Rheology and texture of cheese and a vegan cheese analogue

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Introduction

What is cheese? Cheese is fermented milk with the right taste and the right texture. While taste is far beyond its capabilities, a rheometer can definitely help to analyse texture. This becomes especially helpful when trying to create a vegan substitute for cheese, since the consumer expects a similar look and feel compared to a milk-based cheese.

The texture is an important part of a cheese's properties. Depending on the kind of cheese and its age this can range from creamy to solid. Rheological measurements can be used to quantify the viscoelastic properties of cheese and cheese formulations. On top of that, a modern rheometer is equipped with a normal force sensor and therefore offers capabilities beyond the classic rheological measurements. In combination with its automatic lift, a rheometer can also be used to run texture analysis tests. In the case of a cheese, this could be used to quantify its bite or its cutting properties.

This report summarizes the results of various rheological measurements and a penetration test on a milk-based cheese and a vegan cheese substitute.

Materials and methods

For the measurements described here, a sliced butter cheese and a sliced vegan alternative were used. Both products are commercially available and were purchased at a local grocery shop. The milk-based cheese consisted mainly of protein and fat (25% and 24% respectively). The main components of the vegan alternative were fat and starch (20% and 17% respectively) while its protein content was below 1%.

Figure 1: The Thermo Scientific HAAKE MARS iQ Rheometer.

The rheological tests were performed using a Thermo Scientific™ HAAKE™ MARS™ iQ Air Rheometer (Figure 1) equipped with a Peltier temperature module for cone-plate- or parallel-plate geometries. To be able to adapt to the thickness of the cheese slices, a parallel-plate-geometry was used. To prevent slippage, serrated plates were used on both sides (Figure 2).

To get a general idea about the properties of both products, amplitude sweeps at 20 °C and 37 °C were performed over a strain range from 0.01% to 100% at a frequency of 1 Hz. The measurements at 20 °C were intended to show the sample properties at room temperature, where cheese is cut or a piece is bitten off, for example. At 37 °C the behavior during chewing or swallowing was investigated.

Figure 2: Upper and lower serrated plate (left) and measuring geometry with cheese sample (right).

Discs with a diameter of 35 mm were cut from the cheese slices and placed onto the lower plate of the measuring geometry. The upper plate was moved downwards onto the sample with reduced lift speed until an axial force of 5 N was detected. A waiting time of 10 min was selected for thermal equilibrium and mechanical relaxation. During the measurement at 20 °C, an axial force of 2 N was applied to ensure good grip, especially at larger deformations. At 37 °C the lift stopped at 3 N and for the milk-based cheese, the axial force had to be reduced to 0.7 N to prevent the cheese from being squeezed out of the gap. The end of the linear-viscoelastic range (LVR) was calculated based on the storage modulus G' using a 10% deviation from the plateau value.

The temperature-dependent behaviour of both products was examined between 5 °C and 90 °C. The sample loading procedure was identical to that used for the amplitude sweeps. After the measuring position was reached, the outer edge of the sample was protected against drying out with a little oil. During the measurement, the rheometer applied a constant oscillation with 1% strain and 1 Hz to the sample while the temperature was increased with a heating rate of 2 °C/min. From the start of the measurement on a constant axial force of 1 N was applied to the sample. In order to avoid the sample being pushed out of the measuring gap when it became too soft due to the temperature increase, the measuring gap was kept constant with the Thermogap function below a complex modulus |G*| of 20.000 Pa.

Figure 3: 4-blade vane rotor used to simulate cutting or biting the product.

Finally, the cutting or biting resistance of both products was tested by running penetration tests with a 4-bladed vane rotor of 22 mm diameter at 20 °C. Discs of 35 mm diameter were placed onto the lower plate. In this case a lower plate with a smooth surface was used instead of a serrated one, because there was no risk of slippage due to the nature of the test. The vane rotor was moved downwards to a position of 5 mm above the lower plate and the sample was left to rest for 10 min to adapt to the temperature. Afterwards the vane rotor was moved downwards at a rate of 0.1 mm/s. The position at which the surface of the sample was detected by an axial force of 0.1 N was set as the starting point for the relative gap Δh. The vane rotor continued to move into the sample at 0.1 mm/s until it almost touched the lower plate.

