Elsevier Editorial System(tm) for International Dairy Journal
Manuscript Draft

Manuscript Number: INDA-D-12-00175R2

Title: Improvement of the quality of low-fat cheese using a two-step strategy

Article Type: Special Issue: Cheese Ripening

Corresponding Author: Dr. Siv Borghild Skeie, Ph.D.

Corresponding Author's Institution: Norwegian University of Life Sciences

First Author: Siv Borghild Skeie, Ph.D.

Order of Authors: Siv Borghild Skeie, Ph.D.; Gerd Marit Alseth, MSc; Hilde Marit Østlie, Ph.D; Roger K Abrahamsen, Ph.D; Jorun Øyaas, Ph.D

Manuscript Region of Origin: NORWAY

Abstract: A two-step strategy was applied to overcome the quality changes observed in low-fat cheese. Cheese texture was first improved using microparticulated whey proteins and buttermilk as ingredients added to the cheese milk. Second, the flavour of the cheese was improved by selected Lactobacillus ssp. isolated from good-quality cheese.

A 10 % fat Dutch cheese, Norvegia, with the optimal mixture of microparticulated whey proteins and buttermilk had an improved texture compared to the regular cheese without any additional ingredients. The obtained optimal recipe for cheese texture was subsequently used, and Lactobacillus (Lb.) casei TINE36 or Lb. plantarum TINE18 isolated from good quality cheese were added as adjuncts for flavour production. It was found that the adjunct Lactobacillus ssp. also influenced the texture of the cheese, making it less firm.

*Manuscript
Click here to view linked References

Improvement of the quality of low-fat cheese using a two-step strategy

S. Skeie[1*], G.M. Alseth[2], H. Østlie[1], R.K. Abrahamsen[1], A.G. Johansen[1,2], J. Øyaas[2]

[1]*Norwegian University of Life Science, Department of Chemistry, Biotechnology and Food Science, Norway;*

[2]*TINE SA, Norway*

Corresponding author: siv.skeie@umb.no

Tel: +47 64 96 58 44

Fax: +47 64 96 59 01

Postal address: Box 5003, N-1432 Ås, Norway

Abstract

A two-step strategy was applied to overcome the quality changes observed in low-fat cheese. Cheese texture was first improved using microparticulated whey proteins and buttermilk as ingredients added to the cheese milk. Second, the flavour of the cheese was improved by selected *Lactobacillus* ssp. isolated from good-quality cheese.

A 10 % fat Dutch cheese, Norvegia, with the optimal mixture of microparticulated whey proteins and buttermilk had an improved texture compared to the regular cheese without any additional ingredients. The obtained optimal recipe for cheese texture was subsequently used, and *Lactobacillus* (*Lb.*) *casei* TINE36 or *Lb. plantarum* TINE18 isolated from good quality cheese were added as adjuncts for flavour production. It was found that the adjunct *Lactobacillus* ssp. also influenced the texture of the cheese, making it less firm.

1. Introduction

Consumers often regard cheese with a reduced fat content as having unsatisfactory quality; the cheese is often too elastic and has a cohesive texture and a deficient flavour. Measures to improve the quality of reduced-fat cheese have been the focus of researchers for the past 20 years (Banks, 2004). However, reduced-fat cheese is still regarded as having inferior quality. The strategy is often to improve both texture and flavour at the same time. However, an alternative strategy to achieve improvements in the quality of low-fat cheese may be to work on improving texture and flavour separately.

Microparticulated whey protein (MWP) is made by the controlled denaturation and shear of whey protein concentrates which later form gel particles. Microparticulated whey protein may be tailored to specific applications by controlling the degree of denaturation of the whey proteins, the shear used in the processing and the composition of the whey preparation (Sanchez & Paquin, 1997). The functional properties of MWP are often better compared to native proteins, and MWP may be used as fat replacers (Kelly, Huppertz, & Sheehan, 2008; Renard, Lavenant, Sanchez, Hemar, & Horne, 2002). The particles of MWP in cheese must be small enough not to interrupt the casein network adversely during coagulation, but they must be large enough to be entrapped in the matrix and not lost with the whey. Microparticulated whey protein can break the casein network in the same manner as fat globules, but it also has a higher water binding capacity than the casein network, therefore rendering the cheese softer and likely to be regarded by consumers as having a higher fat content than cheese without MWP (Steffl, Hafenmair, Hechler, & Hinrichs, 1999).

Buttermilk (BM) is a valuable by-product of butter making. Buttermilk is rich in milk fat globule membranes (MFGM) and membrane components with an increased amount of

phospholipids, sphingolipids, glycoproteins and other minor compounds compared to skimmed milk (Morin, Jiménez-Flores, & Pouliot, 2007). The MFGM components have been reported to be of particular nutritional interest and are also reported to have beneficial health effects (Dewettinck et al., 2008). In previous studies using buttermilk in pizza cheese manufacture (Govindasamy-Lucey, Lin, Jaeggi, Johnson, & Lucey, 2006; Govindasamy-Lucey et al., 2007), commercial buttermilk from creameries was used; however, the authors did not report the type of heat treatment that was used for the cream and buttermilk. The buttermilk had most likely been subjected to a severe heat treatment because the treatment of cream at 85-95 °C for at least 15 seconds or more is often recommended for butter-making. Such heat treatment of the cream for butter-making implies a certain degree of denaturation of the whey proteins in the cream, and the whey proteins may attach to the MFGM. This effect will also most likely influence the properties of the buttermilk used for cheese-making, such as an increased water binding capacity of the cheese. In the present study and in a previous experiment (Romeih, Moe, & Skeie, 2012), sweet buttermilk was used. The buttermilk was subjected to a controlled temperature protocol from raw milk until the addition of buttermilk to the cheese vat. Romeih et al. (2012) showed that the buttermilk added had an emulsifying effect on the fat globules in the cheese, and the cheese structure was observed to be smoother and softer by scanning electron microscopy. This softening effect of buttermilk on cheese structure has also been shown by other researchers (Mistry, Metzger, & Maubois, 1996; Poduval & Mistry, 1999).

Lactobacillus ssp., a part of the non-starter lactic acid bacteria (NSLAB) flora in cheese, is important for the flavour formation in cheese (Beresford, Fitzsimons, Brennan, & Cogan, 2001). The starter culture suppliers offer a range of adjunct cultures of lactobacilli, in addition to the different lactococci starters, for increased flavour formation in cheese.

However, different lactobacilli give different flavour profiles, depending on the type and strain used, the technology used during production and the development and evolution of the microbial flora during ripening. Lactobacilli have also been connected to the development of off-flavours in cheese (Urbach, 1995). In an ongoing project, we are aiming to identify isolates of lactobacilli from Norwegian cheeses with excellent quality. A number of these isolates have been used in the study presented here.

Norvegia is a Gouda type cheese which is one of the most popular cheeses in Norway. This cheese is sold as a cheese with and without a rind and with fat contents ranging from 16 % to 45 % fat in dry matter (FDM). The reduced-fat varieties do not have high acceptance among Norwegian consumers and constitute only 1.7 % of the total production of Norvegia, which is approximately 23 000 tonnes annually.

The objective of this study was to address the low-fat cheese problem with a two-step approach. The first step was with respect to texture; the objective was to determine the optimal combination of BM and MWP as ingredients to be added to the cheese milk to improve the texture of low-fat Norvegia cheese. In step 1, flavour was not the focus. Step 2 involved an approach to flavour, where the best combination of BM and MWP, as decided in step 1, was used, and selected strains of *Lactobacillus* (*Lb.*) *casei*/*paracasei* or *plantarum* isolated from commercial cheeses with excellent flavour were added to the cheese milk to improve both the texture and flavour of the low fat Norvegia cheese.

2. Materials and Methods

2.1. Buttermilk

The buttermilk was made by the continuous churning of sweet cream. The cream prior to churning was pasteurised at 72-73 °C for 15 s. After churning, the fat was removed from the BM by separation, and the BM was pasteurised at 72-73 °C for 15 s. The BM was subsequently transported from the creamery at <4 °C to the pilot plant of the university and used within 1 to 3 days of churning. Before addition of BM to the cheese milk, the BM was pasteurised again at 72-73 °C for 15 s and cooled to 32 °C before addition to the cheese vat. The average composition of the BM was 8.8 % dry matter, 3 % protein and 0.5 % fat, and the pH was 6.6.

2.2. Microparticulated whey proteins

The liquid MWP, delivered from TINE SA, was produced from whey protein concentrate 60 % (WPC60) by heating to 85-90 °C in the presence of a high shear rate. The whey protein denaturation in the liquid MWP was > 85%. The MWP contained particles between 1 and 10 µm, to simulate milk fat globules. In step 1 of the investigation, the age of the fluid MWP used varied between 4-13 days, while in step 2, the age was 5 and 7 days. The average composition of the MWP was 13.5 % dry matter and 7.4 % protein, and the pH was, on average, 6.3.

2.3. Cheese Milk

The milk for the cheese was obtained from the university herd (Norwegian University of Life Sciences, Ås, Norway). The milk was skimmed and pasteurised (72 °C, 15 s) and standardised in the vat to a fat content of 1.0 % with pasteurised cream (74 °C, 15 s). Buttermilk and/or MWP were added to the vat as described in section 2.6. and the cheese milk was stirred for at least 50 minutes before rennet addition.

124 *2.4. Adjuncts*

125 The two adjunct cultures used were isolated from high quality Norvegia cheeses; *Lb.*
126 *plantarum* TINE18 was isolated from a 16 % fat cheese, and *Lb. casei/paracasei* TINE36
127 was isolated from a 28 % full-fat cheese. The strains were isolated and characterised as
128 described by Porcellato et al. (2012). Because we could not distinguish *Lb. casei* from *Lb.*
129 *paracasei* by the methods used, the name *Lb. casei* TINE36 will be used for the remainder of
130 this paper. The adjunct lactobacilli were inoculated (1 %) in De Man, Rogosa, Sharpe broth
131 (MRS, Difco, Sparks, MI, USA) and incubated at 30 °C for 20 h. The inoculation in the
132 cheese vats was 0.11 % for both *Lactobacillus* ssp.

133

134 *2.5. Cheese making*

135 Washed-curd, brine salted cheese was made with 10 % fat in the cheese, yielding 20 % fat in
136 dry matter (FDM^{-1}). The cheese was made from 350 L milk as described by Skeie, Lindberg
137 and Narvhus (2001) with several modifications. The starter culture used was Probat Visbyvac
138 505 (Danisco, Copenhagen, Denmark), and the pre-ripening of milk and starter was
139 performed for 45 min at 30.5 °C. The rennet used was Naturen Premium 225 (Chr. Hansen,
140 Hørsholm, Denmark), and the coagulation time (from set to cut) was 36 (±2.5) min. Whey
141 drainage was 45 % (vol/vol), and water addition was between 30 and 40 % (vol/vol). The
142 scalding temperature was 35.5 (±0.5) °C, and the process was performed for 25-30 min.
143 Plastic cheese moulds (Laude b.v., Ter Apel, The Netherlands) yielding 5-kg cheese wheels
144 were used. The cheeses were salted in a saturated brine at 10 °C for 10 h. Before and after
145 cheese-making, the dairy equipment were washed and disinfected with steam. The cheese
146 was kept for 10 days at 10 °C and plastic coated twice with Ceska-coat (Producan, Kolding,
147 Denmark). The cheese was later stored in the curing room for 14 days at 19 °C and was
148 vacuum-wrapped in plastic bags and stored at 4 °C for the remaining ripening period.

