

Processed Dairy Products with the Addition of a Fruit Component

Bsc. Akhilesh Kumar

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- [3] Bachmann, H.-P. Cheese analogues: a review. *International Dairy Journal*, 2001, 11, 4-7, 505-515.
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L.S.

prof. Ing. Roman Čermák, Ph.D.
Dean

Ing. Robert Gál, Ph.D.
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ABSTRAKT

Tavené mléčné výrobky jsou ceněny pro svou krémovou texturu, jemnou chuť a všestrannost v různých aplikacích. Vylepšení jejich organoleptických a funkčních vlastností přírodními ingrediencemi, jako je ovoce, může dále zvýšit jejich atraktivitu pro spotřebitele. Tato práce si kladla za cíl posoudit přidání mangového pyré (0–20 % hm.) do tavených mléčných výrobků se dvěma obsahy sušiny (40 a 45 % hm.) za účelem zlepšení jejich organoleptických, texturních a reologických vlastností. Bylo vyrobeno a analyzováno deset vzorků receptur z hlediska sušiny, pH, aktivity vody, instrumentální analýzy barvy (L^* , a^* , b^*), texturních parametrů (tvrdost, lepivost, roztíratelnost), viskoelastických vlastností a organoleptických vlastností. Přidání mangového pyré významně snížilo tvrdost, elastický, viskózní a komplexní modul pružnosti a komplexní viskozitu, zejména u vzorků s obsahem sušiny 40 % hm. Instrumentální analýza barvy ukázala posun chromatičnosti do oblasti červené a žluté a snížení světelnosti se zvyšujícím se obsahem mangové složky. Z výsledků senzorického hodnocení lze vyvodit, že výrobky s 15–20 % hm. mangového pyré (bez ohledu na obsah sušiny) dosáhly nejlepší rovnováhy mezi chutí, texturou a vzhledem a byly hodnotiteli nejvíce preferovány. Tato zjištění ukazují na vhodnost použití mangového pyré v tavených mléčných výrobcích. Lze doporučit další výzkum v této oblasti, zaměřený např. na použití alternativních druhů ovoce, rostlinných receptur a rozsáhlých spotřebitelských testů.

Klíčová slova: tavené mléčné výrobky, mangové pyré, senzorické hodnocení, texturní profil, reologie, viskoelastické vlastnosti, barva

ABSTRACT

Processed dairy products are valued for their creamy texture, mild flavor, and versatility across various applications. Enhancing their sensory and functional properties with natural ingredients like fruits can further increase their consumer appeal. This thesis aimed to assess the incorporation of mango puree (0–20% w/w) into processed dairy products with two dry matter levels (40% w/w and 45% w/w) to improve their sensory, textural, and rheological qualities. Ten sample formulations were developed and analyzed for dry matter, pH, water activity, color attributes (L^* , a^* , b^*), texture characteristics (hardness, stickiness, spreadability), rheological properties, and sensory attributes. Mango puree addition significantly reduced hardness, storage, loss and complex moduli and complex viscosity, particularly at 40% w/w dry matter. Color analysis showed enhanced redness and yellowness and reduced lightness with increasing mango content. Sensory evaluation indicated that products with 15%–20% w/w mango puree regardless dry matter content achieved the best balance between flavor, texture, and appearance and were the most preferable. These findings support the use of mango puree as a natural enhancer in processed dairy products. Further research is recommended on alternative fruits, plant-based formulations, and large-scale consumer testing.

Keywords: processed dairy products, mango puree, sensory evaluation, texture profile, rheology, viscoelastic properties, color

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INTRODUCTION

Processed cheese (PC) has become a popular staple in diets worldwide due to its versatility, taste, texture, and nutritional value. Recently, there's been a growing interest in making these dairy products even more appealing by adding fruit components. This not only brings a burst of flavor and color but also enhances the health benefits of dairy products by incorporating vitamins, antioxidants, and fiber from fruits. As more people seek healthier and tastier options, this combination of creamy dairy and sweet or tart fruit has captured the attention of both consumers and the food industry. The idea of enjoying the familiar comfort of dairy with a fresh, fruity twist makes these products a perfect choice for people looking for something both delicious and nutritious (Salehi, 2021).

However, adding fruit to dairy products isn't as simple as mixing the two ingredients together. Fruits come with their own unique properties like acidity, moisture, and flavor, which can all influence the final product's taste, texture, and shelf life. For example, some fruits are quite acidic and can affect the dairy's proteins, leading to changes in consistency that might not always be desirable. To create a smooth and stable product, food scientists use various processing techniques and additives like emulsifiers and stabilizers to maintain the right texture and prevent separation. This careful balancing act is essential to ensure that the final product is not only tasty and appealing but also has the right texture and lasts as long as possible on the shelf. The challenge is to enhance the dairy with fruit without compromising the flavor, consistency, or quality of the product (Adil et al., 2019).

This thesis explores how fruits can be successfully added to processed dairy products while keeping quality and consumer appeal in mind. It dives into how different fruits, processing techniques, and ways of incorporating them into dairy affect the product's texture, flavor, and overall appeal. By examining factors like pH balance, consistency, and sensory characteristics (such as taste and aroma), this study aims to provide insights into creating fruit-infused dairy products that are both delicious and nutritious. The goal is to help develop dairy products that not only meet the growing demand for healthy, flavorful foods but also stand out in the market for their innovative qualities. Ultimately, this research aims to bridge the gap between scientific understanding and consumer enjoyment, making it easier for food scientists to craft dairy products that are satisfying, healthy, and aligned with modern dietary trends.

I THEORETICAL PART

1 DEFINITIONS AND CHARACTERISTICS OF PROCESSED CHEESE

PC is a type of cheese product made by blending a combination of natural cheeses with additional dairy and non-dairy ingredients. Unlike natural cheese, which is made directly from milk, PC uses cheeses like Cheddar, Mozzarella, white brined cheeses, Dutch-type cheeses or Swiss-type cheeses as the main base. These are melted down and combined with stabilizers, emulsifiers, and sometimes flavorings or vegetable proteins to achieve a smooth, consistent texture and longer shelf life. The ingredients used vary by region, with Cheddar and Mozzarella being popular in places like the USA and Canada, while white brined cheeses are common in Mediterranean and Middle Eastern countries. Dutch-type cheeses like Edam cheese together with Gouda cheese are traditionally the two predominant Dutch-type cheeses, Edam cheese is characterized by a semi-hard to hard consistency, and a smooth texture having small eyes (about the size of a pea – diameter between 2 and 10 mm) with a flavor intensity that ranges greatly, which are mainly produced in the Netherlands. Swiss-type cheeses are hard or semi-hard brine-salted cheeses, of nutty flavor, containing characteristic eyes, resulting from the metabolism of various substances (Bakry and Mehta, 2022).

1.1 Definitions

Different countries and continents have their own parameters for PC. Below are the definitions of PC according to various standards worldwide (Bakry and Mehta, 2022).

1.1.1 Codex Alimentarius

According to the Codex Alimentarius, PC is a dairy product obtained by mixing, melting, and emulsifying natural cheese with permitted dairy ingredients, using heat and emulsifying salts (ES) to produce a homogeneous, smooth, and stable oil-in-water emulsion. The process involves controlled heating to achieve a uniform texture and extended shelf life. The proposed classification categorizes PC based on its cheese content: at least 75% cheese (on a dry matter (DM) basis) for full cheese-based products, at least 51% cheese for standard PC, and spreadable PC, where cheese remains the largest dairy ingredient with regulated fat content (FC) (Codex Standard 283-1978).

1.1.2 European Union

PC and PC preparations are made by grinding, mixing, melting, and emulsifying one or more varieties of cheese, with or without the addition of other milk products (such as cream, milk powder, or whey) and/or other foodstuffs (such as flavoring agents, stabilizers, and preservatives). This process is carried out with the aid of heat to ensure uniform texture and consistency and may include the use of processing/ESs (such as sodium citrate or phosphates) and/or emulsifying agents to improve smoothness, enhance shelf stability, and prevent separation of fat and moisture. The final product has a consistent texture, extended shelf life, and improved melting properties, making it suitable for a wide range of culinary applications, including sandwiches, sauces, and processed food products (ASSIFONTE, 2018).

1.1.3 Czech Republic

In the Czech Republic, the regulations around PC are outlined in a decree that covers milk products, ice creams, and edible fats and oils nr. 397/2016. PC is defined as cheese that has been thermally treated by melting. If the product has more than 5% lactose, and simultaneously more than 50% of DM comes from cheese, it's labeled as a "PC product." Furthermore, product with more than 5% of lactose (and less than 50 % of DM coming from cheese) is labelled as "processed milk product." As opposed to PC, PC/milk products can contain sugars (Czech Republic, 2016).

1.2 Characteristics

PC exhibits a range of key characteristics that define its quality and functionality. These include a stable texture, consistent melting properties, uniform composition, and structural stability. These attributes contribute to its widespread application in various culinary and industrial settings, ensuring reliability in processing and consumption (Marcus, 2014).

1.2.1 Stable texture and emulsion

PC is created as a stable mixture where fats are evenly dispersed in water, thanks to ESs. These salts bind the water and fat together to form a consistent, creamy texture. This is why PC melts smoothly without separating into oil and clumps, making it perfect for cooking and melting (Marcus, 2014).

1.2.2 Ingredient flexibility and customization

One of the key features of PC is its customizable nature. Manufacturers blend different ingredients like natural cheeses, casein (milk proteins), depending on the type and flavor of cheese they want. Starches and other carbohydrates may be added to improve texture or provide a specific mouthfeel. This flexibility lets producers create all sorts of PCs from creamy spreads to firm slices for sandwiches and also allows them to adjust flavor, melting characteristics, and nutritional content to fit consumer preferences (Komorowski, 2011).

1.2.3 Consistent melting and texture

PC is all about uniformity. Thanks to ESs, the cheese maintains a smooth texture and melts evenly, making it a favorite for food applications like sandwiches, burgers, sauces, and pizza. Unlike natural cheese, PC won't break down, separate, or become greasy when heated. This even melting and controlled stretchiness make it a popular ingredient for foodservice and home use, providing predictable results every time (Fox et al., 2017).

1.2.4 Longer Shelf Life and Stability

One of the biggest advantages of PC is its extended shelf life and stability. It's designed to last much longer than natural cheese and can often be stored without refrigeration. The lower moisture content, preservatives, and heat treatment during production reduce the risk of spoilage and microbial growth. In addition, the packaging of PC is airtight and vacuum-sealed, which further helps to keep it fresh for weeks or even months (Bubelová et al., 2014).

1.2.5 Healthier options and functional ingredients

With growing consumer interest in healthier options, PC is evolving. Lower-fat and low-sodium versions are being developed to meet dietary needs without compromising on taste and texture. Fat can be replaced with water, starches, or proteins to keep the creamy mouthfeel while reducing calories. Sodium levels can be lowered by using potassium-based salts as alternatives. PC can also be enhanced with functional ingredients like prebiotics, probiotics, or added vitamins and minerals to create more nutritious products. This ensures that it caters to those seeking health benefits, making it a versatile option for different dietary needs (Bakry and Mehta, 2022).

1.2.6 Quality control and microstructure

Quality control in PC production is essential due to the complex interactions between natural cheese composition, ESs, and processing conditions. The final textural and functional properties depend on factors like protein solubilization, salt equilibria, and water mobility, which influence the homogeneity and stability of the cheese matrix. Given the variability in cheese aging and physicochemical properties, operator experience currently plays a major role in maintaining consistent quality, highlighting the need for a deeper scientific understanding of these mechanisms. The microstructure of PC is largely governed by the formation and stability of the para-casein matrix, influenced by casein concentration, ionic composition, temperature, pH, and water availability. These factors determine the structural integrity, protein interactions, and rheological behavior of the final product. A better understanding of mineral balance, emulsification dynamics, and protein behavior will help optimize cheese formulation, enhance texture, and ensure batch-to-batch consistency in quality (Deshwal and Huppertz, 2021).

2 SPECIFICATION OF RAW MATERIALS USED IN PRODUCTION OF PROCESSED CHESSE

Main ingredients in the production of PC include natural cheeses, milk fat, dairy powders, ESs, other additives and water (Kapoor and Metzger et al., 2008).

2.1 Natural cheese

The quality requirements for PC are stringent, as high-quality natural cheeses are essential for producing a superior final product. These cheeses should be of a standard suitable for direct consumption. Cheeses with minor physical defects, such as irregular shapes or offcuts, may be used, provided they are free from off-flavors and microbial contamination. However, cheeses with mold or discoloration are unsuitable due to potential health risks. The age and maturity of the natural cheese used for processing should ideally be moderately ripe, containing 20–30 mg of soluble nitrogen per 100 g. The selection criteria for natural cheese significantly influence the functional and sensory properties of PC. Key factors such as age, pH, flavor, calcium content, and the amount of intact casein play a crucial role in determining the final product's consistency and quality (Kapoor and Metzger et al., 2008).

2.2 Milk fat

The FC in PC is standardized using butter and cream, which are the most commonly used ingredients. These fats must be of high quality and free from any flavor defects to ensure the desired taste and texture of the final product. The regulations governing the use of butter and cream in PC vary by country and are defined by specific food standards applicable to each region (Mashta, 2022).

2.3 Dairy powders

Different types of powders like whole milk, skimmed milk, buttermilk, whey, whey concentrates, whey isolates, casein, and caseinates are used in various formulations. Quality assurance of these powders is assessed based on suppliers' certificates, sensory evaluations, and microbiological analyses, focusing on spore content and sulfite-reducing bacteria (Mashta, 2022).

2.4 Emulsifying Salts

Function and quality of these salts play a crucial role in creating a stable PC without undesirable features. The pH level of these salts is particularly important; a pH greater than 6.0 may affect flavor negatively and reduce shelf-life due to bacterial growth. pH of these salts is typically tested in a 10 g per 100 g solution to ensure they meet the required standards (Zheng et al., 2021).

2.5 Natural flavoring ingredients

Natural flavoring ingredients play a crucial role in enhancing the sensory appeal of PC, as the heating process during production can diminish its natural flavors. To compensate for this, various natural flavoring agents such as enzyme-modified cheeses, starter distillates, and wood smoke extracts are commonly used. Additionally, a diverse range of herbs, spices, and other natural ingredients are incorporated to create unique flavor profiles. Commonly used additions include herbs like basil and oregano, smoked ingredients, and spices, along with vegetables such as tomatoes, paprika, and onions. Savory elements like ham and mushrooms are also frequently included, while some varieties experiment with sweet and unique flavors, such as fruit or even chocolate, to cater to evolving consumer preferences. These natural ingredients not only enhance taste but also contribute to product differentiation, ensuring PC meets regional taste preferences and market demands (Moatsou, 2019).