Results

The first difference between the two products was already visible during the 10 min waiting period after reaching the measuring position.

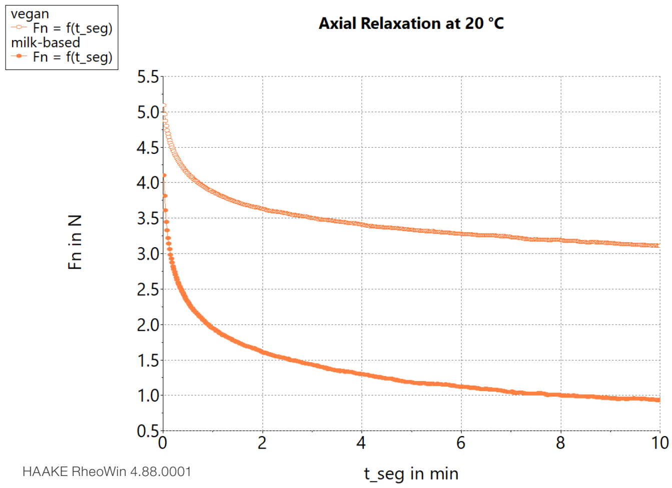

Figure 4: Axial relaxation of both samples after being exposed to 5 N at 20 °C.

While the milk-based product relaxed quickly at the beginning and the axial force reached 0.9 N (19 %) after 10 min, the vegan product showed a slower initial decrease in axial force and was still at 3.1 N (62%) at the end of the waiting time (Figure 4). This comparison shows the milk-based product is much softer whereas the vegan product contains a stronger and less flexible structure.

The amplitude sweeps at 20 °C show some similarities between the two products (Figure 5). The end of the LVR for vegan and milk-based product was calculated at 0.6% and 0.7% deformation respectively.

A look at the corresponding shear stress values is much more informative. The end of the LVR for the vegan product is at 441 Pa while it is at 929 Pa for the milk-based product.

Another significant difference between the two products can be seen in the phase angle δ. Below 0.1% deformation, the vegan product shows a plateau value of 4.0° while the milk-based product shows a value of 16.7°. Towards higher deformations, the vegan product shows a steeper increase of δ exceeding the δ-values of the milk-based cheese above 6% of deformation.

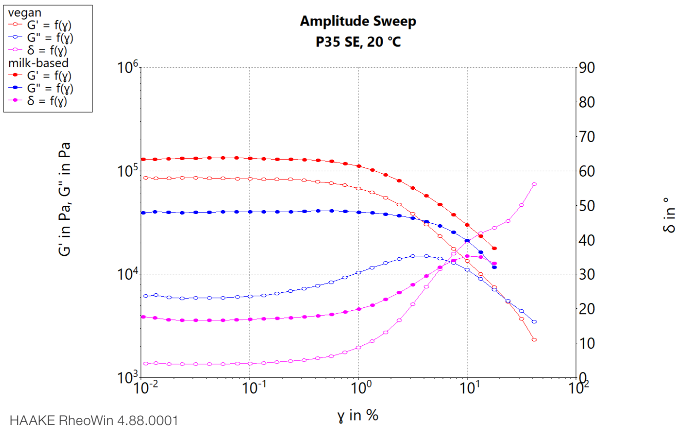

Figure 5: Results from the amplitude sweeps at 20 °C plotted over the deformation γ in %.

In spite of all measures taken to prevent slippage, the stiffness of the milk-based cheese at 20 °C led to the upper plate breaking loose before the crossover point was reached.

In summary, the vegan product is much more elastic but its structure is weaker, breaking even with a smaller shear stress or force.

Repeating the same measurements at 37 °C amplified the differences in certain properties. While the axial force in the vegan product relaxed to roughly the same percentage as before, 53% (1.6 N), it dropped significantly further in the milk-based product to 1.8% (0.05 N) (Figure 6).