149

150 *2.6. Experimental design*

151 Two different cheese making experiments were designed, hereby referred to as step 1 and
152 step 2.

153

154 Step 1: Cheese was made using two experimental factors, i.e., the addition of either MWP or
155 BM to the cheese milk, in 3 replicate blocks. The experimental factor MWP was added at
156 three levels, 0, 3 and 6 % of the milk volume. The experimental factor BM was added at two
157 levels, 0 and 15 % of the milk volume. Each replicate block consisted of 6 cheese vats made
158 over 2 days; all the replicate blocks were made in a period of 5 days. As the cheese of each
159 replicate block were made over 2 days, 2 extra control vats with no addition of MWP and BM
160 were made to adjust for the possible variation in milk quality and composition. In total, 20
161 vats of cheese were made. Chemical and microbial analyses of the cheese were performed
162 after 24 h and 6 weeks, and sensory and texture analyses were made after 12 weeks of
163 ripening.

164

165 Step 2: Cheese was made with the addition of 3 % MWP and 15 % BM to the cheese milk
166 and with one experimental factor, namely, the inoculation of adjunct cultures, in three levels
167 and in 2 replicate blocks. The three levels of adjunct were the following: no adjunct addition,
168 the addition of *Lb. plantarum* TINE18 or the addition of *Lb. casei* TINE36. In total, 6 vats of
169 cheese were made. Chemical and microbial analyses of the cheese were performed after 24 h,
170 8, 16, 20 and 28 weeks. Sensory and texture analyses were made after 16, 20 and 28 weeks of
171 ripening.

172

173 *2.7. Sampling and analysis of milk and cheese*

Sampling for the gross composition and microbial analyses were made according to the IDF-standard 50C (IDF/FIL, 1995). Microbial counts, pH and dry matter were measured immediately after sampling. Dry matter was determined according to IDF standard 4A (IDF/FIL, 1982), salt was determined according to IDF standard 88 (IDF/FIL, 1988), fat was determined according to IDF standard 222 (IDF/FIL, 2008) and protein was determined according to IDF standard 20B (IDF/FIL, 1993). The pH of the samples was measured as described by Skeie, Lindberg & Narvhus (2001). Presumptive lactococci were enumerated on M17 broth (Merck, Darmstadt, Germany) with 15 g L^{-1} Bactoagar (Saveen Werner AB, Malmø, Sweden) after aerobic incubation for 2 days at 30 °C. Presumptive lactobacilli and *Leuconostoc* ssp. were enumerated on *Lactobacillus* selective agar (LBS agar, Difco) after anaerobic incubation in an anaerobic incubator (W.C. Hearaeus GmbH, Hanau, Germany) with 10 % v/v CO_2 for 4 days at 30 °C.

Cheese hardness was measured using the Texture Profile Analysis (TPA) technique on a TA-XT2i Texture Analyser (Stable Micro Systems (SMS) Ltd., Surrey, UK) with a measuring cell of 25 kg and an SMS P/45 flat aluminium plunger (Ø 75 mm). From each cheese, 12 cylinders (15 mm in height, Ø 23 mm) were sampled, packed in aluminium foil and tempered at 15 °C before analysis. The samples were compressed axially in two consecutive cycles without yield with 75 % deformation from the initial sample's height at a 1 mm s^{-1} rate of force application. The result of the 6 samples which was most consistent was further used in the statistical analyses. The force required to attain a given deformation or the maximum force during the first compression is the TPA hardness, as measured in Newtons.

Volatile compounds were determined in headspace vials containing 10 g of grated cheese, sealed with 20-CBT-3 Teflon coated septa and aluminium crimp caps using headspace gas

chromatography (HSGC) according to the method of Narvhus, Østeraas, Mutukumira and Abrahamsen (1998) and with modifications described by Skeie, Kieronczyk, Næss and Østlie (2008).

Organic acids and lactose were analysed using high performance liquid chromatography (HPLC) as described by Skeie, Narvhus, Ardö, Thorvaldsen and Abrahamsen (1997) and Skeie et al. (2001) with modifications described by Skeie et al. (2008).

Sensory quality gradings were made by at least 3 trained quality assessors at TINE SA using a scale extending from 1 to 5, where 5 is a very high-quality cheese. The cheeses were evaluated as a full fat Norvegia by the quality grading panel, and the cheese was fit for sale as a full-fat Norvegia if it had a grade higher than 3. Sensory profiling of 20 texture and flavour attributes were made by 5-7 trained assessors from TINE SA using a scale of 1-9. Before the profiling of the experimental cheese, the assessors agreed upon the attributes using a reference cheese as a standard. A hedonic sensory evaluation (liking) was performed by a trained panel of 5 assessors at the Norwegian University of Life Sciences using a scale from 1 to 5, where 5 was liked very much.

2.8. Statistical treatment of data

Significant differences ($P<0.05$) between replicate blocks and treatment factors were found by ANOVA using SAS Enterprise guide 4.0 (SAS Institute Inc., Cary, NC, USA). In step 1, the treatment factors were the replicate block, MWP and BM, and their interaction MWP × BM. In step 2, the treatment factors were the replicate block and the adjunct culture of lactobacilli. An ANOVA was made at each ripening step. Principal component analysis was made by using the Unscrambler X 10.0.1 (CAMO Process AS, Oslo, Norway). The organic

acid data and the volatile component data were weighted by dividing each response variable by the standard deviation of that variable, while the sensory data sets were not weighted. A full cross-validation was used for the validation of the data set.

3. Results

3.1. Step 1. Texture approach

As shown in Table 1, the addition of 15 % BM reduced the dry matter and protein content of the cheese milk, while the addition of MWP increased the dry matter and protein content of the milk. The pH of the cheese milk was not influenced by the addition of BM. The addition of 6 % MWP did reduce the pH weakly, but it was statistically significant. In cheese 24 h after the start of the cheese making process and after 6 weeks of ripening (Table 2), the addition of BM and MWP lowered the content of dry matter compared to cheese without these additions. The pH of the cheese 24 h after the start of cheese-making was not influenced by the additions, but after 6 weeks of ripening, the pH was lower in cheeses with 6 % MWP (Table 2). The salt in moisture was 2.9 % on average and was only slightly influenced ($P<0.02$) by the addition of 6 % MWP, which increased the salt in moisture to an average of 3 % (results not shown). Fat in dry matter was 21.4 % on average and was not influenced by the experimental factors. Only the addition of BM influenced the set to cut time, which increased significantly ($P<0.05$) by 3 min with the addition of 15 % BM.

The addition of MWP and BM significantly ($P<0.0001$) reduced the hardness of the cheese, as measured by texture analysis (Figure 1) and sensory profiling (Figure 2). The sensory profiling showed that addition of MWP and BM, separately and in combination, moved the cheeses from the firm, dry and grainy area to a more doughy and soluble character. The doughiest cheeses were those with a combination of BM and 6 % MWP. None of the cheeses

obtained a texture quality grade >3, which was needed to be comparable with full-fat Norvegia cheese (Table 3). The liking panel could differentiate among the treatments, and cheeses with added BM or 3 % MWP obtained significantly better texture liking scores; the cheese with the combination of BM and 3 % MWP had the highest liking score. As shown in Table 3, the addition of 6 % MWP was not beneficial for texture, as these cheeses obtained the lowest score both by the quality grading panel and by the liking panel. This cheese was also the doughiest cheese, regardless of BM addition. The sensory profiling (Figure 2) revealed that the cheeses with added MWP and BM had a more acidic and pungent flavour than did cheeses without these additions. Because the combination BM and 3 % MWP yielded cheese with the highest texture likings, this cheese was used in step 2, despite its somewhat acidic and pungent flavour.

3.2. Step 2. Flavour approach.

The cheeses produced in step 2 were made from cheese milk with 15 % BM, 3 % MWP and one of the two different strains of adjunct lactobacilli. These cheeses were more similar in composition than the cheeses made in step 1, and no significant differences in gross composition or pH were found among the cheeses. The dry matter of the cheese was, on average, 42.51±1.44 % 24 h after the start of cheese-making and 49.07±0.81 % after 16 weeks of ripening. Fat in dry matter was, on average, 22.01±0.94 %, and salt in moisture was 2.88±0.11 % after 16 weeks of ripening. The adjuncts did not significantly influence the pH of the cheeses; the pH increased from 5.22±0.02 in the young cheese to 5.51±0.06 after 16 weeks of ripening. However, the control cheese generally had the highest pH throughout ripening. No significant difference between the cheeses was found with respect to hardness as measured by the texture analyser; the TPA hardnesses were 78, 60 and 55 N in the control and in the cheeses with added *Lb. plantarum* TINE18 and *Lb. casei* TINE36, respectively.

All the cheeses had high cell numbers on LBS agar at 24 h, between log 7.5 (control) and 8.5 (cheeses with adjunct) cfu g^{-1}. A mesophilic aromatic starter with *Leuconostoc* ssp. was used; therefore, high cfu numbers on the LBS agar were also expected for the control cheeses 24 h after the start of cheese-making. After 8 weeks of ripening, the cell numbers enumerated on LBS in the control cheese were reduced to log 6.7 cfu g^{-1}, while the cheese with added *Lb. casei* TINE36 had an average cell number of log 7.7 cfu g^{-1} and the cheese with added *Lb. plantarum* TINE18 had an average of log 8.1 cfu g^{-1} at this stage. During further ripening, the cell numbers on LBS agar decreased for the control cheese and for the cheese with added *Lb. casei* TINE36 (log 6.05 and 7.14 cfu g^{-1}, respectively, after 28 weeks of ripening), while the cell numbers remained stable in the cheese with added *Lb. plantarum* TINE18. The adjuncts clearly influenced the ripening of the cheese, as shown by the development of organic acids and volatile flavour compounds throughout ripening (Figure 3 and Figure 4, respectively). As shown in Figure 3, the control cheese and cheese with added *Lb. casei* TINE36 clustered closely together, while the cheese with added *Lb. plantarum* TINE18 (the ellipse in Figure 3) differed from these two because of its higher content of formic and acetic acids. The PCA analysis of the volatile flavour compounds clustered the treatments clearly into three groups, with the control cheese having the lowest development of volatile aroma compounds throughout ripening. Additionally, the cheeses with added adjuncts were grouped clearly into two groups, with the cheese with added *Lb. plantarum* TINE18 exhibiting the highest content of most of the identified volatiles.

