http://www.diva-portal.org

Preprint

This is the submitted version of a paper published in *International Dairy Journal*.

Citation for the original published paper (version of record):

Berta, M., Muskens, E., Schuster, E., Stading, M. (2016)
Rheology of natural and imitation mozzarella cheese at conditions relevant to pizza baking
International Dairy Journal, 57: 34-38
https://doi.org/10.1016/j.idairyj.2016.02.038

Access to the published version may require subscription.

N.B. When citing this work, cite the original published paper.

Permanent link to this version:
http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-428

Rheology of natural and imitation mozzarella cheese at conditions relevant to pizza baking

Marco Berta [a,*], Erwin Muskens[a,b], Erich Schuster [a], Mats Stading[a, c]

a SP Food and Bioscience, Soft Materials Science, PO Box 5401, SE-402 29 Gothenburg, Sweden

b University of Applied Sciences HAS Den Bosch, Department of Food Technology, Onderwijsboulevard 221, 5223 DE's-Hertogenbosch, Netherlands

c Chalmers University of Technology, Department of Materials and Manufacturing Technology, SE-412 96 Gothenburg, Sweden

*Corresponding author: Tel.: +46(0)105166635, Fax: +46(0)313351363, E-mail address: marco.berta@sp.se

---

ABSTRACT

The rheology of mozzarella and imitation cheese was studied at the temperature of 60 ºC, with small amplitude oscillatory shear (SAOS), shear and extensional flow measurement at low strain rates in the range 0.01-1 s^{-1}. These conditions were chosen to replicate those experienced by the cheese during pizza baking and consumption. The extensional viscosity measurements were carried out by means of Hyperbolic Contraction Flow. The shear rheology results differed significantly for the two cheese materials and could be related to the structural observations made by confocal laser scanning microscopy (CLSM). The extensional flow curves were similar for both materials, with a higher extensional viscosity of the mozzarella compared to that of imitation cheese. The extensional viscosity is proposed to be connected to the experienced quality of a stringy pizza cheese.

Keywords: mozzarella, imitation cheese, Hyperbolic Contraction Flow, rheology

---

1. Introduction

The capacity to melt, flow and stretch of low moisture (45-52%) mozzarella makes it the ideal cheese for pizza and similar food products such as calzone(Kindstedt, 1993). The rheological characterization of mozzarella cheese has been extensively used to assess its meltability(Kiely, McConnell, & Kindstedt, 1991) and stretchability. Along with the taste, those are quality demands for the product(Ma, James, Zhang, & Emanuelsson-Patterson, 2013), especially since mozzarella is often substituted by cheaper imitation cheese for pizza. The earliest rheological comparisons of mozzarella and mozzarella imitation cheese date back to the early 80's(Hennelly, Dunne, O'Sullivan, & O'Riordan, 2006; J. S. Mounsey & O'Riordan, 1999; Nolan, Holsinger, & Shieh, 1989). Due to the importance of stretchability for the consumer's acceptance of the molten cheese on pizza, dedicated extensional viscosity tests were designed to be carried out in addition to the common shear test (Apostolopoulos, 1994; Timothy P. Guinee & O'Callaghan, 1997; J. S. Mounsey & O'Riordan, 1999). Extensional measurements of mozzarella cheese were performed with the Sentmanat Extensional Rheometer (SER) but had to be corrected for the drying of the sample during testing (Merrill, Oberg, McManus, Kalab, & McMahon, 1996), and the issue was targeted in another study using a special ring and ball device where the cheese sample was immersed in mineral oil (Hicsasmaz, Shippelt, & Rizvi, 2004). In this work, extensional viscosity of mozzarella is measured by means of Hyperbolic Contraction Flow(Nyström, 2015; Stading & Bohlin, 2001; Wikström & Bohlin, 1999), with the advantage of using a versatile standard test where drying of the sample is minimized. Extensional measurements were compared for both natural and imitation mozzarella cheese to those made in shear, with temperature and deformation rate conditions as close as possible to those of pizza baking(Zhu, Brown, Gillies, Watkinson, & Bronlund, 2015). This characterization aims to estimate the effect of cheese quality on its rheological properties, and possibly to help relating those to the consumer perception.