2.6 Water/Steam

Quality requirements for water is that it must be potable and comply with local regulations on water quality intended for human consumption. Monthly laboratory tests by suppliers are required to ensure the absence of coliform bacteria, yeasts, and molds. Yearly tests by government bodies check for physicochemical properties and bacteriological safety. The separation of non-processing water should have a separate flow system, and pipelines should be distinctly marked to avoid contamination (Feng et al., 2021).

3 PRODUCTION OF PROCESSED CHEESE

The production of PC follows two main methods: batch processing and continuous processing (McSweeney and Fox, 2017).

3.1 Batch processing

In batch processing, ingredients like natural cheese, ESs, and water are blended and heated in a batch cooker, ensuring a smooth, homogenous consistency before cooling and packaging. This method is flexible and suited for smaller-scale production (McSweeney and Fox, 2017). Flow chart for PC manufacture (batch) is shown in Figure 1.

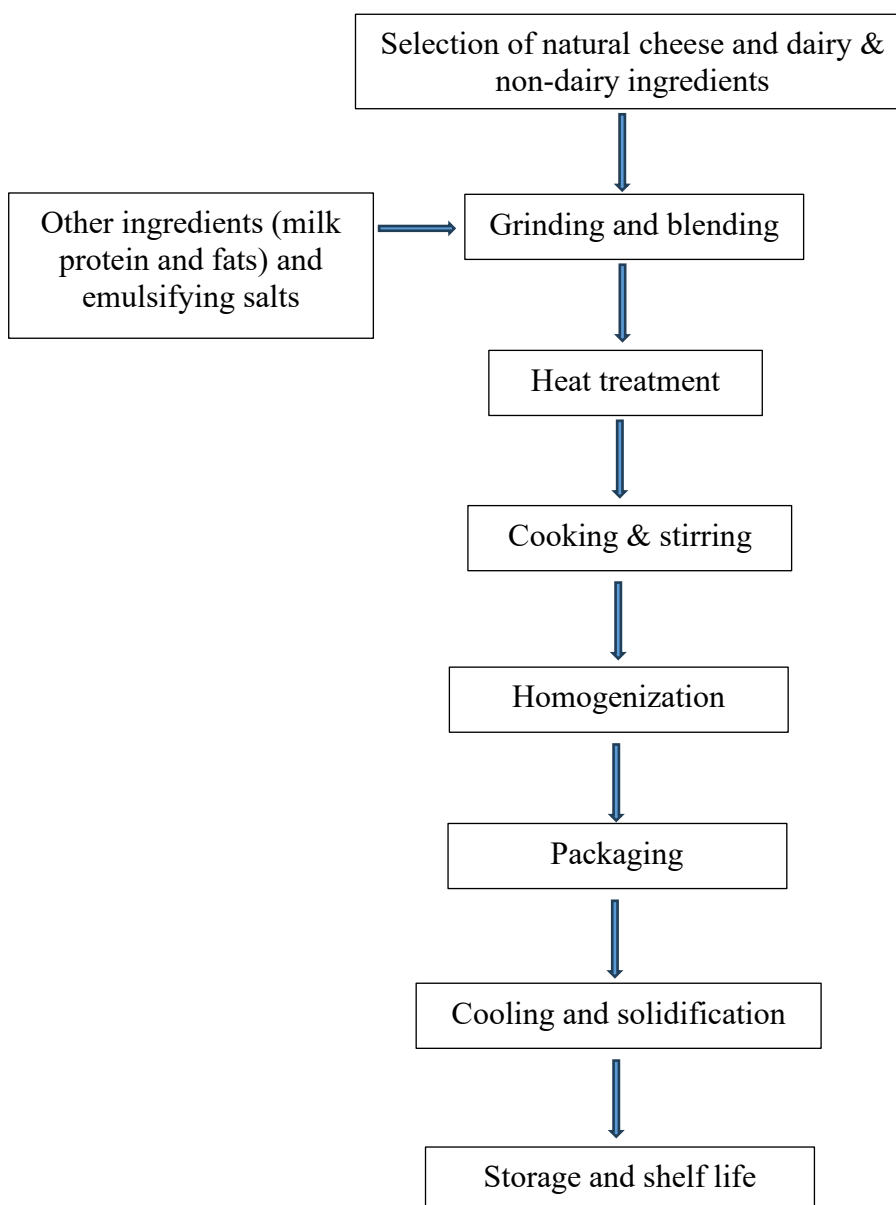


Figure 1. Process flow chart of Processed cheese production (Batch process) (McSweeney and Fox, 2017)

3.1.1 Selection of natural cheese and dairy & non-dairy ingredients

The foundation of PC lies in the careful selection and blending of natural cheeses. Common choices include Cheddar, Mozzarella, white-brined cheeses (WBC), Dutch-type varieties like Edam and Gouda, and Swiss-type cheeses such as Emmental. The age of the cheese plays a significant role—mature cheeses contribute bold, intense flavors, while younger cheeses offer superior meltability and a smoother, creamier texture. Often, a combination of both is used to strike a balance between flavor and functionality. In addition to natural cheese, dairy-based ingredients such as milk proteins (casein or caseinates) are incorporated to enhance the protein content and improve the structural integrity of the final product. Water is also a key component, used to adjust the moisture content, which directly affects texture—higher moisture levels yield softer, more spreadable cheese, whereas lower moisture creates a firmer consistency. This thoughtful formulation ensures that the PC meets both sensory expectations and functional performance (Kosseva and Webb, 2020).

3.1.2 Grinding and blending

Once the ingredients are selected, the natural cheeses are ground into small, uniform particles. This ensures that the cheese blends well with the other ingredients. Grinding is crucial for producing a homogeneous mixture, allowing for even distribution of fats, proteins, and water. This step is often performed using industrial-grade grinders that can handle large volumes of cheese efficiently. After grinding, the cheese is combined with ESs, water, milk proteins, and any other ingredients in large industrial mixers. This blending process is where the ingredients come together to form a cohesive mixture. The aim is to achieve a smooth, consistent mixture where all components are fully integrated. This mixture is continuously stirred to ensure uniform distribution of all the ingredients (Dixon, 2011). In Figure 2 there is the image of one shaft ribbon blender.



(A)



(B)

Figure 2. One shaft ribbon blender. (A) Whole equipment (B) Ribbon assembly (Dixon, 2011).

3.1.3 Other ingredients (milk protein and fats) and emulsifying salts

Milk proteins and fats are critical components in the formulation of PC. Rennet casein is commonly used for its excellent structural and functional properties, particularly its ability to form a firm yet meltable matrix. Other proteins such as acid casein, caseinates, milk protein concentrates, and skim milk powder may also be incorporated to adjust texture and nutritional profile. Fats, whether from dairy sources like cream, butter, or anhydrous milk fat, contribute to mouthfeel, softness, and melting behavior. The selection of fat sources affects not only sensory attributes but also product functionality and nutritional value. A key component in PC manufacture is the ES. These include sodium phosphates but also diphosphates, polyphosphates, pyrophosphates, and citrates, with both sodium and potassium salts commonly used. Their principal role is to modify the protein matrix during heating by replacing calcium ions in casein with sodium ions, which enables caseins to function effectively as emulsifiers. This exchange enhances hydration, promotes emulsification of fat, and stabilizes the emulsion, thereby preventing fat separation during heating or storage. ESs also help control the final product's pH, influencing its meltability, texture, and flavor. Without them, PC would likely exhibit phase separation and undesirable texture (McSweeney et al., 2017).

3.1.4 Heat treatment

The cheese mixture is then subjected to heat treatment, typically at temperatures ranging between 70°C and 90°C. The heating process serves multiple functions. It pasteurizes the mixture, ensuring that any harmful microorganisms are eliminated. This is essential for food safety and extends the product's shelf life (Clark, 2023).

3.1.5 Cooking & stirring

The heated mixture is continuously stirred during the cooking process. Stirring helps prevent the cheese from burning and ensures the heat is distributed evenly throughout the mixture. Cooking also allows the proteins to solubilize fully, leading to a smooth texture. Depending on the desired outcome, the speed and time during melting ranges from a few seconds to 20 minutes (in experimental or traditional batch production), with typical industry practice being around 4 to 15 minutes at 70–95°C in batch processes. Faster cooking results in a finer, creamier product, while slower cooking can create a firmer PC (Solak and Akin, 2019). In Figure 3 there are the visuals of batch cooker.



(A)



(B)



(C)



(D)

Figure 3. Batch cooker. (A) High shear blade, (B) scraper, (C) inner view of scraper and lama scraper, (D) batch cooker unit with PLC (Programmable Logic Controller) control (Kapoor and Metzger, 2008).

3.1.6 Homogenization

Homogenization is often used to improve the texture and consistency of PC. During homogenization, the cheese mixture is subjected to high pressure, which breaks down the fat globules into smaller particles. This step ensures that the fat is evenly distributed throughout the cheese, resulting in a creamier, smoother texture. Homogenization also improves the product's stability, preventing fat separation during storage or melting (Kapoor & Metzger, 2008).

3.1.7 Packaging

Once the cooking or homogenization is complete, the PC is ready for packaging. The hot cheese mixture is transferred to molds or containers while still molten. PC can be packaged in various formats, including individually wrapped slices, blocks, jars, or tubes. The type of packaging chosen depends on the intended use of the cheese—slices for sandwiches, blocks for grating, or jars for spreads. During packaging, care is taken to minimize exposure to air, which can lead to oxidation and spoilage. The packaging must also ensure that the cheese remains fresh throughout its shelf life. Many PCs are packaged in vacuum-sealed or airtight containers to maintain freshness and prevent moisture loss (Mohammadi and Fadaei, 2017).

3.1.8 Cooling and solidification

Once the cheese is packaged, it is allowed to cool and solidify. Cooling is a critical step because it determines the final texture of the cheese. Rapid cooling can lead to a softer texture, while slow cooling can create a firmer product. Cooling also helps the cheese stabilize, allowing the proteins and fats to form a cohesive structure. The cooling process is typically done in refrigerated environments to ensure that the cheese solidifies at the right rate. If the cooling process is not properly controlled, the cheese can develop textural defects such as being too crumbly or too rubbery. Therefore, manufacturers closely monitor the cooling process to ensure that the cheese achieves the desired texture and consistency (Felfoul and Attia, 2022).

3.1.9 Storage and shelf life

PC has the advantage of a longer shelf life compared to natural cheeses. This extended shelf life is due to the use of ESs, lower moisture content, and preservatives all dairy products that are only pasteurized (not sterilized) must be stored under refrigeration. Only those PCs produced using a continuous sterilization process and subsequently packed aseptically can

be stored at ambient temperatures. During storage, the flavour and texture of the cheese can continue to evolve. For example, some PCs may develop more complex flavors over time, while others are designed to retain their original flavour profile. Storage conditions, such as temperature and humidity, play a significant role in determining how the cheese's flavor and texture develop over time. Manufacturers aim to balance these factors to ensure a consistent product for consumers (Liu et al., 2024).

3.2 Continuous processing

In continuous processing, ingredients are fed into an automated system where precise heating, emulsification, and mixing occur in a continuous flow, ensuring efficiency and consistency for large-scale manufacturing. Both methods aim to produce high-quality PC with desirable texture, meltability, and shelf life (Bakry and Mehta, 2022). Flow chart for PC manufacture (Continuous) is shown in Figure 4.

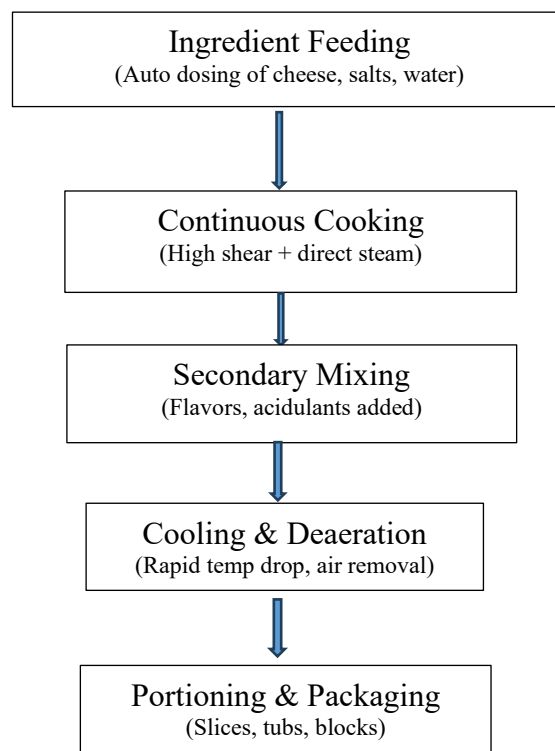


Figure 4. Process flow chart for PC production (Continuous process) (Bakry and Mehta, 2022).

3.2.1 Ingredient feeding

In continuous processing, ingredients such as natural cheese, water, ESs, milk proteins, and fats are automatically dosed into the production line. This is done using precision feeders, pumps, and sensors that ensure consistent and accurate delivery. Automated ingredient feeding minimizes human error and guarantees product uniformity, which is crucial in large-scale production. This step sets the foundation for a standardized and repeatable process, where the recipe parameters can be monitored and adjusted in real-time using PLC (Programmable Logic Controller) systems (Lee et al., 2004).

3.2.2 Continuous cooking

The heart of the continuous system is the cooking zone. Here, the blend of ingredients enters a pressurized environment where high shear mixing and direct steam injection rapidly heat and emulsify the mixture. Temperatures typically approx. around 130°C, enabling efficient pasteurization and protein solubilization. This step creates a smooth, homogenous PC mass. Unlike batch cooking, this system operates non-stop, allowing for consistent thermal treatment and reduced energy loss (Adhikari et al., 2010). Continuous cooker unit is shown in Figure 5.

