, Chen et al. 2013). Post-melt chewing resistance is one of the most important quality factors in LMMC for consumers, which correlates with firmness in the melted state (Metzger and Barbano 1999).

Freezing during transport or storage does not cause ice-crystal formation in LMMC, and subsequent breakdown in its protein structure, to the same degree as for high-moisture mozzarella.

Colour

The preferred appearance of mozzarella on pizza is the formation of browning and blisters spread evenly over an otherwise yellow and white surface (McMahon and Oberg 2017). The browning is caused by caramelization of galactose when exposed to heat (Svensson 2015).

Shreddability

Before melting, the most important rheological functionality of LMMC is its shreddability (Fox, Guinee et al. 2017). Shredded LMMC dominates a large part of the market for pasta filata cheese (McMahon and Oberg 2017) since size reduction of cheese before heating helps with spreading and layering over a surface and makes it much easier to combine with other ingredients (Fox, Guinee et al. 2017). Good shreddability in LMMC is characterized by being sufficiently firm that it can resist being crushed during the shredding process, as crushing damages the casein-complex and leads to faster syneresis, in the same manner as freezing. Another important factor for shreddability is to prevent it from sticking to surfaces or other strands during handling or transport. Lowering stickiness leads to better flowability when being deposited on pizzas in production lines. These factors depend on the rheology of the finished cheese, which in turn depends on the level of moisture in the cheese and percentage of fat. The ideal time to shred LMMC is normally 4-5 days after stretching, when the hydration of the protein-matrix is finished (McMahon and Oberg 2017). If aged for 20 days or more the firmness gets severely reduced, making shredding much more difficult. To prevent cheese shreds from sticking to each other further, producers often mix in anti-caking agents, such as powdered starch or cellulose (Guinee; and Kilcawley 2017).

2.4 Plant-based cheese alternatives

Traditionally, vegan, and plant-based alternatives to animal products have been regarded as a niche market, motivated by allergies or ethical issues, health issues, climate footprint, area use, etc. connected with livestock farming. The market and production have therefore been given relatively little attention for legal definitions, compared to how fast it has grown over the last few years. To this date, there is no legal definition for the term "vegan" as a descriptive of a food item in the EU, nor for "plant-based". The Codex Alimentarius, which provides the legal definition of dairy cheese in many countries, does not include a term for products made from vegetal ingredients with the intention of imitating the flavour and texture of cheese. Terms for the products vary greatly between companies and researchers, including "plant-based cheese alternative", "vegetal cheese substitute", and "vegan cheese analogue". Since the Codex' definition of the word "cheese" is that of a product that is produced from milk and contains casein-protein to some extent, it must be said that the terminology of plant-based cheese alternatives is limited. The term for the food group is therefore always affixed with "-alternative" or "-option". For this thesis the term was chosen to be "plant-based cheese alternatives" (PBCA), which is based on the description used by Grossmann and McClements (2021), with the addition of "purely plant-based", which is an important aspect of veganism:

"Plant-based cheese alternatives is an edible material prepared from purely plant-based ingredients that is designed to have a similar appearance, texture, and flavour as animal-based cheeses."

PBCA make a relatively small part of the total market of plant-based food alternatives overall, which was worth a total of 20,4 billion USD in 2021 and grows steadily. The global market size for PBCA reached 2,7 billion USD in 2023, and projected growth in the period of 2024-2032 varies between 8,0% - 12,5% per year (ProQuest Documents, Imarc vegan cheese market, Grand view research).

Drivers of choice for plant-based alternatives to dairy

The reasons for the growing popularity of plant-based alternatives to animal foodstuffs can be divided into two categories: (i) growing awareness of allergies and intolerance to dairy product (Vanga and Raghavan 2018); (ii) the growing desire to eat in an environmentally sustainable manner and the ethical considerations for animals involved in food production (Schiano, Harwood et al. 2020, Ghaffari, Rodrigo et al. 2022).

Milk protein allergy is among the most common food allergies present in childhood, which may also follow some into adulthood. Those with this condition can trigger allergic reactions by consuming proteins that belong in either the whey- or casein-fraction of milk. Between 0,3-3,0% of the world's population will have this condition before they are 6 years old, and approximately 15,0% of those will continue to be affected into adulthood where most others will lose it shortly after turning 6 (Jaiswal and Worku 2022). Cow's milk allergy manifests as a reaction that can be mediated or non-mediated by immunoglobulin E (IgE). Those mediated by IgE include gastrointestinal symptoms such as vomiting and diarrhoea, respiratory issues, and anaphylactic shock (Jaiswal and Worku 2022). The occurrence of food allergy in children has been on the rise in recent decades, and growing awareness makes parents anxious about their children's diet. In 2013 it was estimated that 20% of people falsely believed that they had an allergy to a food group (Elizur, Cohen et al. 2013).

Lactose intolerance is an often much less severe condition in which the body lacks the enzymes the properly break down the sugars in milk. Symptoms manifest as gastrointestinal issues with varying degrees of intensity and rarely in a dangerous way, although it is recorded as having a large negative effect on quality of life for intolerant people. This condition occurs in large parts of the world-population, including up to 25% of people in Europe and almost all the population in African countries and Native Americans. (Catanzaro, Sciuto and Marotta 2021)

According to the United Nations, sustainable development is defined as "Meeting the needs of the present without compromising the ability of future generations to meet their own needs". The goal of achieving a sustainably functioning world will be applied in three dimensions: economic, social, and environmental. A generalized aspect of the GHG emissions of food production, which is often communicated to consumers, is the impact of animal products in comparison to plant-based products. The production of meat, dairy, aquaculture, and eggs use approximately 83,0% of global farmland and contribute between 56,0% and 58,0% of the emissions of food, but only provide 37,0% of the proteins and 18,0% of the calories in our diet (Poore and Nemecek 2018). Several of the strategies developed to mitigate food-system emissions include reducing the consumption of animal products through the efforts of both producers and consumers as an essential part (Poore and Nemecek 2018). In a study where plant-based alternatives to dairy beverages was assessed for the perceptions of the consumers, there was found a strong overlap in consumers' perspective on sustainable dietary choices and healthy choices, even if there is no apparent evidence that one necessarily leads to the other (Schiano, Harwood et al. 2020).

The most common motivation for consumers to adopt veganism is ethical treatment of animals and animal welfare (Janssen, Busch et al. 2016, Tobias-Mamina and Maziriri 2021, Ghaffari, Rodrigo et al. 2022). Consumers' perceptions of ethical livestock treatment are connected with terms such as "naturalness", freedom of movement, and the option of social interactions between animals (Alonso, González-Montaña and Lomillos 2020, Beaver, Proudfoot and von Keyserlingk 2020). While it is challenging to objectively measure the mental well-being of cattle (Noordhuizen and Lievaart 2005), there are strong correlations between freedom of movement and positive social behaviour and physical well-being in dairy-cattle (Améndola, Solorio et al. 2016, Smid, Weary and Von Keyserlingk 2020, Crump, Jenkins et al. 2021). The large majority of dairy-cattle in the US is raised with no access to pasture in 2014, and approximately 40% are raised in tiepens (Wagner 2016), which are created as indoor living areas with little to no mobility for animals. These conditions are generally contrasting to consumers' perceptions of ethical animal treatment, causing many to seek foods that do not use cow's milk, including alternatives which mimic their abilities (Janssen, Busch et al. 2016).

2.4.1 Production of plant-based mozzarella alternatives

PBCA is a highly processed food group which is created by combining refined functional ingredients, with the intention of mimicking the taste and functionality of dairy cheese. The materials required to produce PBCAs are sources of carbohydrates, lipids, and proteins from plants, each of which fulfils a rheological purpose. Various recipes and plant-based ingredients have been attempted, which can fall into the two main processing routes named "material fractionation" and "tissue disruption" (Grossmann and McClements 2021).

Material fractionation is performed with the purpose of treating raw plant-based materials to isolate and purify polysaccharides, proteins, or fats. This production method is typically performed with the intention of completely mimicking the sensory profile of conventional cheese. The functional ingredients are blended to form an oil-in-water emulsion, which is made into a three-dimensional gel network with the addition of either starch (polysaccharide-based) or proteins (protein-based).

Tissue disruption involves using a single plant based raw material as a basis for the product, so that the PBCA embraces some or all the unique flavours derived from plant-ingredients (Grossmann and McClements 2021, Short, Kinchla and Nolden 2021). Both methods involve the crucial step of combining ingredients in a way that promotes a solid-to-gel transition. These methods employ raw materials that naturally include a significant amount of protein and/or fats, such as soybean, peas, or nuts. Tissue disruption involves using a single plant based raw material as a basis for the product, so that the PBCA embraces some or all the unique flavours derived from plant-ingredients (Grossmann and McClements 2021, Short, Kinchla and Nolden 2021). Especially cashew has become a popular base-ingredient for many PBCA-producers.

Raw materials for PBCA

Extracted carbohydrates, particularly starches, are the most common ingredients used to form structures in cheese-analogues. Starch is one of the world’s most abundant biopolymers, who function as an energy-reserve in most cereals, tubers, roots, fruits, and seeds. They consist of long chains of anhydrous glucose molecules that are divided into two categories: (i) single chained amylose, and (ii) the more complex and branched amylopectin (Watcharakitti, Win et al. 2022). Starches are used most often due to the relative ease of extraction in comparison with extracting pure proteins. Starch-structures are based on gelatinizing and retrogradation. Gelatinization is the process of making starch-granules absorb water and swell when heated before they rupture and release amylose-molecules. Retrogradation is the term for hardening the three-dimensional gel structure by forming hydrogen-bonds between helical regions on the chains of starch molecules. This process creates a polysaccharide-based viscoelastic emulsion in which the 3D-structure of starch entraps water and oil (Grossmann and McClements 2021).

The structure and properties of the starch gel depend on the ratio of amylose and amylopectin. Amylose solutions have a low viscosity and form strong, irreversible gels with a low melting point, while amylopectin solutions have high viscosity, soft gel-formation, and a higher melting point (Schirmer, Jekle and Becker 2015).

The ratio between the two decides: (i) degree of retrogradation in the cooling-process; (ii) pasting temperature, which is the highest temperature before the starch-granules break; (iii) softening temperature, i.e. the melting temperature for the final cheese analogue; (iv) the strength of the final three-dimensional gel structure when cooled; and various other viscoelastic properties (Grossmann and McClements 2021). The ratio of amylose has also been found to affect the total adhesiveness of the starch, where a high content of short amylose is correlated to a lower stickiness (Li, Fitzgerald et al. 2017), though the mechanisms that cause stickiness in starch gels is unclear and unexplored (Watcharakitti, Win et al. 2022). A starch’s ratio depends on the source of the starch, where the most used starches for PBCAs are tapioca, potato, and corn. PBCAs intended for melting use starch with high percentage of amylopectin to achieve a lower degree of retrogradation. This gives a softer texture and generally shows melting properties relevant for pizza. To achieve the optimal amylose-amylopectin ratio, starches with a high amylopectin-content, such as tapioca and potato, get combined with those of high amylose-contents, such as corn (Grossmann and McClements 2021). Other carbohydrates can also be used, such as alginate and carrageenan. Various patents have been made of specific starch-ratios and processes to improve different aspects of PBCA over the years. For example, Bergsma (2017) proposed a mix of 22,0% unmodified potato starch, 0,5-8,0% potato protein, 15-35% short chain fatty acid oil (see next sections), and 25-45% water. This mixture then gets heated to 70-90 °C to induce gelatinization and cooled to 4 °C to become a solid gel and finished semi-solid cheese analogue. A different patent performs similar processes, but instead employs a dry blend comprising starches from tapioca, wheat, and rice, to be mixed with an oil-blend and water for the final product (Atapattu and Fannon 2014).

In PBCAs, fats are added to promote functional qualities (Lyu, Sala and Scholten 2023). Oils are trapped in three-dimensional starch- or protein structures and have a significant influence on the mechanical properties of both conventional cheese and PBCA. To maintain a solid structure before melting, it is preferrable to employ fats that have high SFC, which can partially or fully crystallize at room temperature or below. Fats with high SFC also mimic milk fat to the best degree. Most natural plant-based oils have a low degree of saturation and so are liquid at room-temperature, such as sunflower-, olive-, and rapeseed oil. Coconut and palm oil are among the few plant-based ingredients that can produce fats with a high SFC, and which crystallize at room-temperature (Grossmann and McClements 2021).

Table 5. The fatty-acid composition of coconut oil in various forms and their respective melting-points (Liau, Lee et al. 2011, Boateng, Ansong et al. 2016)

Saturated	**Fatty acid**	**Mean content (%)**	**Melting point**
4:0	Butyric acid	0,0 – 0,6	1,0
6:0	Caproic acid	2,2 – 9,0	-4,0
8:0	Caprylic acid	8,6 – 13,0	16,0
10:0	Capric acid	6,4 – 6,8	31,0
12:0	Lauric acid	47,3 – 49,6	44,0
14:0	Myristic acid	15,8 – 19,2	54,0
16:0	Palmitic acid	6,7 – 7,6	63,0
18:0	Stearic acid	1,5 – 2,4	70,0
Unsaturated			
18:1	Oleic acid	4,2 – 5,3	16,0
18:2	Linoleic acid	1,1 – 1,3	-5,0
18:3	Linolenic acid	0,	-12,0

Proteins for PBCA are derived from pea, soy, corn, potato, and nuts, which include cashews in most cases. These are either isolated and added to mixtures via material fractionation, or having its source incorporated as an ingredient via tissue disruption (Grossmann and McClements 2021).

Legume proteins (pea and soy) comprise small globulins of ribosomal S7 and S11 are salt-soluble and weigh 22 kDa. While legume proteins are small, they are known to form colloidal dispersions similar to casein, though they still behave differently in terms of meltability and produce a mouthfeel which is considered unpleasant for consumers. Their solubility is highest at pH below 4,5 and above 7,0 and are considered the most fat-soluble proteins available, with soy being most soluble. Most legume proteins will denature at the temperatures above 80, which is the temperature-range for gelation in producing starch-based cheese alternatives.

Potato protein comprise the large (88 kDa) glycoprotein "patting" and smaller (5-25 kDa protease inhibitors. They are a byproduct of several potato starch extraction-processes and can be isolated at purities ranging from 60% to 88%. Allergies for potato protein are much rarer than for cow's milk protein, and like casein can perform bioactive functions in the human body, including antioxidative properties (Mishra and Rai 2006, Hussain, Qayum et al. 2021).

The main source of protein from corn (approximately 60% of the total content) is Zein, which is a collection of several proteins found in its endosperm. The most prominent type, ɑ-zein (21-26 kDa), is a hydrophobic protein which has recently been discovered to contribute greatly to create an elasticity in melted PBCAs but is often considered quite expensive to produce (Mattice and Marangoni 2020). Nut proteins are relatively underexplored in the market of PBCA, the most famous source of which is cashew protein due to its relatively high percentage of fats and protein, essential fatty acids, antioxidative properties and richness in minerals (Fm 2017). Proteins derived from cashew have little solubility in the ordinary pH range of mozzarella cheeses, and contain potent thickening-abilities by undergoing a solid-gel transition when heated to 100 °C.

The rheological properties in starch-based PBCA can be improved substantially by introducing additional proteins from sources commonly used in the tissue-disruption methods, which have the ability to raise both the melting rate and the melting temperature (Lyu, Sala and Scholten 2023).

