Universitetet i Stavanger

**FACULTY OF SCIENCE AND TECHNOLOGY**

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# TEXTURE MEASUREMENTS OF PROTEIN ENRICHED FOODS FOR ELDERLY

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Manjusha Kema,
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# ABSTRACT

Elderly people require nutritious food with a high protein content in their diet, and at the same time the food should be attractive and easy to swallow. A good diet not only helps in protecting the health but it also speeds up recovery during illness. There were two main aims of this thesis. The first was to examine how protein enrichment of a barley porridge influenced sensory and texture properties of the porridge. In the second part, commercial dairy products were classified based on sensory, viscosity and texture analysis. In both the experiments correlations between sensory and instrumental texture methods was examined.

The barley porridge was enriched with two protein sources, Skim Milk Powder (SMP) and Whey Protein Concentrate 80 (WPC80). The design factors in porridge development, in addition to protein sources, were protein concentrations (4%, 7% and 10%) and protein addition time (before and after cooking). In the SMP porridge samples, sensory scores for the attributes <sweet, total taste, milk, cooked, elastic, sticky> increased with the increase in protein concentration. The protein addition time (before and after cooking) had a greater influence on WPC80 porridge samples compared to protein concentration. The instrument texture results of firmness, consistency, cohesiveness and index of viscosity were correlated with sensory attributes <firm, elastic and sticky>. Colour analyses showed that the yellow tone was significantly different ($p<0.05$) for the factor protein concentration. The increase in protein concentration shifts colour saturation towards yellow.

Based on sensory analysis and texture and viscosity measurements of 14 commercial products it was possible to characterise the products into International Dysphagia Diet Standardisation Initiative (IDDSI) classification system for people with chewing and swallowing problems. The sensory attributes thickness with spoon, thickness in mouth and swallow had a high correlation ($R^2$= 0.90, 0.89 and 0.89) with instrumental measured texture properties.

The main conclusions were that the protein concentration affected SMP protein enriched porridge samples significantly, whereas protein addition time significantly affected WPC80 porridge samples. Additionally, the denaturation of proteins in the WPC80 porridge affected the appearance, texture and sensory properties of the porridge. Test of commercial dairy products showed that the international classification system, IDDSI provided a simple classification system for products aimed for elderly people with swallowing problems.

# TABLE OF CONTENTS

# SYMBOLS & ABBREVIATIONS

| | |
|---|---|
| $\Delta E_{ab}$ | Euclidean distance in CIE L* a* b* colour space |
| a* | Colour coordinate - green/red |
| ANOVA | Analysis of Variance |
| b* | Colour coordinate - blue/yellow |
| C* | Cylindrical colour coordinate - Chroma |
| CIE | International commission of illumination |
| cP | centipoise |
| DA | Descriptive Sensory Analysis |
| dl | decilitre |
| $\dot{\gamma}$ | Shear rate |
| GLM | General Linear Model |
| g | gram |
| h° | Cylindrical colour coordinate - Hue angle |
| HIS | Tristimuli colour system - Hue, Intensity, Saturation |
| IDDSI | International Dysphagia Diet Standard Initiative |
| ImageJ | Image processing and analysis in Java |
| ISO | International Organization for Standardization |
| L* | Colour coordinate - Lightness |
| LV | Low Viscosity |
| mPa.s | millipascal-second |
| $\eta$ | Viscosity |
| PC1 | Principal Component 1 |
| PC2 | Principal Component 2 |
| PCA | Principal Component Analysis |
| PLSR | Partial Least Squares Regression |
| $R^2$ | Regression coefficient |
| RGB | Tristimuli colour system - Red, Green, Blue |
| RPM | Revolutions Per Minute |
| s | second |
| SMP | Skim Milk Powder |
| $\tau$ | Shear stress |
| WPC | Whey Protein Concentrate |
| WPC80 | Whey Protein Concentrate with 80% protein content |
| WPH | Whey Protein Hydrolysate |
| WPI | Whey Protein Isolate |

# 1. INTRODUCTION

Elderly people require a good nutritious diet to stay healthier and active. A nutritious diet not only helps in protecting health but also in recuperating (speedy recovery) during an illness thus, having a significant contribution to quality of life. The advance in medicine and healthcare and increased standards of living is resulting in people living longer. The percentage of elderly people in the population is growing steadily. In the developed countries, the individuals of chronological age above 65 years are accepted as elderly (Aguilera & Park, 2016). In Norway, by 2020 one person in five people will be over 65 years of age (www.ssb.no).

Though many elderly people are active and enjoy life with few health problems, some are delicate and more prone to illness and may have danger of undernourishment. The daily diet should cater to 1.0 – 1.2 g protein/kg body weight as minimum to healthy elderly people and 1.2 – 1.5 g protein/kg body weight for elderly people who are malnourished or at risk of malnutrition due to acute or chronic ailment (Nordic nutrition recommendations, 2012). Compared to young, elderly people need more protein in their diet because the muscular mass degenerates in the elderly people (sarcopenia) (Landi et al., 2016). Foods that require less chewing, and that are cohesive and moist, are regarded as safer to swallow (Chen, 2009).

## 1.1 Food texture

Appearance, flavour, texture and nutrition are four main important quality factors for acceptability of food (Bourne, 2002). The first thing that comes into mind, when we look at food is texture. The awareness of texture is often subconscious, when texture expectations are met, then the focus shifts on aroma and flavour of that specific food (Chen & Engelen, 2012).

There are several definitions available of food texture. The definition for food texture was defined by Szczesniak (2002) as "the sensory manifestation of the structure of the food and the manner in which this structure reacts to the applied forces, the specific senses involved being vision, kinesthesis, and hearing" (Szczesniak, 2002).

The master thesis was divided into two parts, Part I was to develop and produce a protein rich barley porridge with added dairy protein. Two protein sources, Whey Protein Concentrate (WPC80) and Skim Milk Powder (SMP) were used for protein enrichment. The comparison of sensory and instrumental texture properties of whey protein concentrate and skim milk powder enriched porridge was examined. The colour difference between samples and image analysis were also carried out.

The texture of the commercially available dairy products from TINE was evaluated in the second part. Sensory, texture, viscosity measurements were correlated and the products were classified into the International Dysphagia Diet Standardisation Initiative (IDDSI) framework using IDDSI flow test. The illustration of overall work done is given in Figure 1-1.

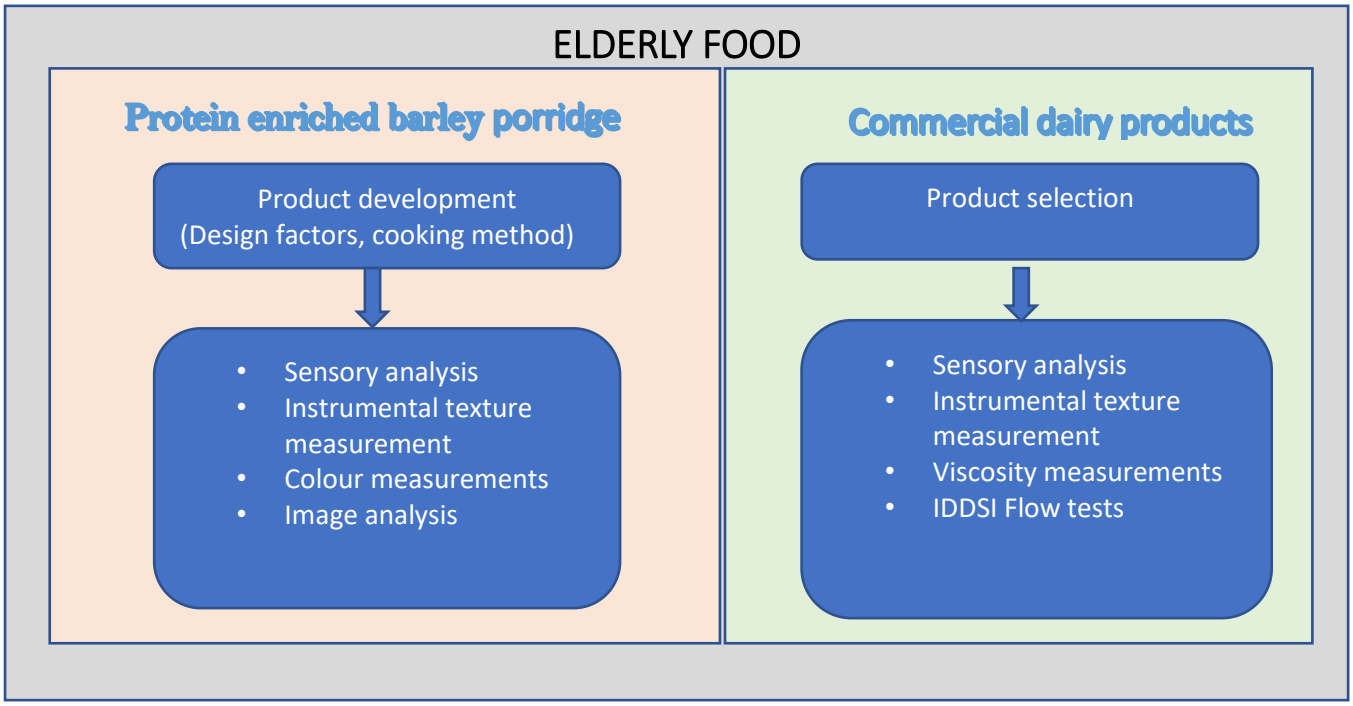



*Figure 1-1: Illustration of overall work done in this project.*

# 2. BACKGROUND STUDY

Porridge called "grøt" in the Norwegian language is a dish made of whole grain cereals boiled with water or milk and sugar until a thick consistency is formed. The original term for porridge is "pottage" which means thick stew or soup made of vegetables/meat (Webster dictionary). Porridge is usually served as a sweet dish but in some places as a savoury with spices. Porridge is a staple food in many European countries and is often made of barley (Newman & Newman, 2008). Barley porridge/byggrynsgrøt (Figure 2-1) is prepared with whole milk and enriched with dairy proteins for this project work.

*Figure 2-1: The image of barley porridge with blueberries on top. Picture courtesy https://www.bbcgoodfood.com.*

## 2.1 Barley

Barley (*Hordeum vulgare*) belongs to the grass family Poaceae and the tribe Triticeae (Newman & Newman, 2008). Barley is a most ancient cereal crop in the world (Jadhav, Lutz, Ghorpade, & Salunkhe, 1998). Barley is used in human diet and animal husbandry as animal feed. Cereals like wheat, oats and rye are rich in proteins and carbohydrates. Barley not only provides protein and carbohydrate, but is also a source high in dietary fibre. In ancient times, it has been consumed mainly as a staple food, whereas in modern times it is mostly used as animal feed and in preparing alcoholic beverages, for example, beer (Jadhav et al., 1998).

The world production of barley amounts to 147 million tons in 2017 (US department of agriculture, 2017) and it ranks fourth largest cereal (Sharma & Kotari, 2016). The barley

cultivation area in Norway is approximately half of the total grain cultivation area, and the production is around 574 000 tons (Statistics Norway).

Barley is classified as spring or winter type, two-row or six-row type, hulled or hull-less type, and malting or feed type. The barley spike consists spikelets attached to the nodes of rachis (Main axis of spike which is flat & zigzag) (Figure 2-2). Each spikelet has a single floret and there are three spikelets at each node, alternating on each side of barley head or spike. In the hulled type barley, the hull is tightly attached to the grain. For usage in food the hull is removed by pearling. In hull less or naked type barley the hull is loosely attached to the grain, and falls off during harvesting (Baik & Ullrich, 2008).

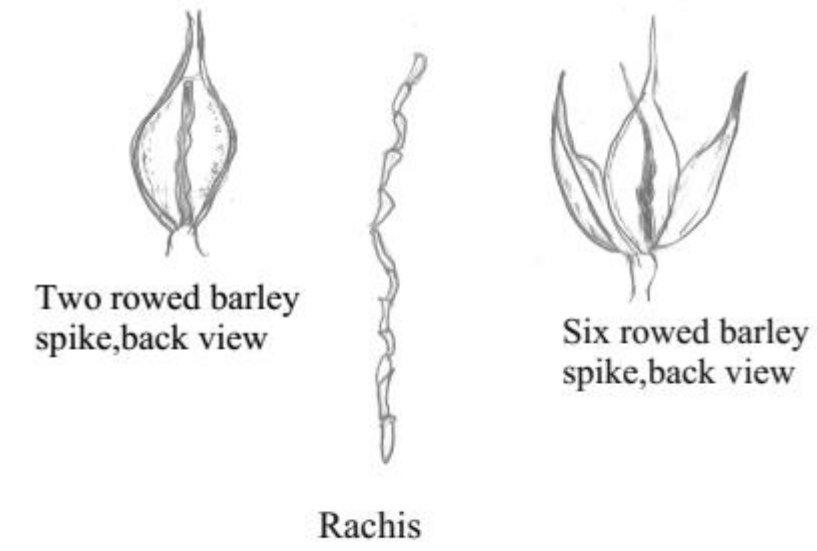



*Figure 2-2: Morphological description of two and six rowed barley spikes with single rachis in the centre. The drawing was inspired from https://www.morebeer.com/brewingtechniques/bmg/graphics/rachis.gif*

### 2.1.1 Structure of barley grain

The barley grain consists of husk (formed from lemma and palea), pericarp, testa, aleurone layer, endosperm and embryo (Figure 2-3). Husk and pericarp consists of major insoluble fibre and endosperm is surrounded by aleurone layer (Jadhav et al., 1998). The anthocyanin pigment present in aleurone layer and husk is responsible for grain colour. Endosperm represents 75% of barley grain and is mainly filled with starch (Arendt & Zannini, 2013).

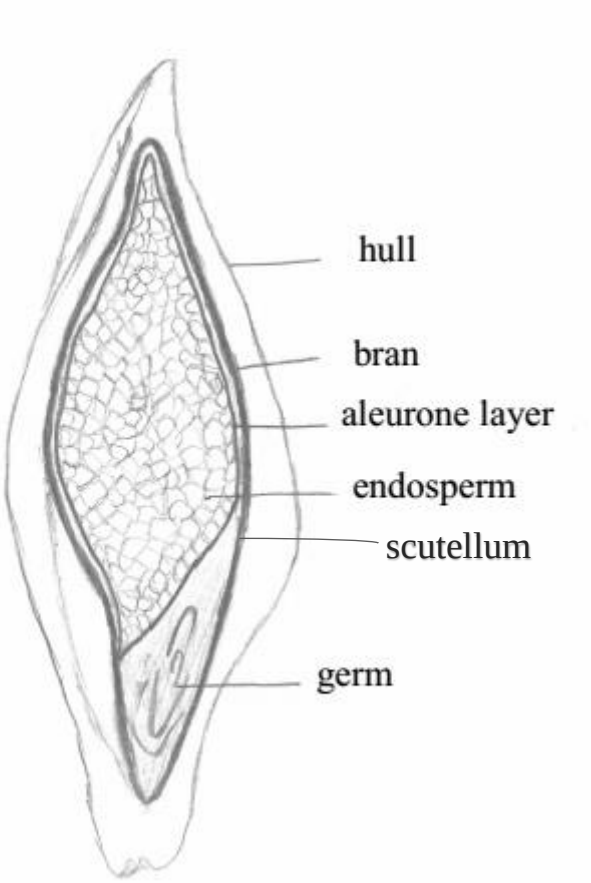



*Figure 2-3: Barley kernel structure with outermost layer called hull followed by bran and aleurone layer. The endosperm and germ(embryo) separated by a layer called as scutellum.*

The barley grain contains of starch (65-68%), total dietary fibre (11-34%), proteins (10-17%), has a low content of fat (2-3%) and minerals (1.5-2.5%) (Baik & Ullrich, 2008). Barley is an excellent source of vitamin B complex which includes vitamin B1, B2, B6, Niacin and pantothenic acid (Hockett, 2000). It is also a good source of minerals as P, K, Mg, Ca, Na, Fe, Zn, Mn and Cu (Liu, Robbins, & Pomeranz, 1974).

### 2.1.2 Beta glucans

With the discovery of the health benefits provided by barley, recent studies have increasingly focused on the nutraceutical components in barley. The mixed linkage (1 → 3, 1 → 4) β -D-glucans, commonly known as β -glucans, are the major constituents in barley dietary fibre. The content of β-glucans ranges from 2.5% to 11.3%. β -glucans are non-starchy polysaccharides and structural components in barley endosperm cell walls (Tiwari & Cummins, 2009; Yu & Shahidi, 2012). Intake of barley in daily diet as a porridge, bread, or any other barley based food helps in reducing the risk of cardiovascular diseases because of the reduction of bad cholesterol in blood, decrease in diabetes due to control of blood glucose levels (Limberger-Bayer et al., 2014) and some types of cancer. Beta

glucan binds to the bile acid in the gut and limits the absorption of LDL cholesterol in the blood. Soluble fibre helps to feel full for long time by slowing down the process of carbohydrate and lipid absorption (Lifschitz, Grusak, & Butte, 2002). In addition to β - glucans, the other health promoting compounds mostly studied in barley are phenolic compounds. They are reported to play an important role in the prevention of and protection from oxidation-induced diseases (Dvorakova et al., 2008; Yu & Shahidi, 2012).

### 2.1.3 Barley for food

In many European countries, barley grits are used in porridges (cereals cooked in milk and sugar) and bakery products. Barley is a staple food in Asian countries, people from these regions used barley grains to prepare, savoury (barley cooked with salt, spices) (Sai Manohar, Urmila Devi, Bhattacharya, & Venkateswara Rao, 2011). Barley has gained a lot of interest in the food industry with the discoveries of several health benefits. The dietary fibre in barley lowers plasma cholesterol, improves lipid metabolism and reduces glycaemic index (Izydorczyk & Dexter, 2008; Yu & Shahidi, 2012).

## 2.2 Composition of milk

Milk is the biological fluid produced by mammals, although cow milk is widely used there are other animal milk which is also used for food purposes. The average composition of cow milk is 87.3% water, 4.8% lactose, 3.4% milk proteins and 3.7% milk fat (Fox, Uniacke-Lowe, McSweeney, & O'Mahony, 2015). Several types of proteins have been found in milk but only a few groups of proteins are present in large quantities. The two important groups of proteins are caseins and whey proteins. Caseins constitute 80% of the protein in milk, and whey proteins the rest 20% of the milk protein These two groups are divided based on their solubility at pH4.6 (Fox et al., 2015).

### 2.2.1 Milk proteins

Proteins are large complex molecules and are essential for human body functioning. Among dietary proteins, dairy proteins are one of the nutritionally complete protein and best researched (Farkye & Shah, 2014; Fox et al., 2015). The most common milk proteins are caseins (CN), whey proteins and milk fat globule membrane (MFGM) proteins, minor proteins and enzymes that naturally occur in milk (Paulsson, 1990). Apart from these, some other proteins are proteins involved in transporting nutrients, proteins involved in disease resistant and growth factors, etc., (Boland, Singh, & Thompson, 2014). Thus, this high protein quality of milk makes it an important part of the human food and has high consumption.

#### 2.2.1.1 Caseins

Caseins are four phosphoproteins that are in suspension in milk as large colloidal particles (micelles). Casein micelles are composed of several thousand molecules with molecular weight of $10^6$ - $10^9$ Da. The light reflection from micelles gives white colour to skim milk (Bylund, 2015). Caseins are synthesised only in mammary gland and cannot be found anywhere else (Fox et al., 2015). They precipitate from milk at pH 4.6 at 20°C.

The stable amino acid structure in casein helps in the growth of youth and casein is a major source of nutrient supplement for neonate and infants. Caseins are heat stable and can withstand heat at 140°C for up to 20 minutes. Continuous high heating of milk induces several changes in the composition of milk, leading to precipitation of casein at pH 4.6 (Qi, 2007; Fox et al., 2015).

#### 2.2.1.2 Whey Proteins

Whey, also called as serum protein, is a liquid part of milk that remains dissolved in the liquid portion after the coagulation of casein into curd during the manufacture of cheese. The remnant whey has high amounts of lactose and minerals (Hoppe et al., 2008).

Whey proteins appear light cream in colour and represent 20% of the total milk proteins and consist mainly of α -lactalbumin (α -LA), β -lactoglobulin (β -LG), Bovine serum albumin (BSA), immunoglobulins (Igs) and protease peptone fractions. It also contains indigenous milk enzymes and MFGM proteins (Farrell et al., 2004). They are globular proteins with high levels of secondary and tertiary structures. Each of these proteins has specific biological activity (Paulsson, 1990). In general whey protein denatures at heat above 70°C temperature (Boland et al., 2014).

## 2.3 Dairy proteins used in food

Milk proteins increase the nutritive value of several food products e.g. beverages and porridges and are relatively less expensive when compared to animal proteins. They also give physical properties to various food products. Often whey powders are used in ice-creams, milkshakes and sometimes as a coffee creams (Walstra, 1999). Whey protein is easily digested protein when compared to animal proteins. Whey protein concentrate and skim milk powder are used in grounded meats to minimise fat content and lactose in whey reduces bitter taste produced by salts and phosphatases and acts as a stabilising agent (El-Magoli, Laroia, & Hansen, 1996).

### 2.3.1 Whey Protein Concentrate (WPC)

Whey powder is a complex mixture of lactose, proteins and minerals, with a minimum amount of moisture and fat. The liquid whey undergoes several processes such as pre-treatment, filtration, evaporation under vacuum and spray drying to form whey powder. There are mainly three different types of whey powders available in the market. These are whey protein concentrates (WPC), whey protein hydrolysates (WPH) and whey protein isolates (WPI). WPC is available in different concentrations, WPC34%, WPC50%, WPC60%, WPC75% and WPC80%. WPC has raised lactose content which may react with protein to impart non-enzymatic browning (Dissanayake, Liyanaarachchi, & Vasiljevic, 2012). WPI contain high percent protein powder, approximately 90% water soluble milk proteins and low level of fat, lactose and bioactive compounds (Park & Haenlein, 2013). WPH can be easily absorbed by the gut and helps in digestion and are mostly used in infant formulas (Fox & McSweeney, 2007).

### 2.3.2 Skim Milk Powder (SMP)

Skim milk powder is prepared by vaporization of water from milk, condensation and powdering of dry matter (Oldfield, Taylor, & Singh, 2005). Skim milk powder also known as non-fat dry milk (NDM) or dried skim milk (DSM) is defined by having a low fat (0.8 g/100 g) content. SMP has a high nutritional value and carbohydrate content, mainly lactose. SMP is used in food products because of its nutritional value and stable structure (Akal & Yetişemiyen, 2016). Unlike whole milk powder which cannot be stored for a longer period, SMP, when stored in cool conditions and dry places, has an average shelf life of 2-3 years (Hoppe et al., 2008).

## 2.4 Heat induced reactions

### 2.4.1 Maillard reaction

The non-enzymatic browning of food products during heating is called as Maillard reaction. It was named after a French chemist Louis-Camille Maillard. He first published his research in 1912 describing reaction between amino acids and reducing sugars (Zhang, Ames, Smith, Baynes, & Metz, 2009). Food contains proteins and sugars, and upon heating, this reaction activates to the brown colour formation. The Maillard reaction has considerable consequences for the quality of heated milk and milk products. Some of the by-products of Maillard browning have strong flavours, which alter the typical flavour of milk (Van Boekel, 1998).

### 2.4.2 Denaturation of proteins

The structure of proteins is thermodynamically stable and has strong inter-intra networking forces and disulphide bonds. Denaturation of proteins simply means changes in the structure without breaking backbone peptide bonds. When there is a change in environmental conditions, both external and internal protein denaturation occurs (Ling, 1983). The extent of protein denaturation depends on pH, temperature and holding time.

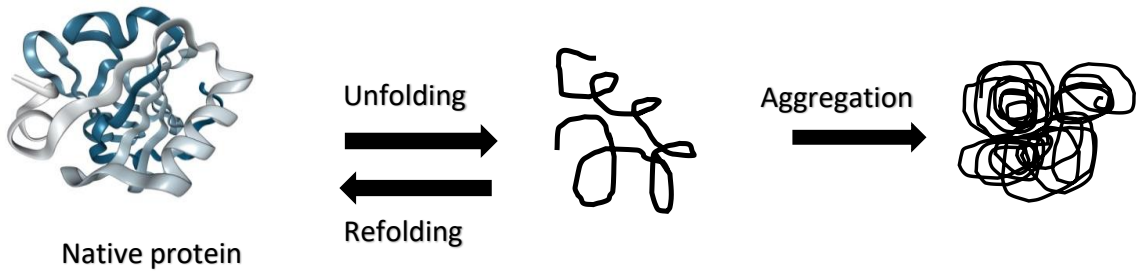



*Figure 2-4: Schematic illustration of denaturation of whey protein. The unfolding of protein followed by aggregation. The chemical structure of native whey protein (image) is from https://professionalwhey.com.au/what-is-the-difference-between-wpi-and-wpc/.*

"Thermal denaturation occurs when hydrogen, hydrophobic and other non-covalent bonds ruptured by heat" (Mulvihill & Donovan, 1987). Denaturation is reversible in some proteins, but it is practically impossible to return to its complete native structure due to the interference of several intermediate reactions (Mulvihill & Donovan, 1987). In Figure 2-4, the unfolding of native protein is associated to form protein aggregates which may further denature to form a gel network. The whey protein denaturation influences solubility, emulsification, foaming and other functional properties of whey proteins (Morr & Ha, 1993).