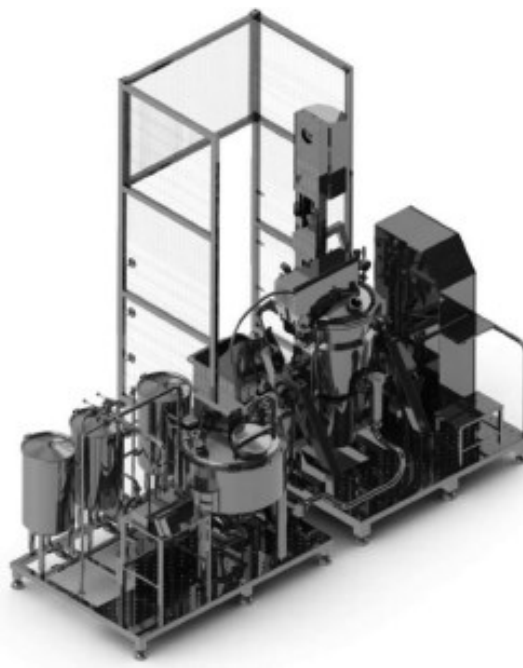


Figure 5. Continuous cooker unit with CIP (Clean-In-Place) system (Adhikari et al., 2010).

3.2.3 Secondary mixing

After cooking, the molten cheese mass flows into a secondary mixing chamber where additional ingredients such as flavorings, coloring agents, preservatives, and acidulants (e.g., citric acid) can be added. This stage fine-tunes the sensory and functional characteristics of the final product. Mixing also ensures uniform distribution of all components and provides a final opportunity to adjust pH and flavor before packaging. The flexibility of adding ingredients at this point improves product quality and consumer appeal (Cumhur and Akyilmaz, 2022).

3.2.4 Cooling and deaeration

The cheese mixture is then rapidly cooled using jacketed tunnels or vacuum chambers. Deaeration is carried out simultaneously to remove trapped air, which improves texture, prevents spoilage, and enhances shelf life. Quick cooling is essential to stabilize the emulsion, allowing the cheese to maintain a smooth and cohesive structure. This step also prepares the product for immediate packaging while ensuring microbiological safety and structural integrity (Tunick, 2013).

3.2.5 Portioning and packaging

In the final step, the PC is automatically portioned into desired formats—slices, blocks, tubes, or spreadable containers. High-speed packaging machines ensure hygienic and efficient operations. Vacuum sealing or modified atmosphere packaging is commonly used to extend shelf life and maintain product freshness. Additionally, aseptic filling and packaging, when combined with sterilization temperatures used during processing, enables the product to be stored at ambient temperatures without compromising safety or quality. This method further reduces the need for refrigeration, lowers distribution costs, and enhances shelf stability. The continuous line enables a seamless transition from production to packaging, reducing contamination risk and increasing throughput (Hussein and Shalaby et al., 2018).

4 THE FACTORS INFLUENCING THE CHARACTERISTICS OF PROCESSED CHEESE

PC characteristics are influenced by raw material composition, target parameters (e.g., fat, protein, calcium), processing conditions (e.g., heating, cooling), time, temperature and storage. These factors impact the cheese's consistency and texture, which can be evaluated using rheological and textural methods (Udyarajan et al., 2007).

4.1 Raw material quality, Composition and formulation

The characteristics of PC are largely determined by the type, quality, and proportion of natural cheeses used, along with non-dairy ingredients like milk proteins, ESs, and stabilizers. The balance of mature and young cheeses influences flavor and texture, while ESs control protein interactions, fat emulsification, moisture retention, and meltability. Moisture content, protein-to-fat ratio, and ESs affect consistency, with higher moisture yielding softness and higher protein providing firmness. Stabilizers enhance texture, water-binding, and prevent syneresis, while functional salts and additives improve spreadability, stability, and sensory characteristics. These ingredients contribute to the overall texture, shelf-life, and microbiological safety of the product (Salek et al., 2022).

4.2 Processing conditions

The parameters during manufacturing, including agitation, heating rate, cooking temperature, holding time, and cooling rate, significantly impact the physical properties of PC. For example, a faster cooling rate typically results in a softer cheese, while slower cooling may lead to a firmer product. Proper heat treatment is crucial to achieve the desired structure and consistency, and to ensure the PC forms a stable oil-in-water emulsion. Overheating can lead to moisture loss, resulting in a crumbly texture. The equipment and technology used in processing (e.g., cookers, mixers, homogenizers) are vital for achieving the desired characteristics in terms of texture and functionality. High-shear equipment results in a finer texture and better emulsification (Buňková and Buňka, 2017).

4.3 Storage and shelf-life

Storage conditions, such as temperature and duration, can significantly influence the quality and textural properties of PC. Higher storage temperatures tend to increase firmness due to

enhanced protein interaction, while storage time can lead to flavor development. The use of preservatives can prolong shelf life by preventing microbiological spoilage (Tamime, 2011).

4.4 Microstructure and microbiological aspects

The microstructure of the cheese is closely related to its rheological properties; processing methods and equipment used can affect the cheese's structure by altering its fat globule distribution and protein matrix arrangement. From a microbiological standpoint, ensuring the quality and safety of PC is essential. Heat treatments and proper sanitation prevent contamination, while the action of ESs can also inhibit microbial growth (Sivakami, 2021; Abdalla, 2011).

II PRACTICAL PART

5 AIM OF THE THESIS

The primary objective of this thesis is to evaluate the feasibility and implications of incorporating mango puree into processed dairy products with different DM contents (40% w/w and 45% w/w). Specifically, the thesis aims to:

- Develop and manufacture samples: Formulate ten distinct samples of processed dairy products, with five samples at each DM percentage (40% w/w and 45% w/w), incorporating varying levels of mango puree (0% w/w, 5% w/w, 10% w/w, 15% w/w, and 20% w/w).
- Conduct comprehensive analyses: Perform a series of basic chemical, color, textural, rheological, and sensory analyses to assess the impact of DM and mango puree levels on the product's overall quality.
- Evaluate the functional and sensory properties: Investigate how different concentrations of mango puree influence the chemical composition, color characteristics, texture, rheological behavior, and sensory attributes (such as flavor, appearance, and texture) of the processed dairy products.
- Assess the viability of mango puree as an ingredient: Conclude whether the addition of mango puree to processed dairy products enhances their properties and whether these modifications make the products viable and acceptable for consumer consumption.
- Contribute in the research on processed dairy products with fruit component: Provide valuable insights into the potential of fruit-based ingredients, specifically mango puree, for improving the functionality and sensory appeal of dairy-based products. Processed dairy products containing fruit ingredients, which is common in some Asian markets, but remain relatively uncommon in European markets, where primarily similar products such as cream cheese or quark-based desserts are available. Therefore, this research seeks to explore the integration of mango puree into dairy products, potentially enriching and diversifying the European dairy market. Such innovations could offer new opportunities for product development, consumer acceptance, and advancement in dairy product formulation within food technology.

6 MATERIALS AND METHODOLOGY

The samples were categorized into two groups based on DM content (40% w/w and 45% w/w), with each group containing five variations of mango puree concentrations (0% w/w, 5% w/w, 10% w/w, 15% w/w, and 20% w/w). After formulation, analyses including chemical, color, texture, rheological, and sensory evaluations were conducted.

6.1 Characteristics of the samples

Ten distinct samples of processed dairy products were prepared in this study, incorporating varying levels of mango puree and different DM contents. Specifically, five samples were formulated with 40% w/w DM, and five additional samples were prepared with 45% w/w DM. Each sample contained 30% w/w FC in DM. The mango puree content in each sample varied at five different concentrations: 0% w/w, 5% w/w, 10% w/w, 15% w/w, and 20% w/w, allowing for an in-depth analysis of the effects of mango puree on the product's physical, chemical, and sensory properties. In Table 1 below characteristics of samples produced in this thesis are simplified.

Table 1. Composition of samples: DM content and mango puree concentration (% w/w)

Dry matter (% w/w)	Fat in dry matter (% w/w)	Mango puree (% w/w)				
		0	5	10	15	20
40	30	0	5	10	15	20
45	30	0	5	10	15	20

6.2 Production of the samples

The specific raw materials and their quantities used for the production of the samples are not mentioned in this thesis as they are subject to commercial confidentiality.

The manufacturing process was carried out sequentially, the following steps illustrated in the flowchart shown in Figure 6 below.

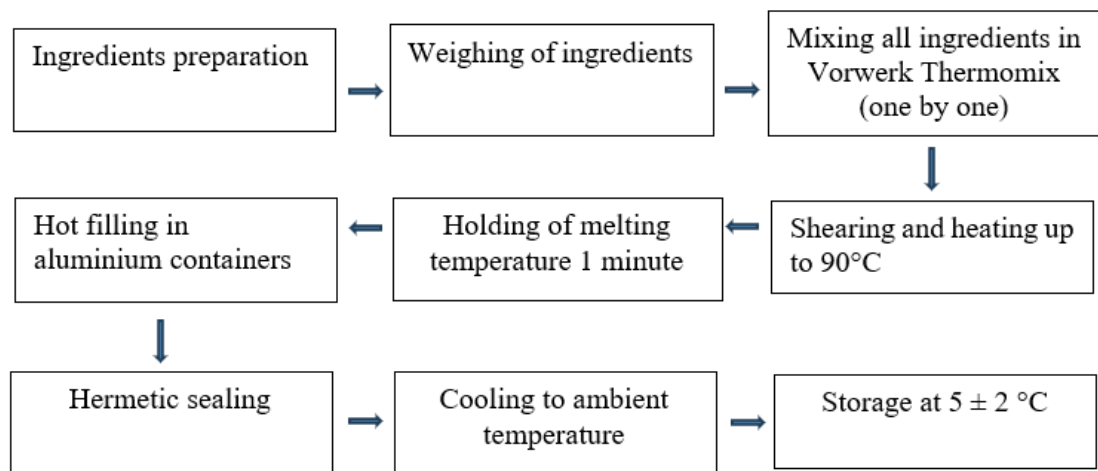


Figure 6. Process flow chart of manufacturing of the samples

The production process can be described in detail as follows:

1. All necessary ingredients were obtained, and the equipment—such as the analytic scale, mixing tools, and heating/shearing device (e.g., Vorwerk Thermomix®)—was cleaned, was calibrated, and was prepared for use.
2. Each ingredient was carefully weighed using an analytical scale. Precision was ensured in this step to maintain consistency and reproducibility of the final product.
3. All the ingredients were combined one by one in a thermomixer and mixed until a smooth, homogeneous base was formed. The mixture was simultaneously sheared at 5000 RPM using the Vorwerk Thermomix® and gradually heated, ensuring even dispersion, preventing clumping, activating functional properties of the ingredients, and promoting their full integration.
4. The mixture was maintained at 90 °C and was continuously sheared for 1 minute. This high-shear, high-temperature treatment was applied to enhance texture, promote uniformity, and improve interactions between the ingredients for better product consistency.
5. Immediately after shearing, the hot mixture was filled into pre-prepared aluminium containers. The containers were hermetically sealed to prevent contamination. Once sealed, they were allowed to cool to ambient temperature and, furthermore, transferred to a refrigerator and stored at 5 ± 2 °C until further analyses.

After a storage period of one week, all the samples exhibited a distinct texture and characteristic flavor upon inspection. These observations indicate that the processing method was effective, and all samples can be considered successfully manufactured. To document the results, photographs of the final products were taken, and the visual records are presented in Figure 7 & 8 below.



Figure 7. Processed dairy product samples with 40% w/w dry matter content, incorporating varying levels of mango puree (0–20% w/w). The sample on the left contains 0% mango puree, while the sample on the far right contains 20% mango puree.



Figure 8. Processed dairy product samples with 45% w/w dry matter content, incorporating varying levels of mango puree (0–20% w/w). The sample on the left contains 0% mango puree, while the sample on the far right contains 20% mango puree.

6.3 Methodology

All measurements were performed using the previously manufactured samples described above. The analyses were carried out after one week of the production, ensuring that the samples had undergone appropriate storage conditions prior to evaluation.

6.3.1 Dry matter content

The determination of DM content was carried out in accordance with the ISO 5534:2004 standard (ISO, 2004). An aluminium container, pre-filled with approximately 20 grams of sand to aid in heat distribution, was initially weighed using an analytical balance with a precision of 0.1 mg to determine its tare weight (denoted as M1).

Subsequently, approximately 3.0 grams of the test sample were added to the container, which is denoted by M2. The container was then placed in a drying oven set at 105 °C and maintained for approximately 6 hours, until a constant mass was achieved, ensuring complete removal of moisture.

Upon completion of the drying process, the container was transferred to a desiccator to cool to laboratory temperature. This step minimizes reabsorption of ambient humidity by the sample. Once cooled, the container and dried sample were weighed again (M3) to determine the final mass.

The DM content (w_t) of the sample, expressed as a percentage of the initial (wet) weight, was calculated using the following formula:

$$W_t = \frac{M3 - M1}{M2} \cdot 100 \%$$

Where:

W_t = DM content (%)

M3 = Weight of container with sample after heating (g)

M1 = Weight of container with sand (g)

M2 = Weight of sample (g)

Each sample was measured in triplicate to ensure reliability and reproducibility of results. The standard deviation (SD) was calculated using the standard statistical formula for sample variance, and all final results are reported as mean $\pm$ SD, rounded to two decimal places.

$$\sigma = \sqrt{\frac{1}{N} \sum_{i=1}^N (x_i - \bar{x})^2}$$

Where σ stands for the standard deviation, N for the number of measurements, x_i for one particular measurement and $\bar{x}$ for the average of the measurements from i to N .

6.3.2 Water activity

The determination of water activity (a_w) was carried out in accordance with the ISO 18787 standard (ISO, 2017a), employing the AquaLab Dew Point Water Activity Meter 4TE. Prior to measurement, all samples were equilibrated to a consistent temperature of 25 °C to ensure accuracy and comparability. The instrument was calibrated before each measurement session using a certified standard solution with a known water activity value of 0.9200, as specified by the manufacturer.

Each individual measurement involved carefully loading the sample into the designated tray of the AquaLab device, ensuring that the sample was evenly distributed to avoid inconsistencies. The tray was then inserted into the device, and the water activity was recorded once the reading stabilized. For each sample, three replicate measurements were performed to account for potential variability and ensure reliability. Between each set of triplicate measurements, the instrument was recalibrated using the same standard solution to maintain measurement accuracy throughout the process.

The standard deviation for each set of measurements was calculated using the same methodology described in 6.3.1 sub-chapter. Results are presented as the mean value of the three replicates, expressed to three decimal places and accompanied by the corresponding standard deviation (mean $\pm$ SD).

6.3.3 PH

The pH of the samples was measured using the HI 99161 pH meter, manufactured by Foodcare®. Prior to measurement, all samples were equilibrated to a temperature of 20 °C to ensure consistency and accuracy. The pH meter was calibrated using standard buffer

solutions with pH values of 4.00 and 7.00, in accordance with the manufacturer's instructions and standard laboratory practices.

