

Rheology, texture and meltability of different types of cheese.

Elling-Olav Rukke, Roger K. Abrahamsen, and Reidar Barfod Schüller

Faculty of Chemistry, Biotechnology and Food Science, Norwegian University of Life Sciences, P.O.Box 5003, N-1432 Aas, Norway

ABSTRACT

A MCR301 rheometer from Anton Paar, fitted with a PP50 plate/plate system was used to investigate the rheological properties of some cheeses. The test conditions were relevant to cheese melting during preparing of typical food dishes. Both initial elastic modulus, stress and strain at the limit of the linear viscoelastic region, were measured before and after heat treatment of the cheeses. The cheeses were heated from 20 °C to 90°C at a rate of 0.5 °C/minute, and then cooled to 20°C at the same rate. The storage modulus, G' , as a function of temperature, was measured to characterize changes in the stiffness of the cheese with temperature.

Heat treatment caused large variations in the measured parameters. Low fat cheeses behaved very different from full fat cheeses. The results show significant differences between the chosen cheeses on all the measured parameters.

INTRODUCTION

Large amounts of cheese are used in food as an ingredient in various food retail applications. In these dishes, the cheese's melting properties are of crucial importance to sensory properties of the finished products. Typical products where the melting behavior influence the final product's characteristics include pizza, lasagna, gratin, different sauces, toasts, sausages, cheeseburgers, cheese sticks, some baked foods and grilled products. In addition, some

products such as frozen- and grilled fishmeal's can contain cheese as an ingredient. As an example, the amount of Jarlsberg cheese used for Grandiosa Pizza is very large in Norway.

The cheese's melting properties are different for various types of cheese. The treatment of milk, cheese-making technique, salting method and maturation conditions are all factors affecting the melting properties of the cheese. The composition of the cheese, such as dry matter, fat-, protein- and calcium content, are also factors determining the melting abilities of cheeses. In addition, these conditions also influence on how thread-like the cheese will be in the melted state.

The cheese structure determines, to a large extent, the mechanical and technological properties of cheese, as claimed in a recent comprehensive review of Lamichhane et al.². According to these authors, the full extent of the relationships between cheese structure and the functionality of the cheese is not fully understood. Heating causes the cheese to melt and to release fat to a certain degree, whereby the original structure is altered by a complex melting process³. Melted fat may coalesce and result in the separation of fat from the protein matrix. This causes the undesirable effect of oiling off or fat leakage. The resolidification of fat during cooling may cause a less homogeneous distribution of fat, and a significant alteration of the cheese structure⁴. Above 40°C, milk fat is

considered as melted into a liquid form⁵. Other factors such as the dissolving of proteins are likely to govern the thermal softening of the cheese. Proteins (mainly caseins) do not melt, but their interaction with each other can change to produce an effect that we call melt⁴.

The rheological properties of Mozzarella cheese have been widely studied⁶. These studies collectively show that compositions and flow conditions affect the rheology of cheese. Zhu et al⁷, developed a model to predict the impact of shear rate, temperature and moisture content on the shear viscosity of Mozzarella cheese. They chose conditions, which were similar to Mozzarella cheese flow during pizza baking.

Rheological behaviour of cheese can be measured by an array of tests. These tests are useful in characterizing cheese as a viscoelastic material exhibiting the properties of ideal solids and liquids. Other tests employ strains outside the viscoelastic range. Such as large strain compression or torsion geometry and yield quantities (e.g., fracture stress, fracture strain, and/or hardness). These factors are more empirical, but simulate the stresses and strains encountered during

consumption and commercial size-reduction operations (including shredding and grinding). The rheological characteristics of cheese are controlled by its macrostructure, microstructure, composition, and internal environment (e.g., pH, temperature). The primary structural component controlling the deformation of cheese for a given stress, is the protein matrix, with its concentration and degree of proteolysis and hydration being critical^{8, 9, 10, 11}.

Another aspect influencing rheology and melting properties of cheese relates to the age of the product and the degree of ripening¹². An example is the formation of few long fibres or strips in melted matured cheese, compared to the more tough and fibrous behaviour of melted young cheeses⁶. pH of cheese determines to a large extent the cheese structure, which in turn decides the cheese shredability and meltability properties¹³.

The objectives of the studies reported in this paper was to:

- investigate- and compare the melting properties of a selection of cow milk cheeses related to the composition of the cheese and the cheese making technique.