## 2.5 Measurement of textural features of food

The structure of food determines the texture of food as perceived by senses. In general, the foods are classified as liquids, semisolids and solid. Liquids are the drinks and fluid items which can be swallowed. Products from water to thick soups are considered as liquids. There are a wide range of semi solid foods available in the market like soft cheese, different kinds of yogurts and porridges. The products that need very less chewing are mainly considered as semi solids. There are several words to describe the texture of these products, for example, thin/thick, sticky and creamy, etc. Solid foods have firm structure, for example, fruits, biscuits and meat, need to bitten and chewed several times to form a

bolus in the mouth. Texture attributes for solid foods are firm, chewy, elasticity, particle size etc.

### 2.5.1 Texture measurements

Force measuring instruments are the most common of the texture measuring instruments. There are different types of testing instruments available in the market, ranging from simple instruments to motorized food firmness testers to fully software controlled texture analysers. In this project a TA.*X*T plus texture analyser (Stable micro system) with a modified back extrusion rig was used to measure firmness (g), consistency (g.s), cohesiveness (g) and index of viscosity (g.s) (Figure 2-5). This test measures a combination of elastic strength, rupture strength and viscosity. Firmness, consistency are measured when the probe travels forward (applying compression) and cohesiveness, index of viscosity are measured when the probe travels backwards to the original position (Bourne, 2002).

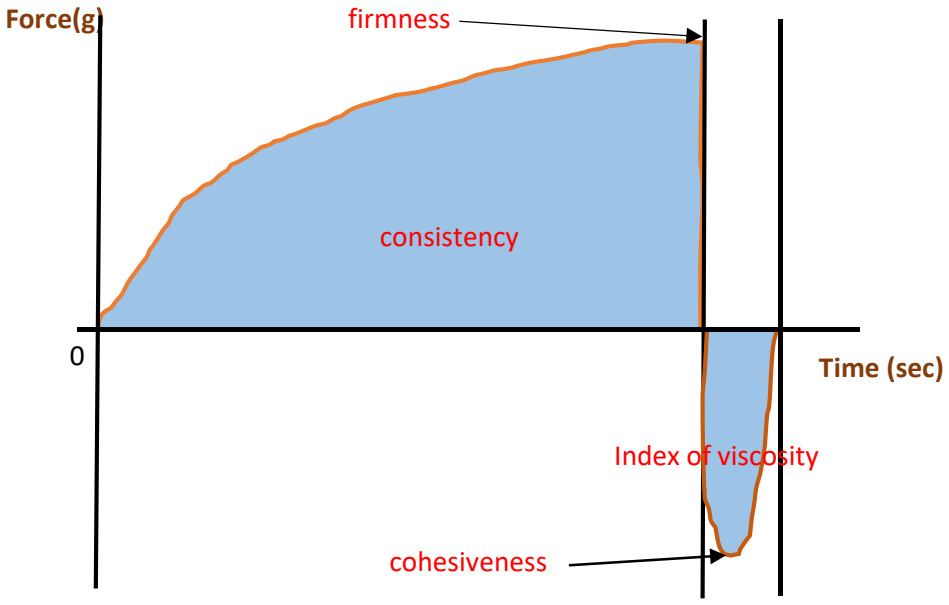



*Figure 2-5: Texture force measurement graph drawn inspired from exponent software (TA.XT plus texture analyser). The graph with firmness, consistency on positive value and cohesiveness, index of viscosity on the negative side.*

The definition of texture properties firmness, consistency, cohesiveness as given by Szczesniak (2002) are:

**Firmness:** "Force necessary to obtain a given deformation. Force required to compress a substance between molar teeth (in the case of solids) or between tongue and palate (in the case of semi-solids)" (Szczesniak, 2002).

**Consistency:** "Consistency relates to the 'firmness', 'thickness' or 'viscosity' of a liquid or fluid semi-solid. Stirring a fluid or semifluid food with a spoon or a finger is frequently used by consumers to give an indication of viscosity or consistency" (Szczesniak, 2002).

**Cohesiveness:** "Extent to which a material can be deformed before it ruptures. Degree to which a substance is compressed between the teeth before it breaks" (Szczesniak, 2002).

The index of viscosity was referred by Angioloni and Collar (2009) as "work of cohesion". The resistance during the backward moment of the probe is expressed by the area under the negative region (Figure 2-5), which represents the cohesiveness and viscosity of the sample (Angioloni & Collar, 2009).

### 2.5.2 Viscosity measurements

Rheology is defined as 'the study of the deformation and flow of matter' (Bourne, 2002). Rheological measurements have become an essential tool in food industries for quality control, product development and customer's quality assurance. The addition of proteins to different food ingredients influences rheology and texture property (Sahin & Sumnu, 2006). Viscosity is defined as internal resistance to flow when a sheer force is applied. Viscosity is defined mathematically by the formula given below.

$$\eta = \text{viscosity} = \frac{\tau}{\gamma} = \frac{\text{shear stress}}{\text{shear rate}}$$

Viscosity is measured in centipoise. The less viscous the liquid, the easy it flows. Brookfield Viscometer (DV2T Extra) (Figure 3-10) was used to measure viscosity of protein enriched products from TINE.

## 2.6 Colour measurements

The human perception of colour is affected by the characteristics of light reflected from the object. This perception of the colour is the response from the different spectral sensitivity ranges of the cones in the eye. Corresponding to red, green and blue colours, the cones in the human eye are separated into three primary groups (Gonzalez & Woods, 2006). Therefore, most imaging devices are designed to optimize this tristimuli (three-dimensional) red, green and blue (RGB colour model). Humans describe the colour by its hue, saturation and intensity (HSI). RGB colour model is ideal for image colour generation whereas HSI colour model is suitable colour description as perceived by the human eye (Gonzalez & Woods, 2006). In the RGB colour model, the range of colours are produced

by adding together red, green and blue colours in different ways, and the RGB colour model is device dependent.

In 1976 Commission Internationale d'Eclairage (CIE) adopted an international standard for colour measurements based on colour opponent theory of colour vision L*, a*, b* colour model or L*, C*, h° colour model. The L*, a*, b* colour model (Figure 2-6) is device independent colour model in rectangular coordinates where L* indicates lightness, a* is green/red coordinate, b* is blue/yellow coordinate. Similarly, L*, C*, h° colour model is a device independent colour model in cylindrical coordinates where L* indicates lightness, C* is chroma/saturation and h is hue angle. Chroma and hue are derived from a*, b* coordinates (Yam & Papadakis, 2004).

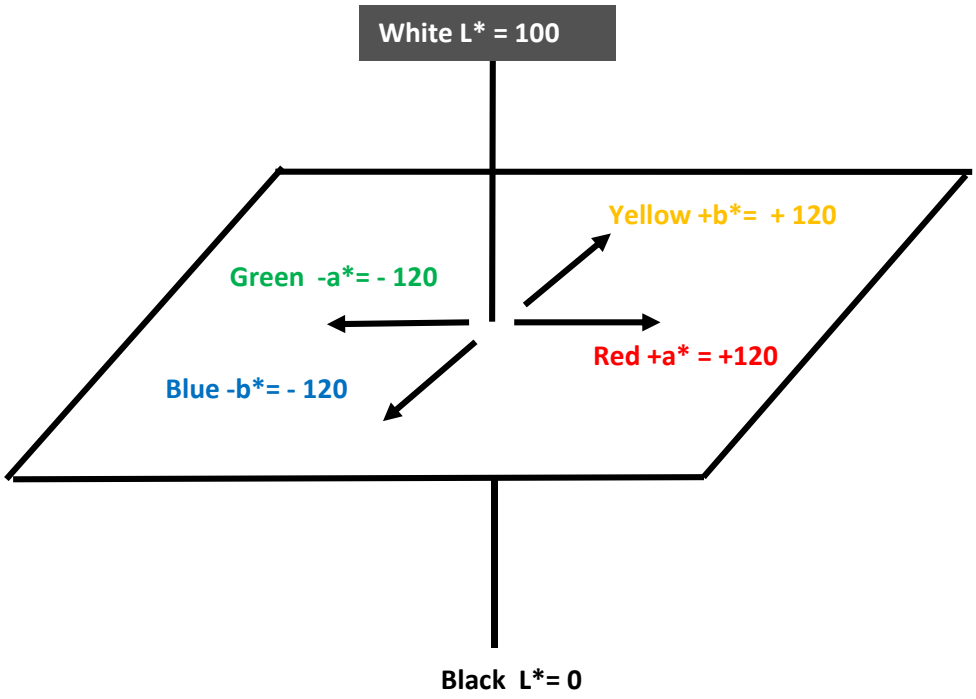



*Figure 2-6: CIE (International commission of illumination) L* a* b* colour coordinate system. L* is lightness, a* is green - red and b* is blue - yellow.*

### 2.6.1 Digital image capture using DigiEye

Digi Eye is a non-contact digital colour imaging system. Samples are placed in a cabinet which has a specific lighting zone, and the pictures are taken by digital camera. The captured image is then displayed on a calibrated monitor. DigiEye allows the measurement of very small or irregular shaped samples by selecting and retrieving colour data from any pixel in the high-resolution image ("Digi Eye system," 2016).

## 2.7 Image analysis

A digital image is composed of a finite number of elements called pixels, each of which has a particular location and value (Gonzalez & Woods, 2006; Pascau & Pérez, 2013). The image analysis involves sequence of steps sample preparation, image acquisition, pre-processing, segmentation, feature extraction, analysis and evaluation. Pre-processing of the image involves initial processing of raw image data. It helps in reducing the distortion, noise removal, adjusting blurring.

Image segmentation is generally divided into three categories which include thresholding, edge based segmentation and region based segmentation (Brosnan & Sun, 2004). Thresholding is the simple technique for distinguishing a certain part of an image from remaining part of image with grey scale level or colour intensity lower than a certain value (Sun, 2000). For the image analysis of a porridge sample a thresholding technique has been applied after pre-processing the image.

## 2.8 Dysphagia

"Dysphagia—a term describing neurological or physical related difficulties that reduce the ability to swallow safely" (Brook, 2015). Dysphagia is related to aspiration pneumonia, chocking, malnutrition and dehydration. Irrespective of age any individual can be affected with swallowing disorders, mainly infants (<1) and the elders (above 65) are two important age groups suffer from swallowing problem. Dysphagia is diagnosed and managed through coordinated efforts of physicians, speech language pathologists, occupational therapists, nurses and dietitians (J. A. Cichero et al., 2013). The passage of bolus from mouth through food passage track is explained in the image (Figure 2-7). Any change in the process results in swallowing problems, chocking, etc.

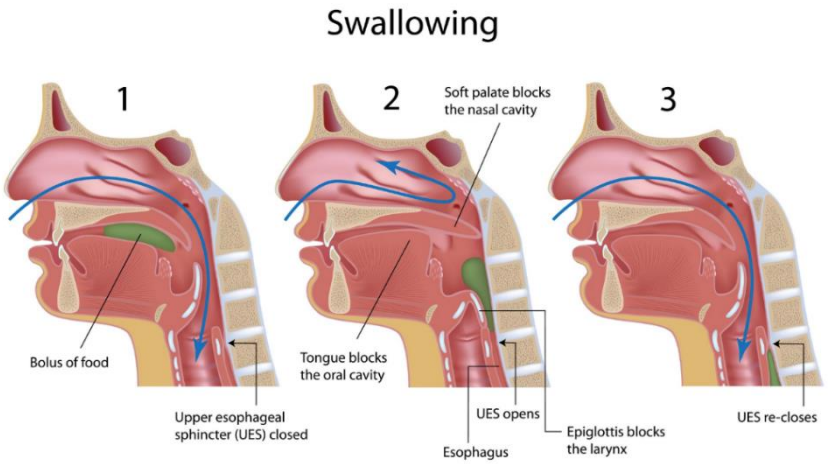



*Figure 2-7: Food swallowing process in human being. The passage of bolus from mouth through food passage track is explained in the above image.*
*Picture Courtesy (http://www.westsidehn.com/swallowing-disorders/)*

### 2.8.1 International dysphagia diet standardisation initiative (IDDSI)

The International dysphagia diet standardisation initiative is a non-profit organisation founded in 2013. The aim of the organisation is to provide a standard international terminology for foods, mainly texture modified foods and thickened liquids for a person with dysphagia and all other swallowing related difficulties in all cultures (Steele et al., 2015).

The IDDSI committee released a dysphagia diet frame work with eight different levels from level zero to level seven (Figure 2-8). Each level has assigned with different colour codes (Table 2-1). Level three and four was used for both drinks and foods. (J. A. Y. Cichero et al., 2016). The colours were reviewed in detail by the IDDSI committee and assessed for suitability for people with colour blindness.

*Table 2-1:The table showing IDDSI levels and colours representing each level. In total eight levels with eight different colours.*

| IDDSI Level | Colour Code |
|---|---|
| Zero | White |
| one | Gray |
| Two | Pink |
| Three | Yellow |
| Four | Green |
| Five | Orange |
| Six | Blue |
| Seven | Black |

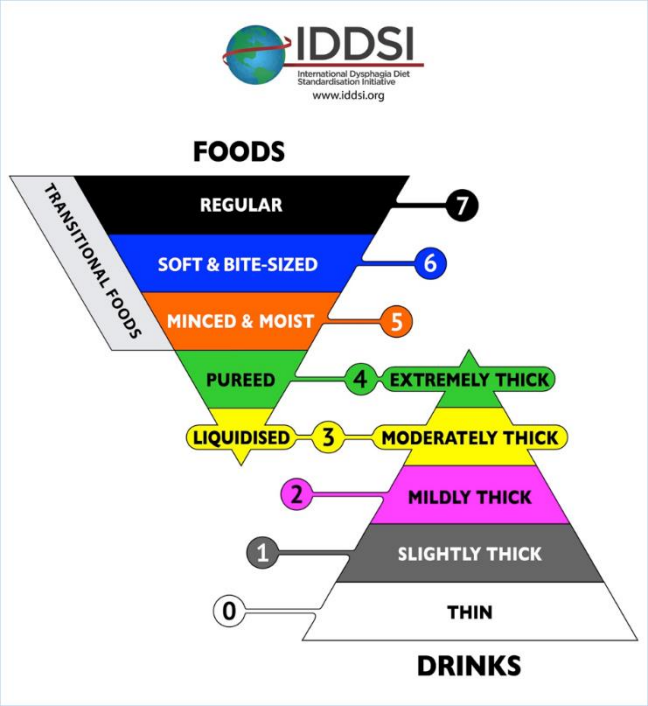



*Figure 2-8: IDDSI framework for drinks and foods with description of each level with colour. Picture (c) The International Dysphagia Diet Standardisation Initiative 2016 @http://iddsi.org/resources/framework/.*

International terminology will help to choose the right food irrespective of tradition and culture. It mainly helps people suffering from dysphagia and clinicians and food serving staff in facilitates and hospitals. As travelling is quite common nowadays, the necessity of having a common language in choosing the right product is increased (IDDSI, 2016).

To classify the food product into the IDDSI frame work (Figure 2-8), the food products must pass certain simple tests. These tests include the following:

***Flow test*:** Flow test, also known as the syringe test, is mainly for liquids. A 10-ml syringe is filled with sample, and the nob is closed. With the help of a stop watch the amount of time required to empty the sample in syringe is noted. Fluid thickness will be decided based on the flow of sample.

***Fork drip test*:** A fork full of sample sits on top of fork without continuously dripping or flowing through prongs.

***Spoon tilt test*:** In this test, the food sample is placed on a spoon. After tilting the spoon gently, the food should fall off, or only a small amount should stick to the spoon.

***Spoon/fork pressure test:*** To assess mechanical properties associated with hardness of food fork/spoon pressure test is adopted. This test can be used to assess foods in levels 4 – 7 and transitional foods. Pressure is applied on the food sample using a fork or spoon, and the behaviour of the food under this pressure is observed. The pressure applied is quantified as pressure needed when a thumb nail blanch is made noticeably white. This pressure is approximately 17 kPa which is consistent with tongue force applied during swallowing (Steele et al., 2015).

***Finger test*:** There are two types of finger tests.
*First test*: The food sample is placed between two fingers, and the softness and moisture of food sample can be detected.

*Second test*: This test is mainly for transitional foods. 1ml of water is added to a small amount of sample (1.5x1.5cm) and then pressed between the index finger and thumb nail by certain pressure (till nail colour changes to white).

***Chopstick tests:*** In some places where forks are not available, or chopsticks are traditionally used. Testing the texture by taking piece of food particle between sticks and breaking into pieces.

# 3. MATERIALS AND METHODS

The project was divided into two parts. In part I, protein enriched porridge samples were prepared and texture analysis performed. In part II, commercial dairy products texture was tested. The materials and methods of part I are explained in section 3.1-3.10, and part II explained in section 3.11.

## 3.1 Materials used for porridge

TINE SA, Stavanger provided the ingredients required for preparing the porridge. The porridge was prepared using two different types of milk proteins (WPC80 & SMP), whole milk and barley. The whole milk was stored in a refrigerator (4°C) until preparation of porridge for all the samples. The barley was sourced from a Norwegian producer, "Skjåkgryn" barley a special kind of barley from Ottadalen Mølle (http://www.matmerk.no/no/spesialitet/spesialitet-produsenter/ottadalen-molle-avd-ofossen-molle) containing 80% of grain components. Fine grained local store bought salt (Jozo fint salt) was used.

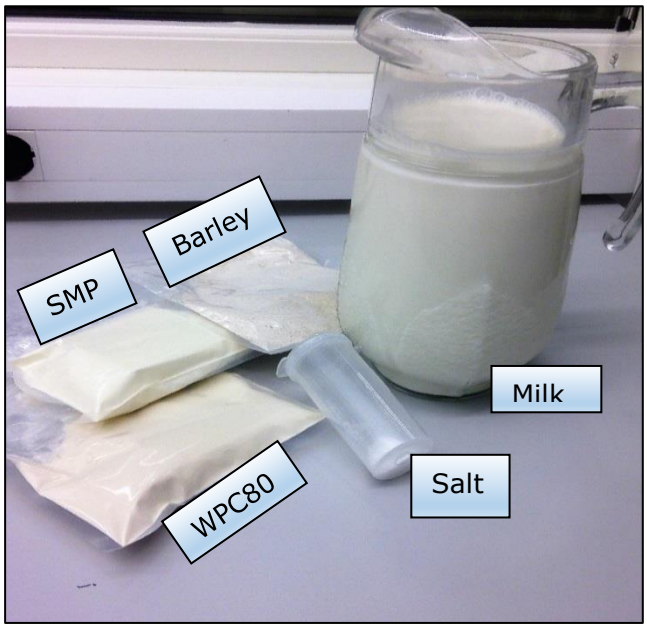



*Figure 3-1: The list of ingredients used for cooking barley porridge shown in above figure.*

All the porridge samples were prepared using the same quantities of barley, whole milk and salt. The protein source and amount of protein vary for each porridge sample. The basic porridge was prepared in a condition still to be able to add protein and have a porridge that was not too thick. The raw ingredients and their protein content (provided by TINE SA) are shown in Table 3-1, The protein content values of barley, whole milk and

milk proteins (SMP and WPC80) were provided by TINE, these values were used in calculating the total protein content of individual porridge samples (Table 3-2).

*Table 3-1: The barley porridge recipe includes following ingredients. The protein percentage per 100g for each ingredient listed below.*

| Ingredients | Protein % per 100g |
|---|---|
| Barley | 11.1 |
| Whole Milk | 3.3 |
| Salt(NaCl) | 0.0 |
| Skim milk powder | 35.5 |
| Whey protein concentrate 80 | 77.4 |

## 3.2 Cooking equipment

Initially different cooking methods with various ratio of ingredients were tested to optimise a production method, Stephan vessel was one amongst them. For final cooking the Kenwood cooking method explained in Chapter 3, sec. 2.2 was selected.

### 3.2.1 Stephan vessel

The Stephan vessel is a compact system consisting of a tiltable vessel, equipped with a double jacket (Figure 3-2). The vessel can be closed airtight with the help of sealing ring attached to the operated lid, this helps no escape of steam while cooking. The mixing arm is driven by a shaft through the bottom of the vessel. It is equipped with scrapers following the shape of the wall. Deposits on the inner vessel surface are then avoided (Stephan Machinery GmbH, Germany).

The vessel was filled 50 dl of whole milk (3.2% fat), milk in 10 litre cartons was stored at 4°C temperature. 750 g specially cut barley grains (protein 11.1%) and salt (20g) were also added into Stephan vessel and cooked for 30 minutes. Speed 1 was maintained for the first 15 minutes and changed to speed 2 for the last 15 minutes. It took 15 minutes to reach milk boiling temperature at 100°C. After 30 minutes of cooking the porridge temperature was measured to 78°C. In this cooking method, there was wastage of resources as Stephan vessel need minimum 5000g of ingredients to cook each sample.

*Figure 3-2: Stephan vessel from Stephan food processing machinery*

### 3.2.2 Kenwood cooking chef

The Kenwood cooking chef (http://www.kenwood.com) is a food mixer with built in induction cooking (Figure 3-3). It has a base induction plate through which heat is supplied. The cooking temperature can be set using temperature control. High temperature flexible beater was used for continuous stirring and its speed can also be set. Kenwood cooking chef was used to cook all porridge samples at controlled mixing speed and temperature. Grains were milled /ground in a small glass jar mixer. Approximately 100g of barley grains was ground in the Kenwood mixer grinder for 1.5 minutes at speed setting 3. This coarsely grounded barley grains were weighed in quantities of 150g and packed in sous vide bags before cooking porridges.


*Figure 3-3: Kenwood cooking chef with the equipment used for cooking.* ***a.*** *Kenwood cooking chef.* ***b.*** *High temperature flexible beater.* ***C.*** *Mixer attached on top of Kenwood where the lid was removed and mixer with a blade was fixed to attachment outlet.*

## 3.3 Protein content calculations

The recipe calculations (EuroFIR recipe guideline, 2015) were performed to find the protein content of the protein enriched porridge samples. (EuroFIR guidelines for calculating nutrient content of foods). These calculations may not be accurate but give approximate values. For each ingredient, the protein content per 100 g in the cooked porridge is given by the following equation.

$$\text{Protein content per 100 g} = \frac{\text{Protein content per 100 g ingredient} * \text{Raw weight of ingredient (g)}}{\text{Total cooked weight (g)}}$$

The total protein content in the porridge is the sum of its content in each ingredient. In the calculations yield factor of 1 is used i.e. the total cooked weight is taken as the same as the total raw weight. An example of calculation shown in Table 3-2, protein source WPC80 with 7% concentration and addition time before.

For example, milk protein content per 100g = (3.3x1250)/1462 = 2.8 g

Barley protein content per 100g = (11.1x150)/1462 = 1.1 g

Whey protein content per 100g = (77.4x58)/1462 = 3.1 g

Total Protein content per 100g in cooked porridge = (2.8+1.1+3.1) = 7.0 g

*Table 3-2: Recipe calculation of WPC 80 Sample for 7% protein concentration with addition time before.*

| List of ingredients | Weight of ingredients (g) | Protein content per 100 g of input ingredient | Protein content per 100 g of cooked porridge |
|---|---|---|---|
| Milk, 3.2% fat | 1250 | 3.3 | 2.8 |
| Barley, Pearled | 150 | 11.1 | 1.1 |
| Protein whey WPC80 | 58 | 77.4 | 3.1 |
| Salt | 4 | 0 | 0.0 |
| **Total (g)** | **1462** | _ | **7.0** |

## 3.4 Protein enrichment of porridge

After finalising the suitable cooking equipment and protein calculations, the protein enrichment of porridge was carried out by adding protein to the commercial (Fjordland) porridge to understand the texture and the taste of whey/SMP enriched porridge. Protein enrichment of a commercial (store bought) porridge was an initial trial to gain insights into the taste, texture of the protein enriched porridge.

Fjordland's byggrynsgrøt (4.3% protein content) was bought in a super market, this porridge was enriched with WPC80 protein powder to attain 10% protein content. Whole milk and whey protein powder (WPC80) were mixed in a Kenwood cooking bowl with temperature control set at 80°C and stirring speed1 for 5 minutes. Milk and whey powder was initially mixed to avoid lumps. To this mixture, 500g of porridge was added and reheated for 10 minutes with the same temperature and speed settings. The tasting of the sample by sensory experts and instrumental texture measurement readings helped to proceed further in the experiment.

## 3.5 Experimental design for the main porridge preparation

The factorial design of porridge preparation is shown in Table 3-3. Two different types of milk based protein sources, skim milk powder (SMP) with protein content 35.5 g per 100g and whey protein concentrate 80 (WPC80) with protein content 77.4g per 100g were

selected. Three variates of porridge with different protein content (4, 7 and 10%) were prepared. Protein addition time with before and after cooking was another factor included (Figure 3-4). Two replicates of each porridge were prepared with the design factors protein source (SMP, WPC80), protein concentration (4%, 7%, 10%) and protein addition time (before, after). There was a total of 24 samples (Table 3-3). The amount of milk, barley and salt were kept constant for all porridges.

