A NOVEL PRE-TREATMENT FOR CHEESE PRODUCTION:

BIOCHEMISTRY, SENSORY PERCEPTION AND CONSUMER ACCEPTANCE

KEVIN CÁRTHAIGH DEEGAN

ACADEMIC DISSERTATION

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Custos: Professor Hely Tuorila  
Department of Food and Environmental Sciences  
University of Helsinki, Finland

Supervisors: Professor Hely Tuorila  
Department of Food and Environmental Sciences  
University of Helsinki, Finland  
Professor Tapani Alatossava  
Department of Food and Environmental Sciences  
University of Helsinki, Finland

Reviewers: Doctor Antti Knaapila  
Department of Biochemistry  
University of Turku, Finland  
Professor Zata Vickers  
Department of Food Science and Nutrition  
University of Minnesota, USA

Opponent: Professor Erminio Monteleone  
Department of Agricultural, Food and Forestry Management  
University of Florence, Italy

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“Never commit yourself to a cheese without having first examined it”

T.S. Eliot
ABSTRACT

Homogenisation is a physical process which results in the reduction in the size of fat-globules to reduce creaming. It is not generally used in cheesemaking as it allows access of the indigenous enzyme lipoprotein lipase (LPL) to the triacylglycerol core of the fat globule, resulting in uncontrollable lipolysis and rancidity both in the milk and cheese made therefrom. It was hypothesised that the inclusion of low-pressure homogenisation in a controlled fashion could be used to improve the sensory characteristics and consumer acceptability of cheese relative to un-treated cheeses.

A pre-processing treatment was developed wherein raw milk was homogenised (at 0, 5 or 10 MPa pressure), incubated for 1 h at 37°C and either batch pasteurised (63°C for 30 min) or high-temperature short-time pasteurised (75°C for 15 s). Control milks were treated similarly, but bypassed the homogenisation step. Cheddar and Emmental cheese were produced from the pre-treated milk and ripened according to respective ripening schemes. Reduced-fat Emmental cheese (20% fat) was also produced, using both homogenisation pressure of 10 MPa in the pre-treatment and with a control milk.

Biochemical analyses showed higher moisture and NaCl levels in homogenised milk cheeses, while free fatty acids (FFA) were in some cases twice that of the control cheeses. The difference in amount of FFA can be attributed primarily to the lipolysis experienced in the pre-treatment. No differences were found in levels of bacteria in cheeses in any study. Confocal laser scanning microscopy (CLSM) showed a greater distribution of smaller homogenised fat globules throughout the cheese matrix.

Sensory characteristics of the cheeses produced using the pre-treatment and Emmental cheesemaking were evaluated by descriptive sensory profiling using trained panels. Cheeses produced with homogenisation were rated higher for taste intensity and salty taste and were smoother, fattier and crumblier, lacked characteristic eyes and were less yellow and more colour consistent than those without homogenisation in the pre-treatment. Dynamic sensory characteristics were evaluated with the temporal dominance of sensations (TDS) method, where the evolution of the most dominant sensory attribute during mastication was followed. Homogenisation caused a drastic change in the texture during mastication. The control cheese was dominantly elastic at the start and then crumbly until swallowing while the homogenised milk cheese was experienced as crumbly-fatty-smooth.

Evaluation of consumer responses and market positioning was carried out by projective mapping (PM), where respondents (n = 46) positioned the control and homogenised full-
fat and reduced-fat test cheeses with six commercial cheeses. Similar cheeses were positioned closer together and different cheeses further apart. Participants were free to use their own criteria to position the cheeses. The reduced-fat homogenised cheese was rated as higher as more pleasant and positioned apart from similar commercial Emmental cheeses and the control cheeses. The full-fat homogenised milk cheese, ripened for 3 months, was rated higher for liking and positioned far from the other test cheeses, close to Gruyère-type (ripened for 7 months) and Gouda (ripened for 8 months) cheeses, described with words like ‘full’, ‘tasty’, ‘melt-in-mouth’ and ‘creamy’. The positioning close to longer-ripened cheeses suggests a potential saving, through attainment of similar characteristics in a shorter ripening time.

The effect of information on the expectations and perceptions of consumers was investigated. Participants (n = 229) completed a questionnaire with demographic and psychographic measures and were divided into four balanced groups based on age, sex, food neophobia and food technology neophobia. Each group received the same cheese sample and a different description, either, ‘traditional’, ‘new-type’, ‘technology’ or ‘cheese’. Participants rated expected/actual pleasantness and purchase intent, as well as the suitability of descriptive words. Descriptions affected expected purchase intent, where the ‘new-type’ group reported highest purchase intent, while no effect was found on expected pleasantness. Communication of novelty and technology raised the purchase intent of those with low food neophobia and low food technology neophobia, respectively.

The pre-treatment is a viable and valuable addition prior to cheesemaking. Improvements in certain key sensory taste and texture attributes were seen, as well as improved positioning and consumer responses, indicating market potential and potential reduction in ripening costs. Although care should be taken in communication of both novelty and the technological nature of the process, the potential advantages of the pre-treatment are clear. Not only could the pre-treatment be applied prior to the manufacture of other types of cheeses, but potentially to other types of ripened-dairy products.
Homogenoinnissa maidon rasvapisaroiden koko pienenee, jolloin kerman erottuminen vähenee. Homogenointia ei käytetä yleensä juuston valmistuksessa, sillä prosessi mahdollistaa maidon lipoproteiinilipaaasi (LPL) -entsyymin pääsyn rasvapisaran triasylyglyseroli-ytimeen aiheuttuen hallitseman lipolyysian ja eltaantumista valmissa tuotteessa. Tutkimuksen hypoteesina oli, että matalapainehomogenoinnin kontrolloitu käyttö parantaa juuston aistinvaraisia ominaisuuksia ja siten hyväksyttävyyttä kuluttajien keskuudessa.

Työssä kehitettiin esikäsittely, jossa raakamaito homogenoitiin (0, 5 tai 10 MPa), inkuboitiin (1 t 37°C) ja joko pastöroitiin (30 min 63°C) tai pastöroitiin korkeassa lämpötilassa lyhytaikaisesti (15 sek 75°C). Kontrollimaidot käsiteltiin samalla tavalla, paita että niitä ei homogenoitu. Cheddar- ja emmentaljuustot valmistettiin esikäsittelystä maidosta ja kypsytettiin vakiintuneen menetelmin. Työssä valmistettiin myös kaksi vähärasvaista emmentaljuustoa (20 % rasvaa), joista toisen pohjana oleva maito homogenoitiin esikäsittelyssä (10 MPa) ja toinen oli kontrollijuusto.

Kemialliset analyysit osoittivat, että homogenoidusta maidosta valmistetuissa juustoissa oli suuremmat kosteus- ja suolapitoisuudet, ja vapaiden rasvahappojen (FFA) määrä oli jopa kaksinkertainen kontrollijuustoihin verrattuna. Vapaiden rasvahappojen suuri määrä johtunee lipolyysista esikäsittelystä. Bakteerien määriissä ei ollut eroja eri juustojen välillä. Konfokaalimikroskooppikuvista nähtiin, että koejuustoissa proteiinimatriisin homogenoidut rasvapisarat olivat pienempiä ja laajemmalle levinneitä kuin kontrollijuustoissa.


Juuston kulutajavasteita ja markkina-asemia arvioitiin projektiivisella kartoituksella (projective mapping), jossa vastaajat (n = 46) asettivat kontrollijuostot, homogenoidun täysirasvaiseen testijuustoon ja homogenoidun vähärasvaiseen testijuustoon kaupallisen juuston joukkoon. Samankaltaiset juustot asetettiin läheille toisiaan ja erilaiset juustot kauemmaksi toisistaan. Vastaajat päättivät itse asettelun kriteereistä. Vähärasvainen homogenoidusta maidosta valmistettu juusto arvioitiin miellyttävimmäksi.


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Thanks to the Masters students who have assisted in various projects throughout my studies; Sibel Alak, Jenni Jaakkola, Elena Karpik, Heidi Vicente and Maria Luis Gomez Pastrana. Dr. David Fewer is thanked for his extensive language-check of the thesis and for his all-round friendship and breeze-shooting capabilities. Many thanks also to my buddies from both university and the real world; Göker, Alex, Elina, Marta, Bhawani, Pauliina, Niamh, Niamh and Dave, Cliff, Darren, Conor, James, Peter, Matti and Soila, Annika and Mete and Juha and Lena. You have all contributed to my wellbeing over the last four years, which I thank you all for! Also, a word of thanks to my fantastic work colleagues, Paula, Elina, Mikko, Ekaterina, Ulla, Carina, Airi, Johanna and Marja-Leena, who have been very supportive over the last year of full time work and thesis work on the side!

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Helsinki, October 2014

Kevin Cáirthaigh Deegan
This thesis is based on the following publications:


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**Contribution of the author to papers I to IV**

I-IV Kevin C. Deegan planned the study together with the other authors. He analysed and interpreted all results and was the corresponding author on all articles. The co-authors assisted at all stages of the work, in planning, analysis, practical work, writing and commenting on manuscripts.
# ABBREVIATIONS

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ADV</td>
<td>Acid degree value</td>
</tr>
<tr>
<td>ANOVA</td>
<td>Analysis of variance</td>
</tr>
<tr>
<td>CATA</td>
<td>Check-all-that-apply</td>
</tr>
<tr>
<td>CLSM</td>
<td>Confocal laser scanning microscopy</td>
</tr>
<tr>
<td>FAA</td>
<td>Free amino acid</td>
</tr>
<tr>
<td>FFA</td>
<td>Free fatty acid</td>
</tr>
<tr>
<td>FNS</td>
<td>Food neophobia scale</td>
</tr>
<tr>
<td>FTNS</td>
<td>Food technology neophobia scale</td>
</tr>
<tr>
<td>GC</td>
<td>Gas chromatography</td>
</tr>
<tr>
<td>GM</td>
<td>Genetic modification</td>
</tr>
<tr>
<td>GPA</td>
<td>General procrustes analysis (GPA)</td>
</tr>
<tr>
<td>HSD</td>
<td>Honestly significant difference</td>
</tr>
<tr>
<td>LAB</td>
<td>Lactic acid bacteria</td>
</tr>
<tr>
<td>LPL</td>
<td>Lipoprotein lipase</td>
</tr>
<tr>
<td>MDS</td>
<td>Multidimensional scaling</td>
</tr>
<tr>
<td>MFA</td>
<td>Multiple factor analysis</td>
</tr>
<tr>
<td>MFGM</td>
<td>Milk fat globule membrane</td>
</tr>
<tr>
<td>MRS</td>
<td>de Man, Rogosa and Sharpe</td>
</tr>
<tr>
<td>NSLAB</td>
<td>Non-starter lactic acid bacteria</td>
</tr>
<tr>
<td>PC</td>
<td>Principal component</td>
</tr>
<tr>
<td>PCA</td>
<td>Principal component analysis</td>
</tr>
<tr>
<td>PCR</td>
<td>Principal component regression</td>
</tr>
<tr>
<td>PLS</td>
<td>Partial least squares regression</td>
</tr>
<tr>
<td>PM</td>
<td>Projective mapping</td>
</tr>
<tr>
<td>RCT</td>
<td>Rennet coagulation time</td>
</tr>
<tr>
<td>TDS</td>
<td>Temporal dominance of sensations</td>
</tr>
</tbody>
</table>
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About the author
Cheese is a staple found in most homes in the Western world. In the European Union (EU), per capita cheese consumption was 12.0 kg in 2012, expected to grow to 19.8 kg by 2023. The EU produces almost 50% of the cheese made in the world and with the abolition of the milk quota system in the EU in 2015, the cheese industry is expected to boom, reaching predicted production levels of nearly 11 million tonnes by 2023 (European Commission 2013). Given the situation, industrial cheesemaking, already at a high level, is set to need greater efficiency in production and innovations to help efficiency and profitability.

The ultimate goal of any development of a product is for that product to be accepted by the consumer. What complicates matters is that such acceptance of a product is based on a multitude of factors, not all of which the producer can control (Cardello and Schutz 2006). However, ensuring that the product meets the sensory demands and expectations of consumers is an important step towards product acceptance (Lawless and Heymann 2010; Tuorila 2007).

The work described in this thesis strives to develop and thoroughly examine a relatively simple pre-treatment for milk which incorporates low-pressure homogenisation with the aim of causing controlled lipolysis and subsequent exploitation to improve the sensory characteristics and consumer acceptability of cheese, while, at the same time being of benefit to producers of cheese. The thesis covers the work presented in the four original articles where investigation began with development and examination of the pre-treatment prior to Cheddar cheese manufacture on a relatively small scale, up to increasingly larger-scale Emmental cheese trials, where sensory characteristics and consumers responses were evaluated and interpreted.

The following literature review gives an overview of the wide range of subjects relevant to the experimental work. First, a brief background of milk and cheese is given, followed by a more detailed description of the biochemistry underlying the complex process of cheese ripening. The process of homogenisation is described; along with the limited information available regarding its limited use in cheesemaking and effect on cheesemaking characteristics. The sensory characteristics of cheeses; flavour, texture and appearance are described, as well as the types of tests used in evaluation of cheeses. The methodology of two sensory evaluation techniques used in the thesis work, namely descriptive sensory profiling and temporal dominance of sensations, is discussed while the projective mapping consumer evaluation method is also detailed. Finally, an overview is given of the responses of consumers to food.
2 LITERATURE REVIEW

2.1 Milk

Milk is a fluid secreted by the female of all mammals with the primary function of supplying the neonate with its complete nutritional requirements and, in some species, immunological protection (Fox 2003). Milk contains lipids, proteins, salts, carbohydrates and many other miscellaneous constituents. The nutritional requirements of mammals are species-specific and change as the neonate matures, as a result, the composition of milk varies widely between species (Fox 2003). The composition of bovine milk is shown in Table 1.

The composition of milk varies widely and depends on a number of factors including stage of lactation, age, pregnancy, nutrition, season, infection and milking procedure (Jenness 1999). Energy requirements of the neonate are fulfilled by lipids, lactose and protein in the milk, with protein supplying essential amino acids and amino groups for the synthesis of non-essential amino acids (Fox 2003). Essential fatty acids, vitamins, inorganic elements and water are also supplied by milk. Physiologically important peptides and proteins, namely immunoglobulins, enzymes, enzyme inhibitors, growth factors, hormones and anti-bacterial agents, have protective or other physiological roles (Fox 2003). The nutrient dense nature of milk has led it to be described as “nature’s perfect food” (Balcao and Malcata 1998).

<table>
<thead>
<tr>
<th>Component</th>
<th>Average content in milk (% w/w)</th>
<th>Range</th>
<th>Average content in dry matter (% w/w)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water</td>
<td>87.1</td>
<td>85.3-88.7</td>
<td></td>
</tr>
<tr>
<td>Solids-not-fat</td>
<td>8.9</td>
<td>7.9-10.0</td>
<td></td>
</tr>
<tr>
<td>Fat in dry matter</td>
<td>31</td>
<td>22-38</td>
<td></td>
</tr>
<tr>
<td>Lactose</td>
<td>4.6</td>
<td>3.8-5.3</td>
<td>36</td>
</tr>
<tr>
<td>Fat</td>
<td>4.0</td>
<td>2.5-5.5</td>
<td>31</td>
</tr>
<tr>
<td>Protein(^1)</td>
<td>3.25</td>
<td>2.3-4.4</td>
<td>25</td>
</tr>
<tr>
<td>Casein</td>
<td>2.6</td>
<td>1.7-3.5</td>
<td>20</td>
</tr>
<tr>
<td>Mineral substances</td>
<td>0.7</td>
<td>0.57-0.83</td>
<td>5.4</td>
</tr>
<tr>
<td>Organic solvents</td>
<td>0.17</td>
<td>0.12-0.21</td>
<td>1.3</td>
</tr>
<tr>
<td>Miscellaneous</td>
<td>0.15</td>
<td>1.2</td>
<td></td>
</tr>
</tbody>
</table>

\(^1\) Nonprotein nitrogen components not included.

Milk and dairy products are a major part of the human diet, particularly in Western countries, where they contribute approximately 30% of dietary proteins and lipids and
80% of dietary calcium (Fox 2003). The chemical and physico-chemical properties of milk result in it being a flexible raw material. Even though some of the milk produced is consumed as is, the vast majority of milk is converted to dairy products, with thousands of types of dairy products produced from milk around the world (Fox 2003).

### 2.1.1 Milk lipids

Milk fat globules were first noted by van Leeuwenhoek in 1674 from his microscopic analysis of milk. Lipids are esters of fatty acids, or similar compounds, with glycerol, which are soluble in non-polar organic solvents and insoluble, or sparingly soluble, in water (Mulder and Walstra 1974). Milk lipids are found mainly in the form of spherical droplets ranging in size from <0.2 to >15 μm in diameter with >10^10 fat globules per mL (Huppertz and Kelly 2006). The majority of the fat globules (80%) are less than 1 μm diameter but contain <10 % of total milk fat volume; the globules between 1 and 8 μm diameter contain more than 90% of total milk fat volume, and the globules >8 μm in diameter contain 1-3% of the total fat volume (Mulder and Walstra 1974).

Triacylglycerols (TAGs) are present in milk fat at high concentrations (98.3% w/w of lipids) and have a major effect on the properties of milk fat including hydrophobicity, density and melting characteristics (MacGibbon and Taylor 2006). TAGs consist of three fatty acids esterified on to a glycerol backbone with 3 bonding positions (sn-1, sn-2 and sn-3; **Figure 1**).

![Fischer projection diagram of a triacylglycerol showing the stereospecific numbering (sn-) convention.](image)

There are approximately 400 fatty acids present in bovine milk (Jensen 2002) with around 15 present at concentrations exceeding 1% (w/w). The position of fatty acids on the triacylglycerol structure is not random and there is in fact a highly specific distribution of fatty acids in the triacylglycerides of bovine milk fat, when the cow has been fed a normal diet (Jensen 2002). As the combination of fatty acids esterified onto the triacylglycerol influences the melting point of that triacylglycerol, selectivity of position of fatty acids is important. For example, triacylglycerols are the most abundant lipid in the milk fat globule membrane, and their melting point must be ≤ 39ºC to ensure the fluidity of the membrane relative to the body temperature of the cow (Jensen 2002). Approximately 220
triacylglycerol species account for 80% of the triacylglycerols present in bovine milk (Gresti et al. 1993).

Phospholipids, although present at low concentrations in bovine milk (0.8% w/w or lipids; Walstra and Jenness, 1984), play a very important role in the milk fat globule membrane (MFGM). The stabilisation of milk fat in the aqueous phase of milk can be attributed to the presence of phospholipids, as their structure, through hydrophobic interactions with the long chain fatty acids and through hydrophilic interactions with the polar group, facilitates this stabilisation (Deeth 1997). Sterols are another class of lipids which are present in small quantities and cholesterol represents 95% of the total sterols present in bovine milk (Jensen and Newberg 1995; MacGibbon and Taylor 2006). Carotenoids are present at trace levels in bovine milk (MacGibbon and Taylor 2006), while fat-soluble vitamins are also present in small amounts in bovine milk fat; vitamin A as retinol, retinal and retinoic acid; vitamin E, an important antioxidant, and vitamins D and K at very low concentrations in milkfat (MacGibbon and Taylor 2006).