2. Materials and methods

2.1. Materials

Commercially available dry mozzarella (Wernersson Ost AB, Ulricehamn, Sweden) and an imitation cheese sold as "pizza mix" (Axfood AB, Solna, Sweden), that contained palm oil and potato starch, were purchased from local retailers in Sweden. Rheological differences between other mozzarella cheese brands were minimal and results are reported only for one brand. All materials were stored at 5 ºC and tests were carried out well before the cheese expiry date. Although the oven temperatures used to bake pizza are typically 200-250 ºC, mozzarella melts early in the baking process in the temperature range of 40-80 ºC(Zhu, et al., 2015). Therefore, results for our study were collected within this range, for cheese samples heated to 60 ºC.

2.2. Rheological measurements

2.2.1 Shear rheology

Rheological tests were carried out at 60 ºC and the sample temperature was periodically checked using a thermocouple. Steady shear viscometry was performed over a shear rate range of 0.01–10 s^{-1}, relevant to pizza baking conditions(Zhu, et al., 2015), using an Ares-G2 (TA instruments, Waters LLC, USA) strain controlled rotational rheometer equipped with a parallel plate geometry having a 40 mm diameter. These measurements are not straightforward since considerable slippage occurs for the mozzarella cheese shear measurements (Bähler, Back, & Hinrichs, 2015; Nolan, et al., 1989; Sharma, et al., 2015). Sandpaper (60 grit) was glued to the parallel plates geometry using double sided tape, to prevent as much as possible the sample slippage. Oscillatory shear measurements were carried out using a stress-controlled rheometer (StressTech, Reologica Instruments AB, Lund, Sweden) equipped with a 30 mm diameter serrated plate-plate geometry. Preliminary amplitude sweeps were carried out to determine the linear viscoelastic regions at which the frequency sweep of the samples was obtained. For the mozzarella samples, a gap of no more than 1mm had to be used in combination with serrated plates to avoid sample slippage. Mechanical spectra of mozzarella cheese were recorded at a constant stress of 80 Pa, within the linear viscoelastic region. This stress level was sufficient to obtain good rheometric signals from the material mechanical response but not so high as to cause slippage.

2.2.2 Hyperbolic Contraction Flow (HCF)

The cheese apparent extensional viscosity was measured using a Hyperbolic Contraction Flow rig(Nyström, 2015; Stading & Bohlin, 2001) mounted in an Instron 5542 Universal Testing Instrument (Instron Corporation, Canton, USA). Measurements were performed at 60 ºC using a die with inlet radius of 10 mm and outlet radius of 3 mm, imposing a Hencky strain of 3.6 for the cheese samples. The extensional strain rates were in the same range of continuous shear flow measurements, 0.01 s^{-1} to 1 s^{-1}. The transient extensional stress was monitored until a stable plateau value was reached from which the steady-state, and the transient extensional viscosity was calculated as described by Wikström and Bohlin . The Power-law parameters acquired with the continuous shear measurements were used to calculate the extension rates, the Hencky strain and to compensate for the shear stress contribution to the total stress (Wikström & Bohlin, 1999). The shear contribution was small in all cases (<1 %).

2.3. Confocal laser scanning microscopy (CLSM)

Samples for microscopy were stored frozen and molten at 60 ºC prior to freezing in order to correlate at best the structure imaged to the rheological results. The microstructures of the cheese samples were examined with CLSM using a Leica TCS SP5 confocal laser scanning microscope (Leica

Microsystems, Heidelberg, Germany). BODIPY FL C16 (Molecular Probes, Eugene, Oregon, USA) and Texas Red® sulfonyl chloride (Molecular Probes, Eugene, Oregon, USA) were used as fluorescent dyes that bind preferentially to fat and protein, respectively. The dyes were dissolved in methanol and water respectively prior to application to the sample and dried on microscope slides. The frozen cheese was sliced and placed on microscope slides stained with the dyes, and analyzed under the microscope at room temperature after thawning. The light sources were a HeNe laser with λ_{ex}=543 nm (Texas Red) and an Ar/ArKr laser with λ_{ex}=488 nm (BODIPY). Signals from the samples were captured at wavelengths of 555–700 nm and 500–535 nm for Texas Red and BODIPY, respectively.

