Rheological characterization of non-dairy alternatives to milk.

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ABSTRACT

The viscosity of daily consumed beverages is one parameter used to describe its qualities. However, popular words like "good viscosity", "mouthfeel" and other sensory ratings seems rather subjective to understand key sensory profiles of the products. Milk and non-dairy alternatives are normally consumed cold.

The viscosity of a selection milk and some non-dairy alternatives were measured at 5 °C. The tests employed in rotation were shear rate sweeps including low shear rates and hysteresis tests to detect thixotropic behavior. The results were fitted to the Herschel-Bulkley model. Conventional start-up tests were also performed.

Amplitude sweeps were performed in oscillation to determine stiffness, strength and limiting strain if the fluids formed a structure.

The results show variations in rheological behavior and show that some of the products exhibited non-Newtonian behavior either being pseudoplastic or thixotropic. Some of the milk alternatives had a much higher viscosity than milk itself. Most products behaved like viscoelastic liquids. None of the products exhibited yield properties.

INTRODUCTION

Cow's milk is a popular and essential part of the diet to many people. Normally it is consumed as a beverage or used together with cereals eventually added to smoothies, tea, or coffee. While milk is a popular choice for many people, some also prefer not to drink milk. Reasons for choosing non-dairy alternatives to milk may be due to some of the following reasons: personal preferences, dietary restrictions, allergies, intolerances, lifestyle, environmental footprint of the livestock, United Nations sustainable development goals etc. [1,2]. An increased attention has been paid to plenty of the non-dairy beverages available the last decades.

Milk from cow, buffalo, goat etc. is the oldest beverage in the world, and still widely used. It belongs to the most important traditional food emulsions containing most of the nutrients our body need through a lifetime. But during the last decades there has been an increased availability and consumption of nondairy beverages and a decrease in consumption of cow's milk[3]. Commonly available nondairy beverages are derived from almond, cashew, coconut, hazelnut, hemp, oat, rice, and soy.

Nondairy beverages are normally manufactured by extracting plant material. Then it is homogenized, and thermally treated to improve suspension of particles and to increase shelf life. They are made to visually resemble cow's milk and often include the word ''milk'' in the beverage name. The nutritional contents of these plant-based products depend on the source, methods of processing, and whether the products are fortified or not[3,4].

The nondairy beverages primarily derived from plants that contain the word ''milk'' are increasingly available[2]. Many manufacturers add the word ''milk'' to the product's name, suggesting a healthy beverage that would provide an advantage to their products. In this year 2021, there is a special interest associated with products based on fruit and vegetables. United Nations (UN) has designated 2021 the International Year of Fruits and Vegetables. "The international year of fruit and vegetables 2021", was proclaimed by the General Assembly in Dec. 2019 to raise awareness on the important role of fruit and vegetables in human nutrition, food security and health. Important in this context is also the goals in achieving sustainable developments[5].

In this study, however, it was not the purpose to compare nutritional constituents between nondairy beverages and cow's milk. The primarily interest with this study was to investigate rheology issues between cow's milk and some nondairy beverages primarily derived from plants that contain the word ''milk'', Fig. 1. This study is focused on the physical state of the substances in the fortified beverages and its interaction between them[6].

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

Investigate and compare rheological properties, pH and stability of some commercially produced non-dairy alternatives to milk.

Figure 1: The 5 different UHT non-dairy beverage alternatives investigated together with the UHT milk as a reference.

Table 1: Approximate composition (% w/w) of the UHT-milk and the 5 non-dairy UHT beverages investigated. Values declared by the manufacturers except for the pH.

Beverage	Appr. dry matter	Protein	Carbo-hydrate	Fat content	SFA	Salt	pH	kJ pr.100 ml
Milk	9.3	3.5	4.5	1.2	0.7	0.1	6.84	180
Soy	9.5	3.7	3.6	2.1	0.3	0.1	7.17	207
Rice	11.9	0	11.0	0.8	0	0.1	7.37	219
Oat	8.3	1.0	6.7	0.5	0.1	0.1	6.81	157
Almond	2.0	0.4	0.3	1.1	0.1	0.1	7.59	53
Coconut	2.4	0.7	0.3	1.3	1.1	0.1	7.87	63

MATERIALS AND METHODS

<u>Milk and non-dairy alternatives</u>

The 6 different samples tested given in Table 1, were purchased from ordinary Norwegian grocery stores.

pH in the beverages was measured directly at 20°C. Each sample rested for 30 minutes before pH measurement (Thermo Scientific PH meter, Orion Star A 211, SN X25276, Indonesia).

<u>Instrumental analysis and experimental set-up</u>

The Physica MCR301 rheometer (Paar Physica, Anton Paar, Stuttgart, Germany, 2010) fitted with a Titanium CC27 Bob/Cup. The following tests were run:

- Shear rate sweeps in rotation from 0.001 1/s to 2 1/s.
- Slow shear rate tests varying shear rate from 1e-3 to 1e-6 1/s.

- Hysteresis test for thixotropic behaviour from 2.5 1/s to 50 1/s and back down to 2.5 1/s.
- Amplitude sweeps in oscillation from 0.01 to 100% strain at 10 rad/s to investigate stiffness, strength, and strain limit.
- Start-up test in rotation at a constant shear rate of 0.1 1/s.

The measurements were recorded at 5 °C.