2.5 Challenges in plant-based cheese alternatives

Though the market for PBCAs is one of the fastest growing in the world (ref), there are challenges that inhibit their performance in comparison to conventional LMMC.

One of the positive aspects that consumers attribute to plant-based diets and alternatives to animal food products in general is healthiness (McCarthy, Parker et al. 2017, Kim, Caulfield and Rebholz 2018, Aschemann-Witzel, Gantriis et al. 2021). A common public health concern in recent years was that products with animal-based protein also contained higher amounts of saturated fats and cholesterol, which negatively affects cardiovascular health when consumed in relatively low amounts (Aschemann-Witzel, Gantriis et al. 2021). Previous population studies correlated a vegetarian diet of whole plant-based ingredients (whole grains, fruits, vegetables, nuts, and legumes) with lower occurrence of coronary heart-disease. This is due to several reasons, including decreased BMI due to their general low caloric density, reduced LDL, and lower systolic and diastolic blood pressure (Kim, Caulfield and Rebholz 2018). Unhealthy vegetarian diets, which include ingredients and foods like fruit juice, refined grains, and high intake of sugar, have shown no such positive effect (Koutentakis, Surma et al. 2023).

These conclusions are somewhat simplified and do not apply in the same extent to dairy products. The me that assess health-impact of diets typically define food products in a binary manner: either plant-based- or animal-based, and with an index of either healthy or unhealthy affixed to each group (Koutentakis, Surma et al. 2023). Not all animal-based products have the same negative impacts on human health when consumed in high amounts, as mentioned previously. Increased consumption of milk and fermented dairy-products have an inverse-to-none association with cardiovascular disease or higher overall mortality (Guo, Astrup et al. 2017, Hu, Tan et al. 2022), and reduced dairy consumption means reduced intake of the essential amino acids, positive bioactive peptides found in casein, calcium, and other micronutrients mentioned previously (2.2) (Weaver, Wijesinha-Bettoni et al. 2013).

When producing PBCA as pizza-toppings, the main ingredients are almost always highly processed starch and fats with high contents of saturated fatty acids, i.e. coconut oil and palm oil. The mix of ingredients can range from purely isolated and processed, to a moderate amount of whole tissue in a mix with other isolated ingredients, which excludes several micronutrients from the final product, unless directly fortified. In a study to assess the nutritional quality of PBCAs found in the US and Europe, Craig, Mangels and Brothers (2022) found that only one fifth of products were fortified with calcium, 15% were fortified with vitamin B12, and only 1% was fortified with vitamin D. Very few starch-and-oil (106 of 245 products) PBCAs contained any protein at all, the exception of which were the 14 that had been fortified with protein to improve the rheological properties. Products made from cashew and coconut oil (61 of 245 products) are the only ones which contained more than 5% protein by weight (Craig, Mangels and Brothers 2022). PBCA and dairy cheese are equally likely to contain high levels of saturated fat, due to the functional requirement of the cheese to be solid at room-temperature.

The meltability of dairy cheese is especially related to the composition and structure of casein, which is one of nature's most unique compounds that can only be found in milk from mammals. Producing a protein which can mimic the abilities of casein is difficult, often because of the high energy-demand and complexity of protein extraction. In addition, plant-based foodstuffs have a lower content of protein in general (Aschemann-Witzel, Gantriis et al. 2021). This is particularly true for zein-protein, which helps to give plant-based cheeses positive rheological abilities (though it has only been recorded in non-melted PBCA) (Mattice and Marangoni 2020). Finding a combination of plant-based oils which can accurately mimic the rheological abilities of cow's milk fat is proving difficult as well. As mentioned, cow's milk fat is built made from over 400 different fatty acids and is constructed in a micelle which is uniquely applicable to emulsification.

There is currently a lack of available market analyses pertaining to the consumption of plant-based cheese alternatives (Grossmann and McClements 2021, Short, Kinchla and Nolden 2021). The few available market retail overviews shows that overall consumption of PBCA in the US has declined slightly in the period of 2022-2023 after a large growth in the preceding years (Pierce, Ignaszewski et al. 2023), though it is projected for further growth by other market outlooks.

3 Materials and method

The methods used to meet the goals of this thesis will be presented in this chapter. A flowchart showing the complete design of the study will be shown (Figure 2) followed by an overview of the raw materials purchased for the study, consisting of commercial Low-Moisture Mozzarella Cheeses and Plant-Based Cheese Alternatives intended for pizza. The various methods to assess the cheese and cheese-alternatives' rheological- and melt-properties, chemical and nutritional composition, and sensory properties will be presented.

3.1 Study design

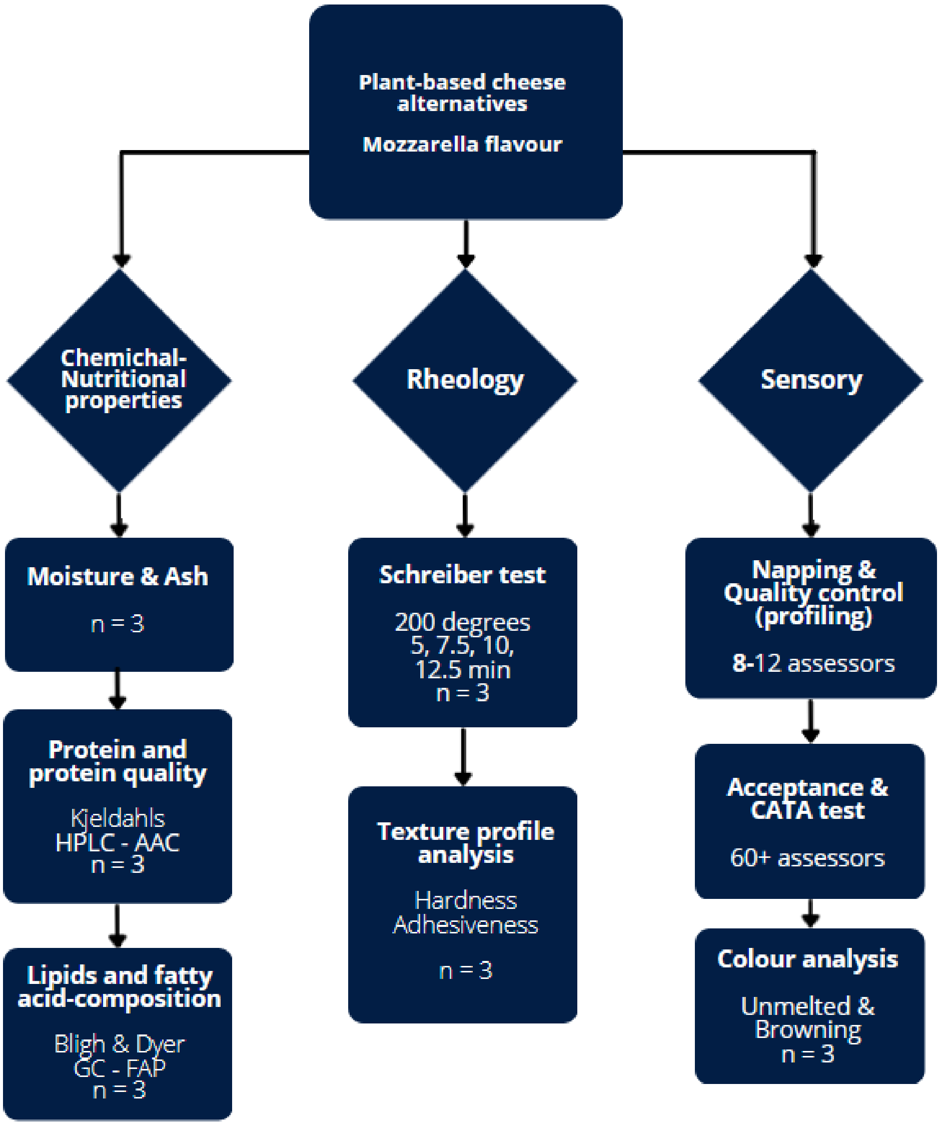

Figure 2. Overview of the chosen methods. LMMC = Low-moisture mozzarella cheese, PBCA = Plant-based cheese alternative, HPLC = High-performance liquid chromatography, AAC = Amino-acid composition, CATA = Check-all-that-apply test

3.2 Raw materials

Five samples of commercially available plant-based cheese alternatives were selected by consulting two experienced vegans from Norway and the United States, and one milk-protein atopic, for their opinion about popular alternatives to mozzarella cheese on the market. The selection of products from the US was based on the overview of PBCA-brands created by Grossman et al. (2021) and on web-searches. Care was taken to only include PBCA that use the term "mozzarella" in its designation, for example as "mozzarella-alternative" or "mozzarella-flavoured". Norwegian samples were selected based on web-searches and store-catalogues. One product based on cashew milk via tissue disruption (A) and four products based on various sources of starch via material fractionation (B, C, D and E) were purchased, along with two samples of dairy LMMC that were pre-shredded (1) and sold as blocks (2) respectively.

At the time of writing, sample B (starch) was the only plant-based alternative to LMMC which is produced in Norway and is available in the ten most popular store-chains. Sample E is produced in Greece and available for delivery in Norwegian online stores. The samples A (cashew), C (starch), and D (starch) are produced and sold in the US.

An overview of the selected products and their referral-code as samples, along with ingredients and overall nutritional information, can be seen in Table 6.

Table 6. Sample codes for chosen commercial products, with product designation and given list of ingredients. A, B, C, D and E = PBCA, 1 and 2 = LMMC, E1422 = Acetylated distarch adipate, E1450 = starch sodium octenyl succinate, E1404 = oxidized starch, kcal = 1000 calories

Code	**Designation & Ingredient information**	**Nutritional information (per 100 g)**
A (cashew)	Plant-based Cashew Milk Mozzarella Flavour Organic Cashew Milk, Organic Coconut Oil, Organic Tapioca-Starch, Sea Salt, Mushroom extract, Organic Konjak, Cultures, Potassium Sorbate	214,3 kcal 17,9 g total fats - 10,7 g saturated 3,9 g total carbohydrates 3,5 g total protein 0,75 g salt
B (starch)	Shreds with Mozzarella Flavour Water, Modified Starch (E1422, E1450, E1404), Vegetal Lipids (Coconut Oil & Shea Oil), Salt, Calcium phosphate, Citric Acid, Flavour, Beta-Carotene (colour), Potato Starch	207,1 kcal 12,0 g total fats - 7,0 g saturated 25,0 g total carbohydrates 0,0 g total protein 1,8 g salt
C (starch)	Dairy-Free Finely Shredded Mozzarella Filtered Water, Coconut Oil, Potato and Corn Starch, Expeller-Pressed Canola Oil, Sea Salt, Natural flavours, potato Protein, Calcium Phospate, Organic Vegan Cane Sugar, Vegetable Glycering, Cellulose, Sodium Citrate, Citric Acid, Lactic acid	285,7 kcal 22,1 g total fats - 17,5 g saturated 21,4 g carbohydrates 1,8 g protein 1,0 g salt
D (starch)	Non-Dairy Mozzarella Filtered Water, Expeller-pressed Coconut Oil, Modified Potato Starch, Modified Tapioca Starch, Potato Starch, Sea Salt, Olive-Extract, Natural Flavours	285,7 kcal 22,1 g total fats - 21,1 g saturated 22,1 g total carbohydrates 0,0 g protein 0,75 g salt
E (starch)	Block Mozzarella Flavour Water, Coconut Oil, Starch, Modified Starch, Sea Salt, Mozzarella Aroma, Olive-Extract, Beta-Carotene, Vitamin B12	270,0 kcal 21,0 g total fats - 19,0 g saturated 21,0 g total carbohydrates 0,0 g protein 1,8 g salt
1 (dairy)	Shredded Mozzarella Pasteurized Milk (Bovine), Potato Starch, Salt, Acid-culture, Microbial Rennet	301,0 kcal 21,0 g total fats - 13,0 g saturated 3,2 g total carbohydrates 24,0 g protein 1,4 g salt
2 (dairy)	Block of Mozzarella Pasteurized Milk (Bovine), Salt, Acid-culture, Microbial Rennet	317,0 kcal 23,0 g total fats - 15,0 g saturated 0,6 g total carbohydrates 27,0 g protein 1,2 salt

3.2.1 Lipid extraction

Purification and extraction of lipids in both plant-based cheese alternatives and natural mozzarella was performed using a modified version of Bligh & Dyer's method (Bligh and Dyer 1959). Samples (5-10 g) were placed in a container with 16.0 ml deionized water, 40.0 ml methanol, and 20.0 ml chloroform, and homogenized with homogenizer (Kinematica Polytron PT3100 D, Kinematica AG, Malters, Switzerland) at 2400 rpm. 20.0 ml of chloroform was added and homogenized a further 40 seconds, followed by 20.0 ml deionized water and homogenized another 30 seconds. These were then centrifugated at 5000 rpm for 15 minutes. The bottom layer of chloroform was extracted from each sample tube, and a volume of 2.0 ml was left in a warming closet with a constant supply of nitrogen-gas for at least one hour. The lipid mass was measured to assess the concentration of fats in the product.

3.2.2 Fatty acid composition

The fatty acid composition of the lipid fraction was assessed by isolating the oil (0,60 g) in a solution of 0,5 M methanolic potassium hydroxide (3.0 ml), which were then mixed and heated to 80 °C for 20 minutes. The samples were then cooled and added 5.0 ml boron trifluoride etherate, before being heated to 80 °C for 5 minutes. Samples were cooled again and added butyl-acetate 2.0 ml, and sodium-chloride solution. The organic solution of fatty acid methyl esters (FAMEs) was carefully extracted with a thin glass pipette. About 1,0 µl of FAMEs were analysed via gas chromatography with the Agilent 6850 (Agilent technologies, United states). Samples were introduced in an evaporation inlet to 260 °C at 1,8 psi, whereupon the gas travelled through a 30 m long polyethylene glycol column with a 0,25 µm film and width of 0,25 mm. Hydrogen was the carrier-gas. The various compounds in the sample were detected with a flame ionization detector adjusted to 310 °C. The detected compounds were compared with a standard solution FAME-mix (Supelco 37 component FAME mix, Merck Life Sciences, Norway).

3.2.3 Protein determination and amino acid composition

The concentration of proteins in each product was assessed via the Kjeldahl-method () and according to the manufacturers protocol. The method was performed with the Büchi Kjeldigester K-449 with a program of 420 °C for 125 minutes. Digestion was done by adding 15.0 ml 1 M Sulfuric acid (H_2SO_4) and titanium-tablets, as well as a pinch of stearic acid to prevent foaming. Measuring was done with the Büchi Kjelmaster K-375, with 0,1 M Sulfuric acid. In many organic compounds the amount of nitrogen is proportional to the amount of protein, since proteins, peptides, and amino acids are their largest source of nitrogen. The concentration of nitrogen per weight was calculated to protein-concentration using different conversion-factors depending on the source of protein for each sample. For most foodstuffs, the factor of conversion is close to 6,25, since most studies agree that the nitrogen-percentage of proteins is 16% and non-protein sources of nitrogen are negligible. It is speculated that animal protein has a slightly higher protein-to-nitrogen ratio, so dairy products are converted with a factor of 6,38. (Sáez-Plaza, Michałowski et al. 2013) A factor of 5,46 is common for ground nuts, and was chosen for PBCA based on cashew milk. A factor of 5,71 is used for vegetal foodstuffs like soybean and flour and so was chosen for the starch-based PBCAs (Toufeili 2007, Sáez-Plaza, Michałowski et al. 2013).