Each pH measurement involved the direct insertion of the electrode into the sample, after which the pH value was recorded. Following each reading, the electrode was thoroughly rinsed with distilled water to prevent cross-contamination, then gently dried before proceeding to the next measurement.

For each sample, six individual measurements were performed. To maintain the integrity of the results and account for any heterogeneity within the sample, each measurement was taken from a different location within the sample. The standard deviation for each set of measurements was calculated using the method described in sub chapter 6.3.1. Results are reported as the mean pH value, rounded to two decimal places, accompanied by the standard deviation (mean $\pm$ SD).

6.3.4 Color

The color evaluation of the samples was conducted under standardized laboratory conditions using the UltraScan PRO spectrophotometer, developed by Hunter Lab. Prior to initiating the measurements, the instrument was meticulously calibrated according to the manufacturer's specifications, utilizing black ($L^* = 0$), white ($L^* = 100$), and D65 daylight illumination standards. This calibration ensured accurate and reproducible color readings across all samples.

Each sample was measured three times to account for any potential variability and ensure reliable results. The spectrophotometer recorded the transmitted light intensity and translated it into coordinate values within the CIE Lab* color space. These values were used to assess the lightness (L^*), the red-green axis (a^*), and the yellow-blue axis (b^*) for each sample. The results were expressed as the mean values of the three measurements, accompanied by the standard deviation (mean $\pm$ SD), to represent the variability within the measurements. Down below in Figure 9 is the Schematic diagram of the lab system.

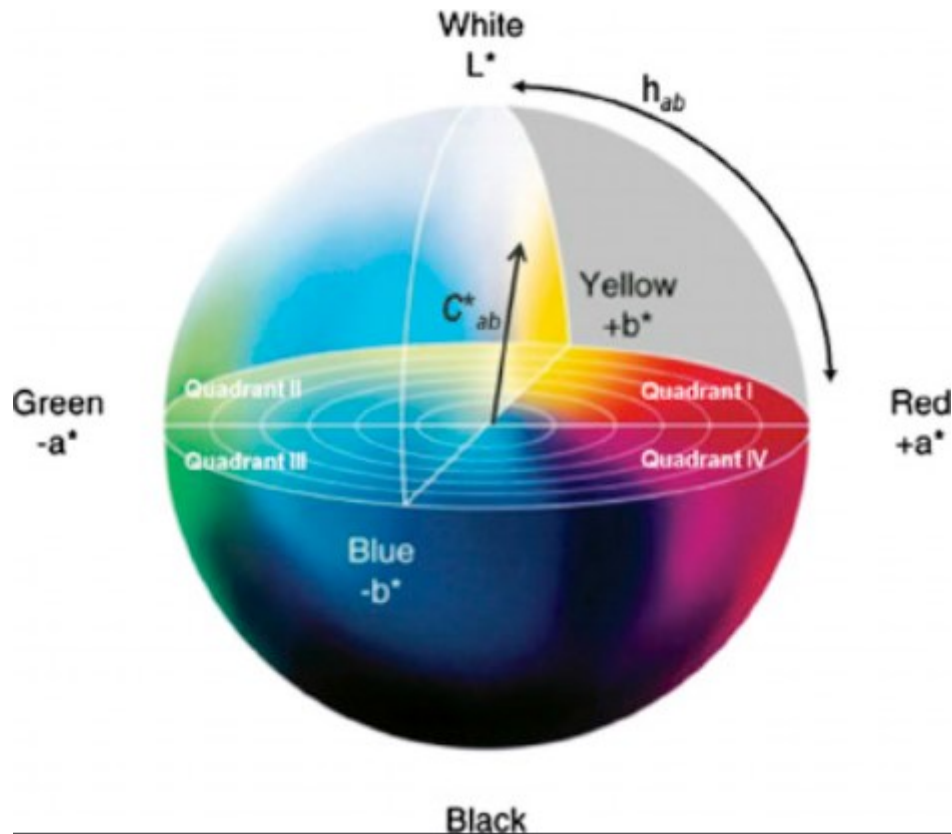


Figure 9. Three-Dimensional Representation of CIELAB Color Space: Visualizing L^* , a^* , b^* , Chroma (C^*), and Hue Angle (h) (Choodum et al., 2016).

6.3.5 Texture Profile Analysis and Spreadability

In this study, texture profile analysis (TPA) was employed to evaluate key mechanical properties of the samples, specifically focusing on hardness and stickiness. These parameters were selected due to their significant influence on consumer perception and overall product quality.

The TPA was conducted by subjecting the sample models to a two-cycle compression test at a controlled temperature of 20 °C, during which the force exerted on the samples was measured over time. All measurements were performed in triplicate to ensure the reliability and reproducibility of the results. The resulting data provided a comprehensive insight into the resistance of the samples to deformation and their behavior under applied stress.

Figure 10 presents a representative TPA curve, illustrating the relationship between the applied force (measured in Newtons) and time (in seconds). This graph visually captures the textural dynamics of the samples, with distinct peaks and troughs corresponding to the specific textural attributes under investigation. Hardness is identified as the peak force during the first compression, stickiness is observed as the negative force upon probe withdrawal.

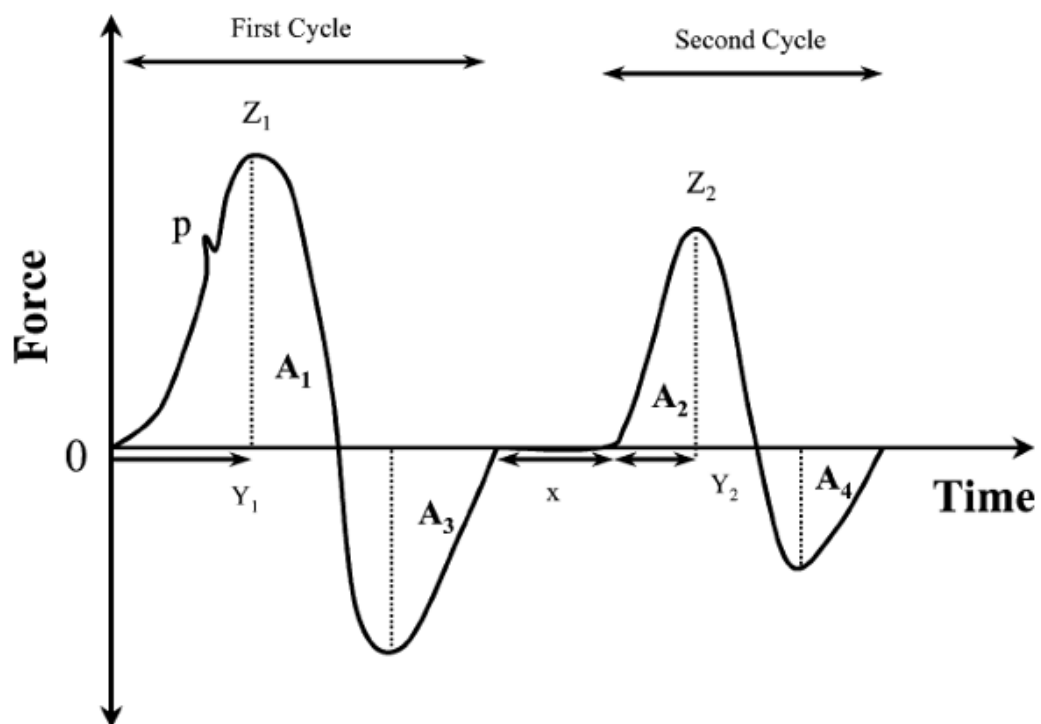


Figure 10. Graphic explanation of TPA – force dependency on time (Rahman, 2005).

The first textural attribute examined in the analysis of sample was hardness, also referred to as the product's structural strength. Hardness is defined as the amount of force required to cause deformation or penetration of the sample. In practical sensory terms, this parameter is perceived during consumption as the resistance encountered when compressing the sample between the teeth and the palate. Within the framework of TPA, hardness is quantitatively determined from the texture curve by identifying the maximum peak force (A_1) recorded during the first compression cycle. This peak represents the highest force applied before the sample begins to deform. Higher A_1 values are indicative of a firmer texture, meaning that greater force is needed to compress the product. Therefore, a PC with a more pronounced

maximum peak is considered to have a higher hardness level, suggesting increased resistance to deformation and a firmer mouthfeel (Szczesniak, 2002).

Relative stickiness is another critical parameter in the evaluation of food texture, particularly relevant for soft and semi-solid products such as PC. This attribute describes the force required to overcome the adhesive interaction between the surface of the food sample and the contacting probe during withdrawal. In sensory terms, it correlates with the effort needed to dislodge food that clings to the teeth, palate, or other oral surfaces during consumption. From a TPA standpoint, relative stickiness is derived from the negative peak force observed after the first compression, which corresponds to the adhesive force during probe retraction. It is quantitatively expressed as the ratio of the absolute value of the negative peak area (A_3) to the positive peak area (A_1). This ratio provides a standardized measure of stickiness relative to the product's overall hardness. A higher A_3/A_1 ratio indicates a more adhesive texture, suggesting greater stickiness and a stronger interaction between the food surface and external contact points (Lee and Klostermeyer, 2001).

All samples underwent both TPA and spreadability testing to comprehensively evaluate their mechanical and functional textural properties. The measurements were carried out using a TA. XT Plus Texture Analyser (Stable Micro Systems Ltd.®, Godalming, UK), a widely recognized instrument for precision in food texture assessments. For the TPA, the samples were analyzed directly in aluminium containers, with the detachable lids removed immediately prior to testing to allow unobstructed access for the probe. A cylindrical stainless-steel probe with a diameter of 20 mm was employed to perform the double compression tests necessary for TPA, enabling the determination of parameters such as hardness, and relative stickiness. Each sample was tested three times for TPA to ensure reliable and reproducible results. The mean values of the three measurements were calculated and expressed along with the standard deviation (mean $\pm$ SD). In contrast, the spreadability tests required the samples to be evenly distributed within a P/60C antipole container, specifically designed to standardize sample shape and volume. These tests were conducted using a P/60C conical probe, which is optimized to simulate the shearing motion involved in spreading. Three measurements were also taken for each sample, and the mean force required for spreading was calculated and expressed along with the standard deviation (mean $\pm$ SD). This setup allowed for accurate and repeatable assessment of the force needed to spread the samples, reflecting its ease of application and consumer usability.

6.3.6 Rheological Analysis

The viscoelastic properties of the samples were assessed using a Malvern Kinexus Pro+® rheometer, equipped with a plate–plate geometry featuring a diameter of 35 mm. A fixed gap of 1 mm was maintained between the plates throughout the measurement to ensure consistency and reproducibility. Prior to testing, approximately 2 grams of each sample were left to equilibrate at room temperature (20 °C) for a period of 4 hours, allowing the internal structure of the samples to stabilize. Following this equilibration, each sample was carefully placed between the rheometer plates and subjected to a temperature conditioning phase at 20 °C for 5 minutes to replicate typical consumption.

The rheological analysis was carried out in oscillatory mode, with a constant shear stress amplitude of 5.0 Pa, ensuring that all measurements were conducted within the linear viscoelastic region (LVR) of the material. The test recorded the frequency-dependent behavior of the samples by measuring both the storage modulus (G') and the loss modulus (G'') across a frequency of 0.1–10 Hz. We are providing high-resolution data across the frequency spectrum to ensure accurate analysis and interpretation.

Following the completion of the frequency sweep, several key rheological parameters were obtained directly from the rheometer: the complex modulus (G^*), which represents the total viscoelastic resistance of the material and complex viscosity (η^*), which provides an overall measure of the material's resistance to deformation under oscillatory conditions. Together, these parameters offer a comprehensive understanding of the sample's structural integrity, flow behavior, and textural stability under dynamic mechanical stress. To facilitate comparison across samples, a reference frequency of 1 Hz can be used for presenting the results. Each sample was tested three times to ensure reliable and consistent results. The mean values of the three measurements were calculated and expressed along with the standard deviation (mean $\pm$ SD), ensuring the accuracy and repeatability of the findings.

6.3.7 Sensory Analysis

The sensory analysis aimed to evaluate seven specific attributes of the manufactured samples, each assessed using a seven-point intensity scale. These attributes were yellow color intensity, hardness, spreadability, mango flavor intensity, sweet flavor intensity, quark/milk flavor intensity, off-flavors. The intensity scale ranged from 1 (imperceptible) to 7 (extremely high). Furthermore, overall impression was assessed with a seven-point hedonic scale (1 – outstanding, 7 – unacceptable).

The sensory analysis was carried out in accordance with ISO 6658 (ISO, 2017b) in sensory laboratory at the Department of Food Technology at Tomas Bata University in Zlin, Czechia, involving a panel of 15 informed assessors.

Samples were presented anonymously, each identified by a code, and served on white plates accompanied by a spoon, knife, and neutralizer—specifically wheat pastry and still water—to cleanse the palate between tastings. Samples with different DM content were assessed separately (i.e. 5 samples in one assessment). Both sensorial evaluations were performed on the same day with a 3-hours break. Assessors were instructed to evaluate the samples using a structured questionnaire, provided in Appendix I.

7 RESULTS AND DISCUSSION

This chapter presents the experimental results obtained from the comprehensive analysis of the developed samples, with a focus on evaluating key quality parameters. These include DM content, pH, water activity, color attributes, texture profile, rheological properties, and sensory characteristics. Each parameter is discussed in detail to assess its relevance to product quality, stability, and overall consumer acceptability.

7.1 Dry matter content

The DM content (results are presented in Table 2) of the processed dairy products varied with both the target DM levels (40% w/w and 45% w/w) and the concentration of mango puree (0–20% w/w).

Table 2. Results of basic chemical analysis as a function of dry matter and mango puree content in processed dairy products. Results are presented as average value $\pm$ standard deviation ($n \geq 3$).