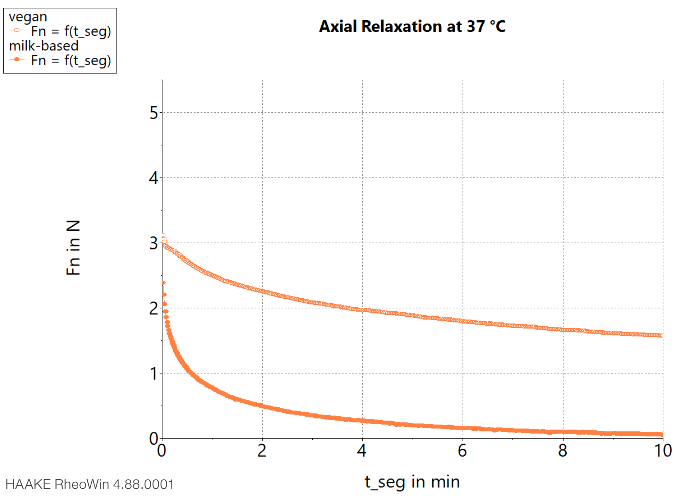

Figure 6: Axial relaxation of both samples after being exposed to 3 N at 37 °C.

For the amplitude sweeps at 37 °C, the values for the end of the LVB change only slightly (Figure 7). Here the vegan product and the milk-based product show an end of the plateau at 396 Pa and 914 Pa respectively but the corresponding deformation values are higher and differ more with 1.1% and 5.3% respectively. The vegan product shows a plateau value for the phase angle at 2.1° indicating that under these conditions it is even more elastic or rigid. In contrast, the milk-based product behaves softer and shows a plateau value of 24.8°.

At 37 °C the two products are more flexible; they only break at higher deformations. Compared to their behaviour at 20 °C, the vegan product became more elastic whereas the milk-based product became less elastic.

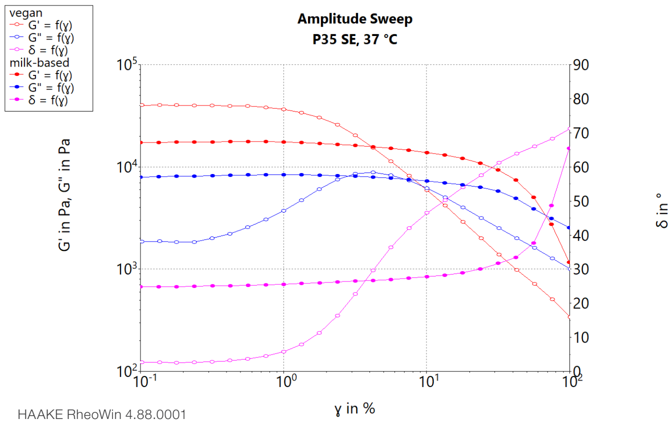

Figure 7: Results from the amplitude sweeps at 37 °C plotted over the deformation γ in %.

The results of the temperature sweeps show the behavior of the two products over a wider temperature range. At "fridge temperature" of +5 °C, the milk-based cheese had a viscosity of 27000 Pa·s. With increasing temperature, its viscosity dropped continuously to 45 Pa·s at +90 °C i.e. 0.2% of its value at +5 °C (Figure 8). The vegan product showed a more complex viscosity curve. It started with about half the viscosity of the milk-based cheese at +5 °C but showed a much smaller decrease in viscosity up to +55 °C. Above +23 °C its viscosity was higher than that of the milk-based product. Above +55 °C the slope of the viscosity curve changed drastically and dropped to 100 Pa·s at +90 °C i.e. 0.8%.

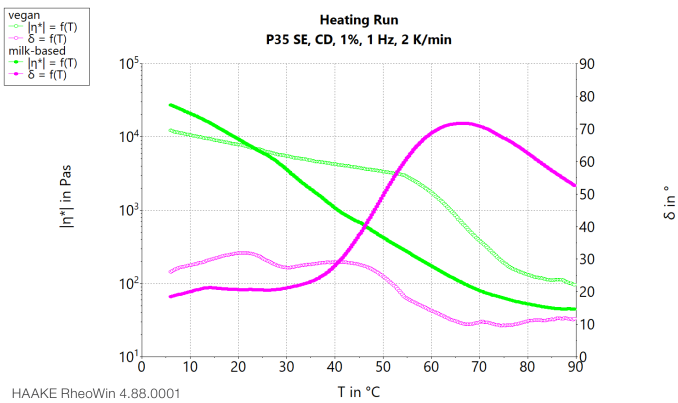

Figure 8: Development of viscosity and phase angle during heating up to 90 °C.