Protein quality was determined based on HPLC, after samples were hydrolysed. Sample size was calculated to achieve a total weight of 50,0 mg protein. The samples were dissolved in 1,0 ml 6 M Hydrochloric acid (HCl) in a 105 °C heating-cupboard for 22 hours. After hydrolyzation the solutions were neutralized by adding sodium hydroxide. Once neutral, the solutions were filtered through a Whatman glass microfilter GF/C and transferred to a container to be diluted to 10,0 ml with deionized water. The solutions were diluted further to a 1:500 ratio and filtered through 0,22 µm filters. 0,205 ml of the solutions were put into vials for HPLC, which was performed by experienced personnell at Kjemi 3 Gløshaugen, NTNU.

3.2.4 3.x Moisture and ash content

The moisture content was assessed by leaving a measured amount of sample in a heating-cabinet at 105 °C for 24 hours and weighing the dehydrated mass. The concentration of ash was measured by leaving a measured amount of the products in a “Nabertherm LV 9/11/B410” ashing furnace overnight and weighing the remaining ash.

3.3 Colour

The surface-colour was measure of samples of PBCA and LMMC before and after melting in a 200 °C conventional oven for 12 minutes. Measurements were made using DigiEye Enclosed Illumination Cube (DigiEye, VeriVide Ltd. UK).

The samples were homogenized in a blender to achieve as even surface and minimize shadows between individual shreds. Homogenized samples were placed as a round shape on a white board. The samples were placed in a standardized light-box (daylight, 6400 K) and photographed using a digital camera. The software DigiPix was used to calculate the L*a*b- and HCL-values of the chosen surfaces. L describes the sample lightness on a scale from pure black (0) to pure white (0). The factor a* describes the scale from green (-100) to red (100), while b describes the scale from blue (-100) to yellow (100) (Figure 3).

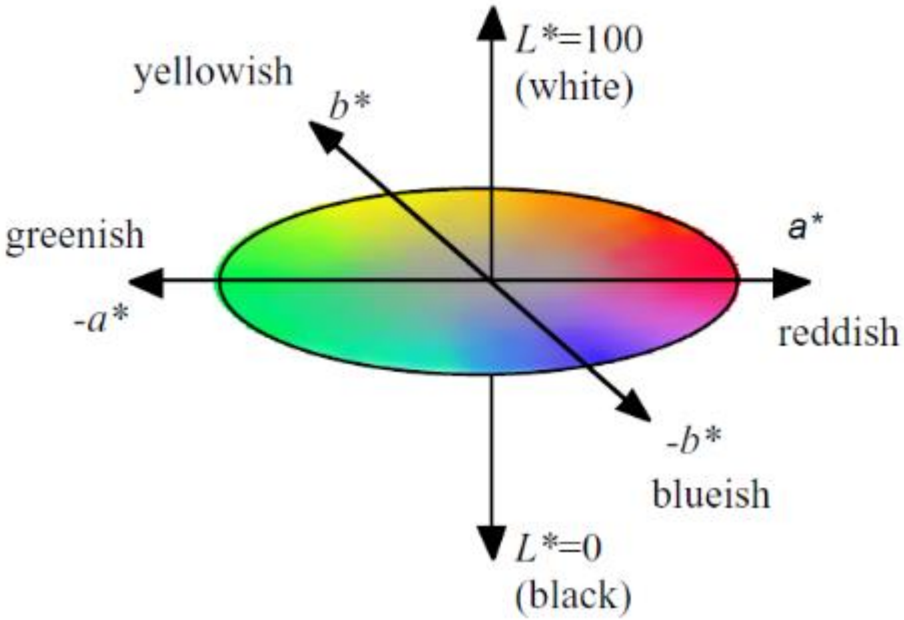

Figure 3. Illustration of the L*a*b colour space (Andersen 2013)

Measurements were repeated on samples after melting. The surface of the melted samples was measured in three different ways: (i) the whole melted area; (ii) the parts which showed the least degree browning; and (iii) the parts which showed the greatest degree of browning.

3.4 Rheology

3.4.1 Pizza-baking conditions

For measuring the rheological properties and meltability in pizza-baking conditions, the conditions for melting were selected based on the specifications displayed on the samples' packaging. The samples were purchased from grocery stores and retailers online and designed to be heated in household ovens in temperatures ranging from 180 to 225 °C for 9-15 minutes in conventional (heating-elements from above and below) or warm air (heated airflows inside the oven). The chosen conditions for this thesis involved baking at 200 °C for 12 minutes in conventional oven-setting, as an average of the various designated temperatures and timespans.

3.4.2 Schreiber test

Meltability of the products was assessed using the modified Schreiber test as described by Grasso et al. (2021), with additional modifications. Samples that were not pre-shredded as sold were shredded by a hand shredder and kept at 4,0 °C until analysis. Sample amounts of up to 10 grams were placed in a metal cylinder at 41,0 mm in diameter on top of a baking pan with a baking sheet (Figure 4). A circle was marked around the metal cylinder. The circles were divided into eight sectors and marked with four diagonal lines.

Samples were heated at 200 °C for 5,0 min in the middle of the oven. Pictures were taken of the samples as soon as they had been removed, and the diameter was measured by hand along the four lines drawn inside the circles. The samples were then replaced in the oven for an additional 2,5 minutes and measured again. This was repeated until the total time spent in the oven was 12,5 minutes.

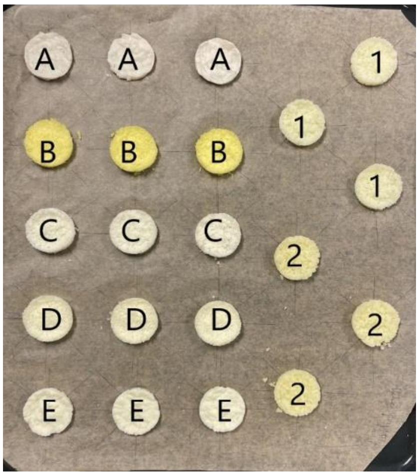

Figure 4. Homogenized samples of plant-based cheese alternatives (PBCA) and low-moisture mozzarella cheese (LMMC) on a baking sheet, before melting at 200 °C for a Schreiber's test. (Knudsen 2024)

3.4.3 Texture profile analysis

The adhesiveness, hardness, and cohesiveness of each of the samples was assessed with Stable Micro Systems TA. XT plusC Texture analyzer (Stable Micro Systems, Godalming, UK). Samples were prepared by homogenizing 15,0 g of each Sample in triplicate and placing them in a small ceramic cup with an opening approximately 20,0 mm diameter * 45,0 mm height (Figure 5). The method of analysis involved lowering a probe with a given speed on the material and letting it sink into the material with a predetermined depth, before returning the probe to its original height (**Feil! Fant ikke referansekilden.**). The measurement would be triggered by a sufficiently strong resistance. Materials were prepared with the purpose of maintaining a melted texture for as long as possible, where the texture would be measured when the internal temperature was 45,0 °C ± 3,0 °C, measured by a handheld thermometer. The temperature was chosen as the ideal serving-temperature for melted cheese for consumer comfort (Lachenmeier and Lachenmeier 2018).

Figure 5. Samples intended for texture profile analysis before melting, on a white cutting board, from left to right: A, B, C, D, E, 1 (top) and 2 (bottom). (Knudsen 2024)

The program used for assessing the properties of the melted PBCAs and LMMCs involved affixing the tip of the analyser with a 1s/PS spherical plastic probe with 20 mm diameter; test speed of 2,0 mm/s; material depth of 9,0 mm; and return speed of 10,0 mm/s. The point at which the analyser registered physical contact with the material was at 4,0 grams of force. A higher trigger-force is advised for future tests, because performance was regularly hampered by early triggering due to a high-density of water-vapour above the melted samples.

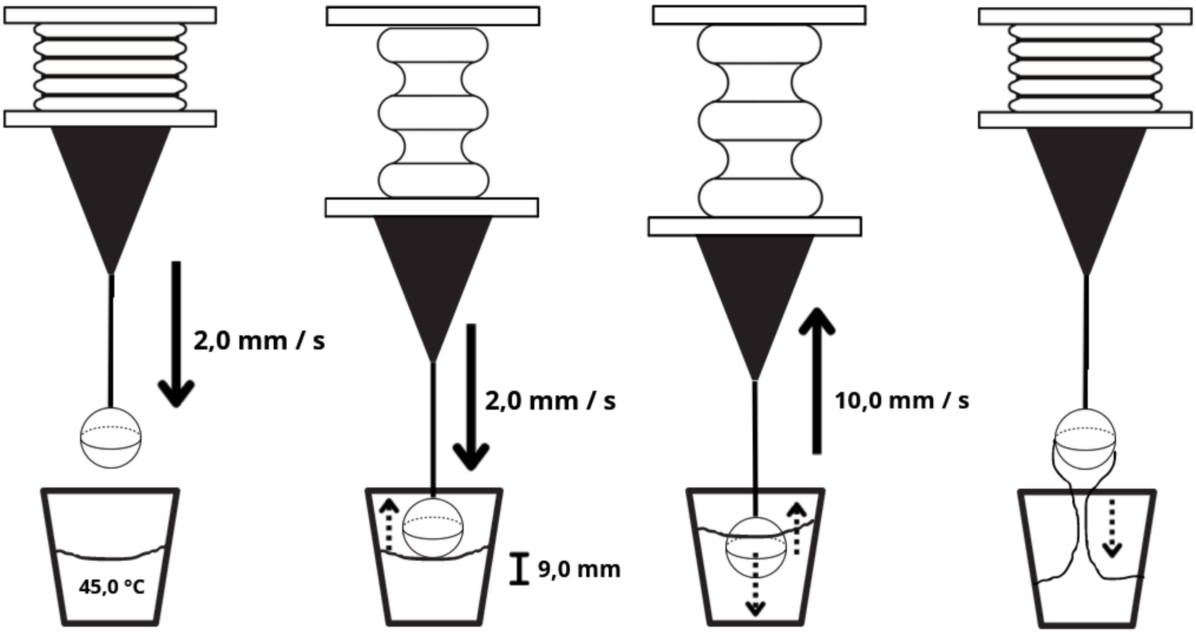

Figure 6. Performance of texture profile analysis with TA. XT plusC Texture analyzer with chosen program and temperature of melted samples. Drawn using the design-software Canva® (Knudsen, 2024)

3.5 Sensory evaluation

3.5.1 Sample preparation

For the assessment of each cheese and cheese alternative's sensory properties, the samples were prepared in a manner for which they were designated as commercial products. Each sample of PBCA and LMMC were served as a topping on mini pizzas with Eldorado "Pizzabunn" Original xxl pizza dough and a simple tomato sauce made from Mutti® Solo Pomodoro Pulpa canned tomatoes. These were chosen from a local market for their neutral flavour, consistent texture and shape, and price. The density of topping per surface area was kept as consistent as possible throughout the sensory tests [legg til konsentrasjon]. The topping and sauce were baked together to simulate the intended use for the commercial products, despite the risk of the sauce interfering with the meltability due to higher moisture and possible variable factors being introduced. Samples were put on a long pan lined with a baking sheet, and equilibrated to 4 °C. Before sensory analyses the samples were baked for 12 minutes at 200 °C in an oven with conventional setting.

Figure 7. A baking sheet with previously frozen samples of plant-based cheese alternatives (PBCA) A (cashew), B (starch), C (starch), D (starch) and E (starch) and dairy-based low-moisture mozzarella cheese (LMMC) 1 (dairy) on pizza dough and tomato sauce, before (left) and after (right) heating in a 200 °C conventional oven for 12 minutes. Prepared as samples for CATA (check-all-that-apply)- and acceptance sensory test. (Knudsen 2024)

3.5.2 Napping (Ultra flash profiling)

In order to find appropriate descriptive properties for each of the plant-based samples and assess the observed difference between them, a Napping with Ultra Flash Profiling (UFP) was performed with a panel of 12 semi-trained judges. The judges were informed that they would judge PBCAs as pizza-toppings, which might contain milk. The judges were presented with mini pizzas topped with each of plant-based cheese alternative and one with shredded dairy-based mozzarella cheese as topping. The judges were not told that one of the samples contained pure dairy-based mozzarella, instead that some samples would contain milk to prevent atopic and vegan assessors from joining. The judges were then asked to place the sample as a three-digit code on a background, in which the samples were placed in comparison to each other based on how overall different they were perceived as, with similar samples being placed close to each other, and dissimilar samples being placed far apart. The judges would then write descriptive words and sentences and place them on individual samples or “clusters” of similar samples. (Dehlholm, Brockhoff et al. 2012). Terms written in Norwegian have been translated to English in this report. Napping was performed using electrical tablets with the app “EyeQuestion”.

3.5.3 CATA- and acceptance tests

A set of “check-all-that-apply" (CATA) tests were performed in combination with Acceptance. Two sessions were performed with separate sets of samples. The first was performed with all PBCAs and the sample of LMMC chosen as reference in the quality-reference test (see “Quality-reference”). The second session was performed with only PBCAs, where Sample A (cashew), B, D and E (starch) were chosen. Sample C was omitted from the second test due to lack of material.

Descriptive words were selected from the Napping with UFP test and from literature, with guidance from experts in sensory science and dairy technology.

The tests were performed by the main entrance of Akrinn Øst at Kalvskinnet Campus, where a mobile set of eight sensory booths were prepared with tables and chairs. Passing students and faculty from campus of all genders and backgrounds, between ages 17-60, were invited to participate. The analysis was performed on electrical tables with the app EyeQuestion, in which the participants were asked to choose from a list of descriptive terms that they felt were true for the sample in question. The list of possible sample-descriptors and their definition can be found in Table 12. After choosing several descriptors for one sample, the participants were asked to grade their acceptance on a scale of 1 (low acceptance) to 9 (high acceptance).

3.5.4 Sensory profiling (quality control)

To compare the intensities of the relevant sensory properties of PBCAs with those of a Dairy-based LMMC, a modified sensory profiling (from now named quality control) was performed with a panel of 8 assessors. The panel consisting of four men and four women was selected from various backgrounds and varying degrees of experience as sensory assessors, ranging from consumer to experts in sensory evaluation of cheese. They attended sessions of training to recognize the sensory properties and assess them correctly, in preparation for the final test. Relevant sensory properties were selected from the Napping with UFP as well as from relevant literature. The panellists were invited to choose descriptors that they felt were most relevant and supplement with other properties based on an evaluation of three of the samples in a preliminary training session. During the preliminary session the panellists were asked to grade three samples consisting of two toppings of PBCA and one topping of pure-dairy LMMC. Each property was graded on a scale from 1-9, typically on a scale where 1 was considered as representing a low degree or low intensity of the property in question, and 9 of a high degree or intensity. The final list of sensory properties and their descriptions can be seen in Table 7.

Table 7. Sensory properties and their descriptions, used for the quality control test.