Dry matter (% w/w)	Mango puree (% w/w)	Dry matter (% w/w)	PH (-)	Water activity (-)
40	0	41.84 $\pm$ 0.77	6.35 $\pm$ 0.07	0.967 $\pm$ 0.009
	5	41.98 $\pm$ 0.63	6.22 $\pm$ 0.01	0.968 $\pm$ 0.005
	10	41.95 $\pm$ 0.10	6.20 $\pm$ 0.01	0.967 $\pm$ 0.008
	15	42.24 $\pm$ 0.31	6.15 $\pm$ 0.01	0.966 $\pm$ 0.001
	20	41.74 $\pm$ 0.70	6.09 $\pm$ 0.01	0.966 $\pm$ 0.008
45	0	46.87 $\pm$ 0.25	6.27 $\pm$ 0.04	0.962 $\pm$ 0.001
	5	46.34 $\pm$ 0.43	6.19 $\pm$ 0.05	0.962 $\pm$ 0.004
	10	45.84 $\pm$ 1.22	6.10 $\pm$ 0.02	0.959 $\pm$ 0.001
	15	46.38 $\pm$ 1.15	6.06 $\pm$ 0.01	0.961 $\pm$ 0.005
	20	46.80 $\pm$ 1.57	6.04 $\pm$ 0.02	0.958 $\pm$ 0.001

At 40% w/w DM, the measured values ranged from 41.74 % w/w to 42.24 % w/w, while at 45% w/w DM, values ranged from 45.84% w/w to 46.87% w/w. The results show that the actual DM content remained within an acceptable and expected range for both formulation levels, confirming the effectiveness of the processing method in achieving the targeted solids concentration. Slightly higher DM content (than calculated) was caused by raw material

composition. At 40% w/w DM, a slight increase was observed at 10% w/w and 15% w/w mango puree, possibly due to the addition of mango solids; however, no consistent linear trend was observed. In contrast, the 45% w/w DM group exhibited a slight decrease in DM content with increasing mango puree levels, particularly noticeable at 5% w/w and 15% w/w. This could be attributed to the higher moisture content of mango puree, which may have diluted the total solids. Despite these minor variations, the DM content across all formulations remained within the desired range, supporting product consistency and formulation reliability. The similar DM content of the samples allows their comparison with each other.

In the study by Černíková et al. (2017), the authors explored the effects of different DM contents (35% and 45% w/w) on the texture and rheology of PCs, noting that an increase in DM content resulted in higher rigidity and smaller fat globules. Similarly, in the results of processed dairy products samples, the DM content at both 40% w/w and 45% w/w remained within the expected range, with slight variations due to the addition of mango puree. At 40% w/w DM, the addition of mango puree led to small increases in the DM content at 10% w/w and 15% w/w puree, likely due to the contribution of mango solids. These findings support Černíková et al.'s conclusion that higher DM contributes to product consistency, and the results reinforce this by maintaining the DM content within acceptable limits despite the variations in mango puree concentrations. Furthermore, the slight decrease in DM content at higher levels of mango puree in the 45% w/w DM group corresponds to Černíková et al.'s observation that changes in the composition of ingredients, such as the addition of moisture-rich substances, can dilute total solids and impact the final product's rigidity (Černíková et al., 2017).

Deshwal et al. (2025) examined the influence of fat content and homogenization of milk on PC, observing that higher fat content and the interaction between fat and DM significantly affect cheese texture and meltability. Their study found that increased fat content led to reduced rigidity of the PC. In the results of processed dairy products sample, the addition of mango puree, which introduced higher moisture content, led to minor decreases in DM content, particularly in the 45% w/w DM group at 5% and 15% w/w puree concentrations. This slight dilution effect is akin to the moisture-dilution observed in Deshwal et al.'s work, where increased fat content (which may contain more moisture) reduced rigidity. While this thesis focus was on mango puree, the underlying principle observed in both studies is consistent: changes in the ingredient composition, particularly moisture and fat content, can

influence the DM levels and thus affect the texture and consistency of PC (Deshwal et al., 2025)

7.2 PH values

The pH values of processed dairy products as influenced by two levels of DM content (40% and 45% w/w) and varying concentrations of mango puree (0–20% w/w) are presented in Table 2. Overall, the results indicate that both the DM level and mango puree concentration significantly influenced the pH of the samples.

At 40% w/w DM, the pH exhibited a decreasing trend with the increasing concentration of mango puree. The control sample (0% mango puree) had the highest pH value of 6.35. As the mango puree content increased to 5%, 10%, 15%, and 20% w/w, the pH values gradually decreased to 6.22, 6.20, 6.15, and 6.09, respectively. This decline in pH can be attributed to the natural acidity of mango puree, which contributes organic acids such as citric and malic acid, thereby lowering the pH of the composite product. This acidification effect becomes more pronounced with higher additions of mango puree. A similar decreasing trend in pH values was observed for the samples containing 45% w/w DM. The pH of the control sample (0% mango puree) was 6.27. With increasing mango puree levels, the pH values decreased progressively to 6.19 (5%), 6.10 (10%), 6.06 (15%), and 6.04 (20%). Although the trend mirrors that of the 40% w/w DM group, the pH values at each mango puree level were generally slightly lower than those in the 40% w/w DM group, especially at higher puree levels. This suggests a compounding effect of both DM and mango content on acidity. Comparing both DM levels reveals that samples with higher DM content (45% w/w) generally exhibited slightly lower pH values at corresponding mango puree concentrations compared to the 40% w/w DM group. This could be due to a higher concentration of solids intensifying the impact of mango puree acids, reducing the buffering capacity of the milk matrix and enhancing acidification.

In the study by Talbot-Walsh et al. (2019), the effect of pH on the physical, microstructural, and sensory properties of PC was investigated with the addition of starches. The researchers found that pH adjustments significantly influenced the starch distribution in the cheese matrix, especially at pH levels of 4.8–5.3, where a continuous starch network was formed. This result mirrors the findings in the thesis, where increasing mango puree concentrations led to a gradual reduction in pH, causing changes in product composition. However, while Talbot-Walsh et al. (2019) primarily focused on starch interactions in PC and their effect on

texture and sensory attributes, the thesis demonstrates that fruit-based acids, such as those from mango puree, also modify pH in dairy products, leading to similar alterations in product characteristics. Both studies confirm that pH plays a significant role in influencing texture, with the thesis highlighting the role of fruit purees in acidification.

In the research by Bulut-Solak and Akin (2019), pH variations were shown to impact the textural properties of PC, with changes in pH affecting hardness, gumminess, and meltability. Similarly, in the thesis, the pH of dairy products decreased with increasing mango puree concentrations, which likely contributed to changes in texture and composition. The research by Bulut-Solak and Akin (2019) observed that pH adjustments during cheese processing affected the final texture, with a significant effect on product hardness. In the thesis, a similar acidification trend was noted, where increasing mango puree concentrations led to a reduction in pH and likely influenced the product's overall texture, as seen in the progressive decrease in pH with higher mango puree levels. Both studies emphasize the role of pH in controlling the final characteristics of dairy products.

7.3 Water activity

Water activity is a critical parameter in determining the microbial stability, shelf life, and texture of food products. The results were obtained from samples with varying DM and mango puree contents.

In the group with 40% w/w DM, water activity showed minimal but consistent changes with increasing mango puree levels. The control sample (0% w/w mango puree) had a water activity of 0.967. As mango puree concentration increased to 5% w/w, 10% w/w, 15% w/w, and 20% w/w, the water activity values fluctuated slightly between 0.966 and 0.968, with the lowest value being 0.966 (15% w/w and 20% w/w puree). The minor reduction in water activity can be attributed to the presence of soluble solids and sugars in mango puree, which bind free water and reduce its availability. However, the impact is relatively modest at this DM level, likely due to the overall lower concentration of solids in the system.

In contrast, the samples with 45% w/w DM exhibited slight fluctuations in water activity with increasing concentrations of mango purée. The control sample (0% w/w mango purée) had a water activity of 0.962. This value remained unchanged at 5% w/w mango purée. At 10% w/w concentration, water activity decreased slightly to 0.959, followed by a small increase to 0.961 at 15% w/w. The lowest value, 0.958, was observed at 20% w/w mango purée. This trend suggests that while the changes are minor, increasing mango purée may

reduce water activity marginally, likely due to the combined effects of higher DM and mango-derived solids enhancing water binding through interactions with carbohydrates, proteins, and sugars in the matrix.

Water activity remained high (above 0.9) across all samples, indicating susceptibility to microbial deterioration. Although the 45% w/w DM group showed slightly lower water activity values compared to the 40% w/w group at corresponding mango purée concentrations, these differences were minimal and not statistically significant. Therefore, it can be concluded that all samples require refrigeration to ensure microbial stability and extend shelf life.

The water activity results obtained in the current study are consistent with the findings reported by Møller et al. (2012), who investigated the influence of cream cheese composition on water activity and microbial survival. In both cases, water activity values remained high (above 0.9) across all formulations, indicating limited effectiveness of compositional changes alone in reducing microbial risk. Møller et al. observed that varying fat, salt, and pH levels caused only marginal changes in water activity (ranging from 0.986 to 0.997), which did not significantly impact microbial stability. Similarly, in this thesis, incremental additions of mango purée and increases in DM resulted in only minor reductions in water activity (to a minimum of 0.958), insufficient to shift the system out of the microbial growth-permissive range. Both studies underline the importance of complementary preservation strategies such as refrigeration, as water activity reductions from ingredient modifications alone were not statistically or microbiologically substantial (Møller et al., 2012).

The current findings are also in agreement with the theoretical framework established in *Water Activity in Foods: Fundamentals and Applications* (Barbosa-Cánovas et al., 2020), which underscores the central role of water activity in determining microbial stability and product shelf life. The textbook emphasizes that solute addition—particularly sugars and soluble solids—can slightly reduce water activity by binding free water, but such effects are often modest unless coupled with other hurdles. In the study under discussion, the small decreases in water activity resulting from mango purée incorporation align with this concept, as the puree's sugar content marginally limited free water availability without significantly affecting the overall microbial safety profile. Furthermore, the sustained water activity above 0.958 supports the assertion by Barbosa-Cánovas et al. (2020) that maintaining water activity below 0.90 is generally necessary to inhibit pathogenic growth, a threshold not reached in this formulation context.

7.4 Color analysis

Color is a key sensory attribute influencing consumer acceptance of food products. The color parameters analyzed in this study were L^* (lightness), a^* (red-green axis), and b^* (yellow-blue axis). The results presented in Table 3 clearly show that both DM and mango puree content significantly affected the color characteristics of the processed dairy products.

Table 3. Results of color parameters (L^* , a^* , b^*) as a function of dry matter and mango puree content in processed dairy products. Results are presented as average value $\pm$ standard deviation ($n \geq 3$).

Dry matter (% w/w)	Mango puree (% w/w)	L^* (-)	a^* (-)	b^* (-)
40	0	84.14 ± 1.59	-1.14 ± 0.09	20.05 ± 0.42
	5	79.23 ± 2.94	1.70 ± 0.08	29.94 ± 1.37
	10	78.51 ± 0.62	3.46 ± 0.03	35.76 ± 0.42
	15	76.18 ± 0.68	4.84 ± 0.03	41.08 ± 0.25
	20	74.94 ± 0.42	5.75 ± 0.08	43.70 ± 0.61
45	0	84.39 ± 0.33	-1.03 ± 0.05	24.35 ± 0.37
	5	81.94 ± 0.17	2.08 ± 0.27	33.27 ± 0.19
	10	79.29 ± 0.28	3.82 ± 0.05	38.46 ± 0.40
	15	76.42 ± 0.56	5.54 ± 0.15	43.09 ± 0.41
	20	74.89 ± 0.16	6.83 ± 0.12	50.09 ± 0.54

The L^* values represent the lightness of the sample, with higher values indicating a lighter appearance. At 40% w/w DM, lightness decreased progressively with the increase in mango puree content. The control sample (0% w/w mango puree) had the highest L^* value (84.14), indicating a very light appearance. With 5% w/w, 10% w/w, 15% w/w, and 20% w/w puree additions, L^* values decreased to 79.23, 78.51, 76.18, and 74.94, respectively. This decrease is likely due to the naturally deeper yellow-orange pigments in mango puree reducing the brightness of the product. A similar trend was observed at 45% w/w DM. The L^* value decreased from 84.39 (0% w/w mango puree) to 74.89 (20% w/w mango puree). Notably, the rate of reduction in lightness was slightly more pronounced at this higher DM level, possibly due to the increased concentration of both milk solids and mango compounds, creating a more saturated and darker appearance.

The a^* values indicate the red-green hue of the sample. Negative values denote green, while positive values denote red. At 40% w/w DM, the control sample had a negative a^* value (-1.14), indicating a slight greenish hue typical of milk-based systems. As mango puree was added, a^* values increased significantly, reaching 5.75 at 20% w/w puree. This clearly reflects the red-orange color contribution of mango, shifting the color balance from green toward red. At 45% w/w DM, the a^* values followed a similar increasing trend, from -1.03 (0% w/w puree) to 6.83 (20% w/w mango puree). The slightly higher a^* values compared to the 40% w/w DM group suggest that the denser matrix at 45% w/w DM may enhance the visibility and intensity of red-orange tones from the mango puree.

The b^* values denote the yellow-blue axis, where higher values reflect greater yellowness. At 40% w/w DM, b^* increased from 20.05 in the control sample to 43.70 at 20% w/w mango puree. This consistent rise confirms the impact of mango puree on yellowness, as mango pulp is rich in yellow-orange carotenoids such as beta-carotene. The 45% w/w DM samples also showed a similar increasing trend, with b^* values ranging from 24.35 (0% w/w mango puree) to 50.09 (20% w/w mango puree). Notably, the b^* values in the 45% w/w DM group were generally higher than those in the 40% w/w DM group, particularly at higher mango concentrations. This suggests a synergistic effect of higher solids and pigment intensity leading to a richer yellow hue.

In conclusion, the color analysis shows that increasing mango puree content significantly alters the visual properties of the processed dairy products—reducing lightness (L^*) and increasing both redness (a^*) and yellowness (b^*). Additionally, higher DM content (45% w/w) amplifies these effects, resulting in deeper and more intense color tones. These findings are important for product development, as color is directly linked to consumer perception of flavor, freshness, and quality.

These objective changes are in accordance with the findings of Wadhwani and McMahon (2012), who demonstrated that altering the levels of annatto and titanium dioxide in low-fat Cheddar cheese significantly influenced color attributes and affected consumer perception. They reported that cheeses with overly white or translucent appearances received lower preference scores, whereas those exhibiting an ideal orange-yellow hue were more favorably rated. Similarly, in the present study, the incorporation of mango purée progressively enhanced the yellow-orange coloration of the samples, with the highest overall impression scores observed at 15% and 20% mango purée. This suggests that the intensified color at

higher purée levels positively influenced visual appeal and consumer liking, aligning with the preference for products that exhibit vibrant and natural-looking color attributes.

