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A method for predicting baking performance through evaluation of short crust dough

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A master thesis project for AarhusKarlshamn AB (AAK) in Malmö, Sweden at the

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Abstract

The three major components of short-crust cookie dough are flour, sugar, and fat. Since high fat contents have been shown to have a major effect on the development of the gluten network, studying how these ingredients could affect the texture of the dough and the baked product became interesting. In addition, there are no existing methods on short crust cookie dough that allow predicting the characteristics of the baked product based on those of the dough. Therefore, the task was to study whether developing such a method is possible or not. In this paper, the amount of ingredients was varied and textural analyses were run on dough and baked samples. The results were analyzed using chemometrics and statistical tools and different graphs were plotted to visualize the relations between the variables and parameters. The analyses showed that the fat and egg amounts have a significant effect on the texture of the dough in terms of hardness and gumminess. In addition, the hardness of the baked product was shown to be positively correlated with dough hardness and gumminess, which in turn can be controlled by the addition of fat and/or eggs according to requirements on the final product. Thus, prediction of baking performance based on dough characteristics was shown to be possible.

Acknowledgments

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Abbreviations

Timeuntilmeasurement	Time between preparation and the first measurement.
RHinRoom	Mean value of relative humidity in the rheology room where the textural measurements were done. RH was measured before the first measurement and after the last measurement
TempinRoom	Mean value of temperature in the rheology room before the first measurement and after the last measurement.
TempWB	Temperature of the water bath during preparing the dough.
RHinLab	The relative humidity in the lab where the dough was mixed and sheeted.
TempinLab	The temperature in the lab
DoughTemp	Mean temperature of the dough before and after sheeting
SamplingTime	Time for sheeting the dough and cutting the samples.
DB-	Prefix used for textural parameters obtained by double compression method.
HUT-	Prefix used for textural parameters obtained by hold until time method.
TPB-	Prefix used for textural parameters obtained by three point bend method.
PCA	Principle Component Analysis
PLS2	Partial Least Square
CCD	Central Composite Design

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1 Introduction

1.1 Background

This master thesis project was suggested by AarhusKarlshamn AB (AAK) in Malmö. The idea originated from the existing methods for predicting bread baking performance through dough evaluation. Since such evaluation methods do not exist when it comes to short-crust cookie dough, the aim was to find out whether it is possible to develop such a method or not. Perhaps, in case of developing a method, it would be helpful in predicting the influence of different ingredients and other baking parameters on the final baked product.

Short-crust pastries are considered one of the most popular groups of baked products (Kweon et al. 2014) (Miskiewicz, Nebesny & Rosicka-Kaczmarek 2013). Proper selection of the ingredients and their quantity determines the quality and stability of the final product even during storage, such as fragility and oxidation. Besides the sensory properties, the quality is also determined by the chemical properties of the ingredients, e.g. the fat type (Miskiewicz, Nebesny & Rosicka-Kaczmarek 2013) (Pareyt & Delcour 2008). Studying how these ingredients and their variation affect the dough before baking and relating these properties to those of the finished product, i.e. predicting the final characteristics, helps maintaining the quality of the final product.

In order to develop an evaluation method, literature studies and pre-trials were made to develop standardized methods. Contact with suppliers of analytical instruments for descriptions was also done to help accomplishing this task. Rheological methods were used to characterize the short-crust cookie dough and, by means of chemometrics and multivariate analysis, correlate these characteristics to the final product. All dough making including baking and rheology measurement was performed in Malmö at Lantmännen's hygiene lab. However, the microscopy was done at the Food Technology Department at LTH in Lund.

1.2 Objectives

The main objective of this project was to develop an evaluation method that enables prediction of the properties of the final product based on those of the dough. This objectives were divided into the following sub-objectives:

- Perform a literature study for the different parts of the project. On that basis, design the experiments with samples of varying composition and characteristics.
- Develop a standardized method by conducting some pre-trials to test preliminary proceedures as well as microscopic examinations of the different fat types.
- Perform multivariate analysis and use chemometrics to analyze the results.

1.3 Scope

The following provides a description of the features and functions included in the project.

- The literature study: includes researches of for instance the fat type, the analytical instruments and what methods should be used, statistics and chemometrics, as well as recipes and ingredients' role in the dough. This will lay ground for the development of the method.
- Development of standardized methods: different texture analysis methods, including measurements on dough and finished product, were evaluated to find out to what limits the ingredients may be varied without influencing the robustness of the method. This also included testing different sheeting and sampling methods, as well as defining a proper baking method.
- Chemometrics: a Central Composite Design was used to design a scheme of ingredient variations. The results were evaluated using Principle Component Analysis (PCA), Partial Least Square (PLS2), and other appropriate statistical tools (see section 3.5.3). Sensory evaluations were outside the scope due to the limited time provided for this project.

1.4 Constraints

The following limitations were endured during the project:

- The method development was limited to the instruments available in the lab in Malmö and in Lund. If an instrument broke it had to be fixed as soon as possible to avoid delays.
- The experimental work in the bakery had to be adapted to the availability of the instruments and oven.
- The time frame was limited to 20 weeks.
- Only scientific references were to be used in this project to ensure the reliability of the work.
- The ingredients used had to come from the same batch.

1.5 Assumptions

The following assumptions were made during this project:

- The texture of the final product was not affect by the storage time used (2-4 weeks).
- The dough samples were not deformed or affected by the manual handling.

1.6 Deliverables

In order to meet the objectives of this project the following deliverables had to be obtained:

- A method that enables prediction of the properties of the final product based on those of the dough.
- A thorough literature study about the dough and the role of the ingredients.
- A standardized method for textural analysis on dough and finished product.
- A standardized method for mixing, sheeting, sampling, and baking.
- A Central Composite Design that can be used for other types of dough for instance cookies and pound cakes.

2 Theory

The art of using dough and bread baking have developed over time and resulted in a wide range of bakeries, pastries, cakes, and many other sweet products. In daily life, at least at home, only basic knowledge is required to be able to produce bread and other bakery products. However, in order to improve baking, especially when it comes to industrial processing and applications, proper scientific understanding of the components and their interactions would be one of the priorities before starting a large scale production. Taking this to another level, it becomes of interest to be able to predict baking performances and the characteristics of the finished product based on those of the dough. This will help improving the production in terms of quantity and quality, since not only time and materials will be saved, but it also facilitates the optimizations of the product. Methods for predicting bread-baking performance through dough evaluation already exist, but when it comes to short-crust cookie dough, no such methods have been developed.

2.1 Dough: role of ingredients and processing

Wheat flour contains monomeric proteins gliadins, globulins, and albumins as well as the more complex proteins called glutenins. Upon addition of water to wheat flour, together with mechanical energy, the hydration of glutenins and glaidins generates a gluten network. This network is crucial in preserving air and carbon dioxide gas during baking. (Cauvain & Young 2012). Therefore, the type and the intensity of mixing as well as the time are important factors that influence the rheology and the microstructure of the dough. This means that the resulting dough development could be optimum, incomplete, or overdone (Anderssen, Gras & MacRitchie. 1998) (Cuq, Yildiz & Kokini. 2002).

A study conducted by Codina and Mironeasa (2013) showed by epi-fluorescence light microscopy (EFLM) that the amount of protein network increased when increasing the mixing speed and mixing time. At low speed (80 rpm) and short time (3 min), EFLM showed an early stage of protein connection and free starch granules. By increasing either the speed to 160 rpm or the time to 5 min, the protein matrix formation starts to improve gradually and starts to cover some starch granules. However, the dough still had an inhomogeneous structure with some separate areas of starch granules. By increasing both speed (160 rpm) and time (5 min), the results showed a continuous network where the proteins stretched and surrounded most of the starch granules.

Considering short-crust cookie dough, flour, sugar, and fat are the three major components (Zucco, Borsuk & Arntfield 2011). Fat could be added as butter, shortening (solid oil at room temperature), or margarine. In order to allow interactions between the fatty phase and the aqueous phase (in margarines for instance) emulsifiers are required. Different emulsifier types have been used but the most commonly used emulsifiers in baked goods are monoglycerides and diglycerides that are added at a level of 0.75-1% (Huschka et al. 2011) (Stauffer 1999). Addition of emulsifiers has shown to improve the fat distribution in the cookies, prevent moisture migration, and improve texture of baked product (Mahdi & Dawoud 1986).

Margarine is a water-in-oil emulsion with at least 80% fat. Initially, the oil is hydrogenated to obtain a consistency like that of butter, then water, emulsifiers, and perhaps flavor and colorants are added according to needs. The most widely used oils are derived from soybeans and palms (Coultate 2009) (Goli et al. 2009) (Saadi et al. 2011). The effect of fat type on the characteristics of the dough and baked products have been investigated in several studies in terms of dispersion, lubrication, softening, interactions with the starch phase, etc. (Huschka et al. 2011).

High content of fat increases the air incorporation in the dough especially when subjected to a creaming stage (mixing) (Kweon et al. 2014). In addition, fat act as a lubricant and competes with the aqueous phase and limits the gluten formation, which is desired in the case of short-crust cookies (Maache-Rezzoug 1998) (Wade 1990) (Slade 1994). However, during baking fat melts and together with sugar they increase the mobility of the dough and hence result in larger dough spread (Pareyt et al. 2009). The dough components thus influence the dough rheology, dough making and handling, and baking quality and thereby also the textural characteristics of the final product (Pedersen et al. 2004).

Moreover, the addition of fat may have other influences on the dough such as improving the heat transfer, extending the shelf life of the product, and providing structure and texture according to desires. Studies have also been made to investigate the effect of lipids on the starch phase, showing that interactions between fat and starch affected starch gelatinization and retrogradation (Eliasson & Gudmundsson 1996) (Goesaert et al. 2005).

Short-crust cookie dough contains high levels of fat and sugar, which both have a limiting effect on the development of the gluten network (Hadnadev, Torbica & Hadnadev 2013). However, a study performed by Kweon et al. (2014) has shown that hydration of gluten by a weak sugar solution gives better gluten development than hydration by water alone. Yet, gluten development is negatively affected if the sugar concentration increases, as well as other typical enzymatic reactions are inhibited (Kweon et al. 2014). This was observed when a protease enzyme was added to a dough containing 50% sucrose solution, the enzyme had no effect on gluten since it had not developed at this high sugar concentration. For dough with high sugar content, the starch gelatinization has been seen to be delayed and/or inhibited during baking. The extent to which the gelatinization temperature is elevated depends on the type of sugar used and the particle size as well as the concentration (Bean & Yamazaki 1978).

2.2 Textural analysis methods

In order to mimic the sensory properties perceived by consumers, textural analysis methods should be chosen and used in a sensitive and objective way (Bourne 1990). There are a variety of different principles used for texture measurements. Some principles are related to the type of sample to be measured for example meat, vegetables, or dough, and others are dependent on whether the sample is baked/cooked or raw (Bourne 1990).

1. *Puncture principle:* A probe is pushed into the food and the force required for that is measured. This method has the potential to be used on dough and baked products.
2. *Extrusion principle:* A force is applied to a food sample forcing it to flow through holes or slots.
3. *Gentle compression:* A small nondestructive force is applied to a sample to measure deformability. 2 ways: i) measure bread firmness by measuring the force required for standard compression, and ii) applying a standard force and measure the distance the sample deforms under these circumstances.
4. *Crushing principle:* The food sample is subjected to a high compression force until the sample breaks.
5. *Tensile principle:* Measures the required force to break or deform the food sample in tension.
6. *Bending-snapping:* The food sample is bend and snapped, and the force required for that is measured. The food usually has the shape of a bar, cylinder, or sheet.
7. *Torque principle:* The torsional force required to rotate or twist a part of the sample around an axis is measured.
8. *Distance principle:* the distance in terms of length, area, or volume, is measured for example before and after baking.
9. *Time principle:* measuring time for example to cut through a sample with a small saw.

Considering dough samples, some of the methods mentioned above could be used to measure a range of textural parameters. These involve extrusion principle, puncture principle, gentle compression, tensile principle, and torque principle. Methods appropriate for baked products include puncture principle, crushing principle, tensile principle, bending-snapping, distance principle, and time principle (Bourne 1990). The compression methods imitate the action of the jaw (biting and/or chewing). The recording of the measurement data starts when the pre-set trigger force was reached. Thereafter, the probe compresses the sample to a pre-set specific distance and then returns to its starting position. After a pre-set holding time, the probe continues and subjects the sample to another compression cycle.

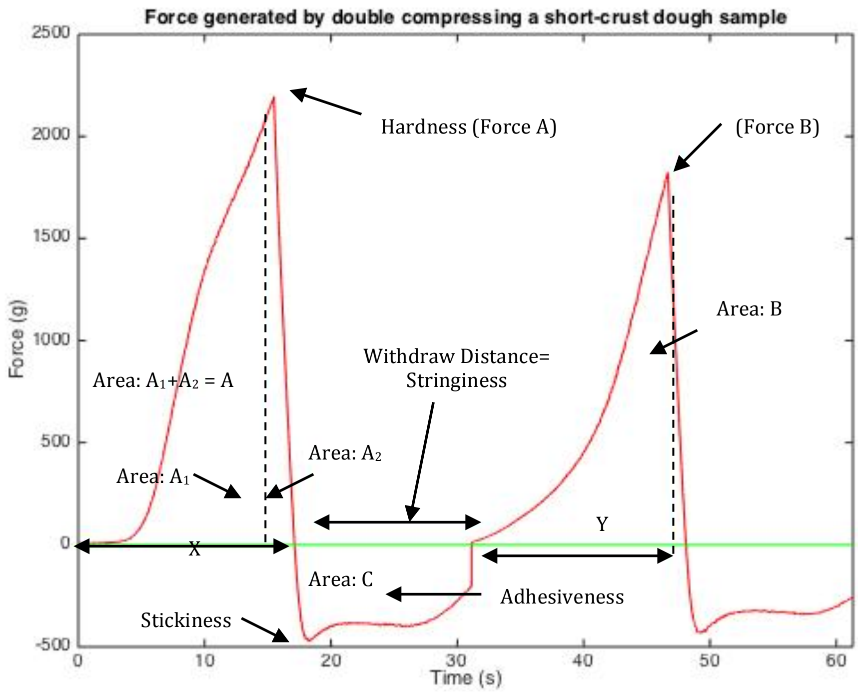

Figure 1 Texture profile analysis curve by double compressing a short-crust dough sample

A double cycle compression method generates texture profile curves (Figure 1) that simulate mastication providing the values of the stiffness, springiness, resilience, stringiness, adhesiveness, cohesiveness, gumminess, and chewiness of the sample. The stiffness is defined as the hardness of the sample (Force A), i.e. the maximum peak force required to compress the sample a defined distance. The springiness (Equation 1) is defined as the extent to which the sample is able to spring back after the deformation caused by the compression, also known as elasticity. Resilience (Equation 2) is how much force the sample can withstand without causing permanent deformations. Stringiness is defined as the distance during which the sample is connected to the probe as it moves away from the sample. Integrating the curve below the x-axis marked as Area C, gives the adhesiveness of the sample. The negative force generated due to the stringiness of the sample gives the stickiness value. The ratio between the second peak force area (Area B) and the first one (Area A), gives the value of the cohesiveness (Equation 3) of the dough, i.e. the ability of the sample to hold together as one piece (Bourne 1978). Gumminess (Equation 4) and chewiness (Equation 5) are indirect parameters since they are dependent on other ones. Gumminess is usually used for semisolid food products and chewiness mostly for solid foods. Therefore, either gumminess or chewiness values should be reported for the same food product (Bourne 2002). The following equations are those used to calculate the value of the different parameters. The values of Y, X, A_2, A_1, B, and A are derived from Figure 1.

$$Springiness = \frac{Y}{X} * 100\% \quad (1)$$

$$Resilience = \frac{A_2}{A_1} \quad (2)$$

$$Cohesiveness = \frac{B}{A} \quad (3)$$

$$Gumminess = Force\ A * Cohesiveness \quad (4)$$

$$Chewiness = Gumminess * Springiness \quad (5)$$

Another compression method that generates additional dough textural parameters is when compressing and holding until a certain time. A typical profile curve is presented in Figure 2. Springiness (also known as Elasticity) can be calculated from the graph using Equation 6. Force A is the maximum peak force and Force B is the plateau force after a pre-defined time.

$$Springiness_{hold} = \frac{Force\ B}{Force\ A} * 100\% \quad (6)$$

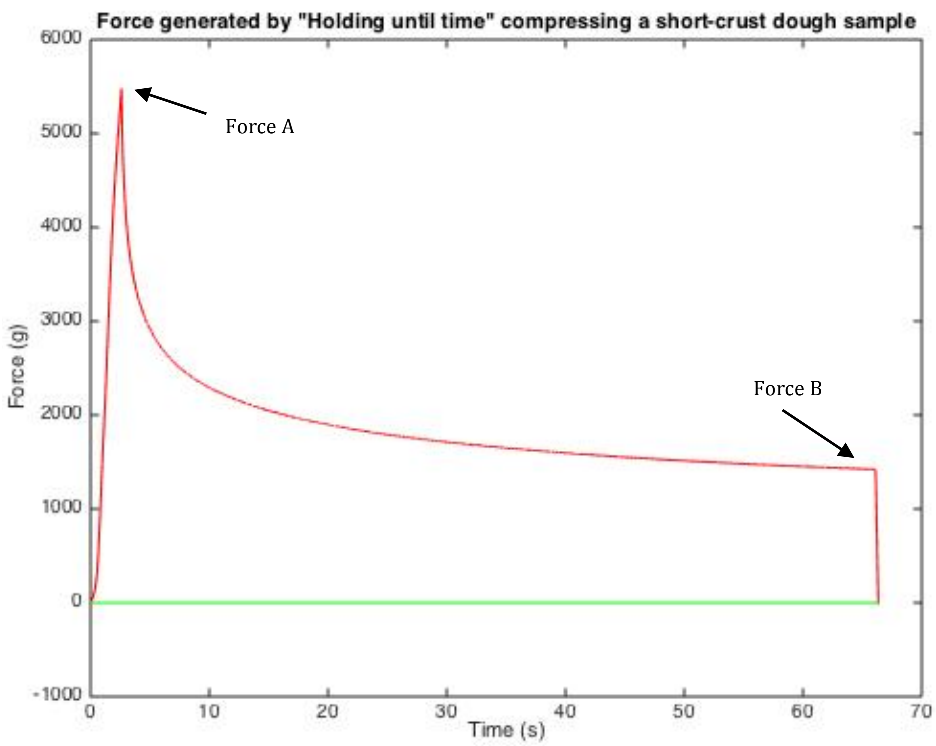

Figure 2 Force-Time curve by compressing a short-crust dough sample for a specific amount of time.

The bending-snapping principle used on baked product gives the hardness and the fracturability of the sample. Both parameters could be obtained from Figure 3.

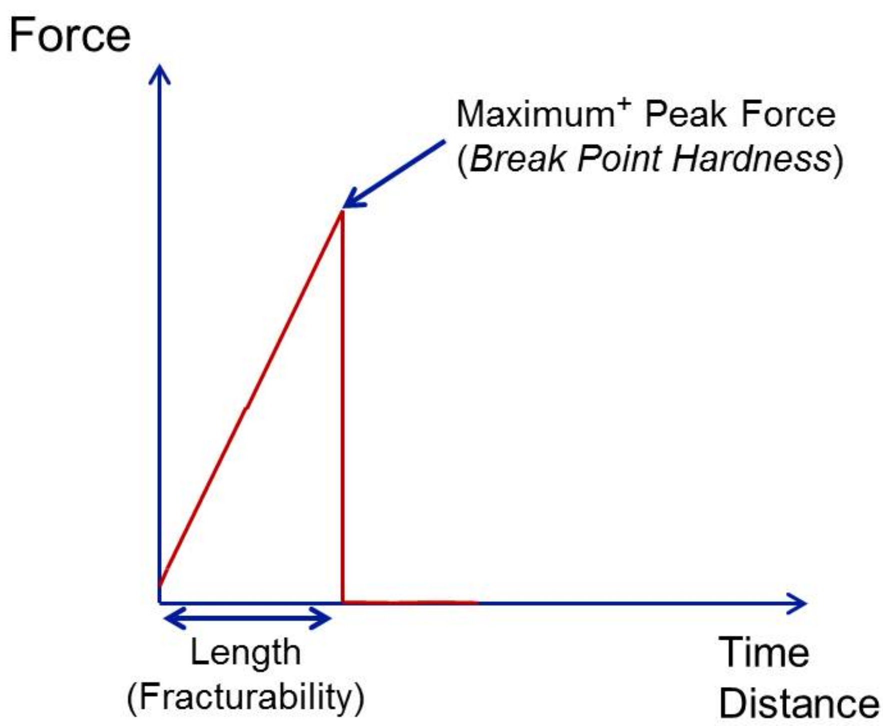

Figure 3 Texture profile analysis curve by snapping a baked short-crust pastry sample

2.3 Statistics/chemometrics

2.3.1 Central Composite Design

A complete factorial design allows studying the interactions between the different factors as well as the effect of each factor alone, since a one-at-a-time design it not enough to detect such impacts and in addition, requires more measurements than a complete factorial design. However, it becomes inconvenient to conduct such experiments when the number of variables increases especially if these variables are to be varied at 3 levels instead of 2. For instance, varying 6 variables at 3 levels would result in 729 (3^6) experiments, which is unreasonable. Therefore, a facilitated method, Fractional Factorial Design, was established by reducing the number of experiments needed without risking loosing valuable information. For example, if 3 variables are to be varied at 2 levels it results in 8 experiments (the yellow dots in Figure 4), however, when using fractional factorial design dots points 1-4 will be included (Brereton 2003).

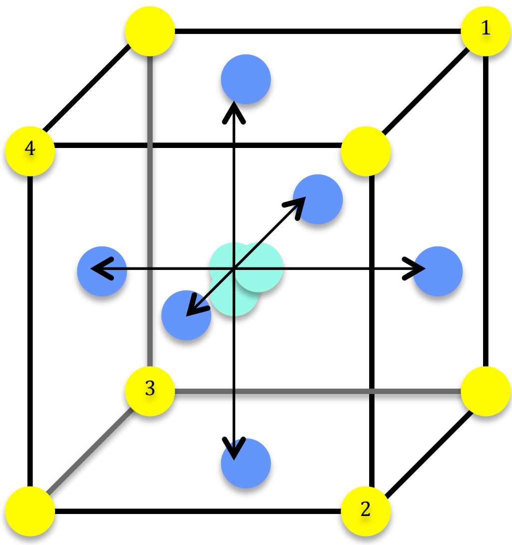

Figure 4 An illustration of a CCD design. Points 1-4 represent the corner points in a fractional factorial design.