Table 1. Approximate composition (% w/w) of the different cheeses investigated (SFA- Saturated Fatty Acids). Values declared by the manufacturers.

Cheese	Appr. dry matter	Protein	Carbo-hydrate	Fat Content	SFA	Salt	pH
Cheddar	60	25.0	< 0.1	33.0	21.0	1.8	5.12
Go`Vegan	45	< 1.0	34.0	9.0	6.0	1.8	7.50
Jarlsberg	55.4	27.0	<0.01	27.0	17.0	1.1	5.51
Jarlsberg Lett	48.4	31.0	<0.01	16.0	10.0	1.0	5.56
Norvegia	55.5	27.0	<0.01	27.0	17.0	1.2	5.44
Norvegia Lett	48.4	31.0	<0.01	16.0	10.0	1.1	5.47
Raclette	57.5	24.0	<0.05	30.0	18.0	2.0	5.76
Mozzarella	40	18.0	1.5	19.0	13.0	0.4	6.08

MATERIALS AND METHODS

Cheeses

The seven different variants of cow milk cheeses tested, are listed in Table 1 together with a non dairy “cheese” called Go`Vegan. The cheeses were purchased from local Norwegian food shops.

Cheddar, Mozzarella and Raclette cheese are considered as well known internationally. Jarlsberg- and Norvegia cheese are Norwegian cheese specialties mainly manufactured according to the protocol of the cheese making of Gouda cheese. Jarlsberg cheese has, however, in addition to the mixed strain mesophilic starter of lactic acid bacteria, added an adjunct culture of *Propionibacteria freudenreichii* subsp. *shermanii* as outlined by Abrahamsen et al¹⁴.

pH in the cheeses was measured according to guidelines given by The Norwegian Dairies Association¹⁵. 25 g of grounded cheese was added 10 ml of distilled water. Each sample rested for 30 minutes before pH measurement.

Instrumental analysis and experimental set-up

The Physica MCR301 rheometer (Paar Physica, Anton Paar, Stuttgart, Germany, 2010) was used in oscillation to characterize the cheeses.

A PP50 plate/plate system was used. The gap size varied between the different cheeses tests from approximately 1.5 mm to 5 mm since the thickness of the slices differed.

The cheese was placed on the Peltier plate. The plate was lowered until the normal force was 10 mN. The gap was then locked in this position.

Initially an amplitude sweep was run at 1 Hz up to 100% strain at 20°C. Then the cheese was heated to 90°C at a rate of 0.5°C/min. The sample was then cooled to 20°C at a rate of 0.5°C/min. A new amplitude sweep was carried out after the temperature treatment.

RESULTS

Fig 1, 2 and 3 show results from the amplitude sweep before and after heat treatment. In Fig. 4 the melting- and solidifying temperatures for the different cheeses are compared. Fig. 5 and 6 are visual illustrations of changes in Raclette cheese before- and after heating to 90°C. Fig. 7 illustrate the variation in Storage Modulus G' as a function of temperature for the various cheeses investigated.