3. Results

3.1. Confocal scanning laser microscopy (CLSM)

The microstructures of mozzarella and imitation cheese are illustrated by the CLSM micrographs in figure 1. The mozzarella cheese displays a protein matrix, in blue, often interrupted by small pockets of fat, in green. These pockets act effectively as lubricant when the cheese is heated up to its melting temperature (Merrill, et al., 1996). Liquid pockets are fewer for the imitation cheese and a more heterogeneous structure is observed. The microstructural heterogeneity in the imitation cheese can be explained by the additional incorporation of starch, which is not present in mozzarella. Starch is contained within grainy domains, observable in figure

1b.

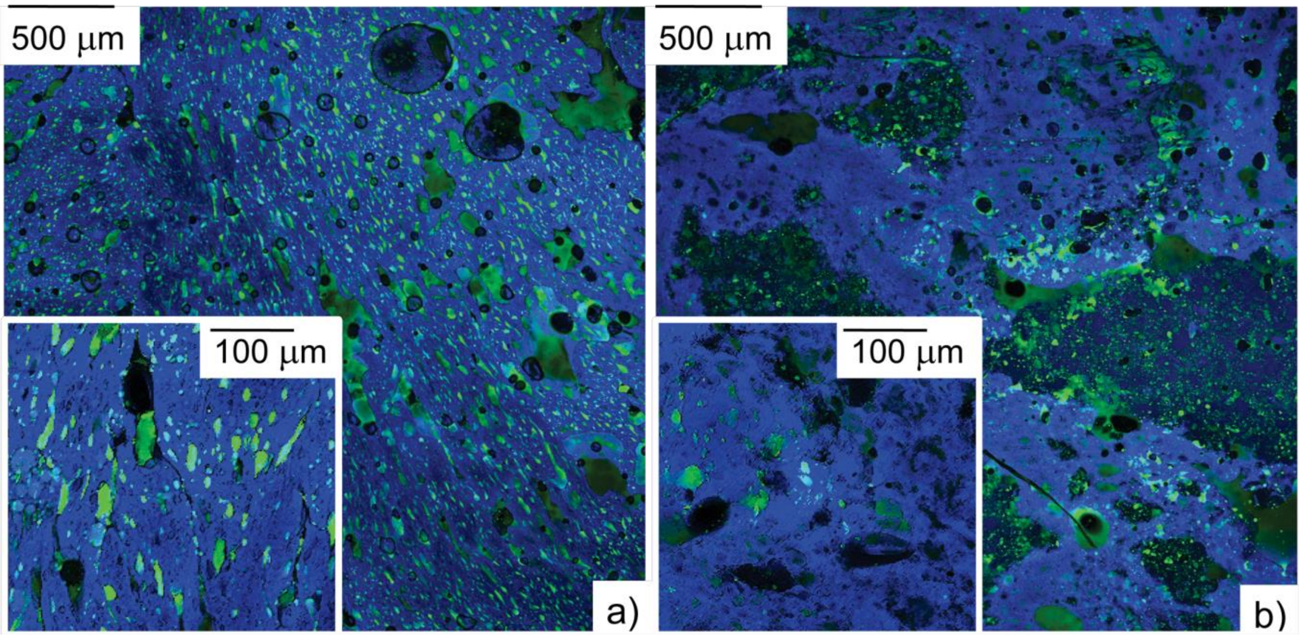

Figure 1. CLSM micrographs illustrating the microstructure of a) mozzarella and b) imitation cheese.

Close-up insets illustrate the protein matrix structure at higher magnification. Proteins appear coloured in blue while fat in green. The darker grainy areas observable for the imitation cheese are likely lumps of starch.

Starch has been reported in the literature as an effective ingredient to improve the cheese elasticity and decrease the mobility of water, thus imparting non-melting behaviour with increasing temperature(J. S. Mounsey & O'Riordan, 1999; John S. Mounsey & O'Riordan, 2008). These characteristics make starch a valuable ingredient to mimic the properties of mozzarella when imitation cheese is added to pizza pies. The protein matrix close-up micrographs in the inset shows an anisotropic structure for the mozzarella, that typically results from the pasta filata process(Timothy P Guinee, Auty, & Mullins, 1999). Such elongated protein structure cannot be observed for imitation cheese.