The randomized run order was used in preparing the porridge to minimise the effect of other variables that are not included. The randomized run order was generated using MINITAB (version 17.0) statistical software, design of experiments, general factorial design.

*Table 3-3: Factorial design of porridge sample preparation. Total 24 samples were prepared, number of replicates n=2.*

| Protein source | Addition time | Protein concentration 4% | Protein concentration 7% | Protein concentration 10% |
|---|---|---|---|---|
| SMP | before | n=2 | n=2 | n=2 |
| | after | n=2 | n=2 | n=2 |
| WPC | before | n=2 | n=2 | n=2 |
| | after | n=2 | n=2 | n=2 |

### 3.5.1 Cooking porridges with addition time before and after.

In the experimental set up along with factors protein source, protein concentration a new factor called as protein addition time was introduced. This factor defines addition time of protein to the porridge i.e. 1) adding protein from the start which was called "before" 2) addition of protein to the cooked porridge called "after".

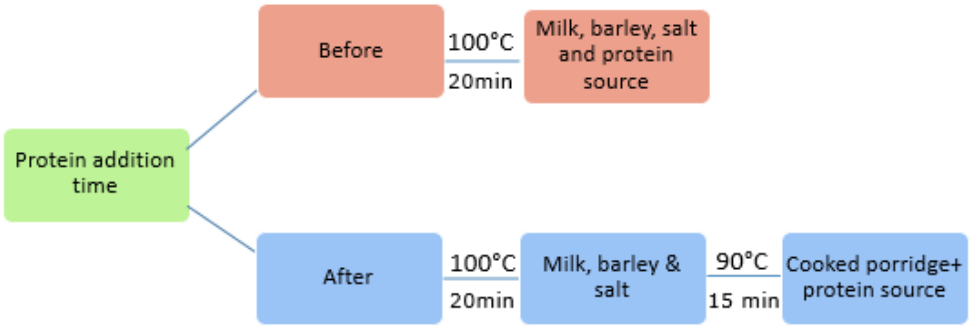



*Figure 3-4 Process representation of before and after cooking.*

Before:

The ingredients milk, barley, protein and salt were weighed and added accordingly to Kenwood bowl. Cooking temperature was set to 100°C on speed 1. For all the samples, cooking time was kept constant for 20 minutes.

After:

In this cooking procedure two steps were performed:

In first step milk, barley and salt were added to the bowl, and the cooking temperature was set to 100°C on speed 1. The porridge was cooked for 20 minutes. The porridge was immediately cooled down to 4°C in an ice bath, packed in vacuum bags and stored in a refrigerated room (4°C) for two days.

In the second step the vacuum-packed porridge was brought to room temperature, and then the weight of the porridge is taken. Based on the weight of porridge the amount of protein quantity to be added for each of 12 samples was calculated. The cooked porridge was placed in a Kenwood bowl; the mixing speed was set on low and the temperature control was set at 90°C. The protein was added using measuring spoons for every 5 seconds. After 5 minutes the speed was increased and reheated to 90°C for another 10 minutes.

## 3.6 Storage of porridge samples

For rapid cooling, porridge sample was transferred immediately into four plastic bags after cooking. The plastic bags are heat resistance up-to 121°C. The porridge in the bags was cooled down using an ice bath. The samples were then vacuum packaged using a high-pressure vacuum sealer (supermax C 3000, WEBOMATIC maschinenfabrik GmbH) with approximately 99.5% pressure. All the bags were labelled and allowed to rest for two weeks before further analysis in cold room at 4°C.

## 3.7 Descriptive sensory analysis (DA)

Descriptive analysis was first developed in the year 1970 (Lawless, Heymann, & SpringerLink, 2010). It is a total system covering sample selection, panellist screening, vocabulary development, testing and data analysis (Bourne, 2002). Six trained panellists were engaged from TINE for the sensory analysis.

### 3.7.1 Profiling of attributes (vocabulary development)

TINE panel conducted the descriptive analyses, which consisted of a training session and the main experiment. During vocabulary development, panellists tasted random samples and described the appearance, aroma, taste and texture of each porridge sample, and

most of them had differentiated the given porridge samples. Vocabulary is in accordance with ISO standard 5492 ("ISO-5492," 2008).

After tasting the samples, each attribute was defined, and possible reference standard was identified. The intensity scale 1 to 9 was developed for all the attributes, as defined in ISO standard 4121 ("ISO-4121," 2003). The scale extremes of each attribute are shown in the appendix. For most of the attributes, scale 1 = no/low and scale 9 = high. In total 19 attributes were finalised with description.

### 3.7.2 Sensory evaluation

All assessments were conducted in the sensory laboratory (Måltidets Hus) built according to ISO standard 8589 ("ISO-8589," 2007). The porridge samples stored in vacuum bags were brought to room temperature. The sensory room and test booths were maintained at room temperature at 20±1°C. Approximately 50g of the samples were served in plastic cups and labelled with random three-digit code (Figure 3-5).

#### 3.7.2.1 Panel training

During panel training/calibration, four porridge samples were tested. For panellists to understand the original taste and aroma of products used in experiment, three references were given a) and b) 100g of SMP and WPC80 protein powders were mixed separately into 1000g of warm water (40°C) to achieve 10%weight/volume, c) Barley (150g) was cooked in 1000g of water for 20 min using Kenwood cooking chef at 100°C (Figure 3-5 right). Panellists were calibrated by obtaining the mean rating. Discussions between sensory experts were facilitated before the final experiment. Those whose ratings were not close to the mean were asked to re-evaluate the standard and adjust their rating until a consensus was reached. The attribute definitions are listed in Table 3-4.

#### 3.7.2.2 Final experiment

Total 12 samples were presented to the sensory panel for evaluation, of which, six were WPC80 enriched samples, and the other six were SMP enriched samples. Samples were supplied randomly to each panellist based on Eye Question software. Panellists were not permitted to eat or drink anything other than water one hour prior to the sensory analysis. The panellists cleared their palates with spring water and plain crackers between samples. The descriptive analysis experiment took approximately 2 hours. Panellists' data was collected using Eye Question software.

*Table 3-4: Description of attributes used in sensory analysis, defined in both Norwegian and English.*

| Descriptor(Norsk) | | Descriptor(English) | | Definition |
|---|---|---|---|---|
| Utseende | Fargetone | Appearance Attributes | Colour | Surface colour of porridge ranging from grey (0)to yellow(9). |
| | Blankhet | | Glossy | Appearance of surface showing bright reflection |
| Konsistens (med skje) | Fasthet | Consistency with Spoon | Firm | Mechanical textural attribute relating to the force required to achieve a given deformation or penetration of a product |
| | Seighet | | Elastic | The degree to which a deformed material reaches to undeformed condition when deformation force is removed. |
| I munn | Klebrig | Mouthfeel | Sticky | Textural attribute realting to the force required to remove material that adheres to mouth |
| | Kornstørrelse | | Grain size | Geometrical textural attribute relating to the perception of size & shape of particles in a product |
| | Melen | | Mealy | In the mouth it is related to the effort required to disintegrate the product to the state ready for swallowing |
| | Tyggemotstand | | Chewing resistance | Mechanical textural attribute related to cohesiveness and to the length of time or the number of chews required to masticate a solid product into a state ready for swallowing |
| | Løselig | | Soluble | It is related to being dissolved in mouth before swallowing |
| | Tørr | | Dry | Surface textural attribute which describes the perception of water absorbed by or released from a product |
| Lukt | Bygglukt | Smell/Odour | Barley smell | The odour of barley perceived through the nose by means of the olfactory nerves |
| Smak | Total smaksstyrke | Taste | Total taste | Overall taste of porridge |
| | salt | | Salty | Describes the basic taste produced by aqueos solutions of various substances such as sodium chloride |
| | søt | | Sweet | Describes the basic taste produced by aqueos solutions of various substances such as sucrose |
| | Bitter | | Bitter | Describes the basic taste produced by dilute aqueous soluions of various substances such as quinine and caffeine. |
| Aromaer | kokt | Aroma | Cooked | cooked porridge aroma |
| | Bygg | | Barley | Cooked barley aroma |
| | Melk | | Milk | Aroma of fresh milk |
| | Myse | | Whey | Whey powder dissolved in warm water |


*Figure 3-5: **Left**: porridge samples served(50gm) in plastic cups for the sensory panel, R**ight**: (a)Milk, (b) whey and (c) barley cooked in water given to panellists for understanding the original taste.*

## 3.8 Instrumental measurements of textural properties

Texture analysis was performed using Texture Analyzer (Stable Micro System Ltd., Godalming, UK) equipped with a 5kg load cell, back extrusion rig and aluminium cylinder probe (SMS P/20). The texture analysis was performed at two different temperatures 20°C and 60°C. During the measurements at 60°C the temperature varied around ±5°C for the three runs (at the time of measurements, 55-60°C).

### 3.8.1 Selection of suitable probe

Three different probes were tried in this experiment (Figure 3-6) to find which probe was best suited for measuring the textural properties of the porridge. The cylinder probe p/20 had given enough compression force into the sample, and the readings were stable.

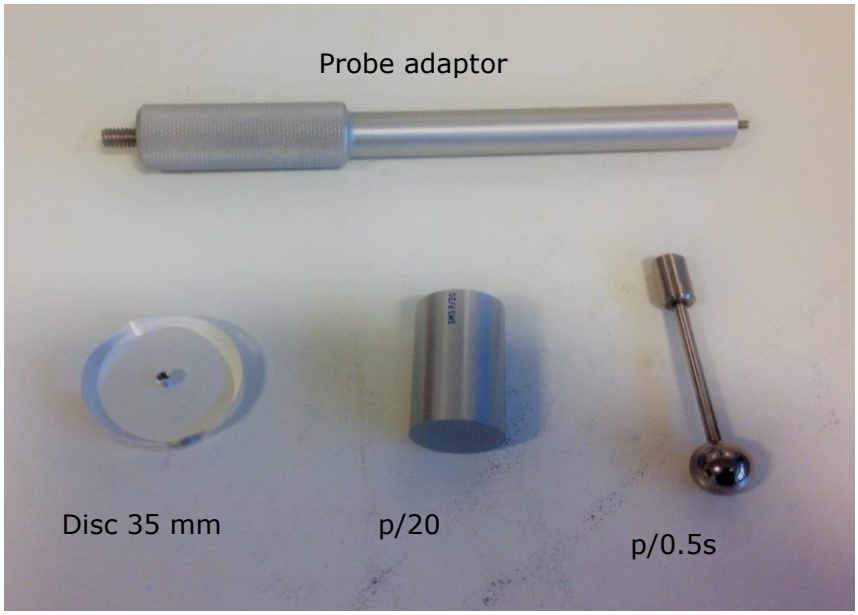



*Figure 3-6: Different probes used for instrumental texture measurements.*

### 3.8.2 Procedure

The probe P/20 was connected to the loading arm with the help of probe adapter (Figure 3-7). Sterile plastic container (straight sample container) of 52mm internal diameter, 67mm height was placed on the extrusion base under the probe. The movement, alignment of the probe was checked, by lowering the probe to a few centimetres above the sample surface. The sample container was repositioned to allow the probe travel to the desired depth into the sample without touching the walls of the container. After the alignment was satisfactory, the thumbscrews were tightened to prevent further movement.

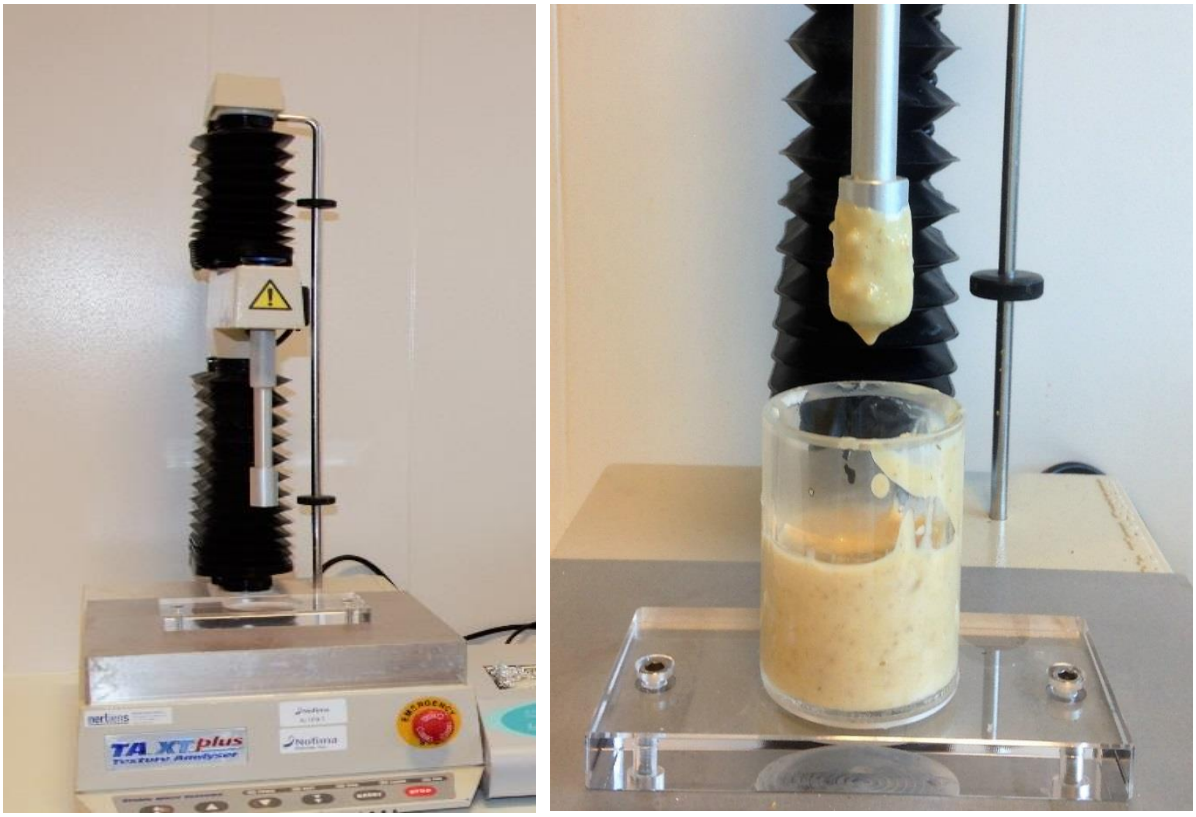



*Figure 3-7:**Left**: TA.XT plus texture analyser with the probe (P/20) and back extrusion rig. **Right**: Probe travelling back to its position after compression.*

The porridge samples from the cold room (4°C) was initially bought to room temperature, and then at 20±1°C analysis were measured. For the 60°C temperature analysis, the porridge filled sample containers were placed in a water-bath for 20-30 minutes to reach 60°C core temperature. A warm heat block was placed on the flat base of the instrument and temperature was set at 60°C. Aluminium foil and thermocol (insulating material) were placed inside the heating block to prevent loss of heat. The settings for the texture analysis are shown in Table 3-5.

*Table 3-5: Texture analyser probe settings*

| Test parameters | Settings |
|---|---|
| Test Type | Compression |
| Pre-Test Speed | 4.0 mm/s |
| Test Speed | 1.0 mm/s |
| Post-Test Speed | 10 mm/s |
| Target Mode | Distance |
| Distance | 20 mm |
| Trigger Type | Auto (force) |
| Trigger Force | 0.2 g |

Exponent software (Version 6.1.9.0, Stable Micro System Ltd., Godalming, UK) was used to prepare the test runs and extract the values from measurements. The *macros* were created to extract firmness, cohesiveness, consistency, index of viscosity values automatically from the graph. The values and graphs were stored in Excel sheets for further statistical analysis. Three runs for each sample in triplicate for two batches were performed.

## 3.9 Colour measurement

A DigiEye system (VeriVide Limited, UK) was used for measuring colour and appearance of porridge. The porridge samples stored in the refrigerated room (4°C) in vacuum bags were brought to room temperature. The porridge was then transferred into petri dishes (92mm x 16.2mm) for further colour analysis. The petri-dishes were placed in the system's light box (standardized day light 6500 K) where the sample was photographed. The photographs were taken with Nikon D90 digital camera, of the DigiEye system. The system was first calibrated before taking a picture of the sample. Petri plates were filled with sample and excess porridge was wiped off using cling film. The surface of sample was made flat and uniform with spatula. Pictures were analysed and the porridge colour in CIEL*a*b* colour space coordinate values were extracted using program DigiPlex (Version 2.53, VeriVide Ltd., Leicester, UK). Each porridge was analysed by triplicate samples.

## 3.10 Image analysis

The images were acquired from digital camera (Nikon D90 35 mm Focal length, Tokyo, Japan) equipped DigiEye system at 96 dpi resolution and 24bit colour. The images were saved in TIFF format. The digital images were processed for image analysis. The GIMP (version 2.8.18, GNU image manipulation programme) was used to crop the images. The **ImageJ** software (image processing and analysis in Java) was used for pre-processing and thresholding. The image was split to 8-bit red, green and blue channels. Compared to red and green the blue channel had clear distinguishable features. The blue channel was selected for further processing and feature extraction. Thresholding was applied to the image using the default Black &White (B&W) settings in the software.

## 3.11 Commercial products textural properties

The textural properties of the commercial dairy products were evaluated using sensory analysis, TA.XT plus texture analyser and Brookfield viscometer. The list of products selected for the analysis in this experiment are listed in Table 3-6. Norwegian name of the

products are listed on the left Column and description of product and flavour in English are given in the right column

*Table 3-6: List of products used in part II with description in English given below.*

| Serial number | Product name (Norsk) | Description/flavor English |
|---|---|---|
| 1 | Kesam Original | Quark |
| 2 | Kesam mager Naturell | Quark (light) |
| 3 | TINE Yoghurt Vanilje | Yogurt vanilla |
| 4 | TINE Yoghurt Fyldig Vanilje | Yogurt vanilla (rich) |
| 5 | Biola Bringebærdrikk | Sour milk (raspberry) |
| 6 | Biola Syrnet Lettmelk | Sour milk (light) |
| 7 | TINE Kefir | Kefir/kephir |
| 8 | E+Plussdrikk kaffe | E+ cold coffee |
| 9 | E+Plussdrikk kakao | E+ chocolate milk |
| 10 | E+Plussdrikk blåbær | E+ blueberry shake |
| 11 | E+Plussdrikk bringebær | E+ raspberry shake |
| 12 | E+ Suppe | E+ soup (asparagus) |
| 13 | Vaniljesaus original | Custard (vanilla) |
| 14 | Vaniljesaus fyldig | Custard (vanilla) rich |

### 3.11.1 Descriptive sensory analysis (DA)

DA was first developed in the year 1970 (Lawless et al., 2010). For this experiment, ten panellists were selected. The procedure is described in Chapter 3, sec. 6. In total 14 commercial products were used for sensory evaluation (Table 3-6).

The temperature of the sensory room was set to ±16°C. Approximately 100ml of each sample was poured into a plastic glass. To measure the consistency with spoons, serving table spoons (disposable) were provided (Figure 3-8). The list of attributes is given in Table 3-7. Eye Question software was used to generate random codes and for rating the products. Three samples A, B and C were provided for panel training. The discussion was allowed between panellists during training.

The identified standards were rated from 1 to 9 intensity scale (appendix) for each attribute as defined in ISO standard 4121 (ISO 2003). Vocabulary is in accordance with ISO standard 5492 (ISO 1992), ISO standard 11036 ("ISO-11036," 1994).

*Table 3-7: List of textural attributes used in sensory evaluation of commercial products.*

| Norsk | English |
|---|---|
| • **Konsistens med skje** | • **Consistency with spoon** |
| 1. Tykkelse | 1. Thickness with spoon |
| 2. Sammenhengende | 2. Cohesiveness |
| • **I munn** | • **In mouth** |
| 3. Tykkelse | 3. Thickness in mouth |
| 4. Fyldighet | 4. Body |
| 5. Tørrhet | 5. Dryness |
| 6. Tørrhet i munn etter svelging | 6. Dryness in mouth after swallow |
| 7. Svelgbarhet | 7. Swallow |


**a.** Samples in tray for final experiment

**b.** Panel training with A,B and C samples

*Figure 3-8: **a.** The samples placed in tray with random three digit codes. **b.** Three samples A, B and C used for panel training.*

### 3.11.2Instrumental measurements of Textural properties

The texture of commercial products was measured using TA.*X*T plus texture analyser (Stable Micro System Ltd., Godalming, UK). The back-extrusion test performed to find firmness, consistency, cohesiveness and index of viscosity of given samples. The back-

extrusion test kit was provided with three measuring cups and disc plunger. The disc plunger was attached to the probe adapter during the test. The texture analyser TA.*X*T plus was equipped with 5kg load cell, back extrusion rig and disc probe (40mm). The texture analysis was performed at 16±1°C temperature.

#### 3.11.2.1 Procedure

On the loading arm of the texture analyser probe adapter, the disc plunger was connected. The back-extrusion fixture base was placed on the base of the instrument and the thumb screws were loosely tightened to enable some degree of mobility (Figure 3-7). A measuring cup of 55mm internal diameter, 72mm height was placed on the extrusion base. After the alignment was satisfactory, the thumbscrews were tightened to prevent further movement.

*Figure 3-9: The disc plunger ready to immerse into the sample placed on the centre of fixed base.*

The settings include the probe which travels into the sample to 2 cm depth compressing the sample with a speed of 1mm/sec and then withdrawn to initial position with a speed of 10mm/sec. The trigger force was 10g. Triplicate readings of each product were taken.

The products from cold room (4°C) were placed in an incubator (16°C) for 12 hour (overnight) before taking measurements to achieve the desired temperature. About 75% of a measuring cup was filled with sample and then firmness, consistency, cohesiveness and index of viscosity were measured.

Exponent software (Version 6.1.9.0, Stable Micro System Ltd., Godalming, UK) was used to interpret graphs/results. A set of instructions listed in a *macro,* automatically collected data from the graph. The *macro* was created to extract firmness, cohesiveness, consistency, index of viscosity values automatically from the graph. The values were recorded in spread sheets for further statistical analysis.

### 3.11.3Viscometer measurements

Brookfield Viscometer DV2T Extra was used for viscosity measurement (Figure 3-10). Fourteen different products were selected with different viscosity ranges as listed in Table 3-6. Products from the original packages were poured into a griffin beaker (600ml). The same glass beaker was used for all the measurements of the test. The samples in packages were shaken/stirred 10 times before pouring into glass beaker. The beaker was filled with the fluids up-to 500ml level mark. Three repetitions for each product were performed and the measurements were conducted in a room with 16±1°C temperature.

First step in viscometer readings was to ensure the best zero value. The viscometer level was adjusted using the two feet at the bottom and monitoring the bubble level on the front of head. The autozero (calibaration) was carried out to ensure the best zero value. Low viscosity spindle (LV-4) with rotation speed of 100 RPM was used for all the products.

The viscosity test was configured by setting the spindle type and rpm. The sample temperature was recorded, and the test was stopped after 30s for all the readings. The single point data collection was used to collect the readings from the viscometer

### 3.11.4IDDSI flow test

There is an international dysphagia diet standard initiative program to develop international standardized terminology and definitions for texture modified foods and thickened liquids for persons with dysphagia. A gravity flow test using 10 ml standard syringes (HSW SOFT-JECT®) with Leur-lock tip was performed for classifying drinks and liquidized foods by IDDSI. The products are classified based on their rate of flow (Table 3-8). The equipment is simple and internationally standardized. The temperature of the samples was maintained at 16±1°C throughout the test.