Most of the lipids in bovine milk are in the form of fat globules which are secreted and covered in a membrane, a loose layer of bipolar materials, phospholipids, proteins, cholesterol and enzymes, the MFGM. Lipids and proteins represent approximately 90% of the total dry weight of the MFGM (Keenan and Mather 2006). The lipid composition of the membrane is dominated by TAGs (Fong et al. 2007) which contain higher proportions of longer chain fatty acids than the TAGs of the core globule fat which gives the MFGM a more rigid nature (Fong et al. 2007; McPherson and Kitchen 1983). Phospholipids represent a considerable proportion of total lipid in the MFGM and 60% of total phospholipids in milk are located in the MFGM (Keenan and Mather 2006). The proteins in the milk fat globule membrane constitute approximately 1% of the total protein concentration in milk (McPherson and Kitchen 1983) and represent 25-60% of the total mass of MFGM material.

### 2.2 Cheese

Cheese is a generic name given to a group of fermented milk-based food products, thought to originate around 8000 years ago in the region known as the ‘Fertile Crescent’, the area surrounding the Tigris and Euphrates rivers in the Middle-East. Converting the main constituents of milk into cheese proved advantageous for preservation, storage and ease of transport; hence cheesemaking became established in ancient civilisations (Fox and McSweeney 2004). Cheesemaking has spread and diversified through the migration of people, initially throughout Europe, then the Americas, Oceania and Africa. Today, over 1000 varieties of cheese exist, produced from essentially the same raw material (McSweeney et al. 2004).
2.2.1 Cheese production

The production of most cheese varieties follows the same basic procedure, the main stages of which are shown in Figure 2. Milk is selected on the basis of microbiological quality and may be standardised to the desired fat and protein concentration. The milk can then be subjected to a heat treatment, e.g. pasteurisation (commonly HTST, high-temperature short-time; 72°C x 15 s) which is used commonly to reduce the microbial content of the milk, to kill pathogens and to inactive certain enzymes (Fox et al. 2000). In most cheeses, acidification is the basic operation in manufacture and can be initiated by either adding a culture (starter) of lactic acid-producing bacteria (LAB), acid production by the indigenous milk microflora, or by directly adding acid (Fox and McSweeney 2004). In rennet-coagulated cheeses, coagulation of the acidified milk is the next stage of the production. Coagulation is usually carried out by adding enzyme preparations known as rennets (Fox et al. 2000), which contain chymosin (EC 3.4.23.4), a proteinase which originates in the stomach. Chymosin acts on κ-casein at the surface of the casein micelle in milk, splitting the molecule at the phenylalanine 105-methionine 106 bond (Phe$_{105}$-Met$_{106}$), which results in a loss of steric stabilisation of the casein micelles. Aggregation of the rennet-altered micelles, promoted by calcium, results in the formation of a coagulum or gel, with a large increase in viscosity (Crabbe 2004; Upadhyay et al. 2004). Following aggregation and coagulation, the gel is cut to promote syneresis, or dehydration, resulting in contraction of the gel and the removal of whey (Fox and McSweeney 2004). After a cooking step, curds and whey are separated by various variety-specific methods and transferred to moulds. Prior to moulding, curds for pasta-filata cheeses are kneaded and stretched and curds for Cheddar-type cheeses undergo a process known as ‘cheddaring’, a process of cutting, stack and milling. Salt is added at the end of manufacture, either as brine (the majority of cheeses) or by dry-salting, to minimise spoilage, prevent pathogenic bacterial growth and for flavour (Guinee and Fox 2004; McSweeney et al. 2004).

**Figure 2.** The major stages of cheesemaking (adapted from McSweeney 2007).
Classification of cheese can be by texture, method of coagulation and/or ripening indices (McSweeney et al. 2004). General classification usually covers; very hard bacterial-ripened (e.g., Parmesan), hard internal bacterially-ripened (e.g., Cheddar), hard internal bacterially-ripened with eyes (e.g., Emmental), semi-soft internal bacterially-ripened (e.g., Gouda), bacterial surface-ripened (e.g., Limburger), internal mould-ripened (e.g., Roquefort) and soft surface mould-ripened (e.g., Brie) or unripened (e.g. Cottage; Fox et al. 2000). Emmental cheese is often referred to as ‘Swiss cheese’. Usage of the term ‘Swiss cheese’ in this thesis refers to Emmental, unless otherwise stated.

2.2.2 Biochemistry of cheese ripening

On the first day of ripening, most cheeses are similar in terms of appearance, structure and taste. Rennet-coagulated cheeses undergo ripening after manufacture during which time, through important biochemical pathways, the specific flavour and texture characteristics of the variety are formed (Engels et al. 2003; McSweeney 2004). The major biochemical changes which occur in cheese are grouped under the headings: proteolysis and amino acid (AA) catabolism, degradation of the casein matrix to peptides and amino acids, with subsequent degradation of AA; lipolysis, liberation of FFAs; and the metabolism of residual lactose, lactate and citrate (McSweeney and Sousa 2000). The major biochemical pathways involved in cheese ripening are shown in Figure 3.

![Figure 3. General overview of the biochemical pathways in cheese ripening (adapted from McSweeney et al. 2006).](image-url)
2.2.2.1 Glycolysis, proteolysis and amino acid catabolism

Glycolysis and associated metabolism

Bovine milk contains approximately 4.6 % lactose, most of which is lost in the whey during cheese production, leaving low levels (0.8-1.0 %) in cheese (McSweeney 2004). Starter LAB convert lactose to lactic acid (lactate) during the preparation of curd and in the early stages of cheese ripening (Fox et al. 2000). The production of lactic acid influences many important properties of the cheese. In terms of cheese texture, the conversion of lactose to lactate influences the pH of the cheese which directly affects casein solubility and indirectly affects the activity of enzymes and retention of coagulant in the curd (McSweeney 2004). Residual lactose is quickly metabolised at a rate determined by temperature and salt-in-moisture (S/M) levels. In dry-salted varieties, the S/M levels of cheese rapidly increases during the salting step, the activity of the starter bacteria is stopped and the remaining lactose is probably metabolised by non-starter lactic acid bacteria (NSLAB), which also produce D-lactose (McSweeney and Fox 2004).

The catabolism of lactate is a key biochemical event in ripening and greatly influences the properties of numerous cheese varieties. Lactate can be metabolised by 5 pathways, namely: racemisation to D-lactate by NSLAB; by strains of Propionibacterium to produce water, carbon dioxide, propionate and acetate; by mould-species such as Geotrichum candidum and Penicillium spp. to produce water and carbon dioxide; by NSLAB to produce formate and acetate; or by the anaerobic metabolism of lactate to produce butyrate, hydrogen gas and carbon dioxide, known as ‘late gas blowing’ (Fox et al. 2000; McSweeney and Fox 2004). The second of these pathways is extremely important in Swiss cheese, where selected strains of Propionibacterium (usually P. freudenreichii) are used to give the characteristic eyes. CO₂ is produced and diffuses through the cheese where it accumulates at a centre of future eye formation and begins to produce holes or eyes in the cheese (Frölich-Wyder and Bachmann 2004). The propionate and acetate produced by this pathway also influence heavily the nutty flavour of Swiss cheese.

Bovine milk contains approximately 8 mmol L⁻¹ citrate, of which around 94% is lost in the whey during cheesemaking (McSweeney and Sousa 2000). The remaining citrate is an important precursor for certain flavour compounds produced by mesophilic starter cultures, CO₂, which is important for eye formation in some cheeses, and diacetyl and acetate, which are important flavour compounds and precursors to other flavour compounds (McSweeney and Sousa 2000; Parente and Cogan 2004).

Proteolysis and amino acid catabolism

Proteolysis is the most complex and most important biochemical event in cheese ripening (McSweeney 2004). The process plays an integral role in ripening due to: changes in texture due to casein network breakdown, decreased water activity (aw) and increase in
pH; direct contribution to cheese flavour/ off-flavour by peptides and free amino acids (FAA); liberation of amino acids for secondary amino acid catabolism reactions; and changes to the cheese matrix, which allow the release of sapid compounds on mastication (McSweeney and Sousa 2000). In general, initial hydrolysis of caseins is due to coagulant and also plasmin and somatic cell proteinases (McSweeney 2004) causing the production of large water-insoluble and small water-soluble peptides which are then hydrolysed by coagulant and enzymes from the starter LAB or NSLAB. The enzymes involved in proteolysis are derived from the coagulant, the milk (plasmin, cathepsin D and perhaps other somatic cell proteinases), starter bacteria, NSLAB, secondary starter or from an exogenous source (McSweeney and Sousa 2000).

Catabolism of amino acids plays an important role in flavour development in cheese during ripening (Curtin and McSweeney 2004; McSweeney and Sousa 2000) resulting in the production of volatile sulphur compounds, α-ketoacids and in some cases ammonia, the latter having an important role in the flavour of Camembert, Gruyère and Comté (Curtin and McSweeney 2004; Fox et al. 2000; McSweeney and Sousa 2000; McSweeney 2004).

2.2.2.2 Lipolysis

Lipids in cheese are broken down into FFAs and partial glycerides in cheese mainly through hydrolytic degradation, as the low redox potential (ca. -250 mV) and presence of natural antioxidants in cheese, prevent oxidative degradation at any appreciable level (Collins et al. 2004; Fox and Wallace 1997; McSweeney and Sousa 2000).

Extensive lipolysis occurs in Blue (e.g. Gorgonzola, Roquefort and Danablu) and hard Italian cheese (e.g. Parmigiano-Reggiano, Grana Padano and Pecorino) where it plays a pivotal role in flavour formation (Cantor et al. 2004; Collins et al. 2004; Deeth and FitzGerald 2006; Gobbetti 2004). Less extensive lipolysis occurs in cheese like Emmental, where FFAs are produced simultaneously with the growth of the propionic acid bacteria.

Lipolytic agents

In cheese, there are six possible sources of lipolytic enzymes, namely; milk, rennet paste, starter bacteria, secondary organisms, NSLAB and exogenous lipases (Collins et al. 2004).

Milk of different species contains two indigenous enzymes, bile salt-stimulated lipase (BSSL) and lipoprotein lipase (LPL); the former is not present in bovine milk (Olivecrona et al. 2003). Bovine milk contains 1-2 mg/L LPL (i.e., 10-20 nM) and 80% of LPL in bovine milk is associated with casein micelles (Fox et al. 1967; Hohe et al. 1985). Milk contains sufficient LPL for potentially high lipolysis, but this is prevented by the protective effect of the MFGM, which separates LPL from its substrate. However, if the
membrane is damaged, for example by homogenisation or temperature abuse, lipolysis will occur (Driessen 1983).

In cheese, LPL is immobilised in the casein gel system and thus makes only a small contribution to the overall level of lipolysis during ripening (Fox and Stepaniak 1993). Also, the relatively low pH of young cheese (approximately 5.1) is sub-optimal for LPL, which has an optimum between pH 8 and 9. LPL is thought to be most important in lipolysis in raw milk cheeses, since pasteurisation reduces LPL activity (McSweeney and Sousa 2000). LPL is a relatively heat-labile enzyme (Farkye and Imafidon 1995) with complete inactivation occurring at 75°C for 15 s (Andrews et al. 1987). LPL has been shown to have a preference for short- and medium-chain fatty acids in milk fat triacylglycerols and positional preference with acids esterified at the sn-1 and sn-3 positions hydrolysed first (Somerharju et al. 1978).

Rennet pastes are traditionally used in the manufacture of some hard Italian varieties, such as Provolone and Romano, and some traditional Greek cheeses, such as Feta, as a source of both coagulant and lipolytic agents. Rennet pastes are prepared by drying and grinding the abomasa or stomach, and its contents, of calves, kids or lambs after suckling and holding for approximately 60 d. Rennet pastes are slurried with milk and used as the rennet preparation for coagulating the cheesemilk (Fox and Stepaniak 1993; Gobbetti 2004). Rennet pastes contain a lipase known as pregastric esterase (PGE) which is very important for flavour development in these cheeses (Collins et al. 2003; Gobbetti 2004; McSweeney and Sousa 2000). More recently, there has been a drive to find alternatives to rennet pastes due to their poor hygienic quality (Collins et al. 2004) and as their use is not permitted in many countries (Gobbetti 2004).

In general, starter bacteria have very weak lipolytic activity (Fox and Stepaniak 1993) but can contribute to ripening through autolysis and release of their intracellular enzymes (Khalid and Marth 1990). *Lactococcus* spp. are weakly lipolytic while thermophilic LAB (like *S. thermophilus* used in Swiss and Italian cheeses) have been shown to exhibit noticeable lipolytic activity *in vitro* (McSweeney and Sousa 2000). The esterases of starter LAB are the main contributors to lipolysis in Cheddar cheese, with a significant level of lipolysis occurring in the vat during cheesemaking while NSLAB are thought to have a minimal effect on total lipolysis. Propionic acid bacteria are 10 to 100 times more lipolytic than LAB and are the main agents in lipolysis in Emmental cheese (Chamba and Perreard 2002; Collins et al. 2004).

**Fatty acid catabolism**

Fatty acids produced as a result of lipolysis have a direct flavour in cheese but are also precursors for the production of other volatile flavour compounds, through a series of catabolic reactions (McSweeney and Sousa 2000; McSweeney 2004). Flavour compounds
produced include methyl ketones, lactones, esters, alkanes and secondary alcohols (Collins et al. 2003).

## 2.3 Homogenisation

### 2.3.1 Homogenisation of milk

Homogenisation of milk was developed by Gaulin in 1899 and has since seen widespread use in the dairy industry to prevent creaming during storage of milk (Tunick 2009). Fat globules in milk are less dense than the surrounding plasma, thus they tend to move upwards and coalesce (creaming). Homogenisation reduces the size of fat globules thus retarding the separation of globules enough to prevent a cream layer being formed in homogenised milk products during their shelf-life (Huppertz and Kelly 2006). In conventional homogenisation of bovine milk, pre-warmed milk at 45-50°C is passed through two small orifices in a two-stage homogeniser at pressures between 10-20 MPa, where various forces split the fat globules into smaller globules (Hayes et al. 2005). Homogenisation results in a reduction in size from 1-10 μm to smaller droplets, typically ≤ 1 μm in diameter, as shown in Figure 4 (Hayes and Kelly 2003; Huppertz and Kelly 2006).

Following homogenisation, the majority of fat in milk exists as damaged fat globules covered by the original MFGM and absorbed caseins (Michalski et al. 2002). The new membrane is formed due to an increase in the total surface area of fat by 5-10 fold which is too large to be stabilised by the original amount of MFGM material and which therefore adsorbs casein micelles (preferentially) and whey proteins (Darling and Butcher 1978; Lee and Sherbon 2002; Michalski et al. 2002; Sharma and Dalgleish 1994). The protein content of the membrane surrounding fat globules in homogenised milk can be 3.5 fold higher than that of the MFGM in non-homogenised milk (Lee and Sherbon 2002). This rearrangement of milk protein affects many processing capabilities as the newly formed fat globules can act as pseudo-casein particles, which can form part of a rennet-induced gel (Huppertz and Kelly 2006). The technological, rheological and sensory properties of milk products, like cheese, can also be affected greatly by the size distribution of fat globules (Michalski et al. 2002).

Another consequence of homogenisation of milk and subsequent damage to the MFGM is the increased susceptibility of the milk fat to hydrolysis by lipases (mainly LPL), which are normally blocked from accessing the milk fat by the MFGM (Deeth and Fitz-Gerald 2006). Homogenisation induces lipolysis in raw milk, with milk becoming perceptibly rancid within 5 min of treatment (Mulder and Walstra 1974), however, this is prevented by pasteurisation directly following homogenisation, which largely inactivates LPL.
2.3.2 Homogenisation in cheesemaking

Homogenisation of cheesemilk prior to cheesemaking produces deleterious consequences in the resultant cheese (see below) and is not usually used in the manufacture of most cheese types (Jana and Upadhyay 1992). However, homogenisation has been used for various reasons in the past. Since 1916, homogenisation of cream from bovine milk has been used in the production of the Danish blue cheese (Danablu), with the objective of making the cheese as white as Roquefort (made from sheep’s milk) and also to accelerate ripening (Cantor et al. 2004). Homogenisation of milk has also, in some instances, been used in the production of Roquefort, Swiss, Mozzarella, Kashkaval and Cheddar cheese, to limited success (Jana and Upadhyay 1992).

2.3.3 Effect on cheesemaking characteristics

The small size of fat globules in homogenised milk and the presence of protein on the newly formed fat membrane allows them to behave as casein micelles (Huppertz and Kelly 2006). Rennet coagulation time (RCT) is lower for homogenised milk than for non-homogenised milk (Ghosh et al. 1994; Robson and Dalgleish 1984). κ-casein is spread over a larger surface area of fat globules upon homogenisation than over the surface of casein micelles in un-homogenised milk, allowing a greater amount of it to be available for chymosin action in coagulation and subsequent decrease in RCT (Guinee et al. 1997). More κ-casein becomes available as homogenisation pressure increases, further reducing RCT (Ghosh et al. 1994).

![Figure 4](image.jpg) Effect of conventional homogenisation on the volume frequency distribution of fat globules in milk (modified from Huppertz and Kelly 2006).
Homogenisation of milk decreases the rate of syneresis of renneted milk due to the incorporation of the casein-covered fat globules into the para-casein network formed on coagulation, which hampers its contraction (Green et al. 1983; Walstra et al. 1985). This effect increases with increasing homogenisation pressure and results in a weaker rennet coagulum and poor matting of curd in cheesemaking (Ghosh et al. 1994; Green et al. 1983; Jana and Upadhyay 1992; Metzger and Mistry 1994).

Greater firmness in cheese made from homogenised milk relative to non-homogenised milk cheese, has been found by several authors and has been attributed to the reduction of fat globule size allowing casein micelles to associate more closely and hence form a stronger matrix (Kheadr et al. 2002; O’Mahony 2005; Tunick et al. 1995). Some of the detrimental effects of homogenisation on the protein matrix can be avoided by selective homogenisation of the cream only (Nair et al. 2000).

Homogenisation of cheesemilk has varying effects on the composition of cheese. As the compositional specifications of commercial cheeses are strictly controlled, any drastic change in composition from that of what is normally attained can be regarded as undesirable. Moisture increased in Cheddar cheeses made from homogenised milk (Jana and Upadhyay 1992; Peters 1956; Peters and Moore 1958) due to the fat globules in homogenised milk cheese becoming part of the casein matrix, causing interference in micelle aggregation and fusion to form a less compact structure with increased moisture and poor syneresis (Walstra et al. 1985). Curd is also formed more slowly in homogenised milks, resulting in greater moisture retention (Green et al. 1983). Fat levels in cheeses made from homogenised milk increase with increasing homogenisation pressures with an associated reduction of fat loss in whey (Jana and Upadhyay 1992; Nair et al. 2000; Peters 1956). Lower protein contents have been reported in Cheddar cheese made from homogenised milk, probably due to the dilution effect of higher moisture and salt contents in the homogenised milk cheeses (Nair et al. 2000). Salt content and salt-in-moisture (SM) both increase with increasing homogenisation pressure as there is lower syneresis (Walstra et al. 1985). The pH of Cheddar and Mozzarella increases on homogenisation due to a slower rate of acid development (Jana and Upadhyay 1992). Homogenisation of milk for cheesemaking results in increased yield attributed to increased moisture and decreased losses in whey, which taken alone, is positive (Rao et al. 1985). Cheese has been shown to become whiter in colour, when homogenised milk was used for its production in Cheddar (Peters 1956) and Swiss-type cheese and Mozzarella (Jana and Upadhyay 1992; Peters and Moore 1958).