3.2. Shear rheology

Both oscillatory and continuous flow measurements were carried out to characterize the cheese samples rheology. Mechanical spectra (frequency sweeps) were obtained to investigate the linear viscoelastic properties of mozzarella and imitation cheese. The results are presented in figure 2.

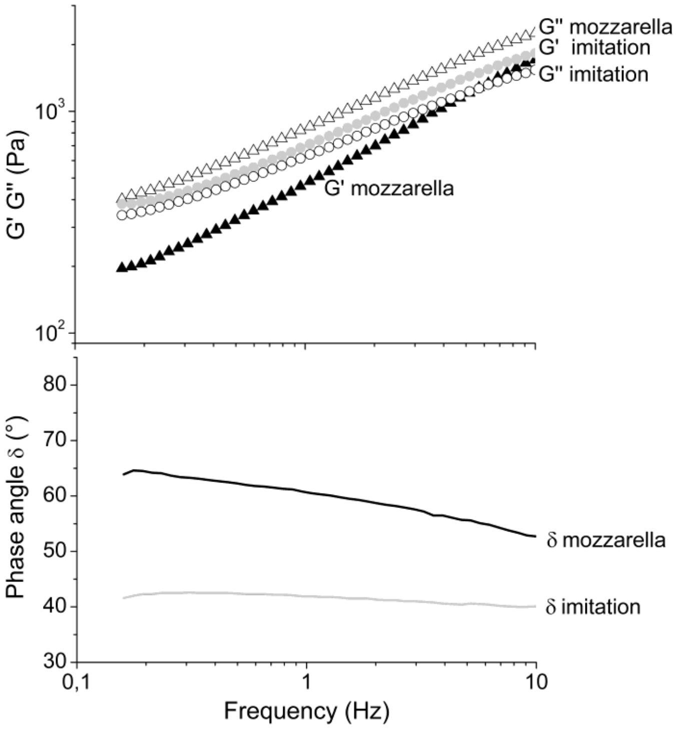

Figure 2. Oscillatory frequency sweeps measurements of mozzarella and imitation cheese, carried out at a constant temperature of 60°C. Dynamic shear moduli G' and G'' and the respective phase angle curves are plotted as a function of frequency. Upper graph: full black triangles – G' mozzarella, empty triangles – G'' mozzarella, full grey circles – G' imitation cheese, empty circles – G'' imitation cheese. Lower graph: black line – mozzarella phase angle, grey line: imitation cheese phase angle.

The moduli are within the same range for both cheese types. It is important to note that the loss modulus G'' is constantly higher than the storage modulus G' for the mozzarella cheese at this temperature (60°C) and within this frequency range. The corresponding phase angle is within the range of 55-65°, consistently higher than 45°. This indicates a liquid-like behavior of the mozzarella cheese for these measuring conditions. Contrary, the phase angle is consistently below 45° instead for the imitation cheese and it displays a viscoelastic behavior typical of soft semi-solid materials, with G'>G''. It is important to stress that the stress amplitude for the oscillatory measurements is within the linear viscoelastic region while cutting and mastication impose higher stresses that plastically deform the material. For a complete rheological characterization it was necessary to also perform shear flow measurements, where the samples are subjected to continuous plastic deformation. Results are presented in figure 3.