To optimize the model, it is important to improve the model with more details in order to find maximum and minimum values, for example the hardness of a dough sample. Another reason behind this improvement is to produce a model that can predict the relations between responses and variables. Therefore, a central composite design (CCD) is found to be appropriate in such contents. A CCD includes 8 corner points at levels +1 and -1 (yellow dots in Figure 4) that are derived from a complete factorial design. In addition, a *star design* is included, which is illustrated as dark blue dots in Figure 4. These points account for variations at three levels: +1, 0, and -1. Finally, some replicates in the center of the cube (the light blue dots) are included to be able to estimate the experimental error (Brereton 2003).

2.3.2 Principle Component Analysis (PCA)

Consider a matrix X with N rows and K columns. To be able to extract and display systematic variations in this matrix, a method has been developed. This method is called "principle component analysis" PCA which consists of multivariate projections of the observations onto a two-dimensional plane. This enables visualization of the structure of the investigated data set and reveals the relationships between variables and observations as well as the relationships within the variables themselves. A PCA plot is obtained by computing the first and the second principle components, PC1 and PC2 that represent the maximum variance direction and the second largest source of variation in the data, respectively (Miller & Miller 2010).

However, before proceeding with this method, the data matrix should be generated and pretreated in an appropriate way. First of all the data should be organized such that the rows represent the observations and the columns the variables. As mentioned earlier, PCA is a projection method, which means that some errors may be present depending on the nature of the data set. If one variable has a relatively higher variance than another variable, the latter would not be expressed in the same extend as the former. In order to avoid this issue, the data should be standardized. Mean centering is also a good approach since it facilitates the interpretation of the model (Miller & Miller 2010).

2.3.3 Partial Least Square (PLS)

Partial Least Square (PLS), or Prediction to latent Structures by means of partial least square is a projection method as PCA that handles complex models as well as strongly correlated responses or parameters (Eriksson et al. 2001) (Brereton 2003). It also allows conducting analysis even when the number of observations is less than the number of variables. This method is used to observe relations between variables and parameters as well as within parameters themselves. PLS is categorized according to the number of responses in the analysis, PLS1 stands for one response and PLS2 for two or more responses (Håkansson 2012). In this report PLS2 was used since many responses were included in the study.

PLS allows predicting the final properties without direct contact with the product. For example if a company wants to control the amount of fat in a product by IR-spectroscopy, PLS could be used by constructing a chemometric model with already known values where the amount of fat is considered the response and IR-spectrogram is the variable. Based on this model, it will be enough to measure IR-spectroscopic data to be able to predict the fat amount of the final products in future (Håkansson 2012).

However, as PCA, this method could also include errors associated with prediction parameter. Therefore, the uncertainty could be described by the standard error and checked by constructing null hypothesis and calculating confidence intervals (Håkansson 2012).

2.3.4 ANOVA

Usually, there would be two sources of variation when comparing two or more means. The first one would be due to the fact that random errors would always be present in measurements, and the second one would be due to the controlled or fixed-effect factor, e.g. the method of analysis chosen or due to error in repeating an experiments by the same person, probably not doing it exactly in the same way every time (Miller & Miller 2010).

Analysis of variance or ANOVA is one of the most powerful tools that tells and estimates the differences in variation. In this paper, one-way ANOVA have been used, which test if the null hypothesis (H_0, Equation 7) is true or if it should be rejected. The null hypothesis is that all the samples (means) belong to the same population, i.e. the means (μ) are equal. The H_1 (Equation 8) will then be if at least one of the means is significantly different than the others and thus does not belong to the same population (Miller & Miller 2010)

$$H_0 = \mu_1 = \mu_2 = \mu_2 = \mu_4 = \cdots = \mu_n \quad (7)$$

$$H_1 \neq \mu_1 \neq \mu_2 \neq \mu_2 \neq \mu_4 \neq \cdots \neq \mu_n \quad (8)$$

To test whether H_0 is true or not, ANOVA uses a one-sided F-test and compares to a tabulated critical values of F. If the calculated value of F is higher than the critical one, then the null hypothesis can be rejected and it can be assumed to a certain degree of significance, that the sample means are different. (Miller & Miller 2010)

3 Materials and methods

3.1 Materials

The flour used was Kärnvetemjöl (ARTNR 140233) from Nord Mills with water content less than 15.5%, 11.5% protein content, and 2% fat as it was declared on their homepage (Nord Mills 2014). The flour was kept in its original package or in plastic containers with secure lid to protect it from humidity. Normal granulated sugar from Nordic Sugar was used. As flour, the sugar was stored either in its original package or in plastic containers. The egg powder (1531006-105 heläggspulver) used was produced by Källbergs Industri AB with a water content of 4%, protein content of 48%, and 43% fat. The egg powder was stored in the fridge at 4°C, however, the egg powder that was going to be used within a short period of time was stored in a small plastic container at room temperature.

Information such as product specification of the whole eggs that were used is missing. Drinkable tap water was used in all experiments in this report that required water. The fat types used and tested are listed in Table 1.

Table 1 A list of the different types of fat that were used depending on the experiments.

Name	**Ingredients**	**Production specification**
S50SStand	S50 shortening	Manufactured by AAK
S100SStand	S100 shortening	
S50MLab	Margarine composed of S50SStand + 20% water.	Produced in the lab by hand
S100MLab	Margarine composed of S100SStand + 20% water.	
Marba Delikatess	Marba Delikatess margarine	Manufactured by AAK
S100S0AAK	Processed S100SStand	Produced in AAK's facility by pumping S100 shortening (S100SStand) through the machine that produces margarine. (Special order)
S100S2AAK	Processed S100SStand with 2% emulsifier	
S100M0AAK	Margarine based on S100SStand + 20% water	
S100M2AAK	Margarine based on S100SStand + 20% water and 2% emulsifier	
S100S1AAK	Processed S100SStand with 1% emulsifier	Produced by blending S100S0AAK and S100S2AAK by ratio 1:1.
S100M1AAK	Margarine based on S100SStand + 20% water and 1% emulsifier	Produced by blending S100M0AAK and S100M2AAK by ratio 1:1.

The emulsifier used in the fat types (S100S0AAK, S100S2AAK, S100M0AAK, S100M2AAK, S100S1AAK, and S100M1AAK) that were prepared in AAK's facility in Karlshamn, was monoglyceride Dimodan HP from DuPont (former Danisco). Dimodan HP is made from distilled monoglycerides obtained from palm oil. Its application area ranges from bakery, oils, fats, dairy, frozen desserts, confectionery to plastics[1]. Emulsifier was added to the shortening to be able to compare it to the other fat types as well as to have a standardized method where emulsifier amount can be varied independently of the fat type.

3.2 Experimental design

Before planning the experiments in terms of ingredient variations, it was important to plan how the major experimental steps should look like. Therefore a schematic overview shown in Figure 5 was drawn to present the order of the different steps.

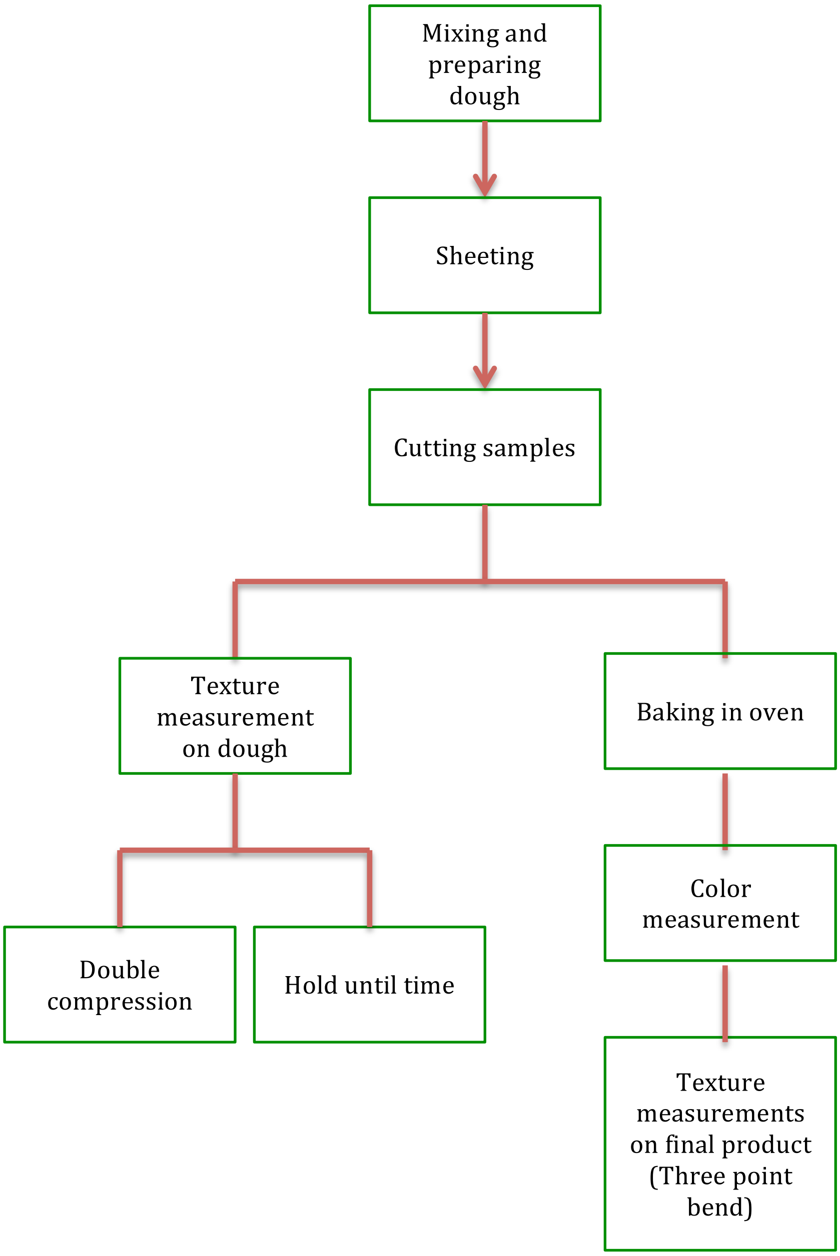

Figure 5 a schematic overview of the major experimental steps and their order

[1] This information was provided by the supplier.

3.3 Factorial design

Figure 4 presents the Central Composite Design that was used to generate a scheme of experiments. The ingredients were varied at 3 levels as it is shown in Table 2. The ingredient amounts that the levels (-1 0 +1) correspond to are presented in Appendix 5, Table 22. Note that in this design, the shortening and margarine used were those produced on S100 in AAK's facility (S100S0AAK, S100S2AAK, S100M0AAK, S100M2AAK, S100S1AAK, and S100M1AAK).

Table 2 CCD table where the parameters are varied on three levels to obtain responses that consider factorial interactions.

Experiment	Wheat flour	Sugar	Fat type		Egg[1]	Emulsifier
			Shortening	Margarine		
1	0[2]	+	+		+	+
2	0	+	+		-	+
3	0	+	-		+	+
4	0	+	-		-	+
5	0	-	+		+	+
6	0	-	+		-	+
7	0	-	-		+	+
8	0	-	-		-	+
9	0	+	+		+	-
10	0	+	+		-	-
11	0	+	-		+	-
12	0	+	-		-	-
13	0	-	+		+	-
14	0	-	+		-	-
15	0	-	-		+	-
16	0	-	-		-	-
17	0	+	0		0	0
18	0	-	0		0	0
19	0	0	+		0	0
20	0	0	-		0	0
21	0	0	0		+	0
22	0	0	0		-	0
23	0	0	0		0	+
24	0	0	0		0	-
25	0	0	0		0	0
26	0	0	0		0	0
27	0	0	0		0	0
28	0	+		+	+	+
29	0	+		+	-	+
30	0	+		-	+	+
31	0	+		-	-	+
32	0	-		+	+	+
33	0	-		+	-	+
34	0	-		-	+	+

35	0	-	-	-	+
36	0	+	+	+	-
37	0	+	+	-	-
38	0	+	-	+	-
39	0	+	-	-	-
40	0	-	+	+	-
41	0	-	+	-	-
42	0	-	-	+	-
43	0	-	-	-	-
44	0	+	0	0	0
45	0	-	0	0	0
46	0	0	+	0	0
47	0	0	-	0	0
48	0	0	0	+	0
49	0	0	0	-	0
50	0	0	0	0	+
51	0	0	0	0	-
52	0	0	0	0	0
53	0	0	0	0	0
54	0	0	0	0	0

1) Egg stands for egg powder.
2) "0" represents the standard level, "+" represents the high level (+1), and "-" represents the low level (-1) of a specific ingredient.

3.4 Standardization of procedures

3.4.1 Production of margarine in lab

Margarines based on S50 (S50MLab) and S100 (S100MLab) with 20% water were first prepared in the lab by melting a specific amount of fat in a beaker and adding 20% water of the total mass. Then the mixture was homogenized using a homogenizer and transferred rapidly to an ice bath. The mixture was constantly stirred by hand as fast as possible until it thickened properly. Thereafter, the produced margarines (S50MLab and S100MLab) were stored in the fridge over night to allow crystallization.

3.4.2 Dough recipe

The standard amount of the flour, sugar, and fat used for producing short crust cookie dough were obtained from two chefs that use such recipes for commercial production. The chefs come from different countries (Sweden and England) and the recipes were provided by AAK. Table 3 presents the different recipes and the standard recipe that was to be followed in this study. The fresh eggs were replaced by egg powder for convenience issues.

Table 3 the standard amounts of the different ingredients that are followed by two chefs. The standard recipe was based on the two other recipes and was adapted in the study.

Ingredients	Swedish chefs	English chef	Standard recipe

	Gram	%	Gram	%	Gram	%
Flour	300	46.1	750	50.0	300	49.0
Margarine (80%)	200	30.8	500	33.3	200	32.7
Sugar	100	15.4	250		100	16.3
Fresh eggs	50	7.7	---	16.7	---	---
Egg powder	---	---	---	---	12.5	2.0

3.4.3 Mixing

After weighing the specific amounts of the different ingredients, the following scheme was followed using Hobart N50 5-Quart Mixer.

1. Sugar, fat, and egg powder were added to the mixing bowl and mixed for 30s at speed 1 (60 RPM).
2. The ingredients that got stuck to the edges were scraped down. Water was added and a new mixing was performed for 30s, speed 1.
3. The dough on the edges was scraped down once again and the mixing speed was increased to speed 2 (124 RPM) to obtain a creaming process. The mixture was creamed for 4min.
4. The dough stuck on the edges was scraped down and flour was added.
5. The content was mixed for 90s at speed 1.
6. The dough on the edges was scraped down and the dough was mixed for 3min 30s at speed 1.

However, when margarine was used instead of shortening, in step 1 the content was mixed for 60s instead of 30s, and step 2 was ignored since no water needs to be added, margarine already contained 20% water.

3.4.4 Sheeting and sheeting behaviors

The effect on sheeting behavior by different factors was studied by varying fat type, water content, egg content and egg type, as well as storage time. The different types of shortenings and margarines that were used are S50SStand, S100SStand, S50MLab, S100MLab, and Marba Delikatess, see Appendix 1 for more details. Moreover, since recipes of making short-crust cookie dough were found to differ in egg content, some experiments were done to study how the addition of eggs could affect the dough properties when sheeting. Figure 6 shows an example of a good sheeting behavior (6a) and a bad one (6b).

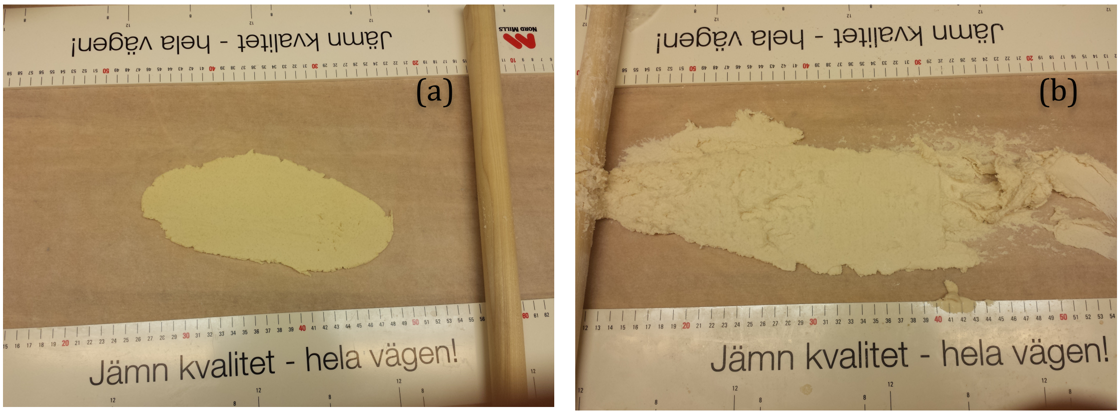

Figure 6 Examples of a good sheeting behavior (a) and a bad one (b)

Some dough samples were stored for a specific time (0-6 days) and tested for sheeting at different temperatures (10-22°C) after storage. This was done to study whether the sheeting temperature had a significant impact on the sheeting behavior or not. Further details on this study are available in Appendix 1.

The sheeting was performed after mixing. The dough was sheeted on baking paper. Two rulers with the same height (6 mm) were placed on each side of the baking paper, and the sheeting was performed by allowing the edges of a rolling pin to roll on the rulers so that the dough will obtain a standardized height.

3.4.5 Sampling and calculating sample diameter

Calculations were preformed to know what sample size to used for the texture measurements (Appendix 2). To cut the samples, a forming mould with a diameter of 42 mm was used. After cutting the samples (at least 15 samples), the excess dough surrounding them was carefully removed by lifting or pushing away. Using a knife, the baking paper was cut around the sample and a thin pie lifter was used to lift the samples with the baking paper and transferred onto a small petri-dish. In this way sample deformation would be avoided and thus obtaining a standardized method.

The samples were then divided into three groups for different measurements composed of five samples each. They were then marked with experiment number, date, and sample number (1,2,3,4, or 5).

3.4.6 Changes in water content and water activity during dough storage time

To be able to plan the experiments in best way possible, knowledge of time impact on dough properties could be helpful. Therefore, samples were made (sheeted samples) and water content, water activity, and textural measurements were performed. The water activity was measured using an AQUA LAB CX-2 (Aqua Lab, USA). The water content was studied by measuring the sample weigh, and then after leaving the dough samples (in covered petri-dishes at room temperature) for different time intervals (1, 2, 3, and 18 h), the weight was measured again. The lost mass was considered to be the water content loss.

3.4.7 Testing baking and temperature profile in oven

The baking process was studied in Revent internation 626 oven (Revent, Sweden) at two temperatures, 180°C and 200°C since temperatures in this range have been used before ((Manohar & Rao 1999) (Pareyt, Brijs & Delcour 2010) (Hadnadev, Torbica & Hadnadev 2013)). Notes were made every 5 minutes to be able to follow the changes in size and color of the samples. The color judgment was subjective, i.e. according to individual preferences and what was considered to be good. However, the recording of the temperature profile in the oven was done only at 180°C since this was found to be the appropriate method to use in the future trails. The temperature profile was studied by using two thermocouples, one at the edge and one in the middle of the oven, to measure the difference in temperature at different points in the oven. The oven was set at 180°C and measurements were taken every 15 seconds.

3.4.8 Baking

The samples were weighed and using a caliper the diameter was measured. A baking dish covered with baking paper was prepared, and the oven was set at 180°C. The samples were lifted and tilted over (upside-down) on the baking dish, and the small baking paper was gently removed to avoid deformation. Thereafter, the baking dish was placed in the oven and the baking process was allowed to take place for 20 min.

3.4.9 Dough temperature and room condition impact on texture analysis

Another temperature test was conducted to study if the texture analyses (see section 3.5.2) varied depending on what temperature the dough had while mixing, sheeting, sampling, and measuring. Moreover, the current relative humidity, room temperature, and water bath temperature were noted as well.

3.4.10 Microscopy on fats

Marba Delikatess and S100MLab, as well as S100S0AAK, S100S2AAK, S100M0AAK, and S100M2AAK were studied under the microscope at different magnifications ranging between 16X- 100X with and without polarized light. This was done to compare the microstructure of the fat crystals and the water incorporation. For more information and results see Appendix 3.

3.5 Evaluation of products

3.5.1 Color measurements

After baking, the samples were stored for at least 2 weeks. Before performing textural analysis on the final product, the color was measured using CR-400 Chroma Meter (Konica Minolta, Japan). The device gave values of Lx (brightness), ax (red to green), and bx (blue to yellow). Since the different experiments resulted in cookies with very different brown color intensity, it was of interest to measure the brightness (Lx) to be able to compare them to each other. The brightness of the samples was integrated with the other textural parameters of the finished product when analyzing the results using chemometrics.

3.5.2 Methods used for textural analyses

Compression and puncture methods are suggested to be the most common ones when using TVT Texture Analyzer (Perten Instruments, Sweden) to study short-crust cookie dough samples2. To determine the textural characteristics of the samples (both dough and baked), the following methods were adopted.

Method 1. Double cycle compression: compression distance of 4 mm over plate and a 50s pause between cycles. A 75 mm diameter cylindrical aluminum probe was used and the pre-test, test-, and post-test speed were set to 0.2 mm/s. This method provided the hardness, springiness, resilience, stringiness, adhesiveness, cohesiveness, gumminess, and chewiness of the dough sample. These parameters were assigned a prefix DB when performing chemometrical analysis.

Method 2. Hold until time compression: a single cycle with compression distance to 4 mm over plate and a holding time of 62s. A 75 mm diameter aluminum probe was used and the pre-test, test-, and post-test speed were set to 1.0 mm/s. This method provided the elasticity and the hardness (ForceA and ForceB) of the dough samples. These parameters were assigned a prefix HUT when performing chemometrical analysis.

Method 3. Three point bend: a single cycle break test that breaks the sample with a compression of 10% of the sample height. A break probe and a three point bend rig were used with the distance 22.8 mm between the plates. The pre-test, test-, and post-test speed were set to 1.0 mm/s. This method provided the hardness and fracturability of the baked samples. However, fracturability was not included in this study. The textural parameters of the baked product were assigned a prefix TPB when performing the chemometrical analysis.