Excessive production of FFAs results from lipolysis in cheeses produced with homogenisation; an effect normally prevented by pasteurisation (Green et al. 1983; O’Mahony 2005). Homogenisation causes a breakdown on the compartmentalisation of fat in the MFGM allowing access by LPL and subsequent rancidity. Homogenisation of milk may also cause the release of LPL from the surface of casein micelles by disruption of electrostatic interactions between LPL and the micelle (Anderson 1982).
2.4 Sensory characteristics of cheese

2.4.1 History and types of tests

With over 1000 varieties of cheese in existence and given the extremely long history of production worldwide, it is no surprise that cheese is primarily characterised and evaluated based on flavour and texture. The most widespread form of sensory test carried out in the cheese industry worldwide is quality scoring and grading, based on specific quality terms (Delahunty and Drake 2004). The aim is to evaluate the potential use of the cheese and to give an measure of ‘quality’ relative to specifications (Partridge 2009). While fast and practical in an industrial setting, many of the terms used are outdated and ambiguous, the results do not describe the sensory profile of the cheese and results are not associated with either consumer preference or acceptance (Drake 2007). A similar method involves the use of scorecards, which consists of a list of factors which contribute to the overall quality of the cheese. This system is mainly used in the United States and Canada in competition settings, with the aim of promoting excellence in dairy manufacturing (Clark and Costello 2009). Neither of these methods allow the application of statistical methods, which would permit investigation of relationships between cheese variables (Delahunty and Drake 2004). For this reason and the reasons mentioned above, these methods should not be used in research (Drake 2007).

Modern sensory analysis of cheese is based on psychological, physical and physiological responses of humans to external stimuli, which ensure that potentially biasing factors are minimised (Drake 2007; Lawless and Heymann 2010). Such methods can range from the simple (e.g. a discrimination test to determine if a difference exists between two or more products) to more extensive (e.g. descriptive sensory profiling, discussed below). As a result of extensive sensory characterisation of cheeses, an extensive amount of information is available regarding variety-specific flavour and texture, definitions of attributes, suitable reference standard and methods of analysis.

2.4.2 Flavour

Cheese flavour is the combination of olfactory, taste and chemesthetic stimuli (Delahunty and Drake 2004). The flavour of a cheese is affected by the starting raw material, processes used during processing and production (e.g. pasteurisation, homogenisation) and the biochemical changes which occur during ripening.

The ripening of cheese (glycolysis, proteolysis and lipolysis, described above) transforms a product, which on day one is quite bland and shows little variation between varieties, to a product which has a complex and characteristic flavour (McSweeney and Sousa 2000). As previously described (and shown in Figure 3), biochemical pathways aided by enzymes from the starter bacteria, secondary starters, coagulant, exogenous sources and
the milk itself, result in the production of large variety of volatile flavour compounds. While certain compounds are essential for the correct flavour of a cheese variety (e.g. propionic acid in Emmental cheese), it is the delicate balance between the multitude of compounds produced from ripening which is responsible for the characteristic flavour of a cheese variety. This is the basis of the Component Balance Theory of Cheese Flavour (Mulder 1952).

It should also be mentioned that, while volatile flavour compounds are key to correct flavour formation, taste compounds in the cheese also contribute (Delahunty and Drake 2004). Sodium chloride (added as part of the production process) and, to a lesser extent, other salts of calcium, potassium and magnesium cause saltiness (Engel et al. 2000), lactic acid contributes to sourness, glutamic acid to umami (Drake 2007) and hydrophobic peptides and some free amino acids to bitterness (McSweeney and Sousa 2000; McSweeney 2004). Chemesthesis describes chemical-induced sensations which are in part tactile, such as burning, tingling and coolness (Lawless and Heymann 2010). Such sensations can also be found in cheeses, for example the pungent, prickliness and sharpness in mature Cheddar (Delahunty and Drake 2004).

The scientific literature contains many applications of sensory tests to determine the intensity of specific named flavour and chemesthesia attributes, usually through descriptive sensory profiling (see later). An excellent review of such attributes is included in Delahunty and Drake (2004). A list of flavour and chemesthesia attributes from recent cheese research studies (2002-2013) is shown in Table 2.

2.4.3 Texture

Cheese is a viscoelastic protein (para-casein) gel containing fat and moisture, dissolved solutes and enzymes (Lucey et al. 2003; O'Callaghan and Guinee 2004). Texture results from the senses of touch, vision and hearing perceiving the physical properties (size, shape, nature and number of structural parts) of the cheese (Delahunty and Drake 2004). The perception of cheese texture can occur at each stage of consumption, from assessing the softness on cutting, the smoothness on spreading (a soft cheese), the firmness, crumbliness and stickiness during mastication and the mouth-coating or oiliness on swallowing.

The physical properties of a cheese, including texture, are determined by the initial composition of the milk, the production process and ripening conditions (Lucey et al. 2003). Like flavour, the characteristic texture of a cheese variety is an important quality factor and can vary widely depending on the ripening conditions. Generally speaking, at the start of ripening, the gel network is a loose network of particles of casein protein, and as ripening progresses, the particles fuse, resulting in a tightening of the network (O'Callaghan and Guinee 2004). Such changes occur primarily through proteolysis with enzymatic action from microorganisms and the coagulant as well as changes in mineral content.
Table 2. Examples of taste, odour and chemesthetic attributes and definitions in recent cheese research.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Study(^a)</th>
<th>Definition (from study number)(^b)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall intensity</td>
<td>2,3,6,7</td>
<td>Perceived total intensity of flavour (3)</td>
</tr>
<tr>
<td>Umami</td>
<td>1,5,8,10</td>
<td>Chemical feeling factor elicited by certain peptides and nucleotides (1)</td>
</tr>
<tr>
<td>Salty</td>
<td>1-10</td>
<td>Basic taste sensation generated by salts (1)</td>
</tr>
<tr>
<td>Sour/ Acidic</td>
<td>1-10</td>
<td>Basic taste sensation generated by acids (1)</td>
</tr>
<tr>
<td>Sweet</td>
<td>1,2,3,4,7,8,9,10</td>
<td>Basic taste sensation generated by sugars (1)</td>
</tr>
<tr>
<td>Bitter</td>
<td>1-10</td>
<td>Basic taste sensation generated by caffeine (1)</td>
</tr>
<tr>
<td>Milky</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Creamy</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Diacetyl</td>
<td>1,5,8,10</td>
<td>Aroma associated with diacetyl (5)</td>
</tr>
<tr>
<td>Milk fat</td>
<td>1,5,8</td>
<td>Aromatics associated with milk fat/lactone (5)</td>
</tr>
<tr>
<td>Soured milk</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Buttery</td>
<td>1,2,7</td>
<td>The clean, fatty, mild flavour of fresh butter (9)</td>
</tr>
<tr>
<td>Nutty</td>
<td>1,2,3,5,7,8,10</td>
<td>Nut-like aromatics with different nuts (5)</td>
</tr>
<tr>
<td>Plastic</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Stale</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Earthy</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>Toasted</td>
<td>1,9</td>
<td>Aroma associated with a nutty, caramelized, browned character of</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Maillard browned starches and sugars.(9)</td>
</tr>
<tr>
<td>Brothy</td>
<td>5,8</td>
<td>Aromatics associated with boiled meat or vegetable soup (5)</td>
</tr>
<tr>
<td>Butyric/Rancid</td>
<td>2,4,5,7,9,10</td>
<td>Rancid aromatic associated with butyric acid (9)</td>
</tr>
<tr>
<td>Malty</td>
<td>3</td>
<td>Flavour of malt (3)</td>
</tr>
<tr>
<td>Sulphur</td>
<td>- eggy</td>
<td>3,5,8                      Sulphur aroma associated with hard boiled eggs (5)</td>
</tr>
<tr>
<td></td>
<td>- match</td>
<td>5                         Sulphur aroma associated with a freshly struck match (5)</td>
</tr>
<tr>
<td></td>
<td>- cabbage</td>
<td>8                         Aromatics associated with cooked cabbage (8)</td>
</tr>
<tr>
<td>Goaty</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Cowy</td>
<td>5,8</td>
<td>Aromas associated with barns and stock trailers (5)</td>
</tr>
<tr>
<td>After taste</td>
<td>6</td>
<td>Intensity of the taste determined 30s to 1 min after swallowing (6)</td>
</tr>
<tr>
<td>Caramel</td>
<td>7</td>
<td>Dairy caramel, toffee that has been made with sugar or melted further</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(7)</td>
</tr>
<tr>
<td>Dairy-sweet</td>
<td>7</td>
<td>Taste associated with sweetened culture dairy products such as fruit</td>
</tr>
<tr>
<td></td>
<td></td>
<td>yoghurt. Fruity sweet taste (7)</td>
</tr>
<tr>
<td>Silage</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>Sweaty</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>Mushroom</td>
<td>9</td>
<td>An aroma generally associated with fresh raw mushrooms (9)</td>
</tr>
<tr>
<td>Floral</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Green</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>Cheddarary</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Fruity</td>
<td>5,8,10</td>
<td>Flavour associated with different fruity identities- apple, pineapple,</td>
</tr>
<tr>
<td></td>
<td></td>
<td>banana, peach (10)</td>
</tr>
<tr>
<td>Cooked milk</td>
<td>5,8,10</td>
<td>Flavour associated with milk cooked at 85ºC for 40 min (10)</td>
</tr>
<tr>
<td>Whey</td>
<td>5,8</td>
<td>Aromatics associated with Cheddar cheese whey (5)</td>
</tr>
<tr>
<td>Pungency</td>
<td>3,7</td>
<td></td>
</tr>
<tr>
<td>Astringency</td>
<td>1,7</td>
<td></td>
</tr>
</tbody>
</table>


\(^b\) Definitions quoted directly from the referenced studies.
equilibrium (Lucey et al. 2003). Numerous studies have investigated and characterised aspects of texture, resulting in various texture attributes, some of which use study-specific terms. An extensive list can be found in Delahunty and Drake (2004). A selection of textural attribute terms and definitions from more recent studies of cheese (2002-2014) is shown in Table 3.

### 2.4.4 Appearance

Appearance characteristics of cheese generally involve the surface; colour, presence of eyes, mould, rind, visual texture and the market image; shape, size and packaging (Delahunty and Drake 2004). Each cheese variety has specific appearance properties which are essential for consumer acceptance. Emmental cheese, for example, is characterised not only based on the nutty aroma, or slightly elastic texture, but on the presence of round or slightly oval-shaped eyes or holes (Frölich-Wyder and Bachmann 2004). The proper formation of such eyes is important for determining commercial value and consumer acceptance (Cakir and Clark 2009).

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Study</th>
<th>Definition (from study number)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Firm</td>
<td>1,4, 5, 7, 8, 10</td>
<td>Amount of force required to completely bite through the sample (1)</td>
</tr>
<tr>
<td>Hard</td>
<td>2,3,6</td>
<td>The extent of the initial resistance offered by the cheese (8)</td>
</tr>
<tr>
<td>Tough</td>
<td>6</td>
<td>Difficulty of chewing as determined when a piece is ready to be swallowed (6)</td>
</tr>
<tr>
<td>Hand firm</td>
<td>5,6,9,10</td>
<td>Force required to completely compress the sample (5)</td>
</tr>
<tr>
<td>Elasticity/Rubbery</td>
<td>2,3, 6,7,8</td>
<td>Rapidity and degree of recovery from a deforming force (3)</td>
</tr>
<tr>
<td>Fracturability</td>
<td>5</td>
<td>The amount of factorability in sample after biting (5)</td>
</tr>
<tr>
<td>Friability</td>
<td>2,4</td>
<td>Capacity of a sample to break up into numerous pieces from the beginning of mastication (4)</td>
</tr>
<tr>
<td>Crumbly</td>
<td>7,8</td>
<td>The extent to which the cheeses structure break up in the mouth (7)</td>
</tr>
<tr>
<td>Sticky</td>
<td>1,6</td>
<td>The degree to which the chewed sample sticks to the surfaces of the mouth and teeth (1)</td>
</tr>
<tr>
<td>Adhesive</td>
<td>5,10</td>
<td>Degree to which mass sticks to the roof of the mouth or teeth (10)</td>
</tr>
<tr>
<td>Grainy</td>
<td>1,2,3, 7,8</td>
<td>The extent to which granular structures are formed as the sample</td>
</tr>
<tr>
<td>Sandy</td>
<td>4</td>
<td>breaks down (1)</td>
</tr>
<tr>
<td>Crystallinity</td>
<td>6</td>
<td>Perception of small particles in a texture (3)</td>
</tr>
<tr>
<td>Smooth</td>
<td>1, 5</td>
<td>The smoothness of the cheese against the palate as it breaks up during mastication (1)</td>
</tr>
<tr>
<td>Moist</td>
<td>1,2, 4,8</td>
<td>The perceived moisture content of the cheese (1)</td>
</tr>
<tr>
<td>Cohesive</td>
<td>5</td>
<td>The degree to which the chewed mass sticks together in the mouth</td>
</tr>
<tr>
<td>Slimy</td>
<td>1</td>
<td>Of the nature of slime, soft, glutinous or viscous substance, soft, moist and sticky (1)</td>
</tr>
<tr>
<td>Greasy/oily</td>
<td>7,8</td>
<td>The extent to which a greasy/oily residue is deposited in the mouth after the cheese is broken down. (8)</td>
</tr>
<tr>
<td>Residue/</td>
<td>5,7,8</td>
<td>The extent to which the cheese coats the palate and the teeth during mastication (7)</td>
</tr>
<tr>
<td>Mouth coating</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>


*Definitions quoted directly from the referenced studies*
2.5 Methodology relevant to this study

2.5.1 Descriptive sensory profiling

Descriptive sensory profiling is the most sophisticated tool used in sensory science and results in a detailed specification of the sensory attributes of a product or series of products (Lawless and Heymann 2010; Stone and Sidel 2004). It is widely used at various stages of research and product development, for example; quality control, determination of changes due to shelf-life and packaging, product optimisation and in defining sensory-instrumental relationships (Lawless and Heymann 2010; Murray et al. 2001). Various different methods of descriptive profiling exist, representing different philosophies and approaches, for example; Flavour Profile Method, Quantitative Descriptive Analysis® and Sensory Spectrum®, to name a few (Lawless and Heymann 2010). Generic descriptive analysis, or profiling, uses aspects of these methods to meet specific project objectives (Murray et al. 2001).

Descriptive sensory profiling involves the use of a trained panel to accurately quantify the intensity of pre-determined attributes on scales. The number of panellists is quite low (from 8-20) and panellists are usually required to have a good level of sensory acuity and motivation (Murray et al. 2001). Training begins with the development or adaptation of a common sensory language or lexicon, elicited from exposure to a range of products from the category of interest. Following this, panellists are trained to use a common frame of reference, in order to provide context (Lawless and Heymann 2010; Murray et al. 2001). This context can be achieved by the use of reference standards (Stone and Sidel 2004) which can be any ‘chemical, spice, ingredient, or product’ used to characterise an attribute or attribute intensity (Rainey 1986). While external standards (e.g. chemical standards) are useful, panels trained with product-specific standards perform better (Murray et al. 2001).

Product evaluation is performed by panellists, individually, seated in isolation. Attributes are rated on graphic line scales with the end-points (or anchors) labelled. Evaluation sessions should be replicated. Visual representation of descriptive sensory profiling results can be in the form of ‘spider-web’ or radar plots, and bar charts (Lawless and Heymann 2010; Stone and Sidel 2004). Statistical analysis of the results of descriptive sensory profiling are usually handled with univariate techniques, such as analysis of variance (ANOVA) with repeated measures, where effects and interactions of product, panellist and replication are computed. Multivariate methods, like principal component analysis (PCA) can be utilised to characterise how products differ across all attributes and products (Lawless and Heymann 2010).

One potential drawback in descriptive sensory profiling is the focusing of the panellists on individual attributes, which as single attributes, may not accurately reflect the overall sensory mode (especially in odour; Murray et al. 2001). However, the use of descriptive
sensory profiling in collaboration with other sensory tests may help to prevent or reduce this issue.

2.5.2 Temporal dominance of sensations

While the usefulness of sensory tests like descriptive analysis is apparent, the dynamic nature of food in mastication, breathing, salivation, tongue movement and swallowing is an important area of investigation (Lawless and Heymann 2010; Piggott 2000). Static measurements of sensory scaling, as in descriptive analysis, require integration by the assessor of dynamic sensations into an average or single point, usually the maximum intensity, which may result in the loss of valuable information (Cliff and Heymann 1993).

Time intensity (TI) is a dynamic sensory method which has been used in various forms since 1937 when Holway and Hurvich had assessors measure the change in sensation of a drop of NaCl solution directly onto the tongue by drawing a curve (Holway and Hurvich 1937; Lawless and Heymann 2010). In the early stages of TI research, the method was used as a means of investigating the persistence of sweetness, bitterness and astringency before being extended to other sensations and applications, such as flavour release, taste and odour adaptation and texture change, to name a few (Lawless and Heymann 2010). Although modifications have taken place over the lifetime of TI, the result of TI has consistently been a curve, of intensity of the sensation versus time (Piggott 2000). From this curve, parameters of interest such as maximum intensity, time to maximum intensity and area under the curve can be calculated for each individual attribute (Lawless and Heymann 2010).

While TI is an efficient and robust method for investigating the evolution of a single attribute over time, it is quite time consuming, and can result in ‘halo dumping’, i.e. the exaggeration of intensity of an attribute when a limited number of attributes are considered (Lawless and Heymann 2010). In order to reduce the duration of dynamic evaluation and avoid the ‘halo-dumping’ effect, a method known as temporal dominance of sensations (TDS) was developed (Pineau et al. 2009).

TDS examines the sequence of dominant sensory attributes over a certain period of time (Di Monaco et al. 2014; Pineau et al. 2009). A typical TDS evaluation procedure involves placing the test sample in the mouth and choosing the most dominant attribute from a list of attributes. As the sample is chewed, the dominant attribute may change and hence the assessor is free to choose the attribute from the list until swallowing (Pineau et al. 2009). In general, the presentation of attributes on the list is randomised and balanced across assessors (to prevent bias of choice) and it is recommended that the attribute list should not number more than 8-10 (Pineau et al. 2012). Originally, the TDS method included not only the choice of dominant attribute, but also an evaluation of its intensity, however this is now understood to be unsuitable, as it mixes two cognitive tasks, namely a qualitative task (selection of the dominant attribute) and a quantitative task (scoring the intensity).
The results of TDS are usually shown as curves on a plot where the y-axis represents the dominance rate (i.e. the percentages of assessors who chose the same dominant attribute at the same time) and the x-axis representing the time (Pineau et al. 2009). To aid in interpretation of the curves, two levels are marked on the curves; the chance level ($P_0$), the dominance rate below which an attribute was obtained by chance and the significance level ($P_S$), the minimum dominance rate level to be considered significantly higher than $P_0$.