The adjuncts significantly ($P<0.05$) influenced the flavour profile of the cheeses (Figure 5). However, more surprisingly, these adjuncts also had a significant ($P<0.05$) influence on the texture perceived by the sensory profiling analysis. The cheeses with the adjunct culture were

299 considered less firm and less dry than the control cheese. As shown in table 4, all of the
300 cheeses made in step 2 obtained a quality grading higher than 3 for both texture and flavour,
301 proving a quality comparable to full-fat Norvegia. However, the quality was highest after 20
302 weeks and declined after 28 weeks ripening, indicating that the cheese did develop in an
303 undesirable direction during the prolonged ripening period. The terms used to describe the
304 quality deficiency, particularly for the 28-week cheeses, were grainy, cohesive, pungent and
305 acid. However, the liking panel did appreciate these cheeses notably, giving several of them a
306 score of 4 out of 5 for flavour. The quality grading panel gave the cheese with added *Lb.*
307 *plantarum* TINE18 the lowest score for flavour (table 4) during the evaluation at 20 weeks,
308 while the liking panel liked this cheese and the control cheese better than the cheese with
309 added *Lb. casei* TINE36. Furthermore, at 28 weeks, this difference was significant ($P<0.05$).
310 No further significant differences between the treatments were found by the sensory gradings,
311 neither by the quality nor by the liking panel.
312
313 ***4. Discussion***
314 The use of a two-step strategy for the improvement of the quality of low-fat Norvegia seemed
315 to be successful. However, a premise in these experiments was to use sensory methods for
316 profiling and determining the liking of the cheeses in addition to the traditional quality
317 grading. It would have been optimal to do consumer tests, as well, but that approach would
318 have required more cheese, and it would have been much more costly and out of the scope for
319 this work. By the approach used, the cheeses could be made in a pilot plant, and the number
320 of experimental cheese vats could be minimised. Using a one-step approach with the same
321 experimental factors would have required at least 36 cheese-makings (using 2 replicate
322 blocks), and cheese-makings of the same replicate blocks would have had to be spread over

3-4 days. In the two step approach, the number of cheese makings was reduced to 26, and it allowed us to use the 3 replicate blocks in step 1.

Only the addition of BM to cheese milk influenced the set to cut time, while MWP did not influence the observed coagulation time. An increased set to cut time and a reduced gel firmness caused by BM addition was also observed by Morin, Pouliot and Britten (2008), who linked the reduced coagulation properties of the cheese milk with added BM to the heat treatment of the cream before churning and to the MFGM components of the BM. By adding different commercial MWPs to milk, Lucey and Gorry (1994) observed little effect on rennet coagulation, while Fenelon and Guinee (1997), Guinee et al. (1997) and Schenkel, Samudrala and Hinrichs (2011) reported impaired rennet coagulation properties.

The texture measurements of the cheeses produced in step 1 showed that cheeses with BM and MWP added to the cheese milk had a reduced hardness, and the sensory profiling analysis indicated that these cheeses had a somewhat pungent and acidic flavour. As shown by Saint-Eve, Lauverjat, Magnan, Déléris, and Souchon (2009), the texture perception of model cheeses with exactly the same texture was influenced by the flavour of the cheese, and the flavoured cheese had a much better texture grading than did the unflavoured cheese. The texture of the cheeses from step 1 was not acceptable according to the quality grading panel when comparing these low fat cheeses with the texture of a full-fat variety of the same cheese (Norvegia). This reduced acceptability is most likely due to a confounding with the inferior flavour of these cheeses, as all the cheeses produced in Step 2 were evaluated according to the same standard and had a better flavour quality. The texture analysis and the sensory profiling showed that BM and MWP had a beneficial effect on the texture of the low-fat cheese, making it less firm, less cohesive and less dry, which is in accordance with the

findings of others for both BM (Mistry et al., 1996; Poduval & Mistry, 1999; Romeih et al., 2012) and MWP (Fenelon & Guinee, 1997; Lobato-Calleros, Robles-Martinez, Caballero-Perez, Aguirre-Mandujano, & Vernon-Carter, 2001; Lucey & Gorry, 1994; Schenkel et al., 2011). However, using 6 % MWP, the cheese became too doughy and had a textural quality which was not appreciated neither by the quality graders nor by the liking panel. In this experiment, the optimal addition of MWP was therefore 3 %. The BM reduced the firmness of the cheese, and a combination with 3 % MWP seemed to have a positive effect on the texture properties of the cheese; however, a combination of BM and 6 % MWP resulted in a cheese that was overly doughy. Based on the observations from the experiments in step 1, it was decided to continue to step 2 with the 3 % MWP and 15 % BM additions to the cheese milk.

The control cheese in step 2 had a slightly softer texture than the corresponding cheese in step 1, as measured on the texture analyser, but the differences as evaluated by the quality graders were considerable. The control cheese now obtained a notably good texture grading, which was within the standard for full fat Norvegia after 20 weeks of ripening. The texture quality was, however, reduced by further ripening. In step 1, the sensory evaluation was made after 12 weeks, thus the cheese may have been too young, and this characteristic might explain the differences obtained in the quality gradings in the two different steps. It might be that the optimal texture of this cheese can be obtained between 12 and 28 weeks of ripening. Therefore, further work has to be undertaken to determine the ripening time necessary for optimal texture quality and to find the ageing period wherein the quality of the cheese is satisfactory. The reduction of cheese firmness caused by the adjunct lactobacilli was somewhat surprising, as the species added are considered weakly proteolytic. However, a reduced firmness of the cheese with added adjunct *Lb. casei* and *Lb. plantarum* have also

been observed by other researchers (Hynes et al., 2003; Sallami, Kheadr, Fliss, & Vuillemard, 2004).

The development of the organic acids and the volatile flavour compounds showed that the adjunct lactobacilli influenced the production of flavour compounds in the cheeses, which has also been shown in previous experiments with washed-curd cheese varieties (Antonsson, Ardo, Nilsson, & Molin, 2002; Skeie et al., 2001; Skeie et al., 2008). The biochemical changes caused by the adjuncts were also reflected in the sensory profiling analysis. However, the results of the sensory grading and liking were not influenced by the adjunct lactobacilli, and the grading panel and the liking panel responded conversely to the effects of the adjunct cultures. The grading panel liked the cheese with added *Lb. plantarum* TINE18 the least, which means that this lactobacilli most likely gives the cheese a flavour that is somewhat unusual for full fat Norvegia. However, this strain was isolated from a high-quality Norveiga cheese with 16 % fat, where it was dominant. Østlie, Eliassen, Florvaag and Skeie (2004) found that Norvegia cheese is usually dominated by *Lb. casei/paracasei*, and it is possible that the dominance of *Lb. plantarum* in low-fat Norvegia is producing a flavour in the low fat variety that diverges from the full fat Norvegia. However, the liking panel liked the cheese with added *Lb. plantarum* TINE18 and the control cheese the most, while they liked the cheese with *Lb. casei* TINE36 the least. Therefore, determining consumer opinions of low-fat Norvegia with different adjuncts of lactobacilli would be an interesting further study.

5. Conclusions

The texture of low-fat Norvegia was improved by adding 15 % BM and 3 % MWP to the cheese milk, and these additions reduced the firmness and the rubbery texture of the cheese.

The adjunct lactobacilli used influenced the texture positively, while the effects on the flavour were more conflicting. The sensory profiling attributes showed a clear effect of the adjuncts on the cheese flavour; however, the cheese with added adjuncts did not obtain a better quality grading or liking compared with the control cheese.

6. Acknowledgments

The authors would like to acknowledge the Norwegian Research Council, the Norwegian Foundation for Research Levy on Agricultural Products, the Norwegian Agricultural Agreement Research Fund and TINE SA for financial support. The authors also acknowledge the staff at the dairy pilot plant and at the dairy technology laboratory at the Department of Chemistry, Biotechnology and Food Science for their assistance during cheese-making and for their assistance with the microbial and chemical analyses of the cheese.

7. References

Antonsson, M., Ardo, Y., Nilsson, B. F., & Molin, G. (2002). Screening and selection of *Lactobacillus* strains for use as adjunct cultures in production of semi-hard cheese. *Journal of Dairy Research*, *69,* 457-472. doi:10.1017/s0022029902005563

Banks, J. M. (2004). The technology of low-fat cheese manufacture. *International Journal of Dairy Technology*, *57,* 199-207. doi:10.1111/j.1471-0307.2004.00136.x

Beresford, T. P., Fitzsimons, N. A., Brennan, N. L., & Cogan, T. M. (2001). Recent advances in cheese microbiology. *International Dairy Journal*, *11,* 259-274. doi:10.1016/s0958-6946(01)00056-5

Dewettinck, K., Rombaut, R., Thienpont, N., Le, T. T., Messens, K., & Van Camp, J. (2008). Nutritional and technological aspects of milk fat globule membrane material. *International Dairy Journal*, *18,* 436-457. doi:10.1016/j.idairyj.2007.10.014

Fenelon, M. A., & Guinee, T. P. (1997). The compositional, textural and maturation characteristics of reduced-fat Cheddar made from milk containing added Dairy-Lo (TM). *Milchwissenschaft-Milk Science International*, *52,* 385-389.

Govindasamy-Lucey, S., Lin, T., Jaeggi, J. J., Johnson, M. E., & Lucey, J. A. (2006). Influence of condensed sweet cream buttermilk on the manufacture, yield, and functionality of pizza cheese. *Journal of Dairy Science*, *89,* 454-467.

Govindasamy-Lucey, S., Lin, T., Jaeggi, J. J., Martinelli, C. J., Johnson, M. E., & Lucey, J. A. (2007). Effect of type of concentrated sweet cream buttermilk on the manufacture, yield, and functionality of pizza cheese. *Journal of Dairy Science*, *90,* 2675-2688. doi:10.3168/jds.2006-681

Guinee, T. P., Gorry, C. B., O'Callaghan, D. J., O'Kennedy, B. T., O'Brien, N., & Fenelon, M. A. (1997). The effects of composition and some processing treatments on the rennet coagulation

properties of milk. *International Journal of Dairy Technology*, *50,* 99-106. doi:10.1111/j.1471-0307.1997.tb01747.x

Hynes, E., Bach, C., Lamberet, G., Ogier, J. C., Son, O., & Delacroix-Buchet, A. (2003). Contribution of starter lactococci and adjunct lactobacilli to proteolysis, volatile profiles and sensory characteristics of washed-curd cheese. *Lait*, *83,* 31-43. doi:10.1051/lait:2002048

IDF/FIL. (1982). *Cheese and processed cheese: Determination of the total solids content. IDF Standard 4A*. Brussels, Belgium: International Dairy Federation.

IDF/FIL. (1988). *Cheese and processed cheese products. Determination of chloride content (potentiometric titration method). IDF Standard 88A*. Brussels, Belgium: International Dairy Federation.

IDF/FIL. (1993). *Milk determination of nitrogen content (Kjeldal method). IDF standard 20B.* Brussels, Belgum: International Dairy Federation.

IDF/FIL. (1995). *Milk and milk products: Guidance on sampling*. *IDF Standard 50C*. Brussels, Belgium: International Dairy Federation.

IDF/FIL. (2008). *Determination of fat content (Van Gulik method)*. *IDF Standard 222*. Brussels, Belgum: International Dairy Federation.