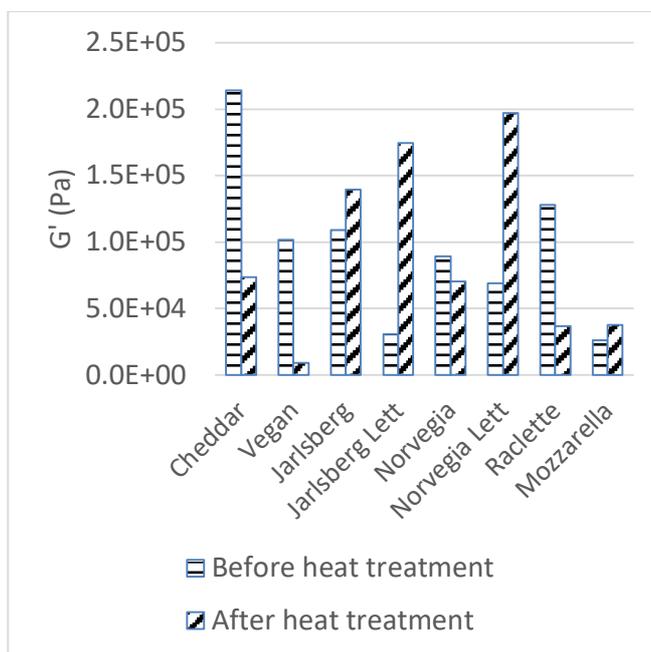


Figure 1. Elastic modulus in cheese at 20 °C before- and after heat treatme

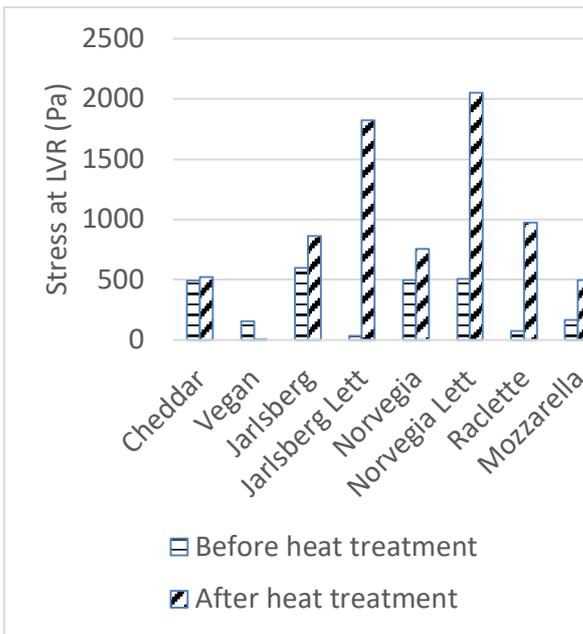


Figure 2. Stress at the limit of the linear viscoelastic region (LVR) at 20 °C before- and after heat treatment of the cheeses.

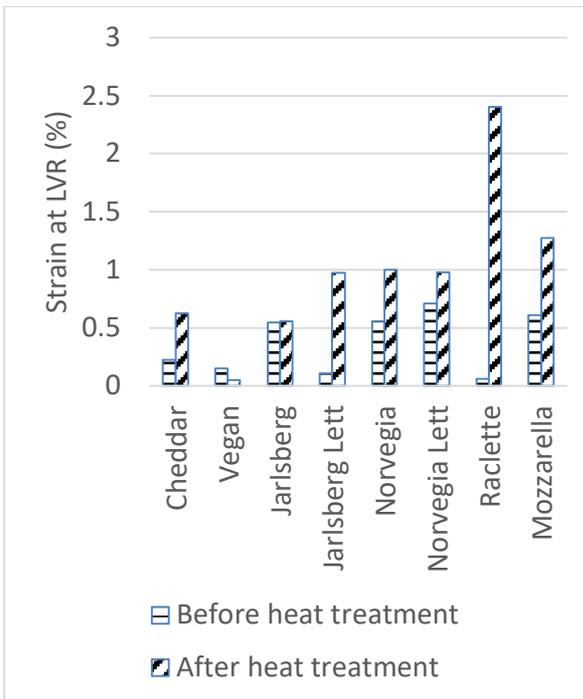


Figure 3. Strain at the limit of the linear viscoelastic region (LVR) at 20 °C before- and after heat treatment of the cheeses.

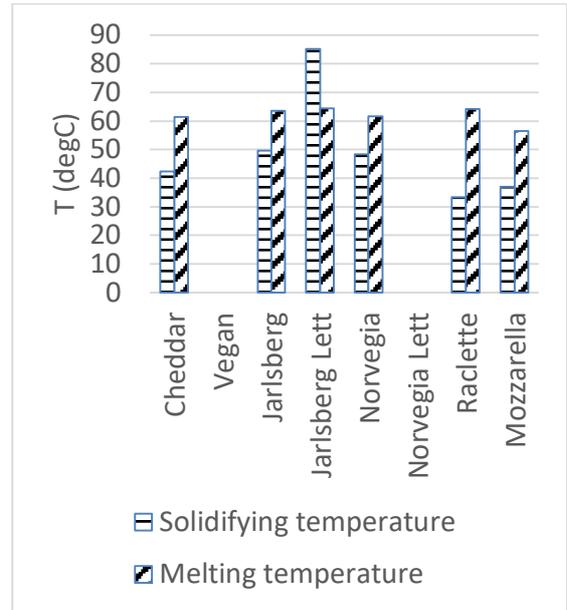


Figure 4. Solidifying- and melting temperatures for the different cheeses investigated (Vegan and Norvegia Lett remained viscoelastic solids at all temperatures. They did not melt at temperatures below 90°C).