As TDS considers multiple attributes at the same time, it is less time consuming than TI and also helps to show the interactions between attributes and sequences of sensations (Déléris et al. 2011; Di Monaco et al. 2014). The use of TDS in conjunction with another sensory methodology, usually descriptive analysis, has been shown to be more effective than TDS alone and adds an extra dimension to the sensory evaluation of foods (Labbe et al. 2009; Ng et al. 2012).

Although still undergoing improvements to the methodology and handling of data, TDS has been applied in studies of properties of a variety of foods, for example; breakfast cereals (Lenfant et al. 2009), hot beverages (Le Révérénd et al. 2008), wine (Meillon et al. 2010; Sokolowsky and Fischer 2012), candies (Saint-Eve et al. 2011), fish sticks (Albert et al. 2012), yoghurt (Bruzzone et al. 2011), flavoured vodkas (Déléris et al. 2011), water (Teillet et al. 2010), blackcurrant cordials (Ng et al. 2012) and olive oil (Dinnella et al. 2012).

2.5.3 Projective Mapping

Projective mapping (PM) is a method which allows comparative evaluation of products in an overall sense by expressing the perceived similarities and/or dissimilarities between the products as a two dimensional perceptual map (Torri et al. 2013). PM was first reported in the 1990s, reported in Risvik et al. (1994) and Risvik et al. (1997), where the authors wanted to overcome the time consuming process of descriptive analysis with a trained panel or (dis)similarity scaling to produce perceptual maps of samples by allowing consumers to position products based on their relationship to each other. This cue was taken from the qualitative market research world, where it was used to find vague and unstructured ideas about the products (Risvik et al. 1994). The authors found the perceptual map derived from the PM was both similar to a map derived from descriptive sensory profiling and more consistent over repeated trials than either descriptive analysis or dis(similarity) scaling. In more recent times, PM has again become popular under the guise of ‘napping’, the term coming from a play on the French word for tablecloth (nappé). This was highlighted by Pagès (2005) and is essentially the same method, except for the inclusion of multiple factor analysis (MFA) for the data analysis stage.

Participants are asked to observe, smell and taste the samples and to use their own criteria to discriminate and position them on a surface (a blank sheet of paper, or by using a
computer program) relative to their similarities or differences (Varela and Ares 2012). Sample coordinates from the ‘maps’ are two dimensional (Nestrud and Lawless 2010) and data can be analysed using multidimensional methods such as multidimensional scaling (MDS), general procrustes analysis (GPA) or principal component analysis/regression (PCA/PCR). Participants can also be asked to describe (usually directly on the sheet) the differences or characteristics of the samples in order to both compliment the PM task and to aid in understanding their reasoning (Ares et al. 2010; Pagès 2005).

PM has been shown to differentiate samples very similarly to other sensory methods such as descriptive analysis and check-all-that-apply (CATA) lists (Ares et al. 2010; Kennedy and Heymann 2009; Mielby et al. 2014). That said, the level of consensus between assessors may be affected by the training or expertise of the assessors (Chollet et al. 2011) and also the criteria used for discrimination by the assessors may also be dependent on their expertise or training.

PM looks at the global perception of a sample set and as a result, has been promoted as a method which mirrors consumer perception in front of the store shelf (Varela and Ares 2012). A number of studies have used PM (or as napping) to study consumer responses to a range of products, for example; wines (Pagès 2005; Ross et al. 2012; Torri et al. 2013), chocolates (Kennedy and Heymann 2009), citrus juices (Nestrud and Lawless 2008), cheeses (Barcenas et al. 2004), apples (Nestrud and Lawless 2010) and teas (Kim et al. 2013). PM is quite quick to carry out, relative to the amount of samples which can be used (10-15) and as assessors do not need to be trained beforehand, unlike descriptive analysis (Risvik et al. 1994; Risvik et al. 1997; Torri et al. 2013). These characteristics make it suitable for use in consumer studies (Nestrud and Lawless 2008), especially where market/category positioning of products is of interest (Lawless and Heymann 2010). Projective mapping may also differentiate better than categorical measurements such as sorting, especially where product sets are relatively similar (King et al. 1998).

2.6 Consumer responses to food

Consumer acceptance of a food is dependent on a number of factors, relating to the product itself (intrinsic properties, e.g. ingredients, storage conditions; and extrinsic properties, e.g. price, information), the consumer (attitudinal, genetic, experience) and the environment (e.g. cultural, religious, convenience, other people; Costell et al. 2010; Cardello and Schutz 2006).

2.6.1 Measures of consumer responses

In consumer research regarding food, investigation of ‘affect’, that is the feeling towards the food, is of upmost importance (Cardello and Schutz 2006). Two terms which are widely used, sometimes interchangeably and misleadingly, in consumer research are
‘preference’ and ‘liking’. ‘Preference’ refers to as choice of a particular product and assumes that two or more products are on offer while ‘liking’ is an immediate affective or hedonic reaction to the food (Mela 2001; Rozin and Vollmecke 1986). The two terms are not synonymous with each other, for example in a choice of two foods, one may be preferred, but neither may be liked (Lawless and Heymann 2010; Mela 2001). That said, affective responses to sensory characteristics contribute to preference for a food and may be the best predictor of food choice, when economic and availability effects are not considered (Cardello and Schutz 2006; Eertmans et al. 2001; Rozin 2006), put simply; liking results in acceptance of a product, disliking leads to rejection (de Graaf 2007).

The most common way of measuring hedonic responses to food, is to ask consumers to rate their liking on a scale, the most common form being a verbally anchored, bi-polar 9-point scale ranging from ‘dislike extremely’ to ‘like extremely’ (Lawless and Heymann 2010). Bipolar scales are useful, as they allow representation of liking or disliking, as well as the neutral point in the middle of the scale, which is a valid response for some participants. This presents a potential problem when using the scale in Finland, as the Finnish language lacks the word ‘dislike’, however, a solution lies in the use of the word ‘pleasantness’ (Keskitalo et al. 2007; Tuorila et al. 2008). Another limitation of the 9-point scale is that, in situations where common well-liked foods are tested; the points 1- 4 may be disregarded, causing it to become truncated into a 5-point scale. This can be avoided by using unipolar scales or bipolar scales measuring ‘pleasantness’ (Lähteenmäki and Tuorila 1995; Tuorila et al. 2008).

2.6.2 Demographics, culture and attitudes

In considering the responses of consumers to food which ultimately affect choice and liking, a composite framework of three components has been described (Rozin 2007; Sobal et al. 2006). This consists of the person, the food and the environment.

Culture, through combinations of environment, ritual, community, mobility, economic and political systems, has a strong influence on food preferences (Mela 1999) and is probably the best predictor of food preferences or attitudes (Rozin 2007). Preferences for certain flavours, for example can even be seen internationally, by the types of dishes which are traditional in countries. For example, spiciness in food, which ranges from bland in middle European and Scandinavian dishes to hot in Indonesian, Szechwan and Mexican cuisine (Sherman and Billing 1999). Such cultural variation could be the result of differing exposures to different flavours and experience (Prescott and Bell 1995).
Age is a major predictor of food preference and choice, especially in the young and old (Rozin 2007). While taste perception is relatively unaffected by aging, the sense of smell is, resulting in altered flavour perception. Preferences for food are stable and develop from an early age. Preferences established as early as 2 years of age can predict preferences in later life (Nicklaus et al. 2004). Early preference for mature cheese predicted preference in later life while no age difference in liking of cheese in French children and adolescents were seen (Fischler and Chiva 1986; Nicklaus et al. 2004).

Moderate differences in gender have been found with regard to food preference (Rozin 2007). Whereas there are likely no gender differences in ability to identify basic tastes (except bitter; Michon et al. 2009), preference for sweetness is associated with women. There are differences between men and women in terms of preferences for food with different sensory properties. Men may favour rich, strong tastes, red meat and higher-fat products, while women are more likely to choose pale, light food as well as those foods associated with healthiness (Kähkönen and Tuorila 1999). Taking cheese as an example, Bogue et al. (1999) found a high percentage of males preferring a vintage Cheddar cheese. Genetic contributions to food and taste preferences have recently been investigated, showing at least partial genetic contributions, for example, to sour (Törnwall et al. 2012) and sweet taste (Keskitalo et al. 2007).

### 2.6.3 Information and expectations

Information about food can influence consumer liking and behaviour and comes from various sources; the brand, the label, nutrition claims, information about technology or processing and advertising, to name a few (Cardello and Schutz 2006). The possible link between information and their effect on hedonic ratings of food is through the consumer’s expectations. Information and pre-existing experience combine to influence expectations.

Deliza and MacFie (1996) described the role of expectations in consumer choice. Information and experience create a certain expectation, while the non-sensory extrinsic attributes of the products are encountered in the store (Cardello 2003). If expectations are low, the product will not be chosen, if they are high, it will be chosen and eventually consumed. The attributes of the products then experienced will then either meet or exceed expectations (leading to satisfaction and repeat usage) or fail to meet expectations (rejection of the product). Four models have been described the relationship of expectations and actual liking; assimilation, where differences between expectations and actual product experience are minimised and actual liking is in the same direction as expected liking; contrast, the opposite of assimilation; generalised negativity, decreased acceptance and assimilation-contrast, where the difference between the expectation and product performance is sufficiently small to be within the limit of acceptance (Anderson 1973; Cardello and Sawyer 1992; Cardello 1995; Deliza and MacFie 1996).
Sensory and hedonic expectations of products can be manipulated by providing information (Cardello et al. 2007), which is especially effective if presented before product exposure (Levin and Gaeth 1988). Numerous examples in the literature show such effects, for example in Kähkönen et al. (1996), nutritional information regarding fat and salt content provided prior to tasting influenced both hedonic ratings and perceived attribute intensities in a low-fat spread. Manipulation of expectations is useful from a product development and marketing point-of-view, however, the risk of overly inflating expectations to levels far greater than the sensory reality of the product must be considered (Kähkönen and Tuorila 1998).

### 2.6.4 Perceptions of consumer risk

Risk is an inherent aspect in food choice where consumers make trade-offs between new unexplored foods and trying to avoid potentially unsafe foods, known as the ‘omnivore paradox’ (de Jonge et al. 2007). When discussing risk in a consumer sense, it is within the normative/value model of perceived risk, where risk is a perception by the public, based on subjective evaluation, not that of experts or scientists (Cardello 2003; de Jonge et al. 2007; Mitchell 1999).

One area of interest in risk perception regards those foods produced with novel or emerging technologies (Cardello and Schutz 2006). While optimisation of the sensory characteristics of a food is important, information regarding the source, nature and processing involved can affect liking, choice and purchase decisions. This is especially true if the processing or technology involved is perceived as a risk. Conversely, perceived benefit is essential in consumer acceptance of new foods (Siegrist 2008). Most of the research in this area has been on controversial or little-known technologies (e.g. genetic modification and engineering, irradiation, high-pressure processing, nanotechnology, to name a few) where consumers are unable to decide whether or not they present a risk.

In order to increase acceptance of novel foods, credible information and education regarding the benefits has to be provided, not just the results of studies (Siegrist 2008). Communication of benefits has been shown to have a positive influence on purchase intent, for example when used to inform Brazilian consumers of the benefits of high-pressure processing in pineapple juice manufacture (Deliza et al. 2005). Also, trust plays a huge role in acceptance (Siegrist 2008). This is shown for example in brand loyalty, which has been shown to be a major reducer of risk for consumers (Mitchell 1999). In this age of instant-information (internet and mass-media), such trust is fragile, as producers of food must test acceptance of new technologies rather than try to hide their use and risk being discovered (Cox and Evans 2008).
2.6.5 Influence of sensory characteristics on consumer responses in cheese

The huge range of cheese varieties available result in a wide range of variability in consumer preferences (Delahunty and Drake 2004). Cheese varieties vary widely in their sensory characteristic, even within the same cheese-type. As aspects of the final cheese can be influenced by pre-treatments, processing modifications and ripening conditions, it is of benefit to the producer understand which aspects affect consumer preference.

Preference mapping techniques have been widely used to ascertain links or relationships between sensory attributes and consumer preference and acceptance in numerous cheese studies (Delahunty and Drake 2004). Internal preference mapping can be used to examine patterns of preference among consumers while external preference mapping can be used to relate descriptive sensory profiling data from a trained panel to hedonic data from consumers (Lawlor and Delahunty 2000). Through the combination of the preference mapping techniques and cluster analysis, specific descriptive attributes rated by trained panels can be linked to preference, giving valuable and actionable insights to the producer. In Lawlor and Delahunty (2000), the odour attributes ‘fruity’ and ‘caramel’ were most preferred in Gruyère cheese while ‘acidic’, ‘astringent’ and ‘mouldy’ flavours (from a commercial blue mould cheese) were most disliked. However, two clusters of consumers (representing around half of the total participants) were identified, in which the blue mould cheese was the most preferred cheese. Liggett et al. (2008) used partial least squares regression (PLS) to link descriptive and consumer liking data in Swiss cheeses, and found that ‘diacetyl’, ‘cabbage’, ‘cooked’, ‘whey’, ‘milk fat’ and umami to be important for consumer liking.

Large variation of sensory characteristics can exist within a specific cheese variety due to differences in production variables or ripening. In Young et al. (2004), Cheddar cheeses of varying ripening time were investigated and six clusters of consumers were identified, one of which was characterised by preference for the attributes characteristic of young Cheddar cheese: ‘cooked/milky’, ‘diacetyl’, ‘milk fat/lactone’ and another by preference for longer-ripened Cheddar. Caspia et al. (2006) conducted a similar study with younger (7- and 9-month ripened) and older (12-month ripened) Cheddar cheeses and found similar results. In a study by Drake et al. (2008), ‘mild’ Cheddar cheeses were examined by consumers and trained panellists and resulted in a large variation in both flavours and consumer preference. The attributes ‘colour’, ‘cooked/milk’, ‘whey’, ‘brothy’ and ‘sour taste’ were found to drive liking.

Various other studies have looked at identifying potential influences of sensory attributes on consumer preference or acceptance; Pagliarni et al. (1997) examined Mozzarella cheese produced from bovine or buffalo milk where ‘sweet’, ‘milky’, ‘creamy’, ‘fibrous’ and ‘elastic’ were important for bovine Mozzarella and ‘cohesive’, ‘acid’, ‘salty’, ‘yogurt odour’ and ‘flaky’ for buffalo milk Mozzarella, with different clusters preferring either.
Bogue et al. (1999) found groups with differing preference for longer or shorter-ripened commercial Cheddar cheeses. Murray and Delahunty (2000) found consumer clusters preferring farmhouse Cheddar cheeses which were either; ‘balanced’, ‘sweet’ and ‘nutty’; ‘Cheddary’, strong, ‘firm’, ‘grainy’ and ‘crumbly’ or ‘rancid’, ‘mouldy’, ‘mushroom’ and ‘bitter’. Zhang et al. (2011) found that ‘milky’, sour milk , milky and slimy were important attributes in a selection of commercial cheeses among young people (aged 12-25) in China.
3 AIMS

The general aim of this study was to investigate low-pressure homogenisation as a viable and useful addition to cheesemaking and to develop the investigation from laboratory-scale to the market.

The aims of the sub-sections were:

- To develop a viable milk pre-treatment incorporating low-pressure homogenisation into a Cheddar cheesemaking routine and investigate the subsequent effects on microbiological and chemical properties of resultant cheeses (I)

- To quantify the sensory and chemical consequences of a low-pressure homogenisation pre-treatment in the production of Emmental cheese (II)

- To characterise the sensory, chemical and structural changes in reduced-fat Emmental cheeses when produced with a low-pressure homogenisation pre-treatment (III)

- To define the market positioning and consumer acceptability of cheeses produced with the low-pressure homogenisation pre-treatment (IV)

- To determine whether information provided could influence or modify expectations or perceptions of cheese produced with the low-pressure homogenisation pre-treatment (IV)
4 MATERIALS AND METHODS

4.1 Overview

The experimental work in Study I was carried out in the Department of Food and Nutritional Sciences, University College Cork, Ireland. Studies II and III were carried out in the Department of Food and Environmental Sciences, University of Helsinki, Finland in 2010-2012. In Study IV, the pre-treatment and cheesemaking was carried out in Valio Ltd., Lapinlahti, Finland, while the subsequent consumer study was performed in University of Helsinki in 2013.

In Study I, the microbiological and chemical effects of pre-treatment homogenisation on the ripening of Cheddar cheese were examined. Study II investigated the effects of pre-treatment homogenisation on Emmental cheese from chemical and microbiological points-of-view as well as sensory consequences, both static and dynamic. In Study III, sensory, chemical and textural changes to full- and reduced-fat cheeses produced with the low-pressure homogenisation pre-treatment were determined, while the market positioning of the test cheeses relative to commercial cheeses was also investigated. Study IV examined the effect of information on consumer expectations and perceptions of an Emmental cheese produced with the low-pressure homogenisation pre-treatment.

4.2 Milk pre-treatment (I-IV)

Raw bovine milk was homogenised at low pressure as part of a pre-treatment process. A schematic overview of the pre-treatment process used in Studies I-IV is shown in Figure 5. A preliminary laboratory-scale trial was carried out in Study I which followed the same protocol shown in Figure 5, but with homogenisation pressures of 0, 5, 10, 15, 20 and 25 MPa. In Study I, approx. 18 L of milk (800 mL in the laboratory-scale trial) was treated for each homogenisation pressure (plus one control, which bypassed the homogeniser). In Studies II and III, approx. 100 L of milk was used for each homogenisation pressure (plus one control). In Study IV, approx. 1000 L of milk was pre-treated.

4.3 Cheese production (I-IV)

Cheddar (Study I) and Emmental cheese (Studies II, III & IV) were produced from the pre-treated milk. Laboratory scale Cheddar cheeses in Study I were produced according to the method described by Shakeel-Ur-Rehman et al. (1998) while pilot-scale Cheddar cheeses were manufactured according to a standard protocol (Fox et al. 2000). Cheddar cheeses were ripened at 8°C for 180 d. Emmental cheeses in Studies II-IV were produced using the method described by Mato Rodriguez et al. (2011) and ripened at 12°C for 14 d, 23°C for 25 d and 5°C for 51 d, giving a total ripening time of 90 d.
In Studies I-III, pre-treatment of milk and subsequent cheesemaking was carried out in triplicate. In Study IV, one large-scale milk pre-treatment/cheesemaking was performed. An overview of the samples produced and examined in each study is shown in Table 4.