<u>Analysis</u>

The shear rate sweep data were fitted to the Herschel-Bulkley model[7] expressed by Eqn. 1.

$$\tau = a + b\dot{\gamma}^{p} \qquad (1)$$

RESULTS

<u>Rheometer results</u>

The results from the shear rate sweep measurements were fitted to the Herschel-Bulkley model using a least squares method in MATLAB. The results are shown in Fig. 2, Fig. 3, and Fig. 4.

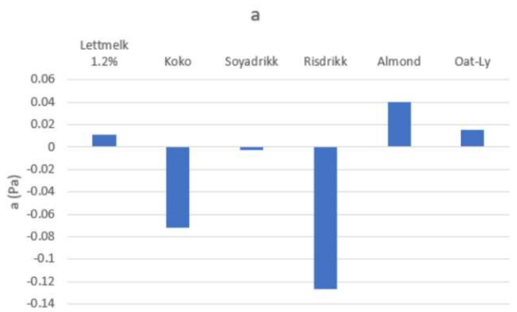

Figure 2: Herschel-Bulkley parameter a.

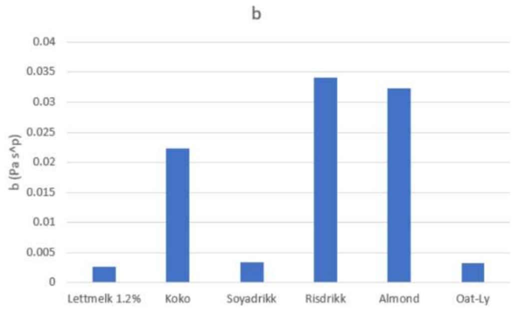

Figure 3: Herschel-Bulkley parameter b.

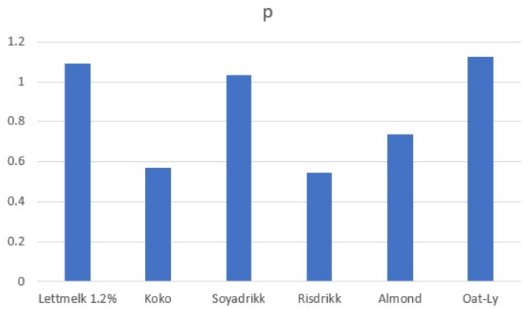

Figure 4: Herschel-Bulkley parameter p.

The results from the low shear rate tests are shown in Fig. 5.

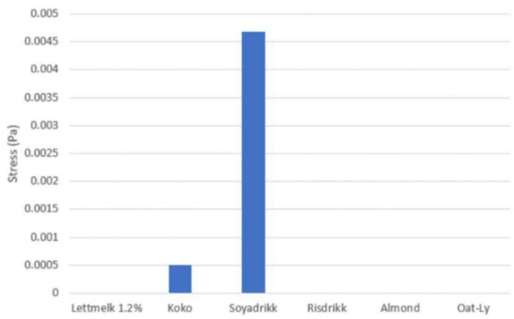

Figure 5: Limiting shear stress at low shear rate.

The results from the hysteresis results are shown in Fig. 6. Finally, the results from the amplitude sweeps are shown in Fig. 7. The shear stresses from the start-up tests were all smaller than 1 Pa and decayed quickly to a lower value. All samples showed the same behaviour in these tests.

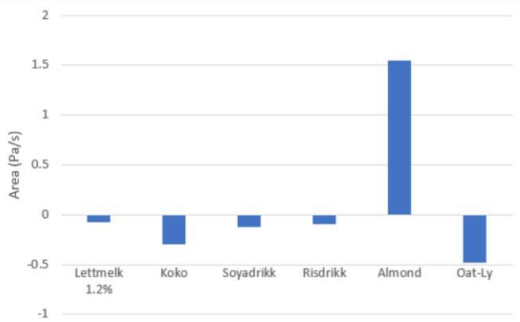

Figure 6: Hysteresis area from shear stress versus shear rate measurements. Positive value indicates recovery, a negative value indicates degradation.

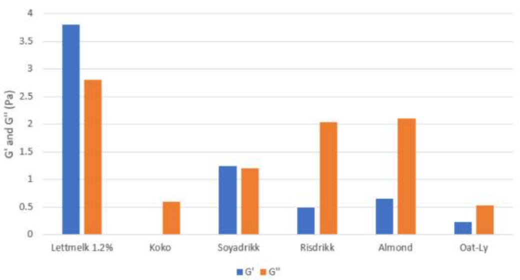

Figure 7:G' and G'' from amplitude sweep measurements.

DISCUSSION

The results from the Herschel-Bulkley analysis show that none of the products exhibit a clear yield stress, although the Soya drink show signs of a definite stress level as the shear rate approaches zero.

The UHT cow milk, the Soy drink and Oat-ly are close to Newtonian in behavior. The Coco, the Rise and the Almond drinks are all pseudoplastic non-Newtonian fluids.

Regarding thixotropy, the Almond drink seems to be rheopectic and the Coco drink and Oat-ly slightly thixotropic.

None of the drinks exhibited strong solid like behavior at low strains, but elastic properties, G', was determined in all the samples but the Coco drink.

CONCLUSIONS

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

- The results show variations in rheological behavior and show that some of the products exhibited non-Newtonian behavior either being pseudoplastic or thixotropic.
- Some of the milk alternatives had a much higher viscosity than milk.
- Most products behaved like viscoelastic liquids.
- None of the products exhibited yield properties.

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