*Figure 3-10: Brookfield viscometer(DV2T) extra with thermometer, spindle and guard leg placed into the sample poured in 600ml griffin beaker.*

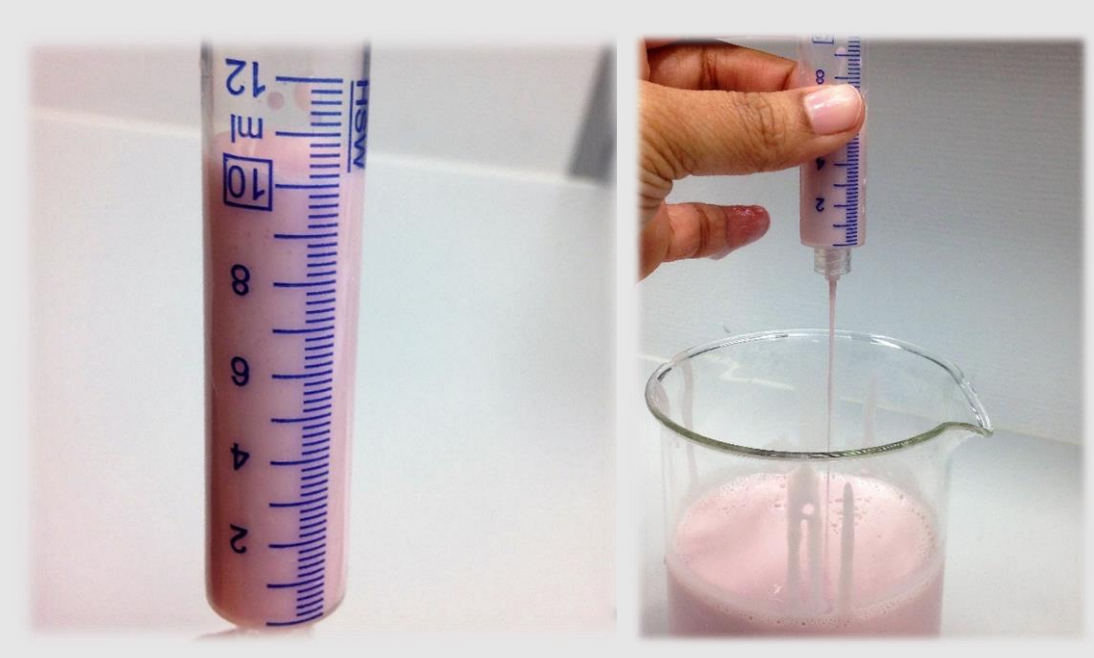



*Figure 3-11: **Left**: syringe with 10 ml of sample and nozzle closed. **Right**: IDDSI flow test of sample*

Two syringes were used for this experiment, the plunger of the first syringe was removed and nozzle closed with finger (Figure 3-11). The sample was filled into the first syringe up to 10ml with the help of the second syringe. The flow of liquids was noted for 10 seconds using the timer. Three runs for each sample were taken. IDDSI level was determined based on the liquid remained in the syringe after completion of the test.

*Table 3-8: Level classification based on liquid remaining at 10 seconds.*

| Liquid remaining in syringe(ml) | Level |
|---|---|
| 1ml – 4ml | One |
| 4ml -8ml | Two |
| 8ml and above | Three |
| 10ml | Four |

## 3.12 Statistical analysis

Analysis of variance using a General linear model (Minitab® 17.0) was performed on the results from different analyses. The variables which differed significantly ($p<0.05$) were identified. A post hoc test was performed. Post hoc tests are also known as posteriori tests. Tukey's Honestly Significant Difference (HSD) post hoc test was performed to determine the specific difference between groups. Multivariate data analysis was performed on data using The Unscrambler® X (Camo software AS, Norway) to study the main sources of systematic variation.

### 3.12.1 Multivariate Data Analysis

Multivariate data modelling techniques are often used in industry and research for the product development to identify the factors which impact the product development /design. The statistical methods employed in multivariate data analysis handle large sets of data, extract important information from the data and present them in easily understood manner/plots. Principal Component Analysis (PCA) and Partial Least Squares Regression (PLSR) are the two methods used in this thesis to understand the variability in the data set, identify the factors influencing the product texture and relate sensory scores to instrument measured values. PCA and PLSR were performed using The Unscrambler® X version 10.4.1 (Camo software AS, Norway).

The basic idea of principal component analysis is to represent the variability in the data set in a few principal components (PCs) to reveal the hidden structure in the data. The

total variance in the data is explained by the contribution from each PC. The PC1 explains the most of the variance in data followed by PC2 and so on. The resulting plots can be used for simple interpretation of relationship between samples and variables (Esbensen, Guyot, Westad, & Camo, 2000). The plots can reveal which variables that are related to each other, why some samples are similar and grouping of samples. To relate two sets of data (X, Y) regression methods are usually used. PLSR was used to relate sensory scores (Y data set) to the instrument measured values (X-data set). PLS regression maximises the covariance between X and Y.

In case of porridge the design factors protein source, protein concentration, protein addition time are defined as categorical variables. These variables were treated as dummy variables as each factor defined with level 0 or 1. So, design factors included in the plots were low weighed/down weighed in order not to influence the results. Downweighed variables were displayed in different colour (green) for recognition. The data was mean centred, full cross validation method was used and NIPALS algorithm was used. The loadings, score and biplot plots were mainly used for this project.

# 4. RESULTS AND DISCUSSIONS

## PART I – Barley porridge

The barley porridge was developed with two different protein sources (SMP and WPC80) and three different protein concentrations (4%, 7%, 10%). The taste and texture of the porridge were evaluated by performing sensory analysis, texture analysis, colour measurements and image analysis.

## 4.1 Sensory analysis

The first set of replicate (n=12) samples from factorial design were selected for the sensory analysis. Out of the 12 porridge samples, six samples were SMP protein enriched, and the other six samples were WPC80 enriched. In total 19 sensory attributes (Table 3-4) were scored by six well trained panellists.

ANOVA was performed on the sensory scores to identify the attributes which differed significantly for the design factors, protein source, protein concentration and addition time. The attributes which differed significantly were highlighted in Table 4-1.

The design factor protein source had shown significant difference in sensory attributes of mouthfeel <sticky, mealy, dry>, aroma <cooked, barley, milk, whey> and taste <salty, sweet>. The significant difference in aroma and taste between SMP and WPC80 samples was mainly because SMP is a dry milk powder and has high amount of lactose and salts, which might influence the aroma and taste attributes. Whey powder (WPC80) has low amount of lactose and milk salts and high percent of whey protein.

In the SMP porridge samples, the attributes of mouthfeel <sticky, soluble, dry>, taste <total taste, sweet, bitter>, aroma <cooked, milk>, appearance <glossy> and consistency with spoon <firm, elastic> differed significantly for the design factor protein concentration. No attribute differed significantly for the factor protein addition time.

In the WPC80 porridge samples, the attributes of appearance <glossy>, consistency <firm>, mouthfeel <sticky, grainsize>, taste <sweet> differed significantly for the design factor protein addition time. Whereas the attribute whey only differed for the factor protein concentration.

No significant difference was observed for barley smell and aroma. This explains that the added protein did not affect the barley smell and aroma for both the protein sources SMP and WPC80 porridge samples

*Table 4-1: P-values from ANOVA for the design factor protein source for all the 12 samples. The design factors protein concentration, addition time, analysed separately for SMP (n=6), WPC80 (n=6) protein source samples. Bold p-values (p<0.05) represent the attributes which differed significantly.*

| Sensory Attribute | Protein Source | Protein Source - SMP | | Protein Source – WPC80 | |
|---|---|---|---|---|---|
| | | Protein Concentration | Addition Time | Protein Concentration | Addition Time |
| Colour | 0.450 | 0.127 | 0.267 | 0.381 | 0.726 |
| Glossy | 0.622 | **0.041** | 0.639 | 0.815 | **0.038** |
| Firm | 0.385 | **0.004** | 0.448 | 0.88 | **0.014** |
| Elastic | 0.083 | **0.010** | 0.571 | 0.286 | 0.173 |
| Sticky | 0.082 | **0.006** | 0.457 | 0.778 | **0.046** |
| Grain size | 0.061 | 0.053 | 0.549 | 0.795 | **0.024** |
| Mealy | **0.036** | 0.260 | 0.802 | 0.303 | 0.269 |
| Chewing resistance | 0.174 | 0.350 | 0.856 | 0.707 | 0.056 |
| Soluble | 0.488 | **0.045** | 0.932 | 0.392 | 0.192 |
| Dry | 0.122 | **0.029** | 0.282 | 0.353 | 0.217 |
| Barley smell | 0.660 | 0.443 | 0.074 | 0.065 | 0.557 |
| Total taste | 0.095 | **<0.001** | 0.425 | 0.13 | 0.762 |
| Salty | **0.014** | 0.907 | 0.062 | 0.785 | 0.177 |
| Sweet | **0.011** | **<0.001** | 0.36 | 0.906 | **0.017** |
| Bitter | 0.134 | **0.026** | 0.607 | 0.053 | 0.622 |
| Cooked | **0.006** | **0.003** | 0.514 | 0.268 | 0.529 |
| Barley | **0.034** | 0.108 | 0.155 | 0.226 | 0.412 |
| Milk | **0.005** | **0.022** | 0.151 | 0.108 | 0.524 |
| Whey | **0.009** | 0.267 | 0.128 | **0.046** | 0.898 |

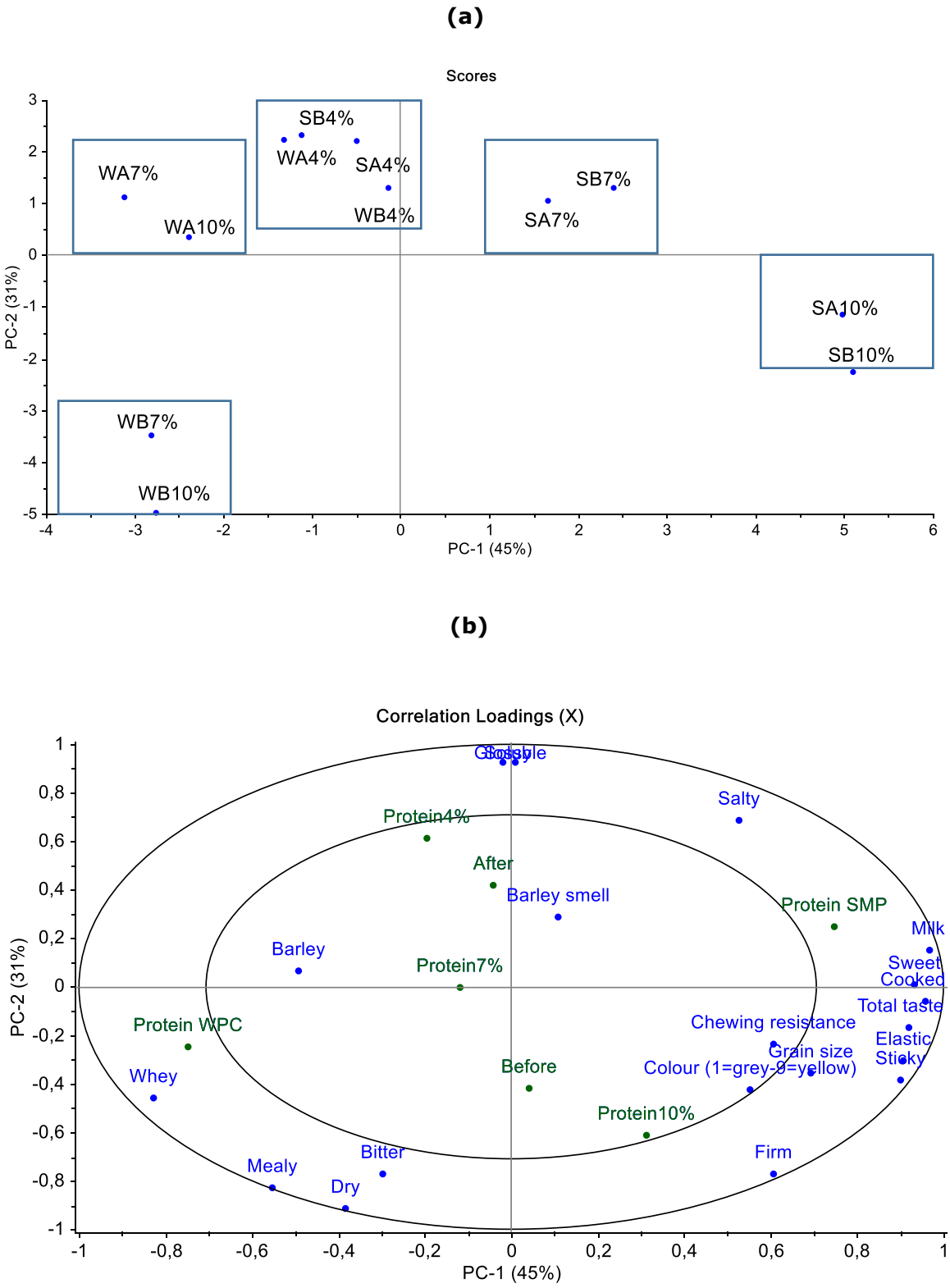



*Figure 4-1: (a) PCA score plot for the 12 porridge samples selected in sensory analysis. The principal components PC1, PC2 explain 76% of total variance of the data. (b): PCA correlation plot for the 12 porridge samples used in sensory analysis. Average scores from six panellists were used in PCA.*

Principal component analysis (PCA) was performed to understand the interaction between the design factors and sensory attributes. All the samples were given with three digit codes (WA4%, SB7%, etc.). They represent W - protein source WPC80, S – protein source SMP and B, A – protein addition time before, after and 4%,7% & 10% - protein concentration. For example, WA4% means WPC80 protein source sample with protein addition time after and 4% protein concentration.

The principal components PC1 (45%), PC2 (31%) explained 76% of the total variance in the data. The PCA score plot (Figure 4-1 (a)) explained the grouping of samples. The correlation loadings plot (Figure 4-1 (b)) depicted the significant attributes. The variation among the SMP, WPC80 porridge samples was represented along PC1. The variation in the protein concentration was represented on the PC2. The design factors protein source and protein concentration were well explained by the model. The effect of protein concentration seems to vary systematically.

In the score plot, the 4% protein concentration samples formed one group. The two samples, SB7% and SA7%, were grouped together, and SB10% and SA10% were together. The pattern explained that the design factor protein addition time (before and after) had less influence on the SMP porridge samples which was also observed in ANOVA results (Table 4-1). On the contrary, the WPC80 protein source samples were grouped based on the factor protein addition time, with WA7%, WA10% in one group and WB7%, WB10% in another group.

The SMP porridge samples were dominated by the taste attributes <total taste, sweet>, the aroma <cooked, milk> and attributes elastic, sticky while the WPC porridge samples were distinguished by the attributes <whey, mealy, dry>. The high scores of total taste and sweet in the SMP porridges is because SMP is rich in lactose which gives a sweet taste to porridges. The other attributes <chewing resistance, barley smell, barley flavour grain size> were not well explained as they did not have enough structural variance in the data.

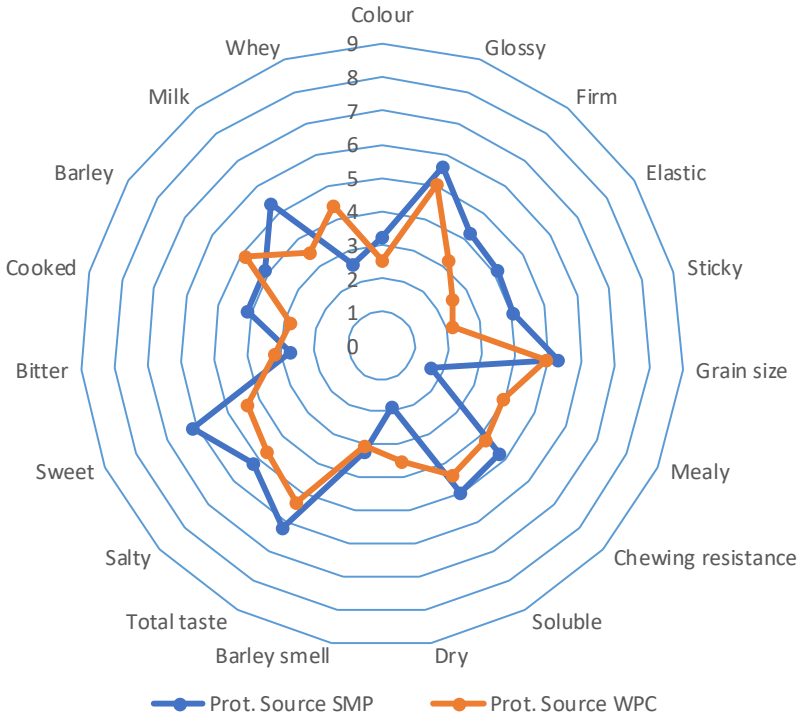



*Figure 4-2: Radial chart showing the variation of sensory attributes for the protein sources SMP, WPC80 for 12 samples. Average values of sensory scores (n=12) were used.*

Figure 4-2 shows the attributes mealy and dry had higher scores for the WPC80 samples. This might be due to hydrophobic interactions between the amino acids (when exposed to heat), which can result in insoluble protein aggregate particles (Anand, Brody, Ward, & Landry, 1998). The protein aggregates have been shown to give mealy and dry mouth feel to WPC80 porridges. The SMP enriched porridge samples had higher scores for the attributes, firm, sticky and elastic. The lactose present in milk powders could be responsible for the stickiness of the products (Fox et al., 2015).

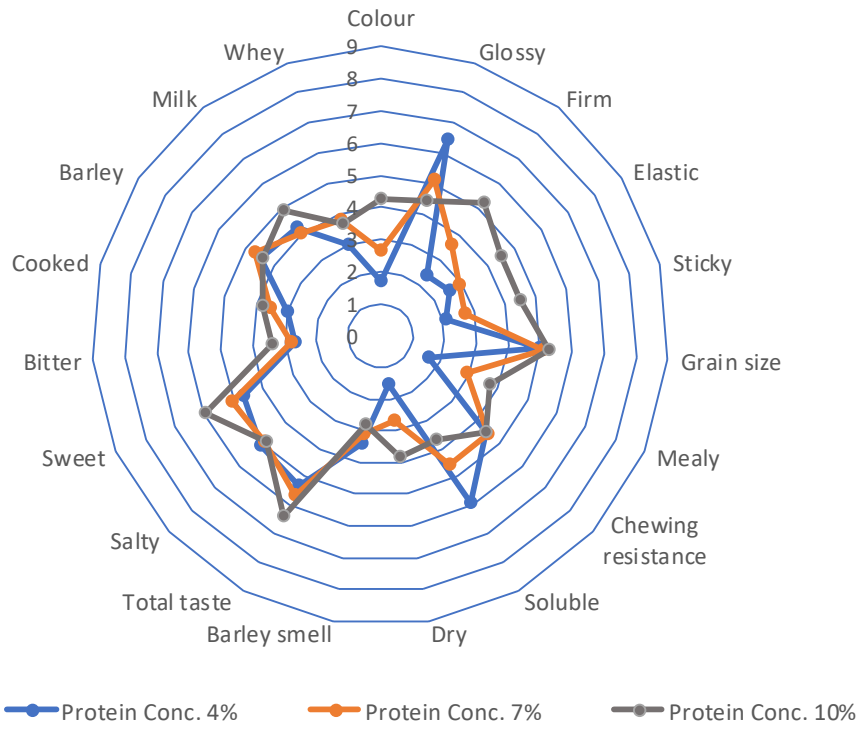



*Figure 4-3: Radial chart of sensory attributes showing variation for protein concentration. Average values of sensory scores for SMP enriched porridge samples (n=6) were used.*

In SMP samples, most of the attributes had shown the higher score for the protein concentration 10% (Figure 4-3). Glossy and soluble attributes had moved the opposite way i.e. as the amount of protein increased, the sensory scores decreased. As the amount of milk was constant for all the porridges, the increase in protein concentration subsides the glossy texture of the milk. The PCA plot also indicated that attributes glossy, soluble were correlated to protein concentration. Grain size had similar values for all the three-protein concentration, probably sensory panellists could not distinguish the grain size, or the porridges were overly cooked. The salt taste remained the same for all the three protein concentrations, increase in protein concentration should influence the salt taste. The sweet and total taste might have masked the salt taste of porridges. The colour of 10% samples was high because the high protein content results in Maillard reaction between reducing sugars and amino acids. (Van Boekel, 1998). The mealy and dry scores were low for all the three protein concentrations. This could be due to heat stability of casein in skim milk powder with less denaturation, causing reduced textural change (Farrell et al., 2004).


*Figure 4-4: Radial chart of sensory attributes showing variation for addition time in WPC80 porridge sample. Average values of sensory scores of six porridge samples (n=6) were used*

In WPC80 porridge samples, the protein addition time (before) samples were firm, mealy and dry (Figure 4-4). When the protein is added from the start and cooked at 100°C temperature, the higher temperature leads to protein denaturation and textural change. The addition time (after) samples were less firm and glossier because in these samples the protein was added to already cooked porridge and reheated. So, the time that the protein was exposed to heat was low in addition time (after) samples. The taste and aroma attributes did not differ between the addition time before and after, this shows that the protein denaturation did not affect the flavour of whey enriched porridges. Overall, the design factor protein addition time had higher influence on the WPC80 porridge samples. This could be due to the "heat labile" nature of whey proteins (Fox et al., 2015).

## 4.2 Texture analysis

Texture measurements of firmness, consistency, cohesiveness and index of viscosity were measured at two different temperatures, 20°C and 60°C. The temperature 60°C was selected to understand the textural behaviour of porridges at normal eating temperature (50 - 60°C). The sensory analysis and colour measurements were performed at normal room temperature 20±1°C, so 20°C in instrumental texture analysis was selected to correlate the results. ANOVA was performed for 20°C and 60°C textural measurements (firmness, consistency, cohesiveness and index of viscosity). All the attributes differed significantly for the factor temperature.

The readings of texture measurements cohesiveness and index of viscosity were negative due to the backward moment of the probe from sample. The absolute values of cohesiveness and index of viscosity were used in the statistical analysis and graphical representations for easy comparisons. Data from triplicate measurements of each sample were used for all the 24 samples.

*Table 4-2: P-values of texture profile attributes for design factors protein concentration, protein addition time of two protein source samples SMP (n=12), WPC80 (n=12). Bold p-values represent the attributes which differed significantly (p<0.05).*

| | SMP | | WPC | |
|---|---|---|---|---|
| Texture properties | Prot. Concentration | Addition Time | Prot. Concentration | Addition Time |
| Firmness 20°C | **<0.001** | 0.570 | 0.087 | **<0.001** |
| Consistency 20°C | **<0.001** | 0.971 | 0.294 | **0.006** |
| Cohesiveness 20°C | **<0.001** | 0.603 | 0.136 | **<0.001** |
| Index of Viscosity 20°C | **<0.001** | 0.338 | 0.506 | **<0.001** |
| Firmness 60°C | **<0.001** | 0.605 | 0.194 | **<0.001** |
| Consistency 60°C | **<0.001** | 0.866 | 0.354 | **<0.001** |
| Cohesiveness 60°C | **0.002** | 0.994 | 0.843 | **<0.001** |
| Index of Viscosity 60°C | **0.001** | 0.776 | 0.466 | **<0.001** |

Table 4-2 shows the results of ANOVA for the SMP and WPC80 protein source samples. In the SMP porridge samples all the measurements differed significantly ($p<0.002$) for the design factor protein concentration. The factor protein addition time had differed significantly ($p<0.006$) for all the measurements in the WPC80 porridge samples.

*Table 4-3: Results of Tukey post-hoc test of SMP protein source porridge samples for the design factor protein concentration. The samples which did not share the same superscript letter (a, b, c) in a column differed significantly.*

| Measurement at 20°C | | | | |
|---|---|---|---|---|
| Protein concentration | Firmness (g) | Consistency (g.s) | Cohesiveness (g) | Index of viscosity (g.s) |
| 4% | 51.62 ±4.41[b] | 701.7 ± 66.2[b] | 35.61 ± 6.08[b] | 66.93 ± 3.81[b] |
| 7% | 41.93 ± 10.13[b] | 517.1 ± 132.1[c] | 29.49 ±16.57[b] | 37.57 ±21.75[c] |
| 10% | 108.90 ± 21.09[a] | 1342.2 ± 213.4[a] | 96.88 ±13.05[a] | 159.53 ± 28.94[a] |
| Measurement at 60°C | | | | |
| Protein concentration | Firmness (g) | Consistency (g.s) | Cohesiveness (g) | Index of viscosity (g.s) |
| 4% | 28.97 ± 2.84[a] | 283.86 ± 30.07[a] | 18.77 ± 3.57[a] | 10.97 ± 6.95[a] |
| 7% | 16.10 ± 6.60[b] | 169.5 ±71.2[b] | 10.19 ± 7.02[b] | 10.37 ± 9.76[b] |
| 10% | 24.73 ± 7.53[a] | 253.0 ± 76.3[a] | 19.61 ± 8.27[a] | 24.55 ± 15.25[b] |

Tukey's honestly significant difference (HSD) post hoc test performed to find the significant difference between protein concentration 4%, 7% and 10% (Table 4-3). The protein concentrations which did not share the same letter were significantly different from each other. At the temperature 20°C samples, the 10% protein concentration samples were significantly different from 4% and 7%. Whereas at 60°C, the 10% protein concentration samples had similar mean value with 4% and 7% samples. For the measurements at 60°C, the porridge samples were reheated in a water bath for 15-20 minutes. This might affect the changes in the texture and viscosity properties of porridge sample. The barley used in the porridge has high starch content and during reheating the redistribution of swollen starch granules might cause a change in viscosity of porridge (Eriksson, 2012). In this experiment, for easy to chew, barley grains were ground and size was exactly not known. Changes in cereal grain (grits) size could also influence the viscosity and texture of porridge (Yadav, Chhikara, Anand, Sharma, & Singh, 2014).