**Figure 5.** Schematic overview of the milk pre-treatment process in Studies I-IV

<table>
<thead>
<tr>
<th>Study</th>
<th>Cheese</th>
<th>Code</th>
<th>Treatment</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Cheddar</td>
<td>C</td>
<td>Control, bypass homogenisation stage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H0</td>
<td>Milk homogenised at 0 MPa in pre-treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H5</td>
<td>Milk homogenised at 5 MPa in pre-treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H10</td>
<td>Milk homogenised at 10 MPa in pre-treatment</td>
</tr>
<tr>
<td>II</td>
<td>Emmental</td>
<td>C</td>
<td>Control, bypass homogenisation stage</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H0</td>
<td>Milk homogenised at 0 MPa in pre-treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H5</td>
<td>Milk homogenised at 5 MPa in pre-treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>H10</td>
<td>Milk homogenised at 10 MPa in pre-treatment</td>
</tr>
<tr>
<td>III</td>
<td>Emmental</td>
<td>FF_C</td>
<td>Full-fat cheese, control (bypass homogenisation stage)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>FF_H</td>
<td>Full-fat cheese, milk homogenised at 10 MPa in pre-treatment</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RF_C</td>
<td>Reduced-fat cheese, control (bypass homogenisation stage)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>RF_H</td>
<td>Reduced-fat cheese, milk homogenised at 10 MPa in pre-treatment</td>
</tr>
<tr>
<td>IV</td>
<td>Emmental</td>
<td>-</td>
<td>Full-fat cheese, milk homogenised at 10 MPa in pre-treatment</td>
</tr>
</tbody>
</table>
4.4 Biochemical analyses (I-III)

The chemical analysis methods in Studies I-III are described in Table 5 and in the original publications (I-III). When the term ‘salt’ is used in this thesis, it refers to NaCl, unless otherwise stated.

<table>
<thead>
<tr>
<th>Method</th>
<th>Reference</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fat</td>
<td>Gerber method</td>
<td>I, II, III</td>
</tr>
<tr>
<td>Fat in whey</td>
<td>Rose-Gottlieb method</td>
<td>I</td>
</tr>
<tr>
<td>Protein</td>
<td>Determination of Nitrogen in cheese (Kjeldahl method)</td>
<td>II</td>
</tr>
<tr>
<td>Moisture</td>
<td>Oven-drying method</td>
<td>I, II</td>
</tr>
<tr>
<td>Salt</td>
<td>Potentiometric determination of salt (NaCl) in cheese (Kjeldahl method)</td>
<td>I</td>
</tr>
<tr>
<td>Acid degree value¹</td>
<td>Hydrolytic rancidity in raw milk method</td>
<td>II, III</td>
</tr>
<tr>
<td>Free fatty acids</td>
<td>Determination of free fatty acids</td>
<td>I, II</td>
</tr>
<tr>
<td>Alkaline phosphatase¹</td>
<td>Alkaline phosphatase test</td>
<td>I</td>
</tr>
</tbody>
</table>

¹ Determined in milk following pre-treatment and prior to cheesemaking

In Studies I-III, microbiological analysis of milk and cheese was carried out as described in the original publications (I-III). Details of growth media and cultivation conditions are shown in Table 6.

Confocal laser scanning microscopy (CLSM) was carried out on representative samples from Study III. Sample preparation and analysis is as described in the original publication (III). Measurement of colour of cheese samples was carried out in Study II and III as described in the publications.

<table>
<thead>
<tr>
<th>Growth medium</th>
<th>Conditions</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lactococci</td>
<td>LM17 agar</td>
<td>I</td>
</tr>
<tr>
<td>Lactobacilli</td>
<td>MRS agar</td>
<td>II, III</td>
</tr>
<tr>
<td><em>Streptococcus thermophilus</em></td>
<td>M17- Lactose agar</td>
<td>II, III</td>
</tr>
<tr>
<td>NSLAB</td>
<td>Rogosa agar</td>
<td>I</td>
</tr>
<tr>
<td>Psychrotrophic bacteria</td>
<td>Plate count agar</td>
<td>I</td>
</tr>
<tr>
<td></td>
<td>Plate count agar</td>
<td>II, III</td>
</tr>
<tr>
<td>Total plate count</td>
<td>Plate count agar</td>
<td>II, III</td>
</tr>
<tr>
<td>Propionibacteria</td>
<td>Sodium lactate agar</td>
<td>II, III</td>
</tr>
</tbody>
</table>
4.5 Sensory methodology (II, III)

In Studies II and III, sensory evaluation of the resultant cheeses was carried out using trained panels. Informed written consent was obtained from all participants and study protocols followed the ethical principles approved by the Ethical Committee of the Viikki Campus, University of Helsinki. Cheeses in studies II and III were evaluated at 90 d of ripening.

4.5.1 Descriptive sensory profiling (II, III)

Descriptive sensory profiling was carried out with trained panels (I: n = 15; 11 female, 4 males, ages 20-54; II: n = 15; 12 female, 3 male, ages 19-54) following the principles of generic descriptive analysis described in Lawless and Heymann (2010).

4.5.1.1 Training and development of lexicon

Panellists were recruited from students and staff of the University of Helsinki. Training of panellists occurred over two week periods, consisting of four three-hour sessions. In the training sessions, panellists were first presented with commercial Emmental cheeses and asked to generate descriptive words representing appearance, texture, odour and taste characteristics of the cheeses. The vocabulary generated was discussed and developed with the group until a consensus was reached on suitable and distinct attributes. A definition for each attribute was decided on, as were suitable reference samples. 22 attributes were chosen categorised under appearance, odour, taste and texture in Study II, while 19 were chosen in Study III. The attributes, definitions and reference samples used are shown in Table 7.

4.5.1.2 Evaluation

Samples were cut 24 h prior to evaluation and stored overnight in a refrigerator. Samples were removed from refrigeration 1 h prior to evaluation in each replication. Samples were coded and the presentation order was randomised. Appearance attributes were rated under white light, from the freshly cut surface of cheese. Odour, taste and texture attributes were then evaluated under red light in individual booths. Red light was used to avoid possible influences of colour differences between samples on odour and taste attributes (Sipahioglu et al. 1999). Panellists were provided with extruded flavourless corn snacks and water to cleanse their palates between samples. Attributes were rated on a 10 cm unstructured line scale with the anchors representing ‘no intensity’ and ‘very high intensity’ and evaluations were replicated once during one day. In total, three days of evaluation took place (one day per cheesemaking trial, each separated by one week). Evaluations were carried out with Fizz Sensory Evaluation Software 2.45 (Biosystemes, Couternon, France).
Table 7. List of attributes, codes, definitions and reference samples used in descriptive profiling & temporal dominance of sensations (TDS). Attributes followed by (T) were also included in the TDS evaluations in Study II.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Code</th>
<th>Definition</th>
<th>Reference sample (lower &lt; upper anchors)</th>
<th>Studies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Appearance</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Yellowness</td>
<td>A-Yellow</td>
<td>Yellowness of freshly cut surface</td>
<td>Feta &lt; Gouda</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Etorki Basque cheese &lt; Gouda</td>
<td>III</td>
</tr>
<tr>
<td>Shininess</td>
<td>A-Shiny</td>
<td>Shininess or glossiness of cut surface</td>
<td>Valio Polar 5 % &lt; Emmental (12 month)</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Valio Polar 5 % &lt; Emmental (18 month)</td>
<td>III</td>
</tr>
<tr>
<td>Eye size</td>
<td>A-Eye size</td>
<td>Average size of eyes in cheese mass</td>
<td>Lentil &lt; 50 euro cent coin</td>
<td>II, III</td>
</tr>
<tr>
<td>Colour consistency</td>
<td>A-Colour</td>
<td>Consistency of colour of freshly cut surface</td>
<td>Salvia Derby cheese &lt; processed cheese</td>
<td>II, III</td>
</tr>
<tr>
<td><strong>Odour</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>O-Intensity</td>
<td>Overall odour intensity</td>
<td>&lt; Emmental (12 month/18 month)</td>
<td>II/III</td>
</tr>
<tr>
<td>Buttery (T)</td>
<td>O-Buttery</td>
<td>Fatty odour from butter</td>
<td>&lt; Butter (room temperature)</td>
<td>II, III</td>
</tr>
<tr>
<td>Rancid</td>
<td>O-Rancid</td>
<td>Odour associated with rancid oxidised fat</td>
<td>&lt; Feta (3 hours at 30°C)</td>
<td>II, III</td>
</tr>
<tr>
<td>Sulphur</td>
<td>O-Sulphur</td>
<td>Odour associated with boiled egg</td>
<td>&lt; Mashed hard boiled chicken egg</td>
<td>II</td>
</tr>
<tr>
<td>Fruity</td>
<td>O-Fruity</td>
<td>Fruity odour</td>
<td>&lt; Fruit salad in juice</td>
<td>II</td>
</tr>
<tr>
<td>Nutty (T)</td>
<td>O-Nutty</td>
<td>Odour associated with ground nuts</td>
<td>&lt; Crushed hazelnuts</td>
<td>II, III</td>
</tr>
<tr>
<td>Acidic</td>
<td>O-Acidic</td>
<td>Acidic or sour odour</td>
<td>&lt; Fat-free sour milk</td>
<td>II, III</td>
</tr>
<tr>
<td><strong>Taste</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intensity</td>
<td>T-Intensity</td>
<td>Overall taste intensity</td>
<td>Finnish squeaky cheese &lt; Emmental (12 month)</td>
<td>II, III</td>
</tr>
<tr>
<td>Salty (T)</td>
<td>T-Salty</td>
<td>Overall salty taste in mouth</td>
<td>Finnish squeaky cheese &lt; Feta</td>
<td>II, III</td>
</tr>
<tr>
<td>Sour (T)</td>
<td>T-Sour</td>
<td>Overall sour taste in mouth</td>
<td>Water &lt; Skim milk (low lactose, enzyme modified)</td>
<td>II, III</td>
</tr>
<tr>
<td>Bitter (T)</td>
<td>T-Bitter</td>
<td>Overall bitter taste in mouth</td>
<td>Water &lt; Fat free sour milk</td>
<td>II, III</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Water &lt; Caffeine solution 0.05 % or 0.02 %</td>
<td>II, III</td>
</tr>
<tr>
<td><strong>Texture</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Elasticity (T)</td>
<td>X-Elastic</td>
<td>Degree of bending before breakage</td>
<td>Feta &lt; Valio Polar 5 %</td>
<td>II, III</td>
</tr>
<tr>
<td>Hardness</td>
<td>X-Hand hard</td>
<td>Degree of hardness when squeezed between thumb and forefinger</td>
<td>Processed cheese &lt; (Parmigiano reggiano)</td>
<td>II, III</td>
</tr>
<tr>
<td>Crumbliness (T)</td>
<td>X-Crumbly</td>
<td>Amount of breakdown in the first 2-3 chews with back teeth</td>
<td>Processed cheese &lt; Emmental (12 month)</td>
<td>II</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Processed cheese &lt; (Parmigiano reggiano)</td>
<td>III</td>
</tr>
<tr>
<td>Fattiness (T)</td>
<td>X-Fatty</td>
<td>Amount of oily/fatty feeling in the mouth during chewing</td>
<td>Finnish squeaky cheese &lt; mascarpone</td>
<td>II, III</td>
</tr>
<tr>
<td>Smoothness (T)</td>
<td>X-Smooth</td>
<td>Degree to which cheese is smooth between tongue and palate during chewing</td>
<td>Parmigiano Reggiano &lt; processed cheese</td>
<td>II, III</td>
</tr>
<tr>
<td>Stickiness</td>
<td>X-Sticky</td>
<td>Amount of sticking of cheese to tongue and palate during chewing</td>
<td>Finnish squeaky cheese &lt; processed cheese</td>
<td>II</td>
</tr>
</tbody>
</table>

1 0.02% caffeine used for the majority of assessors, 0.05% used for those for whom 0.02% not sufficiently bitter
4.5.2 Temporal Dominance of Sensations (II)

4.5.2.1 Training and development of lexicon

Panellists who took part in the descriptive sensory profiling task in Study II also evaluated the cheeses by TDS. During the training sessions for descriptive sensory profiling, panellists were introduced to the concept of TDS. Panellists were presented with commercial Emmental cheeses and asked to generate descriptive words during mastication. Panellists were asked to consult the list of attributes chosen for the descriptive sensory profiling task and to also add to the list if necessary. A consensus was reached in terms of which attributes were suitable for the TDS task. Attributes used in TDS (6 flavour and 5 texture attributes) are shown in Table 7.

4.5.2.2 Evaluation

TDS evaluation was performed on the day following descriptive sensory analysis. Panellists evaluated flavour attributes then texture attributes. An example of an evaluation screen is shown in Figure 6. The order of attributes and presentation of samples were randomised. Panellists placed the cheese sample in their mouth and began chewing. When they perceived a dominant attribute from the list they chose that attribute. As the dominant attribute changed during mastication, they selected the new dominant attribute, which caused the previous attribute to be deselected. Panellists were free to choose as many attributes as necessary and to choose the same attribute as many times as necessary during mastication. The panellists stopped the evaluation on swallowing of the sample. Panellists were provided with extruded flavourless corn snacks and water to cleanse their palates between samples. Evaluations were replicated once during one day. In total, three days of evaluation took place (one day per cheesemaking trial, each separated by one week). Evaluations were carried out with Fizz Sensory Evaluation Software v.2.45 (Biosystemes, Couternon, France).

![Figure 6](image.png)

Figure 6. A TDS evaluation screen example for the flavour attributes sour (*hapan*), salty (*suolainen*), buttery (*voinen*), sweet (*makea*), nutty (*pähkinäinen*) and bitter (*karvas*).
4.5.2.3 Data handling

TDS curves were constructed from the combined flavour evaluations and combined texture evaluations from three replicate trials of cheesemaking. Dominance rate was calculated as the percentage of assessors who chose the same dominant attribute at the same time, and was plotted against standardised time. The chance level $P_0$, the dominance rate at which an attribute could have been selected by chance, was calculated as the inverse of one more than number of attributes used in the evaluation. The significance level $P_S$ was calculated according to the following equation, where $n$ is the number of assessors.

$$P_S = P_0 + 1.64 \sqrt{\frac{P_0(1 - P_0)}{n}}$$

4.6 Consumer studies (III, IV)

4.6.1 Projective mapping (III)

In Study III, respondents (n = 46; 34 female, 12 male, aged 19-55) took part in a PM task followed by a hedonic and use-frequency questionnaire.

4.6.1.1 Projective mapping task

Eleven cheese samples in small transparent cups (4 experimental and 6 commercial cheeses, with one replicate, shown in Table 8), were randomly positioned in the centre of a 60 x 60 cm sheet of white paper. Participants were instructed to evaluate the cheese based on their own criteria and to position the cheese on the sheet so that similar cheeses (or groups of cheeses) were close together and different cheeses (or groups of cheeses) were further apart. They were then instructed to describe the samples by writing descriptive words directly on the sheet beside each sample. Participants were provided with extruded flavourless corn snacks and water to cleanse their palates between samples. When finished, the coordinates of individual sample cups on the sheet were measured by the researchers.

4.6.1.2 Hedonic and use-frequency questionnaire

Following the PM task, participants were asked to complete a questionnaire. They rated their liking of the cheeses used in the PM task on a 7-point scale (1 = extremely unpleasant, 2 = very unpleasant, 3 = quite unpleasant, 4 = neither unpleasant nor pleasant, 5 = quite pleasant, 6 = very pleasant and 7 = extremely pleasant). Next they indicated their consumption frequency of cheese, in general on a 7-point scale (1 = never, 2 = less than
once a month, 3 = once or twice a month, 4 = once a week, 5 = twice a week, 6 = nearly every day and 7 = every day) and how often they consumed the six commercial cheeses used in PM, on 8-category scales (1 = never, 2 = less than once a month, 3 = once or twice a month, 4 = once a week, 5 = twice a week, 6 = nearly every day and 7 = every day, 8 = I don’t know this cheese).

<table>
<thead>
<tr>
<th>Table 8. Cheeses used in the projective mapping task</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Code</strong></td>
</tr>
<tr>
<td>----------</td>
</tr>
<tr>
<td><strong>Experimental cheeses</strong></td>
</tr>
<tr>
<td>FF_C</td>
</tr>
<tr>
<td>FF_H</td>
</tr>
<tr>
<td>RF_C</td>
</tr>
<tr>
<td>RF_H</td>
</tr>
<tr>
<td><strong>Commercial cheeses</strong>&lt;sup&gt;2&lt;/sup&gt; (trade names in parentheses)</td>
</tr>
<tr>
<td>RF_E</td>
</tr>
<tr>
<td>FF_E3</td>
</tr>
<tr>
<td>FF_E9</td>
</tr>
<tr>
<td>FF_E18a</td>
</tr>
<tr>
<td>FF_E18b</td>
</tr>
<tr>
<td>FF_G</td>
</tr>
<tr>
<td>FF_GT</td>
</tr>
</tbody>
</table>

<sup>1</sup>Ripening times of commercial cheeses as indicated by the producer.
<sup>2</sup>All commercial cheeses produced by Valio Ltd, Finland.

4.6.2 Information study (IV)

4.6.2.1 Recruitment and background questionnaire

The overall study design is shown in Figure 7. Participants (n = 229; 183 women, 46 men, aged 19-63) were recruited in the University of Helsinki, Viikki Campus on one day. They completed an ethical consent form. In a background questionnaire they were asked their year of birth and sex, their consumption frequency of cheese and consumption frequency of six commercial cheeses. They completed the food neophobia scale (FNS; Pliner and Hobden 1992), which contained 10 statements about new foods rated with 7-point scales (1= disagree strongly, 2 = disagree moderately, 3 = disagree slightly, 4 = neither disagree nor agree, 5 = agree slightly, 6 = agree moderately and 7 = agree strongly). Next they completed the food technology neophobia scale (FTNS; Cox and Evans 2008), composed of 13 statements about new food technologies and using the same rating scale as in FNS.
Participants were given a vacuum packaged piece of cheese which was produced with an homogenisation pressure of 10 MPa in the pre-treatment.

4.6.2.2 Allocation of participants to groups

Participants were allocated to one of four similar groups based on their age, sex, FNS and FTNS scores. This allocation was performed according to a design which minimised the average of the variances of least squares estimates in a two-way linear regression model and is described in more detail in Publication IV.

4.6.2.3 Home-use test

Each of the four groups was sent an online form, which contained a different description of the cheese sample. The descriptions were ‘Traditional Emmental “blue label”’, ‘”New-type” ripened cheese’, “New-type ripened cheese made from low-pressure homogenised milk’ and ‘Cheese’. The groups are referred to as ‘Traditional’, ‘New-type’, ‘Technology’ and ‘Cheese’.

Before tasting the cheese sample, participants rated expected pleasantness (7-point scale, 1 = very unpleasant, 7 = very pleasant), expected purchase intent (7-point scale, 1 = not at all interested, 7 = very interested) and the suitability of 16 descriptive words (7-point scale, 1 = not at all suitable, 7 = very suitable). The descriptive words are shown in Figure 7. The participants were then asked to taste the cheese and rate actual pleasantness, actual purchase intent and the suitability of the same 16 descriptive words as before. In addition they were asked how much the sample matched their expectations and their expectations of a commercial Emmental cheese (both on 7-point just-about-right, JAR, scales; -3 = not very well, 0 = as expected, 3 = very well). Finally they could describe the cheese in their own words.

The final population, (those who answered the home-use test questionnaire) numbered 217 (43 men, 174 women, aged from 19 to 63, mean age = 30.0, SD = 10.8).