3.5.3 Statistical tools

Different statistical tools were used to evaluate the results such as PCA, PLS2, ANOVA, linear regressions, and spider plots or radar charts. When using PCA, the variables were chosen to be the parameters obtained by textural analysis, i.e. hardness, resilience, adhesiveness, springiness etc., and the observations were the different experiments with different ingredients levels. When using PLS2, the variables and parameters were assigned different matrices/vectors depending on what relations were to be studied (see section 4.2.3 for further information). When performing PLS2, a W*Q-plot was obtained which shows an overview of how the variables (ingredients) are related to the parameters (texture). All data matrices in this report have been normalized (centered and standardized). When using ANOVA or calculating confidence intervals, the level of significance was

[2] Source: Jeanette Purhagen (2014). Personal Communication.

chosen to be 95%, i.e. α=0.05. The linear regression applied to the data points in section 4.2.7 was used to obtain correlation coefficients using Equations 9 and 10.

$$R^2 = 1 - \frac{norm\ of\ residuals^2}{SS_{parameter}} \qquad (9)$$

$$SS_{parameter} = (length(parameter) - 1) * var(parameter) \qquad (10)$$

In Equation 10 "parameter" was substituted by the textural parameters of the baked product, i.e. parameters that have the prefix TPB. The norm of residuals in Equation 9 was obtained by using "Basic fitting" function in MATLAB. Another way to calculate R^2-value is by taking the square root of R-value (Pearson correlation coefficient). The Pearson correlation also provides whether the null hypothesis (hypothesis about nonexistence of a difference between samples in population) was accepted or not. H_0 was rejected if t-value obtained by Equation 11 was equal to or larger than the critical value of the student's t-distribution (Olbjer 2000). The table with the critical values is available in Appendix 7.

$$t = r\sqrt{\frac{n-2}{1-R^2}} \qquad (11)$$

3.5.4 Additional measurements

During the preparation of the dough (for experiments with shortening and some with margarine), different parameters were noted to see if these may have any affected the characteristics of the dough or the baked product. The parameter abbreviations are available in the Abbreviations section of this report.

4 Results and discussion

4.1 Standardization of procedures

4.1.1 Sheeting behaviors

S100 margarine produced by hand was shown to have the best sheeting behavior with no need for cold storage. The produced S50 margarine had almost the same effect as S100 margarine, but since S100 fat was more available it was used in the following experiments. The other fats or margarines showed good sheeting behavior in some of the cases. For the results and combinations from the testing of the different fats and different storage and sheeting conditions see Appendix 2. Adding egg to the dough enhanced the sheeting performance, but no difference was observed between using egg powder or whole eggs. Therefore, egg powder was chosen in the trials that needed egg.

Although cold storage improved the sheeting ability of the dough it was chosen to be avoided due to that the cold conditions might affect the water distribution in the dough. Moreover, since sheeting dough at different temperatures showed different behaviors, it was concluded that a standardized method should be created to ensure that the dough temperature would always be within a specific interval (20-23°C). For this reason, a water bath was attached to the valves of the mixing bowl to allow water recirculation that will maintain the temperature of the content at the desired level.

4.1.2 Calculating sample diameter

Since different compression methods were to be tested and thus different cookie heights, the maximum compression 40% was used to calculate a standard sample diameter. This was done to avoid getting a sample diameter larger than the probe, which would affect the results. The calculations showed that a mould with a diameter of 42 mm would be most appropriate to use, see Appendix 2.

4.1.3 Changes in water content, water activity, and texture during time

The results showed that the water content and water activity decreased with time, but ANOVA showed that this decrease is not significant on 95% level. However, some textural parameters seemed to be influenced by storage time, which was studied further. The radar chart in Figure 7 showed that the samples stored for 1, 2, and 3 hours displayed almost the same properties considering ForceA, ForceB, Gumminess, Adhesiveness, and Resilience, but different Springiness, Cohesiveness, and Stringiness values (Chewiness is not considered since gumminess is taken into considerations instead). The samples stored overnight for about 18 h showed very different pattern compared to the other lines.

The springiness, cohesiveness, and stringiness of the dough were not significantly affected by time. Adhesiveness and gumminess (see section 2.2 for parameters' descriptions), on the other hand, may get affected only if samples were stored over 3 hours. The resilience of the dough was affected by time if the samples were stored for more than 2 hours. However, ForceA and ForceB, i.e. the hardness of the dough, were affected by time even if the samples were stored for just one hour. The F-values can be seen in Table 20 in Appendix 3.

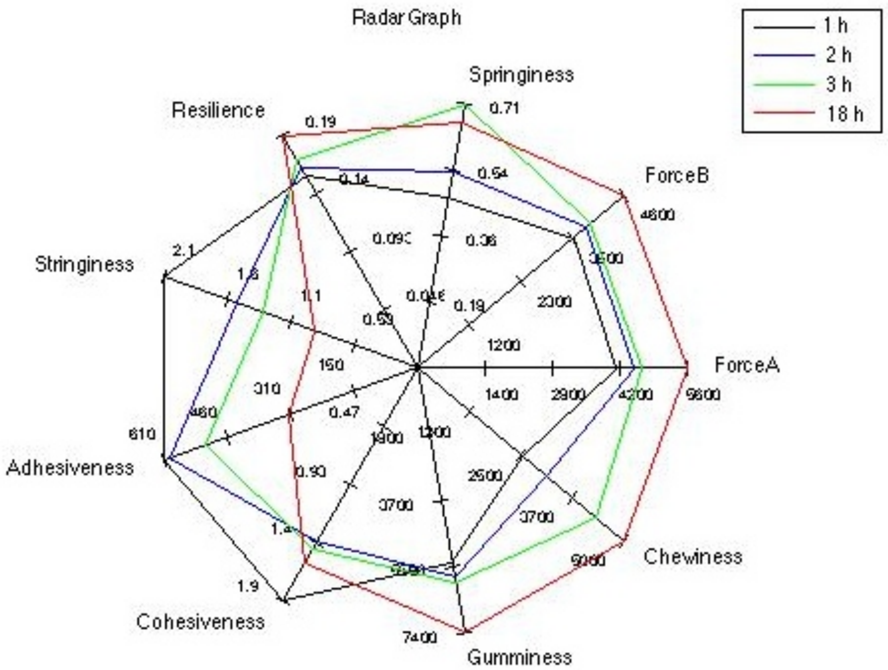

Figure 7 A radar chart visualizing the impact of time on textural parameters. Each line represents the mean value of 2 measurements.

4.1.4 Testing temperature in the oven and temperature profile in oven

To decide a suitable baking temperature, trails were performed at both 180°C and 200°C. By baking the samples at 200°C the samples without egg were done after 15 minutes while the samples with egg got almost burned at the same time. In addition, some samples got burned on the edges but were still soft in the middle. Thereby, a baking temperature of 200°C was not considered to be suitable. On the other hand, baking samples at 180°C showed much better behavior since the color was more evenly distributed and all samples (with and without eggs) were done after 20 minutes.

The baking method adopted was based on the fact that a standardized method was sought. Baking at 180°C showed better baking performances where all samples were finished despite the variation in ingredients. In addition, the chefs from whom the recipes were obtained did also bake their samples at this temperature.

The temperature profile in the oven was studied to check if the temperature varied between the edge and the middle of the oven. Figure 8 shows that there is barely any difference between the curves, which allows assuming the samples to be subjected to the same temperature. Note that since oven uses airflow system, the temperature fluctuates due to the starting and pausing of the blower.

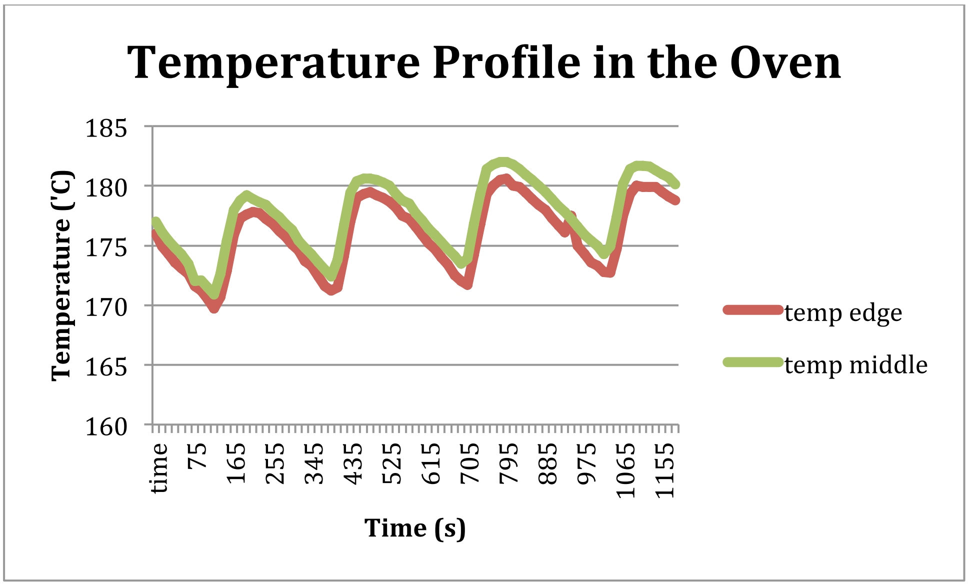

Figure 8 Temperature profile in the oven measured in the middle and on the edge of the oven chamber.

Figure 8 shows that the real mean temperature of the oven was lower than 180°C despite that the temperature was set to 180°C, which means that the samples have been baked at a lower temperature than the specified one.

4.1.5 Dough temperature impact on texture analysis

In order to sense how different textural parameters varied with dough temperature, a test was performed where dough were mixed and sheeted at different temperatures. Samples were then used for texture measurements. To visualize the relations between the experiments, the values were plotted in a radar chart in Figure 9. From the figure, the measurements at 23°C differ the most. Still, some other differences were observed between the other experiments, such as differences in hardness and gumminess. This was expected since the fat in the dough normally gets softer with higher temperatures. This means that the cookie dough samples will have a softer texture than the samples with harder fat (at lower temperatures). Thereby, resulting in less hardness and gumminess values of the dough samples when performing texture analysis. In contrast, the figure showed that stringiness, adhesiveness, and cohesiveness were not affected by the temperature of the dough.

To check whether the differences were significant or not, ANOVA was used on the first three experiments (15°C, 16°C, and 21°C). The f-values are presented in Table 21 in Appendix 3. At 95% level of significance, ANOVA confirmed the observations from the radar chart, i.e. there is no significant difference in the stringiness, adhesiveness, and cohesiveness of the dough at these three temperatures. However, hardness (Force A), springiness, resilience, and gumminess, vary if the dough samples have different temperatures. Therefore, in general, it could be said that the higher the temperature became, more differences could be detected between the samples. This could be related to the effect of temperature on the fat in the dough, as mentioned earlier, higher temperatures result in softer fat texture and thereby affect the dough texture.

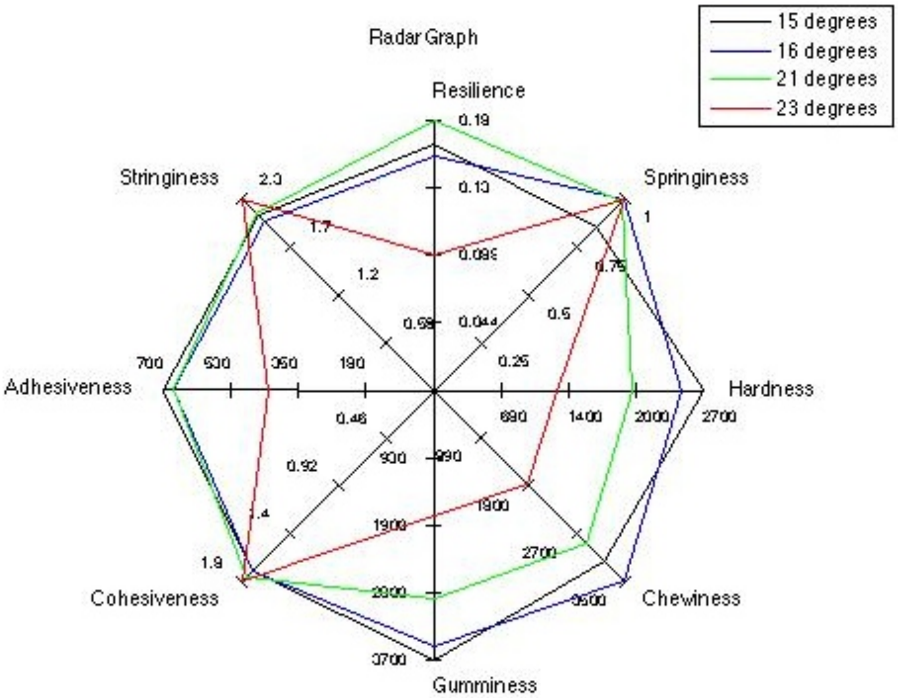

Figure 9 A radar chart visualizing the impact on textural parameters by dough temperature. The different lines represent the mean value of five measurements. The parameters studied are derived from method 1 (double compression).

Since the results above showed that resilience, springiness, hardness, chewiness, and gumminess were affected by temperature, future studies on these parameters should include temperature as a parameter. However, if stringiness, adhesiveness, and cohesiveness were to be studied, then there will be no need to take temperature into account since the results showed that these parameters were not affected by dough temperature (15-23°C).

4.1.6 Microscopy on fats

The different fat types that were produced in AAK's facility (S100S0AAK, S100S2AAK, S100M0AAK, and S100M2AAK) were studied under the microscope with magnification 50X and normal light. Figure 10-a shows the microstructure of S100M0AAK, 10-b for S100M2AAK, 10-c for S100S0AAK, and 10-d for S100S2AAK. The difference between Figure 10-a and 10-b is very clear, in the former it is possible to see how the water build a phase separated from fat (orange arrow), and in the latter the water droplets (red arrows) are very small and clearly more visible. In Figure 10-c and 10-d it is possible to see the fat crystals in the sample (the blue arrows). Conclusively, no differences were found between S100S0AAK and S100S2AAK using microscopy.

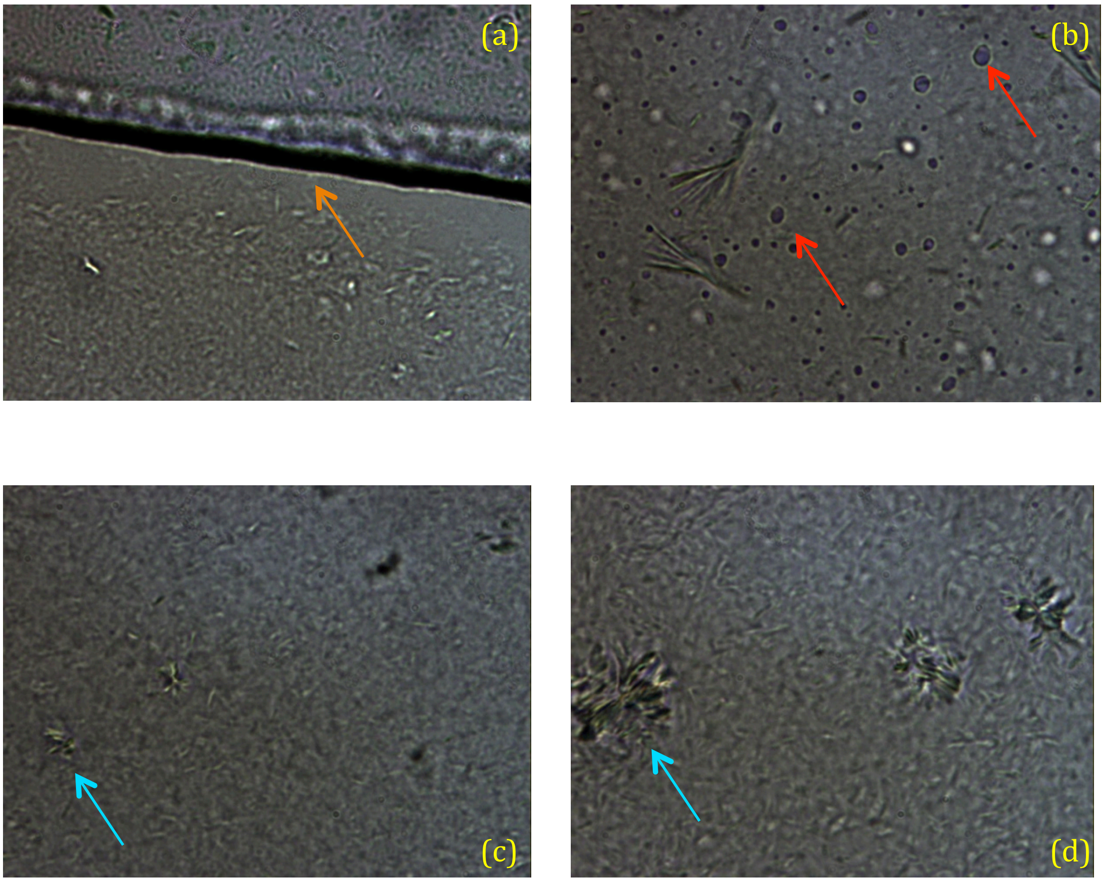

Figure 10 Microscopic pictures obtained by 50X magnification and normal light: a) Margarine without emulsifier. The orange arrow points at the water-fat phase separation. b) Margarine with emulsifier. The red arrows point at the incorporated water droplets. c) Shortening without emulsifier d) shortening with emulsifier. The blue arrows point at the fat crystals.

4.2 Evaluation of products

4.2.1 Comparing all responses and all variables

4.2.1.1 Shortening

The textural parameters obtained for the experiment series that was done using shortenings (S100S0AAK, S100S1AAK, and S100S2AAK) were plotted together with the scores (ingredient variation) in a biplot (see Figure 15 Appendix 6). The degree of determination was 75% for the first two components, which is considered good enough to describe the data. This was also strengthened by the scree-plot and the press-plot since they both have a local minimum at principle component 2 meaning that 2 components are enough to describe the data and predict future observations (see Figures 16-a, b, and c Appendix 6).

From the biplot, it was possible to see that the most expressed parameters were DBAdhesiveness, DBSpringiness, HUTElasticity, and HUTForceA and the most expressed ingredient variations were SHLHH, SLLHL, and SHLHL. The common feature between these three ingredient scores was that they all had low levels of shortening and high levels of egg powder. In addition, some of the other observations (scores) were also more expressed than the majority but not to the same extent as the previous 3 scores (SHLHH, SLLHL and SHLHL). These include SHHLL and SLHLL which had high levels of shortening and low levels of egg powder in common. The least expressed parameters were TPBBrightness, DBStringiness, Diameterchange, Crumblemass, and Massreduction.

4.2.1.2 Margarine

To study if there was a difference between the shortening and the margarine series, the textural parameters obtained for the experiment series that was done using margarines (S100M0AAK, S100M1AAK, and S100M2AAK) were plotted in a biplot together with the scores (see Figure 17 Appendix 6). Validation of the method showed that 2 components (PC1 and PC2) are enough to describe the data but three components would have improved the degree of explanation to 74% (see Figure 18 Appendix 6). The biplot showed that DBStringiness, DBCohesiveness, Diameterchange, Crumblemass, and Massreduction were mostly expressed by the method. The most expressed scores were MHLHL, MLLHL, MHLHH, and MHHLL. These scores (except MHHLL) and the scores SHLHH, SLLHL, SHLHL were composed of the same ingredients with the only difference being the fat type, i.e. shortening or margarine. This means that the shortening and margarine series showed almost the same relations considering the scores. Conclusively, the fat type used had no effect on these scores. Perhaps the fat amount and the egg powder had a dominant effect that might have concealed possible effects of the fat type.

4.2.1.3 Overall comparison

To compile the results obtained from the shortening and the margarine series (all experiments done with S100S0AAK, S100S1AAK, S100S2AAK, S100M0AAK, S100M1AAK, and S100M2AAK), a biplot of all the parameters against all scores was generated. The validation of the component choice showed that 2 components (PC1 and PC2) were enough to describe the data but three components would have increased the degree of explanation to 76% (Figure 20 Appendix 6). The biplot (see Figure 19 Appendix 6) showed that the most expressed parameters were HUTElasticity, TPBBrightness, and DBCohesiveness and the most expressed observations were SHLHH, SLLHL, SHLHL, and MHLHL. The least expressed parameters were DBStringiness, Diameterchange, Crumblemass, and Massreduction. These observations have been mentioned earlier when studying Figures 15 and 17 in Appendix 6. Perhaps, some effects of these parameters might have existed but are hidden by the figure because of the importance of the other parameters that were expressed more significantly. This might be clarified by further analysis later in this report.

Summarizing the results, it could be said that the most expressed parameters were DBAdhesiveness, DBCohesiveness, and HUTElasticity. Since many other parameters such as DBResilience, DBForceA, DBGumminess, TPBForceA, HUTForceB, and HUTForceA form a group together, they will be considered in some of the further analysis.

4.2.2 Relations among important responses and all variables using PCA

4.2.2.1 Most expressed responses against all variables

There was a clear relation between the most expressed parameters and some of the scores. For instance, the dough cohesiveness, resilience, gumminess, and hardness (obtained by double compression and hold until time methods) as well as the springiness obtained by hold until time method showed to be positively correlated with low fat amount (shortening or margarine) and high egg powder content. However, the adhesiveness of the dough showed a negative correlation to these ingredients, i.e. low fat amount and high egg powder content will result in low adhesiveness of the dough. This was also observed when performing the experiments. Relations to other scores were difficult to make since the scores were gathered around the center. The biplot is available in Figure 21 Appendix 6. The explanation degree of the figures was 83%, see Figure 22 Appendix 6.

4.2.2.2 Most expressed variables against all responses

Plotting the most expressed scores against all responses showed that the dough cohesiveness, resilience, gumminess, springiness, and hardness were negatively correlated to high fat and low egg powder amounts. Interestingly, this strengthens the relations observed in section 4.2.2.1 since the biplot (Figure 23 Appendix 6) has an explanation degree of 89% for two components (see Figure 24 Appendix 6).

4.2.2.3 Most expressed responses against most expressed variables

To study whether the relations between ingredients and responses could be strengthened any further, a new biplot was generated using only the most expressed scores and parameters, see Figure 11. From the biplot it could be seen that the color (TPBBrightness) of the baked product was related to the amounts of fat and egg powder (SLHLL, SHHLL, MHHLL, SHLHH, SHLHL). If the egg amount was reduced and the fat amount was increased, then the brightness decreases. This could be interpreted since the angles between the vectors to TPBBrightness (the orange arrow) and to the scores (the purple arrows) were either much greater or smaller than 90°. In addition, these vectors are almost of the same lengths. All of the relations noticed in the previous sections 4.2.2.1 and 4.2.2.2 could still be observed in this figure. The explanation degree was calculated to approximately 95% (Figure 25 Appendix 6).