Interestingly, Racette et al. (2024) reported that while color influenced consumer preferences in Cheddar cheese—with light orange hues favored over white or dark samples, white Cheddar was often perceived as more natural due to traditional expectations. In contrast, the products in the present study were explicitly submitted for sensory evaluation as mango-based dairy items, which likely shaped assessor expectations toward a mango-like appearance. The instrumental analysis showed that color became more saturated with increasing mango purée, and this trend was mirrored in the sensory evaluation, where higher purée concentrations (15% and 20% w/w) received the highest ratings for visual appeal and overall impression. This suggests that the more intense yellow color, while functionally derived from fruit content, also aligned with consumer expectations for this type of product. Thus, unlike traditional cheese, where deviations from pale orange might signal artificiality, the enhanced coloration in mango-enriched samples likely served as a positive visual and sensory cue.

7.5 Texture profile analysis

Texture plays a fundamental role in consumer perception and acceptability of dairy-based products. In this study, the effects of two levels of DM (40% and 45% w/w) and the incorporation of mango puree (0–20% w/w) on the texture profile of processed dairy products were evaluated, with particular focus on hardness and relative stickiness (see results given in Table 4). Hardness, defined as the maximum force required to compress the sample, provides insight into the product's firmness and structural integrity. At 40% w/w DM content, hardness values remained low and relatively consistent across all mango puree levels. The control sample (0% w/w mango puree) exhibited a hardness of 0.13 N, while the mango puree-enriched samples showed slightly reduced but comparable values (0.11 N). These findings suggest that at this DM level, the matrix lacks sufficient structural concentration to develop significant firmness, and the addition of mango puree does not markedly alter the texture. Conversely, a substantial increase in hardness was observed at 45% w/w DM. The control sample recorded the highest hardness (0.60 N), indicative of a denser and more compact structure due to the increased concentration of solids. However, as mango puree concentration increased, a notable decrease in hardness occurred, reaching a minimum of 0.33 N at 15% w/w mango puree, followed by a slight increase to 0.43 N at

20% w/w mango puree. The initial softening effect may be attributed to the water-binding and plasticizing action of sugars and fibers present in the mango puree, which interrupt the protein and fat matrix. The slight rebound in firmness at the highest puree level may reflect the contribution of fruit solids to the structural framework.

Table 4. Results of texture analysis as a function of dry matter and mango puree content in processed dairy products. Results are presented as average value $\pm$ standard deviation ($n \geq 3$).

Dry matter (% w/w)	Mango puree (% w/w)	Hardness (N)	Relative stickiness (-)	Spreadability (N·s ⁻¹)
40	0	0.13 $\pm$ 0.01	0.01 $\pm$ 0.01	0.05 $\pm$ 0.01
	5	0.11 $\pm$ 0.01	0.03 $\pm$ 0.01	0.03 $\pm$ 0.01
	10	0.11 $\pm$ 0.01	0.05 $\pm$ 0.01	0.01 $\pm$ 0.01
	15	0.11 $\pm$ 0.02	0.07 $\pm$ 0.01	0.02 $\pm$ 0.01
	20	0.11 $\pm$ 0.01	0.06 $\pm$ 0.01	0.04 $\pm$ 0.01
45	0	0.60 $\pm$ 0.01	0.17 $\pm$ 0.01	0.12 $\pm$ 0.01
	5	0.47 $\pm$ 0.01	0.13 $\pm$ 0.01	0.10 $\pm$ 0.01
	10	0.36 $\pm$ 0.01	0.18 $\pm$ 0.01	0.13 $\pm$ 0.01
	15	0.33 $\pm$ 0.02	0.17 $\pm$ 0.01	0.11 $\pm$ 0.01
	20	0.43 $\pm$ 0.01	0.12 $\pm$ 0.01	0.12 $\pm$ 0.01

Relative stickiness, an indicator of the adhesive property of the product, was measured in relation to both DM content and mango purée concentration. At 40% w/w DM, the control sample exhibited minimal stickiness (0.01), and while there was a slight increase with mango purée addition, the changes were negligible. The highest stickiness value (0.07) was observed at 15% w/w mango purée, but overall, the effect of purée addition at this DM level was minimal and showed no consistent trend. This suggests that, within this matrix, the addition of mango purée had little impact on adhesive properties. In the 45% w/w DM group, relative stickiness values were generally higher compared to the 40% w/w group, likely due to the denser matrix and reduced free moisture. However, no clear trend was observed with increasing mango purée concentration—the values fluctuated, peaking at 0.18 for the 10% w/w sample before decreasing slightly to 0.12 at 20% w/w. Although mango-derived sugars and soluble fibers are known to enhance stickiness due to their hygroscopic nature, it appears that in this formulation, the influence of mango purée was inconsistent and possibly

moderated by reduced water mobility at higher DM levels. Therefore, it can be concluded that mango purée addition had no clear or consistent effect on relative stickiness.

The texture profile of the processed dairy products was significantly influenced by both DM and mango purée content. Higher DM levels consistently increased product hardness, attributable to reduced moisture content and greater matrix compactness. In contrast, mango purée addition reduced hardness across both DM levels, with the softest textures observed at higher purée concentrations (15% and 20% w/w). These results confirm that while DM is a key determinant of structural firmness, mango purée contributes to softening the product, likely through the introduction of moisture and disruption of protein and starch interactions within the matrix.

The instrumental texture analysis results generally align with the sensory evaluation findings demonstrating a relationship between measured physical properties and perceived texture attributes. Specifically, samples with higher mango purée (MP) additions—particularly those containing 15% and 20% w/w—were found to be more spreadable than the control and the 5% MP sample, as shown in Figures 15 and 16. This trend was evident in both instrumental and sensory data, indicating that MP addition contributes positively to the softening and spreadability of the product, ultimately enhancing overall acceptability. The instrumental measurements showed a reduction in hardness with increasing MP levels, especially at 15% and 20%, which corresponded with panelists' perceptions of a softer, more desirable texture. However, instrumental stickiness did not follow a clear trend across MP concentrations, which is consistent with sensory results showing no notable differences in stickiness. This suggests that while instrumental tools can detect subtle variations, only those large enough to significantly affect mechanical behavior—such as through changes in dry matter (DM) content—translate meaningfully into sensory perception. Furthermore, no consistent sensory differences in spreadability were observed within each DM group, reinforcing the idea that minor instrumental fluctuations may not always be perceptible. Overall, the improved spreadability and softer texture observed in the 15% and 20% MP samples played a key role in shaping a more favorable sensory experience and contributed to their higher overall impression scores.

The present study demonstrated that hardness was primarily influenced by DM content, with significantly higher values recorded at 45% w/w DM compared to 40% w/w. This observation aligns well with the work of Zheng et al. (2016), who found that increased solids and reduced moisture in cheese matrices lead to greater firmness due to enhanced protein-

protein interactions and lower water-mediated plasticization. At 40% w/w DM, hardness remained low across all mango purée concentrations, suggesting an insufficient structural matrix to develop significant firmness—an interpretation consistent with Zheng's conclusion regarding the role of moisture in weakening matrix integrity. Moreover, the softening effect observed in this study with increasing mango purée—particularly at 15% and 20%—supports the findings of Ushkalova et al. (2025), who noted that the inclusion of plant-based additives (e.g., mung bean or soy proteins) reduced hardness through water retention and matrix disruption. Notably, the slight increase in hardness at 20% purée after reaching a minimum at 15% in the 45% DM group mirrors Ushkalova's observation that a higher load of solids may contribute to re-establishing some matrix rigidity, despite earlier softening.

In contrast, relative stickiness in the current study did not follow a consistent increasing or decreasing pattern with mango purée content. At 40% w/w DM, stickiness values remained very low and varied only slightly, indicating a negligible impact of mango purée on this attribute. This partially aligns with Foegeding and Drake (2007), who emphasized that stickiness is influenced more by a combination of factors—including water activity and matrix composition—than by single ingredient additions. At 45% w/w DM, stickiness values were overall higher, which corresponds with the denser matrix and potentially reduced water mobility, but the effect of mango purée addition fluctuated without a clear trend. This behavior differs somewhat from the more predictable increase in adhesiveness reported by Zheng et al. (2016) in moisture-enriched systems, yet resembles the trend noted by Ushkalova et al. (2025), where intermediate levels of plant-based inclusions increased stickiness due to enhanced water-holding capacity, but higher levels led to a decrease as the matrix became more compact. In the current study, the peak stickiness at 10% w/w purée followed by a decrease at 15% and 20% may reflect a similar balancing effect between hygroscopic mango components and matrix densification at higher DM levels.

7.6 Spreadability

Spreadability is an important textural characteristic that influences consumer acceptance and usability of processed dairy products. It reflects the ease with which a product can be spread over the surface and is typically inversely related to firmness or hardness. In this study, the influence of two factors—DM content (40% and 45% w/w) and mango purée incorporation (0 to 20% w/w)—on spreadability was investigated. Results of the analysis are shown in Table 4.

The effect of DM content on spreadability is a general trend observed in the results is that samples with 45% w/w DM content exhibited worse spreadability (higher values in $\text{N}\cdot\text{s}^{-1}$, i.e. samples were more difficult to spread) compared to those with 40% w/w DM content. For instance, the control sample (0% w/w mango puree) had a spreadability of $0.05 \text{ N}\cdot\text{s}^{-1}$ at 40% w/w DM, while the same formulation at 45% w/w DM showed a significantly higher spreadability resistance ($0.12 \text{ N}\cdot\text{s}^{-1}$). This increase in resistance to spreading with higher DM content is expected, as increased total solids generally lead to a denser, more viscous matrix, reducing flowability and increasing hardness.

At 40% w/w DM, the spreadability values showed minor fluctuations with the addition of mango purée, decreasing initially and then slightly increasing at higher purée levels. However, the overall changes were small and did not indicate a clear trend. At 45% w/w DM, spreadability values remained relatively stable across all mango purée concentrations, again showing no systematic effect. These results suggest that the addition of mango purée did not significantly influence spreadability within the tested range. In contrast, a consistent effect of dry matter was observed: products with 45% w/w DM exhibited higher resistance to spreading compared to those with 40% w/w DM. This indicates that higher DM content results in a firmer, denser matrix that limits spreadability, while mango purée concentration had no clear or significant impact on this texture parameter.

In summary, the results indicate that higher DM content negatively affects spreadability, leading to firmer products with reduced ease of spreading. However, no consistent or significant effect of mango purée addition on spreadability was observed at either DM level. Therefore, no definitive conclusions can be drawn regarding an optimal mango purée concentration for improving spreadability based on the current data. Any variation observed in spreadability across purée concentrations should be considered within the context of minor fluctuations rather than meaningful trends.

The current findings on spreadability confirm that higher DM content reduces the ease of spreading, as samples with 45% w/w DM consistently showed higher resistance compared to those with 40% w/w DM. This observation aligns with Bayarri et al. (2012), who reported that dairy matrices with higher fat content or solids tend to develop a denser internal structure, which increases firmness and reduces spreadability. While the addition of mango purée introduced some fluctuations in spreadability values, no consistent trend was observed across the tested concentrations. Unlike Bayarri et al.'s observations in low-fat cheeses—where ingredient interactions led to noticeable changes in texture—mango purée in this

study did not exert a systematic effect on spreadability at either DM level. This suggests that in a high-solids dairy system, the dominant influence of matrix density can mask the softening potential of fruit-derived components such as sugars or pectin. Overall, the results reaffirm that dry matter is a key determinant of spreadability, while mango purée, within the tested range, had no significant or predictable effect on this property.

7.7 Rheological analysis

The results of the rheological analysis, as shown in Table 5, reveal how DM content (40% w/w and 45% w/w) and the inclusion of mango puree (0% w/w to 20% w/w) influence the viscoelastic properties of processed dairy products. These properties were assessed by measuring the storage modulus (G'), loss modulus (G''), complex modulus (G^*), and complex viscosity (η^*), each providing insight into the stiffness, elasticity, and flow behavior of the product.

Table 5. Results of rheological analysis at reference frequency (1 Hz) as a function of dry matter and mango puree content in processed dairy products. Results are presented as average value $\pm$ standard deviation ($n \geq 3$).

Dry matter (%)	Mango puree (%)	Storage modulus G' (Pa)	Loss modulus G'' (Pa)	Complex modulus G^* (Pa)	Complex viscosity η^* (Pa·s)
40	0	159.3 $\pm$ 5.1	171.2 $\pm$ 3.2	234.5 $\pm$ 5.2	37.3 $\pm$ 1.1
	5	70.8 $\pm$ 2.3	101.1 $\pm$ 3.3	123.4 $\pm$ 1.2	19.7 $\pm$ 0.4
	10	30.8 $\pm$ 1.2	50.7 $\pm$ 1.7	59.3 $\pm$ 0.9	9.4 $\pm$ 0.3
	15	24.7 $\pm$ 0.9	41.1 $\pm$ 1.5	47.9 $\pm$ 1.8	7.6 $\pm$ 0.2
	20	20.1 $\pm$ 0.8	32.4 $\pm$ 1.0	38.2 $\pm$ 0.5	6.1 $\pm$ 0.2
45	0	1345.2 $\pm$ 49.5	924.3 $\pm$ 17.6	1635.1 $\pm$ 35.2	260.2 $\pm$ 6.1
	5	1029.5 $\pm$ 37.2	701.8 $\pm$ 10.5	1245.3 $\pm$ 49.7	198.1 $\pm$ 5.5
	10	929.3 $\pm$ 26.1	633.8 $\pm$ 11.9	1095.3 $\pm$ 39.4	174.4 $\pm$ 5.6
	15	695.5 $\pm$ 20.6	482.6 $\pm$ 7.1	846.0 $\pm$ 10.6	134.7 $\pm$ 3.5
	20	544.5 $\pm$ 18.9	398.4 $\pm$ 6.6	674.5 $\pm$ 9.1	107.3 $\pm$ 2.6

At 40% DM, the addition of mango puree resulted in a significant decrease in both the storage modulus (G') and the loss modulus (G''). For example, the storage modulus decreased from 159.3 Pa (at 0% w/w mango puree) to 20.1 Pa (at 20% w/w mango puree).

Similarly, the loss modulus decreased from 171.2 Pa (at 0% w/w mango puree) to 32.4 Pa (at 20% w/w mango puree). This decrease suggests that increasing mango puree content softens the structure, likely due to the water and sugar content in the puree reducing the product's firmness.

The complex modulus (G^*), which represents the overall stiffness of the product, followed a similar pattern, decreasing from 234.5 Pa (at 0% w/w mango puree) to 38.2 Pa (at 20% w/w mango puree), indicating a softening effect of the puree. The complex viscosity (η^*) also decreased significantly, from 37.3 Pa·s (at 0% w/w mango puree) to 6.1 Pa·s (at 20% w/w mango puree), highlighting that the mixture becomes more fluid and easier to spread as the mango puree content increases.