Whiteness	The intensity of the white colour
Yellowness	The intensity of the yellow colour
Browning	The degree of browning on the edges on the minipizza-topping
Meltability	The degree to which the minipizza-topping appears to have melted
Glossiness	The intensity of the shine off of the surface of the minipizza topping
Crust	The degree to which the minipizza-topping has formed a crust
Stickiness	The degree to which the minipizza-topping sticks to surfaces (ex. Inside of mouth, tongue, fingertips)
Firmness	The hardness of the minipizza-topping
Syneresis	The degree to which the minipizza-topping releases liquids when pressed, during chewing
Elastic	The elasticity of the sample, ie. How quickly the minipizza-topping returns to its original shape when pulled, pushed, dented, etc.
Grainy	The concentration of individual particles in an otherwise homogenous mass
Acidity	The degree to which the minipizza-topping tastes acidic
Sweetness	The intensity of sweetness in the minipizza-topping
Saltiness	The intensity of saltiness in the minipizza-topping
Dairy-likeness	The degree to which the minipizza-topping reminds of dairy

The properties of the two PBCAs were assessed, and one pure-dairy LMMC (sample 1) was chosen to act as the reference-topping for the final test, with a predetermined grading of each property. The grading of the reference-topping was chosen based on evaluations from training sessions and counselling from sensory experts.

During the second session, the panel was trained to grade the reference-topping, and their responses were compared to the predetermined values.

The final test was performed on electrical tablets with the EyeQuestion app. The five samples of PBCAs were served as marked with a random three-digit code along with the reference-topping, whose grading was already present on each scale.

3.6 Data collection and analysis

Results of the Chemical Nutritional, Colour and rheological analyses were collected in Microsoft Office 365 Excel (Microsoft, Office, version 2404, USA) to obtain mean values and standard deviation of each test performed with triplicate samples. To assess significant differences, groups were compared using One-way Analysis of variance (ANOVA) with Tukeys’ b post-hoc test (Pairwise) on the statistical platform IBM SPSS Statistics (SPSS, version 29.0.0, New York City, USA). Raw data from Sensory and Acceptance tests were gathered from EyeQuestion (EyeQuestion, version 5.0, Elst, The Netherlands).

The results of the Napping with UFP and CATA-tests were analysed in the EyeOpenR statistical tool on EyeQuestion. Napping with UFP used the “Napping” method with Principal Component analysis (PCA), and selected word frequency of 3 times or more, which produced a Multiple-Factor Analysis plot. CATA- and acceptance data was analysed using Cochran Q-test and McNemar (CATA). Comparison of the two different acceptance tests was compared with One-way ANOVA and Tukey’s b post-hoc as well.

4 Results and discussion

In this chapter, the results of each method presented in the previous chapter will be presented in the order of Chemical and Nutritional composition, Rheology, and sensory evaluation.

4.1 Chemical and nutritional composition

4.1.1 Lipid, protein, moisture and ash

The results of the lipid- and protein-determination (Table 8) aligned with what has been declared on the products' packaging (Table 6).

Table 8. The average result of three parallels in fat analysis, protein determination, moisture, and ash for Samples A (cashew), B, C, D, E (starch). The nitrogen-to-protein conversion factor is 6,38 for Samples 1 and 2 (dairy); 5,96 for Sample A; and 5,11 for Samples B, C, D and E.

Sample	Lipid content (%)	Crude protein (%)	Moisture (%)	Ash (%)
A (cashew)	15,1 (1,1)	2,8 (0,5)	67,5 (0,04)	2,3 (0,1)
B (starch)	10,7 (0,7)	0,05 (0,01)	57,4 (0,2)	2,6 (0,1)
C (starch)	22,9 (1,1)	1,5 (0,1)	49,9 (0,2)	3,2 (0,05)
D (starch)	22,4 (0,3)	0,0	50,4 (0,5)	1,6 (0,0)
E (starch)	19,82 (0,26)	0,0	52,7 (0,3)	1,6 (0,05)
1 (dairy)	19,26 (0,57)	25,8 (0,3)	45,0 (0,1)	3,5 (0,1)
2 (dairy)	n/a	27,5 (0,2)	43,8 (0,3)	3,7 (0,0)

Starch-based PBCAs C and D (starch) had significantly higher lipid content than the sample of LMMC, while A (cashew) and B (starch) had significantly lower percentages than LMMC (see appendix 1). Sample A (cashew) and Sample C (starch) were the only samples of PBCA to contain any nutritionally significant amounts of protein, and both contained far less than LMMC or any other dairy-based cheese. The total protein of Sample A (cashew) can most likely be derived from the core tissue-ingredient of cashew milk, while sample C (starch) contains potato-protein as a declared ingredient.

The caloric content of each sample (Table 6) shows that Sample A (cashew) and B (starch) contained the lowest energy-content, which is due to the lack of carbohydrates and lipids respectively, in comparison to other PBCAs. The energy-content of Samples C, D and E are the same, due to similarly high levels of lipids. LMMC has the highest energy-content because of the high concentration of lipids and crude protein.

4.1.2 Fatty acid profile

The results of the fatty acid determination can be seen in Figure 8. There is a larger content of saturated fatty acids than unsaturated in all samples of PBCA and dairy-based LMMC than in vegetal oil. Due to the process of the Bligh & Dyer analysis, no molecule with a registration-time in gas chromatography shorter than 1,520 could be measured as a separate molecule, excluding fatty acids shorter than C14:0. The content of saturated fatty acids is larger, particularly for coconut oil (Table 5).

All samples of PBCA in this thesis have coconut oil as the main source of fat (Table 6). The composition of the total fats in D and E (starch) were similar to each other and to that of coconut oil except for a higher percentage of stearic acid and oleic acid in relation to myristic acid (Figure 8). The strong resemblance indicates that coconut oil makes up the majority of the total fat, with no other significant source of free fatty acids, compared to other samples. Fat from Sample A contains a larger part of oleic and linoleic acid, most likely due to the inherent fats in cashew milk which are not purified and isolated as through material fractionation. Sample B contains significantly more oleic acid, due to the addition of shea oil, which extracted from the African shea-tree and is rich in precisely these fatty acids. The Combination of coconut and shea oil created a lipid which resembles cow's milk fat, but not that of dairy-based LMMC, which has a different fatty-acid composition due to the cheesemaking process (Buccioni, Mannelli et al. 2022). Sample C contains a lower concentration of myristic acid and more oleic acid due to the addition canola (rapeseed) oil in the fat phase.

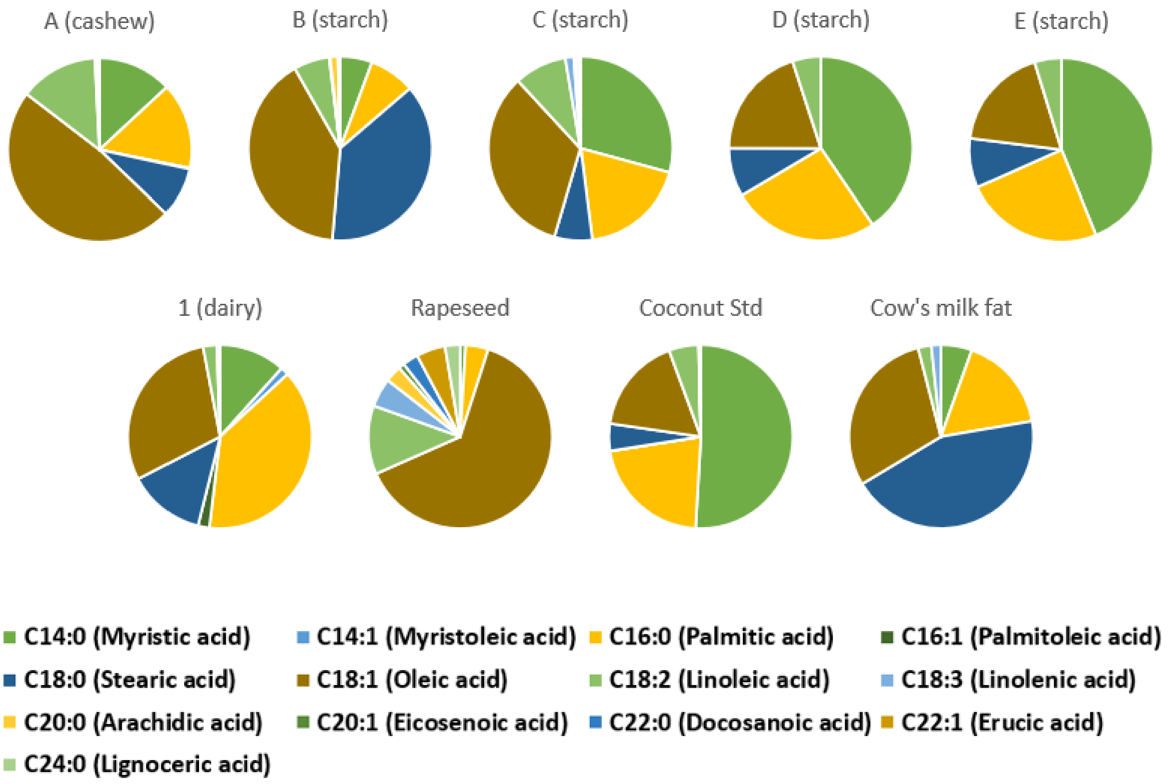

Figure 8. Fatty acid composition in comparison with attention to each sample, and mean composition of standard rapeseed oil, coconut oil, and cow's milk fat with fatty acid chain length between C14:0 and C24:0.

As mentioned in 0.1, an unfortunate effect of the structure and firmness of cheese at room temperature; mechanism of melting; and the positive rheological functions of melted cheese, requires that a large proportion of the lipids are saturated. This contributes to making cheese less healthy as a foodstuff (aside from the biologically available protein and positive micronutrients). This aspect of conventional dairy-based LMMC is fully present in the chosen samples of PBCA and deemed irreplaceable by modern producers. On the other hand, the amount of fat and type thereof influences the flavour through the availability of volatile fatty-acid substances. Good flavour or "taste" is most important characteristic for a PBCA to be bought many times by a consumer (Pierce, Ignaszewski et al. 2023).

4.1.3 Amino acid profile

Most of the rheological properties, flavor compounds, and nutritional value in conventional cheese comes from casein, which is, unfortunately for PBCA-producers, one of nature's most unique compounds. As far as we know, they can only be found in the enteric systems of mammals (Dalgleish 2011). In the case of PBCA various attempts have been made to improve the mentioned factors with combinations of plant-based proteins via changes in pH and heat-induced gelation.

Table 9. The total division percentage distribution of amino acids in samples with a protein-concentration above 1% per weight, namely A (cashew), C (starch), 1 and 2 (dairy). The list does not include Tryptophane or Cystein due to technical difficulties.

Essential AA	A	C	1	2
His	2,15 %	1,2 %	2,6 %	2,7 %
Ile	2,1 %	2,0 %	2,4 %	2,7 %
Leu	7,1 %	8,8 %	9,7 %	9,9 %
Lys	5,2 %	9,0 %	8,65 %	8,9 %
Met	2,0 %	1,2 %	3,4 %	3,65 %
Phe	4,5 %	4,8 %	5,4 %	5,6 %
Thr	3,3 %	3,0 %	3,8 %	3,9 %
Tyr	2,1 %	4,00 %	5,7 %	5,5 %
Val	2,9 %	3,5 %	3,6 %	3,9 %
Total	31,3 %	37,5 %	45,2 %	46,7 %
Non-essential AA				
Ala	6,0 %	4,6 %	4,1 %	4,0 %
Asn	0,06 %	0,2 %	0,02 %	0,01 %
Asp	13,5 %	25,4 %	11,1 %	10,3 %
Gln	0,1 %	0,1 %	0,1 %	0,1 %
Glu	24,8 %	8,75 %	26,6 %	26,0 %
Gly/arg	17,6 %	17,2 %	6,7 %	6,6 %
Ser	6,75 %	6,4 %	6,2 %	6,3 %
Total	68,7 %	62,5 %	54,8 %	53,3 %

Tryptophane is destroyed during acidic hydrolysis and could therefore not be detected, and Cystein is not detected due to technical reasons.

The samples of PBCA have significantly lower content of essential amino-acids than those of the LMMC-samples 1 and 2 (dairy), who are not significantly different from each other. The amino acid-profile of the samples 1 and 2 are also more or less the same (appendix 2). Sample C has a profile which is not significantly different from that of the LMMC samples, whereas sample A different from each other sample.

4.2 Colour analysis

The colour measurements of the PBCA- and LMMC-samples are shown in Table 10**Feil! Fant ikke referansekilden.**, with example colour. Sample A (cashew) had a white colouration with little to no yellow. B (starch) had an intense yellow colour and little to no browning overall. In general, the samples of PBCA would show no overall browning in comparison with the samples of LMMC.

Table 10. Colour analysis of Plant-based cheese alternatives (PBCA) Samples A (cashew), B, C, D and E (starch, and low-moisture mozzarella cheese (LMMC) 1 and 2 (dairy) before and after melting for 12 minutes in a 200 °C conventional oven. Melted samples were measured on their whole surface; particularly browned areas if present; and center-areas with the least browning. Colour examples were taken by filling the L*a*b-values in an online CIELAB calculator (https://www.nixsensor.com/free-color-converter/)

A (cashew)	**L***	**a* (Green-red)**	**b* (blue – yellow)**	**Colour example**
Before melting	87,38	1,47	14,61	■
Whole melted	76,22	7,26	28,31	■
Center melted	77,75	6,58	26,46	■
Browning melted	58,79	23,59	41,34	■
B (starch)				
Before melting	90,51	0,89	51,69	■
Whole melted	84,95	5,65	77,47	■
Center melted	84,46	6,76	79,74	■
Browning melted	76,22	7,26	28,31	■
C (starch)				
Before melting	95,13	-1,02	19,17	■
Whole melted	76,70	6,32	32,64	■
Center melted	85,13	2,03	32,23	■
Browning melted	57,12	19,43	37,02	■
D (starch)				
Before melting	93,55	-0,82	22,70	■
Whole melted	84,22	4,14	44,92	■
Center melted	80,99	5,83	53,24	■
Browning melted	83,31	7,55	35,35	■
E (starch)				
Before melting	96,19	-0,36	22,19	■
Whole melted	89,86	1,11	31,80	■
Center melted	89,95	1,14	31,79	■
Browning melted	86,00	5,40	33,35	■
1 (dairy)				
Before melting	91,20	-0,82	36,54	■
Whole melted	36,86	23,41	27,87	■
Center melted	41,17	25,18	34,92	■
Browning melted	32,95	18,58	18,44	■
2 (dairy)				
Before melting	89,73	0,34	44,85	■
Whole melted	43,02	29,04	37,64	■
Center melted	54,01	27,44	46,90	■
Browning melted	40,59	25,85	31,05	■

4.4 Rheology

4.4.1 Schreiber test of meltability

Table 11 shows the mean of four diameter-measurements taken from triplicate samples of dairy-based LMMC and PBCA, as well as their standard deviation.

The samples of dairy-based LMMC had the greatest increase in diameter. Sample C had the greatest spread of the starch-based PBCAs, the smallest of which was that of sample B. Sample A (cashew) had no significant increase in diameter (appendix 3), and in fact had shrunk from its original diameter after 10 minutes in the oven. All samples except Sample A (cashew) had a significant increase in diameter after five minutes. Samples C (starch) and 1 (dairy) had a significant increase in diameter after a further 2,5 minutes.

Table 11. Schreiber-test for meltability on samples that were stored vacuum-sealed in 4 °C for 60 days. Percentage represents the increase in average diameter and spread of the cheese after being in a 200 °C oven in the given timespan. Mean value of triplicate samples and standard deviation in parentheses.