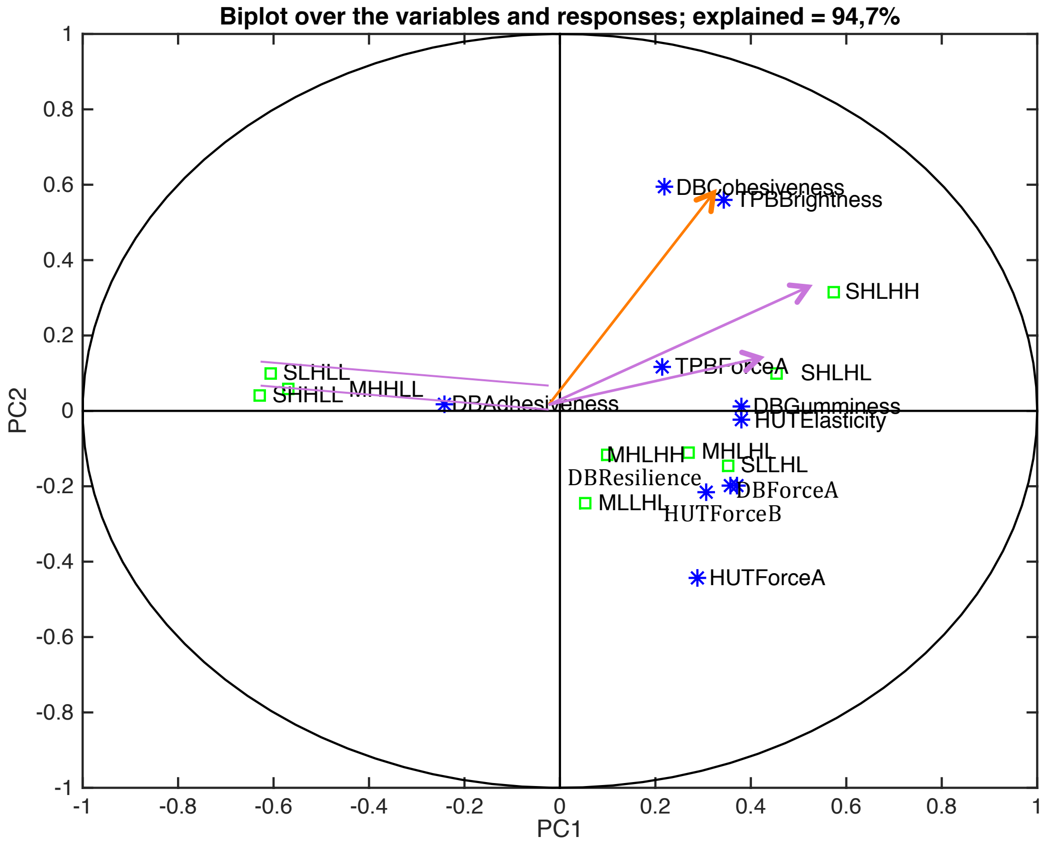

Figure 11 Biplot over the most expressed variables against the most expressed responses with an explanation degree of 95%.

4.2.3 Relations between all variables and all responses using PLS2

Since there were two types of variables in this study, design variables (ingredients) that could be adjusted after desire and rest variables (room conditions) that were measured during the experiments. The rest variables were less controllable since most of them relied on the weather conditions. Therefore, in order to study how the weather or room conditions may have affected the responses (textural parameters), PLS2 was used to find possible relations and effects.

When performing the experiments and noting the room conditions, some missing values occurred. These were only missing from the margarine series. Therefore, studying the shortening series on its own became of an interest. The W*Q-plot obtained by PLS2 (see Figure 26 Appendix 6) shows that almost only the egg powder amount and the shortening amounts (S100S0AAK, S100S1AAK, and S100S2AAK) were important variables and therefore mostly expressed. What could also be seen was that the textural parameters were divided into two groups, one in the upper right quadrant, and one on the lower left quadrant of the graph. However, there was no clear reason to this classification.

Even if there were some missing values in the margarine series, it was still interesting to see if the same observations as in section 4.2.3.1 could be made.

The WQ-plot obtained (Figure 27 Appendix 6) showed that egg powder and margarine amounts (S100M0AAK, S100M1AAK, and S100M2AAK) were still the most expressed variables. However, the relative humidity and the dough temperature seem to be more expressed than in the previous study (section 4.2.3.1)

Compiling the values from the shortening and margarine series and using them to plot a new WQ-plot would give a conclusive overview of the relations between variables and responses. The WQ-plot shown in Figure 28 Appendix 6 showed that Eggpowder and FatAmount were clearly the most important variables and thus none of the room conditions variables might have had a significant effect on the textural parameters.

4.2.4 Effect of rest-variables on responses

Since the room conditions variables were less expressed in the presence of the design variables, some plots were made without them to study whether any changes or relations may appear. As the case in section 4.2.3, the shortening and margarine series will be studied separately before combining them in one graph. The shortening series showed that sampling time, temperature of the water bath, and temperature of the dough were important variables that should be considered. The studies performed in section 4.1.5 showed that the temperature of the dough might affect the value of dough hardness, resilience, and gumminess, which could also be seen in Figure 29 Appendix 6. In addition, section 4.1.3 showed that storage time might affect the hardness of the dough (DBForceA), the gumminess, and resilience depending on the storage time. These relations were also visible in Figure 29 Appendix 6 since the sampling time could be considered as a short-time storage. However, when performing these trails (using S100S0AAK, S100S1AAK, S100S2AAK, S100M0AAK, S100M1AAK, or S100M2AAK) all of the samples were measured within 30 minutes, therefore, only hardness (DBForceA) may have been endured changes and none of the other parameters. The margarine series showed also the same relations as the shortening series. Compiling the two series in one plot showed the same results as the ones seen for the shortening and margarine series (see Figure 30 Appendix 6)

4.2.5 Relations among design variables and responses

After studying how the room condition variables might have affected the textural parameters, it became interesting to study the effect of the ingredients alone. In order to avoid missing any relations, this study was divided into smaller pieces. The relations between the ingredients and the dough texture and between the ingredients and the texture of the baked product were given some focus in this part of the report.

4.2.5.1 Design variables against dough textural parameters

Studying the relations between the ingredients and the textural parameters of the dough showed that the parameters were separated into two groups, one around the egg powder and the other around the fat amount. This means that egg powder positively affected the resilience and gumminess of the dough as well as the hardness (DBForceA, HUTForceA, and HUTForceB) obtained by the two textural methods used (double compression and hold until time). This could be due to the increased protein content of the dough when using egg powder, which gives a firmer structure to the dough samples. The figure obtained also showed that the fat amount had a negative effect on the previously mentioned parameters but a positive one on the adhesiveness, springiness, and stringiness of the dough. The fat type fell in a position where no relations to the parameters could be made (the angel from FatType to these parameters is around 90°) except the springiness obtained by hold until time method (HUTElasticity), see Figure 31 in Appendix 6.

4.2.5.2 Design variables against textural parameters of baked product

This study revealed some hidden relations such as the strong positive relation between sugar content and the mass reduction (water content loss) and change in diameter during baking. In addition, high sugar content seemed to produce harder baked cookies. These observations have also been stated in another study where high sugar concentrations resulted in larger cookie diameters and more moisture loss during baking and thus firmer cookies (Kweon et al. 2014).

The brightness of the baked products (TPBBrightness) showed a strong positive relation to fat amount but a negative one to egg powder. This is due to that the fraction of proteins available in the product is low in addition to the high fat content which cotes these proteins (Maache-Rezzoug 1998) (Wade 1990) (Slade 1994) (Manohar & Rao 1999). This coating may result in unavailable amino groups especially those in the side-chains of the proteins. These amino acids are the most often ones to be involved in Maillard reactions in the presence of reducing sugars (Coultate 2009) (Maillard 1912), thus a shortage in them results in a brighter product upon heating (baking). However, when adding egg especially in higher amounts, the amount of available proteins or side chains increases enhancing the Maillard reactions and thus giving a darker product.

The fat amount and fat type showed a negative relation to the hardness of the baked product (TPBForceA). It means that the margarines (S100M0AAK, S100M1AAK, and S100M2AAK) gave harder cookies than what shortenings (S100S0AAK, S100S1AAK, and S100S2AAK) did. Interestingly, this negative effect has also been observed in many other studies (Manohar & Rao 1999) (Pareyt, Brijs & Delcour 2010) (Pareyt et al. 2009) (Baltsavias, Jurgens & Vliet 1999) (Sudha et al. 2007) and has been related to the influence of the fat on the internal cookie structure. The analysis also showed that the fat amount used in the dough had a positive relation to the Diameterchange of the dough (the spread during baking), which has also been stated in other studies (Maache-Rezzoug 1998) (Pareyt et al. 2009) (Manohar & Rao 1999) and said to be related to the increase in system mobility upon melting of fats during baking. The W*Q-plot is available in Figure 32 in Appendix 6.

In both studies (Figure 31 and Figure 32 Appendix 6) the amount of emulsifier itself did not seem to affect the textural parameters in the analysis, perhaps due to the presence of other factors that had larger impact such as fat and eggs. This may have led to that the model became unable to show all present relations at the same time and thus under-expressed emulsifier due to the presence of the more powerful parameters in the analysis. However, the microscopy on the different fat types showed that there was a difference between margarines with and without emulsifier (see Figures 10a-b). This implies that emulsifier did have an effect but hidden by the figures obtained by chemometrics. In a study made by Manohar and Rao (1999), addition of emulsifier (0.5 % of flour mass) resulted in decreasing the resilience and elasticity of the dough by reducing the gluten development. Moreover, the dough became softer i.e. reducing hardness, adhesiveness, and stickiness of the dough but increasing the cohesiveness. However, in that study, glycerol monostearate, lecithin, and sodium stearoyl lactylate were used as emulsifiers, compared to monoglyceride in this study. Since they are different emulsifiers, and the study by Manohar and Rao (1999) showed different effects by different types of emulsifier, this might be the case here as well why emulsifier did not show an effect on the textural parameters.

The relations between the ingredients and all textural parameters together showed almost the same relations as the ones mentioned formerly. For instance, the negative relation between egg powder and brightness, and the negative relation between fat amount and hardness, gumminess, and resilience were still present. However, no relations could be made to sugar since the length of the vector from the center to sugar (orange arrow) is smaller than the vector lengths to the other parameters (purple arrows) see Figure 33 Appendix 6.

4.2.6 Selected important variables against important responses (PLS2)

From the previous studies (sections 4.2.4 and 4.2.5) it could be concluded that the most important variables to consider are FatType, FatAmount, Eggpowder, Sugar, SamplingTime, TempWB, and DoughTemp. In addition, it was seen that Crumblemass and DBCohesiveness did not show any relations to other parameters or variables since they were always located near the center of the graph. Therefore, in the following analysis, these parameters were excluded.

The major effects on the textural parameters occurred by the fat amount and type added to the dough (margarine or shortening) in addition to egg powder. The room condition variables had a smaller effect compared to the ingredients.

Therefore, in order to make final conclusions regarding ingredient effect on textural parameters, these variables could be removed (Figure 34 in Appendix 6).

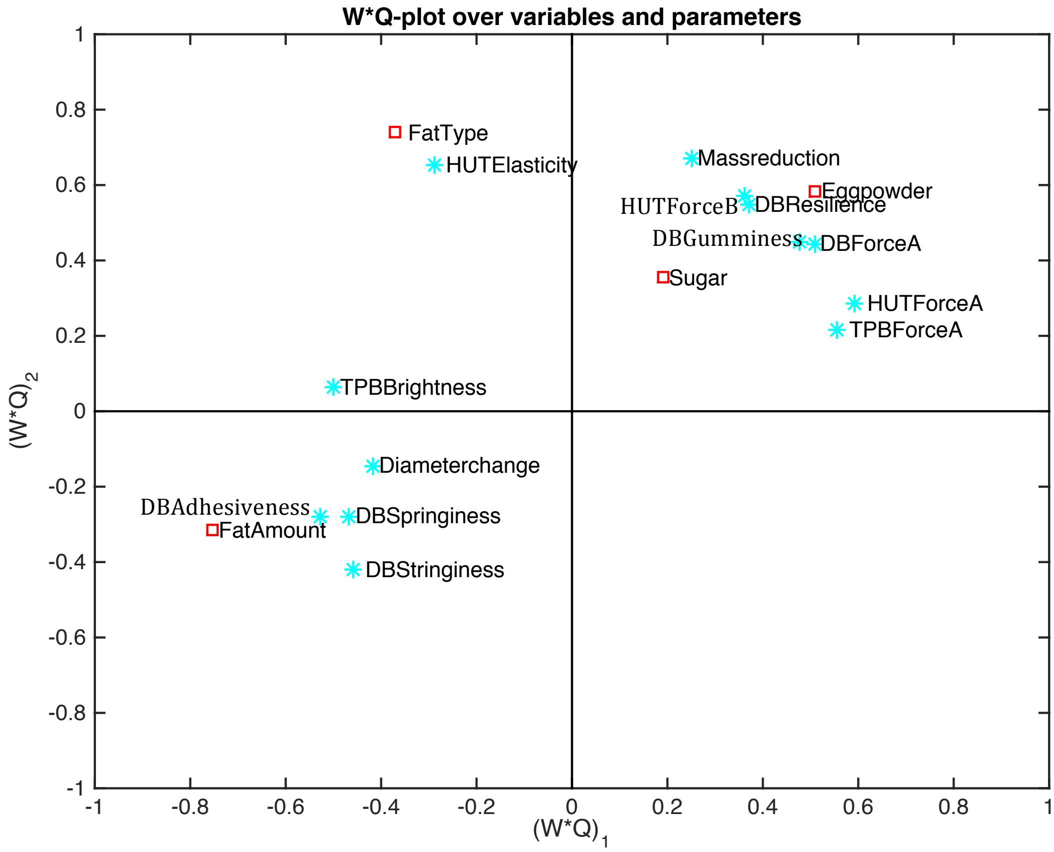

Figure 12 WQ-plot showing the relation between the important responses and the important design variables for all experiments.

Studying the relations between important responses and the important design variables for all experiments, showed that FatType had a positive relation to HUTElasticity (springiness obtained by Hold until time method), see Figure 12. This observation was also documented by Manohar and Rao (1999) and implies that shortening results in less springing dough than margarine does. This might be due to the water availability or distribution in the samples. The margarines used in the study contained 20% water (S100M0AAK, S100M1AAK, and S100M2AAK). When using shortening instead (S100S0AAK, S100S1AAK, and S100S2AAK), 20% water (of the total mass fat + water) was added to the creaming step. However, in the presence of sugar and egg powder (in most cases) the water might have been taken up by these molecules during the creaming process. Thus when later adding flour, the proteins probably had less water available than when using margarine, resulting in less developed gluten network.

Furthermore, the figure showed that the elasticity of the dough (DBSpringiness) was positively correlated with the fat amount. Lai and Lin (2006) stated that high fat amount in dough reduce its elastic properties. The same observation was made by Pareyt, Brijs, and Delcour (2010) on the same type of dough as the one in this report. However, the way the elasticity modulus was measured is different than the measurements done in this study. It was calculated from the slope of the linear part of the force curve (α) as a function of the diameter of the probe (D) (Equation 12, ν represents the Poisson ratio (0.5 for cookie dough)) (Pareyt, Brijs & Delcour 2009).

$$Elasticity\ modulus = \frac{\alpha(1-\nu^2)}{D} * 100\% \qquad (12)$$

Perhaps, in future studies, the elasticity modulus could be calculated and considered in the analysis. This would make these two studies comparable, since the elasticity modulus and the springiness calculated in this report (based on time fractions) are very distinct.

The figure also shows that the hardness of the dough (DBForceA, HUTForceA, and HUTForceB) decreased with increasing fat amounts. This has also been observed and reported in other studies (Maache-Rezzoug 1998) (Pareyt et al. 2009) and have been related to the increasing incorporation of air during mixing and by affecting gluten entanglement interactions and thus limiting the gluten formation (Pareyt, Brijs & Delcour 2010) (Manohar & Rao 1999). The resilience of the dough also decreased when increasing the fat amounts, meaning that the ability of the cookies to deform upon pressure increased. These were suggested to be related to the lubrication of the flour proteins and thus limiting the formation of gluten (Maache-Rezzoug 1998) (Manohar & Rao 1999).

4.2.7 The effect of dough texture on the texture of baked product.

From the previous W*Q-plots such as Figure 12 it could be seen that the textural parameters were divided into two groups that fell in opposite quadrants. For instance, the hardness of the final product (TPBForceA) showed a positive relation to the hardness, resilience, and gumminess of the dough. Figure 13 showed that these observations were still valid. In addition, the hardness, resilience, and gumminess of the dough positively affected the moisture loss but negatively the cookie diameter. This means that if the hardness of the final product and the total moisture loss was to be increased, then the hardness, resilience, and gumminess of the dough should be increased. However, if the cookie diameter was to be increased, then these parameters should be decreased. Since the hardness, gumminess, and resilience of the dough have shown to be negatively affected by the fat amount and positively by the egg powder content in the dough, the fat and egg amounts could be adjusted after desire to achieve a product with required diameter and hardness properties.

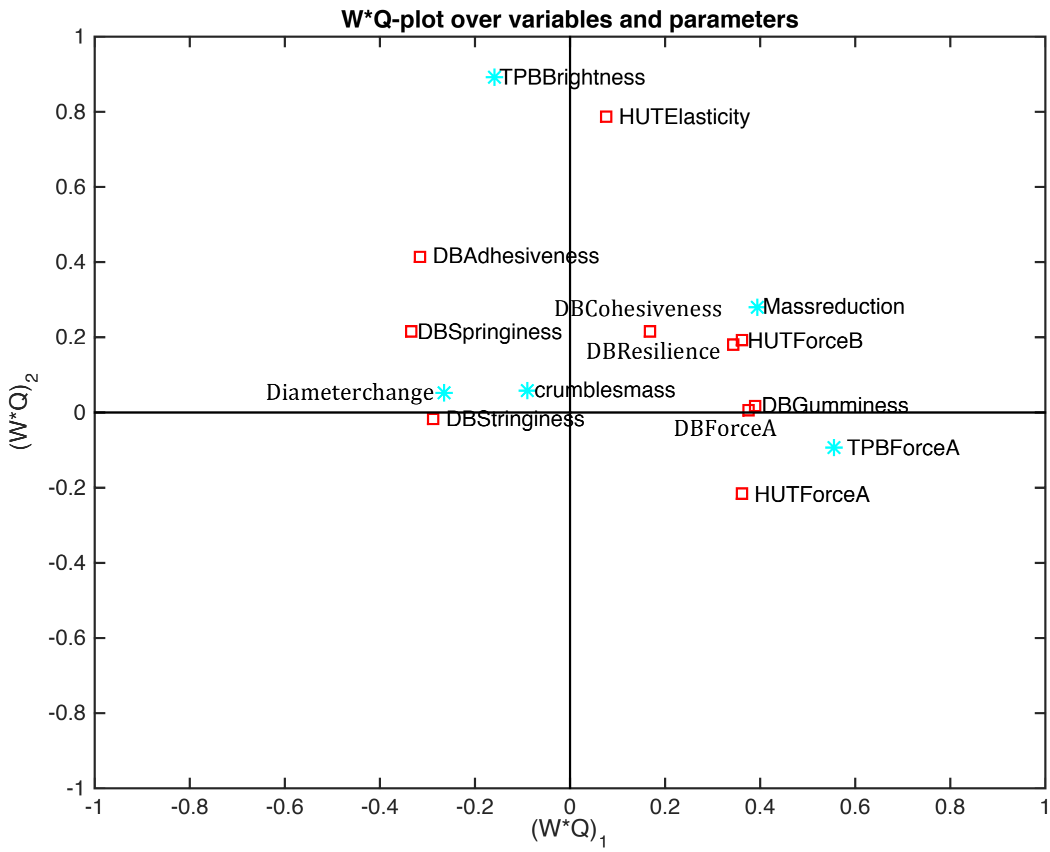

Figure 13 WQ-plot showing the relation between the textural parameters of the dough against the textural parameters of the baked product. The vector of responses is scaled up by 2X.

In order to study if these relations correspond to the actual data obtained from the measurements, as recommended by Bourne (1990), the data points were plotted and linear regression was applied to each pair of parameters that seemed to be related to each other in order to be examined for trend lines (Bourne 1990), (see Figure 14).

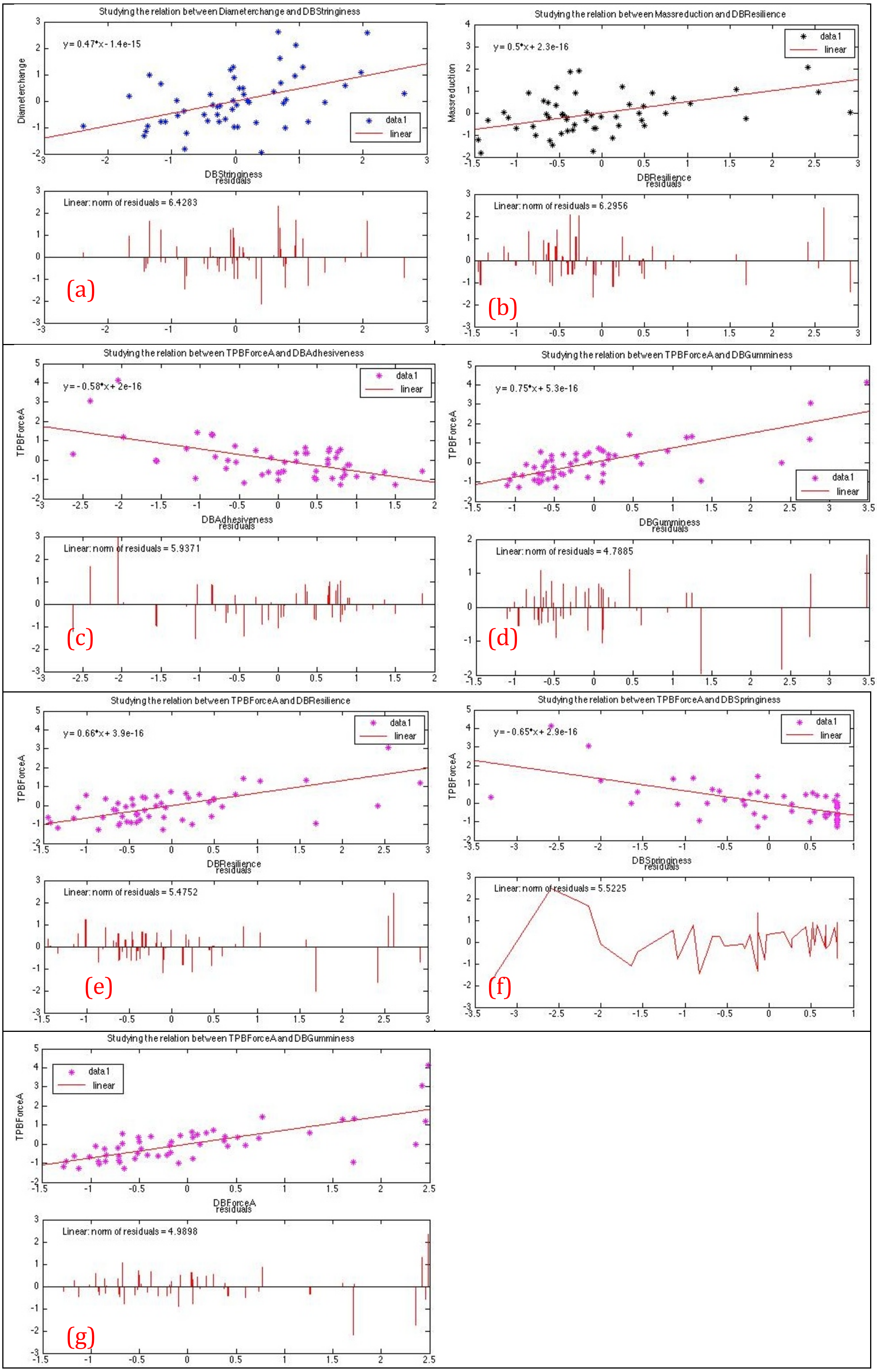

Figure 14 linear regressions applied to each pair of parameters that seemed to be related to each other.

