Rheological analysis of ropy fermented milk

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ABSTRACT

Some fermented milk products show a ropy consistency due to polysaccharides produced by the lactic acid bacteria starter cultures during their growth in milk. The final consistency is a result of the type and amount of polysaccharide produced as well as their interaction with the milk protein gel which is formed due to acid production during the fermentation.

Such fluids represent a challenge for rheological methods. It is therefore of interest to determine suitable methods for characterizing the ropy behavior.

In this introductory study, several rheological methods were used to examine cultured milk produced from eight different bacteria cultures showing different ropy behavior. The methods tested in rotation were normal flow curve, step-strain test and start-up test. In oscillation a standard amplitude sweep was performed. The time dependent results were fitted to the Bird-Leider correlation.

The results show how the ropy behaviour, as assessed by sensory analysis, correlates with the various rheological parameters measured. The shape of the shear stress versus time curve, obtained from start-up tests, gives considerable information about the texture properties and behaviour of the ropy milk.

INTRODUCTION

Fermented milk products have long traditions and are still popular in many parts of the world. They are produced by the fermentation of milk by starter cultures of Lactic acid bacteria (LAB). The fermentation of lactose to lactic acid results in a drop in pH which causes coagulation of milk protein to a gel. Consumption of so-called ropy fermented milk[1, 2] is traditional in Nordic countries and seems to be less popular outside this region. This milk is characterised by a particularly slimy consistency, which enables the fermented milk to be stretched into long strands (Fig. 1). The ropy consistency is due to the production of exopolysaccharides (EPS) by the LAB that carry out the fermentation: *Lactococcus lactis* subsp. *cremoris*. Recently, a traditional source of these EPS-producing bacteria was confirmed as the plant *Pinguicula vulgaris*[3]. Similar products are produced commercially in Norway (Tjukkmjølk), Sweden (Långfil) and Finland (Viili). The consistency of ropy milks presents a challenge for rheological measurement and there is little, if anything, published on the rheology of these products.

MATERIALS AND METHODS

Ropy fermented milk preparation

Ropy fermented milk products were prepared from pasteurised (72 °C for 15 sec) cow's milk and inoculated with 6 different EPS-producing mesophilic LAB starter cultures. The inoculated milk was incubated in 700 mL glass jars at 22 °C for 22 h (to pH 4.2 – 4.3) and cooled to 4 °C. A similar product was prepared using a non-ropy starter culture. Two commercial products were also included (Tjukkmjølk and Cultured milk (Kulturmelk)). Sensory analysis and rheological measurements were carried out after one week storage at 4 °C.

Figure 1. Consistency of ropy fermented milk (Photo: Judith Narvhus).

<u>Rheological methods</u>

An MCR301 rheometer from Anton Paar was used with a Titanium CC27/Ti bob/cup measuring system fitted to a cylindrical Peltier. A test sequence was programmed consisting of the following intervals:

1. Viscosity measurement. Rotation at 10 1/s for 60 s
2. No motion for 600 s
3. Amplitude sweep at 10 rad/s, 0.01-10% strain.
4. No motion for 600 s
5. Step-strain test. 10% strain. 264 points log distributed 0.01-30 s
6. No motion for 600 s
7. Start-up test. Shear rate 0.1 1/s. 264 points log distributed 0.01-30 s.

The temperature was kept at 10 °C during all the intervals.

The test sequence was programmed to be repeated three times.

RESULTS

All products studied had a firm milk protein gel due to the fermentation and coagulation of the milk protein. Sensory assessment of the ropy properties of the fermented milk products showed samples A and E to have a marked greater ropiness compared to the other ropy milk samples B-D, F and Tjukkmjølk (Figure 10). Kulturmelk and Kulturmelk-NMBU showed no ropy consistency.

The results from interval 1 are shown in Figure 2.

Results from the start-up tests (interval 7) and step-strain tests (interval 5) are shown in Figure 3 and Figure 4, respectively.

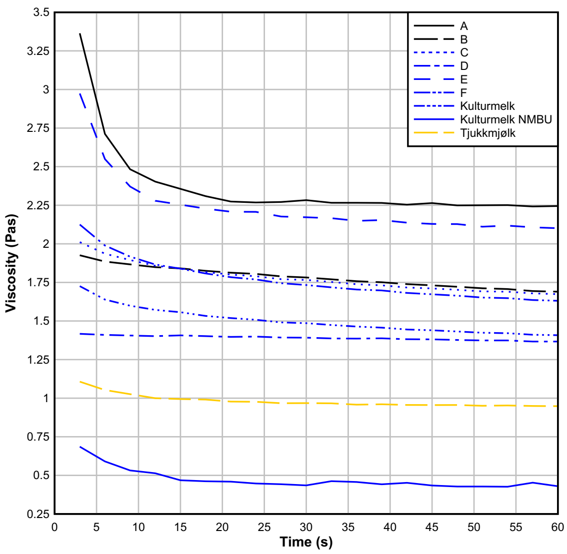

Figure 2. Viscosity results.