Expansion	**5 min**	**7,5 min**	**10 min**	**12,5 min**
A (cashew)	2,84 (3,43) %	2,36 (1,48) %	-0,21 (1,30) %	-1,36 (2,45) %
B (starch)	17,97 (1,43) %	12,54 (1,53) %	13,70 (2,91) %	14,42 (2,18) %
C (starch)	47,17 (2,37) %	47,64 (1,10) %	45,75 (0,51) %	44,34 (1,34) %
D (starch)	33,04 (1,36) %	29,98 (2,09) %	28,57 (3,17) %	29,03 (2,26) %
E (starch)	18,60 (1,78) %	16,26 (2,45) %	15,09 (3,67) %	15,78 (2,17) %
1 (dairy)	63,48 (2,41) %	61,37 (1,27) %	59,96 (2,07) %	59,49 (1,21) %
2 (dairy)	56,91 (1,47) %	56,20 (0,99) %	54,10 (0,60) %	54,10 (0,73) %

Some observations about the melting behavior of the samples include the following: Samples C and D (starch) showed bubbling on the surface in the same fashion as the dairy-based LMMC samples, while Sample B and E (starch) would instead develop a surface-crust and expand "upward" as well as sideways, most likely due to trapped moisture that expanded through evaporation (see Figure 10). Sample B developed a firm crust that held moisture within remarkably well, so that the mass of PBCA within remained in a liquid phase afterwards. Sample C was closest to dairy-based LMMC in terms of flow and spread. Sample A bore no resemblance to the dairy samples. The starch-based samples of PBCA were sticky to touch when liquid but were not sticky when stiffened/retrograded.

Almost all the samples had shrunk at every interval of measurement after five minutes of heating, most likely due to either retrogradation after lipids are expelled from the three-dimensional structure, or due to excessive cooling during the measuring steps and loss of moisture from the oven. The exception is Sample B, which shrank the most of all the samples after the first period of measuring and spread further after following measurements. This is likely because PBCA-mass trapped within the dry crust had been expelled after the first session, making an uneven spread (Figure 11).

There had been a relatively large standard variation in the measurements, particularly between those with smaller diameters. Due to the small original diameter of the samples, measuring by hand proved difficult to perform with precision. All samples began as a mass inside a 36,0 mm diameter circle, and so a difference of 1,0 mm equals 2,77%. Future tests should involve larger circles. Making use of a digital video system for the measurement of area spread would give a more accurate result of the meltability assessment. Another alternative is to employ a dedicated melting-plate with additional lines as well as rings for better visualization of the spread.

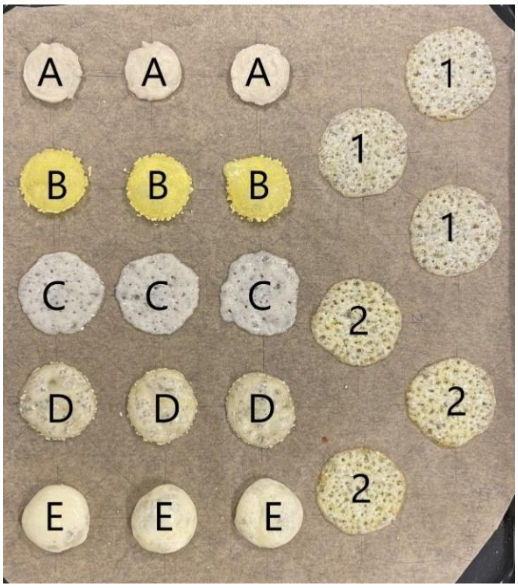

Figure 9. Melted samples from Schreiber test after 5 minutes in 200 °C oven, with Sample A (cashew), B, C, D, E (starch), 1 and 2 (dairy) (Figure 4)

There are two common problems with experimentally assessing the "meltability" of a cheese or cheese alternative: (i) Determining the melting-properties of a cheese involves the thermal stage and softening of a solid, as well as the flow-properties of the melt; and (ii) understanding the external temperature-gradients that affect the melting, such as humidity and the geography of the heating element (size of the oven, direction of the heating, etc.) (Park, Rosenau and Peleg 1984). Another problem when choosing conditions of melting for pizza cheese is the large variability of cooking-methods and the lack of an objectively "better" cooking method. Many traditional pizza restaurants would employ large, high-temperature stone-ovens which can perfectly cook a pizza within a couple of minutes, whereas most ovens found in ordinary western homes have a lower temperature range and can only bake a pizza in more than ten minutes. The dairy- and cheesemaking industry employ simple empirical methods to assess meltability for these reasons. The most common methods since the 1970s were the Schreiber test and the Arnett's test (Park, Rosenau and Peleg 1984), though only the Schreiber test sees much widespread use in today's industry (Atik and Huppertz 2023). The method has many modern variations, such as measuring the spread over time through computer vision systems (Badaró, de Matos et al. 2021).

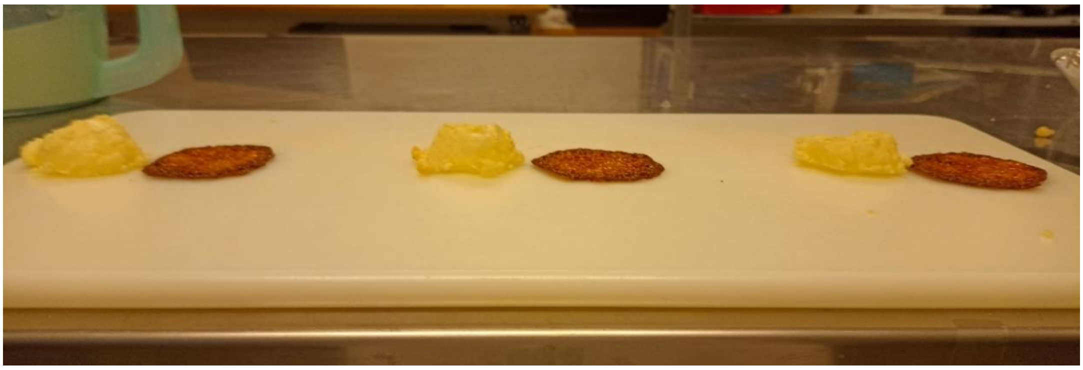

Figure 10. Samples E (starch) (left) and 1 (dairy) (right) in triplicate, placed on a cutting board after being heated for 12,5 minutes in 200 °C conventional oven and cooled for 20 minutes afterwards. Sample E had developed a moisture-tight crust which had "inflated" during heating. (Knudsen 2024)

In the original Schreiber test (Park, Rosenau and Peleg 1984) samples would consist of a cylinder sliced from a whole block of cheese or PBCA. This was done to achieve a homogenous texture before melting, because size-reduction has a significant impact on the melting-abilities of cheese. Since the Samples B (starch), C (starch), and D (starch) were sold pre-shredded, homogeneity was achieved by blending the samples to an equal minimum size. This proved difficult because shreddability varied between the samples. Sample A (cashew) proved impossible to shred due to its inherent softness and high moisture, while Sample E (starch) could only be reduced to grains that were slightly larger than the rest, possibly due to a higher density and low brittleness.

Higher content of fat which can enter the liquid phase through heating has been shown to increase the meltability and flow of cheese. Lipids which are in the liquid state at room temperature or lower contribute to greater softness and reduced brittleness before melting, in a similar manner to how increased moisture affects rheological properties. Sample A (cashew), which apparently boasts the highest content of long-chain unsaturated fatty acids of all the samples, has little to no meltability or flow. Sample B (starch) boasts the highest observable concentration of unsaturated fatty acids of all the samples, due to the addition of shea oil, though it has the second lowest meltability-score only after sample A. This is likely because of its exceedingly low concentration of lipids overall due to the high content of addition of unsaturated fats in sample C is likely to contribute to the overall improved meltability in comparison with the other samples of PBCA.

Figure 11. Triplicate of samples B (starch) after 12,5 minutes in a 200 °C conventional oven. The uneven spread is attributed to breaches in the dry crust, which caused liquid PBCA within to pour out.

4.4.2 Texture profile analysis

The mean hardness (firmness) and the adhesiveness (stickiness) of the samples of LMMC and PBCA are shown in Figure 12 and Figure 13 respectively. Firmness here is defined as the peak stress experienced by the probe travelling through the melted sample. Sample A (cashew) showed the greatest firmness of all the samples, certainly because of the lack of a phase-transition to liquid. Sample D (starch) showed the least firmness. The firmness of Samples B (starch), C (starch), and E (starch) fall between the values of the LMMC-samples.

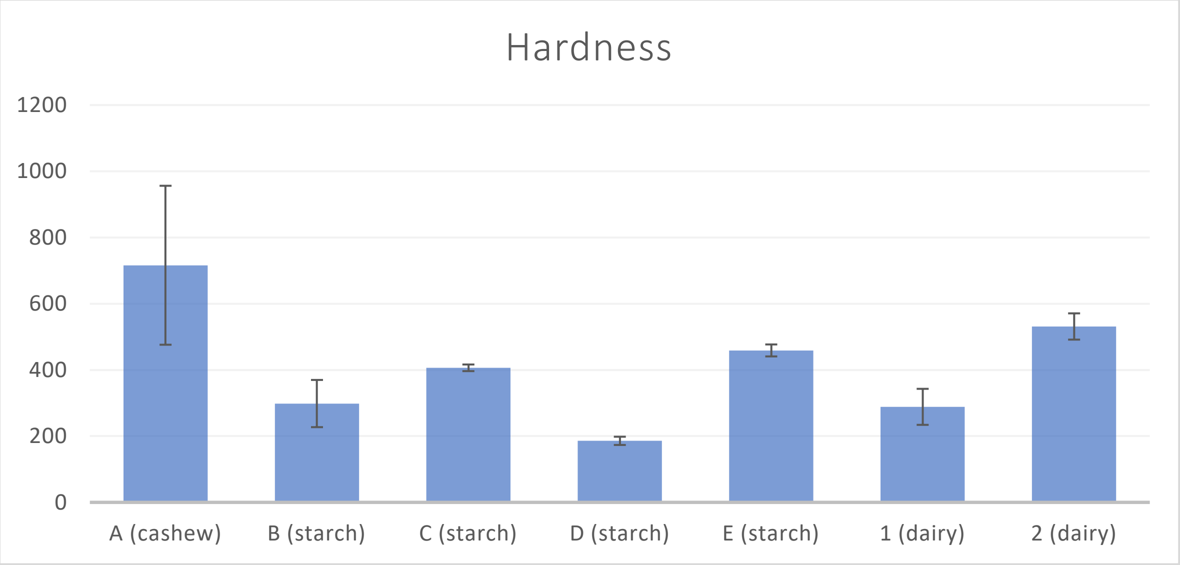

Figure 12. Textural hardness of low-moisture mozzarella cheese 1 and 2 (dairy) and plant-based cheese alternatives A (cashew), B, C, D and E (starch) measured in g force resistance.

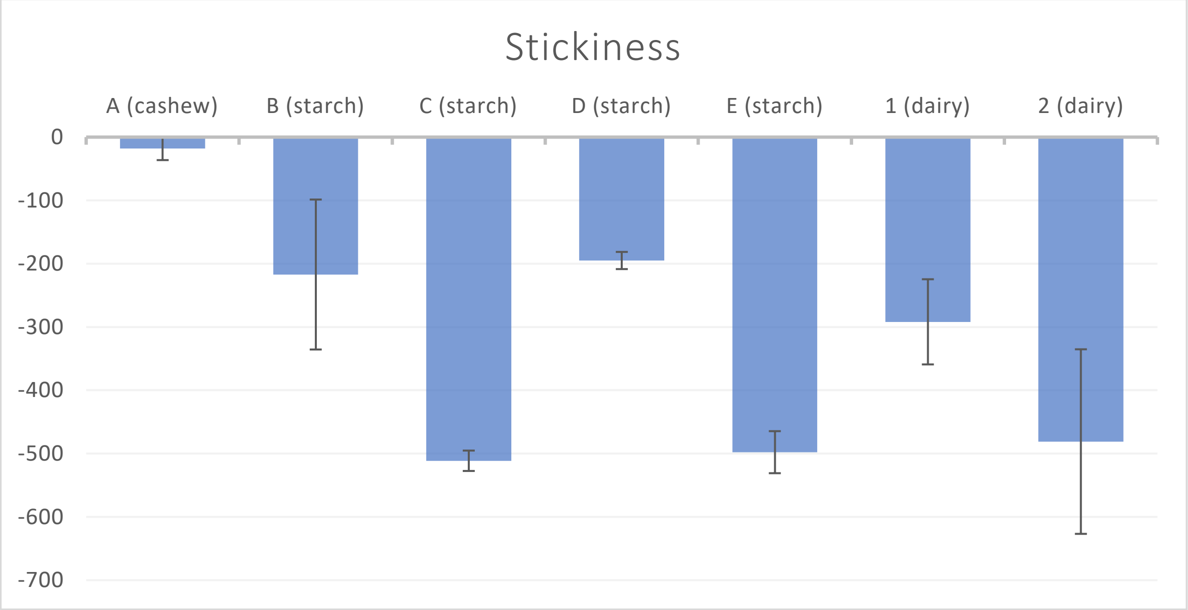

Figure 13. Textural adhesiveness (stickiness) of low-moisture mozzarella cheese (1 and 2) and plant-based cheese alternatives (A, B, C, D and E) measured in g force resistance when returning from measuring firmness, test speed = 10,0 mm/s, distance 60,0 mm – sample height

It is assumed that samples 1 and 2 (dairy) represent a standard which the PBCAs are meant to be imitating as accurately as possible. Therefore, they represent a limit of variation for the optimal firmness of LMMC. Samples which fall outside this limit, like Sample A and D, are considered less than optimal in terms of chewing resistance.

The stickiness of the samples is proportional to their hardness, except for Sample A. Samples C and E show the greatest values, which is also close to the presented adhesiveness of LMMC sample 2. Thus, the adhesiveness of C and E are either close to or past the optimal limit. A higher adhesiveness/stickiness indicates a low degree of free oil-formation, though it may be possible that free oil on the surface only prevents adhesiveness to a minor degree when the probe enters past a certain depth in the sample. Sample A shows little to no adhesiveness, but since Sample A has the least amount of available fats of the samples, it is more likely affected by an enhanced brittleness or composition otherwise.

The texture profile of cheese contains up to 17 measurable characteristics (Fox, Guinee et al. 2017), and a number of them apply to cheese which has been heat treated to enter melt or post-melt stage. Due to limited resources and available instruments, only a program for assessing the firmness/hardness and adhesiveness of LMMC and PBCA was available to be performed in this thesis. Firmness is an important factor for pizza cheese because it reflects chewing-resistance, which is pleasurable for consumers after cooling (Drake and Delahunty 2017).

Stickiness is also an important factor in the quality of cheese. It is considered a negative property of melted cheese, due to the unpleasant sense of having a high-temperature (or otherwise) material stuck to surfaces inside the mouth. Stickiness is a natural property of cheese but is usually inhibited by free oil formation during melting. Free-oil formations involves expelling fat from the three-dimensional structure to form in pockets on the surface, which creates a slippery, shiny surface. Some degree of adhesiveness is deemed necessary, to avoid the eventuality of toppings or the cheese itself slipping off the pizza, but overall it is considered a defect in the sensory experience (Drake and Delahunty 2017). Stickiness is expected in starch-based PBCA, since starch-gels have a naturally adhesive quality.

In future experiments, a texture profile-analysis should be performed with the materials for comparing stretchability/stringiness, which is a function of both cohesiveness and firmness. This is another important function of LMMC pizza cheese, which is generally considered lacking in PBCAs (Banville, Power et al. 2015, Grossmann and McClements 2021).