Kelly, A. L., Huppertz, T., & Sheehan, J. J. (2008). Pre-treatment of cheese milk: principles and developments. *Dairy Science & Technology*, *88,* 549-572. doi:10.1051/dst:2008017

Lobato-Calleros, C., Robles-Martinez, J. C., Caballero-Perez, J. F., Aguirre-Mandujano, E., & Vernon-Carter, E. J. (2001). Fat replacers in low-fat Mexican Manchego cheese. *Journal of Texture Studies*, *32,* 1-14. doi:10.1111/j.1745-4603.2001.tb01030.x

Lucey, J. A., & Gorry, C. (1994). Effect of Simplesse -100 on the manufacture of low-fat Cheddar cheese. In *Cheese Yield and Factors Affecting Its Control, Special Issue No. 9402* (439-447). Brussels, Belgium: International Dairy Federation.

Mistry, V. V., Metzger, L. E., & Maubois, J. L. (1996). Use of ultrafiltered sweet buttermilk in the manufacture of reduced fat Cheddar cheese. *Journal of Dairy Science*, *79,* 1137-1145. doi:10.3168/jds.S0022-0302(96)76467-6

Morin, P., Jiménez-Flores, R., & Pouliot, Y. (2007). Effect of processing on the composition and microstructure of buttermilk and its milk fat globule membranes. *International Dairy Journal*, *17,* 1179-1187. doi:10.1016/j.idairyj.2007.03.010

Morin, P., Pouliot, Y., & Britten, M. (2008). Effect of buttermilk made from creams with different heat treatment histories on properties of rennet gels and model cheeses. *Journal of Dairy Science*, *91,* 871-882. doi:10.3168/jds.2007-0658

Narvhus, J. A., Østeraas, K., Mutukumira, T., & Abrahamsen, R. K. (1998). Production of fermented milk using a malty compound-producing strain of *Lactococcus lactis* subsp. *lactis* biovar. *diacetylactis*, isolated from Zimbabwean naturally fermented milk. *International Journal of Food Microbiology*, *41,* 73-80. doi:10.1016/s0168-1605(98)00036-1

Poduval, V. S., & Mistry, V. V. (1999). Manufacture of reduced fat Mozzarella cheese using ultrafiltered sweet buttermilk and homogenized cream. *Journal of Dairy Science*, *82,* 1-9. doi:10.3168/jds.S0022-0302(99)75202-1

Porcellato, D., Østlie, H. M., Liland, K. H., Rudi, K., Isaksson, T., & Skeie, S. B. (2012). Strain-level characterization of nonstarter lactic acid bacteria in Norvegia cheese by high-resolution melt analysis. *Journal of Dairy Science*, *95,* 4804-4812. doi:10.3168/jds.2012-5386

Renard, D., Lavenant, L., Sanchez, C., Hemar, Y., & Horne, D. (2002). Heat-induced flocculation of microparticulated whey proteins (MWP); consequences for mixed gels made of MWP and β-lactoglobulin. *Colloids and Surfaces B: Biointerfaces*, *24,* 73-85. doi:10.1016/s0927-7765(01)00246-6

Romeih, E. A., Moe, K. M., & Skeie, S. (2012). The influence of fat globule membrane material on the microstructure of low-fat Cheddar cheese. *International Dairy Journal*, *26,* 66-72. doi:10.1016/j.idairyj.2012.03.008

Saint-Eve, A., Lauverjat, C., Magnan, C., Déléris, I., & Souchon, I. (2009). Reducing salt and fat content: Impact of composition, texture and cognitive interactions on the perception of flavoured model cheeses. *Food Chemistry*, *116,* 167-175. doi:10.1016/j.foodchem.2009.02.027

Sallami, L., Kheadr, E. E., Fliss, I., & Vuillemard, J. C. (2004). Impact of autolytic, proteolytic, and nisin-producing adjunct cultures on biochemical and textural properties of Cheddar cheese. *Journal of Dairy Science*, *87,* 1585-1594.

Sanchez, C., & Paquin, P. (1997). Protein and protein-polysaccharide microparticles. In S. Damodaran & A. Paraf (Eds.), *Food proteins and their applications* (pp.503-528). New York: Marcel Dekker Inc.

Schenkel, P., Samudrala, R., & Hinrichs, J. (2011). Fat-reduced semi-hard cheese enriched with a microparticulated whey protein concentrate: Impact on cheese-making properties and rheological characteristics. *Milchwissenschaft-Milk Science International*, *66,* 43-47.

Skeie, S., Narvhus, J. A., Ardo, Y., Thorvaldsen, K., & Abrahamsen, R. K. (1997). The effect of reduced salt content on the function of liposome-encapsulated Neutrase and heat-treated lactobacilli in rindless low-fat cheese. *Lait*, *77,* 575-585.

Skeie, S., Lindberg, C., & Narvhus, J. (2001). Development of amino acids and organic acids in Norvegia, influence of milk treatment and adjunct *Lactobacillus*. *International Dairy Journal*, *11,* 399-411. doi:10.1016/s0958-6946(01)00075-9

Skeie, S., Kieronczyk, A., Næss, R. M., & Østlie, H. (2008). *Lactobacillus* adjuncts in cheese: Their influence on the degradation of citrate and serine during ripening of a washed curd cheese. *International Dairy Journal*, *18,* 158-168. doi:10.1016/j.idairyj.2007.09.003

Steffl, A., Hafenmair, M., Hechler, A., & Hinrichs, J. (1999). Influence of whey protein particles on the renneting properties of milk. *Milchwissenschaft-Milk Science International*, *54,* 510-513.

Urbach, G. (1995). Contribution of lactic acid bacteria to flavour compounds formation in dairy products. *International Dairy Journal*, *5,* 877-903.

Østlie, H. M., Eliassen, L., Florvaag, A., & Skeie, S. (2004). Phenotypic and PCR-based characterization of the microflora in Norvegia cheese during ripening. *International Journal of Food Microbiology*, *94,* 287-299. doi:10.1016/j.ifoodmicro.2004.01.012

516 Table 1. Dry matter, protein and pH of cheese milk with added buttermilk (BM) and or
517 microparticulated whey proteins (MWP) before starter addition (Step 1). Values are means
518 and SD. The p-statistics of each experimental factor and the significant (P<0.05) differences
519 between the least square mean (LSM) of each level of MWP are shown in the last four rows
520 of the table.

BM	MWP	Dry matter %		Protein %		pH	
		Mean	SD	Mean	SD	Mean	SD
0	0	10.08	0.08	3.47	0.05	6.65	0.04
0	3	10.20	0.11	3.56	0.01	6.65	0.04
0	6	10.28	0.08	3.69	0.04	6.63	0.02
15	0	9.98	0.04	3.42	0.03	6.66	0.03
15	3	10.10	0.07	3.48	0.06	6.62	0.03
15	6	10.20	0.12	3.59	0.01	6.61	0.08
p-statistics of the experimental factors (P<0.05, ns= not significant)							
Day		0.0001		ns		0.002	
BM		0.0001		0.003		ns	
MWP		0.0001		0.0002		0.03	
LSM: MWP		0<3<6		0<3<6		0,3>6	

521

522

Table 2. Dry matter and pH of cheese with added buttermilk (BM) and or microparticulated whey proteins (MWP) analysed 24 h after the start of cheese-making and after 6 weeks of ripening (Step 1). Values are means ± SD. The p-statistics of each experimental factor, the interaction BM×MWP and the significant (P<0.05) differences between the mean of each level (LSM) of MWP are shown in the last four rows of the table.

BM	MWP	Dry matter %				pH			
		24 h		6 w		24 h		6 w	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
0	0	45.70	0.92	50.38	0.96	5.24	0.05	5.45	0.03
0	3	43.08	0.66	48.74	0.36	5.19	0.06	5.40	0.17
0	6	41.85	1.67	47.72	2.36	5.17	0.04	5.40	0.10
15	0	42.81	0.53	49.01	1.15	5.22	0.04	5.44	0.06
15	3	42.10	0.27	47.75	1.34	5.20	0.03	5.43	0.08
15	6	40.28	1.14	45.80	0.82	5.18	0.06	5.31	0.12
p-statistics of the experimental factors (P<0.05, ns= not significant)									
Day		ns		ns		ns		0.0100	
BM		0.0040		0.0200		ns		ns	
MWP		0.0007		0.0030		ns		0.0300	
BM×MWP		ns		ns		ns		ns	
LSM: MWP		0>3>6		0>3>6				0,3>6	

530 Table 3. The texture grading of the quality and the liking panel for cheese with added
531 buttermilk (BM) and/or microparticulated whey proteins (MWP) analysed after 12 weeks of
532 ripening (Step 1). Values are means ± SD. The p-statistics of each experimental factor, the
533 interaction BM×MWP and the significant (P<0.05) differences between the mean of each
534 level (LSM) of MWP are shown in the last four rows of the table.

BM	MWP	Texture quality grading		Texture liking	
		Mean	SD	Mean	SD
0	0	2.63	0.48	2.67	0.47
0	3	2.83	0.44	3.44	0.51
0	6	2.46	0.42	3.11	0.19
15	0	2.94	0.38	3.72	0.25
15	3	2.72	0.42	3.94	0.10
15	6	2.22	0.10	2.83	0.17
p-statistics of the experimental factors (P<0.05, ns= not significant)					
Day		ns		ns	
BM		ns		0.0050	
MWP		ns		0.0080	
BM×MWP		ns		0.0400	
LSM: MWP				6,0<3	

535

536

537

538 Table 4. The texture and flavour gradings of the quality and the liking panel for the cheese
539 with 15 % buttermilk (BM), 3 % microparticulated whey proteins (MWP) and different
540 adjuncts analysed after 20 and 28 weeks of ripening (Step 2). Values are means ± SD.
541 Significant ($P < 0.05$) differences within the means for each ripening time are shown with
542 different superscript lower case letters.

Age	Adjunct	Quality Grading				Liking			
		Flavour		Texture		Flavour		Texture	
		Mean	SD	Mean	SD	Mean	SD	Mean	SD
20	Control	3.58	0.12	3.67	0.24	4.00	0.24	3.92	0.12
20	*Lb. plantarum* TINE18	3.33	0.24	3.92	0.12	4.08	0.12	3.92	0.12
20	*Lb. casei* TINE36	3.50	0.00	3.92	0.12	3.75	0.12	4.00	0.24
28	Control	3.08	0.12	3.25	0.12	4.00[a]	0.24	3.67	0.24
28	*Lb. plantarum* TINE18	3.08	0.12	3.58	0.35	4.08[a]	0.12	3.58	0.12
28	*Lb. casei* TINE36	3.08	0.12	3.50	0.24	3.50[b]	0.24	3.50	0.00

543

544

Figure captions.

Figure 1. Hardness, in Newton (N), of cheese with added buttermilk (BM) and/or microparticulated whey protein (MWP), as measured by the Texture Profile Analysis (TPA) technique (Step 1). No BM addition: ─■─, 15 % BM addition •••●•••.