At 45% w/w DM, the overall trend was similar but less pronounced. The storage modulus decreased from 1345.2 Pa (at 0% w/w mango puree) to 544.5 Pa (at 20% w/w mango puree), and the loss modulus decreased from 924.3 Pa (at 0% w/w mango puree) to 398.4 Pa (at 20% w/w mango puree). The complex modulus also decreased from 1635.1 Pa (at 0% w/w mango puree) to 674.5 Pa (at 20% w/w mango puree), and complex viscosity dropped from 260.2 Pa·s (at 0% w/w mango puree) to 107.3 Pa·s (at 20% w/w mango puree). This indicates that the higher DM content leads to a more rigid structure, which is less influenced by the addition of mango puree compared to the 40% w/w DM samples.

The results clearly indicate that higher DM content (45% w/w) results in a firmer and more stable product, as reflected by the significantly higher moduli and complex viscosity values across all mango puree concentrations compared to the 40% w/w DM samples. The influence of mango puree is more pronounced at 40% w/w DM, where its addition reduces the product's overall viscosity and stiffness more significantly. In contrast, at 45% w/w DM, the structural integrity provided by the higher solids content seems to limit the effect of the mango puree.

Below in the thesis, graphical dependencies of storage and loss moduli on frequency (0–10 Hz) for both DM levels are presented (see Figure 11 and 12 for G' and Figures 13 and 14 for G''). As can be seen from the figures (and also from the Table 5), samples with a DM content of 40 % w/w show G'' values higher than G' values. This implies that these samples show more viscous behavior (i.e. behave more like a liquid). In contrast, products with 45 % w/w DM exhibit more elastic character (more solid behavior), since G' values are higher compared to G'' values.

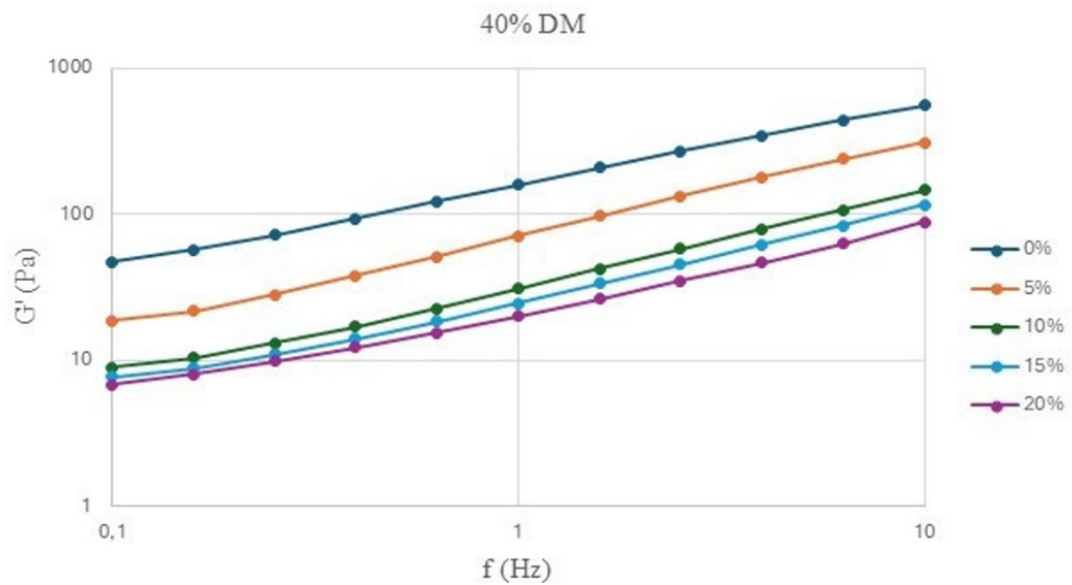


Figure 11. The dependence of storage modulus (G') on frequency of processed dairy products with 40% w/w of dry matter and various addition of mango puree

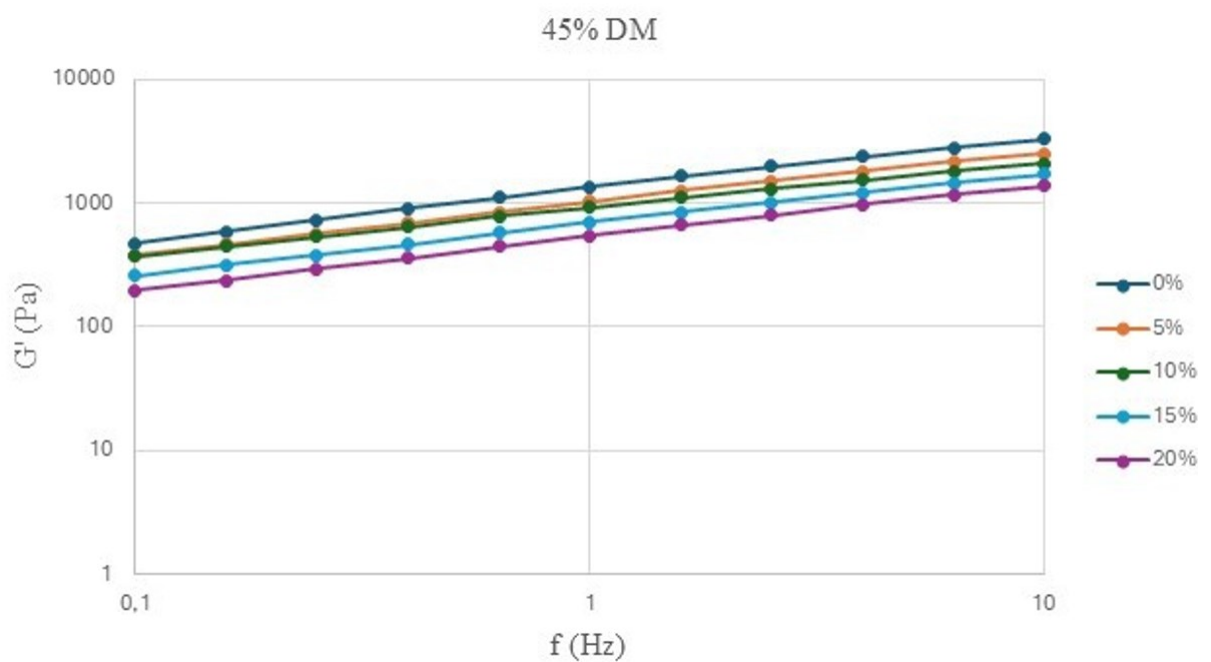


Figure 12. The dependence of storage modulus (G') on frequency of processed dairy products with 45% w/w of dry matter and various addition of mango puree

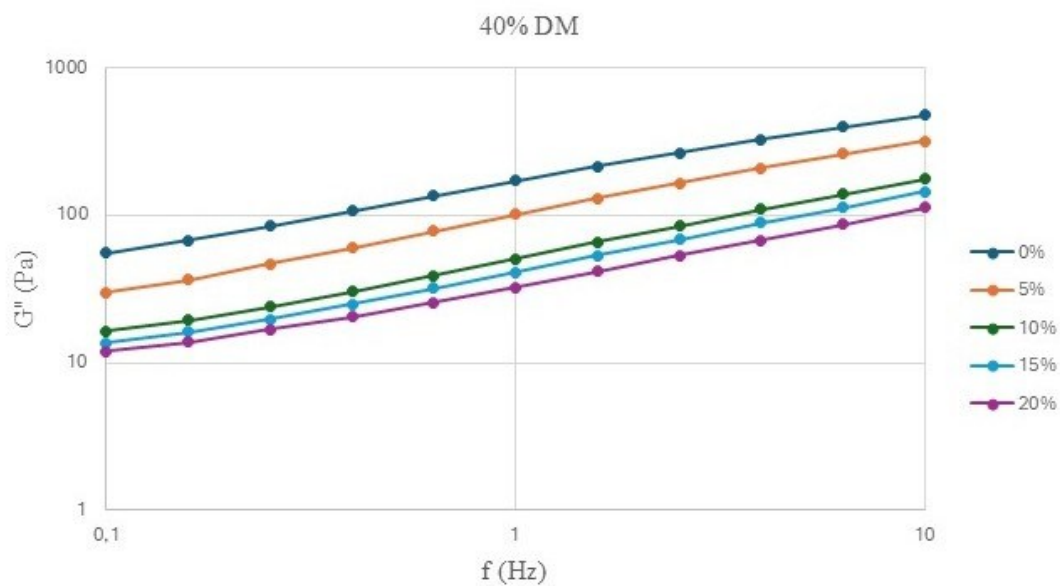


Figure 13. The dependence of loss modulus (G'') on frequency of processed dairy products with 40% w/w of dry matter and various addition of mango puree

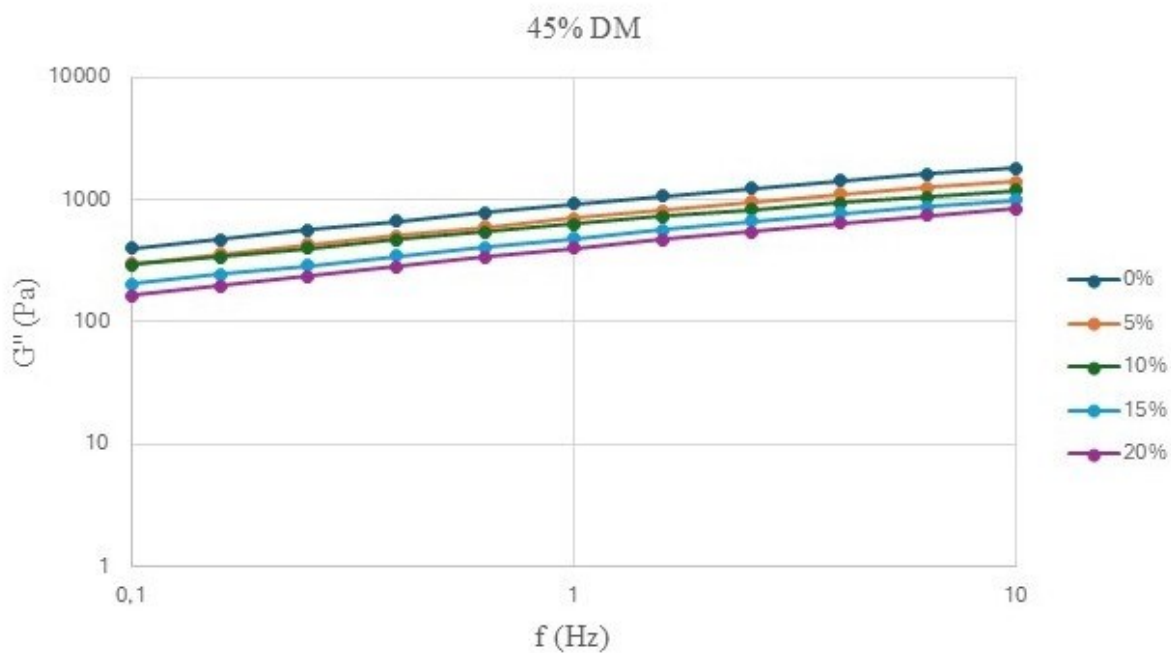


Figure 14. The dependence of loss modulus (G'') on frequency of processed dairy products with 45% w/w of dry matter and various addition of mango puree.

The rheological data from this study clearly demonstrate that both DM content and mango purée concentration significantly influence the viscoelastic behavior of processed dairy products. At lower DM levels (40% w/w), the consistent decrease in storage modulus (G'), loss modulus (G''), complex modulus (G^*), and complex viscosity (η^*) with increasing mango purée concentration suggests a strong softening effect. This softening is likely due to the dilution of the protein-fat matrix and the introduction of low-molecular-weight components (e.g., sugars and organic acids) from the mango purée, which disrupt the structural integrity of the system. Salehi (2021) similarly noted that the incorporation of fruit or vegetable purées often leads to a reduction in viscoelastic moduli due to the interference of fiber, moisture, and sugars with the native dairy gel structure.

Particularly at 40% DM, the observation that G'' exceeds G' indicates a predominantly viscous behavior—characteristic of weak gel structures or systems that behave more like thick fluids than elastic solids. This rheological shift aligns with prior reports that fruit-fortified yogurts and soft cheeses tend to lose their gel-like structure when enriched with high-moisture, low-protein ingredients. In such matrices, fruit-derived fibers may prevent effective casein-casein interactions and promote water mobility, reducing gel strength and increasing flowability. Our findings of reduced η^* also confirm this, highlighting a marked drop in resistance to deformation and a greater ease of flow, making the product more spreadable, though potentially at the expense of structure and stability.

At higher DM content (45% w/w), the rheological parameters remained significantly higher across all mango purée levels, suggesting that the denser, more protein- and fat-rich matrix confers greater structural rigidity. Although a decreasing trend in moduli was still observed with increasing purée, the magnitude of change was less pronounced. Salehi (2021) reported similar buffering effects in high-fat or high-solid dairy systems, where the intrinsic matrix structure is less sensitive to compositional changes from added fruit or fiber components. This resilience could be attributed to the stronger protein network formation and reduced water availability, which limit the ability of fruit components to interfere with gel development.

Furthermore, the frequency sweep results (Figures 11–14) support these conclusions. Samples at 40% DM showed $G'' > G'$ over the tested frequency range, confirming a liquid-like (viscous-dominated) behavior. In contrast, 45% DM samples displayed $G' > G''$, indicating elastic dominance and a more solid-like structure. These findings reflect classic

viscoelastic profiles of weak vs. strong gels and confirm the interaction between composition and rheological character.

7.8 Sensory analysis

As shown in Figure 15, which presents the sensory evaluation results for processed dairy products with 40% w/w DM and varying mango purée concentrations, the overall impression improves consistently with increasing levels of mango purée. The samples containing 15% and 20% w/w mango purée received the highest overall ratings and were categorized as excellent, while the 10% w/w samples were rated as very good, and the 5% w/w and control (0% w/w) samples were rated as good. A clear increase in yellow color intensity was observed with higher mango purée levels, with the 15% and 20% w/w samples showing the most vivid coloration. This indicates the significant visual influence of mango purée, which likely met assessor expectations, as the samples were presented as mango-based products. Off flavors were rated as imperceptible across all samples, with no significant differences between treatments. The intensity of mango flavor and sweetness increased progressively with purée concentration, peaking in the 20% w/w samples, which provided the most pronounced mango sensory experience. Hardness decreased as mango purée concentration increased: the control and 5% w/w samples were rated as harder (high and medium hardness), while the 15% and 20% w/w samples were perceived as the softest (very low hardness).