A possible error of measurement is the small size of the ceramic container used for melting. Sample size was kept small due to reduced availability of materials. Since the probe took a large amount of space in a thin container, which leaves less space for the sample to escape the pressing, there would be a greater pressure on the melted cheese or PBCA underneath, which artificially increases the resistance measured by the probe. For future experiments, a container with a larger diameter and greater volume of sample is recommended. To perform the test by melting a homogenous non-shredded block of cheese or PBCA is also recommended.

The standard deviation in samples A and B is due to the physical shape of the samples. Sample A remained as a solid and was impossible to shred and was therefore cut out of larger blocks to fit the container. The eventuality of air-bubbles beneath some of the samples would lead to reduced resistance compared to those without. In the case of

Sample B, the crust-formation mentioned in 4.2.1 (Figure 11) caused an in-homogenous texture, even when the sample was stirred for the analysis. The ceramic container was held in place by hand, introducing a risk for human error in the measurements.

The size of the ceramic containers may have influenced the measured adhesiveness as well, as sample may have been squeezed past the probe in the thin container and put additional weight on the probe when it was returning to its original position.

4.5 Sensory evaluation

In this sub-chapter, the results of each sensory test will be presented in the order of Ultra Flash Profiling with UFP, CATA-test, Colour-analysis, Quality control, and Acceptance. A comparing discussion of sensory tests' results and acceptance will be shown at the end.

4.5.1 Napping Ultra Flash profiling

The Multiple Factor analysis plot "Sensory overlay plot" (Figure 14) shows the words that were used with a minimum frequency of 3 times. The samples are placed based on their variance to the others, as well as which words most often were used for individual and clustered samples. The samples are indicated to be divided into three clusters. The dairy-based LMMC samples of 1 and 2 are considered highly similar and different from the samples of PBCA; C, D, and E (starch) are considered similar; and A and B are considered somewhat similar. The total variability of the two dimensions in the MFA-plot adds up to 78,8%. Dimension1 along the x-axis has the greatest impact (52,9%) in product- and word-variance. Therefore, the distance between the cluster of LMMC-samples and the clusters of PBCA-samples is most relevant. It is impossible to determine how significant differences are in Napping tests. The Napping test was therefore performed to provide the descriptive terms for the later CATA-test and quality control.

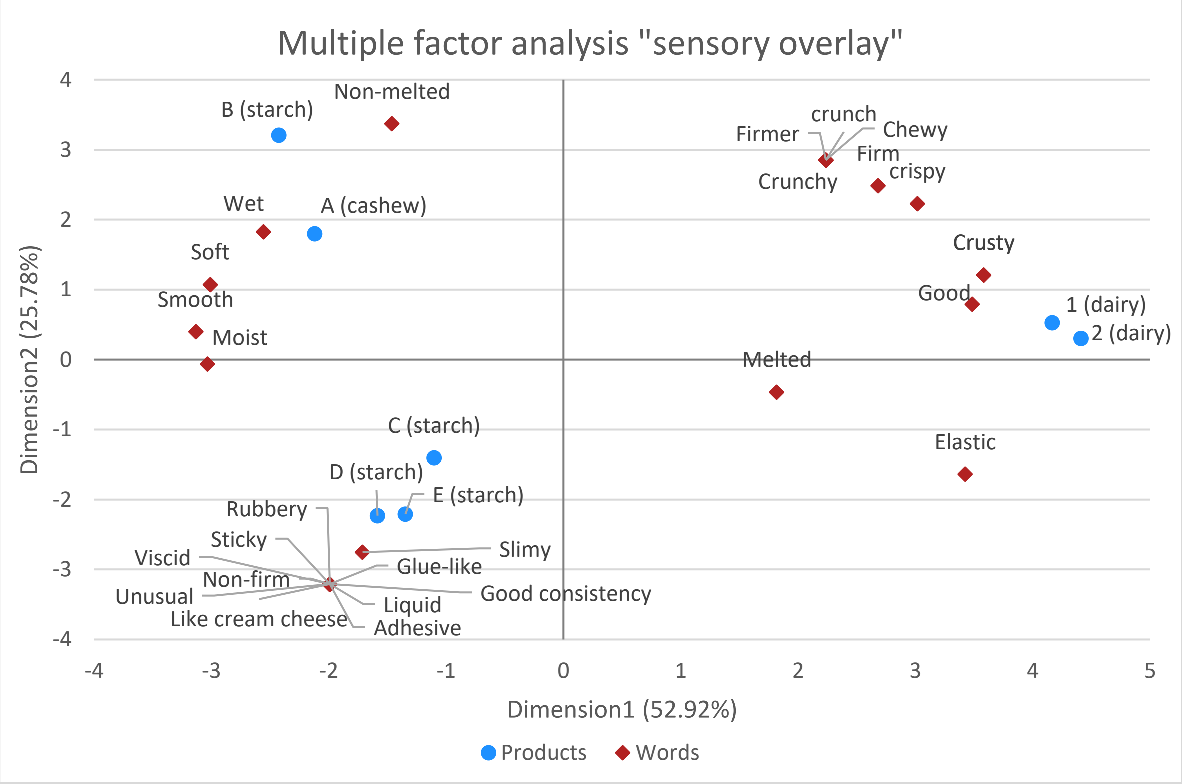

Figure 14. MFA-plot for the perceived difference between samples, and descriptive words that were used with a minimum frequency of 3 times in a Napping test by assessors. Their relative positions depend on how often they are used for given clusters of products. The total impact of variance in this plot is 78,0%, where variance along dimension 1 (52,9%) is most descriptive.

Care was taken to include misspelled words by observing each term used by all assessors in a separate file. 27 words were used 3 times or more by the combined panel. Words like "Sticky", and their synonyms, were used frequently enough to appear as a synonym several times, as in "Adhesive" and "Viscid". The occurrence of several terms also happens with descriptive sentences, such as “glue-like”, which can have several meanings, but likely also means stickiness. This can be seen when choosing words that were used with a frequency of 3 times or more, as in Figure 14.

The terms that best describe samples 1 and 2 (dairy) are “Good”, “Elastic”, “Crispy”, “Melted”, and “Firm”. Samples of PBCAs A (cashew) and B (starch) were associated with “non-melted”, “Wet”, “soft”, “smooth”, and “moist”. Samples C, D and E (starch) are best described as “Slimy”, “Sticky”, “Rubbery”, “Liquid”, “Unusual”, and “Good consistency”.

The use of the word “good” for samples 1 and 2 shows a greater acceptance of LMMC compared to PBCA. Inclusion of the term “melted” makes sense, given that LMMC-samples were empirically measured as having the highest degree in the Schreiber’s melting test. Since the words around the samples 1 and 2 are placed further away from the samples compared to the samples of PBCA, it is indicated that the PBCA-samples shared some of the words, particularly that of “melted” which is furthest from the LMMC-samples.

Sample A (cashew) was likely seen as non-melted, and yet considered wet and soft, which is a direct effect of the melting-functionality of cheese. The perceived wetness may be due to condensation, or an excess of sauce on the samples during preparation. Sample A was the firmest of all the samples in the texture profile analysis, but it never properly melted (Table 11). Sample B was also perceived as non-melted, which reflects the reduced spread, and the dry surface crust, that was observed in the Schreiber’s test. Another possibility is that the addition of dough and sauce causes a completely different melting-process for the samples. Dough and sauce contribute a large amount of moisture beneath the LMMC and PBCA, which also requires more time to properly heat compared to a baking-sheet on a metal pan.

4.5.2 CATA-tests and acceptance

A number of words that aligned with the lists of common descriptive terms used by Kilcawley (2017) and Drake and Delahunty (2017) were selected from the Napping (UFP) test. The terms “Sticky” (8) and “Firm” (7) were added for comparison with the results of the texture profile analysis. The terms “Slimy” (4), and “Rubbery” (3) were selected for their wide descriptive range, respectively “*Soft, glutinous or viscous substance, soft, moist, and sticky*” and “*Springy, returns to original shape after biting, hard”* (Kilcawley 2017). The term “Crusty” was chosen to investigate the observed crust formations in the Schreiber’s test, and “Elastic” was added with reference to importance of the viscoelastic index in the rheological profile of cheese (Banville, Power et al. 2015, Atik and Huppertz 2023).

Relevant terms were further added to the list by consulting an expert in the field of sensory analysis. Terms to describe the flavour of melted cheese and other rheological properties were chosen based on how understandable they would be for the average consumer. The term “high viscosity” was added to assess if the molten PBCA would remain in a liquid state in a longer period of time than PBCA. The terms “slippery” and “glossy” were added to compare free oil formation. Common words to describe the flavour of cheeses in general included “acidic”, “salty”, “sweet”. The term “dairy-like” was selected to serve as an amalgamation of the terms “creamy” and “cheese flavour” used by Henneberry, O'Sullivan et al. (2016) in his sensory profiling of heated mozzarella cheese. Terms relating to flavour-intensity were “strong taste” and “strong aroma”. It was decided that assessors should be allowed to decide the colour of samples on the scale of "White" to "Yellow" and degree of browning as "brown", due to its importance in the presentation of finished meals and presentation in stores (Drake and Delahunty 2017).

Table 12. Descriptive terms used for CATA-test.

White	Yellow	Brown	Glossy	Crusty
Sticky	Slimy	Slippery	High Viscosity	Firm
Soft	Fatty	Elastic	Rubbery	Acidic
Salty	Sweet	Strong taste	Strong aroma	Dairy-like

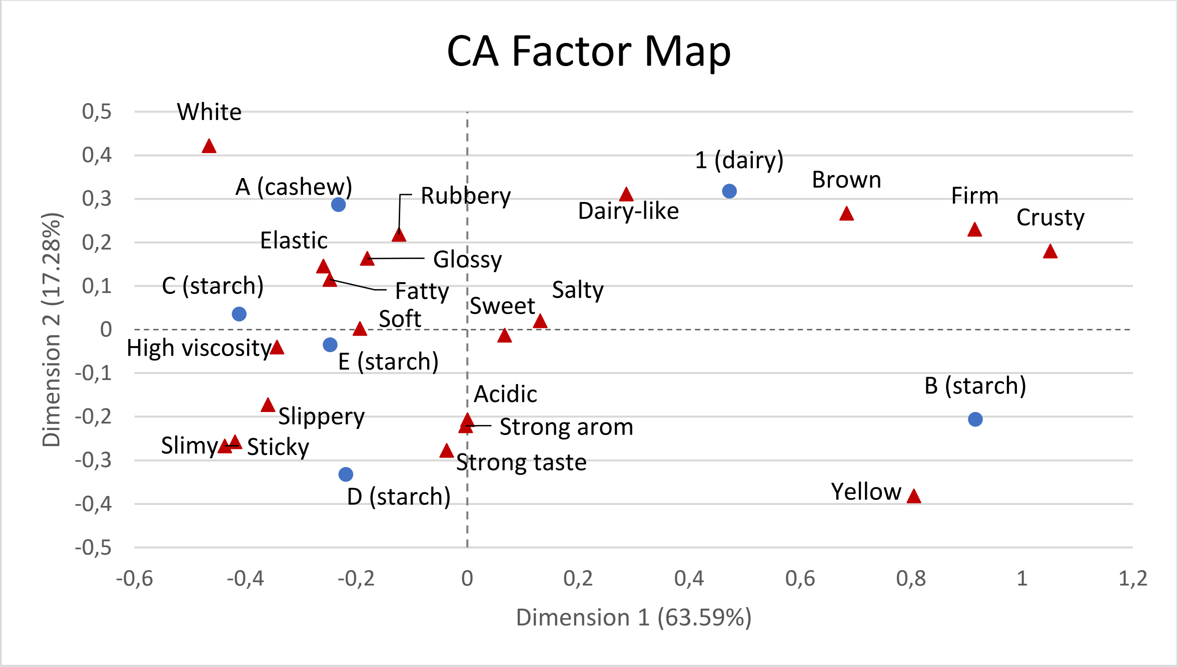

Figure 15. CA-plot from the CATA-test. Chosen terms in correlation with sample is reflected in areal placement. The total impact of variance in this plot is 80,9%, where the variance along dimension 1 (63,6%) is most descriptive.

The samples of PBCA C, D, E (starch) and the dairy-based LMMC were considered glossy by assessors significantly more often than samples A (cashew) and B (starch). Sample B (cashew) and 1 (dairy) were considered crusty significantly more often than other samples. The samples C, D and E (starch) were considered sticky significantly more often than other samples. The samples D and E (starch) were considered as having high viscosity more often than all other samples. Samples A (cashew), B (starch), and the reference sample 1 (dairy) are significantly more often considered as "firm" compared to samples C, D and E (starch). All samples except sample B (starch) are moderately often considered as "soft". All samples were considered significantly fattier and more elastic than Sample B (starch). Sample A (cashew) was considered rubbery significantly more often than the rest. The consumer assessors could not differentiate between the degrees of saltiness, acidity, or sweetness in the samples, and rarely used those descriptors at all. Significantly more assessors used the term "Strong taste" for the samples of PBCA than for Sample 1 (dairy), and fewer assessors used the term "dairy-like" for the PBCA samples than for Sample 1 (dairy).

Table 13. Frequency with which terms were used in CATA (Check-all-that-apply) for plant-based cheese alternatives (PBCA) Samples A (cashew), B, C, D, E (starch) and low-moisture mozzarella cheese (LMMC) 1 (dairy), with McNemar test. Samples with the same lowercase letter are not significantly different from each other in the particular property, p ≤ 0,05 (see appendix 4).

Word	**A (cashew)**	**B (starch)**	**C (starch)**	**D (starch)**	**E (starch)**	**1 (dairy)**
White	41 a	1 d	41 a	8 c	27 b	13 c
Yellow	2 d	51 a	6 cd	30 b	13 c	27 b
Brown	0 a	1 a	0 a	1 a	1 a	3 a
Glossy	7 bc	2 c	22 a	15 ab	20 a	21 a
Crusty	8 b	33 a	4 b	2 b	5 b	27 a
Sticky	11 b	5 b	38 a	36 a	32 a	6 b
Slimy	20 b	6 c	27 b	40 a	24 b	4 c
Slippery	9 ab	3 b	13 a	17 a	12 a	4 b
High Viscosity	12 ab	2 c	10 ab	16 a	16 a	6 bc
Firm	17 b	35 a	1 c	4 c	7 c	28 ab
Soft	22 b	9 c	31 ab	34 ab	36 a	24 b
Fatty	22 a	3 b	22 a	27 a	16 a	19 a
Elastic	14 a	2 b	10 a	13 a	12 a	9 a
Rubbery	36 a	12 b	16 b	18 b	16 b	12 b
Acidic	9 a	9 a	10 a	10 a	6 a	2 a
Salty	16 a	16 a	13 a	13 a	17 a	13 a
Sweet	6 a	10 a	13 a	9 a	14 a	11 a
Strong taste	15 a	16 a	13 a	23 a	16 a	4 b
Strong aroma	9 a	14 a	14 a	18 a	18 a	7 a
Dairy-like	5 c	9 bc	13 bc	11 bc	15 b	33 a

The perceived difference between the products was most apparent between the LMMC-samples and the PBCA samples overall.