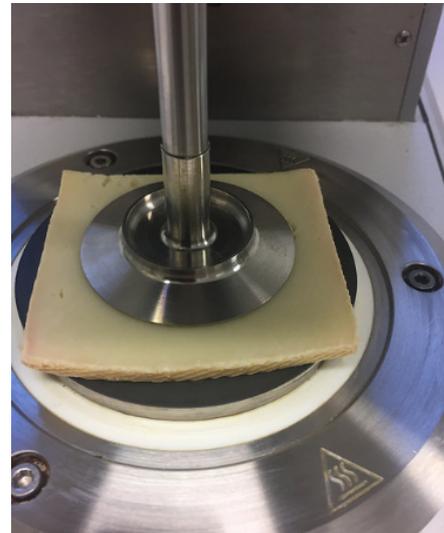


Figure 5. Raclette cheese placed on the Peltier plate before heating. The plate was lowered until the normal force was 10 mN. The gap was then locked in this position during heating to 90°C at a rate of 0.5 °C/min. (Photo: Reidar B. Schüller)



Figure 6. Raclette cheese after heating to 90°C followed by subsequent cooling to 20°C at a rate of 0.5°C/min. (Photo: Reidar B. Schüller)

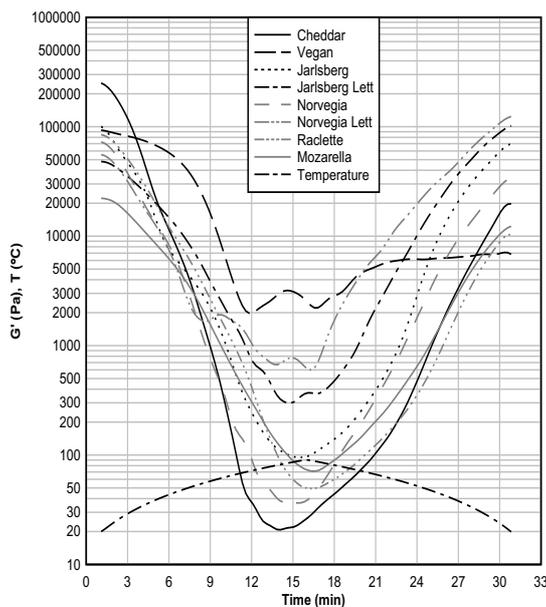


Figure 7. Variation in G' as function of temperature in cheese.

DISCUSSION

The cheese making technique mainly determines the melting properties of the cheese. Compared to for instance the Gouda type of cheeses, Cheddar cheese processing implies a rather strong acidification of the

cheese milk and of the cheese curd during the cheddaring process. No dilution of the whey with water will leave a relatively high amount of lactose in the fresh cheese. This phenomenon will play a crucial role in the development of the pH-value in the cheese. The drop in the pH before pressing of the cheese after cheddaring, dissolves Ca-ions from the casein micelles and the casein matrix of the cheese. Therefore the proportion of undissolved Ca associated with casein particles in Cheddar, is expected to be lower than the proportion in Gouda type of cheeses. In Gouda type of cheeses, the lactose content in the whey has been diluted by washing the curd with water. As underlined by Lucey and Fox¹ this proportion of undissolved Ca associated with the casein particles in the cheese matrix, is considered a more important structure parameter than the total content of Ca-ions in the cheese. A more comprehensive solubilisation of Ca will, according to the dual binding model for casein micelles presented by Horne (the Horn model), result in a weakening of cheese structures. This phenomenon causes an increase in meltability⁶.

For manufacturing of Raclette cheese of pasteurized milk, a pre-acidification temperature of the milk of approximately 32 °C is applied. A mesophilic mixed strain starter of lactic acid bacteria is used. Often an adjunct starter of *Streptococcus thermophilus* is added. The washing of the curd is far less pronounced, than for the Dutch type of cheeses. The pH of the 24 h cheese is therefore somewhat lower (pH 5-5.2) than for the Dutch type cheeses. A relatively high increase in pH during storage of Raclette cheese, is a result of the proteolysis caused by the smear culture administered on the surface of the cheese¹⁶.

The high pH of Mozzarella is a result of killing the starter bacteria during the stretching process at high temperature. This phenomenon is typical for manufacturing of Mozzarella and other pasta filata type of cheeses.