This demonstrates a clear softening effect associated with higher mango purée content. Spreadability improved in parallel with softness, with the 15% and 20% w/w samples exhibiting the highest spreadability scores. Based on overall impression scores, the 15% and 20% w/w samples were the most preferred by panelists.

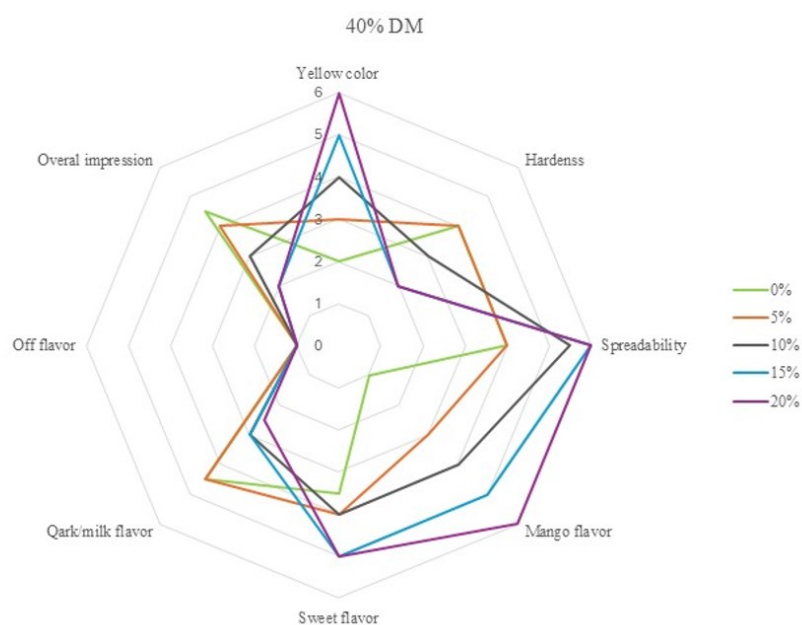


Figure 15. Results of sensory analysis of processed dairy products with 40% w/w of dry matter and various addition of mango puree

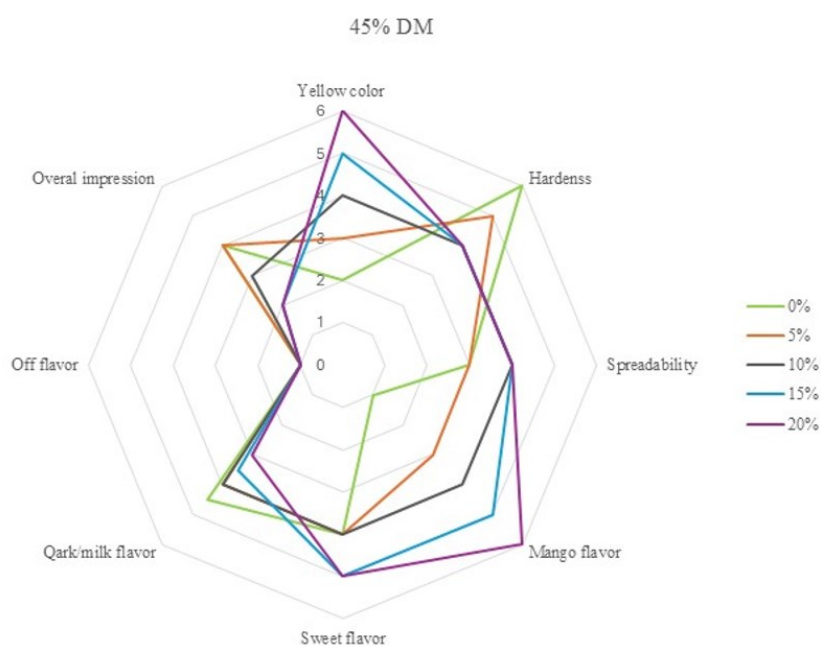


Figure 16. Results of sensory analysis of processed dairy products with 45% w/w of dry matter and various additions of mango puree

Similarly, Figure 16 illustrates the sensory analysis results for samples with 45% w/w DM. Here again, overall impression increased with rising mango purée concentrations. The 15% and 20% w/w samples were rated as excellent, followed by 10% w/w (very good), and then 5% and 0% w/w samples, which were rated as good. The increase in mango purée led to a more intense yellow color, with the 15% and 20% w/w samples showing the strongest visual appeal. As with the 40% DM group, off flavors were rated as imperceptible in all samples, with no significant differences noted. Mango flavor and sweetness were clearly more intense in the 15% and 20% w/w samples, supporting their higher preference ratings. Hardness followed the same trend as in the 40% DM group: the control and 5% w/w samples were perceived as harder, while the 10% w/w sample had medium hardness and the 15% and 20% w/w samples were rated as soft (low hardness). Since hardness is itself a texture attribute, its inverse relationship with spreadability was again observed—samples with higher mango purée concentrations were softer and more easily spreadable. Overall, the 15% and 20% w/w mango purée samples were the most preferred, combining favorable color, flavor, sweetness, softness, and spreadability.

Across both DM levels, sensory results consistently show that increasing mango purée concentration enhances color intensity, perceived mango flavor, sweetness, and spreadability, while reducing hardness. Off flavors were not perceptible in any sample, indicating that higher fruit content did not compromise flavor integrity. The samples with 15% and 20% w/w mango purée were rated highest overall, suggesting they offered the most desirable combination of sensory qualities for a mango-based dairy product.

The instrumental color analysis confirmed a consistent and measurable increase in yellowness (b^* values) with rising mango purée concentrations across both 40% and 45% w/w DM formulations, with the highest b^* values observed at 20% w/w purée. This objective color enhancement was reflected in the sensory evaluation, where panelists consistently rated the 15% and 20% w/w mango purée samples as having the most vivid and appealing yellow coloration. These results demonstrate a clear alignment between instrumental color parameters and human sensory perception, particularly with respect to the yellow-orange hue, which is characteristic of mango. The increase in a^* values (toward red) and decrease in L^* values (lightness) further contributed to a deeper and more saturated color appearance, enhancing the visual appeal. These sensory responses are consistent with the findings of Wadhwani and McMahon (2012), who reported that products with more pronounced orange-yellow hues received higher preference scores than pale or white samples, due to their

association with flavor intensity and freshness. Additionally, the intensified color was likely perceived as natural and appropriate for a mango-based product, aligning with Racette et al. (2024), who emphasized the importance of expectation alignment in color perception. Thus, in the present study, the instrumental and sensory data both support the conclusion that mango purée effectively enhances yellow-orange coloration in a way that meets consumer expectations and positively influences overall impression.

The relationship between instrumental measurements and sensory evaluations was clearly reflected in the trends observed for hardness and spreadability. Instrumental TPA showed that increasing mango purée concentration—particularly at 15% and 20% w/w—resulted in reduced hardness across both DM levels. This objective softening was mirrored in the sensory data, where panelists consistently rated these same samples as softer and more spreadable. Notably, samples with 45% w/w DM showed the highest instrumental hardness, and were correspondingly perceived as firmer by sensory evaluators, confirming the influence of matrix density on textural perception. These findings support the notion that mango purée acts as a softening agent, especially in less concentrated matrices, by introducing moisture and disrupting protein–fat interactions—an effect that was clearly detectable both instrumentally and sensorially. As Foegeding and Drake (2007) emphasized, such structural changes are often reflected in both mechanical measures and mouthfeel evaluations, particularly in semi-solid dairy systems.

For spreadability, while the instrumental measurements indicated that samples with higher DM content were more resistant to spreading, the sensory assessments echoed this pattern: products with 45% DM were perceived as less spreadable. However, no consistent sensory differences were noted across varying mango purée levels within each DM group, which aligns with the instrumental findings showing minor fluctuations and no clear trend in spreadability as a function of purée concentration. This suggests that while instrumental tools detect subtle changes, only those large enough to affect mechanical behavior (e.g., due to DM content) translate meaningfully into sensory experience. These results reinforce the strong link between mechanical and sensory measures of texture, particularly with respect to structural firmness and spreadability. As noted by Bayarri et al. (2012), high solid content in dairy systems often masks the softening influence of added components, such as fruit or fiber, limiting their perceptual impact.

The viscoelastic behavior observed in the rheological analysis showed a strong correspondence with both the instrumental and sensory evaluation of textural properties.

Specifically, the consistent decrease in storage modulus (G'), loss modulus (G''), complex modulus (G^*), and complex viscosity (η^*) with increasing mango purée concentration at 40% w/w DM clearly reflected the softening of the matrix, which was also evident in lower hardness values from TPA and in sensory panel ratings. Samples with higher mango purée (15% and 20%) exhibited both lower rheological strength and mechanical hardness, and were consistently perceived by panelists as softer and more spreadable. This close alignment between rheological softness and both instrumental and perceptual measurements confirms that mango purée acts as a texture-modifying agent, reducing structural firmness through moisture introduction and matrix dilution. As Salehi (2021) noted, such reductions in viscoelastic moduli are characteristic when fruit-derived components disrupt protein gelation and water distribution in dairy systems.

At 45% w/w DM, the product structure was notably more rigid, as reflected by significantly higher rheological moduli, hardness, and complex viscosity, which translated into reduced spreadability both mechanically and sensorially. Although rheological parameters still decreased with added mango purée, the structural density from high solids content appeared to limit the perceptual impact of these changes. This buffering effect was also evident in TPA results, where hardness decreased less sharply and sensory differences in softness were less pronounced than at lower DM. The frequency sweep results further confirmed this behavior, 40% DM samples behaved as weak gels ($G'' > G'$), while 45% DM samples exhibited solid-like properties ($G' > G''$), reinforcing the interpretation that matrix strength governs both mechanical texture and perceived mouthfeel. Collectively, these findings establish a robust correlation between rheological profiles, instrumental texture data, and consumer-relevant sensory perceptions, offering a comprehensive understanding of how formulation adjustments influence the overall textural quality of mango-enriched dairy products.

8 CONCLUSION

This thesis investigated the impact of integrating mango puree at different concentrations (0% w/w, 5% w/w, 10% w/w, 15% w/w, and 20% w/w) into processed dairy products formulated at two distinct DM levels (40% w/w and 45% w/w). The findings demonstrated clear trends, highlighting the significant effects of both mango puree concentration and DM content on the physicochemical, rheological, textural, and sensory attributes of the dairy products.

The incorporation of mango puree notably influenced the rheological properties, especially at the lower DM content (40% w/w). An increase in mango puree concentration consistently resulted in softer, less viscous, and more spreadable textures, as evidenced by decreased hardness, storage modulus (G'), loss modulus (G''), complex modulus (G^*), and complex viscosity (η^*). Conversely, the samples with higher DM content (45% w/w) exhibited greater structural integrity, firmness, and stability, although these attributes were similarly reduced with increasing puree concentrations.

Textural analyses further supported these observations, showing that mango purée addition generally decreased hardness while having no consistent or significant effect on relative stickiness across most samples. Similarly, spreadability was primarily influenced by dry matter content, with products containing 45% w/w DM exhibiting greater resistance to spreading than those with 40% w/w DM. The addition of mango purée, however, did not significantly alter spreadability at either DM level, as values fluctuated without a clear trend.

Color evaluations revealed clear visual trends correlating with mango puree concentration. An increase in mango content enhanced yellowness (b^*) and redness (a^*), accompanied by reduced lightness (L^*), reflecting the intrinsic pigments of the mango puree and imparting a visually appealing color to the dairy products.

Sensory assessments highlighted a consumer preference for products containing higher mango purée concentrations, specifically 15% and 20% w/w. These samples offered an optimal balance of desirable sensory attributes, including flavor intensity, sweetness, fruitiness, and spreadability. Rather than diminishing acceptability, the intensified flavor profile at these levels appeared to align well with consumer expectations for a mango-based dairy product, resulting in the highest overall impression scores.

In summary, the optimal formulation identified in this study featured a 45% w/w DM content combined with 15–20% w/w mango purée, offering the most favorable balance of structural

firmness, sensory appeal, and color intensity. While products with 40% w/w DM showed softer textures, they were perceived as too fluid and more like a semi-liquid spread than a typical spreadable product. Therefore, higher dry matter and mango purée levels are recommended for achieving the best overall quality and consumer acceptance in mango-based dairy applications.

Further research is recommended to extend the applicability of these findings. Future studies could explore different fruit purees (such as pineapple, banana, or peach) to assess how varying acidity, pectin, and pigments affect product quality. Investigating alternative raw materials, including plant-based substitutes, could also align with diverse dietary needs and market trends. Employing advanced analytical methods like microscopy and rheological modeling could offer deeper insights into ingredient interactions. Additionally, extended shelf-life studies under various storage conditions and broader consumer testing would help validate the commercial viability and consumer acceptance of fruit-enhanced dairy products.

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LIST OF ABBREVIATIONS

PC Processed cheese

ES Emulsifying salt

FC Fat content

WBC White-brined cheese

DM Dry matter

TPA Texture Profile Analysis

APPENDIX I: QUESTIONNAIRE FOR THE SENSORY ANALYSIS

Protocol for the sensory analysis of processed dairy products

Name and surname:

Date:

Scale test

Evaluate the samples of mango flavored processed cheese products presented and enter the number chosen from the scales provided under the table.

Parameter	A	B	C	D	E
Yellow color intensity					
Hardness intensity					
Spreadability intensity					
Mango flavor intensity					
Sweet flavor intensity					
Quark/milk flavor intensity					
Off flavors intensity					
Overall impression					

Intensity scale

1. imperceptible
2. very low
3. low
4. medium
5. slightly greater
6. great
7. extremely high

Overall impression scale

1. outstanding
2. excellent
3. very good
4. good (medium)
5. less good
6. bad
7. unacceptable

Protocol for the sensory analysis of processed dairy products

Name and surname:

Date:

Scale test

Evaluate the samples of mango flavored processed cheese products presented and enter the number chosen from the scales provided under the table.

Parameter	F	G	H	I	J
Yellow color intensity					
Hardness intensity					
Spreadability intensity					
Mango flavor intensity					
Sweet flavor intensity					
Quark/milk flavor intensity					
Off flavors intensity					
Overall impression					

Intensity scale

1. imperceptible
2. very low
3. low
4. medium
5. slightly greater
6. great
7. extremely high

Overall impression scale

1. outstanding
2. excellent
3. very good
4. good (medium)
5. less good
6. bad
7. unacceptable