The perception that samples C, D and E (starch) were sticky is not surprising, since stickiness has experimentally been measured to be high in the samples C and E. Surprisingly, some of the assessors describe the samples as having good consistency in the Napping-test (UFP), which indicate that the properties may not be inherently negative, though it is more likely caused by preparation of the samples which made the stickiness or sliminess less prominent for some assessors. Foods which are unusual may not be inherently negative either, since the one of the primary philosophies of PBCA made via Tissue Disruption is to embrace the unique flavors of a plant-based ingredient instead of attempting to fully recreate the experience of LMMC pizza cheese.

Assessors would pick the term "High Viscosity" very infrequently, likely due to many samples being cooled down and having gone through retrogradation before tasting was performed. The low perceived fattiness of Sample B (starch) was expected since has the lowest amount of fat of all samples. Other samples were not considered fatty significantly more often than Sample A (cashew) despite its likewise low percentage.

No specific flavour-descriptors would get selected by significantly more assessors to describe one sample over another. This may be due to cross-modal sensory interactions. A consumer who is asked to describe the "taste" of a cheese product will more often describe their whole and integrated sensation of eating the product, rather than solely describe their sensory experience of their tastebuds (Drake and Delahunty 2017). In the same vein, the assessors assessed all the samples of PBCA with an overall stronger taste than LMMC. The assessors could not differentiate between stronger or weaker aroma. This could have been caused by the fact that all samples were served at once, where the strong aroma from one sample could mask those of different samples. LMMC was, unsurprisingly, significantly more often considered “dairy-like” compared to the samples of PBCA, of which sample E (starch) was considered such more often than sample A (cashew).

Correlation between samples and the words is visualized in the Correspondence-analysis (CA) plot in Figure 15. The correlation between samples in the CATA-test is similar to what was found in the Napping test. The dairy-based LMMC were perceived as very different form the other samples, and the starch-based samples of C, D and E were considered similar. Sample A (cashew) was perceived as more similar to the cluster of samples C, D and E (starch) than the LMMC, but sample B (starch) was perceived as completely different from the other samples of PBCA. Because the Napping-test is designed for an assessor to give their “holistic” view of the product’s sensorial profile, it would likely have presented a more accurate picture of the perceived difference between samples. The CA plot presents differences via association with the descriptive words. This is the reason for the placement of Sample B, because the descriptive word that differentiates it from the other samples to the greatest degree is its colour, which shows a great contrast to Sample A.

Sample A (cashew) and C (starch) were associated with “white”, while Sample B (starch) was most associated with “yellow” (Table 13). The samples which fall between these two opposite ends are the dairy-based LMMC sample 1, and the PBCA samples D (starch) and E (starch), which are considered as more yellow and white respectively.

The overall similarity in perceived differences between samples A (cashew), C, D, E (starch) and 1 (dairy) indicates that the list of words was comprehensive enough for the assessors to portray their sensorical opinion. The exception was Sample B (starch). Overall, the use of CATA and Napping give similar results, and both have their merits when used in combination (Reinbach, Giacalone et al. 2014).

During the first CATA-test, each assessor was asked to grade how enjoyable they found each product on a scale of 1-9. The dairy-based LMMC sample 1 had significantly higher acceptance than the other samples, while no significant difference in acceptance was observed between the plant-based alternatives.

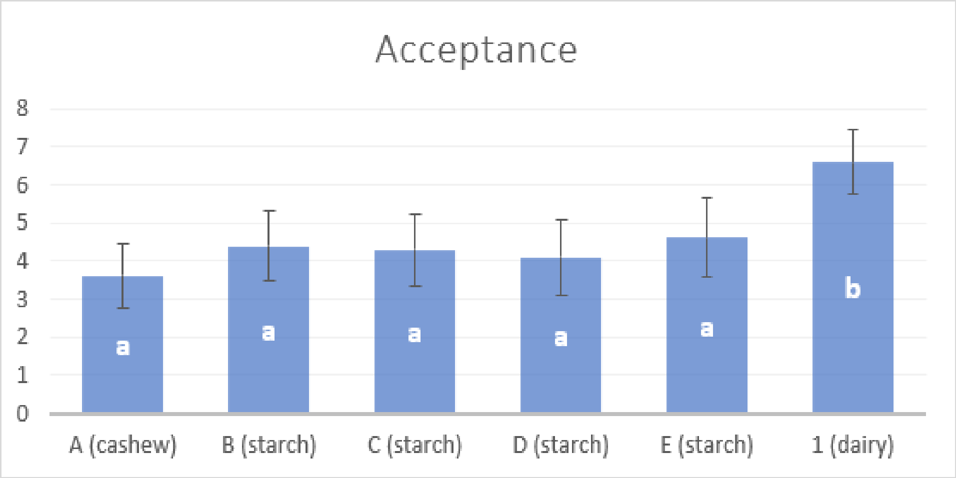

Figure 16. Acceptance from the first test, with plant-based cheese alternative (PBCA) Samples A (cashew), B, C, D, E (starch), and low-moisture mozzarella cheese (LMMC) Sample 1 (dairy), along with standard deviation. Samples with the same lowercase letter are not significantly different from each other (see appendix 5)

While stickiness and sliminess are detrimental qualities in a pizza cheese, the starch-in-oil samples with the properties show a higher acceptance over the cashew-based mozzarella sample which had no such qualities, most likely due to consumers placing a greater importance on meltability in pizza cheese (see 4.2.1).

Another likelihood is that the flavours of the samples, while not easily measured or defined in the sensory tests, played a significant role for the acceptance-rate of the samples. All samples of PBCA were assessed as having a strong flavour more often than LMMC, which deviates from the typical pizza cheese and is a negative aspect if the taste is unpalatable. Additionally, Sample C (starch) showed greater or equal meltability, firmness, browning, and similar overall melting-behaviour as a dairy-based LMMC but was rated with a significantly lower acceptance, indicating that the less used factors. Good taste was reported as the most important reason for consumers to repeat a purchase of plant-based cheese products.

One of the most important rheological properties of LMMC as a melting cheese is the post-melt chewing resistance (Metzger and Barbano 1999). All the samples of starch-based PBCA had a significantly lower association with firmness than the sample of LMMC in one or more of the sensory tests.

4.5.3 Quality control

The mean grading of the sensory properties along with Tukey comparison can be seen in Table 14. The reference-sample of LMMC 1 (dairy) was considered significantly more browned, crusty, elastic, and dairy-like than the samples of PBCA. Sample C had a significantly stronger white colour than every other sample than A (cashew). Sample B had a significantly stronger yellow colour than all Samples except the reference-sample of LMMC 1 (dairy). Sample A (cashew) was perceived as least melted, least glossy, and having the lowest degree of syneresis. Sample B, C, D and E (starch) were considered stickier than the reference Sample 1 (dairy) and Sample A (cashew). Sample C (starch) was considered significantly more acidic than the reference-sample. Graininess, sweetness, or saltiness were similar across the samples, according to the assessors.

Table 14. Quality control results, presented as the average grading on a scale of 1-9 for samples A (cashew), B, C, D, E (starch) and 1 (dairy). Tukey's pairwise comparison Samples with the same lowercase letter are not significantly different from each other (see appendix 5)

Sensory property	**A (cashew)**	**B (starch)**	**C (starch)**	**D (starch)**	**E (starch)**	**1 (dairy) (ref)**
Whiteness	6.4 cd	1,8 a	8.0 d	4.5 bc	5.2 bc	3.0 ab
Yellowness	3.1 b	8.6 d	1,5 a	6.6 c	3.95 b	6.0 c
Browning	2,0 ab	2.65 ab	1,6 a	3.25 c	2.9 bc	5.0 d
Meltability	1,5 a	5,0 b	7.5 c	6,0 b	5.2 b	7.0 c
Glossiness/ shininess	2,7 a	5,0 b	7.05 d	5.75 bcd	5.2 bc	7.0 cd
Crustiness	2,9 a	3,9 a	3.0 a	3,1 a	3,0 a	7.0 b
Stickiness	2,4 a	6.4 b	6.2 b	6.2 b	6.55 b	3,0 a
Firmness	5,0 ab	3,5 a	3,4 a	3,5 a	4,0 a	6.0 b
Syneresis	2,7 a	6.35 b	5.3 b	5.9 b	5.2 b	5.0 b
Elasticity	5,4 ab	4,2 a	4,3 a	3,5 a	4,7 ab	7.0 b
Graininess	4.4 a	4.5 a	3,0 a	3.0 a	2,35 a	3,0 a
Acidity	3,85 ab	4.9 ab	5.2 b	4.6 ab	4.5 ab	3,0 a
Sweetness	3,9 a	4,3 a	3,2 a	3,6 a	4,2 a	5.0 a
Saltiness	4,5 a	4,5 a	4,5 a	5,05 a	4,3 a	5,0 a
Dairy-likeness	2,8 a	3,95 a	3,9 a	4,4 a	4,1 a	7.0 b

According to the declared nutritional information of each product (Table 6), Sample E (starch) has over twice the amount of salt per weight as Samples D (starch) and A (cashew), which suggests that the melting of PBCA changed the flavour in the same manner described by Henneberry, O'Sullivan et al. (2016). It is also possible that the assessors were not trained enough to assess the individual flavours such as saltiness or sweetness. The assessors did, however, grade LMMC Sample 1 (dairy) as significantly more dairy-like, which could have been interpreted as both texture and taste. That the samples were not considered significantly different from the reference sample could imply that they were not considered grainy in general, given that the predetermined grade of the reference was an overestimation.

The colour of the samples has the greatest variation of means in the profiling test. Sample A (cashew) and C (starch) were graded with a significantly whiter colour than Sample B (starch), which had a significantly more yellow colour. These samples were significantly stronger in their respective primary colour than LMMC, placing them past the extreme ends of a typical mozzarella colour. Having a stronger yellow colour can be considered a negative effect on the product. Consumers generally associate more intense colour with more varied or intense flavour (Drake and Delahunty 2017) while Mozzarella is often characterized as a cheese with quite mild flavour, to not distract from the flavour of pizza-toppings (McMahon and Oberg 2017).

The assessors observed much less browning on PBCA-samples than the LMMC during profiling (Table 14), while there was no significant difference in the numbers of assessors who described samples as browned in the CATA-test. The samples LMMC would display a strong browning-reaction in the colour analysis (**Feil! Fant ikke referansekilden.**) when melted in the same temperature and time as the samples presented for the CATA-test. The different browning-intensities between the colour analysis and sensory tests can be explained by the presence of sauce and dough on the CATA-samples. Cheese which is placed on metal heats more efficiently than on moisture, since metal is efficient at conducting heat while water has a higher heat-capacity (Phillips 1971, Sirk, Moore and Brown 2013).

Conclusion

The primary goal of this thesis was to make a comprehensive investigation of the differences between dairy mozzarella cheese and plant-based alternatives under pizza-baking conditions.

For this purpose, a selection of five plant-based cheese alternatives (or PBCA) were compared to mozzarella pizza-cheese, or low-moisture mozzarella cheese (LMMC) in terms of their nutritional and chemical composition. The PBCA products consisted of one product of cashew milk, and four ultra processed products from starch from potato and tapioca and coconut oil. The PBCAs had the generally the same concentration of saturated fats as conventional cheese, with had little to no protein with lower quality than cheese protein.

The study also investigated the colour-change and rheological properties of the cheeses and alternatives when heated in pizza-baking conditions. The thesis covers their degree of browning, overall meltability, firmness, and stickiness. PBCAs showed no browning like that of LMMC. Starch-based PBCAs showed lower meltability, firmness and greater stickiness than LMMC; while PBCA based on cashew nuts showed no meltability or stickiness, and greater firmness than LMMC.

In a series of sensory tests involving Napping with Ultra Flash Profiling, Check-all-that-apply consumer tests, acceptance tests and quality profiling, the cheese and cheese alternatives were assessed for their rheological sensory properties. LMMC was considered with a greater acceptance than the selected products of PBCA, due to a number of sensory defects which some or all PBCA portrayed, foremost of which were stickiness, which is a natural quality in all starch gels, and an amalgamation of various sensory qualities such as viscosity, softness, and stickiness portrayed a sensation of sliminess.

Further research is advised for deepening the understanding which sensory qualities may inhibit the performance of PBCA, particularly those of taste and aroma, which is the most important quality consumers want from a product to buy again.

From the information that the experiments in this thesis provide it can be decided that non-vegan consumers will prefer dairy-based LMMC rather than PBCAs. PBCAs that try to imitate dairy LMMC as closely as possible will have a better chance at the market. Ultra-processed PBCAs produced via material fractionation are more likely to resemble LMMC's rheological qualities.

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Appendix 1

Tukeys Post-Hoc test for Lipid content from Bligh&Dyer

Fat content

	SampleName	N	Subset for alpha = 0.05			
			1	2	3	4
Tukey HSD[a]	BStarch	6	10,6851			
	ACashew	6		15,0522		
	Dairy1	6			19,2562	
	EStarch	6			19,8195	
	DStarch	6				22,4423
	CStarch	6				22,8781
	Sig.		1,000	1,000	,779	,911

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 6,000.

Moisture

	SampleName	N	Subset for alpha = 0.05					
			1	2	3	4	5	6
Tukey HSD[a,b]	Dairy2	2	43,8100					
	Dairy1	3		44,9467				
	CStarch	3			49,8433			
	DStarch	3			50,3767			
	EStarch	3				52,6800		
	BStarch	3					57,4100	
	ACashew	3						67,4733
	Sig.		1,000	1,000	,444	1,000	1,000	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,800.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

Tukey's Post-Hoc test for amino acid profile

EssentAA

	AAProd	N	Subset for alpha = 0.05 1	2	3
Tukey B[a,b]	Dairy2	3	53,2553		
	Dairy1	3	54,8321		
	C	2		62,5181	
	A	2			68,6695

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,400.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

NonEssentAA

	AAProd	N	Subset for alpha = 0.05 1	2	3
Tukey B[a,b]	A	2	31,3305		
	C	2		37,4819	
	Dairy1	3			45,1679
	Dairy2	3			46,7447

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 2,400.

b. The group sizes are unequal. The harmonic mean of the group sizes is used. Type I error levels are not guaranteed.