The viscosity of the different cheese samples investigated in this screening test, are strongly influenced by the temperature range before, during and after heating from about 20°C to 90°C and back again to 20°C.

The measurements of G' before and after heating, Fig. 1, show that G' is reduced for Cheddar, Go`Vegan, and Raclette. This effect for Cheddar and Raclette is most likely the result of a rather low pH in the cheese immediately after the end of the cheese making. G' increases for Jarlsberg, Jarlsberg Lett and Norvegia Lett.

Measurements of the stress at the limit of the linear viscoelastic range, Fig. 2, show that Jarlsberg Lett, became much stronger after heat treatment. Go`Vegan becomes much weaker, whilst Cheddar does not change that much.

The limiting strain measurements, Fig.3, show that all the cheeses but Vegan can be stretched more before structural damage occurs after heating. All the cheeses but Vegan change to viscoelastic liquids during the heat treatment. The value of G' and G'' generally decrease with increase in temperature, meaning that the cheeses become less stiff (softer) and have a reduced viscosity.

The melting temperatures for the different cheeses are shown in Fig.4. Mozzarella melts at a temperature below the other cheeses in the investigation. This may be because of the changes taking place in the cheese matrix during the high temperature applied under the stretching process, and the resulting high pH-value in the cheese.

The solidifying temperatures are also shown in Fig.4. Jarlsberg Lett solidifies at a high temperature. It is behaving much like Norvegia Lett. It did not melt at all. This observation is in accordance with the expected effect of the reduced amount of fat in these cheeses. It is the fat, which actually is melting while the casein does not melt.

The variations in G' with temperature are shown in Figure 7. As expected, the stiffness is generally reduced significantly

when the temperature is increased. The results show that the stiffness is reduced by a factor of approximately 100, when the temperature is increased from 20°C to 90°C.

pH during cheese making before whey drainage and the degree of dissociation of Ca from the casein matrix, is known to influence functional properties in cheese. For some cheeses, the pH will change during storage. This change may also influence the functional properties of the cheese during melting and solidification. From literature it is known that pH above 5.0 seems to have an indirect effect through its effect on calcium solubility. Injecting acid into cheese to lower pH, increases the proportion of soluble calcium in the cheese. Between pH 5.35 and 5.0, such cheeses become softer with increased meltability. Both of these changes are indicative of increased hydration of the protein network brought about by having less calcium bound to the caseins. Below pH 5.0, loss of solubility of the caseins becomes the predominant factor influencing cheese functionality. Such cheeses loose their ability to melt and stretch, even though bound calcium continues to decrease¹⁷.

Regarding pH and its influence on the melting properties in this investigation, none of the cheeses had pH below 5. The pH varied between 5.12 to 6.08 for real rennet cheeses. Cheddar was measured to pH 5.12 and Mozzarella to pH 6.08; lowest and highest, respectively.

The cheeses with high pH, Raclette and Mozzarella, achieved the highest strain after heating to 90°C. The vegan based substitute cheese, which had the highest pH 7.5, is not comparable with real cheeses. Go`Vegan has no fat. This is in contrast to the real cheeses, which contain almost no carbohydrates. Go`Vegan contains carbohydrates at a level of 34%.

Most renneted cheeses range from 5.1 to 5.9 in pH. This is also according to the measurements in this study. However, this range will have exceptions to certain types of cheeses such as Camembert. This cheese has

a pH of 7.4 caused by the extensive brake down of the proteins by the surface mould during ripening.

To determine if pH has an influence on cheese functionality independent of the amount of calcium, it might be interesting to design an experiment using direct acidification to generate cheeses with varying pH, moisture, and calcium levels.

CONCLUSIONS

The conclusions of this screening study can be summarized as follows:

- Heat treatment of cheese caused large variations in the measured rheological parameters. This includes results both regarding initial elastic modulus, stress and strain at the limit of the linear viscoelastic region. Low fat cheeses behaved very different from full fat cheeses. Both stress and elastic modulus at 20°C after heating to 90°C, were significant different from the full fat cheeses. One particular “outlier” was the vegan based cheese substitute “Go`Vegan” completely without fat.
- Regarding melting temperatures, Norvegia Lett and Go`Vegan did not melt at all, at temperatures below 90°C. This means that these cheeses are unsuitable in dishes where cheese's melting properties are of crucial importance. This is also illustrated when it comes to solidifying temperature. Norvegia Lett and Go`Vegan remained viscoelastic solids at all temperatures investigated.
- It seemed that pH in the final cheese had less impact on the results than the fat content of the cheeses, where such comparison is justified (Jarlsberg cheese and Norvegia cheese). Just for strain at the limit of the linear

viscoelastic region after heating, it seems that milk-based cheeses with relatively high pH (Raclette and Mozzarella), achieved higher values than the other cheeses.