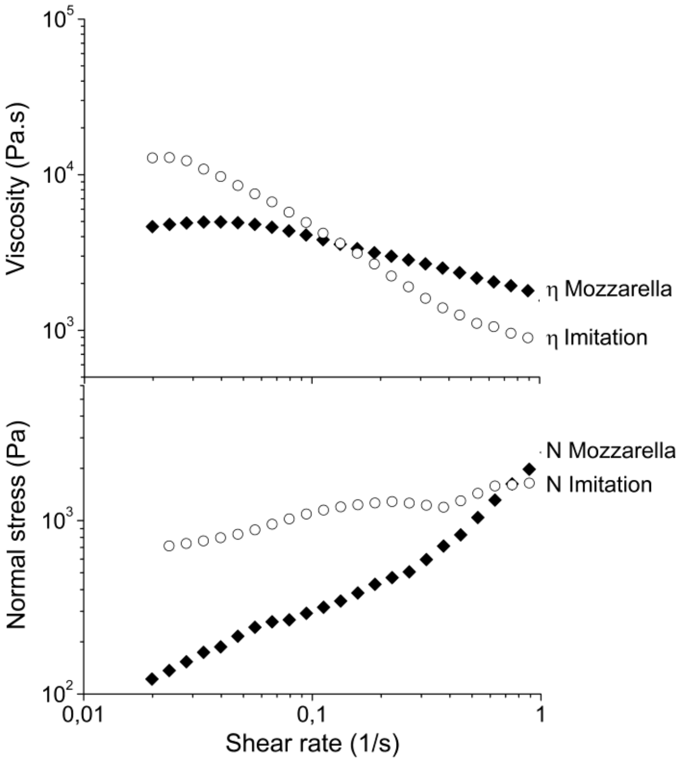

Figure 3. Shear flow curves for the mozzarella and imitation cheese (60°C). The viscosity η (higher) and normal stress N (lower) are plotted as a function of shear rate. The viscosity is a measurement of the material resistance to flow while normal forces are related to the fluid elasticity. Full diamonds – mozzarella, empty circles – imitation cheese.

Both flow curves displayed a classical shear thinning behavior, for which the relationship between viscosity and strain rate ($\dot{\gamma}$) is commonly fitted by the Ostwald de Waele power law:

$$\eta = K \dot{\gamma}^{n-1} \qquad (1)$$

and the values for associated rheological model parameters, the flow index "n" and consistency index "K" were obtained (table 1). The difference between the flow index values of the two cheese samples is due to the different shear thinning behavior. At a low shear rate the imitation cheese displays higher apparent viscosity than the mozzarella cheese due to faster shear thinning, until the two curves cross at $0.14s^{-1}$. Since the consistency index K represents the viscosity for the shear rate value of $1s^{-1}$, its value is higher for the mozzarella than for the imitation cheese. In the lower graph in figure 3, curves of normal stress are shown for both cheese materials. The normal stress increase that is generated by shear is directly related to the material elasticity (Yamamoto, 1958). The normal stress curve for the mozzarella displays a steeper gradient than that of the imitation cheese, indicating a stronger elastic response.

3.3. Extensional flow rheology

The Hyperbolic Contraction Flow measurements results are shown in figure 4. Apparent extensional viscosity and elongation thinning differ significantly from the shear flow curves. No crossover is observed but the extensional viscosity of the mozzarella cheese is constantly higher than that of the imitation cheese within this extension rate range.

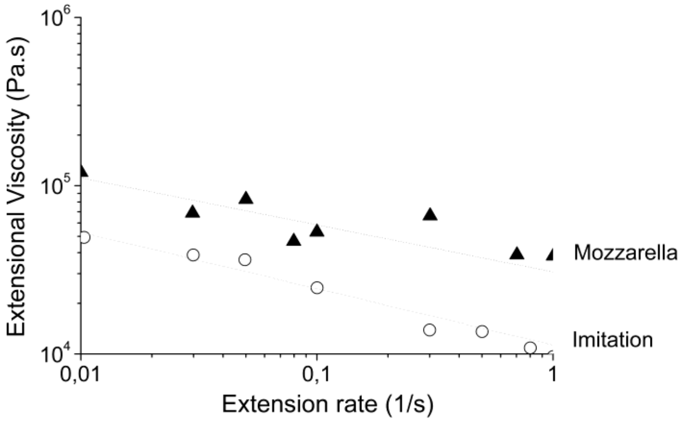

Figure 4. Extensional flow curves from Hyperbolic Contraction Flow measurements of mozzarella and imitation cheese (60°C). Full triangles – mozzarella, empty circles – imitation cheese.

As for the shear measurements, the extensional flow curves could be fitted by the Ostwald de Waele power law. The results for both shear and elongational flow curves fits are presented in table 1.