Figure 2. Scores (a) and loadings (b) of the principal component analysis (PCA) of the sensory profiling attributes of cheese with no added buttermilk (BM) (black) or with 15 % BM (grey) and microparticulated whey protein (MWP); 0 % MWP (──), 3 % MWP (─ ─ ─) and 6 % MWP (·····) after 12 weeks of ripening (Step 1). Sample marking: Replicate block (A, B, C)- % BM- % MWP. The first and the second principal component (PC) explained 86 and 5 % of the variation, respectively.

Figure 3. Scores (a) and loadings (b) of the principal component analysis (PCA) of the development of organic acids during ripening of the control cheese without an adjunct (0) and cheese with added *Lb. plantarum* TINE18 (18)(ellipse) or *Lb. casei* TINE36 (36) from 0 to 28 weeks (Step 2). Each point represents the average of two replicate blocks. All the cheeses had an addition of 15 % buttermilk (BM) and 3 % microparticulated whey protein (MWP). Sample marking: Adjunct-weeks of ripening. The first and the second principal component (PC) explained 68 and 18 % of the variation, respectively.

Figure 4. Scores (a) and loadings (b) of the principal component analysis (PCA) of the development of volatile aroma compounds during ripening of the control cheese without an

adjunct (0, ──) and cheese with added *Lb. plantarum* TINE18 (18, ─ ─ ─) or *Lb. casei* TINE36 (36, ·····) from 0 to 28 weeks (Step 2). Each point represents the average of two replicate blocks. All the cheeses had an addition of 15 % buttermilk (BM) and 3 % microparticulated whey protein (MWP). Sample marking: Adjunct-weeks of ripening. The first and the second principal component (PC) explained 49 and 19 % of the variation, respectively.

Figure 5. Scores (a) and loadings (b) of the principal component analysis (PCA) of the sensory profiling attributes of the control cheese without an adjunct (0, ──) and cheese with added *Lb. plantarum* TINE18 (18, ─ ─ ─) or *Lb. casei* TINE36 (36, - - -) evaluated after 20 and 26 weeks of ripening (Step 2). All the cheeses had an addition of 15 % buttermilk (BM) and 3 % microparticulated whey protein (MWP). Sample marking: Replicate block (A, B)-adjunct-weeks of ripening. The first and the second principal component (PC) explained 79 and 14 % of the variation, respectively.

583 **Figure captions for colour figures to be used in the web version**

584 Figure 3. Scores (a) and loadings (b) of the principal component analysis (PCA) of the
585 development of organic acids during ripening of the control cheese without an adjunct (0,
586 black) and cheese with added *Lb. plantarum* TINE18 (18, blue) or Lb. *casei* TINE36 (36,
587 red) from 0 to 28 weeks (Step 2). Each point represents the average of two replicate blocks.
588 All the cheeses had an addition of 15 % buttermilk (BM) and 3 % microparticulated whey
589 protein (MWP). Sample marking: Adjunct-weeks of ripening. The first and the second
590 principal component (PC) explained 68 and 18 % of the variation, respectively.
591

592 Figure 4. Scores (a) and loadings (b) of the principal component analysis (PCA) of the
593 development of the volatile aroma compounds during ripening of the control cheese without
594 an adjunct (0, black ──) and cheese with added *Lb. plantarum* TINE18 (18, blue ─ ─ ─) or
595 Lb. *casei* TINE36 (36, red ·····) from 0 to 28 weeks (Step 2). Each point represents the
596 average of two replicate blocks. All of the cheeses had an addition of 15 % buttermilk (BM)
597 and 3 % microparticulated whey protein (MWP). Sample marking: Adjunct-weeks of
598 ripening. The first and the second principal component (PC) explained 49 and 19 % of the
599 variation, respectively.
600

601 Figure 5. Scores (a) and loadings (b) of the principal component analysis (PCA) of the
602 sensory profiling attributes of the control cheese without an adjunct (0, black ──) and cheese
603 with added *Lb. plantarum* TINE18 (18, blue ─ ─ ─) or *Lb. casei* TINE36 (36, red - - -)
604 evaluated after 20 and 26 weeks of ripening (Step 2). All the cheeses had an addition of 15 %
605 buttermilk (BM) and 3 % microparticulated whey protein (MWP). Sample marking:

606 Replicate block (A, B)-adjunct-weeks of ripening. The first and the second principal
607 component (PC) explained 79 and 14 % of the variation, respectively.

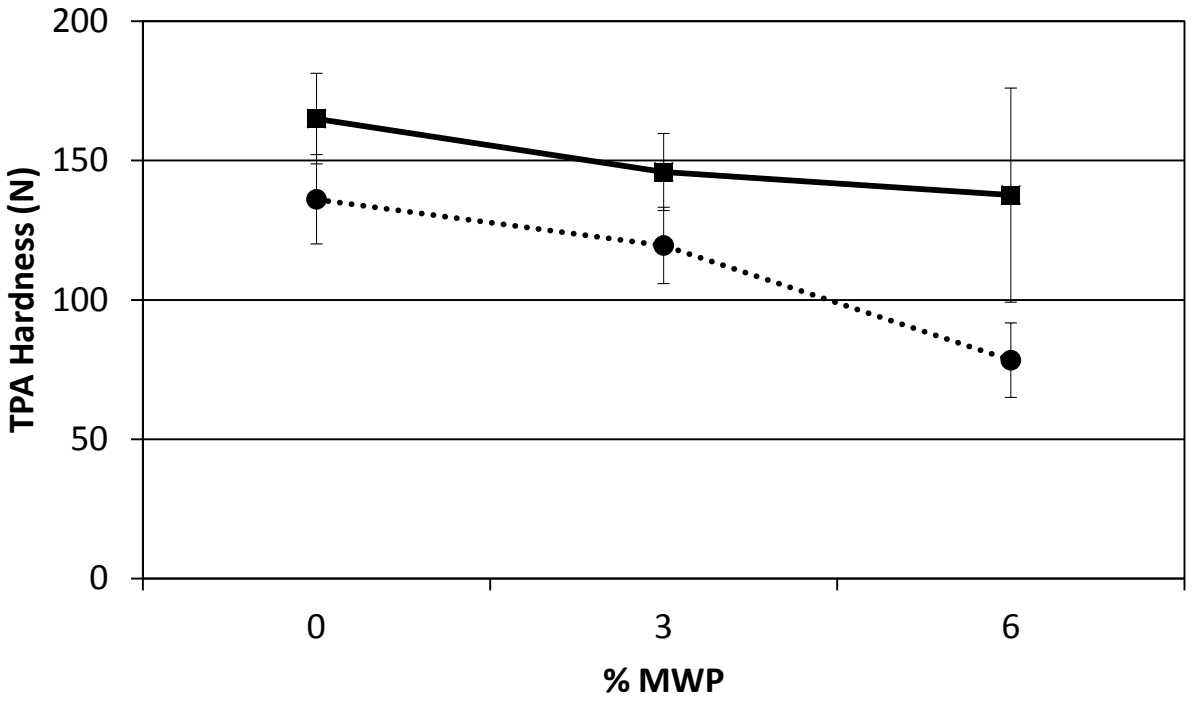
608

609

***Figure 1**

Skeie et al. Improvement of the quality of low fat cheese using a two step strategy

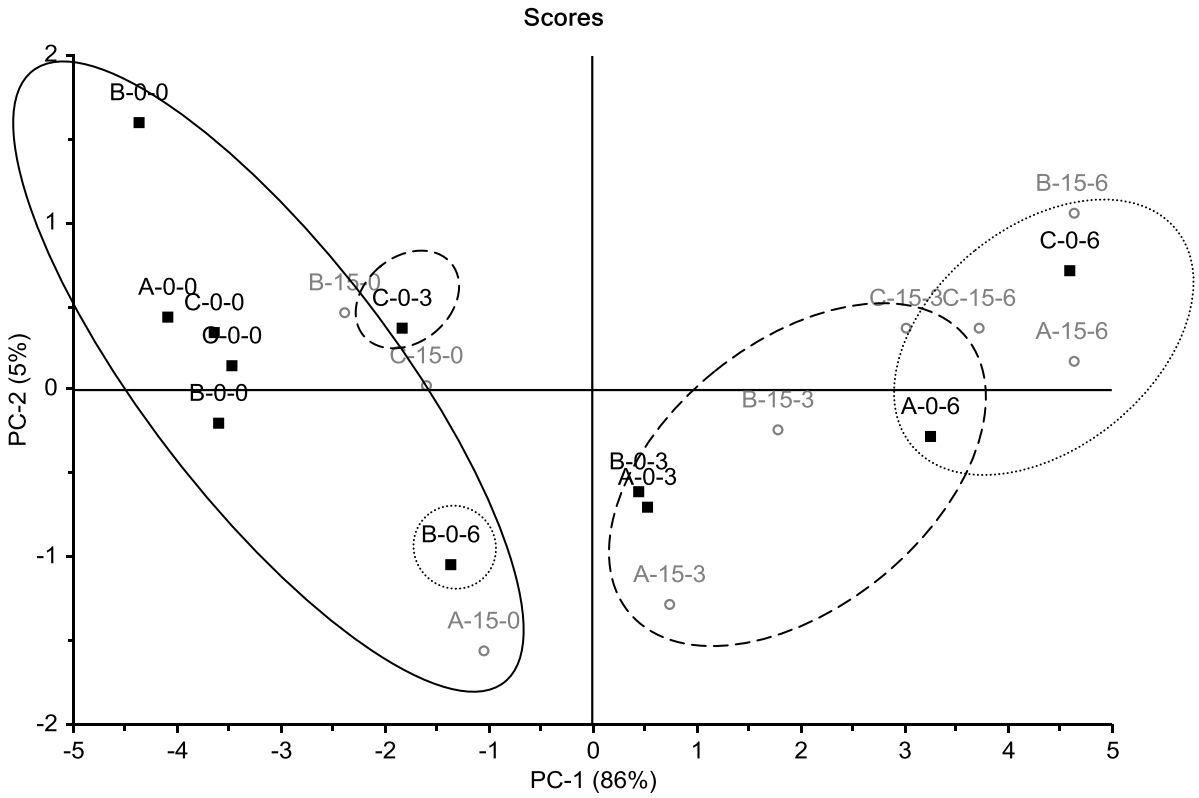
Figure 1.