The slope of the linear regressions applied to the data matched the relations observed in the previous figures, e.g. TPBForceA had a negative relation to DBSpringiness that had also been seen by linear regression since the slope was negative (Figure 14-f). In order to study if these relations were significant, Pearson correlation was applied to calculate a correlation coefficient (R) on 95% significance level. The R^2-value was then calculated using Equation 9. The different values are compiled in Table 4.

Table 4 compiling Pearson correlation coefficient, R^2, and the answer to the null hypothesis

Relation	R (Correlation coefficient)	H_0	R^2
Diameterchange vs. DBStringiness	0,46939	Rejected	0.2203
Massreduction vs. DBResilience	0,50221	Rejected	0.2522
TPBForceA vs. DBAdhesiveness	-0,57872	Rejected	0.3349
TPBForceA vs. DBGumminess	0,75326	Rejected	0.5674
TPBForceA vs. DBResilience	0,65918	Rejected	0.4344
TPBForceA vs. DBSpringiness	-0,65158	Rejected	0.4246
TPBForceA vs. DBForceA	0,72816	Rejected	0.5302

Since the experiments consisted of two different series conducted separately, and since the margarine series have been done before the shortening series, the experience of doing such experiments might have been greater when conducting the shortening series. This might have influenced the margarine series with some errors that are related to non-experienced hands. Thus, this could have affected the spread of the data points observed in Figure 14 (around the regression lines).

The relations seen in Table 4 between TPBForceA and DBAdhesiveness, DBGumminess, DBResilience, DBForceA, and DBSpringiness, seem to be the most accurate relations with R^2-value greater than the others. In addition, looking at the R-value, most of these relations have high correlation coefficients i.e. close to +1 or -1. Regarding the relations Diameterchange to DBStringiness and Massreduction to DBResilience, even though the null hypothesis is rejected, the R-values are not considered high enough to suggest that there are linear correlations since the values are between $-0.5 \leq 0 \leq +0.5$. Considering the effect of margarine series on R^2-values that have been discussed previously, it could be said that even though the relations between dough textural parameters and TPBForceA showed an R^2-value between 0.33 and 0.57, these are still considered high. At least, the relation TPBForceA to DBGumminess and DBForceA is high enough to say that by knowing the hardness and Gumminess of the dough samples, it is possible to predict the hardness of the finished products.

5 Conclusions

- The fat type showed a negative effect on the hardness of the baked product but a positive effect on the springiness of the dough. This means that shortening gives a harder cookies with lower springiness than what margarine does.
- The fat and egg amounts used affected the color of the baked product in opposite manners.
- The fat and sugar amounts affected the cookie spread during baking positively, i.e. increasing the sample diameter. In addition, sugar content increased the moisture loss during baking resulting in a lighter cookie mass.
- High fat amounts increased the springiness of the dough, but decreased gumminess. In addition, hardness and resilience of the dough decreased with increased fat amounts as well as the hardness of the finished product.
- The analysis showed that by knowing the hardness and/or the gumminess of the dough sample, it is possible to predict the hardness of the finished product.

6 Recommendations

In order to use the method developed in this report the following could be done:

1. Set criteria for what characteristics the finished product should have in terms of textural parameters such as hardness.
2. Mix the dough with the desired ingredients paying attention to how the ingredients may affect the texture of the dough and baked product, e.g. consider if margarine or shortening is to be used and in what amounts.
3. Take some dough samples and measure the hardness and gumminess by using a double compression cycle as the one used in this report.
4. Bake some of the samples and measure the hardness of the finished product using the method used in this report, i.e. Three Point Bend.
5. Compare the values to the set criteria. This will function as a reference for further measurements on future batches. For instance, if the hardness of the dough showed to be lower than the desired level, then the hardness and/or the gumminess of the dough mix should be increased. This could be adjusted by for example decreasing the fat amount used in the mix.

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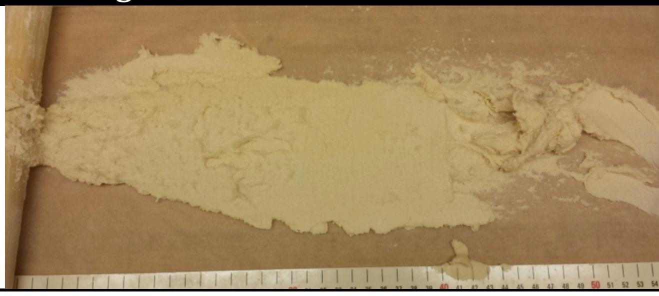
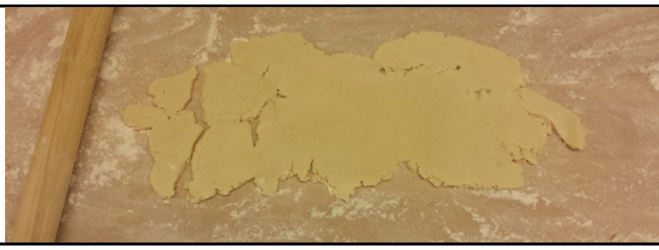
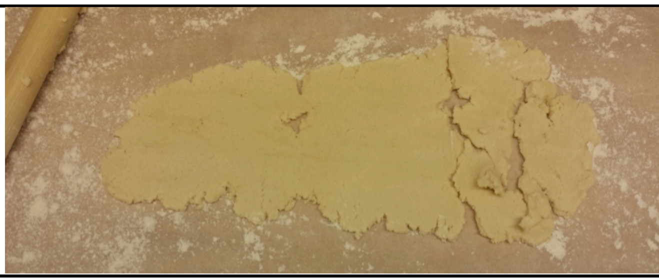
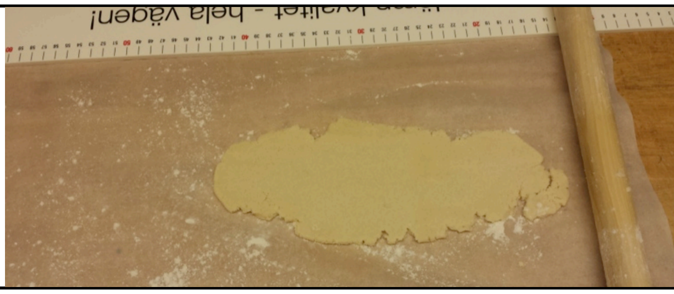
Appendix 1: Studying sheeting behavior

1.1 Testing sheeting at different temperatures and storage conditions (dough with fat S50).

The results are summarized in Table 5.

Table 5 Testing sheeting behavior at different temperatures and storage conditions.

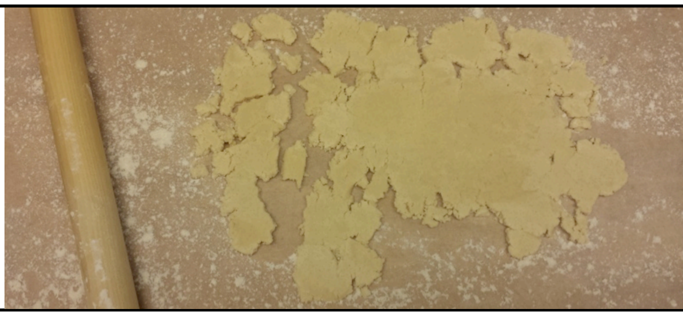
Description	Sheeting
Test 01. Fat S50. no water. Was not stored. Room temperatured	 Comments: Very difficult to sheet. Got stuck to almost everything.
Test 02. Fat S50. 20 % water. Was not stored. Room temperatured	 Comments: Sheeting was easier than the previous one, however it was still difficult. The dough got stuck to the "pin".
Test 1a. With S50 fat and added 20% water. Stored at 6.5 °C for 4 days. Took it out from the fridge and let it cool. Dough temp was 10.2 °C	 Comments: Sheeting of the dough was much better than that of before storage (Test 02). But still cracking. Will be compared to other temp and other doughs with different fat content.
Test 1b. With S50 fat and added 20% water. Stored at 6.5 °C for 4 days. Took it out from the fridge and let it cool. Dough temp 14.5 °C	

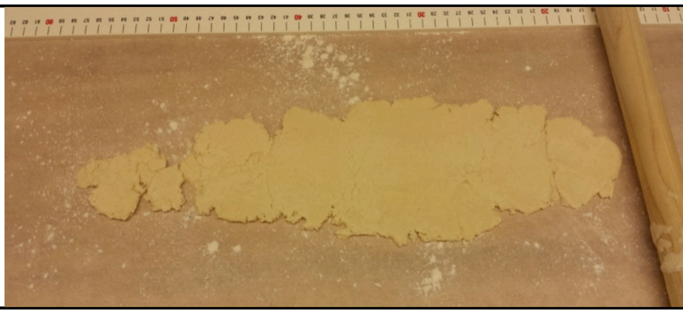
	Comments: Sheeting of the dough was better than that of before storage but cracked more than the one sheeted at 10 °C.
Test 2a. With margarine based on S50 fat and added 20% water. Not stored. Sheeted directly after mixing. Room temperatured (21.0 °C)	 Comments: Best sheeting behavior so far. Almost no problems with sheeting.
Test 2b. With margarine based on S50 fat and added 20% water. Stored for 1 day at 6.5°C. Dough temp 15 °C	 Comments: Sheeting without flour was a bit difficult since some parts of the dough got stuck to the "pin", however when sheeting on flour it was much easier. No cracks.
Conclusions	The first experiments showed that water should be added to the ingredients since no water is present in the fat. Adding water to the mix and sheeting directly after mixing did not improve the sheeting behavior. However, storing the dough in cold conditions improved the sheeting ability especially when sheeting the dough at 10 °C, i.e. when the dough is still cold. Furthermore, the sheeting ability was further improved if margarine was used instead of fat and water. Sheeting directly after mixing was significantly improved. Storing the dough in cold storage for 1 day showed even better sheeting behavior since no cracks were generated when sheeting the dough.

1.2 Test sheeting at different temp and storage conditions (dough with fat S100)

The results are compiled in Table 6.

Table 6 Testing sheeting at different temperatures and storage conditions.

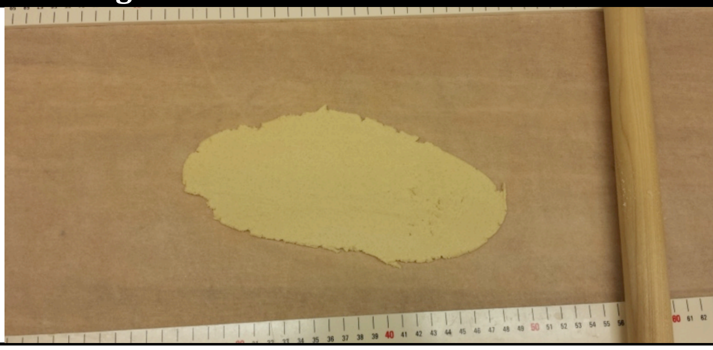
Description	Sheeting
Test 03. S100 fat + 20 % water. Was not stored. Room temperature.	 Comments: Very well sheeted. No problems at all.
Test 3a. With S100 fat and added 20% water. Stored at 6.5 °C for 4 days. Took it out from the fridge and let it cool. Dough temp 11.5°C	 Comments: Difficult to sheet since the dough fell apart. Sheeting without storing the dough was much more successful.
Test 3b. With S100 fat and added 20% water. Stored at 6.5 °C for 4 days. Took it out from the fridge and let it cool. Dough temp 15.5°C	 Comments: A little bit easier than the previous but still not even close to sheeting without storing.
Test 4a. With margarine based on S100 fat and added 20% water. Not stored. Sheeted directly after mixing. Room temperatured (21.5°C)	 Comments: Very well sheeted. Very similar to the behavior of Test 03.

Test 4a. With margarine based on S100 fat and added 20% water. Dough stored for 1 day at 6.5 °C. Dough temp 15.0°C	 Comments: Difficult to sheet without flour, but with flour sheeted well.

1.3. Test sheeting at different temp and storage conditions (dough with margarine Marba Delikatess)

The results and conclusions are presented in the following table (see Table 7).

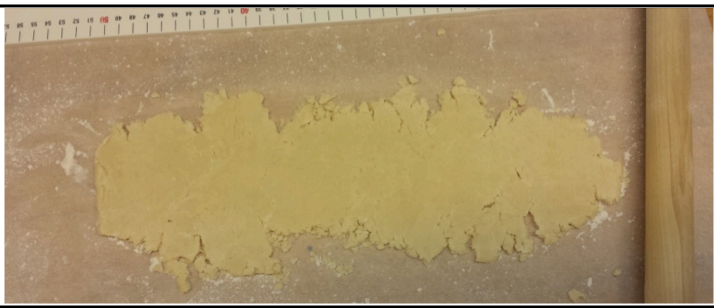
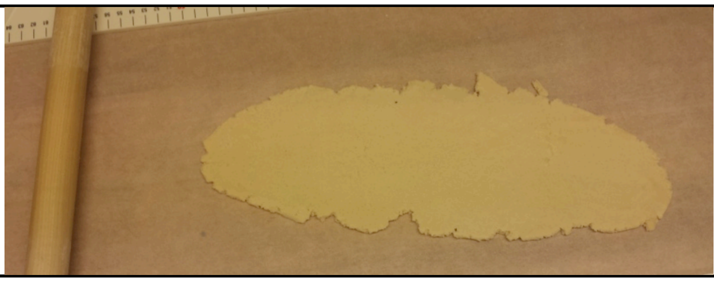
Table 7 Sheeting behavior at different temperatures and storage conditions.

Description	Sheeting
Test 5a. With Marba Delikatess margarine. Not stored and sheeted directly after mixing. Room temperature dough. (21,5°C)	 Comments: No problems at all when sheeting, even without flour.
Test 5b. With Marba Delikatess margarine. Stored for one day at 6,5 °C. dough temperature 10.5 °C.	 Comments: Difficult to sheet with and without flour.
Conclusion	The Marba Delikatess margarine showed a very convenient and easy sheeting behavior, however, if sheeted directly after mixing. When the dough was stored and sheeted at lower temperature, the sheeting was less successful even when sheeting on flour. Therefore, if this margarine was to be used, it would be preferable to sheet directly after mixing.

1.4 Test sheeting dough with eggs at different temp and storage conditions

The results are shown in Table 8.

Table 8 Sheeting behavior with eggs at different temperatures and storage conditions.

Description	Sheeting
Test 6a. With S100 fat, and egg powder. Sheeted directly after mixing. Room temperature dough.	 No sheeting problems even without flour.
Test 6b. With S100 fat, and egg powder. Stored for 6 days. Room temperature dough.	 Cracked in many places and was very difficult to sheet. Poor elasticity was observed.
Test 7a. With S100 fat, and whole eggs. Sheeted directly after mixing at room temperature.	 No sheeting problems even without flour.
Test 7b. With S100 fat, and whole eggs. Stored for 6 days. Sheeted at room temperature.	Picture missing

Conclusion	No difference was observed between using egg powder or whole eggs. But, for convenience sake, it would be easier to use egg powder.

Summing up the results S100 margarine was shown to have best sheeting behavior whether sheeted directly after mixing or after cold storage. The other fats or margarines showed good sheeting behavior in some of the conditions. However, S50 margarine had almost the same properties as S100 margarine, but since S100 fat is more available it will be used in further analyses. Moreover, the good sheeting ability before and after storage would be favorable in case there is not room for making all measurements the same day and thus the dough needs to be stored for the next day. Adding egg to the dough enhanced the sheeting performance, but no difference was observed between using egg powder or whole eggs. Therefore, egg powder will be used in case it is needed.

Appendix 2: Calculating reasonable sample diameter

The volume (Equation 12) of dough before deformation is equal to the volume after. (if 40% compression is used the resulting height will be 60% of the original one)

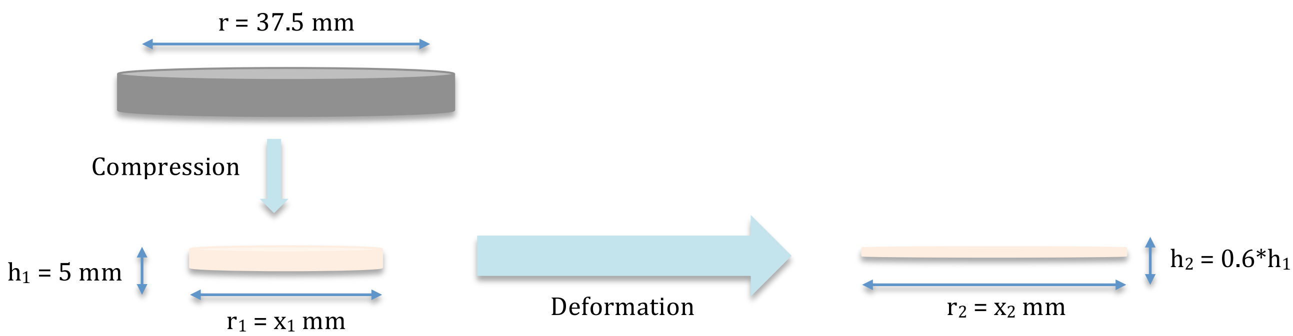
$$Volume = \pi * r^2 * h \tag{12}$$

$$\pi * r_1^2 * h_1 = \pi * r_2^2 * h_2$$

$$r_1^2 * 5 = r_2^2 * 0.6 * 5$$

$$\frac{r_1}{r_2} = 0.77; if\ r_2 \leq 37.5\ mm => \ r_1 \geq 29.1\ \ mm$$

Therefore, a form with a diameter of 42 mm was used to cut out shortcrust samples.



Appendix 3: Statistical calculations

3.1 Changes in water content, water activity, and texture during time

The f-values obtained by ANOVA are presented in Table 9.

Table 9 The f-value vs. the critical f-value obtained by ANOVA showing if the differences are significant or not.

	$F_{(4)}$[a]	$F_{crit\ (4)}$	$F_{(3)}$	$F_{crit\ (3)}$	$F_{(2)}$	$F_{crit\ (2)}$
ForceA	89.84502[b]	6.59138	36.43556	9.55209	116.55953	18.51282
ForceB	53.421	6.59138	33.74962	9.55209	37.74076	18.51282
Springiness	0.27399	6.59138	------------	------------	------------	------------
Resilience	9.531	6.59138	16.61142	9.55209	10.878	18.51282
Stringiness	5.48784	6.59138	------------	------------	------------	------------
Adhesiveness	34.31664	6.59138	4.14322	9.55209	------------	------------
Cohesiveness	0.86248	6.59138	------------	------------	------------	------------
Gumminess	40.98682	6.59138	4.61896	9.55209	------------	------------
Chewiness	0.5028	6.59138	------------	------------	------------	------------

a) The suffixes 4,3, and 2 stand for the number of times included (2 for 2 times (1h and 2h)).
b) The numbers in green are significantly different but not those in red.

3.2 Dough temperature impact on texture analysis

The f-values obtained by ANOVA are presented in Table 10.

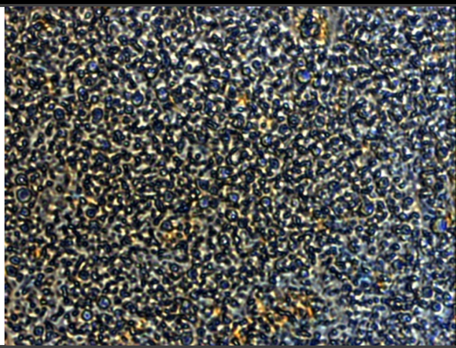
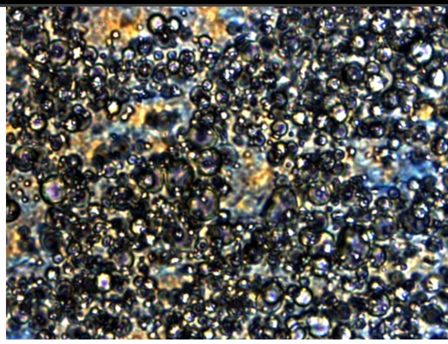
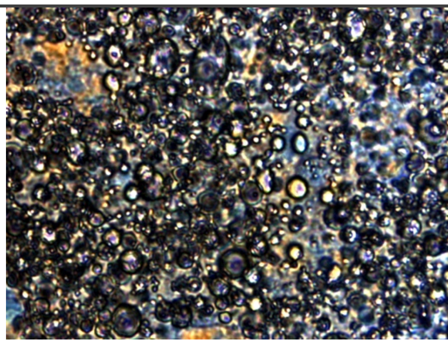
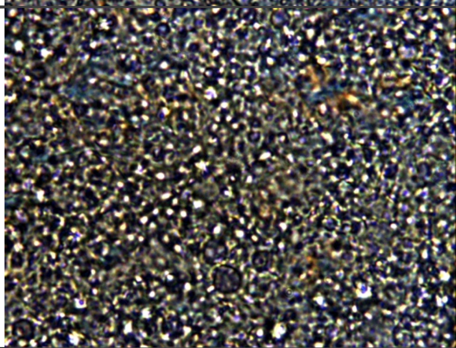
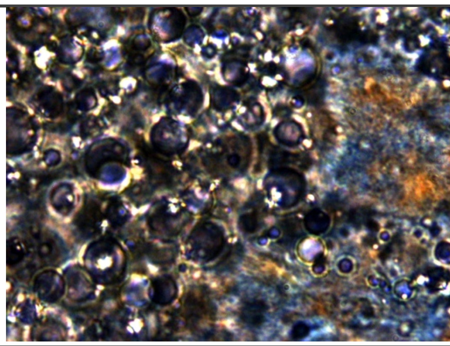
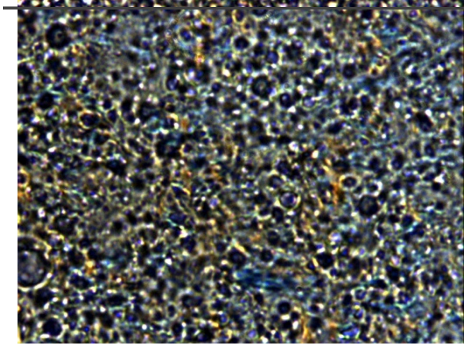
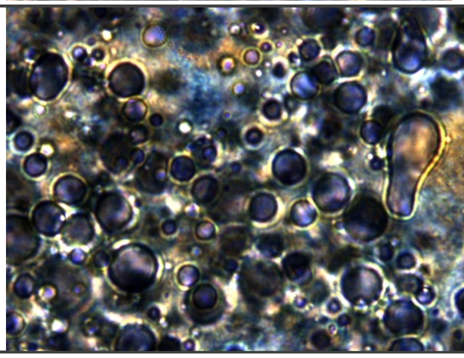
Table 10 The f-value vs. the critical f-value obtained by ANOVA showing if the differences are significant or not. The numbers in green are significantly different but not those in red.