Table 1. Ostwald de Waele power law (equation 1) coefficients from the fit of the mozzarella and imitation cheese flow curves. Values are reported both for shear and extensional viscosity measurements.

Cheese	Shear [60°C]		Extension [60°C]	
	K	n	K'	n'
Mozzarella	2040	0.74	34500	0.75
Imitation	920	0.28	11300	0.67

The flow index values for the extensional measurements, n', show close values unlike those obtained in shear. This is due to the similar slopes of the extensional flow curves in figure 4.

4. Discussion

The structure in figure 1a is typical of low moisture mozzarella. Longitudinally aligned casein fibres with entrapped columns of fat and serum have been observed in several studies on mozzarella cheese(Timothy P Guinee, et al., 1999; Merrill, et al., 1996). The many fat-containing liquid pockets in the mozzarella cheese act as a lubricant as the cheese melts at the temperature of 60°C. This lubrication induces the slippage that occurs during the shear rheology measurements of mozzarella cheese. The mozzarella liquid-like behavior during the oscillatory shear test in figure 2 has been observed by previous studies on this type of cheese(Timothy P Guinee, et al., 1999; Ma, et al., 2013) and, as for the slippage, is also produced by the high amount of liquid pockets and fat globules within its structure. The soft solid-like behavior within the linear viscoelastic region for the imitation cheese (figure 2) is produced instead by the starch(John S. Mounsey & O'Riordan, 2008). When the cheese samples are continuously sheared to strains well above the linear viscoelastic domain, the casein matrix elasticity has a significant effect on the rheological measurements (figures 3 and 4). The material elasticity is measured during continuous shear flow experiments by the normal stress increase with the shear rate, and is higher for the mozzarella than for the imitation cheese. The milder slopes of the mozzarella cheese shear flow curve compared to that of imitation cheese also suggest that its structure is more resistant to this type of deformation. The results of Hyperbolic Contraction Flow measurement show a different behavior when extensional deformation is imposed, with the two flow curves having similar slopes and mozzarella a consistently higher viscosity than the imitation cheese. Similar results were reported for yoghurt extensional viscometry(Raphaelides & Gioldasi, 2005). An increased response to extensional deformation with the yoghurt content of casein was related to cross links between the casein molecules, which made the gel network more cohesive and resistant to compression. For the mozzarella, this can be related to a stronger and more elastic protein network than that of the imitation cheese.

5. Conclusions

Mozzarella and imitation cheeses rheology was determined at conditions relevant to pizza baking by oscillatory and continuous shear flow rheometry, and by Hyperbolic Contraction Flow extensional rheometry. Shear results differed significantly for the two cheese types and could be related to their respective microstructural features. The lubrication of the many serum pockets and oil droplets contained by the mozzarella cheese determined a liquid-like behaviour at low oscillatory strain while the soft-solid like behaviour of the imitation cheese reflects the presence of starch in its composition. The different elasticity of the two materials protein matrix was shown by the normal stresses measured during the continuous shear flow experiments. The flow curves also show a marked shear thinning behaviour of the imitation cheese compared to that of mozzarella cheese, while the two are more similar when an extensional deformation is imposed. This was also shown by the flow index values. It can be concluded that shear rheometry measurements are useful to distinguish the two types of cheese and the results can be readily explained by different microstructural features. On the other hand, the extensional viscosity results obtainable by Hyperbolic Contraction Flow rheometry, provide complementary information about the cheese elasticity (hence stretchability). Since mastication and swallowing are deformation processes that impose extensional stresses to the ingested food, the Hyperbolic Contraction Flow results can help to relate rheological measurements to the consumer perception of the cheese products especially regarding the important quality parameter of stringiness(Wendin, et al., 2010).

References

Apostolopoulos, C. (1994). Simple empirical and fundamental methods to determine objectively the stretchability of Mozzarella cheese. *Journal of Dairy Research*, *61*, 405-413.

Bähler, B., Back, R., & Hinrichs, J. (2015). Evaluation of oscillatory and shear strain behaviour for thermo-rheological plasticisation of non-ripened cheese curd: Effect of water, protein, and fat. *International Dairy Journal, 46*, 63-70.