Looking at δ as a measure for the viscoelastic properties, a clear difference can be seen right from the start of the measurement. Initially, the vegan product had an average δ-value of 29.3° whereas the milk-based cheese showed only 20.5°. In comparison, the vegan product was the less elastic one.

A much more significant difference between products showed in the change of δ above +27 °C. The δ-values of the milk-based product increased, showed a melting point (δ = 45°) at +48 °C and continued to increase until +66 °C. (After the measurement, it was found that despite the oil film, the outer edge of the sample had become harder, which must have led to the decrease in δ above +66 °C.) In contrast, the δ-values of the vegan product remained almost constant above +27 °C until they started to decrease above +42 °C down to 10°. With further increase of temperature, δ slightly increased and reached 12° at +90 °C. The vegan product did not show a melting point.

At higher temperatures, the milk-based cheese melted and behaved like a liquid. The vegan product on the other hand did not melt but became an even more elastic gel. This difference in behaviour also showed when opening the measuring geometry at +90 °C after the measurements were finished. The milk-based cheese stuck to the plates and pulled strings while the upper plate moved upwards. The vegan product came off the upper plate and remained on the lower plate like a compact gel or dough. This difference explains the observation of vegan consumers that some vegan cheese alternatives did not melt and form a single layer but still showed the original pieces that have been used on top of a pizza or a gratin.

The temperature-dependent measurement showed a large difference in behaviour between the protein-based structure of the milk-based product and a starch-based structure of the vegan alternative.

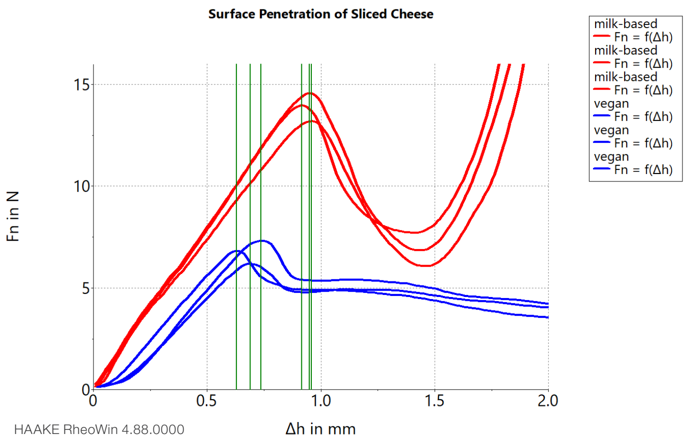

Figure 9: Results of penetration test of both products.

The penetration test was performed 3 times on both samples. Keeping in mind that cheese samples are never exactly identical the results show a very satisfying reproducibility. Although the rheological tests showed that the vegan product has a higher elasticity and a stronger resistance against compression, its cut resistance was significantly lower than that of the milk-based cheese (Figure 9). After 0.69 mm and at a force of 6.8 N the blades of the vane rotor cut into the vegan slice. The milk-based cheese was a bit more flexible and a lot more stable. After 0.94 mm and at a force of 13.9 N its surface was cut. The second increase in force was due to the rotor touching the lower plate since the milk-based cheese slices were slightly less than 1.5 mm thick.

Conclusion

A milk-based cheese and a vegan alternative have been compared with different test methods on a HAAKE MARS iQ Air Rheometer. The rheometer's normal force capabilities were a key feature used for all measurements, either to ensure a reproducible sample loading or as a measured parameter to get texture-related information.

The rheological tests showed differences in the mechanical stability and the temperature-dependent behaviour of the two products. On top of that, texture information could be gained from axial relaxation and penetration tests.

The vegan product showed a higher elasticity but less stability, which can be noticed when cutting or biting into it. Its behaviour during a temperature sweep was fundamentally different from that of the milk-based cheese. Although the selection of the two products compared was arbitrary, the results show general differences between fat/protein-based products and their starch/fat-based substitutes.

The measurements performed on the HAAKE MARS iQ Air Rheometer can be used to quantify the texture of cheese, either to control the quality of milk-based cheese or to better match the texture of vegan substitutes to the original.

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