Skeie et al. Improvement of the quality of low fat cheese using a two step strategy

Figure 2.

a)



b)

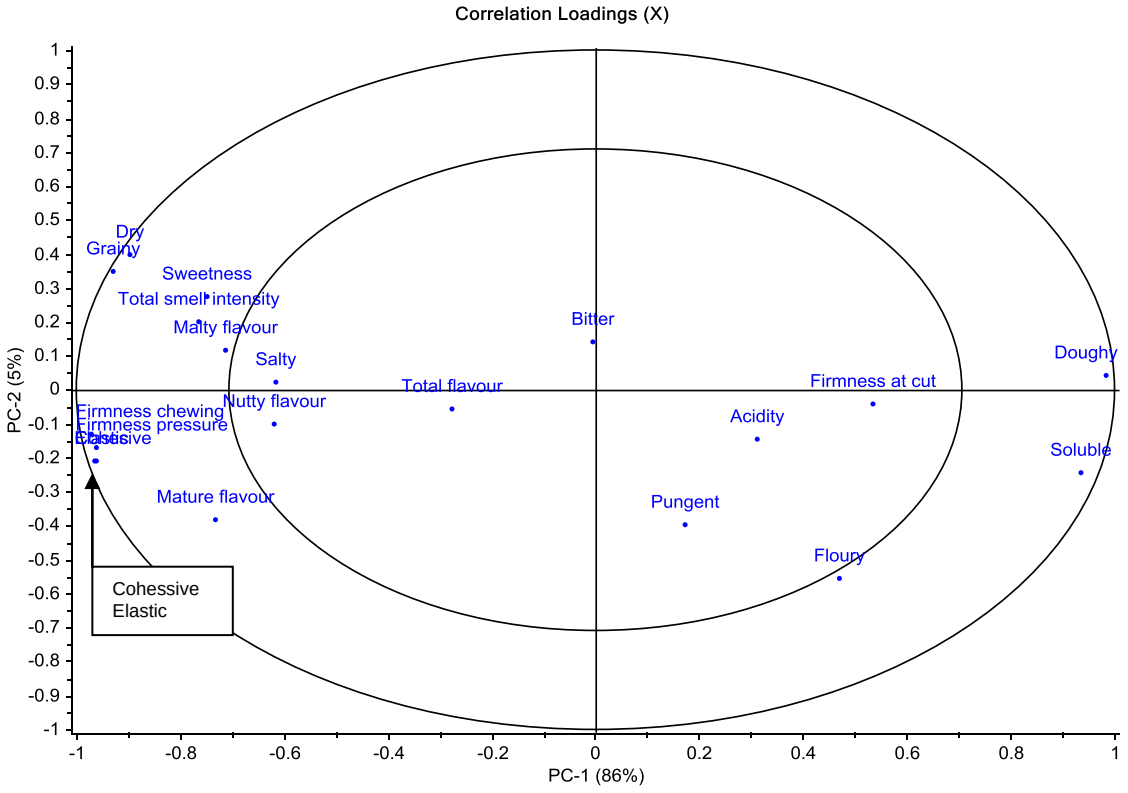
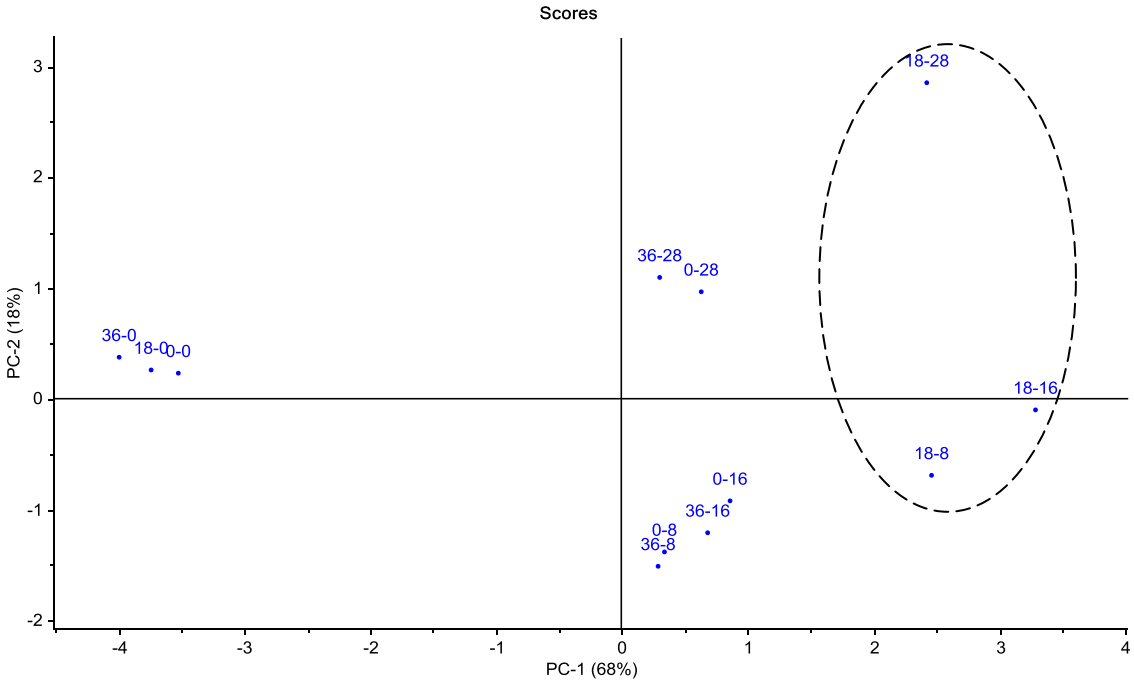


Figure 3.

a)


Scores
18-28
36-28
0-28
36-0
18-0
0-0
18-16
18-8
0-16
36-16
0-8
36-8
PC-2 (18%)
PC-1 (68%)

b)

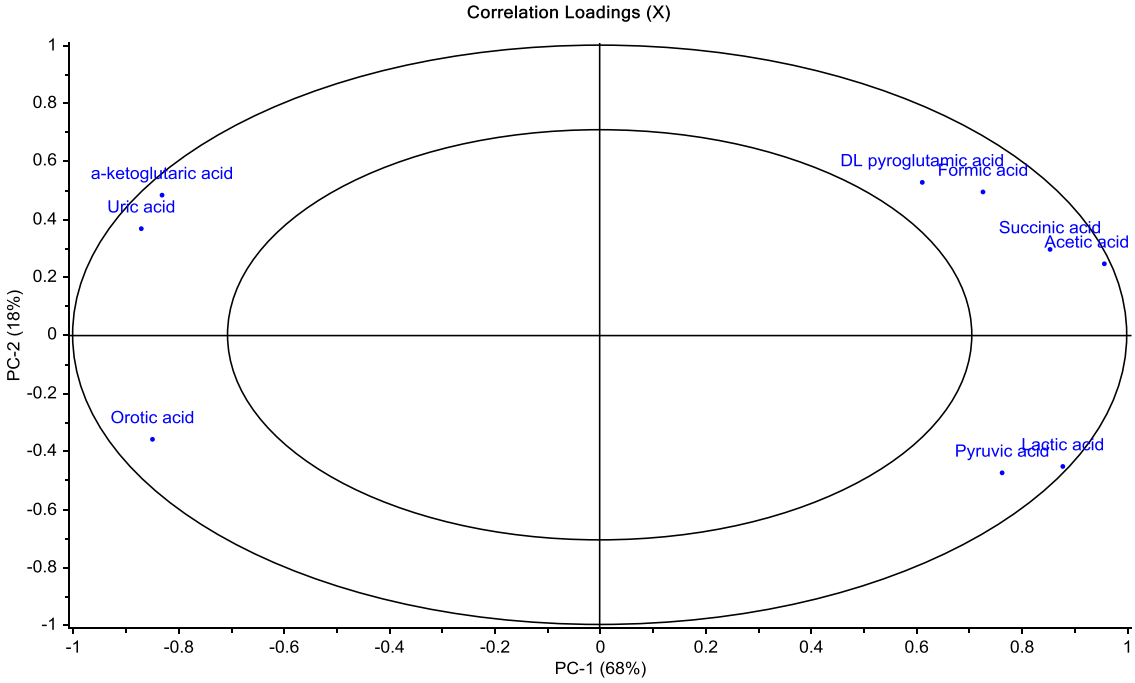
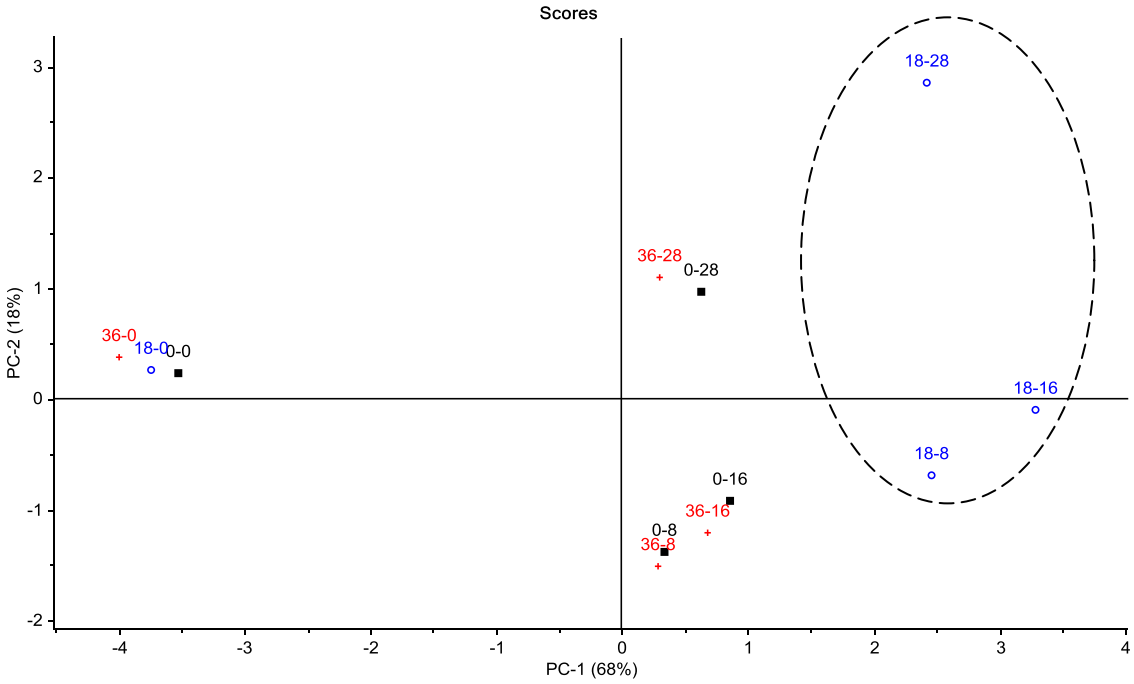

Correlation Loadings (X)
a-ketoglutaric acid
Uric acid
DL pyroglutamic acid
Formic acid
Succinic acid
Acetic acid
Orotic acid
Pyruvic acid
Lactic acid
PC-2 (18%)
PC-1 (68%)

Figure 3. Colour version for the web

a)



b)