	F	F_{crit}
Hardness	34,16918	3,88529
Springiness	12,43127	3,88529
Resilience	9,00893	3,88529
Stringiness	0,37077	3,88529
Adhesiveness	0,24819	3,88529
Cohesiveness	0,09568	3,88529
Gumminess	13,70938	3,88529
Chewiness	10,30336	3,88529

Appendix 4: Microscopy

The major difference observed between Marba Delikatess and S100MLab (produced by hand in the lab see section 3.1) was the size of the water bubbles incorporated see Table 11.

Table 11 microscopic pictures of the different margarine types examined at 50X and 100X.

Magnification	Marba Delikatess	S100 Margarine
50X		
		
100X		
		

Appendix 5: Factorial Design

The amounts that correspond to the sign in Table 2 in section 3.3 are presented in Table 12.

Table 12 The amounts of the different ingredients that were used for the different experiments.

Amounts (g)						
Flour	**Sugar**	**Fat+ water**	**Fat**	**Water**	**Egg amount**	**Total**
300	125	225	180	45	25	675
300	125	225	180	45	0	650
300	125	175	140	35	25	625
300	125	175	140	35	0	600
300	75	225	180	45	25	625
300	75	225	180	45	0	600
300	75	175	140	35	25	575
300	75	175	140	35	0	550
300	125	225	180	45	25	675
300	125	225	180	45	0	650
300	125	175	140	35	25	625
300	125	175	140	35	0	600
300	75	225	180	45	25	625
300	75	225	180	45	0	600
300	75	175	140	35	25	575
300	75	175	140	35	0	550
300	125	200	160	40	12,5	637,5
300	75	200	160	40	12,5	587,5
300	100	225	180	45	12,5	637,5
300	100	175	140	35	12,5	587,5
300	100	200	160	40	25	625
300	100	200	160	40	0	600
300	100	200	160	40	12,5	612,5
300	100	200	160	40	12,5	612,5
300	100	200	160	40	12,5	612,5
300	100	200	160	40	12,5	612,5
300	100	200	160	40	12,5	612,5
300	125	225			25	675
300	125	225			0	650
300	125	175			25	625
300	125	175			0	600
300	75	225			25	625
300	75	225			0	600
300	75	175			25	575
300	75	175			0	550
300	125	225			25	675
300	125	225			0	650
300	125	175			25	625

300	125	175	0	600
300	75	225	25	625
300	75	225	0	600
300	75	175	25	575
300	75	175	0	550
300	125	200	12,5	637,5
300	75	200	12,5	587,5
300	100	225	12,5	637,5
300	100	175	12,5	587,5
300	100	200	25	625
300	100	200	0	600
300	100	200	12,5	612,5
300	100	200	12,5	612,5
300	100	200	12,5	612,5
300	100	200	12,5	612,5
300	100	200	12,5	612,5

Appendix 6: Graphs and tables related to chemometrics

6.1 Biplots and validations obtained by PCA

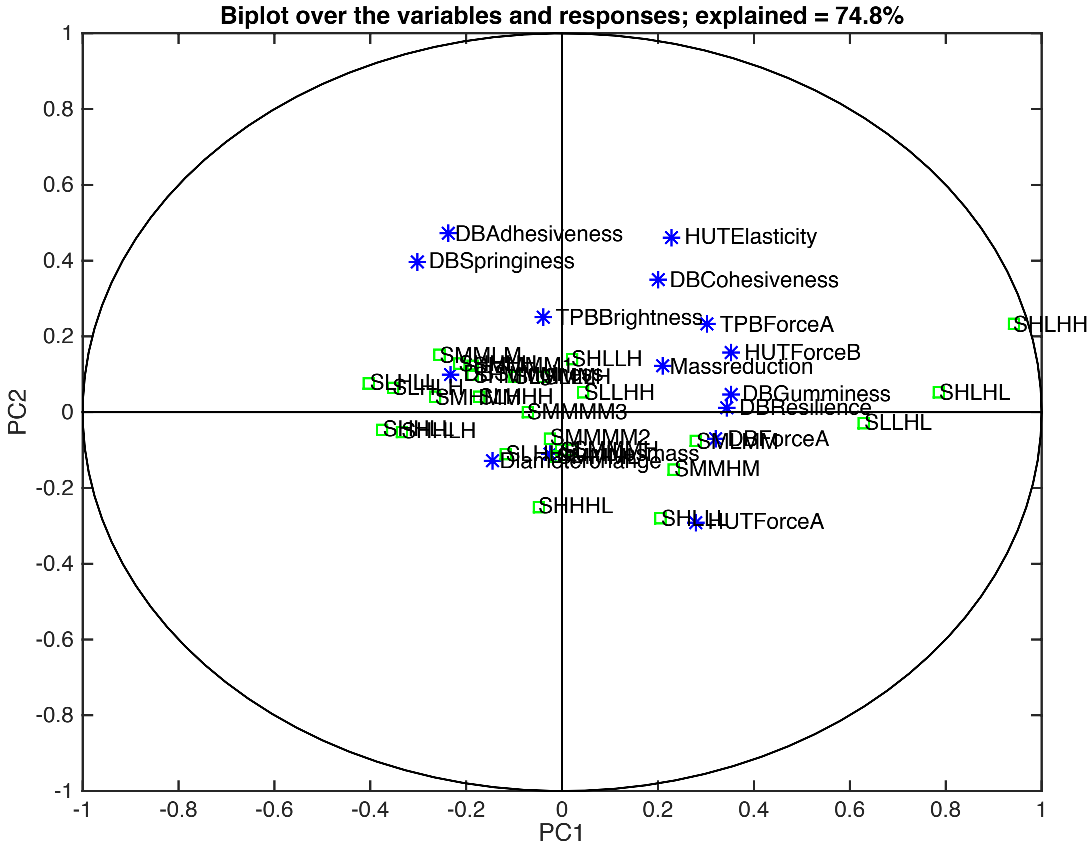


Figure 15 Biplot over the loadings and the scores of the shortening series (S100S0AAK, S100S1AAK, and S100S2AAK).

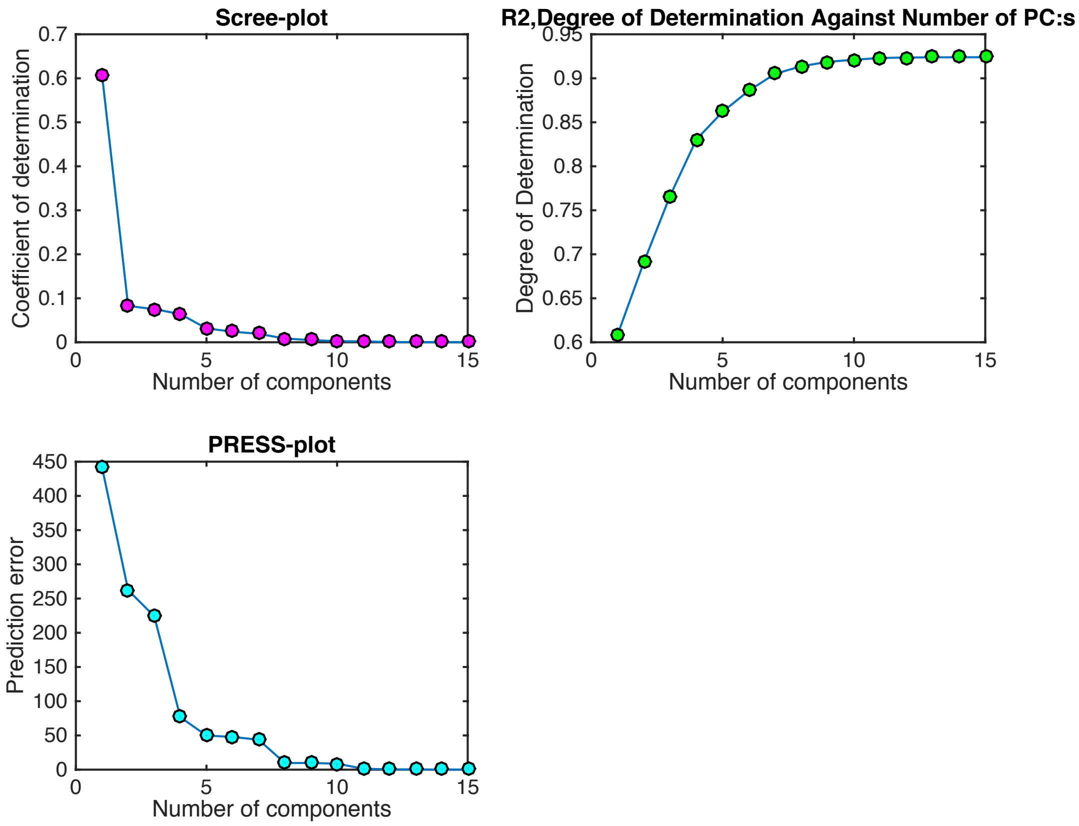


Figure 16 Experiments done with shortenings (S100S0AAK, S100S1AAK, and S100S2AAK). The validation of the PC choice is presented in Figures a, b, and c.

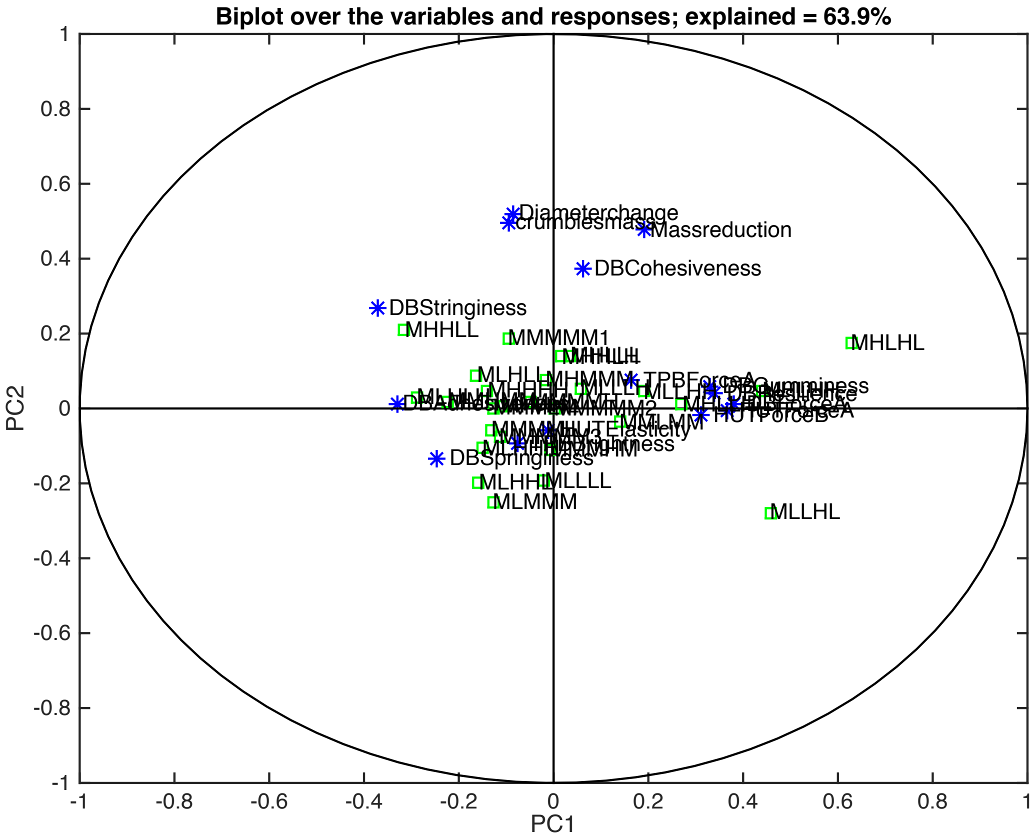


Figure 17 Biplot over the loadings and the scores of the margarine series (S100M0AAK, S100M1AAK, and S100M2AAK).

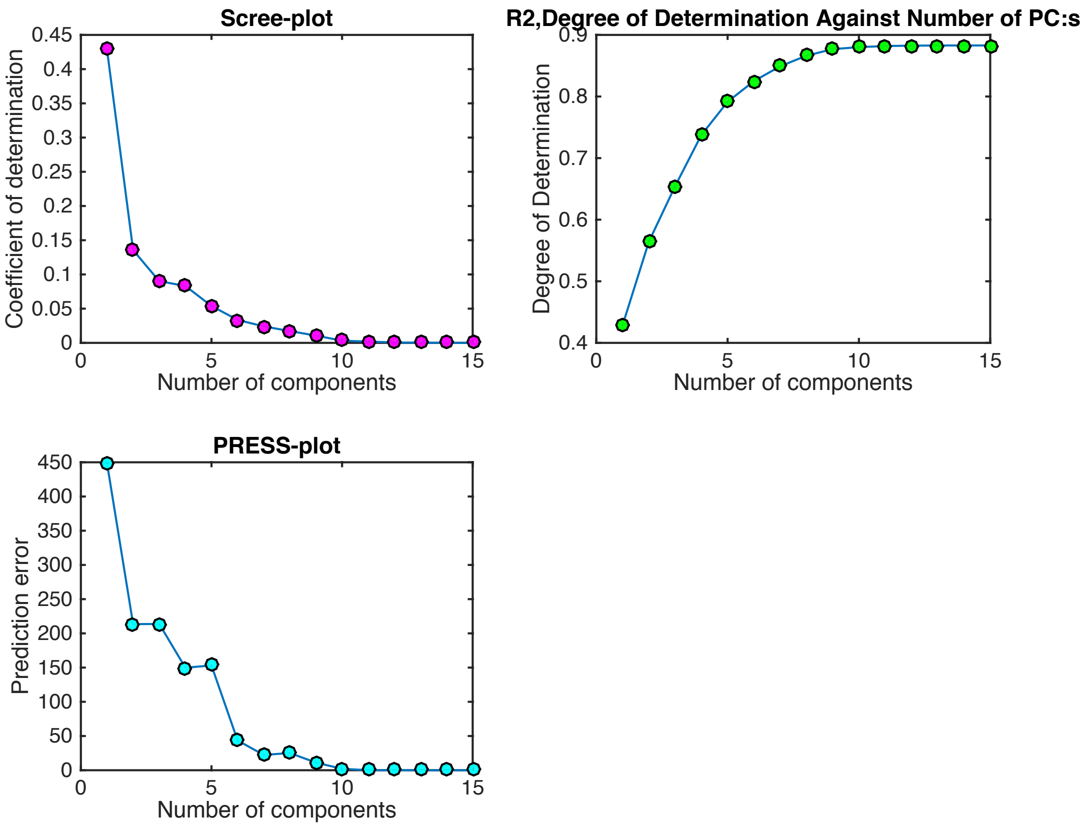


Figure 18 Experiments done with margarines (S100M0AAK, S100M1AAK, and S100M2AAK). The validation of the PC choice is presented in Figures a, b, and c.

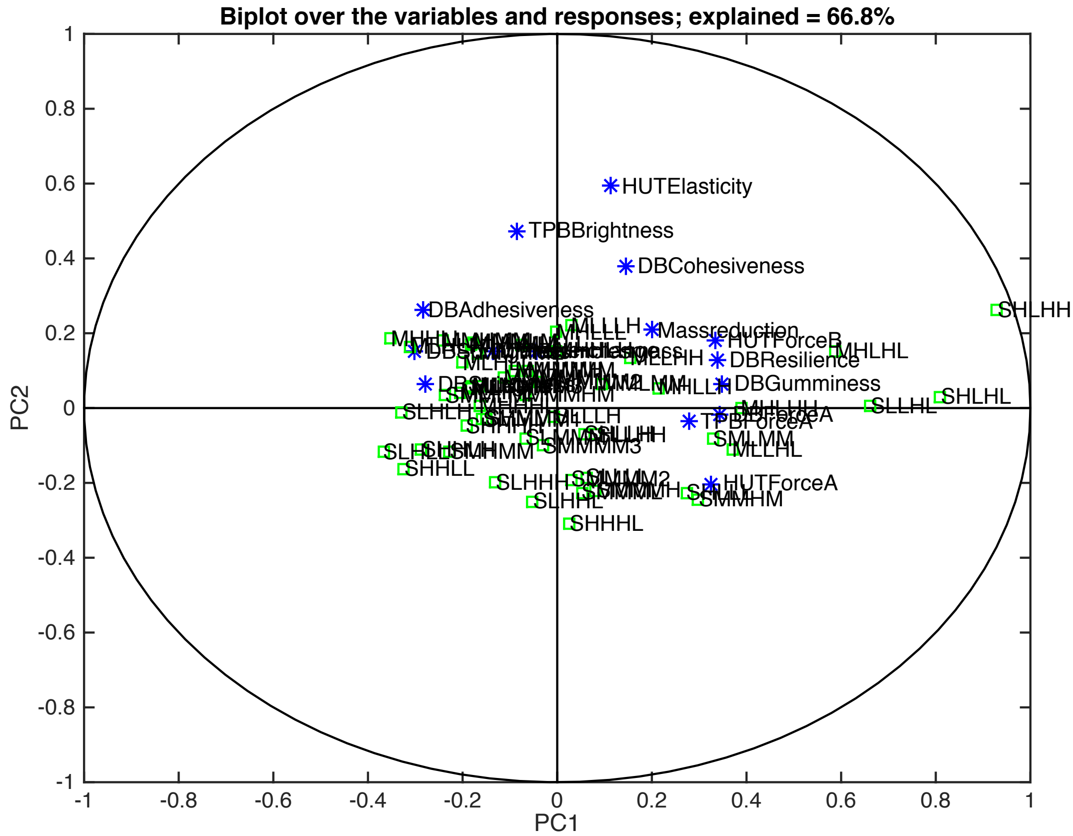


Figure 19 Biplot over the loadings and the scores of all experiments (done using S100S0AAK, S100S1AAK, S100S2AAK, S100M0AAK, S100M1AAK, or S100M2AAK.).

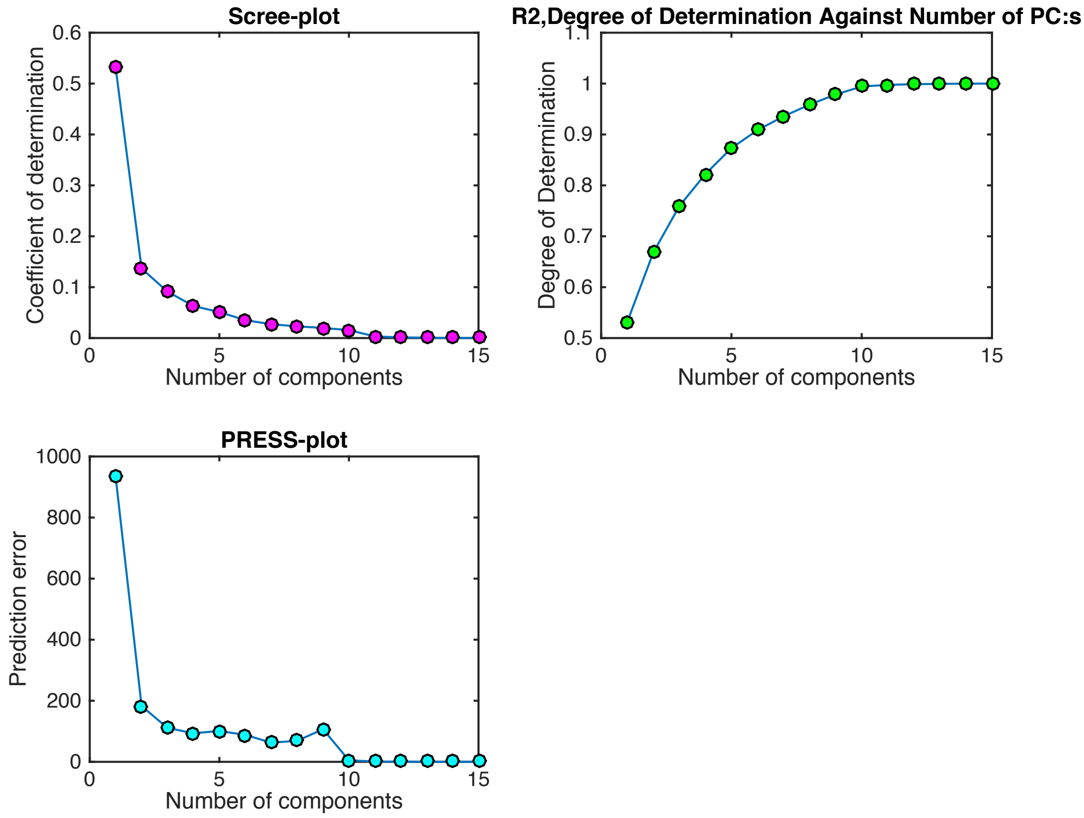


Figure 20 Experiments that were done using . The validation of the PC choice is presented in figures a, b, and c

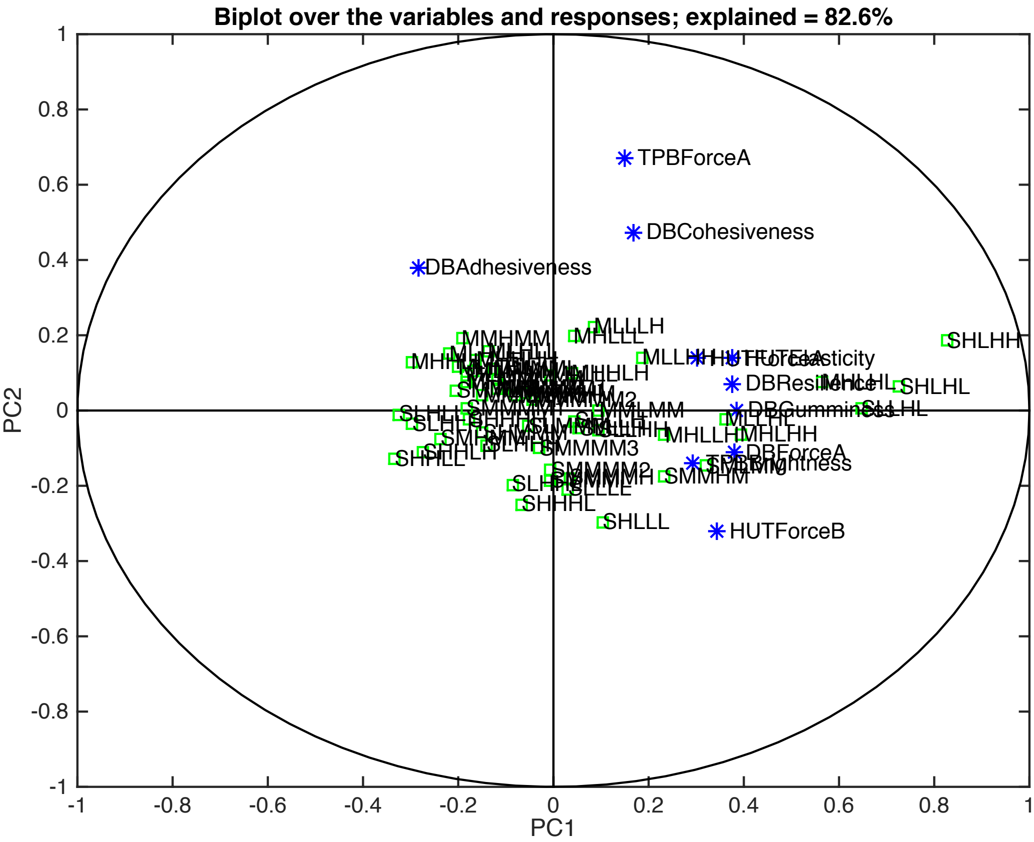


Figure 21 A biplot over the most expressed parameters against all scores.