REFERENCES

1. Lucey, J.A., and Fox, P.F. (1993). “Importance of calcium and phosphate in cheese manufacture: A review”. *J. Dairy Sci.* **76**: 1714-1724.
2. Lamichhane, P., Kelly, A.L., and Sheehan, J.J. (2017). “Symposium review: Structure-function relationships in cheese”. *J. Dairy Sci.* **101**: 2692-2709.
3. Guggisberg, D., Bütikofer, U. and Albrecht, B. (2007), “Melting and solidification characteristics of swiss Raclette cheese measured by small amplitude oscillatory shear measurements”, *Journal of Texture Studies* **38**: 297-323.
4. Gunasekaran, S. and Ak, M.M. (2003). “Cheese Rheology and Texture”, pp. 215–272, 331–375, 399–428, CRC Press, Boca Raton, FL; London; New York, NY; Washington, DC.
5. Mulder, H. and Walstra, P. (1974). “The Milk Fat Globule: Emulsion Science as Applied to Milk Products and Comparable Foods”, *Universities Press*, Belfast, Northern Ireland.
6. Lucey, J.A., Johnsen, M.E. and Horne, D.S. (2003). “Perspectives on the basis of the rheology and texture properties of cheese”. *J. Dairy Sci.* **86** :2725–2743.
7. Zhu, C., Brown, C., Gillies, G., Watkinson, P. and Bronlund, J. (2015). “Characterizing the rheological properties of mozzarella cheese at shear rate and temperature conditions relevant to pizza baking”, *LWT – Food Science and Technology* **64**: 82-87

8. Guinee, T.P. (2011) "Cheese and Cheese Rheology", *Encyclopedia of Dairy Sciences, Second Edition*, ISBN: 978-0-12-374407-4 : 685–697
9. Guinee, T. P., & O'Callaghan, D. J. (2013). "Effect of increasing the protein-to-fat ratio and reducing fat content on the chemical and physical properties of processed cheese products". *J. of Dairy Sci.*, **96**: 6830-6839.
10. Guinee, T. P., Auty, M. A. E., & Fenelon, M. A. (2000a). "The effect of fat on the rheology, microstructure and heat-induced functional characteristics of Cheddar cheese". *International Dairy Journal*, **10**: 277-288.
11. Guinee, T. P., Auty, M. A. E., & Mullins, C. (1999). "Observations on the microstructure and heat-induced changes in the viscoelasticity of commercial cheese". *Australian Journal of Dairy Technology*, **54**: 84-89.
12. Ray, C.A., Gholamhosseinpour, A. Ipsen, R. and Hougaard, A.B. (2016) "The effect of age on Cheddar cheese melting, rheology and structure and on the stability of feed for cheese powder manufacture". *International Dairy Journal*, **55**: 38-43.
13. Jana, A.H. and Tagalpallewar, G.P. (2017). "Functional properties of Mozzarella cheese for its end use application". *J. Food Sci Technol*, **54**: 3766-3778.
14. Abrahamsen, R.K., Byre, O., Steinsholt, K., and Strand, A.H. (2006). «Jarlsberg cheese. History and development», ISBN-100: 82-529-3056-5, Tun Forlag, Oslo, Norway.
15. Norwegian Dairies (1989). "pH in rennet cheeses". *Norwegian Dairies Book of Analysis*, Method 708.
16. Bocquel, D., Marquis, R., Dromard, M., Salamin, P.-A., Rey-Siggen, J., Héritier, J., Kosinska-Cagnazzo, A., and Andlauer, W. (2015). "Effect of flaxseed supplementation of dairy cows' forage on physicochemical characteristic of milk and Raclette cheese". *International Journal of Dairy Technology*, **69**: 129-136.
17. McMahon, D.J., Paulsen, B. and Oberg, C.J. (2005). "Influence of Calcium, pH, and Moisture on Protein Matrix Structure and Functionality in Direct-Acidified Nonfat Mozzarella Cheese". *J. Dairy Sci.* **88**: 3754-3763.