4.7 Statistical data analysis (I-IV)

Statistical analysis of data was carried out as described in the original publications (I-IV). Two-way ANOVAs with repeated measures on composition data in Studies I and II were used to investigate the main effects and interactions of sample (4) and trial (3), followed by Sidak confidence interval adjustment post hoc comparisons. One-way ANOVA was then used where samples showed a significant sample x trial interaction. Three-way ANOVA with repeated measures on descriptive sensory profiling data was used in Studies II and III to investigate the main effects and interactions of sample (4), replicate session (2) and trial (3). Post hoc comparisons were again performed with Sidak confidence interval adjustment. Two-way ANOVA was carried out on home-use test data in Study IV
to evaluate the main effects and interactions of description (4) and questions (2), with a within-subjects design, while effect and interactions of question (4) and background measure (2) were evaluated with a between-subjects design and Tukey’s post hoc test. Correlations between consumption of cheese, FNS, FTNS, expected/actual pleasantness and purchase intent were analysed with Pearson’s correlations in Study IV. All statistical effects were analysed as a significant level of p = 0.05, unless otherwise stated. All ANOVAs and investigation of correlations were performed with PASW 18.0/SPSS 21.0 (SPSS Inc., Illinois, USA).

PCA was conducted in Studies I, II and III, as described in the original publications. PCR was carried out on PM coordinates and words in Study III. All PCA and PCR analyses were performed with The Unscrambler X 10.1 (Camo Software, Oslo, Norway).
Recruitment (paper forms)

Ethical form
Background questionnaire
- Year of birth/sex
- Consumption frequency of cheese
  (1= never, 2= less than twice a month, 3= once or twice a month, 4= once a week, 5= twice a week, 6= every day)
- Consumption of six named commercial cheeses
  (1= I don’t know this cheese, 2= I know this, but haven’t tasted it, 3= I have tasted it but haven’t used it, 4= I use it from time to
time, 5= I use it often)
- Food neophobia scale (FNS)
- Food technology neophobia scale (FTNS)

Distribution of cheese sample packages

Figure 7. Outline of Study IV.
5 RESULTS

5.1 Biochemical effects of pre-treatment

5.1.1 Composition of cheese (I-IV)

The composition of cheeses was determined for the cheese produced in all studies. For the majority of compositional measures in Studies I-III, significant variations between replicates of cheesemaking were found. In each case, the within-trial trends for the particular compositional measure were examined to ensure that a similar trend was seen for each trial (as detailed in I-III). For the purposes of clarity, the combined mean values of the three trials are shown here. In Study IV, one large-scale cheese trial was carried out, without replication. An overview of the compositional data is presented in Table 9.

Table 9. Mean values (and standard deviations) of composition from three trials of cheesemaking of Cheddar cheese (Study I) and Emmental cheese (Studies II-III) cheese and the composition of the cheese produced in a single trial in Study IV.

<table>
<thead>
<tr>
<th>Study Code</th>
<th>pH</th>
<th>Moisture</th>
<th>NaCl</th>
<th>Fat</th>
<th>Protein¹</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>C</td>
<td>4.97 (0.03)</td>
<td>38.62 (1.27)</td>
<td>1.24 (0.06)</td>
<td>34.67 (3.50)</td>
</tr>
<tr>
<td>H0</td>
<td>4.96 (0.09)</td>
<td>38.55 (1.42)</td>
<td>1.24 (0.04)</td>
<td>34.83 (2.96)</td>
<td>-</td>
</tr>
<tr>
<td>H5</td>
<td>4.91 (0.05)</td>
<td>40.55 (1.38)</td>
<td>1.42 (0.27)</td>
<td>33.33 (3.08)</td>
<td>-</td>
</tr>
<tr>
<td>H10</td>
<td>5.03 (0.03)</td>
<td>40.64 (1.08)</td>
<td>1.54 (0.05)</td>
<td>33.00 (3.00)</td>
<td>-</td>
</tr>
<tr>
<td>II</td>
<td>C</td>
<td>5.49 (0.06)</td>
<td>34.32 (0.44)</td>
<td>1.13 (0.11)</td>
<td>30.41 (0.81)</td>
</tr>
<tr>
<td>H0</td>
<td>5.49 (0.05)</td>
<td>35.17 (0.52)</td>
<td>1.17 (0.10)</td>
<td>30.75 (0.61)</td>
<td>29.89 (0.72)</td>
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<tr>
<td>H5</td>
<td>5.54 (0.04)</td>
<td>35.67 (0.17)</td>
<td>1.45 (0.26)</td>
<td>30.17 (0.35)</td>
<td>28.38 (0.57)</td>
</tr>
<tr>
<td>H10</td>
<td>5.51 (0.03)</td>
<td>36.64 (0.46)</td>
<td>1.42 (0.22)</td>
<td>29.66 (0.58)</td>
<td>27.71 (0.83)</td>
</tr>
<tr>
<td>III</td>
<td>FF_C</td>
<td>5.60 (0.11)</td>
<td>36.76 (1.05)</td>
<td>1.54 (0.15)</td>
<td>30.39 (0.49)</td>
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<tr>
<td></td>
<td>FF_H</td>
<td>5.44 (0.24)</td>
<td>39.29 (1.51)</td>
<td>2.03 (0.06)</td>
<td>29.78 (0.83)</td>
</tr>
<tr>
<td></td>
<td>RF_C</td>
<td>5.66 (0.09)</td>
<td>37.77 (1.25)</td>
<td>1.68 (0.17)</td>
<td>20.89 (0.33)</td>
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<td></td>
<td>RF_H</td>
<td>5.58 (0.08)</td>
<td>39.43 (0.98)</td>
<td>2.16 (0.09)</td>
<td>20.83 (0.35)</td>
</tr>
<tr>
<td>IV</td>
<td>-</td>
<td>41.10</td>
<td>1.90</td>
<td>28.10</td>
<td>25.60</td>
</tr>
</tbody>
</table>

¹Protein content was not determined in Studies I and III.

pH showed conflicting results, increasing with the homogenisation pressure used in Study I, while remaining unchanged in Study II. In Study III, pH was lower in the homogenised milk cheeses (FF_H and RF_H) relative to the non-homogenised controls (FF_C and RF_C). The trends seen in moisture and NaCl were consistent in Studies I-III, where cheeses with homogenisation in the pre-treatment had higher moisture and NaCl contents. Overall, fat levels were lower in cheeses made with homogenised milk, except in Study III, where there was no difference between FF_C and FF_H (both full-fat; 30.39 and 39.78%, respectively) or between RF_C and RF_H (both reduced-fat; 20.89 and 20.83%,
respectively). Protein contents were determined in Study II and were lower in the H5 and H10 cheeses than in the C and H0 cheeses.

5.1.2 Acid degree value (I-III)

Determination of ADV of the raw milk and milks following pre-treatment was performed to assess the extent of FFA production in the incubation stage of the pre-treatment. In each study, ADV was higher in the homogenised milks than the control milk (which bypassed the homogenisation step). The extent of the increases in ADV relative to the control milk is summarised in Table 10.

Table 10. Extent of increase of acid degree value (ADV) in pre-treated milks

<table>
<thead>
<tr>
<th>Pre-treatment homogenisation pressure</th>
<th>Fold increase in ADV relative to control milk</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td>Control</td>
<td>1</td>
</tr>
<tr>
<td>0 MPa</td>
<td>1.3</td>
</tr>
<tr>
<td>5 MPa</td>
<td>1.4</td>
</tr>
<tr>
<td>10 MPa</td>
<td>2.5</td>
</tr>
</tbody>
</table>

\(^1\) ADV measured in 2% fat milk
\(^2\) ADV measured in 3% fat milk

5.1.3 Free fatty acids (I, II)

A biplot from PCA of FFAs extracted from cheeses produced in Study I is shown in Figure 8. Principal components (PCs) 1 and 2 explained 74% and 15% of the variance between the samples, respectively. FFAs from each individual trial of cheesemaking are shown, as significant differences in the amount of FFAs detected were found between trials. PC1 separated samples based primarily on the pre-treatment used before cheesemaking. C and H0 cheeses were grouped on the negative side of PC1, while, with a few exceptions, H5 and H10 cheeses were on the positive side. FFAs were not separated to a significant extent by PC1. PC2 generally separated cheeses based on the ripening time, with younger cheeses (1 d ripening) on the top, progressing through 90 d ripening in the middle, to 180 d ripening on the bottom (green and blue dashed lines indicate this separation in Figure 8). The overall level of FFAs increased in all cheese with ripening time, while the level of short chain FFAs decreased (as described in detail in publication I). The highest total concentrations of FFAs were found in the H10 cheeses (shown in I).

In Study II, FFA concentrations were determined at 1 and 90 d of ripening. Similar trends were seen as in I, namely that the overall level of FFAs increased in all cheeses with ripening time and that the highest total concentrations were found in the H5 and H10 cheeses, which did not differ significantly from each other. Component analysis of the
total FFA concentration in combination with compositional and descriptive sensory profiling attributes, is shown later in a PCA plot (Figure 11).

**Figure 8.** Biplot of scores and loadings from principal component analysis (PCA) of free fatty acid (FFA) data of cheese made in Study I. Sample names are coded as treatment pressure_ripening time (days)_trial (a, b or c). FFAs are represented by black circles. Green and blue dashed lines were added to indicate separation of samples and were not determined by the analysis.

5.1.4 Bacterial numbers (I-III)

Total bacterial counts on raw milk were 5.38 log cfu/ml in I, 3.88-4.15 log cfu/ml in II, and 4.40 log cfu/ml in III. In Study I, starter and NSLAB were elucidated at the beginning and throughout ripening. No differences were found between the cheeses at any stage. Counts on M17-L, MRS and sodium lactate agars (II and III) showed no differences between the cheeses at any point of ripening and for that reason; the values were not shown in the publications.

5.1.5 Imaging (III)

CLSM resulted in images where lipid was shown in red and protein in green. Images clearly showed the effect of homogenisation in the pre-treatment on the size of the fat globules, which appeared smaller and more distinct in the homogenised cheeses. Control
cheeses had larger, aggregated pools of coalesced fat. The CLSM images of the reduced-fat control cheese (RF_C) and the reduced-fat homogenised cheese (RF_H) are shown in Figure 9.

5.2 Sensory properties of cheeses

5.2.1 Descriptive sensory profiles (II, III)

Descriptive sensory profiling of cheeses took place with a trained panel, in Studies II and III. In both cases, sensory attributes were grouped into appearance, odour, taste and texture attributes as outlined in Table 7 (p.45) and in the original publications. In both studies, trial-specific influences were seen in descriptive profiling data. In each case, one-way ANOVA was carried out on the descriptive sensory profiling data within the trials to ascertain whether the trends seen were similar. In general, the trends were similar, details of which are given in the original Publications II and III, and from this point on, results refer to the overall mean values from the three replicate trials.

Differences were seen among all appearance attributes in Study II, where the H5 and H10 cheeses were rated as significantly less yellow, more colour consistent, having smaller eyes and in general, less shiny. Odour attributes were similar for all cheeses. Taste intensity, salty taste and acidic taste were all rated significantly higher in the H5 and H10 cheeses (shown in Figure 10). The same cheeses were less elastic and harder than C and H0 cheeses, while H10 was rated highest for sticky, smooth and fatty attributes (also in Figure 10).

![Figure 9](image_url). Confocal laser scanning microscopy images of the reduced-fat cheeses control cheese, RF_C (left), and the reduced-fat cheese produced with milk homogenised at 10MPa, RF_H (right) from Study III. Lipids are visualised with Nile Red stain (shown in red) and proteins with FITC stain (green).
In order to visualise the relationship between the sensory attributes and biochemical measures carried out in Study II, a PCA was carried out (shown in Figure 11). The rotated PCs accounted for 59 and 41% of total variance, with cheeses produced from homogenised milk (H5 and H10) separated from the cheese subjected to 0 MPa homogenisation pressure (H0) and the control cheese (C) on PC1. The biplot shows trends such as close vicinity, for example, of total FFA content with taste intensity and odour intensity and the closeness of salt content with the salty sensory attribute. Positioning of sensory profiling attributes and biochemical measures relative to cheeses reflects the differences described above.

In Study III, reduced-fat cheeses (control; RF_C and homogenised; RF_H) underwent descriptive sensory profiling with full-fat cheeses FF_C and FF_H. The radar plots of texture and appearance attributes are shown in Figure 12. Differences between cheeses were seen in the nutty odour attribute, where homogenised cheeses were rated higher, and in the buttery odour attribute, where RF_C was rated lower than the others. The largest differences between cheeses were seen in texture attributes; reduced-fat cheeses were harder than full-fat cheeses, while smoothness was lowest in RF_C and highest in FF_H. Control cheeses were rated as more elastic and fatty than those that underwent homogenisation.

In terms of taste attributes, taste intensity was highest in FF_H and RF_H, as was salty taste. Similarly to Study II, homogenised milk cheeses (RF_H and FF_H) were more consistent in colour and less yellow relative to control cheeses, while eye size was rated as lowest in FF_H.
Figure 11. Biplot of scores and loadings from principal component analysis of descriptive sensory profiling data (open circles) and biochemical data (composition, hunter colour values and free fatty acid content; pink squares) from cheeses in Study II. Codes are show in Table 7.

Figure 12. Radar plots of texture (left) and appearance (right) attributes showing the mean intensity scores from three descriptive sensory profiling trials in Study III (n = 15 x 3). In the sample codes, FF refers to full-fat cheeses, RF to reduced-fat cheeses, while C represents control and H represents those cheeses produced with 10 MPa homogenisation pressure in the pre-treatment. Attributes marked with an * differ significantly between samples (P ≤ 0.05)
5.2.2 Dynamic sensory measurements (III)

TDS evaluations on flavour and textural attributes resulted in curves showing dominance rate (the percentages of assessors who chose the same dominant attribute at the same time) versus time. Detailed TDS curves for all cheeses evaluated are shown in the original Publication (II) and the curves for textural attributes in the control cheese (C) and cheese made from milk homogenised at 10 MPa (H10) are shown, as an example, in Figure 13.

**Figure 13.** Temporal dominance of sensations (TDS) curves from textural evaluation of cheeses made from control milk (C; top) and milk homogenised at 10 MPa (H10; bottom). The values are averages from 15 assessors in three replicate cheesemaking trials. The dark dashed line represents the significance level, while the lighter dashed line represents the chance level.
Flavour TDS curves indicated that the salty attribute was dominant for all cheeses at the start of mastication, which then changed to dominantly sour and finally bitter. In the C cheese, the sweet attribute was dominant for a short period, while buttery became dominant for the H10 cheese for a short period around half way through mastication.

For texture attributes, changes were much more evident. The C and H0 cheeses were dominantly elastic at the start of mastication. This dominance was replaced by a dominant crumbly attribute at approx. 40% of standardised time in the C cheese and continued to swallowing. In both H5 and H10 cheeses, crumbly was the dominant attribute at the start of mastication, which then was replaced, in the case of H10, by fatty and then smooth just before swallowing. Dominance rates in texture TDS evaluations were noticeably higher than those in flavour evaluations.

The average dominance rate of each attribute (both flavour and texture attributes) was submitted to PCA resulting in the biplot shown in Figure 14. PC1 and PC2 described 62 and 31% of total variance, respectively. PC1 separated samples based on the presence of homogenisation in the pre-treatment, with H5 and H10 on the negative side and non-homogenised milk cheeses on the positive side. The elastic, nutty and sweet attributes were loaded positively on PC1, while salty, fatty, buttery and smooth were negatively loaded.

**Figure 14.** Biplot of scores and loadings from principal component analysis of average dominance rates from temporal dominance of sensations (TDS) evaluation of homogenised milk cheeses H0, H5 and H10 and the control cheese C in Study II. Taste and odour attributes are indicated with + while texture attributes are indicated with X.
5.3 Consumer responses

5.3.1 Market positioning and acceptability (III)

Participants in Study III positioned cheese samples on paper, based on their similarities or differences and then described each cheese directly on the paper. The final coordinates of samples of each individual and the frequency of word use for each sample were submitted to PCR resulting in the score and loading plots shown in Figure 15.

The score plot can be thought of as the average arrangement of the maps of the total group. PC1 and PC2 separated the cheeses into four distinct spatial groups. Long-ripened commercial Emmental cheeses (FF_E18a/b and FF_E9) were grouped on the extreme negative side of PC1/positive side of PC2. The corresponding area in the loading plot was occupied by words such as ‘strong odour’, ‘pungent’, ‘dry’ ‘hard’ and ‘crumbly’.

**Figure 15.** Scores (top) and loadings (bottom) from principal component regression (PCR) of projective mapping coordinates and words of test cheeses and commercial cheeses in Study III. Codes used in score plot are explained in Table 7 and are followed by the mean liking scores (measured on a 7-point scale).
3-month ripened commercial Emmental cheeses FF_E3/RF_E and test control cheeses RF_C and FF_C were grouped together on the positive sides of PC1/PC2, with words such as ‘elastic’, ‘mild’ and ‘low-fat’ used to describe them. The bottom of the plot contained a commercial Gouda and Gruyère-type cheese, grouped with the full-fat homogenised test cheese. ‘Tasty’, ‘pleasant’ and ‘creamy’ were among the words used to describe them. Finally, the reduced-fat test cheese produced with homogenisation in the pre-treatment (RF_H) was positioned alone in the middle of the plot, where ‘nutty’, ‘dense’ and ‘sour’ were present.

Liking scores (also shown in Figure 15) indicated that the commercial Gouda (FF_G) was the most liked. Among the test cheeses, the full-fat homogenised milk cheese (FF_H) was liked most, followed by FF_C, RF_H and RF_C. The reduced-fat homogenised cheese was liked significantly more than the commercial full-fat Emmental cheese (FF_E3) and the commercial reduced-fat Emmental cheese (RF_E).

5.3.2 Effect of information on expectations and perceptions (IV)

Participants in Study IV were divided into four groups, balanced for age, sex, FNS and FTNS scores. The same cheese sample was given to each group for the home-use test. The groups differed only in the description they received about the cheese sample for the home-use test; either ‘Traditional’, ‘New-type’, ‘Technology’ or ‘Cheese’. A table detailing the scores of expected and actual pleasantness and purchase intent, as well as the expected and actual suitability of sensory and evaluative words is shown in Publication IV, while the F-values obtained from two-way ANOVA (main effects of description and expected/actual questions) are shown in Table 11.

While no differences in expected pleasantness were seen between groups, there was a trend of main effect of description, where purchase intent was highest for the ‘New-type’ group. Purchase intent dropped significantly across groups on tasting. Main effects of question (expected/actual; P < 0.05) were seen in the suitability of ‘salty’, ‘elastic’, ‘mild’, ‘full-bodied’, ‘tasty’, ‘necessary’, ‘unnecessary’, ‘artificial’ and ‘normal’, where actual suitability was in most cases higher than expected (lower than expected for ‘elastic’, ‘mild’, ‘unnecessary’ and ‘artificial’). Description effects were seen for the word ‘soft’, which was highest in the ‘Traditional’ group and lowest in the ‘Cheese group’; ‘full-bodied’, highest in the ‘New-type’ group and ‘traditional’ which was, unsurprisingly, highest in the ‘Traditional’ group and lowest in the ‘Technology’ group.

FNS and FTNS scores for the entire group were low. The mean FNS score was 21.7 (possible range 10-70), while the mean FTNS score was 48.1 (possible range 13-91). A positive correlation (significant, while low) was seen between FNS and FTNS in the overall group, while FTNS and expected purchase intent were negatively correlated. Correlations for the entire group are shown in Table 12. Within the ‘New-type’ group,
FNS was negatively correlated with expected purchase intent, while FTNS was negatively correlated with expected purchase intent in the ‘Technology’ group.

Table 11. Results obtained from two-way analysis of variance (ANOVA) of home-use test data in Study IV.