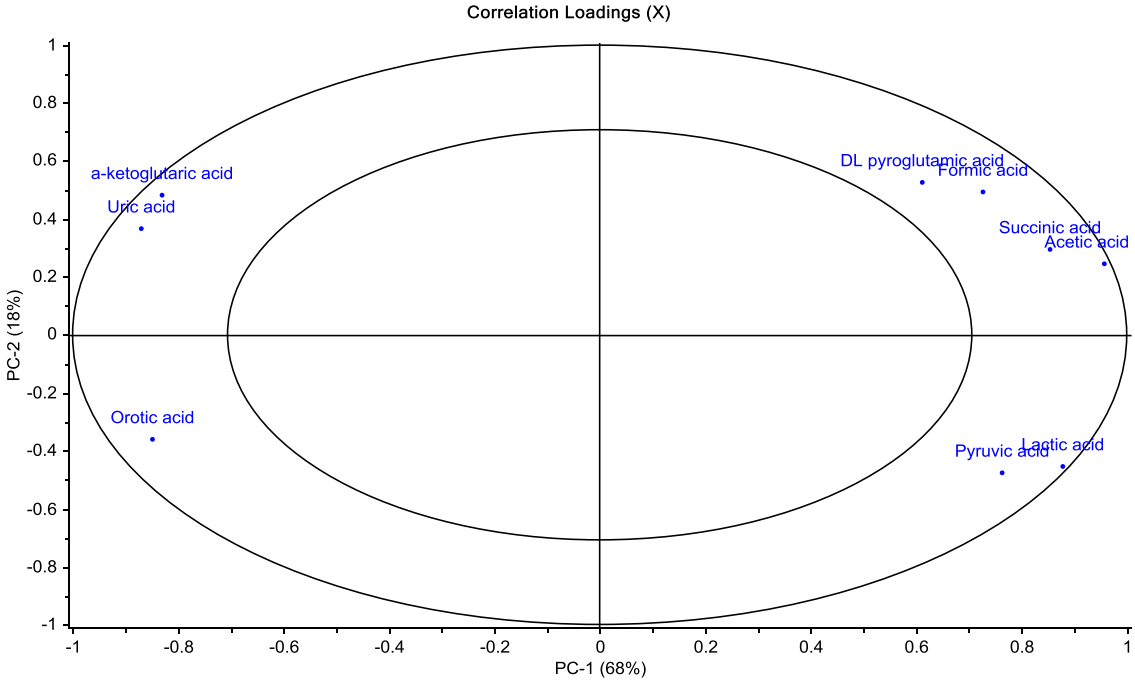
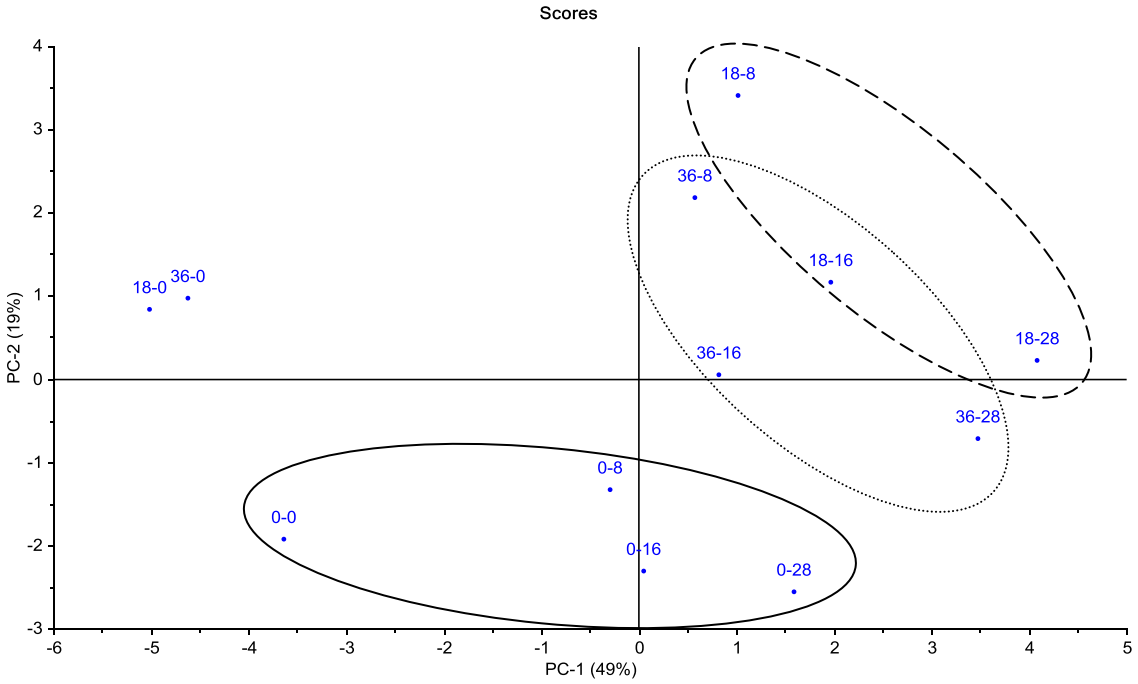


Figure 4

a)


Scores
18-8
36-8
18-16
18-28
36-16
36-28
18-0
36-0
0-8
0-0
0-16
0-28
PC-2 (19%)
PC-1 (49%)

b)

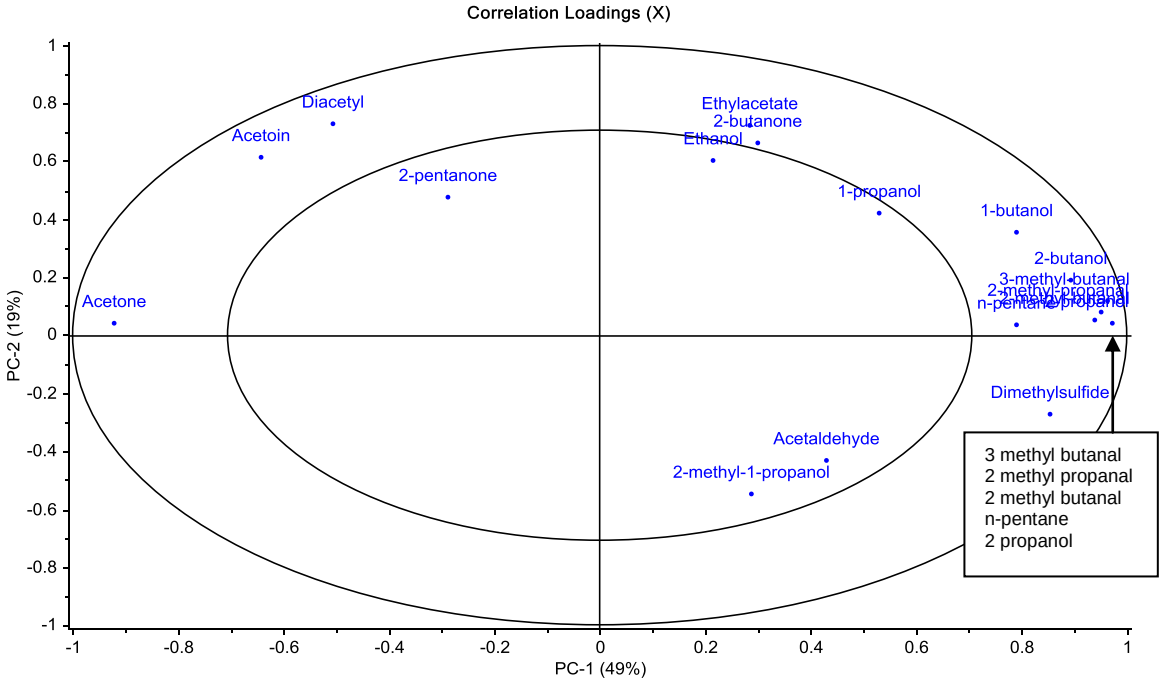
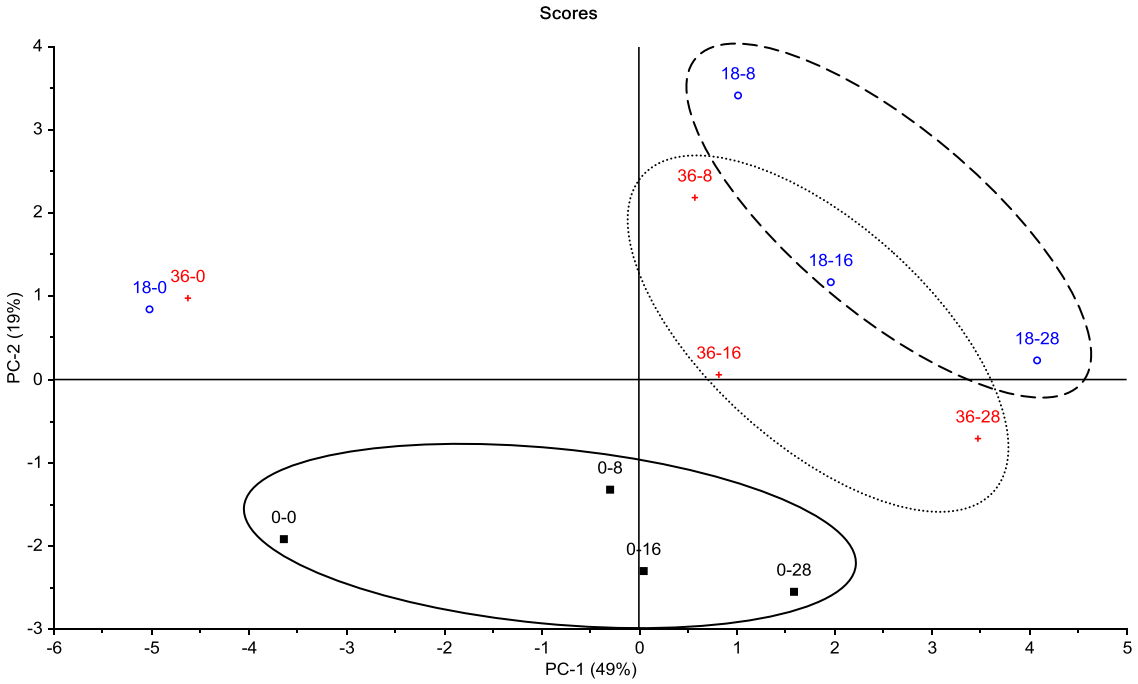

Correlation Loadings (X)
Diacetyl
Acetoin
Ethylacetate
2-butanone
Ethanol
2-pentanone
1-propanol
1-butanol
2-butanol
3-methyl-butanal
2-methyl-propanal
n-pentanal
2-propanol
Acetone
Dimethylsulfide
Acetaldehyde
2-methyl-1-propanol
3 methyl butanal
2 methyl propanal
2 methyl butanal
n-pentane
2 propanol
PC-2 (19%)
PC-1 (49%)

Figure 4 colour

a)



b)