*Table 4-4: The average values of the texture measurement for WPC samples (n=12) separated by the design factor protein addition time before and after at the both temperatures 20℃, 60℃.*

| Texture properties | Before | | After | |
|---|---|---|---|---|
| | Temperature 20°C | Temperature 60°C | Temperature 20°C | Temperature 60°C |
| Firmness (g) | 79.47 ± 22.48 | 42.47 ± 17.02 | 50.92 ± 9.32 | 24.79 ± 5.33 |
| Consistency (g.s) | 1022.53 ± 318.9 | 485.20 ± 193 | 572.67 ± 140.5 | 270.75 ± 73.31 |
| Cohesiveness (g) | 50.41 ± 15.89 | 24.57 ± 9.57 | 27.58 ± 5.76 | 11.21 ± 4.46 |
| Index of viscosity (g.s) | 83.63 ± 32.84 | 30.04 ± 16.24 | 37.91 ± 20.31 | 12.69 ± 5.35 |

In the above table (Table 4-4) the average readings of WPC enriched samples with the factor protein addition time at two different temperatures were shown. The texture properties firmness (79.47) consistency (1022.53), cohesiveness (50.41) and index of viscosity (83.63) exhibited higher readings for addition time before samples than addition time after at 20°C. The textural difference between before and after might be due to protein denaturation. The design factor protein addition time after was chosen to minimize this textural change. In these samples, the whey protein was less exposed to heat when compared to protein addition time before samples.

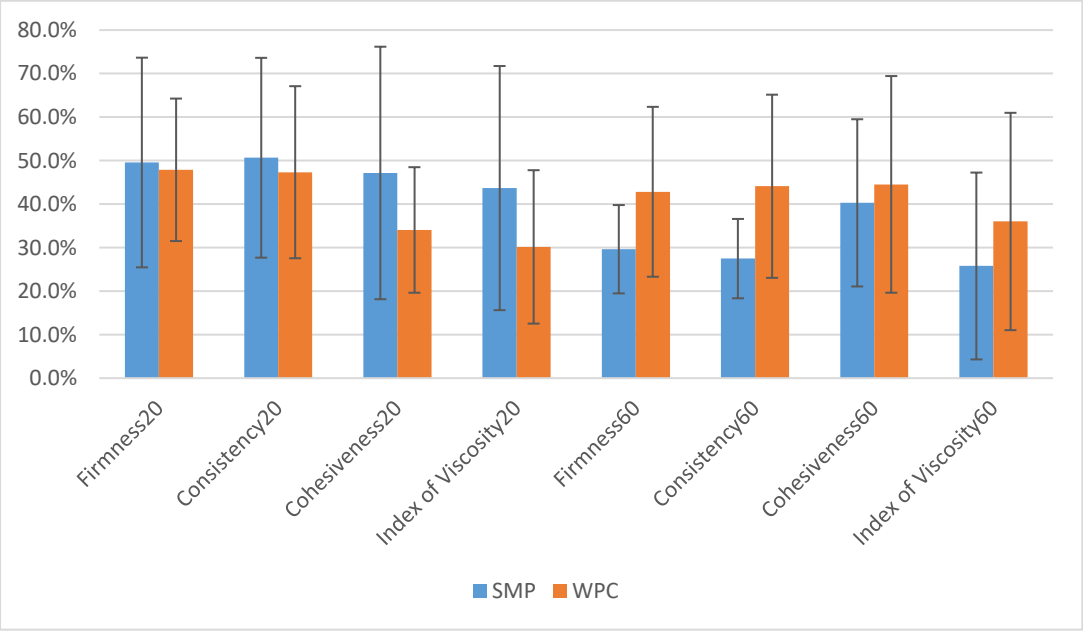



*Figure 4-5: Graphical representation showing the variation of texture profile attributes for the design factor protein source for 24 samples. The percentage calculation was made to draw the graph i.e. average score/individual max score multiplied with 100.*

Figure 4-5 shows the variation of texture measurements at two different temperatures for the design factor protein source. All the texture measurements for 20°C were higher for protein source SMP, indicating that the porridge samples made from SMP were slightly more firm and cohesive compared to WPC80 protein porridge samples. The instrument texture measurements at 20°C were in line with the pattern of sensory attributes firm, elastic and sticky (Figure 4-2). The WPC80 porridge samples had higher scores at 60°C compared to SMP porridge samples. The texture of WPC enriched porridge samples was mealy and dry at room temperature. The temperature for each run was not exactly same due to handling time at room temperature. At 60°C, it varied around ±5°C, and for 20°C it varied ±1°C. The temperature effect was not included in design factor, so it is difficult to evaluate the exact effects

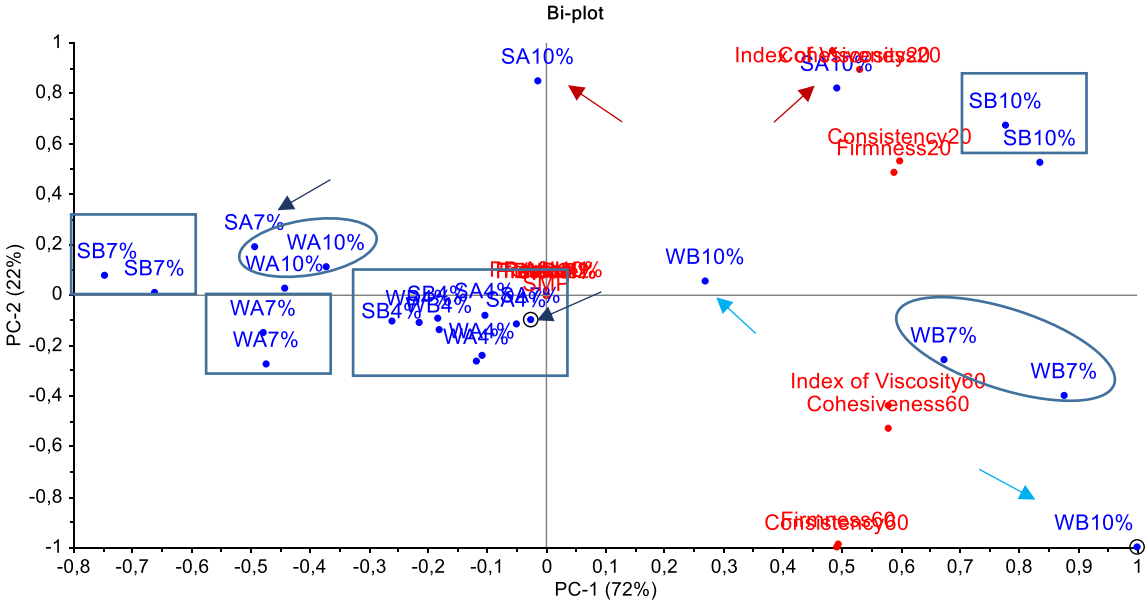



*Figure 4-6: PCA bi-plot of instrumental texture measurements for all 24 samples showing the grouping of the parallels.*

PCA was performed on the 24 porridge samples (Table 3-3) data, using the average value of triplicate measurements for each sample (Figure 4-6). The principle components PC1 (72%), PC2 (22%) explained 94% of total variance in the data. All the samples were given with three digit codes (example WA4%). Parallel/replicate samples carry same code.

The samples that were parallel are grouped in box/ellipse and samples which were not parallel to each other are marked with arrows. All the 4% concentration samples were similar to each other and formed into one cluster. This is mainly because no protein source was added for 4% samples the protein percent from the ingredients (whole milk and barley) in total constituted to 4%. PC1 separated SMP 10% protein concentration samples

from the other SMP protein source samples. The SMP 4% and 7% protein concentration samples had similar textural measurements. The textural properties were highlighted in red colour. The PC2 gives an indication of temperature effect on textural properties on some of the samples (SB10% and WB7%), which needs to be further investigated.

### 4.2.1 Correlation between sensory and instrument analysis

PLS regression was performed to correlate instrument measured texture values to the average scores of textural sensory attributes <firm, elastic, sticky> from the sensory analysis. Only the sensory attributes which described the textural property of the porridge were chosen as these attributes were positively correlated with instrument measured texture properties. In this PLS regression the instrument measured values at both the temperatures 20, 60°C (firmness, consistency, cohesiveness, index of Viscosity) were taken as X- variable and sensory properties (firm, elastic, sticky) were taken as Y- variable.

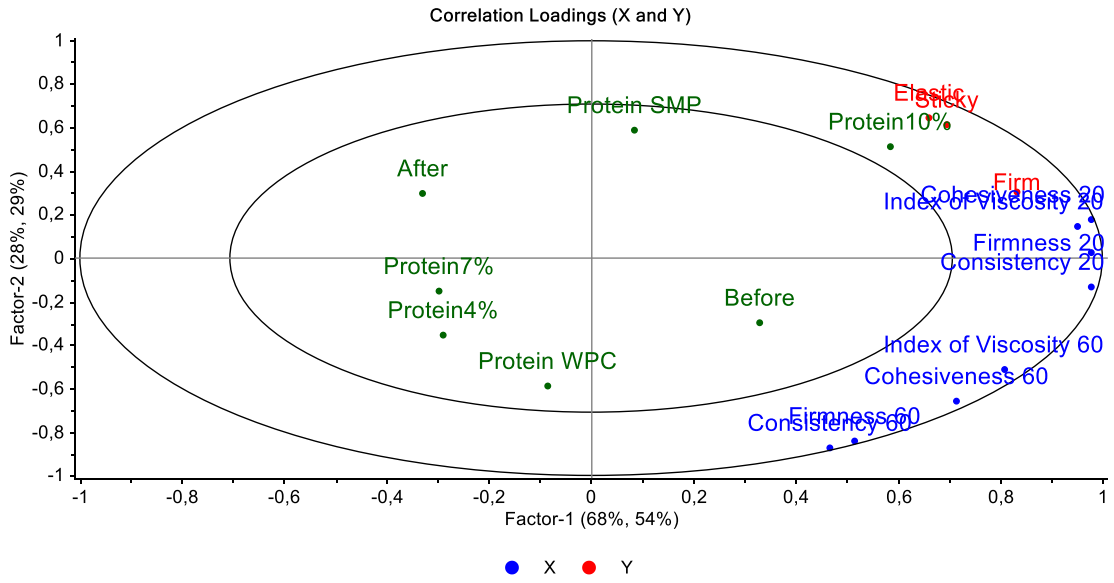



*Figure 4-7: PLS regression correlation loadings (X and Y) plot of sensory scores (red), and textural measurements(blue) for 12 porridge samples. Downweighed variables are shown in green colour.*

The textural attributes firm, elastic and sticky were positively correlated with the measured instrument values of firmness, consistency, cohesiveness and index of viscosity. Two factors were needed to explain the most of the variance in X and Y variables. The predicted and reference Y values had shown good correlation with two factor calibration model. The following plots represent the quality of fitted PLS model.

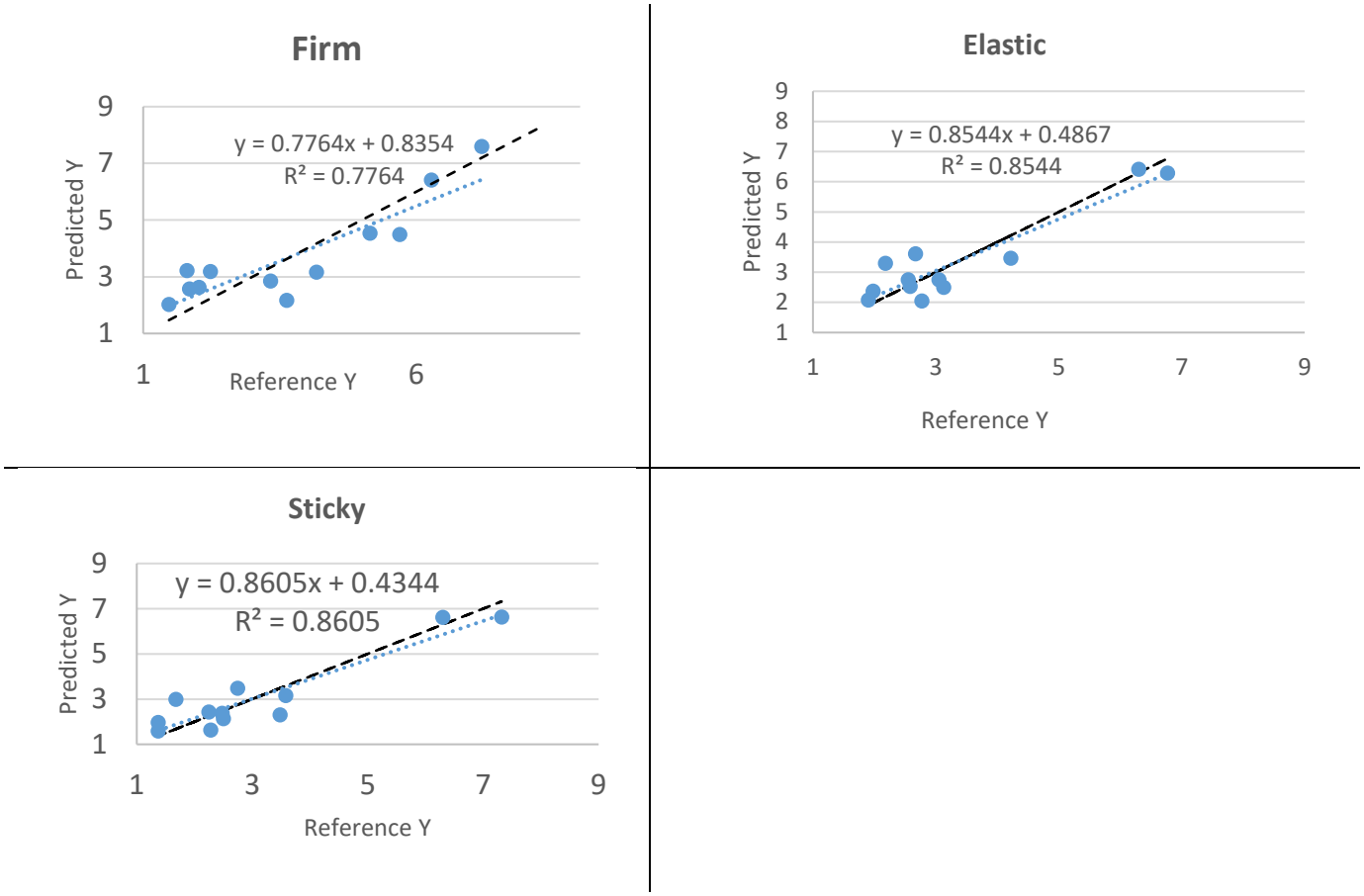



*Figure 4-8: Predicted vs Reference for sensory attributes firm, elastic and sticky from PLS regression model.*

Figure 4-8 shows predicted vs reference plot for sensory attributes <firm, elastic and sticky> respectively from the calibration model of PLS regression with two factors. The regression coefficients ($R^2$) are 0.78, 0.85, 0.86, indicating that the sensory attributes <firm, elastic, sticky> can be reasonably well predicted from the instrument measured values. The model was affected by high values in elastic and sticky.

In the sensory analysis, more attributes could in further work be included to describe the textural properties of the porridge. The predicted model showed good correlation between instrument measured values and sensory attributes, and this may be useful information in improving the texture of porridge. The high correlation could be a result of better agreement and calibration among the panellists. The reference samples supplied to the panellists also helped in the rating of the attributes (Lawless et al., 2010).

## 4.3 Colour measurements

The digital image was captured using the DigiEye system. The digital images for the sample WB7% (WPC 7% before), WA7% (WPC 7% after) are shown in Figure 4-9.

**a** **b**

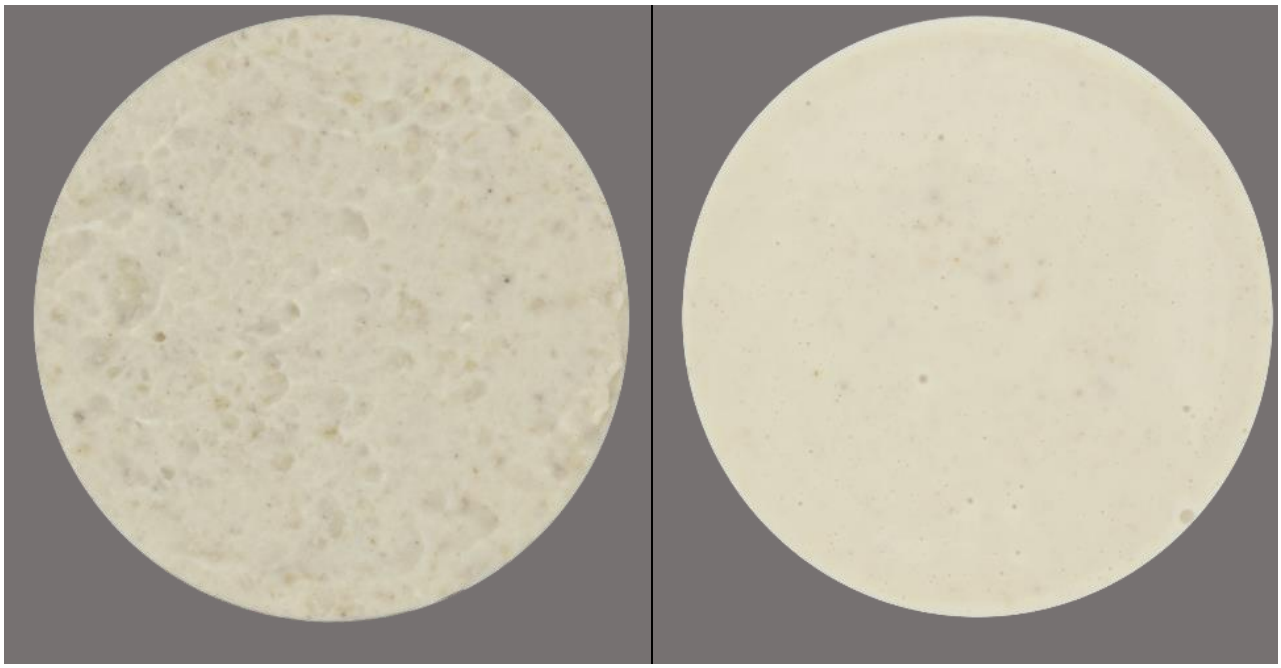


*Figure 4-9: Digital images of porridge samples from DigiEye system. a). WPC 7% **before**, b) WPC 7% **after***

The steps involved in acquiring the images were explained in Chapter 2, sec. 6.1. The quantified colour values of 24 samples were analysed. The general linear model in Minitab was used to identify the colour coordinates which differed significantly for the design factors protein source, protein concentration and protein addition time.

*Table 4-5: P-values of colour coordinates for design factor protein concentration, protein addition time of two protein source samples SMP and WPC80. Bold p values represent significant difference ($p<0.05$).*

| | SMP | | WPC80 | |
|---|---|---|---|---|
| Colour coordinates | Protein concentration | Addition time | Protein concentration | Addition time |
| L* | 0.211 | **0.018** | **0.004** | 0.839 |
| a* | 0.210 | **<0.001** | 0.095 | **0.012** |
| b* | **<0.001** | 0.842 | **<0.001** | 0.125 |
| C* | **<0.001** | 0.912 | **<0.001** | 0.110 |
| h° | **0.001** | **0.001** | 0.969 | **0.033** |

The L*, a*, b* colour model (Figure 2-6) is widely used in research related to food colour measurements (Yam & Papadakis, 2004). In the Table 4-5 the colour coordinate (b*) and Chroma (C*) differed significantly for the design factor protein concentration and did not differ significantly for the design factor protein addition time in both the protein sources. The colour coordinate (a*) and hue (h°) differed significantly ($p<0.05$) for the design factor protein addition time in the both SMP and WPC enriched samples. Also, hue (h°) differed significantly in protein source SMP samples for the design factor protein concentration.

The colour difference between the porridge samples was quantified using the following equation

$$\Delta E_{ab} = \sqrt{(\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2}$$

$\Delta E_{ab}$ is the Euclidean distance, $\Delta L^*$ is difference between the lightness, $\Delta a^*$, $\Delta b^*$ are difference between colour coordinates a*, b*. $\Delta E_{ab}$ is most commonly used for colour difference in general purpose. The observer finds difference as below:

- "$\Delta E_{ab}$ is 0 – 1, the observer does not notice the difference
- $\Delta E_{ab}$ is 1 - 2, only experienced observer can notice the difference
- $\Delta E_{ab}$ is 2 – 3.5, a normal person also notice the difference
- $\Delta E_{ab}$ is 3.5 – 5, a clear difference by observer
- $\Delta E_{ab}$ is ≥5, two colour difference" (Mokrzycki & Tatol, 2011).

*Table 4-6: The average score of L*, a*, b* values of two protein sources with three different percentage are shown. The $\Delta E_{ab}$ values explain the total colour difference of the samples.*

| WPC80 | | | | SMP | | | | |
|---|---|---|---|---|---|---|---|---|
| Protein concentration | L* | a* | b* | Protein concentration | L* | a* | b* | $\Delta E_{ab}$ |
| 4% | 83.747 | 1.981 | 14.847 | 4% | 83.006 | 2.083 | 14.943 | 0.754 |
| 7% | 82.865 | 2.093 | 16.044 | 7% | 83.798 | 1.801 | 16.318 | 1.015 |
| 10% | 85.673 | 2.515 | 18.927 | 10% | 84.375 | 1.776 | 19.918 | 1.793 |

In Table 4-6, the average scores of L*, a*and b* colour coordinates and ΔE values of two protein sources are shown. The a* values exhibited low red tone. The b* values indicated yellow colour and the L* value was towards lightness. The b* value for SMP 10% protein concentration samples was high indicating the colour saturation towards yellow tone. This was also evident in the sensory scores of the colour attribute (Figure 4-3). The non-

enzymatic browning reaction could also affect the colour of porridges (Chapter 2, sec. 4.1). The colour difference between WPC80 and SMP samples was unnoticeable ($\Delta E_{ab}<1$) for 4% samples. As there was no external protein addition in the 4% samples, they should have similar values, which was evident from the measurements above. For 7% and 10% samples the $\Delta E_{ab}$ was between 1 and 2, so, only experienced observer can notice the colour difference (Mokrzycki & Tatol, 2011).

*Table 4-7: The average score of L*, a*and b* values of WPC addition time before and after samples with three different percentage were shown. The $\Delta E_{ab}$ values explain the total colour difference.*

| WPC80 Before | | | | WPC80 After | | | | |
|---|---|---|---|---|---|---|---|---|
| Protein concentration | L* | a* | b* | Protein concentration | L* | a* | b* | $\Delta E_{ab}$ |
| 4% | 82.360 | 1.810 | 14.863 | 4% | 85.133 | 2.152 | 14.830 | 2.794 |
| 7% | 82.082 | 2.000 | 15.497 | 7% | 83.648 | 2.185 | 16.592 | 1.920 |
| 10% | 87.613 | 1.992 | 18.005 | 10% | 83.733 | 3.038 | 19.848 | 4.421 |

The colour coordinate values, colour difference between addition time before and after for protein source WPC80 were shown in Table 4-7. The lightness of protein concentration 4% samples with addition time after were higher than before because the after samples were cooked twice, which might affect the colour. The a*(red tone) values were high for all the protein addition after samples this might be due to the colour of WPC80 which is not as white/cream as SMP. In before samples the WPC80 was added from the start and cooked, so the impact of protein colour was reduced compared to the after samples. The colour difference between before and after samples was clear for 10% protein concentration (4.421) followed by 4% (2.794) and then 7% (1.920). The $\Delta E_{ab}$ value was high in 10% samples, meaning that the colour difference between WPC before and after samples was visible to normal observer. The sensory scores (Figure 4-2) were also high for 10% samples (towards yellow colour). Although $\Delta E_{ab}$ provides the information about colour difference it does not specify which coordinate contributes to the colour difference (Lawless et al., 2010).

All the samples fell into the yellow hue range and were less chromatic. While cooking porridges, only the amount of protein was varied keeping all other ingredients constant, so the protein added might have influenced the change in colour of the samples.