<table>
<thead>
<tr>
<th>df (df error)</th>
<th>Question*</th>
<th>Descriptionb</th>
<th>Question*Description</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 (213)</td>
<td>3(213)</td>
<td>3(213)</td>
</tr>
<tr>
<td>Pleasantness</td>
<td>2.89*</td>
<td>1.26</td>
<td>2.88**</td>
</tr>
<tr>
<td>Purchase intent</td>
<td>7.34***</td>
<td>2.36*</td>
<td>2.05</td>
</tr>
<tr>
<td>Sensory descriptors</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Salty</td>
<td>22.95***</td>
<td>0.68</td>
<td>2.88**</td>
</tr>
<tr>
<td>Elastic</td>
<td>5.05**</td>
<td>1.11</td>
<td>0.39</td>
</tr>
<tr>
<td>Soft</td>
<td>0.01</td>
<td>3.32**</td>
<td>0.90</td>
</tr>
<tr>
<td>Nutty</td>
<td>1.64</td>
<td>0.06</td>
<td>1.43</td>
</tr>
<tr>
<td>Creamy</td>
<td>2.91*</td>
<td>0.674</td>
<td>3.00**</td>
</tr>
<tr>
<td>Mild</td>
<td>38.61***</td>
<td>0.98</td>
<td>2.66**</td>
</tr>
<tr>
<td>Full-bodied</td>
<td>12.02***</td>
<td>3.08**</td>
<td>0.26</td>
</tr>
<tr>
<td>Evaluative descriptors</td>
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<tr>
<td>Tasty</td>
<td>21.66***</td>
<td>1.97</td>
<td>0.79</td>
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<tr>
<td>Necessary</td>
<td>16.19***</td>
<td>1.14</td>
<td>1.14</td>
</tr>
<tr>
<td>Healthy</td>
<td>0.50*</td>
<td>1.26</td>
<td>0.40</td>
</tr>
<tr>
<td>Natural</td>
<td>3.17*</td>
<td>2.33*</td>
<td>0.29</td>
</tr>
<tr>
<td>Unnecessary</td>
<td>4.60**</td>
<td>0.27</td>
<td>0.64</td>
</tr>
<tr>
<td>Traditional</td>
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<td>17.46***</td>
<td>7.60***</td>
</tr>
<tr>
<td>Industrial</td>
<td>1.13</td>
<td>0.55</td>
<td>2.39*</td>
</tr>
<tr>
<td>Artificial</td>
<td>14.32***</td>
<td>1.75</td>
<td>0.21</td>
</tr>
<tr>
<td>Normal</td>
<td>9.24***</td>
<td>2.41*</td>
<td>1.19</td>
</tr>
</tbody>
</table>

Statistical significance is represented by * (P ≤ 0.1), ** (P ≤ 0.05) and *** (P≤ 0.01)

a Questions, 2: expected and actual
b Descriptions, 4: ‘Traditional’, ‘New-type’, Technology’ and ‘Cheese’

The influences of food neophobia and food technology neophobia were further investigated by categorising the participants as having either a low or high FNS score (≤ 19.99 and ≥ 20.00, respectively) and a low or high FTNS score (≤ 47.99 and ≥ 48.00, respectively), based on the median values of the scales. In the ‘low’ FNS group, expected purchase intent was greatest for the ‘New-type’ description, as was the case for those with high FTNS scores. Bar charts showing the influences of FNS and FTNS on pleasantness and purchase intent are shown in Publication IV.

Finally, for an overall confirmative summary of effects, a linear regression model (Publication IV) was carried out. The model indicated a main significant effect of description on expected purchase intent, where both age and FTNS score influenced the model and substantiated the results described above.
**Table 12.** Pearson’s correlations between food neophobia (FNS), food technology neophobia (FTNS), cheese use, expected pleasantness and purchase intent and actual pleasantness and purchase intent.

<table>
<thead>
<tr>
<th></th>
<th>FNS</th>
<th>Cheese use</th>
<th>Expected pleasantness</th>
<th>Expected purchase intent</th>
<th>Actual pleasantness</th>
<th>Actual purchase intent</th>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cheese use</td>
<td>0.140*</td>
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<td>-0.074</td>
<td>-0.085</td>
<td>0.030</td>
<td>0.085</td>
</tr>
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<td>Expected pleasantness</td>
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<td>0.160*</td>
<td>-0.079</td>
<td>0.002</td>
<td></td>
</tr>
<tr>
<td>Expected purchase intent</td>
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<td>0.657*</td>
<td>0.128</td>
<td>0.120</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual pleasantness</td>
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<td>0.217*</td>
<td>0.255*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Actual purchase intent</td>
<td>1</td>
<td>0.826**</td>
<td></td>
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</tbody>
</table>

* Correlation significant at the 0.05 level (2-tailed).
** Correlation significant at the 0.01 level (2-tailed).
6 DISCUSSION

This series of studies had the initial aim of defining the consequences of incorporating low-pressure homogenisation into a pre-treatment routine in milk for subsequent cheesemaking. Beginning on a laboratory scale, pre-treatment and cheesemaking were scaled-up and taken to an industrial pilot-level scale in the last study. Extensive studies of the biochemical characteristics of the cheese produced (first Cheddar, I, and later Emmental, II, III) were carried out to investigate the potential of the pre-processing routine and to ascertain whether it was a viable option for cheesemaking applications. Cheddar cheese was examined in I as it is, by far; the most produced and consumed cheese in Ireland, where the study took place. The choice of Emmental cheese in II, III and IV was due to its large economic importance in Finland and because of the interesting and somewhat unique ripening characteristics that are used in its production. In order to delve deeper into the effects of the pre-treatment on the sensory properties of cheeses, evaluation of both static and dynamic sensory characteristics followed. As a pragmatic next step, and as a move towards the market, examination of the consumer responses to such a cheese was undertaken through a projective mapping study. Finally, and to further investigate consumer responses and potential marketing directions, the effects of information in descriptions of the cheese on the expectations and perceptions of consumers were investigated in a larger-scale consumer study (IV).

6.1 Effects of pre-treatment on cheese properties

Significant differences were seen in composition and sensory characteristics in cheeses that were produced with homogenisation in the pre-treatment (H5, H10 in I and II, FF_H and RF_H in III) when compared to those that passed through the homogeniser at 0 MPa pressure (H0 in I and II) and to those which bypassed the homogenisation step completely (C in I and II, FF_C and RF_C in III).

In terms of composition, and in general throughout the cheesemaking trials, homogenisation in the pre-treatment resulted in cheese which contained higher levels of moisture and NaCl compared to cheeses where homogenisation was not used in the pre-treatment. Increased moisture and NaCl contents of cheese made with homogenised milk have been seen previously (Jana and Upadhyay 1992; Peters 1956; Peters and Moore 1958). Homogenisation causes the formation of casein-covered milk fat globules, which result in poor matting of the curd during cheesemaking and subsequently, poor syneresis and increased moisture in the curd (Walstra et al. 1985). Curd is also formed more slowly in homogenised milks, which also contributes to moisture retention (Green et al. 1983). The reduced syneresis also acts to retain NaCl in the cheese matrix, especially in brine-salted cheeses, resulting in the higher NaCl contents seen in Studies I-III.
The pre-treatment had a large and expected effect on the production of FFAs from the milk lipid by lipolysis, shown as increased ADV in the milk, higher levels of FFAs at the start of ripening and higher levels of FFAs throughout the course of ripening. While the increase in the amount of FFAs during ripening is a normal biochemical process during the ripening of cheese (Collins et al. 2004; McSweeney and Sousa 2000) higher levels of FFAs at the start of ripening suggest the action of the indigenous milk lipase LPL.

Lipolysis was facilitated in the pre-treatment routine, by homogenisation of the milk and subsequent incubation at the optimum temperature for the indigenous LPL enzyme in the milk (Driessen 1983). Homogenisation causes a very strong activation of lipolysis in milk by causing damage to the protective MFGM, allowing access of LPL to its lipid substrate (Deeth and Fitz-Gerald 2006). This activation of LPL, although used in some blue cheeses for the production of excessive amounts of FFAs, is normally not desired in cheese production (Deeth and Fitz-Gerald 2006; Jana and Upadhyay 1992; Rao et al. 1985).

In the homogenisation-incubation-pasteurisation pre-treatment employed in Studies I-IV, facilitated lipolysis was effectively halted by pasteurisation of the milk. This resulted in higher levels of FFA at the beginning and throughout ripening. LPL is a relatively heat labile enzyme which is extensively inactivated by pasteurisation (Driessen 1983; Farkye and Imafidon 1995).

FFAs, especially short-chain FFAs, have a big impact on cheese flavour (Collins et al. 2003). However, in Study II, where the level of total FFAs was almost two times higher in the cheese produced from milk homogenised at 10 MPa than in the control, no differences were found in odour intensity when examined orthonasally. The equivalent cheese to H10 in Study III (FF_H) was also similar to the other cheeses in terms of odour intensity. The ratings for rancid odour in II and III did not differ between cheeses, suggesting that the homogenisation in the pre-treatment did not result in uncontrolled lipolysis leading to rancidity in the ripened cheese. The lack of differences in rancid odour between the cheeses is discussed later.

Where a difference was seen, however, was in the intensity of taste. In both II and III, those cheeses produced with homogenised milk in the pre-treatment were rated significantly higher for taste intensity. This may be due to the combined effect of higher NaCl contents and the contribution to flavour of higher levels of FFAs, perceived retronasally and produced from LPL action in the pre-treatment incubation. NaCl has a major effect on the taste of cheese (Guinee and Fox 2004).

In terms of appearance, the colour of the cheese was less yellow and more colour consistent in the homogenised milk cheeses. These are characteristics of homogenised milk cheeses, likely due to light-scattering by the homogenised fat globules (Everett and Auty 2008). However, the most evident appearance change was the reduction in eye size. Eyes in Emmental cheese result from the catabolism of lactate by propionibacteria to
carbon dioxide which then migrates to weak parts of the curd matrix and gathers to form an eye (Cakir and Clark 2009; Frölich-Wyder and Bachmann 2004; Lucey et al. 2003). However, for proper eye formation, an elastic and pliable texture is needed, unlike the crumbly, hard texture of the homogenised milk cheeses H5, H10, FF_H and RF_H in II and III. Such an effect has been noticed before in Swiss cheese made with homogenised milk (Peters and Moore 1958). The implications of the reduction in eye size will be discussed later.

Perhaps the greatest changes seen in the cheeses made from milk homogenised in the pre-treatment were in texture characteristics. Homogenised milk cheeses were, in general, less elastic, harder, fattier, smoother and stickier than those which did not undergo homogenisation. The reduction in fat globule size and increase of the surface area of fat globules by 5-10 fold, resulting from homogenisation, causes the inclusion of casein-covered fat globules into the matrix, and a tighter, more closely-associated casein network in cheese (Everett and Auty 2008; Gwartney et al. 2002; O’Mahony et al. 2005), which explains the harder, crumblier texture. Higher crumbliness has also been attributed to increased moisture (Fox et al. 2000). The increased fattiness and smoothness seen may be due to the presence of smaller dispersed fat globules throughout the matrix, as suggested in the CLSM images in III. The texture characteristics revealed by descriptive sensory profiling were expanded on by evaluating the change of the dominant attribute throughout mastication in the TDS method. The crumbliness, fattiness and smoothness attributes were dominant in that order, showing that although harder and crumblier, the fatty and smooth characteristics produced in the cheeses resulted in a smooth finish.

6.2 The pre-treatment in reduced-fat cheeses

Reduced-fat cheeses suffer from a number of quality deficiencies compared to their full-fat equivalents, both in terms of flavour: reduced intensity, lack of characteristic taste and bitterness, and texture: more elastic, harder, less smooth and grainy (Banks 2004; Childs and Drake 2009; Johnson et al. 2009; McMahon 2010; Mistry 2001). The modified biochemical and sensory characteristics of cheeses produced with homogenisation in the novel pre-treatment in Studies I and II were hypothesised to help alleviate these characteristic reduced-fat cheese issues. In general, and as described below, such issues were successfully improved.

The reduced-fat Emmental cheese produced with 10 MPa homogenisation pressure in the pre-treatment (RF_H) was significantly more smooth and fatty, similarly hard and crumbly, and was afforded higher ratings of taste intensity and salty taste than the non-homogenised equivalent (RF_C). NaCl and moisture contents were also higher in the homogenised low-fat cheese relative to the control low-fat cheese. As reduced-fat cheeses typically suffer from reduced taste intensity (Madsen and Ardö 2001), this is a very positive finding. When fat is reduced in milk for cheesemaking, the potential amount of FFAs which can be released on ripening is also reduced, which is one of the major causes
of flavour loss in reduced-fat cheese (Mistry 2001). As in Study II, the increased taste intensity can be attributed to the combination of higher NaCl concentrations, and, presumably, higher FFA levels (although these were not determined in III, evidence from I and II point to higher levels). The reduced-fat cheese with 10 MPa homogenisation pressure in the pre-treatments was also rated higher for both nutty and buttery odours by the trained panel. The positive separation of the homogenised reduced-fat cheese from the control was further confirmed by the PM task, where consumers positioned it in the centre of the PCR score plot, removed from the reduced-fat control cheese and commercial reduced-fat Emmental cheese (with a subsequent higher liking score).

In effect, the pre-treatment routine employed before the RF_H cheese manufacture helped to negate the negative effects usually resulting from reducing fat in cheese. Homogenisation of the cream fraction of milk and reincorporation before cheesemaking has been investigated as a means to improve the texture of reduced-fat cheeses (Madadlou et al. 2007; Metzger and Mistry 1994; Metzger and Mistry 1995; Nair et al. 2000; Oommen et al. 2000; Rudan et al. 1999); the intention being to reduce the negative effects of homogenisation on the protein structure of the resultant cheese (Mistry 2001). In Study III, the pre-treatment, without the need of separation and homogenisation of the cream portion of the milk, produced a cheese with reduced fat and improved texture and flavour attributes when compared with the reduced-fat control cheese. As a result, the pre-treatment appears to be a viable option to improve the characteristics of reduced-fat cheese.

**6.3 Positioning and market potential**

Study III was used as an opportunity to assess the effect of the pre-treatment on the positioning of the cheese in a consumer study using PM. Both reduced- and full-fat cheeses were compared with commercially available equivalents.

The reduced-fat cheese which had homogenisation in the pre-treatment (RF_H) was not associated with the reduced-fat control (RF_C) or the commercial reduced-fat Emmental cheese (RF_E) by consumers. Both the reduced-fat control and the reduced-fat commercial Emmental were described as ‘low-fat’, ‘elastic’, ‘tasteless’ and ‘plastic’, which suggests that although improvements have been made in low-fat cheese manufactured industrially (Banks 2004), these cheeses still suffer from quality problems.

Most interestingly, the full-fat homogenised milk cheese (which was ripened for 3 months) was grouped with a commercial Gouda cheese (ripened for 8 months) and a commercial Gruyère-type cheese (ripened for 7 months). Words such as ‘creamy’, ‘full’, ‘pleasant’ and ‘fatty’ were associated with these cheeses by the participants. These words, although from consumers, match well the characteristics of the FF_H cheese when it was evaluated by the trained panel. The pleasantness of the FF_H cheese was also significantly
higher than any other of the test cheeses, on a par with longer-ripened commercial Emmental cheeses.

Cheese has to be kept at a specific temperature and relative humidity for long periods of time so that its characteristic flavour and texture components are attained. This is an expensive process, mainly from the inventory cost of storing at specific temperatures and humidities. Unsurprisingly, extensive investigation into the reduction of ripening time by accelerating cheese ripening has been carried out (McSweeney 2004). The cheese produced with 10MPa homogenisation in the pre-treatment in III exhibited higher intensity of taste and texture attributes associated with longer-ripened cheeses and was positioned closer to longer-ripened cheeses in PM, showing that the pre-treatment effectively resulted in a similar cheese in half the ripening time.

6.4 Information in descriptions

In Study IV, a full-fat Emmental cheese, from milk which underwent the 10 MPa homogenisation pressure pre-treatment, was produced on a large scale. This cheese was equivalent (in terms of the conditions of pre-treatment, manufacturing and ripening) to the H10 cheese in Study II and the FF_H cheese in Study III. The decision to choose this cheese over a cheese produced with any of the other pre-treatment conditions described in Studies I-III was because this was the highest homogenisation pressure used in pilot-scale trials and caused the largest changes in the properties of the subsequent cheese.

The descriptions given to the participants affected the expected purchase intent but not their expected liking of the cheese. Those who received the ‘New-type’ description rated the purchase intent highest, which may be an effect of the relatively low FNS overall (see below). Those who received the ‘Cheese’ description, intended to be a blank, rated the lowest expected purchase intent. While information provided has been previously shown to influence expected liking (for example in Caporale and Monteleone 2004 and Siret and Issanchou 2000), it may be that concept of expected liking was too inert and irrelevant in the present study than expected purchase intent was. It is known, for example, that ‘liking’ does not equate to ‘wanting’ (Berridge 1996; Mela 2006) suggesting that measures of intent may be more valuable for researchers.

Most effects for the suitability of descriptive words were seen in the groups which received the ‘Traditional’ and the ‘New-type’ descriptions. The ‘Traditional’ description contained the word ‘Emmental’, which unsurprisingly triggered a higher expectation of ‘traditional’ and ‘normal’. The ‘New-type’ description caused participants to expect that ‘necessary’, ‘tasty’ and ‘salty’ would be more suitable as descriptive words for the cheese than when tasted. The opposite was true for ‘salty’. It remains unclear whether the suggestion of novelty triggered such responses, especially for ‘salty’, when the cheese produced was much saltier than a commercial Emmental would be.
The word ‘homogenised’ was included in the ‘Technology’ description as the pretreatment used throughout the studies was based on homogenisation and that, from a marketing point of view, the term would have to be communicated in some form to consumers. Overall, the term did not drastically affect purchase intent, expect for those with higher FTNS (see below). The negative effects of novelty on the consumer acceptance of foods can be reduced by providing information of a benefit or reduce the apparent risk (Cox et al. 2004; Frewer et al. 2003). It appears that the content of the ‘Technology’ description did not represent a benefit for the participants.

Background psychographics of the participants, namely food neophobia and food technology neophobia, were examined for influence on expected indices. Overall, and in the ‘Technology’ group, FTNS was negatively correlated with expected purchase intent suggesting that the use of such a ‘technological’ description as the one given to ‘Technology’ description may be challenging if to those with higher FTNS scores. While such an effect has been found when novel technologies were mentioned, no effect was seen for common technologies like pasteurisation (Evans et al. 2010). In terms of FNS, those with higher neophobia scores gave lower expected purchase intent scores when presented with the ‘New-type’ description, an expected effect. Neophobia has been shown to influence on the purchase intent in novel foods, where higher neophobia caused lower purchase intent (Arvola et al. 1999; Raudenbush and Frank 1999; Tuorila et al. 1998).