The results from the analysis of the amplitude sweep data are shown in Figure 5, Figure 6 and Figure 7. The limit of the linear viscoelastic range was taken where G' was reduced by 3%, thus defining strength and limiting strain values.

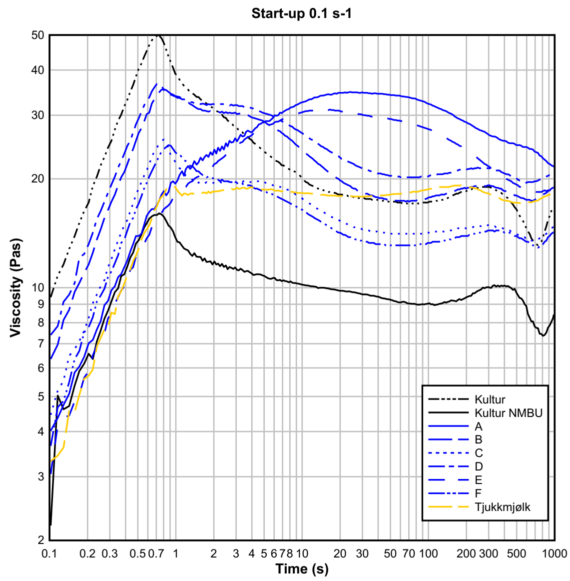

Figure 3. Results from start-up tests.

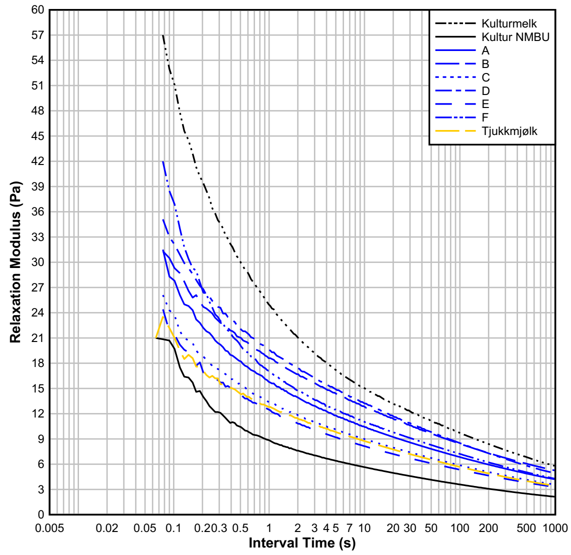

Figure 4. Results from step-strain relaxation tests.

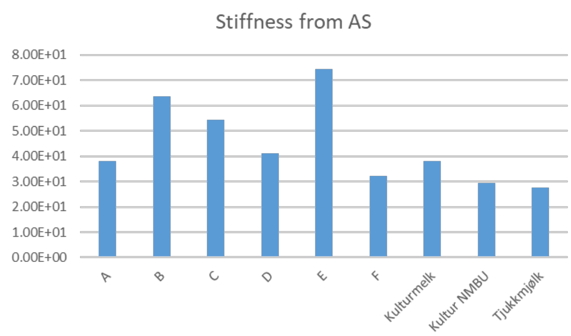

Figure 5. Initial elastic modulus, G', from the amplitude sweep data.

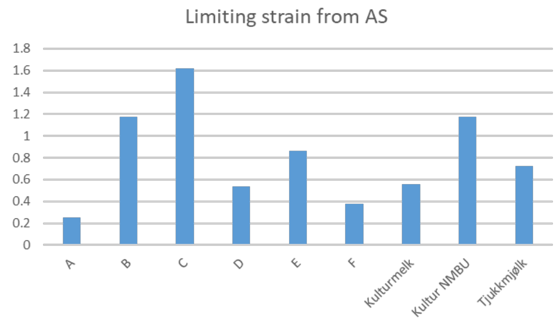

Figure 6. Limiting strain from amplitude sweep data.

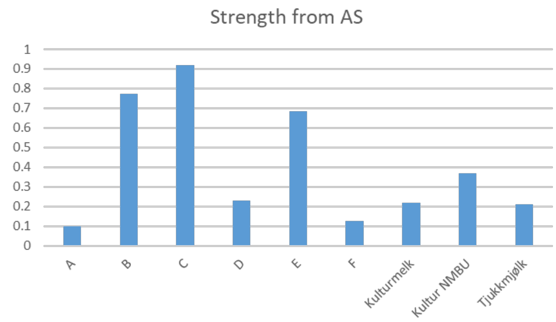

Figure 7. Strength from amplitude sweep data.