Guinee, T. P., & O'Callaghan, D. J. (1997). The use of a simple empirical method for objective quantification of the stretchability of cheese on cooked pizza pies. *Journal of Food Engineering, 31*, 147-161.

Guinee, T. P., Auty, M. A., & Mullins, C. (1999). Observations on the microstructure and heat-induced changes in the viscoelasticity of commercial cheeses. *Australian journal of dairy technology*, *54*, 84.

Hennelly, P. J., Dunne, P. G., O'Sullivan, M., & O'Riordan, E. D. (2006). Textural, rheological and microstructural properties of imitation cheese containing inulin. *Journal of Food Engineering, 75,* 388-395.

Hicsasmaz, Z., Shippelt, L., & Rizvi, S. S. H. (2004). Evaluation of Mozzarella Cheese Stretchability by the Ring-and-Ball Method. *Journal of Dairy Science, 87,* 1993-1998.

Kiely, L. J., McConnell, S. L., & Kindstedt, P. S. (1991). Observations on the Melting Behavior of Imitation Mozzarella Cheese. *Journal of Dairy Science, 74*, 3568-3572.

Kindstedt, P. (1993). Mozzarella and Pizza Cheese. In P. F. Fox (Ed.), *Cheese: Chemistry, Physics and Microbiology* (pp. 337-362): Springer US.

Ma, X., James, B., Zhang, L., & Emanuelsson-Patterson, E. A. C. (2013). Correlating mozzarella cheese properties to its production processes and microstructure quantification. *Journal of Food Engineering, 115*, 154-163.

Merrill, R. K., Oberg, C. J., McManus, W. R., Kalab, M., & McMahon, D. J. (1996). Microstructure and Physical Properties of a Reduced Fat Mozzarella Cheese Made UsingLactobacillus caseissp.caseiAdjunct Culture. *LWT - Food Science and Technology, 29*, 721-728.

Mounsey, J. S., & O'Riordan, E. D. (1999). Empirical and Dynamic Rheological Data Correlation to Characterize Melt Characteristics of Imitation Cheese. *Journal of Food Science, 64,* 701-703.

Mounsey, J. S., & O'Riordan, E. D. (2008). Influence of pre-gelatinised maize starch on the rheology, microstructure and processing of imitation cheese. *Journal of Food Engineering, 84*, 57-64.

Nolan, E. J., Holsinger, V. H., & Shieh, J. J. (1989). Dynamic rheological properties of natural and imitation mozzarella cheese. *Journal of Texture Studies, 20*, 179-189.

Nyström, M. (2015). *Extensional rheometry through hyperbolic contraction.* Chalmers University of Technology.

Raphaelides, S. N., & Gioldasi, A. (2005). Elongational flow studies of set yogurt. *Journal of Food Engineering, 70,* 538-545.

Sharma, P., Dessev, T. T., Munro, P. A., Wiles, P. G., Gillies, G., Golding, M., James, B., & Janssen, P. (2015). Measurement techniques for steady shear viscosity of Mozzarella-type cheeses at high shear rates and high temperature. *International Dairy Journal, 47,* 102-108.

Stading, M., & Bohlin, L. (2001). Contraction flow measurements of extensional properties. *ANNUAL TRANSACTIONS-NORDIC RHEOLOGY SOCIETY, 8*, 181-186.

Wendin, K., Ekman, S., Bülow, M., Ekberg, O., Johansson, D., Rothenberg, E., & Stading, M. (2010). Objective and quantitative definitions of modified food textures based on sensory and rheological methodology. *2010*.

Wikström, K., & Bohlin, L. (1999). Extensional Flow Studies of Wheat Flour Dough. I. Experimental Method for Measurements in Contraction Flow Geometry and Application to Flours Varying in Breadmaking Performance. *Journal of Cereal Science, 29,* 217-226.

Yamamoto, M. (1958). The Visco-elastic Properties of Network Structure III. Normal Stress Effect (Weissenberg Effect). *Journal of the Physical Society of Japan, 13*, 1200-1211.

Zhu, C., Brown, C., Gillies, G., Watkinson, P., & 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.