The FNS score of the overall group (21.7) was very low, when compared to the mean previously measured in Finland (33.9; Tuorila et al. 2001). As FNS is an indicator of willingness to try unfamiliar food, this may in some way explain why the ‘New-type’ description had the highest expected purchase intent scores among the groups. The mean FTNS score of the group (48.1) was also low when compared with recent studies in Australia (mean FTNS of 55.0, 294 participants, 203 female, aged 18-60+; Cox and Evans 2008), Canada (average FTNS of 54.4, 777 participants, 396 female, aged 15-65; Matin et al. 2012) and Italy (FTNS = 60.9, 555 participants, 304 female, aged 17-84; Vernau et al. 2014). To the author’s knowledge, the use of FTNS in Finland has not been reported in prior to this study. The possible reasons for low overall FNS and FTNS scores will be discussed later.

With increasing consumer awareness and access to information about products, it would be valuable to investigate consumer’s responses to ‘everyday’ technologies. With the widespread use of pasteurisation and homogenisation in dairy processing (Kelly et al. 2008), it may be that such technologies are well known and considered acceptable to consumers. On the other hand, certain groups advocate the use of raw milk devoid of processing, claiming that raw milk is more nutritious (MacDonald et al. 2011; Ruusunen et al. 2013), however, neither pasteurisation nor homogenisation have been conclusively shown to affect the health properties of bovine milk (Korpela et al. 2005; MacDonald et al. 2011; Michalski and Januel 2006). While an extensive amount of research has been carried out on responses of consumers to new technologies, for example GM (Caporale
and Monteleone 2004; Siegrist et al. 2006), high pressure processing (reviewed in Olsen et al. 2010) and irradiation (Cardello et al. 2007; Fox et al. 2002) but to name a few, little has been examined about consumers responses to ‘everyday’ technologies. Such an examination would be warranted in the near future, and undoubtedly aid those producers who utilise such ‘everyday’ technologies in determining the most suitable approach to inform consumers of use of technology.

Expectations play an important role in the consumer’s perception of a food (Cardello 1995). The main reason for investigating the descriptions in Study IV was to assess what type of wording or description would work best. As the cheeses did not match to what was considered to be Emmental cheese (in terms of characteristic chemical and sensory qualities), a suitable way to describe the product is needed. The process used in the pre-treatment contained two technologies which, while widely used in the dairy industry, may have affected consumer’s expectations while communication of the technology used raised purchase intent of those with low FNS and FTNS. The psychographic background of the consumer is therefore important when considering the best description to communicate technology and novelty.

### 6.5 Viability of the pre-treatment

From the laboratory-scale investigations in I, through the consumer studies in III and IV, a central aim of this work has been to assess the viability of the pre-treatment, where raw milk was homogenised, incubated and pasteurised, in an industrial sense.

The identity characteristics of a cheese variety lie in the specific sensory and biochemical properties of that cheese. A young Emmental cheese, for example, is recognised and acceptable for consumers when it has an elastic texture, mild taste, nutty odour and the presence of eyes (Cakir and Clark 2009; Frölich-Wyder and Bachmann 2004). The cheeses in Studies I-IV were produced with typical Cheddar and Emmental manufacturing protocols, however, due to the pre-treatment of milk employed before cheesemaking, the resultant cheeses were quite different than commercial equivalents. Although displaying improvements (see below) in some aspects of taste and texture, the cheeses may fall outside the limits of acceptability for certain attributes. In the case of the Emmental cheese produced in II and III, the most striking difference lay in the eyes (or lack thereof). Swiss cheeses (of which Emmental is one type), are among the most recognisable in a retail environment due to the presence of eyes (Cakir and Clark 2009); clearly the homogenised milk cheeses H10 and FF_H would not be recognised as such. Coupled with the other features of the homogenised milk cheeses (increased taste intensity, decreased elasticity, increased smoothness/fattiness and a complete rearrangement of the dynamic textural changes during mastication), it is unlikely that these cheeses would be acceptable to consumers who expect a young Emmental cheese, and the distinctive attributes that are associated with it. However, if expectations are modified accordingly, the novelty of the cheese could be communicated in order to improve its acceptance as a new cheese type.
The positioning of the full-fat homogenised milk cheese FF_H in III and the differences in this cheese compared to what is considered a commercial Emmental suggests that the potential future direction of the cheese (and the pre-treatment in the cheese) lies in cheeses which are similar to the longer-ripened Gouda and Gruyère –type cheese shown in the PM score plot (Figure 15).

Obviously, categorising a drastic change in a characteristic attribute of a cheese as an ‘improvement’ is not straightforward, however in the case of the cheese produced in III, it refers to an improvement in positioning and liking relative to the control cheeses. Those changes which were evident in the homogenised milk cheese (FF_H) from descriptive sensory profiling led it to be liked more and positioned closer to longer-ripened cheeses which were liked more by consumers. Salt (NaCl) contributes to taste and increases the appeal of cheese (Ritvanen et al. 2010), stronger tastes and smoother textures have been shown to appeal to clusters of consumers (Murray and Delahunty 2000; Young et al. 2004).

Interestingly, rancidity was not an issue in the cheeses produced with homogenisation in the pre-treatment. While higher levels of short chain FFAs were present in these cheeses relative to control cheese (in Study II), samples did not differ significantly in rancid odour when evaluated by the trained panel, which is somewhat surprising, as thresholds to flavours are often lower when sensed orthonasally as opposed to retronasally (Bojanowski and Hummel 2012). This absence of difference in rancidity may suggest that the lipolysis during the incubation stage was somewhat controlled, as previously mentioned. Previous studies have found excessive FFA production in cheese produced from homogenised milk and this remains one of the consequences of homogenisation which prevents its adoption in cheesemaking (Green et al. 1983; Mistry 2001; Rao et al. 1985). Although high in II, FFA levels were not higher than what has been reported previously for longer-ripened Emmental. For example, Emmental cheese has been shown to contain anything from approximately 2000 to 4000 mg/kg FFA, varying with ripening time (Collins et al. 2004). Another reason for the lack of rancidity differences may be that any difference was not of a magnitude to produce a difference distinguishable by the panel, or that it wasn’t distinguishable from the other odours present (Livermore and Laing 1998).

An issue which needs addressing is the higher salt content of homogenised milk cheeses relative to control cheeses seen in I, II and III. Although relatively small, consumption of high salt content cheese does contribute to daily sodium intake (Guinee and Fox 2004; Ritvanen et al. 2010). Official guidelines now recommend limiting salt intake to 5 g per day (2000 mg sodium) while salt intakes around the world still far exceed physiological need (Brown et al. 2009; World Health Organization 2012).

NaCl plays a functional role in cheese and contributes to taste (both directly and by reducing bitterness), affects texture and increases consumer appeal (Guinee and Fox 2004; Johnson et al. 2009; McMahon 2010; Ritvanen et al. 2010; Ritvanen et al. 2005). Cheddar
cheese, on average, contains 1.5% w/w NaCl while Emmental contains 0.7% w/w (Guinee and Fox 2004). In Study I, the NaCl content of the Cheddar cheese H10 was 1.54% (similar to commercial Cheddar but still higher than the control) and in Studies II-III the Emmental cheeses H10 and FF_H contained 1.42 and 2.03% NaCl, respectively (much higher than commercially produced Emmental). Due to the higher moisture contents of these cheeses, the NaCl concentrations relative to commercial cheeses are not as dramatic when viewed as salt-in-moisture (S/M), but are nevertheless, higher. As explained, homogenisation causes decreased syneresis from the curd in cheesemaking, increased moisture and better retention of NaCl from the brining stage of cheesemaking (Jana and Upadhyay 1992; Peters 1956). If, due to health issues and/or if the cheese in Studies II-IV is to be considered Emmental (i.e. not as higher levels of NaCl as present), the salt content should be reduced (Johnson et al. 2009). As the cheeses were brined, a simple solution to this would be to reduce the brining time in cheesemaking.

From a practical point-of-view, the inclusion of the homogenisation-incubation-pasteurisation pre-treatment in an industrial setting would require a readjustment of a milk pre-treatment line. However, compared to other methods to accelerate cheese ripening, e.g. high pressure treatment or addition of exogenous enzymes, the pre-treatment detailed here would not require new machinery as everything needed is already available in a multi-functional dairy processing setting (Law 2001; Trujillo et al. 2000). While a common process in dairy product manufacture, homogenisation is not generally used in cheesemaking (Jana and Upadhyay 1992), while pasteurisation is used in the majority of large-scale industrial cheese production (Grappin and Beuvier 1997; Johnson et al. 1990). The potential reduction in storage costs (through decreased ripening time) would need to be weighed up against the capital cost of readjustment of a milk pre-treatment line before an investment decision would be made in industry.

6.6 Methodological considerations

6.6.1 Cheesemaking

An aspect which was evident in the Studies I-III where replicate cheesemaking was carried out was the between-trial differences in some chemical and sensory characteristics. Such trial variation is not unheard of, for example in Collins et al. (2003), where differences were seen in salt and FFA levels between replicate cheeses, attributed to seasonality effects. Seasonality, where milk for cheese production takes advantage of the spring to autumn grass-growing season, could in some part go to explaining differences in Study I, as this is a feature of bovine milk production in Ireland (Geary et al. 2012). Such seasonality results in significant changes in milk composition over the season with subsequent changes in proteolysis and lipolysis in cheese made therefrom (Auldist et al. 1996; Hickey et al. 2006; Lucey 1996). As several months elapsed between the cheesemaking in Trial 1 and the cheesemaking in Trials 2 & 3 in Study I, seasonality
effects may have contributed to differences in the end cheeses. Similar seasonality effects are not seen in Finnish milk, where milk production is more constant (van Arendonk and Liinamo 2003). Although milk was standardised and the time/temperature condition of pre-treatment, cheesemaking and ripening were controlled, any slight variations in any part of the process up to evaluation could have cumulatively acted to cause differences between trials.

6.6.2 Sensory methodology

Descriptive sensory profiling was carried out with panels selected and trained in the University of Helsinki, and featured relatively young participants, with a majority of females. Such demographics should not have an effect on the evaluation of cheese and subsequent results, as proper and extensive training results in participants using the same definitions and frames of references (in terms of reference standards). Such is the acceptance that the gender balance of the trained panel is unimportant, that studies where descriptive sensory profiling of cheese has been carried out with predominantly female trained panels do not mention it (Bárcenas et al. 1999; Downey et al. 2005; Møller et al. 2013; Yates and Drake 2007; Zhang et al. 2011).

Discrimination by the panel in Studies II and III was sufficient to determine the sensory differences caused to taste, texture and appearance attributes predominantly by the pre-treatment prior to cheesemaking. However, the discrimination was not as effective for odour attributes, especially where no significant differences were found in rancidity odour when levels of FFA in the homogenised milk cheese were twice that of the control in II. While the rancid odour may not have been distinguishable from the other odours present (as mentioned above; Livermore and Laing 1998), it may be that the sample handling contributed to loss of volatile FFA before evaluation. Samples were sliced, placed into sealed sample containers (specifically for odour evaluation) and refrigerated 24 h prior to evaluation and containers were removed from refrigeration 1 h before evaluation. Panellists were instructed not to keep containers open for long when evaluating odour. Every practical step was taken to avoid loss of volatile compounds; however, it may have been that this did indeed happen. A possible solution would be to allow participants to slice cheese directly from the block immediately before evaluating the odour, however due to the relatively small amounts of cheese produced in II and III, this was not practically possible.

Dynamic measurements resulting from TDS added an extra layer of understanding in Study II, providing deeper understanding of sensory characteristics than descriptive sensory profiling alone. TDS, as a relatively new method, is constantly undergoing changes, with recent studies investigating the most suitable number of participants, the number and type of attributes to use and how to deal with results (Di Monaco et al. 2014; Meyners and Pineau 2010; Pineau et al. 2009; Pineau et al. 2012). In planning the TDS evaluations before the training sessions, the decision was made to ask participants to
choose the dominant attribute from the list of attributes, without the simultaneous evaluation of intensity, which had been a feature of several previous TDS studies (Albert et al. 2012; Le Révérend et al. 2008; Meillon et al. 2010; Saint-Eve et al. 2011; Teillet et al. 2010). Since then, it has been reported that the simultaneous evaluation of intensity is not necessary, with sufficient data coming from dominance rates alone (Dinnella et al. 2012; Pineau et al. 2012). The simultaneous evaluation of intensity and selection of a dominant attribute requires two different cognitive processes, the former a quantitative task and the latter a qualitative task (Lawless and Heymann 2010; Pineau et al. 2012). The mixing of these tasks may cause undue confusing, without creating deeper insights, and in hindsight, the decision to choose the dominant attribute alone is justified.

6.6.3 Consumer methodology

Participants in the consumer studies in III and IV were skewed towards younger, highly educated, urbanites, of whom the majority were female. The recruitment area for both was the Viikki campus of the University of Helsinki, a hub of natural sciences, which has a majority female population of both students and staff. Perhaps as a result of this skewed distribution towards young adults in Study IV, both food and food technology neophobia scores were, on average, quite low. As exposure to and experience with unfamiliar foods increases with age, neophobia generally decreases from childhood to adult-age (Tuorila et al. 2001). Urban dwellers have been shown to have lower FNS and food neophobia is lower in higher educated people, probably due to increased exposure to unfamiliar foods (Meiselman et al. 2010; Siegrist et al. 2013; Tuorila et al. 2001). Gender differences have also been seen (Camarena et al. 2011; Tuorila et al. 2001). Though not as studied as FNS, suggestive evidence was found for the influences of age and education on FTNS, similar to that of FNS (Chen et al. 2013). These factors combined may have caused the low FNS scores of the group; however, as FNS and FTNS scores were balanced across groups, the influence of the group scores on investigation of effects of description was reduced.

The PM utilised in Study III was rapid, easy for participants to complete and resulted in the distinct separation of samples. Some of the participants remarked that it was fun. The resultant separation further enhanced the results obtained from the trained panel that performed descriptive sensory analysis, even though direct comparison could not be made as the commercial samples included in the PM were not present in the profiling task. Though software interfaces exist to perform PM (for example in FIZZ Sensory Evaluation Software), PM was carried out on paper, in order to best maintain the naturalness, accuracy and holistic nature of the task (Varela and Ares 2012). The task as a stand-alone investigation of product differentiation is possible, if criteria normally investigated by descriptive profiling are those which drive the differentiation of products (Nestrud and Lawless 2008; Varela and Ares 2012), which in retrospect, was the case in Study III. Based on the experiences and results obtained, for cases of rapid discrimination of products by untrained participants, PM is recommended.
The method used in Study IV to create four balanced groups based on the variables age, sex, FNS score and FTNS score; was efficient, quick and very useful. While creating small numbers of groups based on few variables is relatively straightforward but time-consuming, the complexity and time needed increase when greater numbers of variables are considered. The method used in this research allowed the balanced groups to be formed in the short space of time between sample distribution and sending of the online questionnaire, and without such a method, the interval time would have been significantly longer. This could present an issue if the samples provided have a short shelf life. Also, although balanced when sending the questionnaire, the balance of groups still relies on the number of participants that choose to reply to the test.

The consumer research parts of Studies, III and IV were carried out in Finnish, which was the most convenient and relevant option for the participants and consumers involved. Descriptive sensory evaluation was carried out in Finnish, although part of the training was in English. Descriptive sensory panels consisted of native Finnish speakers, while consumers were either native Finns (the vast majority) or foreigners with suitable Finnish language proficiency. The term ‘pleasantness’ (miellyttävyyys in Finnish) was used in Study IV, instead of ‘liking’, as the Finnish language lacks a word for ‘dislike’, making the use of a bipolar scale difficult. ‘Pleasantness’ and ‘liking’ are used interchangeably in the literature (Mela 2006), and for the most part give similar values. However, Tuorila et al. (2008) found pleasantness ratings 0.48 units higher than liking on 7-point scales in the Finnish language. For well-liked and familiar foods, liking was linearly correlated with pleasantness while, at low levels of affection for unfamiliar foods, the relationship was curvilinear (Tuorila et al. 2008). As cheese is a familiar food to all, conclusions regarding pleasantness from Study IV can be equated to liking; however the preceding example shows the need for pragmatism when working in a language other than English.
7 CONCLUSIONS

A milk pre-treatment wherein the novel combination of everyday dairy processing techniques, namely homogenisation and pasteurisation, allowed controlled lipolysis to take place in milk and produced cheese which was acceptable to consumers. Cheese made from this milk was drastically different in many characteristics to those cheeses that did not undergo homogenisation in the pre-treatment.

In most cases, the differences evaluated and determined were major and of a biochemical nature (e.g. higher moisture, higher NaCl, double the level of FFA) resulting in increased taste intensity and saltiness when evaluated by trained panels. As homogenisation is a physical process where fat globules are reduced in size, it is of no surprise that textural changes were the most evident when assessed by the trained panellists and visualised by microscopy. Cheeses produced with homogenisation in the pre-treatment differed from control Emmental cheeses by being smoother, fattier and more crumbly. Appearance was also altered where the cheeses were less yellow and lacking the eyes which are characteristic of Emmental cheese.

Consumer responses to the cheeses produced with homogenisation in the pre-treatment were favourable. When asked to position experimental cheeses with commercial cheeses of various ripening stages in the projective mapping task, the reduced-fat cheese produced with homogenisation in the pre-treatment was removed from the similar reduced-fat commercial cheese and was rated higher for liking. Such positioning signals a potential for the use of the pre-treatment in the improvement of the quality of reduced-fat cheeses, specifically improving those characteristics (taste and textural sensory attributes) which are commonly deficient in commercial reduced-fat cheeses. Consumer responses to the cheese produced from 10 MPa homogenised milk were extremely favourable, positioning the cheese away from Emmental cheeses of a similar age and closer to a Gruyère-type and a Gouda cheese, both ripened for more than double the time of the test cheese. The expense of ripening cheese is very significant for cheese producers. By use of the simple pre-treatment described in this thesis, there is a strong potential to reduce that time. Notwithstanding the added caveat of higher NaCl levels, the exciting market potential of cheeses produced with the pre-treatment is evident, both from positioning and liking scores.

Although consumers responded excellently to the cheese produced with the pre-treatment, the effective marketing such cheeses remains challenging. Such were the drastic changes in biochemical and sensory characteristics of the cheeses produced with the novel pre-treatment, that the description provided and marketing of such cheeses needs to be carefully considered. Though produced with an Emmental cheesemaking scheme and ripened with a typical Emmental ripening routine, the cheese would not be acceptable to consumers as Emmental cheese, due to the lack of the characteristic eyes, the smoother
and creamier texture, a whiter colour and a greater intensity of taste. Combined with this, is the use of a common processing technique (homogenisation) in an uncommon way (prior to cheesemaking), which if communicated, may affect expected purchase intent. If novelty is to be communicated to consumers, it is most effective to those with low food neophobia. Similarly, if technical information is to be provided, perhaps to prevent consumers ‘finding out’ about the technology later or to build trust, then it is most effective when conveyed to those with lower food technology neophobia. The crafting of a suitable description would be essential for the low-pressure homogenised cheese to succeed as a viable product.

The main argument against the use of homogenisation in cheesemaking has always been the excessive production of FFA from uncontrolled lipolysis, which leads to cheese which is rejected by consumers. In this study, homogenisation, through the novel pre-treatment routine has been shown to be a viable and useful tool in improving the sensory aspects and consumer acceptability of ripened cheese. The implementation of such a routine can potentially lead to savings to producers by reducing the time needed to ripen. If suitable descriptions are provided to consumers and the cheese is marketed correctly, cheese produced with the pre-treatment routine could succeed commercially.
8 BIBLIOGRAPHY