DATA ANALYSIS

Bird-Leider correlation

The experimental results from the start-up tests were fitted using non-linear regression tools (*nlinfit*) in MATLAB to the Bird-Leider equation[4] determining the best values of the constants of the equation.

$$\tau = m\dot{\gamma}^n \left[1 + (b\dot{\gamma}t - 1)\exp\left(\frac{-t}{an\lambda} \right) \right]$$

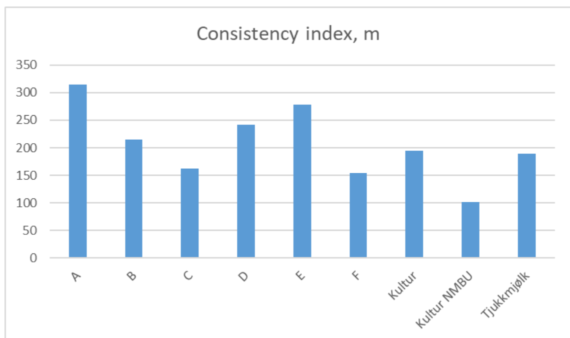

Figure 8. Consistency index from Bird-Leider equation.

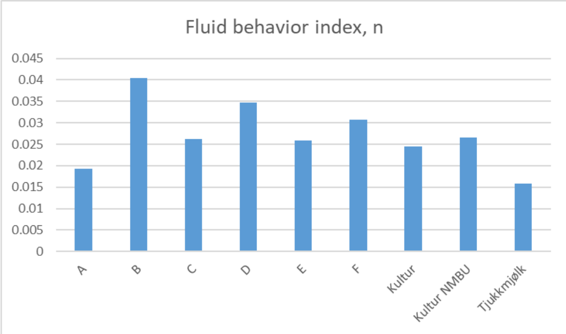

Figure 9. Fluid behaviour index from Bird-Leider equation.

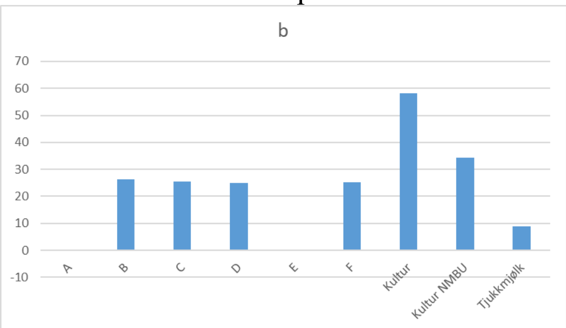

Figure 10. Constant *b* in Bird-Leider equation.

We observe that the value of the constant *b* in the Bird-Leider equation is close to zero for the two milks with very pronounced ropy behaviour, A and E.

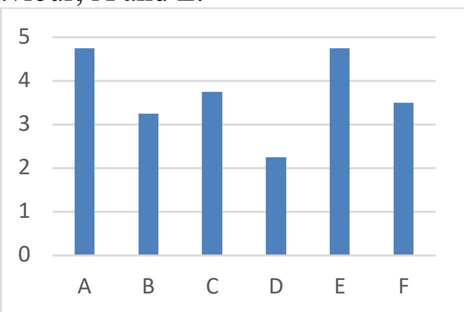

Figure 11: Sensory score for ropy consistency.

DISCUSSION

The fermented milk products differed with respect to the heat treatment of the milk before fermentation. The milk used for the commercial sample of Kulturmelk had been subjected to 95 °C for 5 min. Milk used for preparation of all the other samples was treated by ordinary pasteurisation (72 °C for 15 sec). This difference in heat treatment is important because the strength of the gel, and the viscosity of a fermented milk is greatly increased and improved by the higher temperature used to produce the commercial product, Kulturmelk. This increase is due to denaturation of the whey proteins in the milk used for Kulturmelk, which are then able to participate in the gel along with the casein proteins, thus forming a firmer gel.

In Figure 3, differences can be seen which reflect the variation in consistency in the studied products as shown by the start-up test. All samples show a peak at about 0.7 sec. Kulturmelk, which is produced using a non-ropy culture, shows only this peak. The same peak is also seen in Kulturmelk-NMBU, but the viscosity is much lower due to the much weaker acid gel formed due to a low heat treatment of the milk before fermentation. The ropy samples also show this peak. The increased viscosity in these samples compared to Kulturmelk-NMBU indicates that the production of EPS in these products has increased the strength of the acid protein gel. The other samples of fermented milk, all of which showed ropy behaviour, showed two additional peaks. The peak at 4-5 sec is common for samples B, C, D, F and Tjukkmjølk whereas samples A and E showed a peak with a maximum viscosity at 15-30 sec. Samples fermented with cultures A and E showed an extreme ropy behaviour. This may indicate a difference in molecular structure of the EPS produced by these two cultures as compared with the cultures used for B, C, D, F and Tjukkmjølk.

We observe that ropy behaviour is only connected to a few of the observed variables. The *b* constant in the Bird-Leider equation seems to be close to zero for ropy fluids. The other test that seems to give information about the ropy behaviour is the start-up test.

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