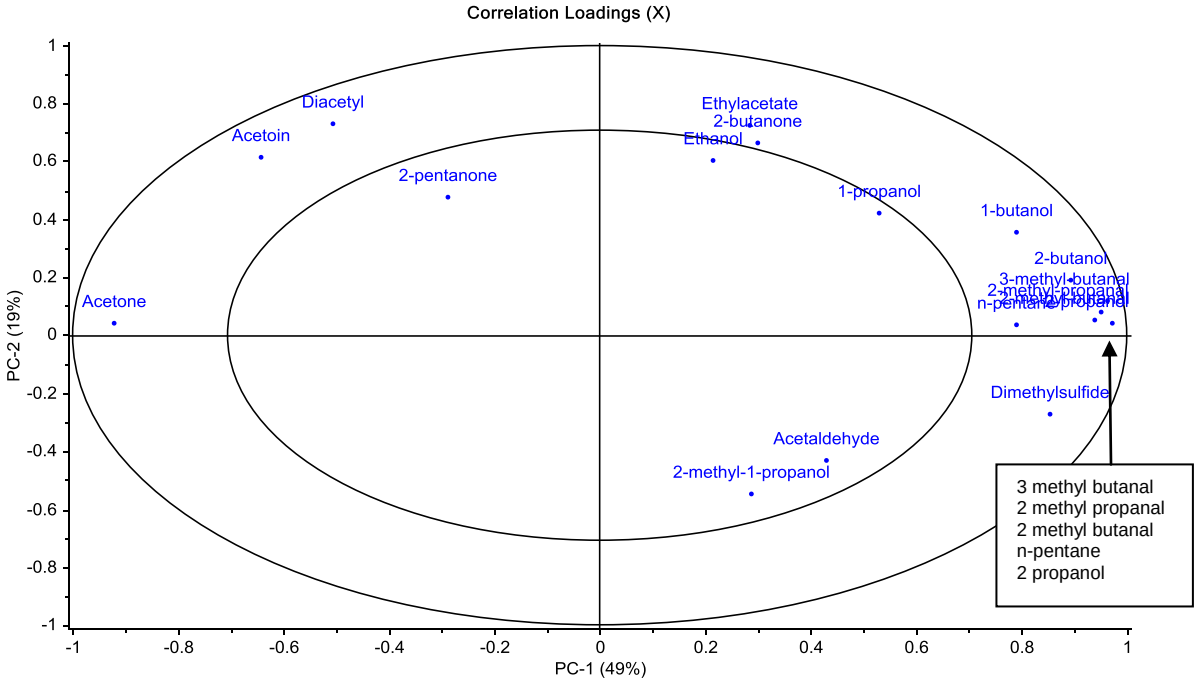
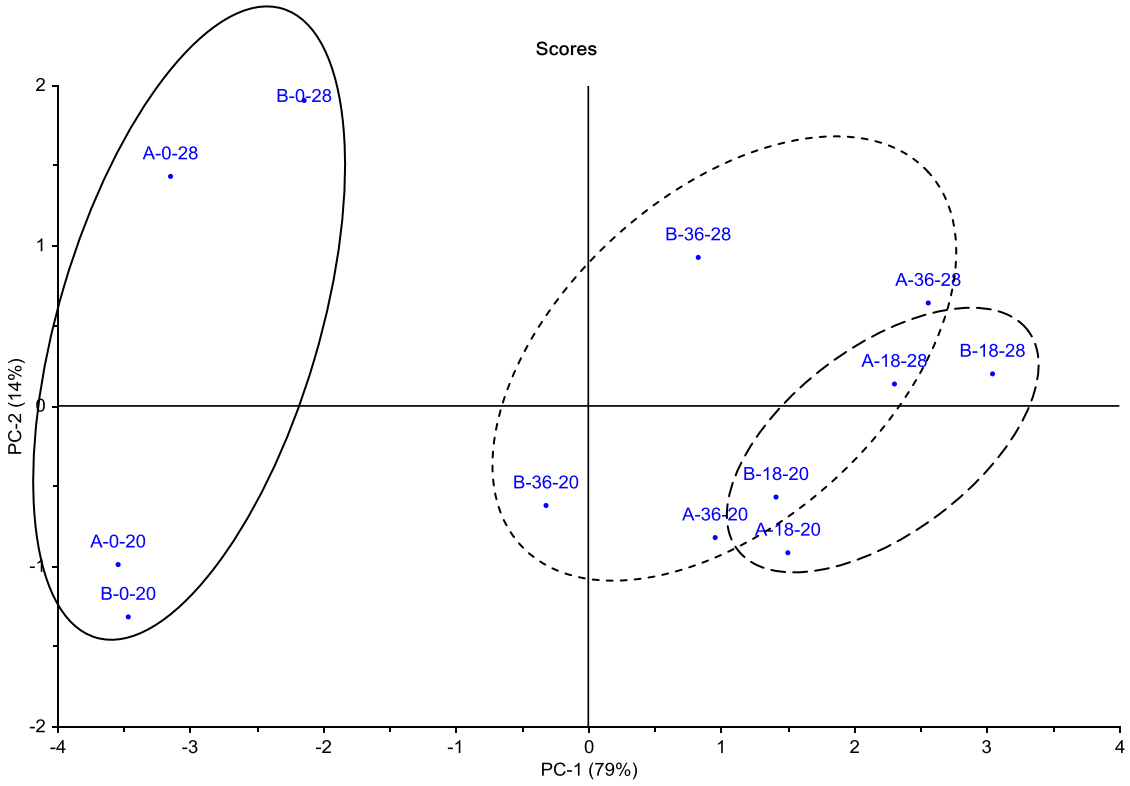


Figure 5

a)


Scores
B-0-28
A-0-28
B-36-28
A-36-28
A-18-28
B-18-28
B-36-20
B-18-20
A-36-20
A-18-20
A-0-20
B-0-20
PC-2 (14%)
PC-1 (79%)

b)

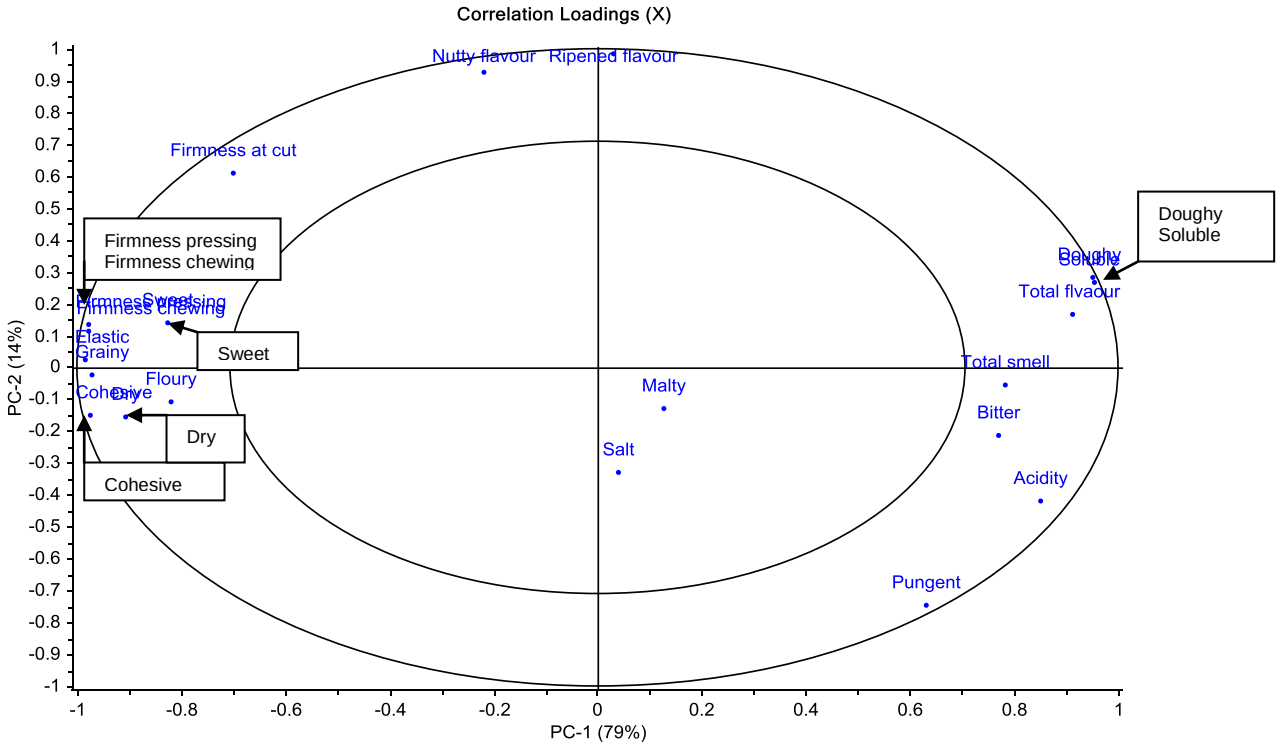
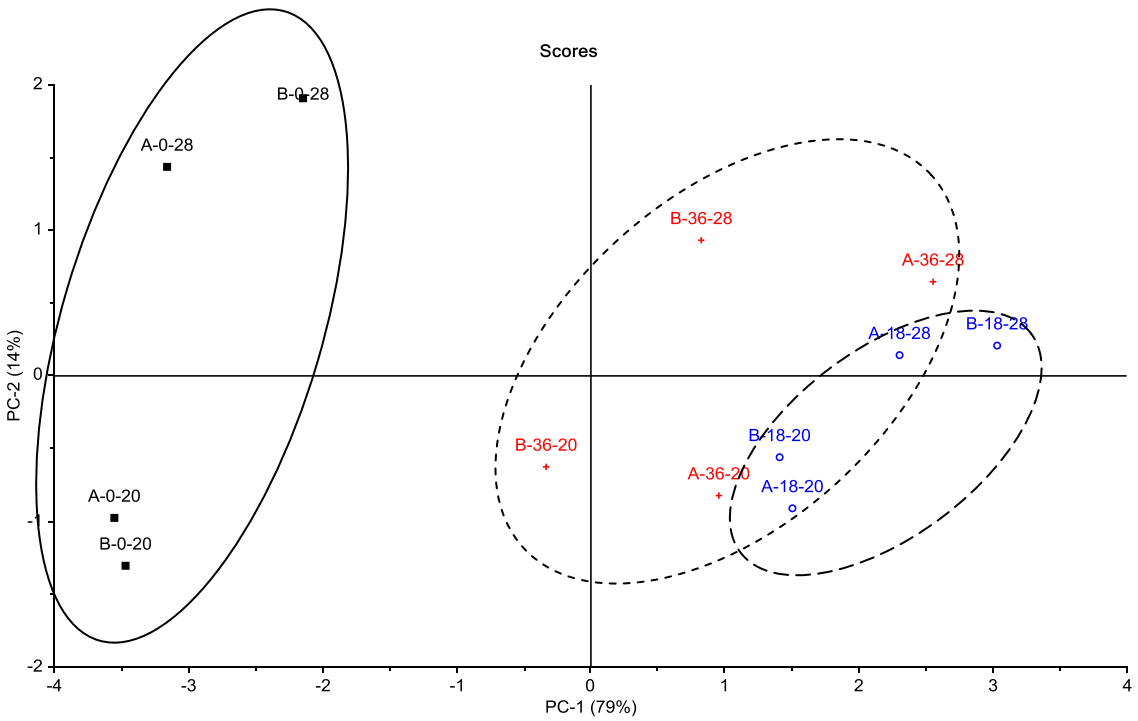

Correlation Loadings (X)
Nutty flavour
Ripened flavour
Firmness at cut
Firmness pressing
Firmness chewing
Sweet
Dry
Cohesive
Doughy
Soluble
Total flvaour
Total smell
Malty
Bitter
Salt
Acidity
Pungent
Elastic
Grainy
Floury
PC-2 (14%)
PC-1 (79%)

Figure 5 Colour

Figure 5

a)



b)