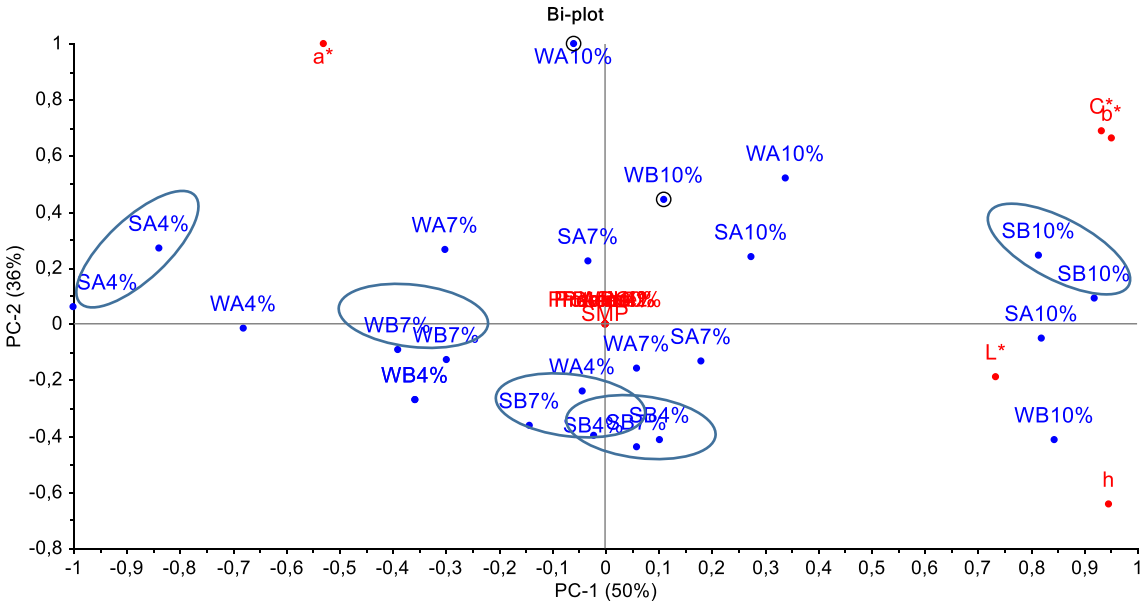
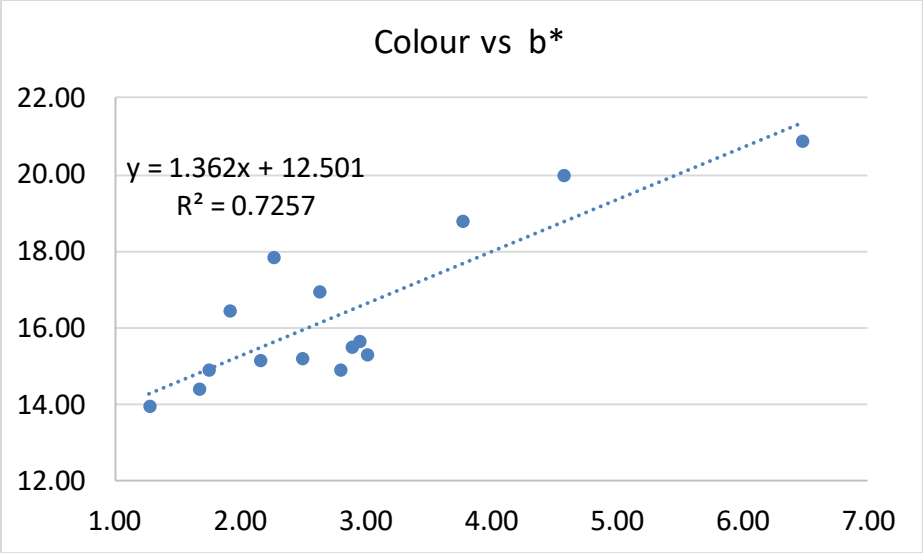



*Figure 4-10: PCA bi-plot of colour properties (L*, a*, b*, c*, h) for all 24 samples showing the grouping of the parallels.*

Principal component analysis was performed on the 24 porridge samples data, using the average value of triplicate measurements for each sample (Figure 4-10). All the samples were given with three digit codes (example WA4%). The principle components PC1 (50%), PC2 (36%) explained 86% of total variance in the data. The PC1 explained variation of the samples on design factor protein concentration and colour coordinate L*. The PC1 separated the 10% SMP samples from the rest of the samples. This was also observed in sensory and instrumental texture measurements. The parallel samples were depicted encircled in ellipses. The parallels with protein source SMP and addition time before were together. The same pattern was observed for WPC80 samples except for 10% samples.

### 4.3.1 Correlation between colour attribute and colour coordinates b* and C*

The correlation between sensory attribute colour and colour measurements b* and C* was studied using the linear regression. The linear regression plots between sensory attribute <colour> and colour measurements b*(yellow) and C*(Chroma) are shown in Figure 4-11. Sensory scores were used on X- axis and colour measurements on Y-axis. The $R^2$ values of 0,72 and 0,71 show good correlation between colour attribute and b*(yellow) and C*(chroma) values. The sensory attribute colour and glossiness (results not shown) were correlated with CIE L* a* b*, only colour attribute was well correlated.



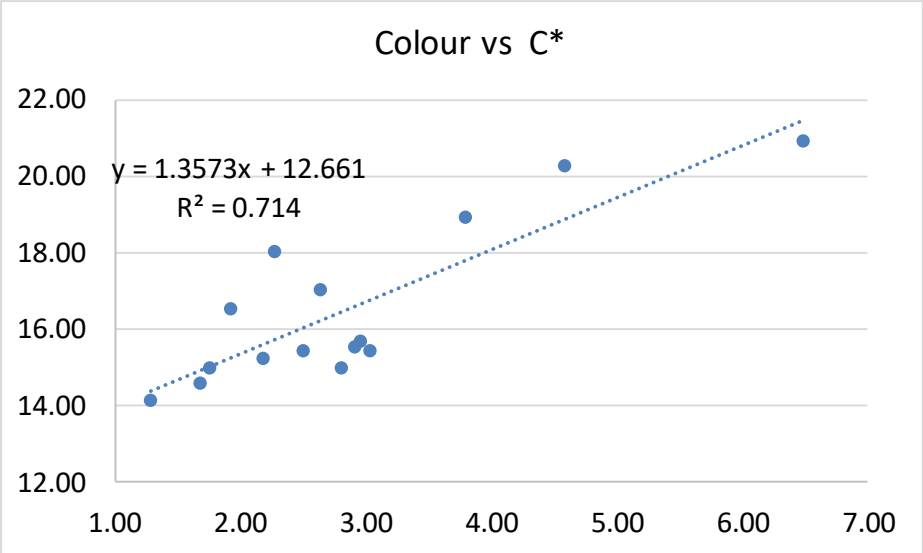




*Figure 4-11: Regression plot correlating sensory attribute <colour> to DigiEye extracted colour coordinate b*, C*.*

## 4.4 Image analysis

Digital images were processed using ImageJ software. Image segmentation was carried out using the thresholding method, explained in Chapter 3, sec. 10.

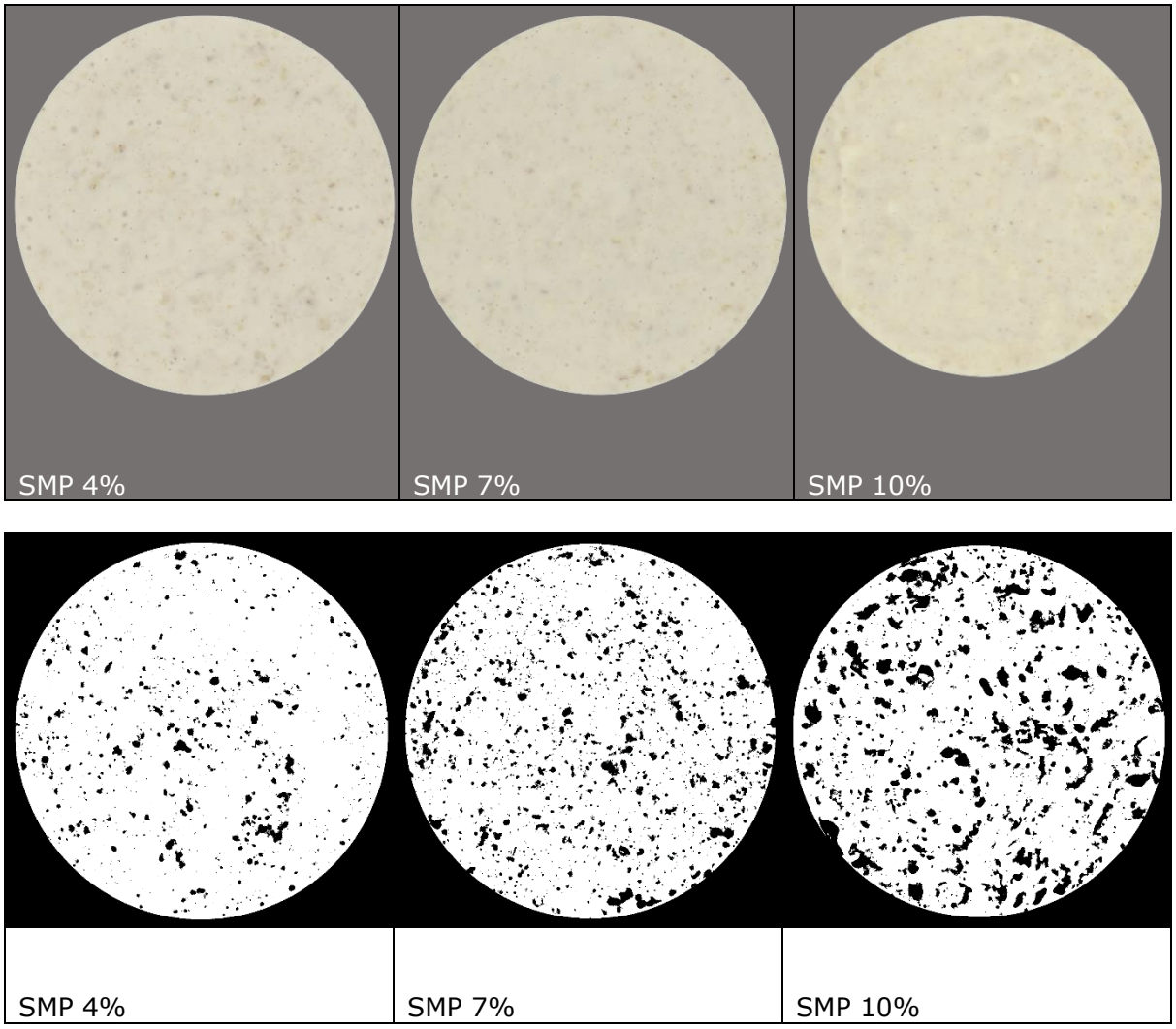



*Figure 4-12: The change in the surface texture for SMP enriched porridge with the increase in protein concentration (4%,7%&10%). The first-row images were the original images acquired using DigiEye system. The second-row images were the processed images obtained after applying thresholding using Image J software.*

The irregular shaped dark colour spots in the Figure 4-12 might be barley particles bounded with protein aggregates. The amount of protein concentration increased the size of dark colour spots in the images of SMP porridge samples. This might be due to aggregation of high protein concentration (Paulsson, 1990). For all the porridge samples, the same amount of barley (150 g) was used. So, the increased size and number of dark spots might be from the protein aggregates. Barley grains along with protein particles (our region of interest) were spotted as black colour shapes. It was difficult to differentiate and

count individual particles because both barley grains (grounded) and protein gels had no specific size.

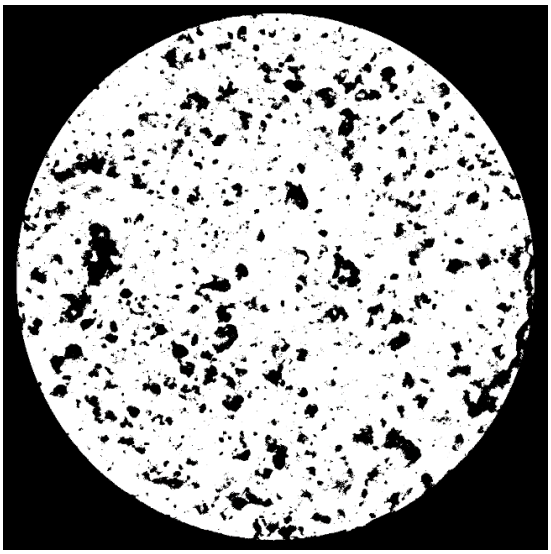
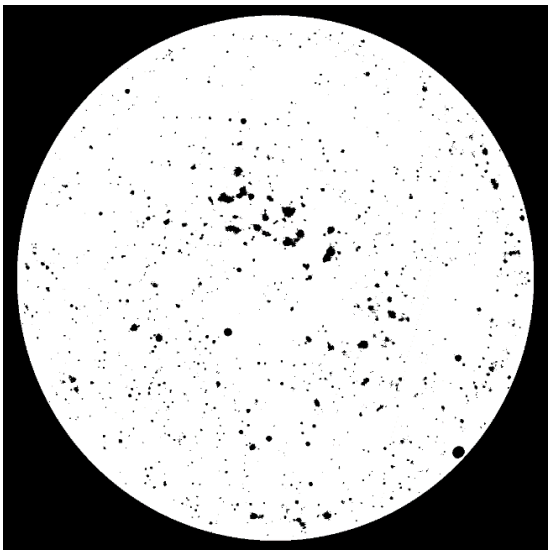
| | |
|---|---|
|  |  |
| WPC 7% before | WPC 7% after |

*Figure 4-13: The change in the surface texture for WPC enriched porridge with the addition time before and after. The images were the processed images obtained after applying thresholding using Image J software.*

From instrumental texture measurement of porridge, the design factor protein addition time had greater influence on the WPC enriched porridge samples compared to SMP porridge samples. The change in the surface texture for WPC porridge sample was shown in Figure 4-13. The left image was porridge sample cooked with protein added before and right image was protein added after. The dark spots were high in number in the left image indicating the denaturation of whey protein when WPC was added from the start. Depending on the conditions, dairy proteins can influence the texture of food products (Ustunol, 2014). In the above image (left), the heat induced changes in whey protein might have influenced the texture of the porridge. Image segmentation is a useful technique for food industries. In this work, it did not extract much information about the protein gels in porridges. This may be due to the disturbance from the grains in the porridges.

### 4.4.1 General discussion about WPC80 (before and after cooking) samples

In case of globular whey proteins, denaturation results in aggregation of proteins affecting their solubility and other functional property. The WPC80 enriched porridges with the design factor protein addition time before might have exhibited protein denaturation and aggregation. The image analysis had shown some insights regarding this which was

captured in an image shown in Figure 4-13. Whey protein exhibit transition between 62-80°C (Fox et al., 2015). The cooking time for the porridge samples with design factor protein addition time before, was 20 minutes at 100°C (Chapter 3, sec. 5.1). At this high temperature, the difference in the textures was noticed while cooking. Protein gels might have formed and when the porridge was cooled down, the small aggregation of particles was observed. NaCl was added from the start, this could also be one factor leading to agglutination and gelation of the protein. The differential scanning calorimetry (DSC) analysis could be an important additional analysis to find the protein denaturation effect.

## PART II – Commercial dairy products

The commercially available dairy products from TINE (n=14) were selected for texture analysis. Sensory evaluation, instrumental texture measurements and IDDSI flow test were carried out. Analysis of variance (ANOVA) was performed, and the descriptors which varied significantly ($p \leq 0.05$) were identified. Multivariate Analysis was performed to understand the correlation between sensory and instrument methods.

## 4.5 Sensory and instrumental analysis

The intension was to classify the given products into different groups (thin to thick). Elderly people find viscous products difficult to swallow, so classifying them by texture and viscosity measurements helps old people to choose the right product.

### 4.5.1 Texture analysis by sensory method

The sensory analysis was performed on commercial products (n=14) with seven sensory attributes given in Table 3-7. The average of scores given by assessors (n=10) for each attribute was used for PCA whereas all the individual scores were used for ANOVA.

All the products were significantly different ($p<0.001$) with each other. This was mainly because the products selected had wide viscosity ranges from being very thin (coffee) to thick product like quark. Tukey's honestly significant difference (HSD) post hoc test was performed to find the grouping of the products (Table 4-8). The products which do not share a same letter in the column were significantly different. Quark, quark (light), yogurt vanilla and yogurt vanilla (rich) shared similar letters (a, b) for all the attributes. The E+ (energy) drinks shared similar letter (similar texture properties).

*Table 4-8: Grouping of TINE commercial products (n=14) based on Tukey posthoc test. The products which do not share the same alphabet are significantly different from each other.*

| Product | Thickness with spoon | cohesiveness | Thickness in mouth | Body | Dryness in mouth | Dryness in mouth after swallow | Swallow |
|---|---|---|---|---|---|---|---|
| Quark | 8.19$^{a}$ | 7.28$^{a-b}$ | 7.16$^{a}$ | 7.06$^{a-b}$ | 4.36$^{a-b}$ | 5.96$^{a-b-c}$ | 5.32$^{a}$ |
| Quark (light) | 8.2$^{a}$ | 7.55$^{a}$ | 7.55$^{a}$ | 7.32$^{a-b}$ | 4.99$^{a}$ | 6.8$^{a}$ | 5.42$^{a}$ |
| Yogurt vanilla | 7.33$^{a}$ | 6.44$^{a-b}$ | 6.53$^{a}$ | 6.71$^{a-b}$ | 3.57$^{a-b-c}$ | 5.12$^{a-b-c-d}$ | 4.62$^{a-b}$ |
| Yogurt vanilla (rich) | 8.14$^{a}$ | 7.43$^{a}$ | 7.38$^{a}$ | 7.18$^{a-b}$ | 4.92$^{a}$ | 6.46$^{a-b}$ | 5.38$^{a}$ |
| Sour milk (raspberry) | 1.81$^{d}$ | 3.81$^{d-e}$ | 1.65$^{c}$ | 3.26$^{d}$ | 3.18$^{b-c}$ | 4.71$^{c-d-e}$ | 2.14$^{d}$ |
| Sour milk (light) | 3.61$^{c}$ | 3.38$^{d-e}$ | 2.19$^{c}$ | 3.54$^{d}$ | 3.54$^{a-b-c}$ | 5.26$^{a-b-c-d}$ | 2.41$^{d}$ |
| Kefir/kephir | 4.03$^{c}$ | 2.98$^{e}$ | 2.13$^{c}$ | 4.19$^{c-d}$ | 2.47$^{c-d}$ | 5.01$^{b-c-d}$ | 2.08$^{d}$ |
| E+ cold coffee | 1.76$^{d}$ | 4.7$^{c-d}$ | 2.01$^{c}$ | 5.66$^{b-c}$ | 2.76$^{c-d}$ | 3.75$^{d-e-f}$ | 2.22$^{d}$ |
| E+ chocolate milk | 2.19$^{d}$ | 5.83$^{b-c}$ | 2.51$^{c}$ | 6.72$^{a-b}$ | 2.08$^{c-d}$ | 3.85$^{d-e-f}$ | 2.62$^{c-d}$ |
| E+ blueberry shake | 2.26$^{d}$ | 6.73$^{a-b}$ | 2.15$^{c}$ | 6.83$^{a-b}$ | 1.57$^{d}$ | 3.15$^{e-f-g}$ | 2.19$^{d}$ |
| E+ raspberry shake | 2.14$^{d}$ | 6.95$^{a-b}$ | 2.01$^{c}$ | 7.44$^{a}$ | 1.27$^{d}$ | 2.9$^{f-g}$ | 2.81$^{c-d}$ |
| E+ soup | 4$^{c}$ | 6.99$^{a-b}$ | 3.97$^{b}$ | 7.12$^{a-b}$ | 1.58$^{d}$ | 2.53$^{f-g}$ | 2.74$^{c-d}$ |
| Custard (vanilla) | 4.63$^{c}$ | 6.92$^{a-b}$ | 3.83$^{b}$ | 7.22$^{a-b}$ | 1.28$^{d}$ | 1.74$^{g}$ | 2.62$^{c-d}$ |
| Custard (vanilla) rich | 5.97$^{b}$ | 6.24$^{a-b}$ | 4.94$^{b}$ | 6.5$^{a-b}$ | 1.34$^{d}$ | 1.47$^{g}$ | 3.81$^{b-c}$ |

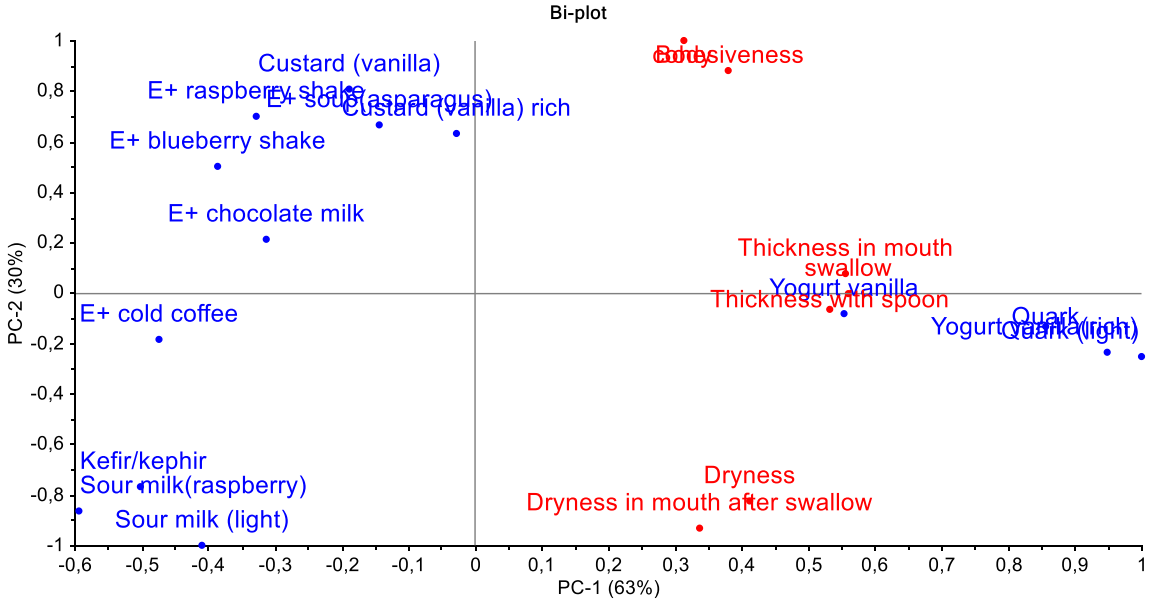



*Figure 4-14: Bi-plot from principal component analysis (PCA) of all commercial products. 93% of total variance was explained by first two components PC1 and PC2.The average readings of judges were plotted.*

In the PCA biplot (Figure 4-14) principal component1 (PC1) explained 63% of variation in sensory properties while PC2 explained 30%. The first PC explained difference between thin and thick products. The bi -plot represent the grouping pattern of the products with the thicker products on the right and thin products to the left. The vanilla custard and vanilla custard (rich) had higher scores for cohesiveness and body this is mainly due to vanilla custards contain milk, sugars, modified starch which gives smooth and cohesive texture (de Wijk, van Gemert, Terpstra, & Wilkinson, 2003).

The products quark (light), quark original, vanilla yoghurt (rich) and vanilla yoghurt influenced the sensory attributes thickness in mouth, spoon and swallow. The principal component 2 explained that the sensory attributes dryness in mouth, dryness in mouth after swallow were negatively correlated, and the attributes body and cohesiveness were positively correlated.

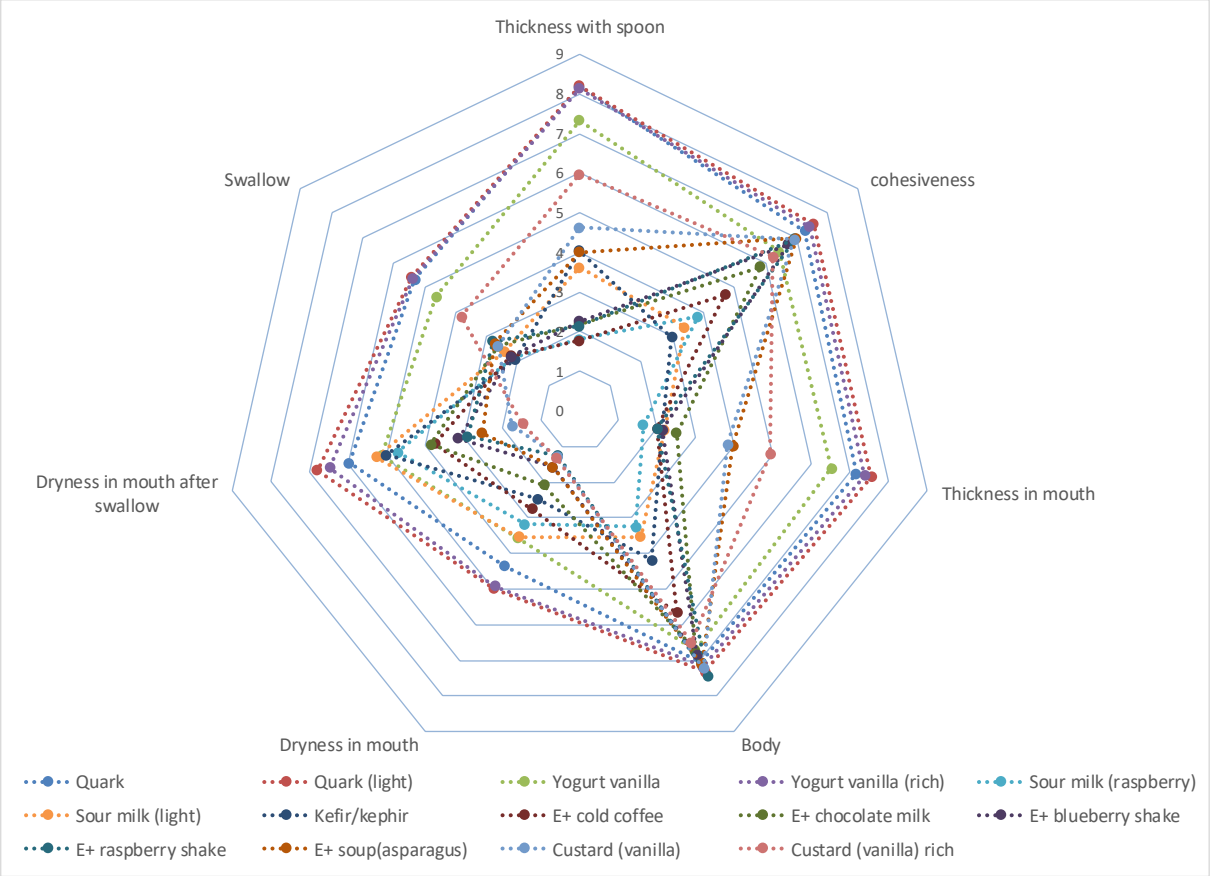



*Figure 4-15: The Radial plot showing the commercial products (n=14) with variation in all the attributes (n=7). The radar value axis of 9 was taken. The average of sensory panel scores were plotted.*

In Figure 4-15, vanilla yogurts and quark products were rated with high score for the attribute thickness with spoon. The viscous nature of the yogurt products is mainly due to the interaction between lactoglobulin and casein micelles during protein denaturation (Ozcan, 2013). All the E+ drinks were low in dryness and high in swallow (scale 1 equal to easily swallow and 9 equals too difficult to swallow). This shows that Energy plus (E+) products were smooth and can be easily swallow compared to others. The scores for kefir and sour milk drinks were comparatively low for all the attributes. The reason could be as these are sour milk (fermented) products and they differ in texture and mouth feel from other milk based products.