His

	Product	N	Subset for alpha = 0.05 1	2	3
Tukey B[a]	C	3	1,1467		
	A	3		2,1500	
	Dairy1	3			2,5633
	Dairy2	3			2,6800

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Ile

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey B[a]	C	3	2,0067	
	A	3	2,0533	2,0533
	Dairy1	3	2,4300	2,4300
	Dairy2	3		2,6933

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Lys

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey B[a]	A	3	5,1233	
	Dairy1	3		8,6533
	Dairy2	3		8,8733
	C	3		9,0067

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Phe

			Subset for alpha = 0.05		
	Product	N	1	2	3
Tukey B[a]	A	3	4,4300		
	C	3	4,7933	4,7933	
	Dairy1	3		5,3700	5,3700
	Dairy2	3			5,6400

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Thr

			Subset for alpha = 0.05		
	Product	N	1	2	3
Tukey B[a]	C	3	2,9800		
	A	3		3,3567	
	Dairy1	3			3,8367
	Dairy2	3			3,9000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Tyr

Product	N	Subset for alpha = 0.05

			1	2	3
Tukey B[a]	A	3	1,9700		
	C	3		3,9967	
	Dairy2	3			5,5167
	Dairy1	3			5,6667

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Val

	Product	N	Subset for alpha = 0.05		
			1	2	3
Tukey B[a]	A	3	2,9633		
	Dairy1	3		3,6167	
	Dairy2	3		3,8800	
	C	3			4,5167

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Ala

	Product	N	Subset for alpha = 0.05		
			1	2	3
Tukey B[a]	C	3	,2600		
	Dairy2	3		4,0067	
	Dairy1	3		4,1000	
	A	3			6,0000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Asn

	Product	N	Subset for alpha = 0.05	
			1	2
Tukey B[a]	Dairy2	3	,0133	
	Dairy1	3	,0167	
	A	3	,0433	
	C	3		,2600

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Asp

	Product	N	Subset for alpha = 0.05

			1	2	3
Tukey B[a]	Dairy2	3	10,2833		
	Dairy1	3	11,0700		
	A	3		13,3167	
	C	3			25,2733

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Gln

	Product	N	Subset for alpha = 0.05 1
Tukey B[a]	A	3	,0400
	C	3	,0467
	Dairy1	3	,0733
	Dairy2	3	,0800

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Glu

			Subset for alpha = 0.05		
	Product	N	1	2	3
Tukey B[a]	C	3	8,7000		
	A	3		24,7100	
	Dairy2	3		26,0267	26,0267
	Dairy1	3			26,6367

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

GlyArg

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey B[a]	Dairy2	3	6,5767	
	Dairy1	3	6,7267	
	C	3		17,0367
	A	3		17,1800

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Ser

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey B[a]	Dairy1	3	6,2033	
	Dairy2	3	6,2700	6,2700
	C	3	6,3867	6,3867
	A	3		6,6667

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Appendix 3

Schreiber’s Melting test of meltability

A

Tukey HSD[a]

TimesRe	N	Subset for alpha = 0.05 1
12,5min	3	3,5333
10min	3	3,5667
Beforemelting	3	3,6000
5min	3	3,6667
7,5min	3	3,6667
Sig.		,332

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

B

Tukey HSD[a]

		Subset for alpha = 0.05	
TimesRe	N	1	2
Beforemelting	3	3,5333	
7,5min	3		3,9667
10min	3		4,0333
12,5min	3		4,0333
5min	3		4,1667
Sig.		1,000	,158

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

C

Tukey HSD[a]

		Subset for alpha = 0.05		
TimesRe	N	1	2	3
Beforemelting	3	3,5333		
5min	3		4,7000	
12,5min	3			5,1000
10min	3			5,1333
7,5min	3			5,2333
Sig.		1,000	1,000	,148

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Appendix 3

D

Tukey HSD[a]

		Subset for alpha = 0.05	
TimesRe	N	1	2
Beforemelting	3	3,5333	
10min	3		4,5667
12,5min	3		4,6000
7,5min	3		4,6333
5min	3		4,7000
Sig.		1,000	,288

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

E

Tukey HSD[a]

		Subset for alpha = 0.05	
TimesRe	N	1	2
Beforemelting	3	3,5667	
10min	3		4,1000
7,5min	3		4,1333
12,5min	3		4,1333
5min	3		4,2333
Sig.		1,000	,195

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Dair1

Tukey HSD[a]

		Subset for alpha = 0.05		
TimesRe	N	1	2	3
Beforemelting	3	3,5667		
10min	3		5,6667	
12,5min	3		5,7000	5,7000
7,5min	3		5,7667	5,7667
5min	3			5,8333
Sig.		1,000	,200	,061

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Dair2

Tukey HSD[a]

		Subset for alpha = 0.05	
TimesRe	N	1	2
Beforemelting	3	3,6000	
10min	3		5,5000
12,5min	3		5,5000
5min	3		5,5667
7,5min	3		5,5667
Sig.		1,000	,242

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 3,000.

Appendix 4

McNemar Test for CATA-results

White					**Glossy**			
	A	B	C	D		A	B	C
PBCA-A	41				PBCA-C	22		
PBCA-C	41				LMMC-1	21		
PBCA-E		27			PBCA-E	20		
LMMC-1			13		PBCA-D	15	15	
PBCA-D			8		PBCA-A		7	7
PBCA-B				1	PBCA-B			2
Yellow					**Crusty**			
	A	B	C	D		A	B	
PBCA-B	51				PBCA-B	33		
PBCA-D		30			LMMC-1	27		
LMMC-1		27			PBCA-A		8	
PBCA-E			13		PBCA-E		5	
PBCA-C			6	6	PBCA-C		4	
PBCA-A				2	PBCA-D		2	
Brown					**Sticky**			
	A					A	B	
LMMC-1	3				PBCA-C	38		
PBCA-B	1				PBCA-D	36		
PBCA-D	1				PBCA-E	32		
PBCA-E	1				PBCA-A		11	
PBCA-A	0				LMMC-1		6	
PBCA-C	0				PBCA-B		5	
Slimy					**Firm**			
	A	B	C			A	B	C
PBCA-D	40				PBCA-B	35		
PBCA-C		27			LMMC-1	28	28	
PBCA-E		24			PBCA-A		17	
PBCA-A		20			PBCA-E			7
PBCA-B			6		PBCA-D			4
LMMC-1			4		PBCA-C			1
Slippery					**Soft**			
	A	B				A	B	C
PBCA-D	17				PBCA-E	36		
PBCA-C	13				PBCA-D	34	34	
PBCA-E	12				PBCA-C	31	31	
PBCA-A	9	9			LMMC-1		24	
LMMC-1		4			PBCA-A		22	
PBCA-B		3			PBCA-B			9

Appendix 4

High Viscosity					**Fatty**			
	A	B	C			A	B	
PBCA-D	16				PBCA-D	27		
PBCA-E	16				PBCA-A	22		
PBCA-A	12	12			PBCA-C	22		
PBCA-C	10	10			LMMC-1	19		
LMMC-1		6	6		PBCA-E	16		
PBCA-B			2		PBCA-B		3	
Elastic					**Salty**			
	A	B				A		
PBCA-A	14				PBCA-E	17		
PBCA-D	13				PBCA-A	16		
PBCA-E	12				PBCA-B	16		
PBCA-C	10				PBCA-C	13		
LMMC-1	9				PBCA-D	13		
PBCA-B		2			LMMC-1	13		
Rubbery					**Sweet**			
	A	B				A		
PBCA-A	36				PBCA-E	14		
PBCA-D		18			PBCA-C	13		
PBCA-C		16			LMMC-1	11		
PBCA-E		16			PBCA-B	10		
PBCA-B		12			PBCA-D	9		
LMMC-1		12			PBCA-A	6		
Acidic					**Strong taste**			
	A					A	B	
PBCA-C	10				PBCA-D	23		
PBCA-D	10				PBCA-B	16		
PBCA-A	9				PBCA-E	16		
PBCA-B	9				PBCA-A	15		
PBCA-E	6				PBCA-C	13		
LMMC-1	2				LMMC-1		4	
Strong aroma					**Dairy-like**			
	A					A	B	C
PBCA-D	18				LMMC-1	33		
PBCA-E	18				PBCA-E		15	
PBCA-B	14				PBCA-C		13	13
PBCA-C	14				PBCA-D		11	11
PBCA-A	9				PBCA-B		9	9
LMMC-1	7				PBCA-A			5

Appendix 5

Whiteness

	Product	N	Subset for alpha = 0.05 1	2	3	4
Tukey HSD[a]	B	8	1,8000			
	Dairy1 ref	8	3,0000	3,0000		
	D	8		4,5375	4,5375	
	E	8		5,1875	5,1875	
	A	8			6,3750	6,3750
	C	8				8,0250
	Sig.		,626	,069	,181	,282

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Yellowness

	Product	N	Subset for alpha = 0.05 1	2	3	4
Tukey HSD[a]	C	8	1,4750			
	A	8		3,0625		
	E	8		3,9500		
	Dairy1 ref	8			6,0000	
	D	8			6,5875	
	B	8				8,5875
	Sig.		1,000	,447	,823	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Browning

	Product	N	Subset for alpha = 0.05 1	2	3	4
Tukey HSD[a]	C	8	1,5625			
	A	8	2,0000	2,0000		
	B	8	2,6500	2,6500	2,6500	
	E	8		2,9000	2,9000	
	D	8			3,2500	
	Dairy1 ref	8				5,0000
	Sig.		,051	,159	,577	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Appendix 5

Meltability

			Subset for alpha = 0.05		
	Product	N	1	2	3
Tukey HSD[a]	A	8	1,5250		
	B	8		4,9750	
	E	8		5,2125	
	D	8		5,9625	5,9625
	Dairy1 ref	8			7,0000
	C	8			7,4875
	Sig.		1,000	,462	,074

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Glossiness

			Subset for alpha = 0.05			
	Product	N	1	2	3	4
Tukey HSD[a]	A	8	2,7375			
	B	8		4,9625		
	E	8		5,2375	5,2375	
	D	8		5,7500	5,7500	5,7500
	Dairy1 ref	8			7,0000	7,0000
	C	8				7,0500
	Sig.		1,000	,772	,053	,268

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Crustiness

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey HSD[a]	A	8	2,8875	
	C	8	2,9750	
	E	8	3,0000	
	D	8	3,1250	
	B	8	3,9375	
	Dairy1 ref	8		7,0000
	Sig.		,562	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Stickiness

	Product	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	A	8	2,3625	
	Dairy1 ref	8	3,0000	
	D	8		6,1625
	C	8		6,2000
	B	8		6,3875
	E	8		6,5500
	Sig.		,949	,994

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Firmness

	Product	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	C	8	3,4250	
	B	8	3,5000	
	D	8	3,5250	
	E	8	4,0375	
	A	8	5,0500	5,0500
	Dairy1 ref	8		6,0000
	Sig.		,113	,644

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Syneresis

	Product	N	Subset for alpha = 0.05	
			1	2
Tukey HSD[a]	A	8	2,7250	
	Dairy1 ref	8		5,0000
	E	8		5,1875
	C	8		5,2750
	D	8		5,8875
	B	8		6,3500
	Sig.		1,000	,297

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Appendix 5

Elasticity

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey HSD[a]	D	8	3,4750	
	B	8	4,2250	
	C	8	4,3000	
	E	8	4,7125	4,7125
	A	8	5,3625	5,3625
	Dairy1 ref	8		7,0000
	Sig.		,244	,095

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Graininess

			Subset for alpha = 0.05
	Product	N	1
Tukey HSD[a]	E	8	2,3500
	D	8	2,9750
	Dairy1 ref	8	3,0000
	C	8	3,0250
	A	8	4,4000
	B	8	4,4750
	Sig.		,097

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Acidity

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey HSD[a]	Dairy1 ref	8	3,0000	
	A	8	3,8500	3,8500
	E	8	4,5375	4,5375
	D	8	4,5750	4,5750
	B	8		4,8625
	C	8		5,2000
	Sig.		,087	,196

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Appendix 5

Sweetness

			Subset for alpha = 0.05
	Product	N	1
Tukey HSD[a]	C	8	3,1625
	D	8	3,6125
	A	8	3,8875
	E	8	4,1875
	B	8	4,3000
	Dairy1 ref	8	5,0000
	Sig.		,060

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Saltiness

			Subset for alpha = 0.05
	Product	N	1
Tukey HSD[a]	E	8	4,2625
	C	8	4,4625
	A	8	4,5125
	B	8	4,5125
	Dairy1 ref	8	5,0000
	D	8	5,0500
	Sig.		,837

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

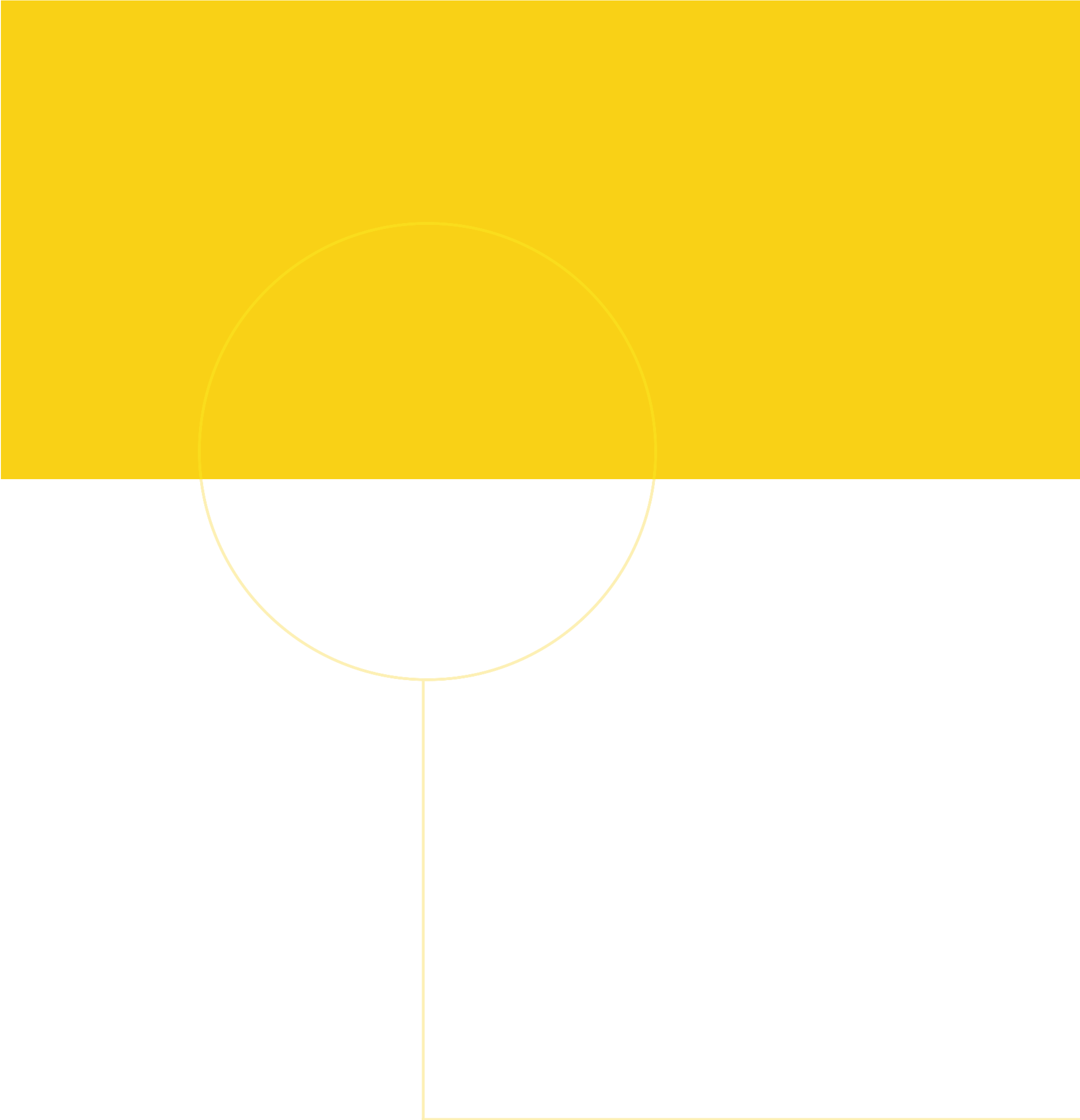
Dairylikeness

			Subset for alpha = 0.05	
	Product	N	1	2
Tukey HSD[a]	A	8	2,8375	
	C	8	3,8875	
	B	8	3,9500	
	E	8	4,1125	
	D	8	4,4000	
	Dairy1 ref	8		7,0000
	Sig.		,144	1,000

Means for groups in homogeneous subsets are displayed.

a. Uses Harmonic Mean Sample Size = 8,000.

Appendix 6



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