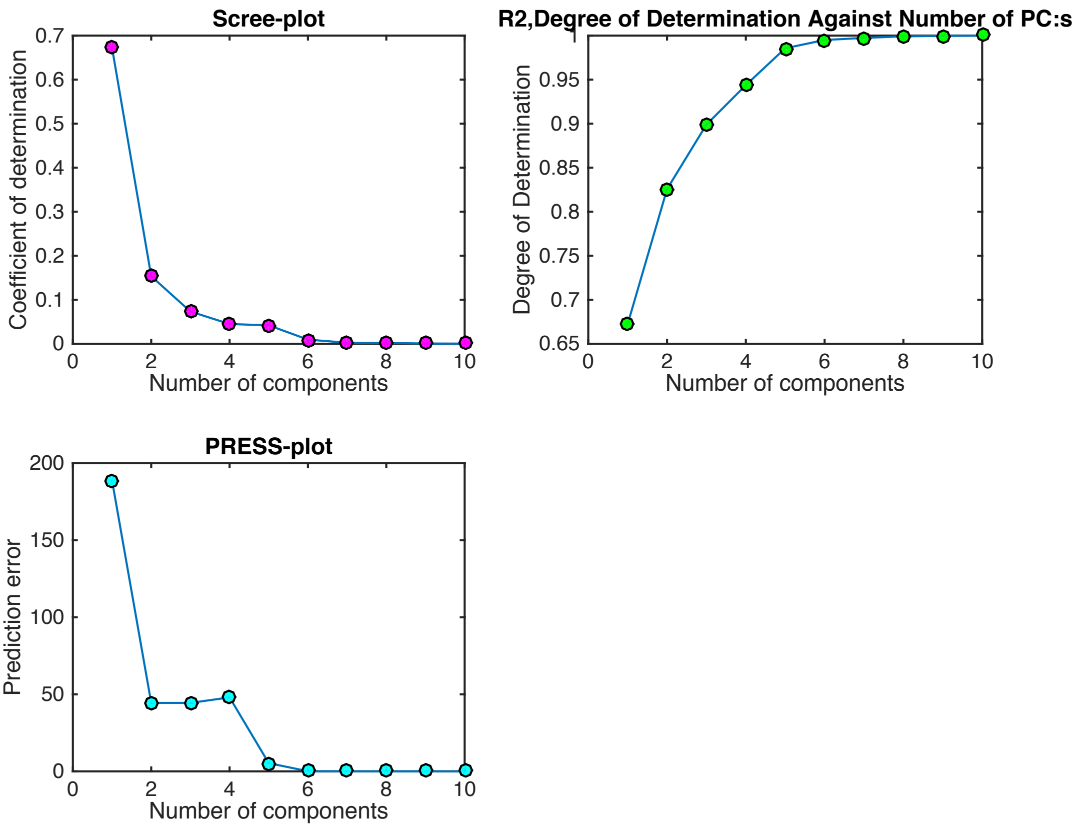


Figure 22 Most expressed parameters against all scores. Validation of the component choice showing that 2 PC:s are enough to describe the data.

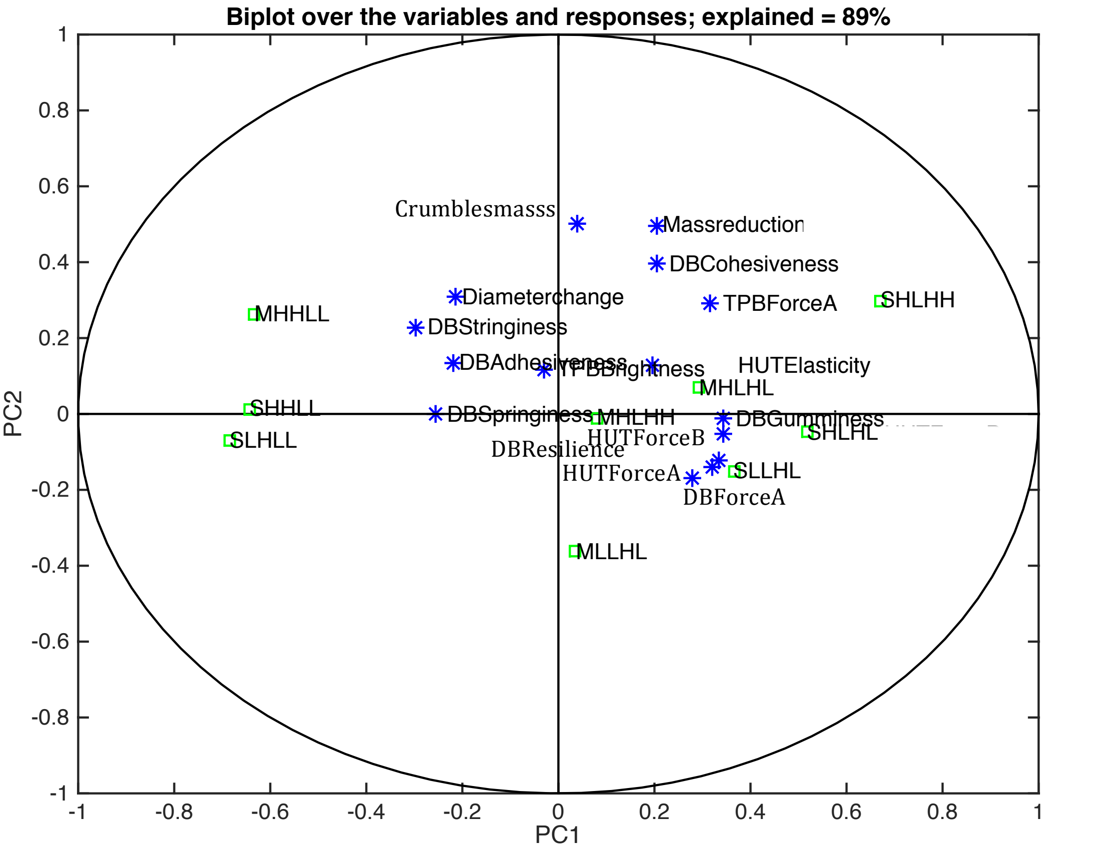


Figure 23 Biplot over the most expressed variables against all responses with an explanation degree of 89%.

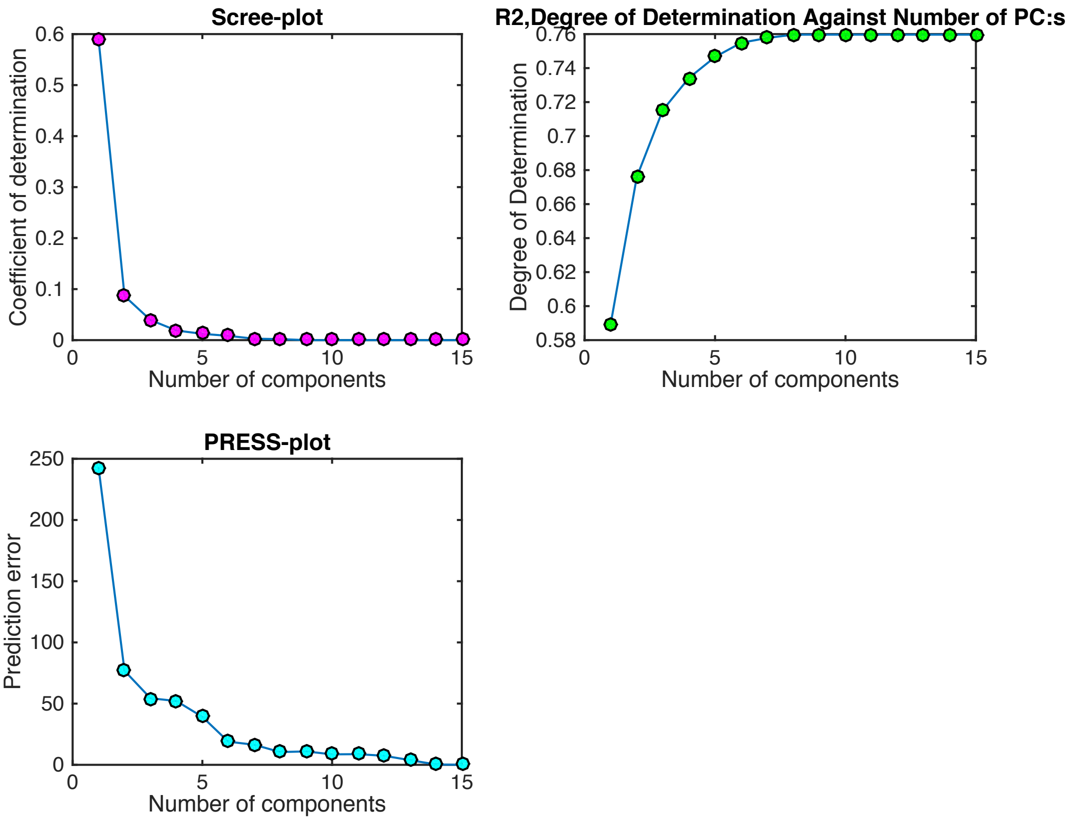


Figure 24 Most expressed variables against all responses. Validation of the component choice showing that 2 PC:s are enough to describe the data.

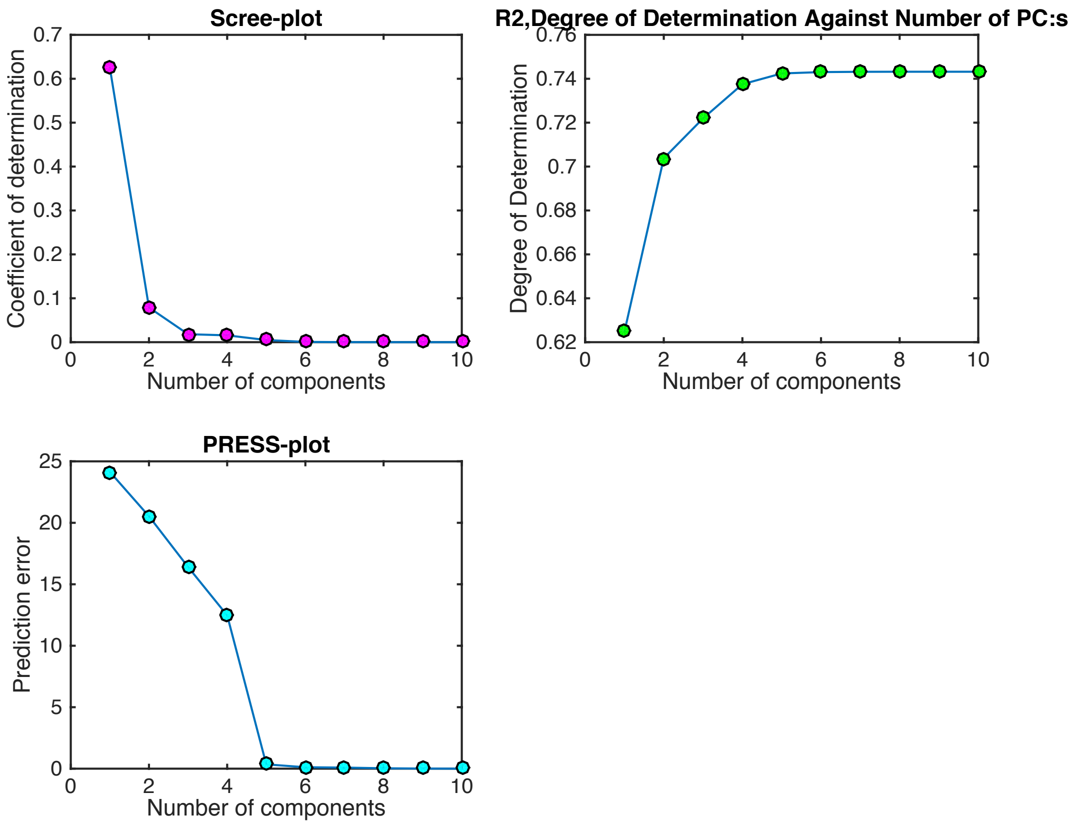


Figure 25 Most expressed variables against most expressed responses. Validation of the component choice showing that 2 PC:s are enough to describe the data

6.2 WQ-plot obtained by PLS2

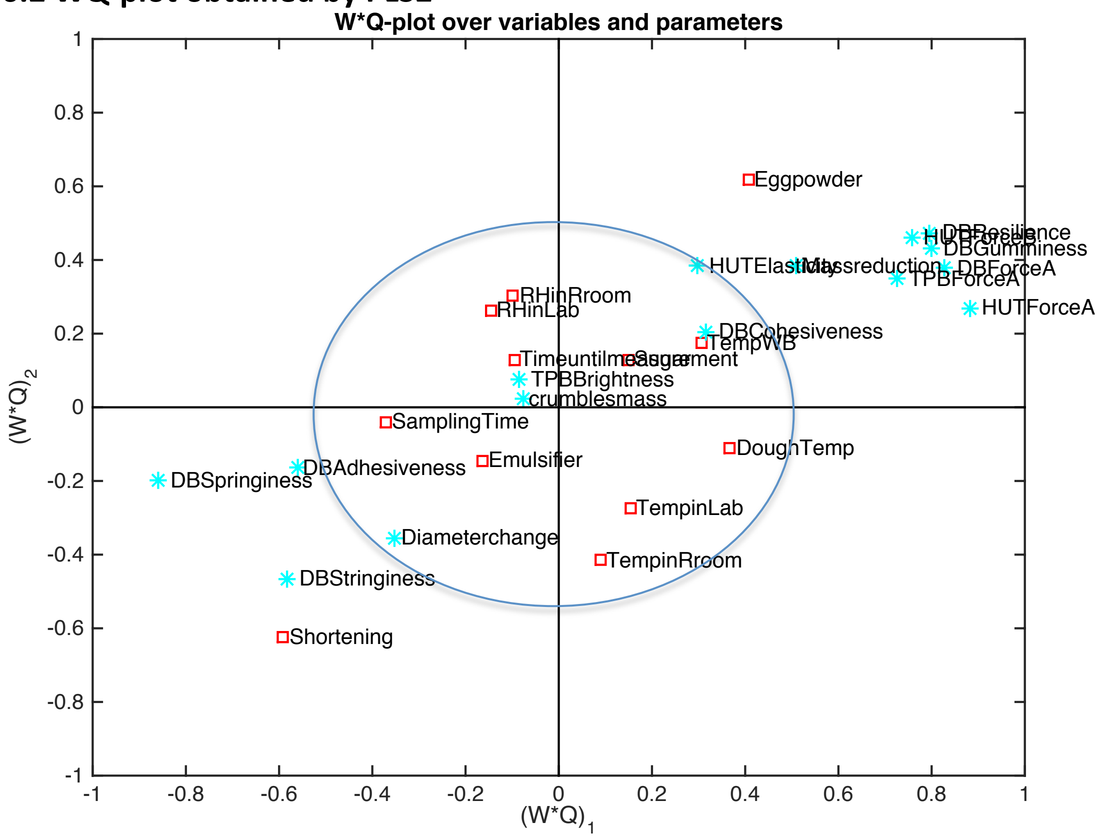


Figure 26 WQ-plot showing the relation between the responses and all variables (ingredients and room conditions) for shortening series. The vector of responses is scaled up by 1.5X.

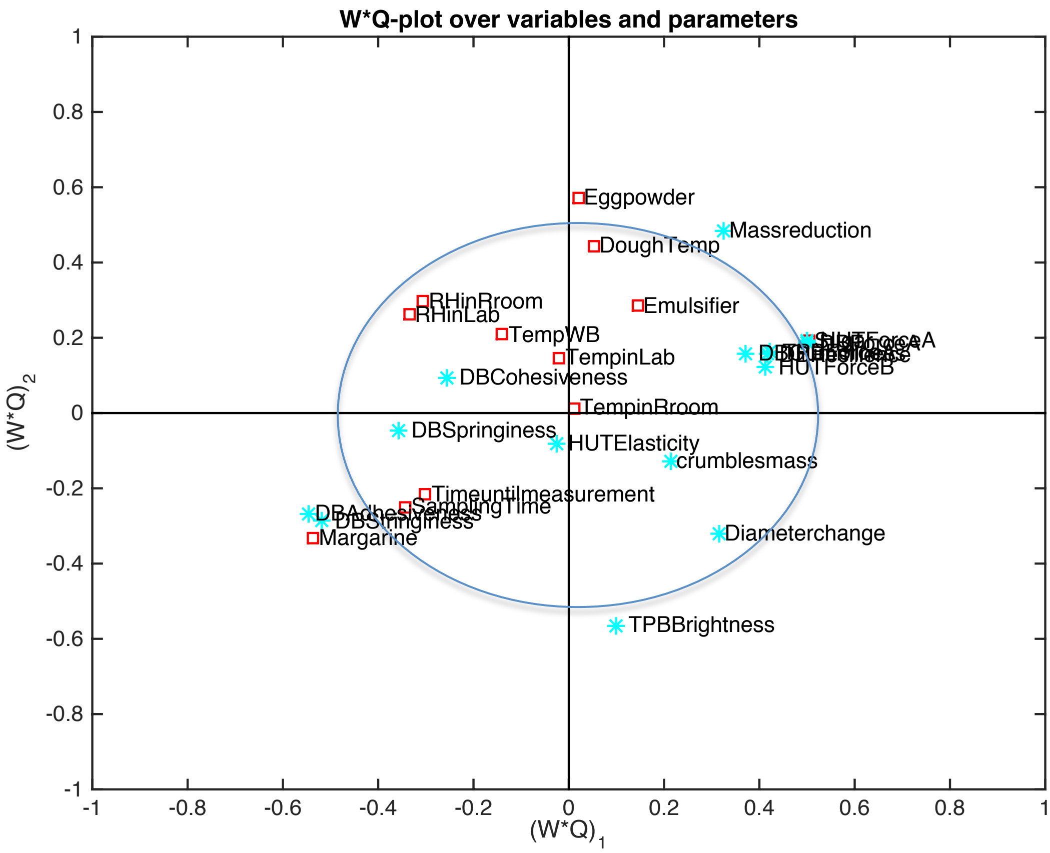


Figure 27 WQ-plot showing the relation between the responses and all variables (ingredients and room conditions) for margarine series. The vector of responses is scaled up by 1.5X

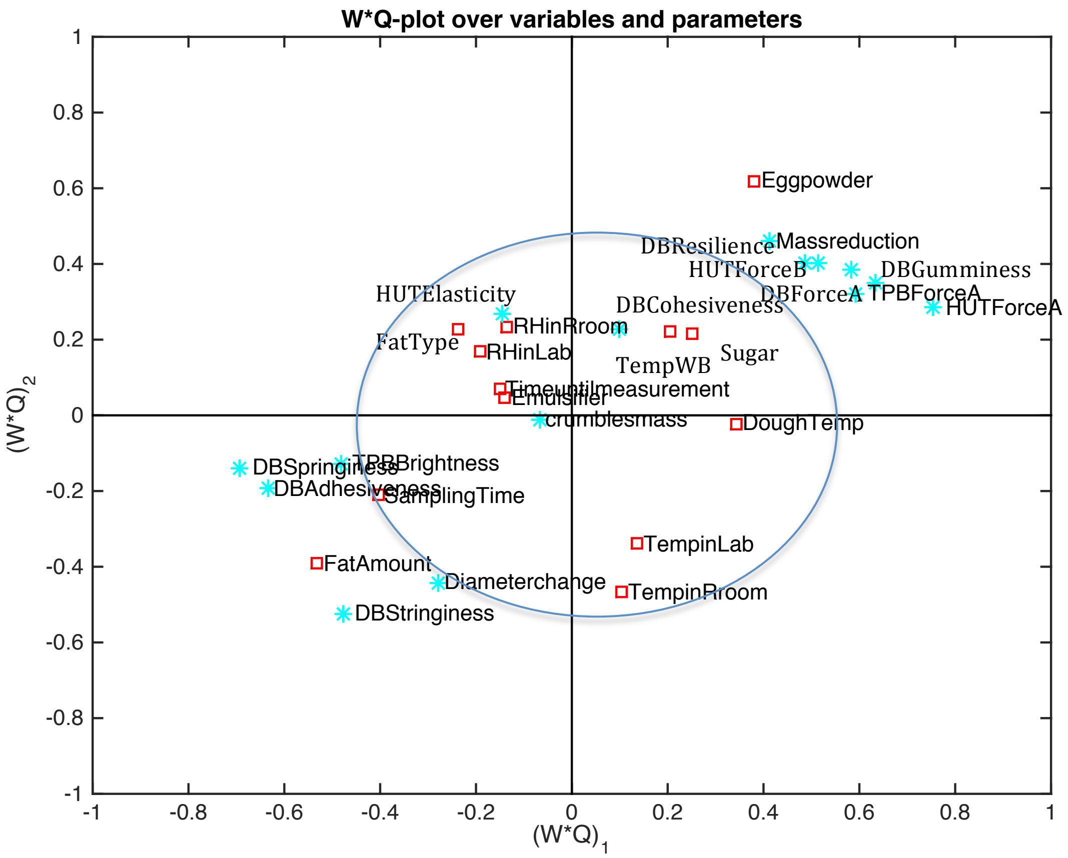


Figure 28 WQ-plot showing the relation between the responses and all variables (ingredients and room conditions) for all experiments (shortening and margarine). The vector of responses is scaled up by 1.5X