### 4.5.2 Instrumental texture analysis

The texture properties firmness, consistency, cohesiveness and index of viscosity were measured using TA.*X*T plus (stable microsystem) texture analyser. The 16±1°C temperature during texture measurement was maintained to correlate the sensory score of textural attributes to the instrument measured descriptors. The values of cohesiveness and index of viscosity were negative (due to with drawl of probe), but the positive values were taken in the statistical analysis and graphical representations. The products were classified into four different groups based on the readings. The low textual property products were grouped as 1 followed by the next highest etc.

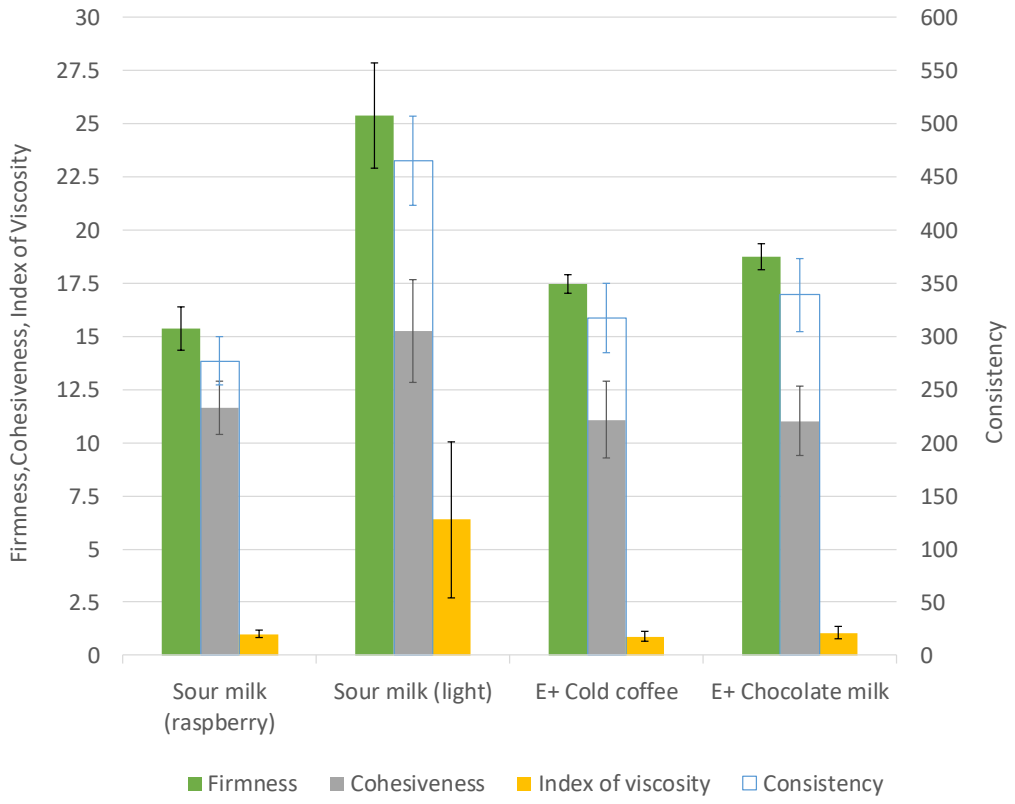



*Figure 4-16: Graphical representation showing firmness, consistency and index of viscosity results on vertical primary axes and cohesiveness results on secondary vertical axes. Error bars represent the standard deviation.*

The liquid products sour milk (raspberry), sour milk (light), E+ cold coffee and E+ chocolate milk were categorized under group one. The index of viscosity was very low (≤1) for coffee, cholate milk and sour milk (raspberry) (Figure 4-16) whereas the sour milk (light) had high value. This variation might be due to dripping of liquid from the probe when travelling backwards to its original position (Rognså & Københavns, 2014).

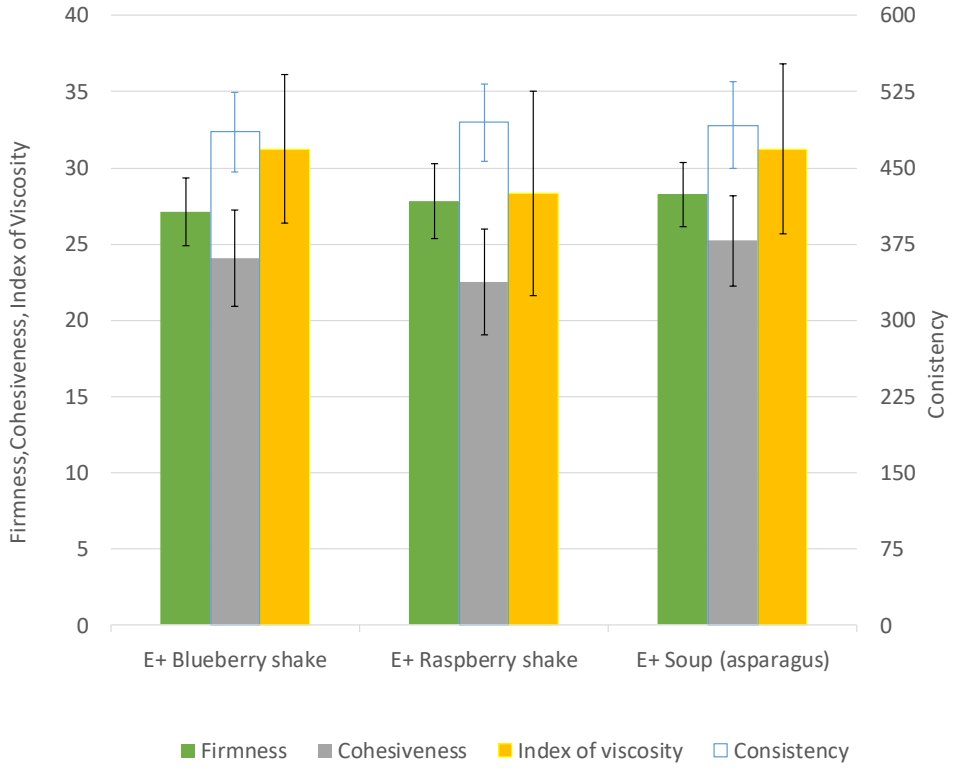



*Figure 4-17: Graphical representation showing firmness, consistency and index of viscosity results on vertical primary axes and cohesiveness results on secondary vertical axes. Standard deviation is represented in error bars.*

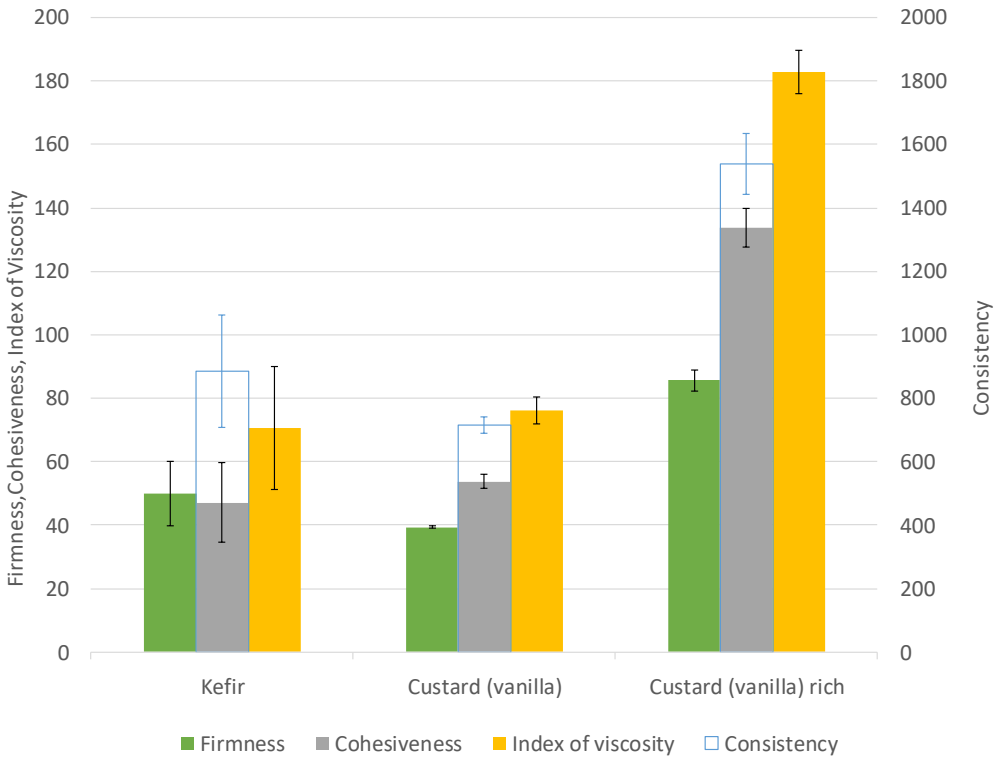



*Figure 4-18: Graphical representation showing firmness, consistency and index of viscosity results on vertical primary axes and cohesiveness results on secondary vertical axes. Standard deviation is represented in error bars.*

The energy plus (E+) drinks, blueberry, raspberry and E+ soup were categorized into group 2. These drinks were mainly for elderly, all the three products had similar values (Figure 4-17). Very minute difference between the readings was observed. All the three products were smooth and similar in texture, and the same had been observed from sensory scores (Figure 4-15).

The third group of products were kefir, vanilla custard and vanilla custard (rich). The product vanilla custard (rich) had higher values of textural properties almost double the measurements of vanilla custard original (Figure 4-18). This is mainly due to the emulsifier (mono and diglycerides of fatty acid monoesters) present in it.

Kefir on the other hand had less cohesiveness of all the three products. Kefir and vanilla custard are two different dairy products and kefir is more of natural product without any added elements. The vanilla custard products consist of emulsifiers and other thickening agents which give cohesiveness and viscous texture to product.

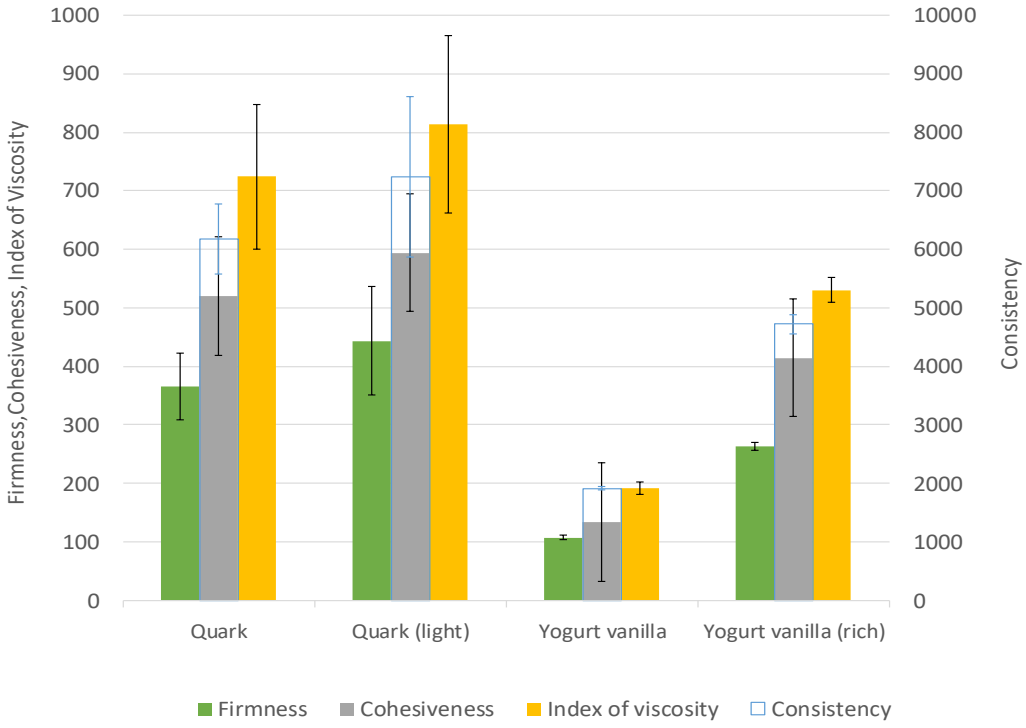



*Figure 4-19: Graphical representation showing firmness, consistency and index of viscosity results on vertical primary axes and cohesiveness results on secondary vertical axes. Standard deviation is represented in error bars.*

The products quark, quark (light), vanilla yogurt and vanilla yogurt (rich) were classified into group 4 (Figure 4-19). The firmness, consistency, cohesiveness and index of viscosity of quark (light) was high compared to other three products (Figure 4-15). The high protein

(12 g) and less amount of fat content (1g) of quark (light) makes it firmer. The textural properties of yogurt vanilla rich were high compared yogurt vanilla, this might be due to "high total solid content and interaction between fat globules and gel network" (Izadi, Nasirpour, Garoosi, & Tamjidi, 2015).

### 4.5.3 Viscosity measurement using viscometer

Brookfield viscometer DV2T extra was used to measure viscosity of samples. The samples were stirred with spoon in one direction to achieve homogeneity. Some products were firm and stirring could help to break the gel structure (Mortazavian, Rezaei, & Sohrabvandi, 2009). The quark (light) had the highest viscosity (3198 cP) and E+ drink coffee showed the lowest viscosity range (30cP) (Table 4-9). The same pattern was observed in TA.XT plus texture measurements. Quarks and yogurts are viscous in nature, because of the interaction of hydrophobic molecules of casein micelles which help to give smooth solid texture (Izadi et al., 2015).

Cichero et al. (2013) collected viscosity measurements internationally to classify the thickened fluids and texture modified foods (J. A. Cichero et al., 2013). The USA NDD (national dysphagia diet) has given viscosity ranges for classifying thickened liquids. The intension was to categorise the commercial products (n=14) to an international standard using viscometer readings. The readings showed that E+ cold coffee, chocolate milk, sour milk were nectar thick (51-350 cP) and E + raspberry, soup, kefir and custard were honey thick (351-1750 cP) and the remaining samples were spoon thick (>1750 cP). The sensory results PCA bi-plot also explained the same, the thick products were to the right and thin to the left.

*Table 4-9: The list of products (from low to high viscosity) with the mean and standard deviation results. The Brookfield viscometer was used for measuring viscosity.*

| product number | Product name | Viscosity (cP) |
|---|---|---|
| 1 | E+ cold coffee | 30.00 ± 4.89 |
| 2 | E+ chocolate milk | 102.8 ± 5.90 |
| 3 | Sour milk (light) | 112.00 ± 15.74 |
| 4 | Sour milk (raspberry) | 204 ± 4.89 |
| 5 | E+ blueberry shake | 286 ± 22.62 |
| 6 | E+ raspberry shake | 478 ± 24.65 |
| 7 | E+ soup(asparagus) | 634 ± 10.19 |
| 8 | Kefir | 968.66± 23.66 |
| 9 | Custard (vanilla) | 1054 ± 51.92 |
| 10 | Custard (vanilla) rich | 2150± 26.98 |
| 11 | Yogurt vanilla (rich) | 2210 ± 146.99 |
| 12 | Yogurt vanilla | 2088 ± 378.93 |
| 13 | Quark | 2433 ± 304.79 |
| 14 | Quark (light) | 3198 ± 254.98 |

### 4.5.4 Correlation between sensory and instrument analysis

PLS regression was performed to correlate instrument measured texture values (viscosity, firmness, consistency, cohesiveness and index of Viscosity) to the sensory attributes. In this PLS regression, the measured instrument values were taken as X- variable and sensory properties were taken as Y- variable. Full cross validation method was used to validate the model and find the appropriate number of factors needed for the model.

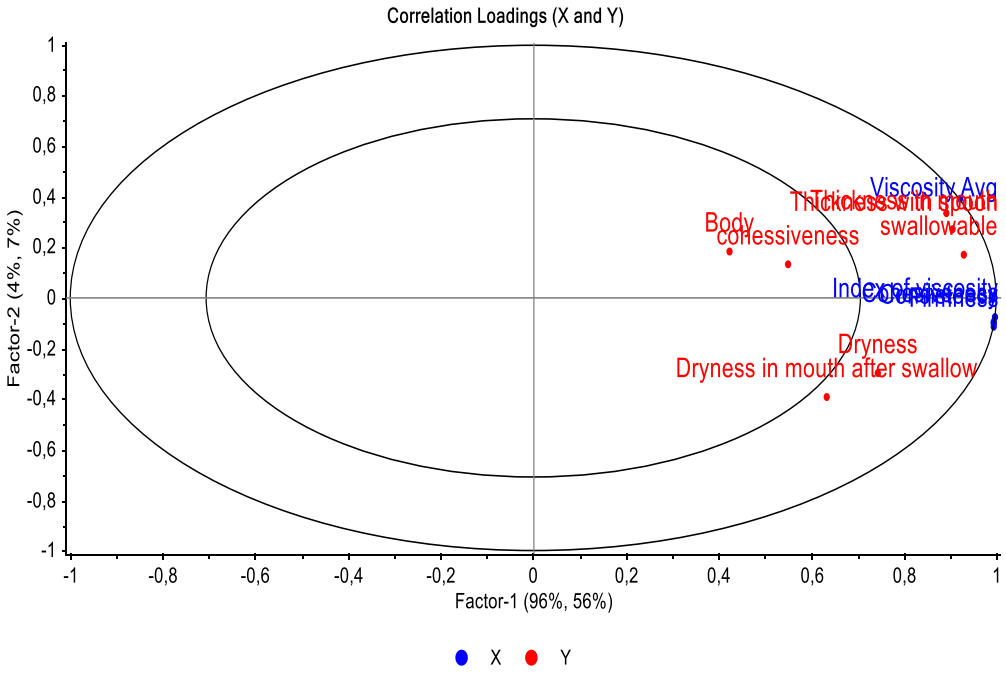
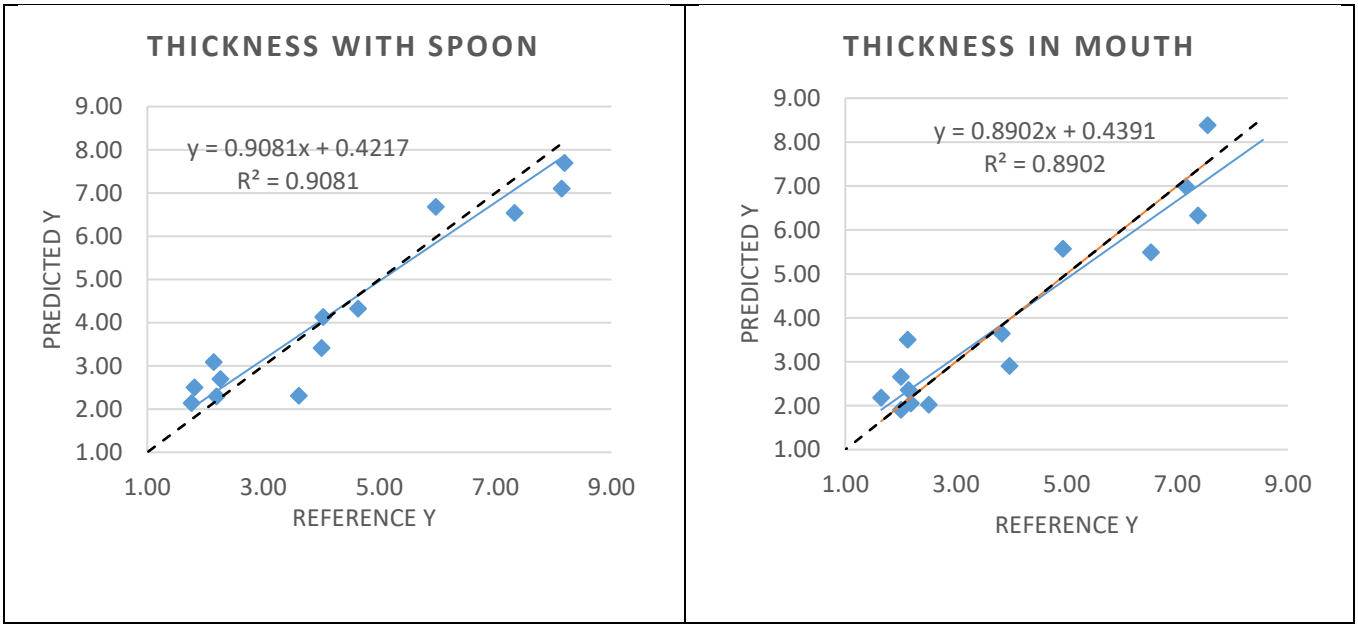



*Figure 4-20: PLS regression correlation loadings (X and Y) plot of sensory scores, textural and viscosity measurements for all 14 commercial product samples.*

The PLSR correlation loadings plot (Figure 4-20) shows that sensory attributes thickness with spoon, thickness in mouth and swallow were positively correlated with the instrument measured values. Two factors were enough to explain the most of the variance in X and Y variables. The predicted and reference Y values showed good correlation with the two factor calibration model. The fitted PLS model predicts sensory scores with high correlation coefficient (0.94-0.95) for the three sensory attributes thickness with spoon, thickness in mouth and swallow.



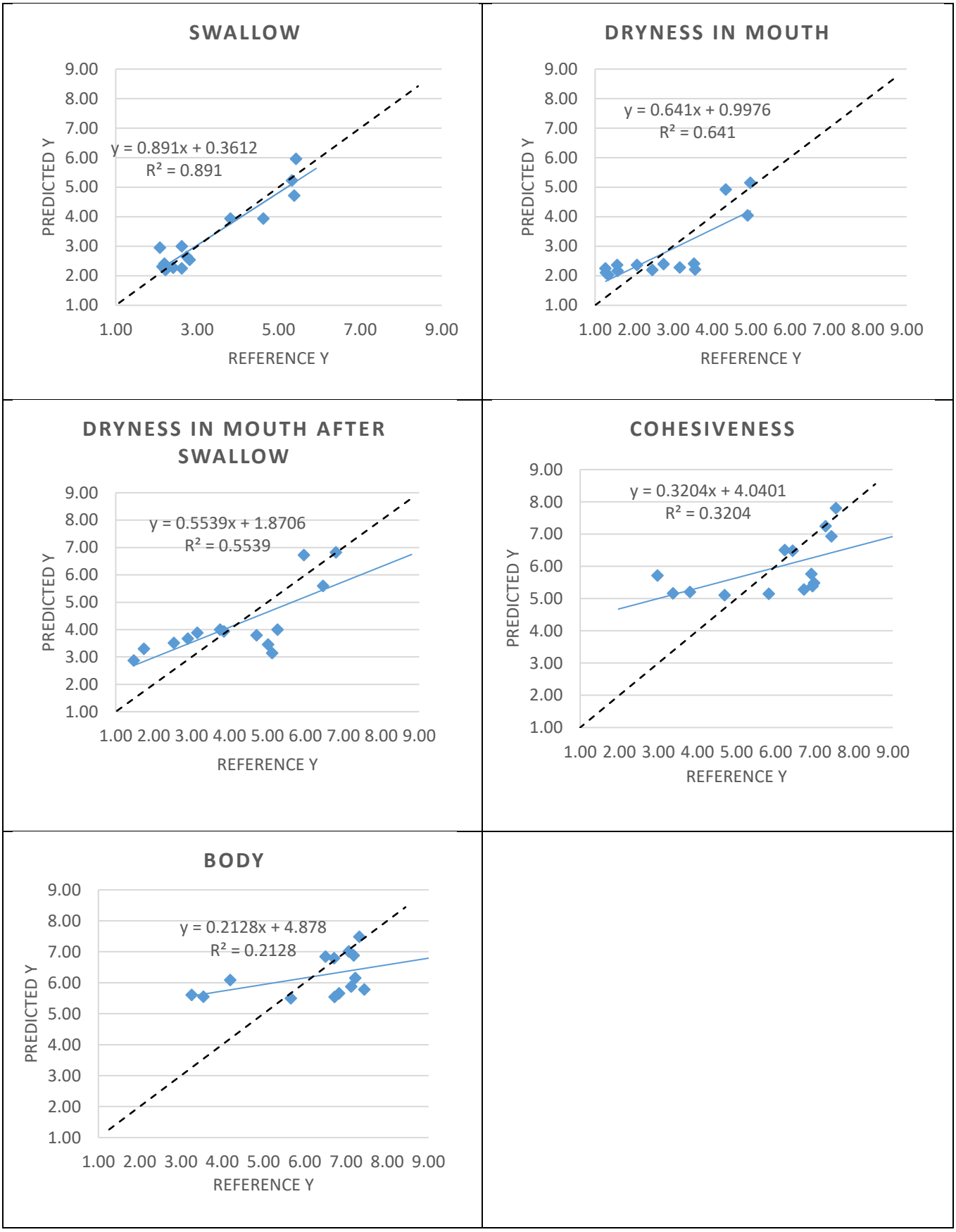



*Figure 4-21: Predicted vs. Reference for sensory attributes from PLS regression model (factor-2). The dotted line with $R^2$ =100% and β coefficient to 1 was drawn to compare the results.*

Figure 4-21 shows predicted vs. reference plot for sensory attributes from the calibration model of PLS regression with two factors. The regression coefficients ($R^2$) 0.90, 0.89, 0.89 indicate that the sensory attributes thickness with spoon, thickness in mouth and swallow can be reasonably well predicted from the instrument measured values. The sensory attributes were carefully selected to match the instrument measured textural attributes but only three attributes were well correlated out of seven.

## 4.6 IDDSI flow test

Using IDDSI flow test, the products were classified based on the liquid remained in the syringe after completion of the test. Based on the results, (Figure 4-22) the samples were placed in IDDSI frame work (Figure 2-8). The E plus drinks coffee and chocolate milks and sour milk drinks were categorised into level 1 (slightly thick). E plus soup, blueberry and raspberry were in level two (mildly thick). Kefir, vanilla custard and vanilla custard (rich) were in level three (moderately thick). Quark, quark (light), vanilla yogurt and vanilla yogurt (rich) were in level four (extremely thick). The results from sensory and instrument analysis also showed similar grouping of products for viscosity with quark and yogurts being the thickest and E plus coffee and chocolate drinks were thinnest. The flow test is simple and useful in hospital kitchens and elderly homes, and even people at home can perform this test for elderly care.

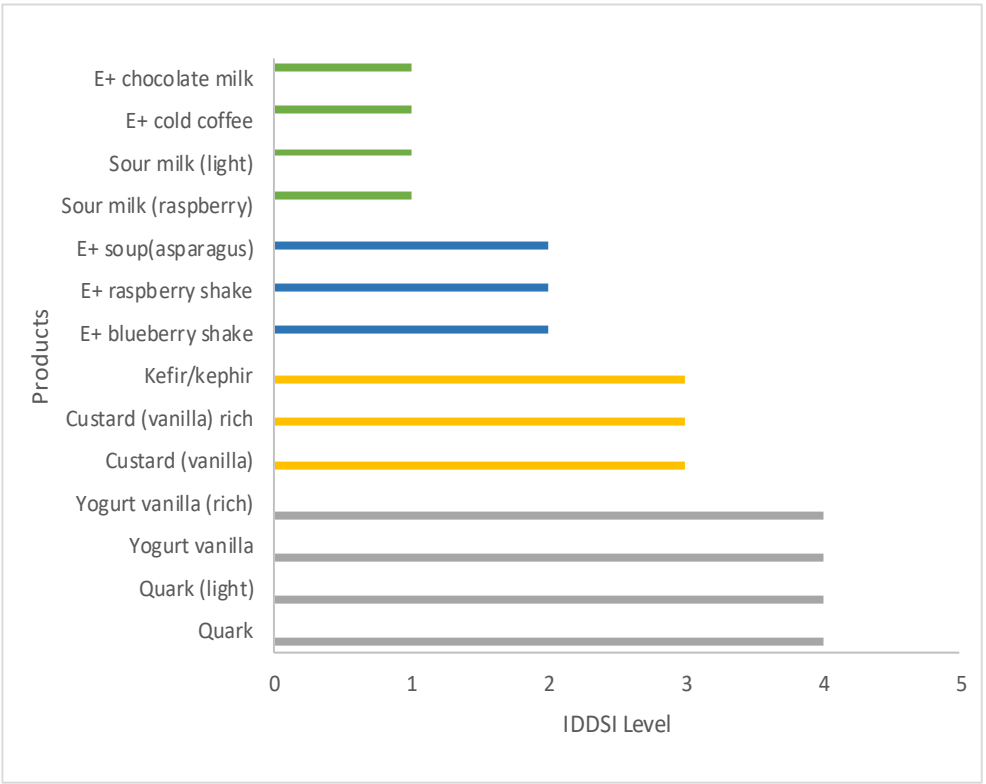



*Figure 4-22: The plot showing the results of IDDSI syringe test. The level of sample on x axis and list of products on y axis.*

The classification of the products in IDDSI framework helps the physicians, therapists and nurses managing the dysphagia patients to choose the right product for individual patient needs.

# 5. CONCLUSION AND FUTURE WORK

The results from this project provide insights on the sensory and textural properties of the protein enriched barley porridge. Such results are valuable for further product development where insight on the preferences and needs for the elderly are taken into consideration. Instrumental measurements have been compared with the sensory analysis in order to improve the design of the product (Kealy, 2006). Food texture is one of the important properties which consumers perceive for accepting the food product. The structure of the particles in food influences the texture. The change in composition of the food therefore modifies the texture of food.

The design factors selected in developing the porridge were protein source (SMP and WPC80), protein concentration (4%, 7% & 10%) and protein addition time (before and after). The following conclusions were found:

- The porridge samples differed significantly for the protein source SMP and WPC80. The porridge samples with SMP had significant higher scores for the attributes total taste, sweet compared with WPC80.
- The sensory scores, texture and colour of the SMP porridge samples was significantly affected by the design factor protein concentration, i.e. higher protein concentration gave higher scores for firm and total taste in the porridge.
- The protein addition time significantly influenced the appearance, consistency, mouthfeel attributes of the WPC80 porridge samples.
- Colour change towards yellow tone was observed with increase in protein concentration (SMP and WPC80 samples) and colour change towards red tone was observed for the design factor protein addition time (WPC80 samples).
- The textural measurements showed that protein addition time was the only factor which was significant in the WPC80 porridge.
- There was significant correlation between sensory and instrumental texture measurements. This can be useful for food producers. In quality / production control instrumental methods are useful, as sensory methods are very dependent on the assessors' availability and training.

The analysis of commercial products showed that all the products were in different viscosity range from thin to thick. The E+ drinks were the thinnest (less viscous) and quark, the thickest products of all samples. All the products were possible to classify in the levels 1-4 in accordance with International Dysphagia Diet Standardisation Initiative (IDDSI).

## 5.1 Future work

Hedonics was not evaluated in this work. Further experiments with insight in elderly consumer preferences would be valuable in order to bring a novel protein enriched product to the market. Then product optimisation by adjusting process factors and combination of SMP and WPC80 in a new experimental factorial design may be carried out for improved texture of the product.

The Kenwood mixer had stable induction heating and continuous stirring. Due to heat loss in the mixing bowl, it was difficult to obtain stable cooking temperatures. Industrial production of dairy products include continuous cooking and pasteurisation processes. Up scaled simulations of how the chosen experimental factors from the simple batch experiments will function in an industrial scale should be carried out.

The Brookfield viscometer with low viscosity spindle is empirical and for quality analysis. A fundamental viscometer should be used for scientific purposes, which can measure stress rates with controlled temperatures, since the temperature plays a crucial role in viscosity measurements.

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# 7. APPENDIX

## BESKRIVENDE TEST Grøt

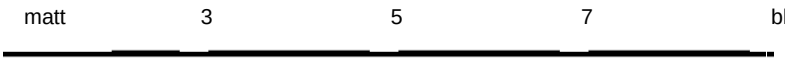
### Utseende:

**Fargetone**

grå 3 5 7 gul

**Blankhet**

matt 3 5 7 blank



### Konsistens (med skje):

**Fasthet**

løs 3 5 7 fast



**Seighet**

ikke 3 5 7 mye



### I munn:

**Klebrig**

ikke 3 5 7 mye



**Kornstørrelse**

fin/jevn 3 5 7 grovkornet



**Melen**

ikke 3 5 7 mye

**Tyggemotstand**

lav 3 5 7 høy

**Løselig**

lite 3 5 7 mye

**Tørr**

ikke 3 5 7 mye

## Lukt:

**Bygglukt**

lav 3 5 7 høy

## Smak:

**Total smaksstyrke**

lav 3 5 7 høy

**Salt**

lite 3 5 7 mye

**Søt**

lite 3 5 7 mye

**Bitter**

ikke 3 5 7 mye

## Aromaer:

**Kokt**

ikke 3 5 7 mye

**Bygg**

lite 3 5 7 mye

**Melk**

ikke 3 5 7 mye

**Myse**

ikke 3 5 7 mye

**BESKRIVENDE TEST FLYTENDE PRODUKTER**

## Konsistens (med skje*):*

1: **Tykkelse**

| | | | | |
|---|---|---|---|---|
| tynn | 3 | 5 | 7 | tykk |

2: **Sammenhengende**

| | | | | |
|---|---|---|---|---|
| ikke | 3 | 5 | 7 | mye |

## I munn:

3: **Tykkelse**

| | | | | |
|---|---|---|---|---|
| tynn | 3 | 5 | 7 | tykk |

4: **Fyldighet**

| | | | | |
|---|---|---|---|---|
| lav | 3 | 5 | 7 | høy |

5: **Tørrhet**

| | | | | |
|---|---|---|---|---|
| ikke | 3 | 5 | 7 | mye |

6: **Tørrhet i munnen etter svelging**

| | | | | |
|---|---|---|---|---|
| ikke | 3 | 5 | 7 | mye |

7: **Svelgbarhet**

| | | | | |
|---|---|---|---|---|
| lett | 3 | 5 | 7 | vanskelig |

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## End Questions

Takk for hjelpa!

**Factorial design table of porridge sample preparation. Total 24 samples were prepared**

| Run Order | Sample no | Protein source | Protein concentration | Prot. Add. time | Milk (g) | Salt (g) | Barley (g) |
|---|---|---|---|---|---|---|---|
| 1 | 23 | WPC80 | 10% | Before | 1250 | 4 | 150 |
| 2 | 15 | WPC80 | 4% | Before | 1250 | 4 | 150 |
| 3 | 19 | WPC80 | 7% | Before | 1250 | 4 | 150 |
| 4 | 4 | WPC80 | 4% | After | 1250 | 4 | 150 |
| 5 | 18 | SMP | 7% | After | 1250 | 4 | 150 |
| 6 | 16 | WPC80 | 4% | After | 1250 | 4 | 150 |
| 7 | 3 | WPC80 | 4% | Before | 1250 | 4 | 150 |
| 8 | 17 | SMP | 7% | Before | 1250 | 4 | 150 |
| 9 | 5 | SMP | 7% | Before | 1250 | 4 | 150 |
| 10 | 22 | SMP | 10% | After | 1250 | 4 | 150 |
| 11 | 20 | WPC80 | 7% | After | 1250 | 4 | 150 |
| 12 | 12 | WPC80 | 10% | After | 1250 | 4 | 150 |
| 13 | 1 | SMP | 4% | Before | 1250 | 4 | 150 |
| 14 | 7 | WPC80 | 7% | Before | 1250 | 4 | 150 |
| 15 | 2 | SMP | 4% | After | 1250 | 4 | 150 |
| 16 | 6 | SMP | 7% | After | 1250 | 4 | 150 |
| 17 | 13 | SMP | 4% | Before | 1250 | 4 | 150 |
| 18 | 14 | SMP | 4% | After | 1250 | 4 | 150 |
| 19 | 11 | WPC80 | 10% | Before | 1250 | 4 | 150 |
| 20 | 9 | SMP | 10% | Before | 1250 | 4 | 150 |
| 21 | 8 | WPC80 | 7% | After | 1250 | 4 | 150 |
| 22 | 21 | SMP | 10% | Before | 1250 | 4 | 150 |
| 23 | 10 | SMP | 10% | After | 1250 | 4 | 150 |
| 24 | 24 | WPC80 | 10% | After | 1250 | 4 | 150 |

**Colour coordinate Measurement of 24 samples, showing average, standard deviation values.**

| Sample | Name | L* | a* | b* | C* | h° |
|---|---|---|---|---|---|---|
| 1 | SB4% | 85.35 ± 0.97 | 1.62 ± 0.43 | 15.16 ± 0.33 | 15.24 ± 0.29 | 83.89 ± 1.73 |
| 2 | SA4% | 80.48 ± 0.24 | 2.47 ± 0.12 | 13.91 ± 0.26 | 14.13 ± 0.25 | 79.92 ± 0.53 |
| 3 | WB4% | 82.36 ± 0.42 | 1.81 ± 0.08 | 14.86 ± 0.27 | 14.97 ± 0.28 | 83.05 ± 0.32 |
| 4 | WA4% | 87.24 ± 0.47 | 1.95 ± 0.06 | 15.27 ± 0.24 | 15.39 ± 0.23 | 82.72 ± 0.29 |
| 5 | SB7% | 83.54 ± 0.30 | 1.41 ± 0.33 | 15.65 ± 0.27 | 15.71 ± 0.25 | 84.84 ± 1.30 |
| 6 | SA7% | 84.58 ± 0.31 | 1.80 ± 0.18 | 16.95 ± 0.19 | 17.04 ± 0.17 | 83.93 ± 0.66 |
| 7 | WB7% | 82.52 ± 0.51 | 2.07 ± 0.21 | 15.30 ± 0.27 | 15.44 ± 0.28 | 82.28 ± 0.71 |
| 8 | WA7% | 84.42 ± 0.34 | 1.83 ± 0.39 | 16.43 ± 0.58 | 16.53 ± 0.56 | 83.63 ± 1.48 |
| 9 | SB10% | 83.51 ± 0.45 | 1.79 ± 0.41 | 20.87 ± 0.02 | 20.95 ± 0.05 | 85.09 ± 1.13 |
| 10 | SA10% | 83.25 ± 1.10 | 2.16 ± 0.14 | 18.80 ± 0.51 | 18.92 ± 0.51 | 83.42 ± 0.40 |
| 11 | WB10% | 88.62 ± 0.76 | 2.89 ± 0.49 | 17.81 ± 0.48 | 18.05 ± 0.40 | 80.76 ± 1.81 |
| 12 | WA10% | 83.05 ± 0.77 | 3.48 ± 0.26 | 19.97 ± 0.43 | 20.27 ± 0.43 | 80.11 ± 0.75 |
| 13 | SB4% | 85.77 ± 0.55 | 1.55 ± 0.35 | 15.49 ± 0.25 | 15.57 ± 0.22 | 84.28 ± 1.36 |
| 14 | SA4% | 80.42 ± 0.88 | 2.69 ± 0.12 | 15.20 ± 0.26 | 15.44 ± 0.24 | 79.96 ± 0.62 |
| 15 | WB4% | 82.36 ± 0.42 | 1.81 ± 0.08 | 14.86 ± 0.27 | 14.97 ± 0.28 | 83.05 ± 0.32 |
| 16 | WA4% | 83.02 ± 0.29 | 2.35 ± 0.15 | 14.39 ± 0.16 | 14.58 ± 0.15 | 80.71 ± 0.63 |
| 17 | SB7% | 84.30 ± 0.80 | 1.67 ± 0.18 | 15.00 ± 0.08 | 15.09 ± 0.1 | 83.63 ± 0.63 |
| 18 | SA7% | 82.76 ± 0.66 | 2.31 ± 0.06 | 17.66 ± 0.32 | 17.81 ± 0.31 | 82.52 ± 0.32 |
| 19 | WB7% | 81.64 ± 0.4 | 1.92 ± 0.21 | 15.69 ± 0.21 | 15.81 ± 0.18 | 83.01 ± 0.88 |
| 20 | WA7% | 82.87 ± 0.18 | 2.54 ± 0.08 | 16.75 ± 0.37 | 16.94 ± 0.38 | 81.38 ± 0.08 |
| 21 | SB10% | 84.26 ± 0.61 | 1.55 ± 0.50 | 20.65 ± 0.16 | 20.71 ± 0.18 | 85.70 ± 1.37 |
| 22 | SA10% | 86.46 ± 0.42 | 1.58 ± 0.11 | 19.35 ± 0.07 | 19.41 ± 0.07 | 85.30 ± 0.33 |
| 23 | WB10% | 86.60 ± 0.52 | 1.09 ± 0.36 | 18.19 ± 0.26 | 18.23 ± 0.26 | 86.57 ± 1.14 |
| 24 | WA10% | 84.41 ± 0.62 | 2.59 ± 0.28 | 19.72 ± 0.32 | 19.89 ± 0.31 | 82.49 ± 0.84 |

**Texture Measurement of 24 samples at 20°C, showing average, standard deviation values**

| | | Temperature 20°C | | | |
|---|---|---|---|---|---|
| Sample | Name | Firmness | Consistency | Cohesiveness | Index of Viscosity |
| | | (g) | (g.s) | (g) | (g.s) |
| 1 | SB4% | 49.27 ± 9.18 | 630.71 ± 19.8 | 27.31 ± 3 | 66.62 ± 1.67 |
| 2 | SA4% | 54.24 ± 1.08 | 664.07 ± 14.45 | 41.49 ± 3.56 | 71.59 ± 4.05 |
| 3 | WB4% | 52.02 ± 1.82 | 610.2 ± 46.94 | 33.82 ± 2.74 | 57.02 ± 6.89 |
| 4 | WA4% | 55.27 ± 3.78 | 666.1 ± 33.04 | 33.57 ± 4.77 | 54.9 ± 13.97 |
| 5 | SB7% | 31.37 ± 0.59 | 440.83 ± 5.57 | 12.06 ± 0.29 | 24.65 ± 3.17 |
| 6 | SA7% | 45.39 ± 2.81 | 506.15 ± 27.38 | 32.8 ± 4.17 | 56.73 ± 10.47 |
| 7 | WB7% | 89.95 ± 18.06 | 1333.21 ± 312.34 | 66.46 ± 16.34 | 120.94 ± 29.28 |
| 8 | WA7% | 51.16 ± 9.43 | 478.19 ± 74.02 | 23.3 ± 5.16 | 15.72 ± 2.86 |
| 9 | SB10% | 130.64 ± 7.48 | 1418.33 ± 196.33 | 107.03 ± 8.92 | 142.34 ± 24.88 |
| 10 | SA10% | 85.9 ± 5.64 | 1040.96 ± 56.45 | 78.99 ± 6.28 | 137.56 ± 12.37 |
| 11 | WB10% | 90.63 ± 8.41 | 1083.01 ± 101.94 | 56.2 ± 6.58 | 89.1 ± 12.79 |
| 12 | WA10% | 53.19 ± 3.79 | 605.04 ± 78.01 | 31.75 ± 1.51 | 56.29 ± 3.13 |
| 13 | SB4% | 51.4 ± 0.36 | 721.12 ± 3.58 | 34.26 ± 0.19 | 63.31 ± 0.59 |
| 14 | SA4% | 51.58 ± 1.56 | 790.91 ± 36 | 39.36 ± 1.71 | 66.18 ± 2.62 |
| 15 | WB4% | 54.12 ± 1.81 | 716.5 ± 77.16 | 28.89 ± 0.19 | 48.44 ± 0.22 |
| 16 | WA4% | 56.28 ± 10.44 | 715.14 ± 89.15 | 28.66 ± 6.83 | 44.93 ± 10.34 |
| 17 | SB7% | 35.48 ± 3.14 | 412.74 ± 50.54 | 19.79 ± 1.14 | 17.15 ± 2.56 |
| 18 | SA7% | 55.47 ± 4.91 | 708.58 ± 111.22 | 53.3 ± 5.22 | 51.73 ± 10.17 |
| 19 | WB7% | 84.1 ± 2.88 | 1311.82 ± 58.17 | 62.04 ± 1.86 | 121.9 ± 4.05 |
| 20 | WA7% | 42.79 ± 7.04 | 412.76 ± 31.75 | 21.25 ± 1.34 | 14.41 ± 1.18 |
| 21 | SB10% | 125.75 ± 7.27 | 1512.67 ± 119.24 | 105.88 ± 7.56 | 159 ± 17.31 |
| 22 | SA10% | 93.28 ± 3.36 | 1396.97 ± 38.76 | 95.61 ± 1.24 | 199.2 ± 2.51 |
| 23 | WB10% | 106 ± 18.73 | 1080.45 ± 262.57 | 55.07 ± 6.73 | 64.4 ± 16.72 |
| 24 | WA10% | 46.84 ± 3.62 | 558.8 ± 44.83 | 26.94 ± 3.55 | 41.25 ± 12.22 |

**Texture Measurement of 24 samples at 60°C, showing average, standard deviation values**

| | | Temperature 60°C | | | |
|---|---|---|---|---|---|
| Sample | Name | Firmness | Consistency | Cohesiveness | Index of Viscosity |
| | | (g) | (g.s) | (g) | (g.s) |
| 1 | SB4% | 29.57 ± 2.02 | 279.26 ± 10.38 | 15.31 ± 2.65 | 5.44 ± 0.31 |
| 2 | SA4% | 28.01 ± 2.75 | 300.43 ± 26.14 | 18.35 ± 2.58 | 15.28 ± 2.33 |
| 3 | WB4% | 25.95 ± 0.84 | 287.24 ± 15.98 | 17.17 ± 0.65 | 17.02 ± 3.11 |
| 4 | WA4% | 30.43 ± 0.95 | 370.06 ± 11.78 | 15.49 ± 2.42 | 18.55 ± 0.96 |
| 5 | SB7% | 10.57 ± 0.26 | 113.38 ± 0.98 | 4.45 ± 0.14 | 3.16 ± 0.36 |
| 6 | SA7% | 14.23 ± 0.21 | 142.75 ± 24.85 | 8.45 ± 1.38 | 7.81 ± 1.55 |
| 7 | WB7% | 53.29 ± 9.2 | 614.28 ± 82.31 | 31.01 ± 7.88 | 46.33 ± 11.62 |
| 8 | WA7% | 25.53 ± 2.53 | 231.39 ± 18.28 | 8.27 ± 0.77 | 5.99 ± 0.93 |
| 9 | SB10% | 31.39 ± 5.12 | 309.99 ± 78.25 | 27.44 ± 4.19 | 39.75 ± 12.57 |
| 10 | SA10% | 13.52 ± 0.66 | 145.88 ± 7.98 | 7.26 ± 0.24 | 8.84 ± 0.73 |
| 11 | WB10% | 34.14 ± 2.82 | 377.11 ± 19.14 | 18.57 ± 3.32 | 20.62 ± 4.68 |
| 12 | WA10% | 18.22 ± 0.5 | 191.99 ± 3.41 | 8.86 ± 0.2 | 12.85 ± 0.85 |
| 13 | SB4% | 31.25 ± 2.74 | 261.6 ± 39.56 | 19.25 ± 2.89 | 5.05 ± 1.82 |
| 14 | SA4% | 27.05 ± 3.15 | 294.14 ± 35.62 | 22.17 ± 3.45 | 18.09 ± 3.56 |
| 15 | WB4% | 24.71 ± 0.63 | 282.2 ± 9.72 | 15.04 ± 0.87 | 15.08 ± 2.02 |
| 16 | WA4% | 28.73 ± 2.91 | 352.34 ± 30.37 | 18.25 ± 2.91 | 17.4 ± 2.42 |
| 17 | SB7% | 12.89 ± 0.33 | 139.46 ± 3.95 | 6.67 ± 0.53 | 7.28 ± 1.51 |
| 18 | SA7% | 26.69 ± 2.13 | 282.51 ± 31.27 | 21.18 ± 2.82 | 23.23 ± 6.63 |
| 19 | WB7% | 48 ± 6.58 | 597.85 ± 89.63 | 27.39 ± 8.15 | 29.36 ± 10.1 |
| 20 | WA7% | 27.9 ± 1.7 | 278.35 ± 5.84 | 7.35 ± 1.22 | 10.4 ± 1.62 |
| 21 | SB10% | 28.13 ± 0.81 | 295.54 ± 1.49 | 24.07 ± 1.85 | 34.79 ± 5.1 |
| 22 | SA10% | 25.88 ± 3.17 | 260.48 ± 30.48 | 19.67 ± 2.14 | 14.82 ± 3.37 |
| 23 | WB10% | 68.73 ± 9.22 | 752.55 ± 108.3 | 38.28 ± 3.23 | 51.85 ± 8.04 |
| 24 | WA10% | 17.94 ± 1.2 | 200.41 ± 18.11 | 9.07 ± 0.62 | 10.93 ± 1.33 |