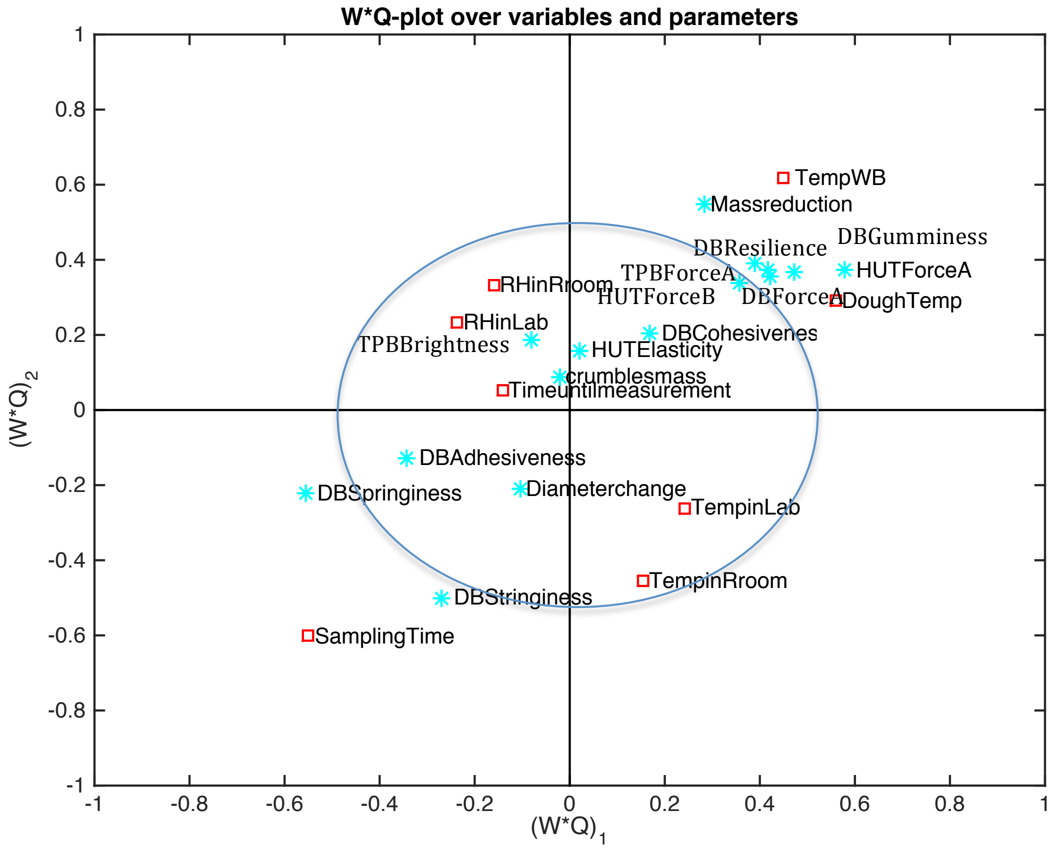


Figure 29 WQ-plot showing the relation between the responses and the room conditions variables for shortening series. The vector of responses is scaled up by 1.5X

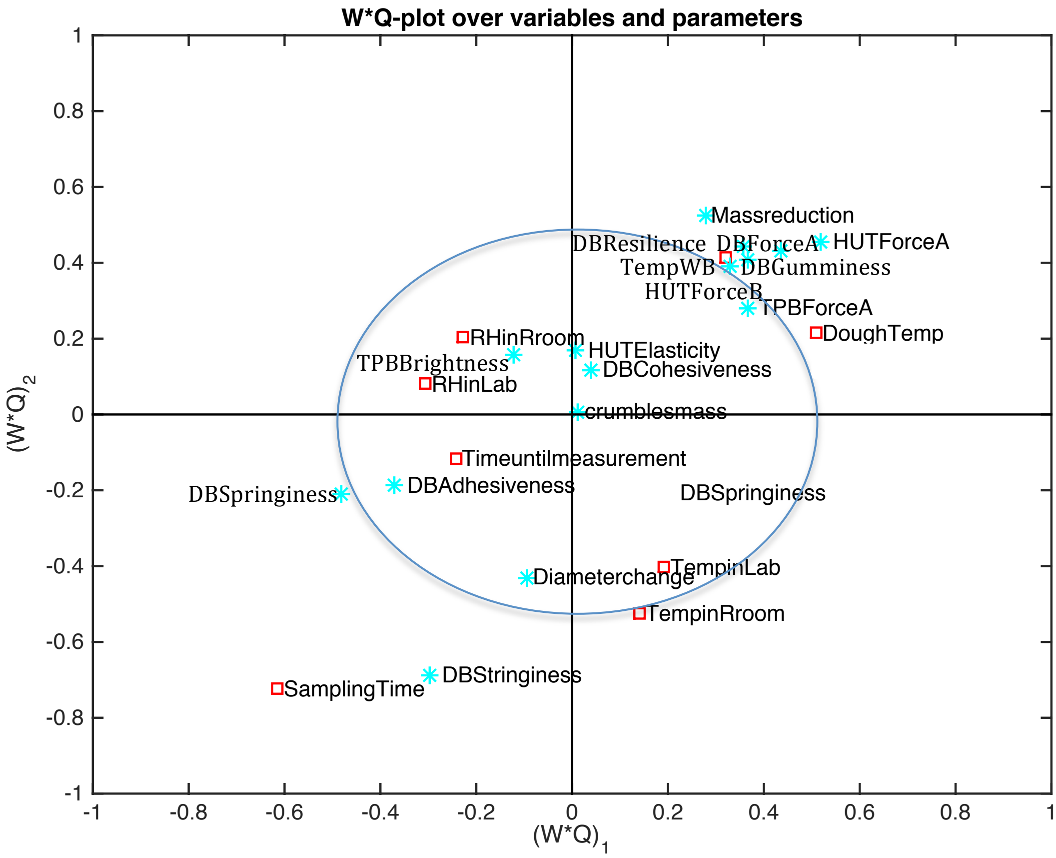


Figure 30 WQ-plot showing the relation between the responses and the room conditions variables for shortening and margarine series together. The vector of responses is scaled up by 1.5X

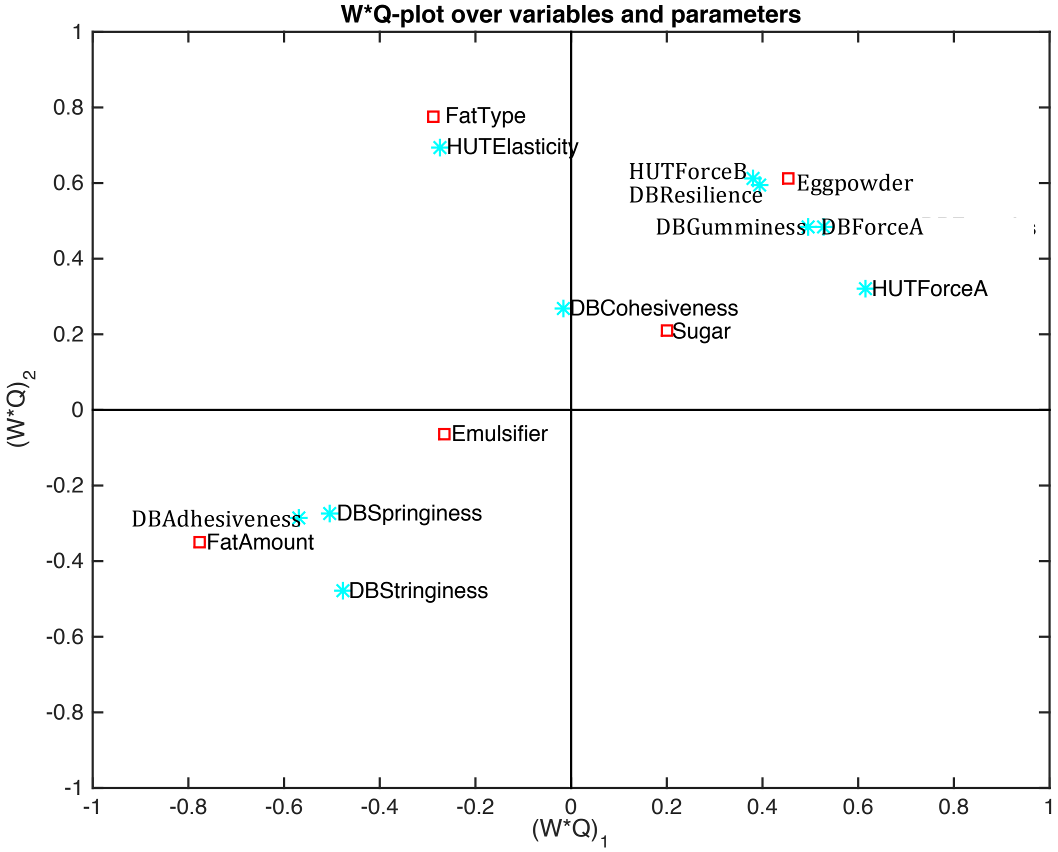


Figure 31 WQ-plot showing the relation between the textural parameters of the dough and the design variables for all experiments.

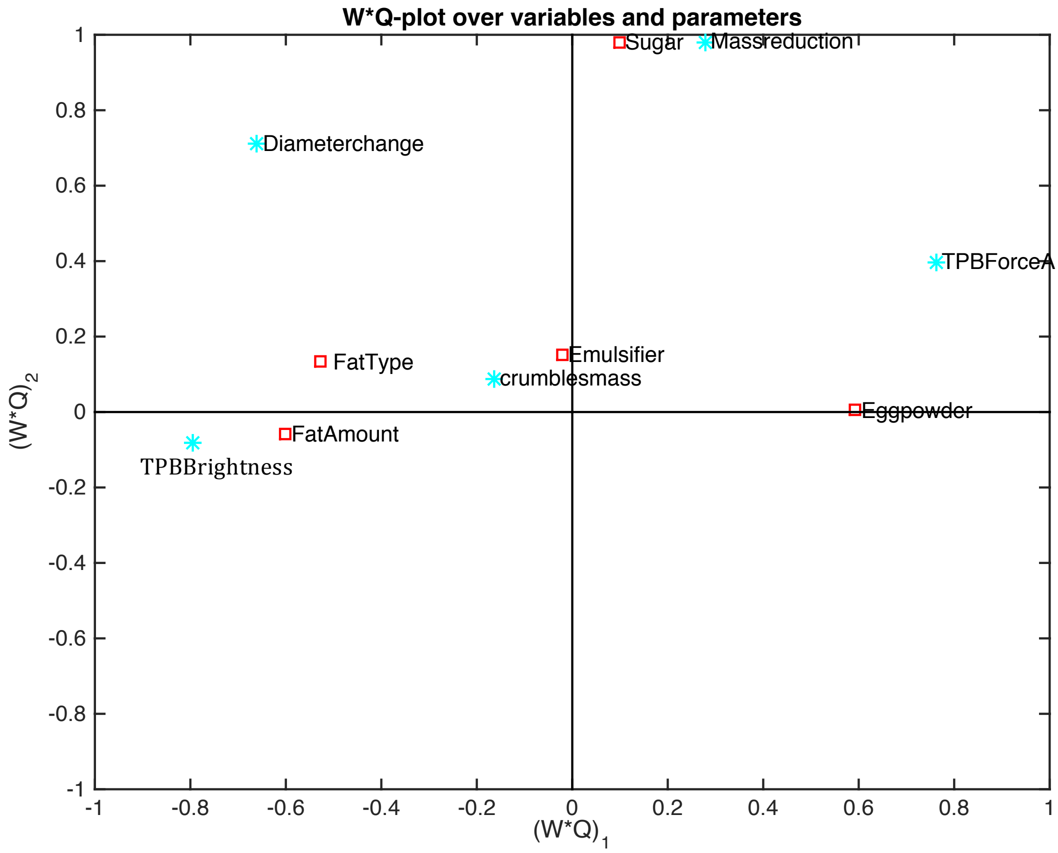


Figure 32 WQ-plot showing the relation between the textural parameters of the baked product and the design variables for all experiments. The vector of responses is scaled up by 1.5X

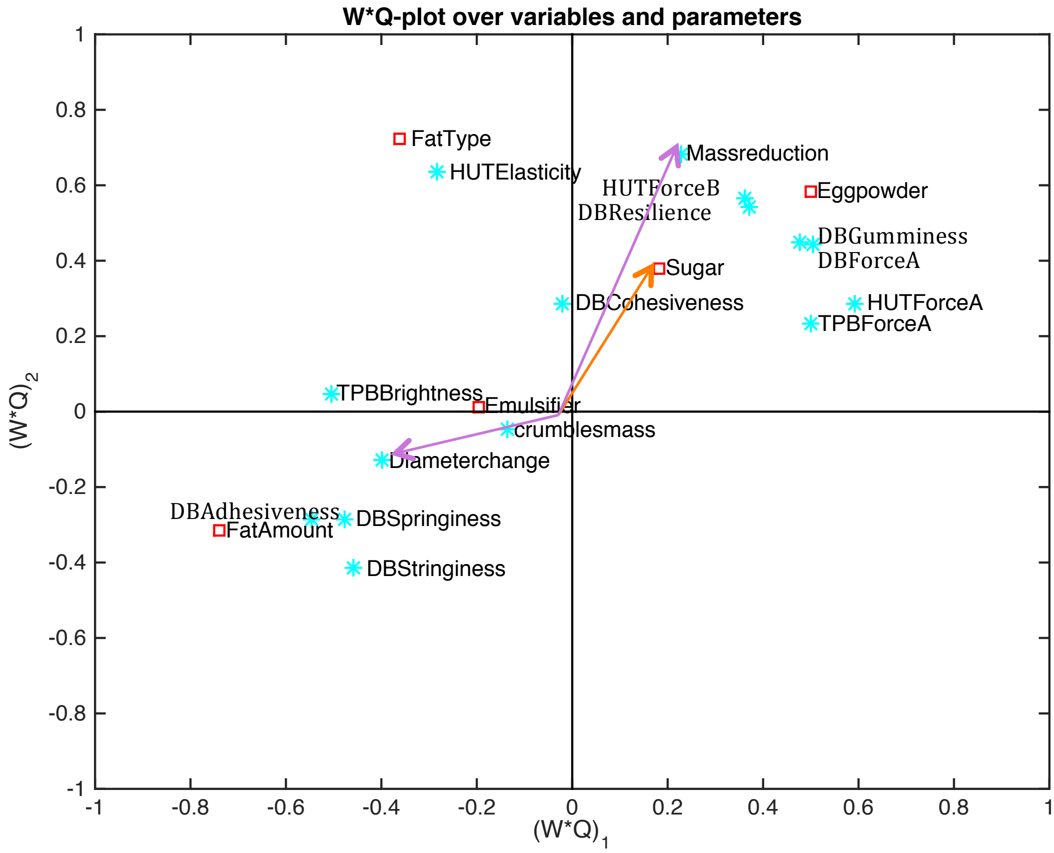


Figure 33 WQ-plot showing the relation between the responses and the design variables for all experiments.

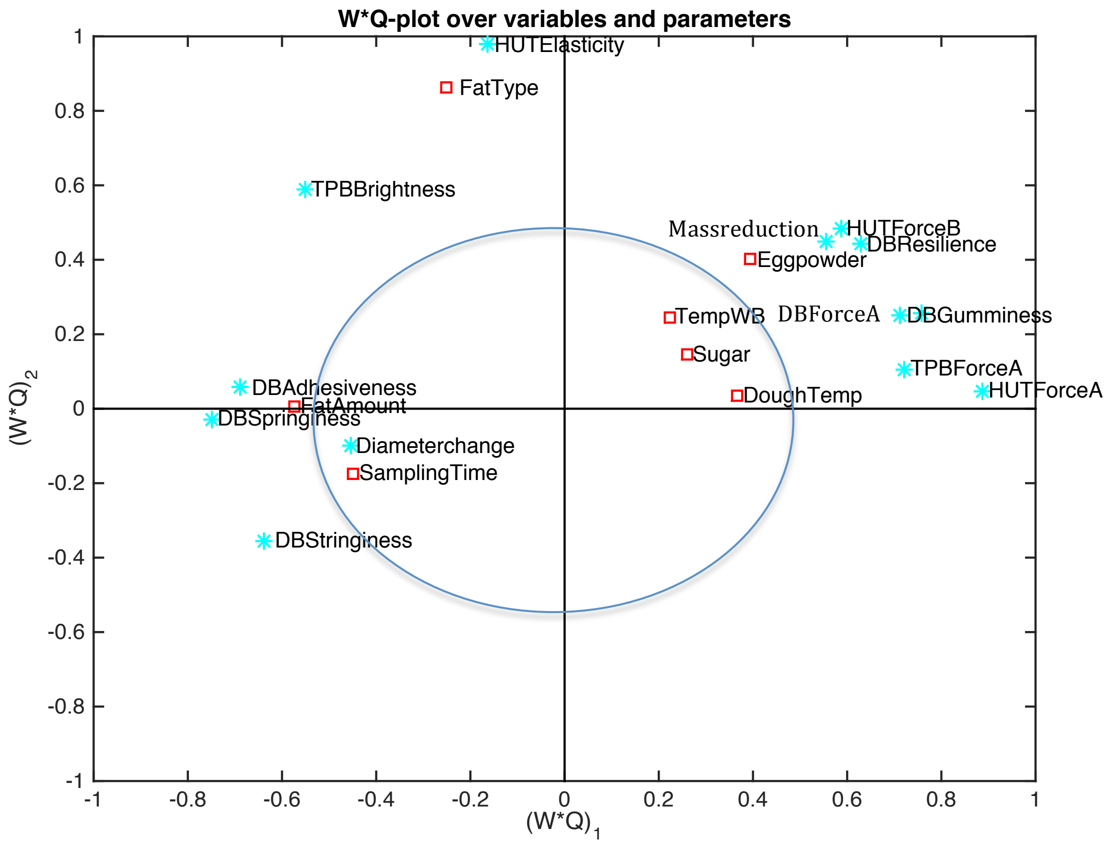
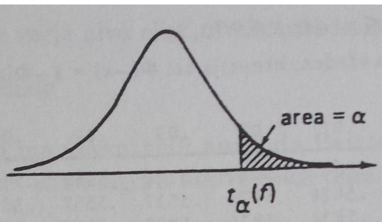


Figure 34 WQ-plot showing the relation between the important responses and the important variables for all experiments. The vector of responses is scaled up by 1.5X

Appendix 7: Critical values of the student's t-distribution

Tabell 3. *t*-fördelningen

$P(X > t_\alpha(f)) = \alpha$ där $X \in t(f)$



f \ α	0.10	0.05	0.025	0.01	0.005	0.001	0.0005
1	3.08	6.31	12.71	31.82	63.66	318.31	636.61
2	1.89	2.92	4.30	6.96	9.92	22.33	31.60
3	1.64	2.35	3.18	4.54	5.84	10.21	12.92
4	1.53	2.13	2.78	3.75	4.60	7.17	8.61
5	1.48	2.02	2.57	3.36	4.03	5.89	6.87
6	1.44	1.94	2.45	3.14	3.71	5.21	5.96
7	1.41	1.89	2.36	3.00	3.50	4.79	5.41
8	1.40	1.86	2.31	2.90	3.36	4.50	5.04
9	1.38	1.83	2.26	2.82	3.25	4.30	4.78
10	1.37	1.81	2.23	2.76	3.17	4.14	4.59
11	1.36	1.80	2.20	2.72	3.11	4.02	4.44
12	1.36	1.78	2.18	2.68	3.05	3.93	4.32
13	1.35	1.77	2.16	2.65	3.01	3.85	4.22
14	1.34	1.76	2.14	2.62	2.98	3.79	4.14
15	1.34	1.75	2.13	2.60	2.95	3.73	4.07
16	1.34	1.75	2.12	2.58	2.92	3.69	4.02
17	1.33	1.74	2.11	2.57	2.90	3.65	3.97
18	1.33	1.73	2.10	2.55	2.88	3.61	3.92
19	1.33	1.73	2.09	2.54	2.86	3.58	3.88
20	1.33	1.72	2.09	2.53	2.85	3.55	3.85
21	1.32	1.72	2.08	2.52	2.83	3.53	3.82
22	1.32	1.72	2.07	2.51	2.82	3.51	3.79
23	1.32	1.71	2.07	2.50	2.81	3.48	3.77
24	1.32	1.71	2.06	2.49	2.80	3.47	3.75
25	1.32	1.71	2.06	2.49	2.79	3.45	3.73
26	1.32	1.71	2.06	2.48	2.78	3.44	3.71
27	1.31	1.70	2.05	2.47	2.77	3.42	3.69
28	1.31	1.70	2.05	2.47	2.76	3.41	3.67
29	1.31	1.70	2.05	2.46	2.76	3.40	3.66
30	1.31	1.70	2.04	2.46	2.75	3.39	3.65
40	1.30	1.68	2.02	2.42	2.70	3.31	3.55
60	1.30	1.67	2.00	2.39	2.66	3.23	3.46
120	1.29	1.66	1.98	2.36	2.62	3.16	3.37
∞	1.28	1.64	1.96	2.33	2.58	3.09	3.29