Rheometers

Texture profile analysis (TPA) of sausage and a vegetarian substitute on a rotational rheometer

An extension of classical rheological measurements

Introduction

In the food industry, there is a growing interest in introducing products to the market that are vegetarian or even vegan. This trend reflects the increasing consumer demand for plant-based options and the recognition of the health, and environmental benefits associated with these diets. The aim is to replace known products that are based on animal ingredients or whose production clearly consumes too many resources (water, energy, acreage, ...). Nevertheless, the new, meatless substitute products should not be inferior to the original and well-known product in any way. In this context, our focus in this report is not on taste and the nutritional value, but rather on the mouthfeel during biting and the behavior while cutting. These aspects play a crucial role in ensuring that consumers have a satisfactory sensory experience and perceive the substitute products as comparable to their traditional counterparts.

Rheological and texture properties play an important role during the entire life cycle of semi-solid or solid food formulations. Rheological measurements, by means of amplitude sweeps and frequency sweeps, provide information about the viscoelastic properties of a sample. With specially designed probes, texture analysis or tribological measurements can be carried out with a rotational rheometer.[1] A specific test used in texture analysis is texture profile analysis (TPA). This test is intended to simulate chewing and thus corresponds to the mouthfeel experience. The characteristic values obtained from a two-bite test extend the rheological study. In this report, it is shown how TPA measurements can also be conducted with a rotational rheometer capable of measuring and applying axial forces. The products investigated and compared are a sausage and its corresponding vegetarian substitute.

Material and methods

All tests were performed using a Thermo Scientific™ HAAKE™ MARS™ iQ Air Rheometer. The rheometer was equipped with a Peltier temperature control module and parallel plate geometries. The TPA measurements were conducted with a diameter of 35 mm, while the oscillation measurements were conducted with a diameter of 20 mm and serrated surface to prevent sample slippage.

A commercially available sausage and a corresponding vegetarian substitute were investigated. Both products have a diameter of 20 mm. This is significantly smaller than the diameter of the upper geometry for the TPA measurements and it is the same diameter as the upper plate for the oscillation measurements. Cylindrical pieces with a length (height) of ~10 mm were cut off for the TPA measurements. For oscillation measurements, discs with a length (height) of ~4 mm were cut off.

TPA

Standard routines for TPA measurements are available in the Thermo Scientific™ RheoWin™ Job Manager Software. An example is shown in Figure 1. The procedure includes all preparation steps (1), the start and execution of the TPA measurement (2), the automatic evaluation of the obtained results (3) and the output of all calculated characteristic values (4).

Part 1 of the HAAKE RheoWin Software job: After the automatic determination of the zero point (contact position between upper and lower plate) and the loading of the sample, the upper plate is moved downwards onto the sample surface with reduced lift speed until an axial force F_N = 0.05 N is detected. Then the time, the height and the axial force are set to zero and the main measurement starts.

Part 2 of the HAAKE RheoWin Software job is the measurement itself. Figure 2 shows a complete TPA measurement and the areas and points required for the evaluation. The measurement consists of two identical compressions and withdrawals with a break of 5 s. In both cycles, the velocity is constant (up and down) and deformation Δh is identical.

Part 3 of the HAAKE RheoWin Software job is the evaluation of the characteristic values directly associated to the measurement. For this it is necessary to use math elements and previously determined or calculated values. The evaluated and calculated TPA parameters are shown in Table 1.

Part 4 of the HAAKE RheoWin Software job is the output of the characteristic values. This contains the determined and calculated values.

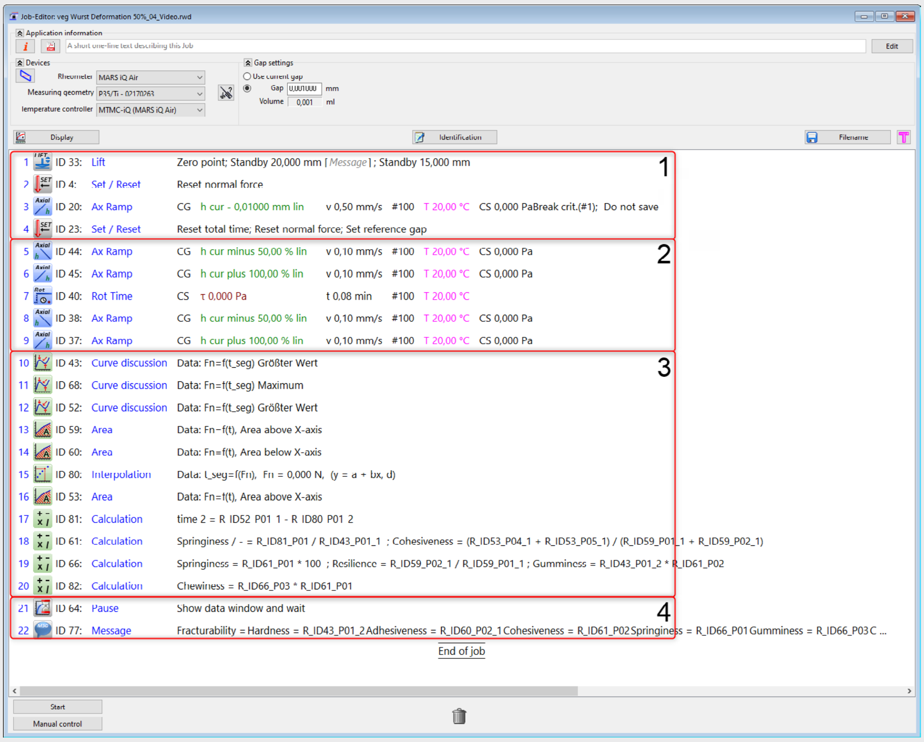

Figure 1: HAAKE RheoWin Software job for Texture Profile Analysis TPA measurement with different segments.

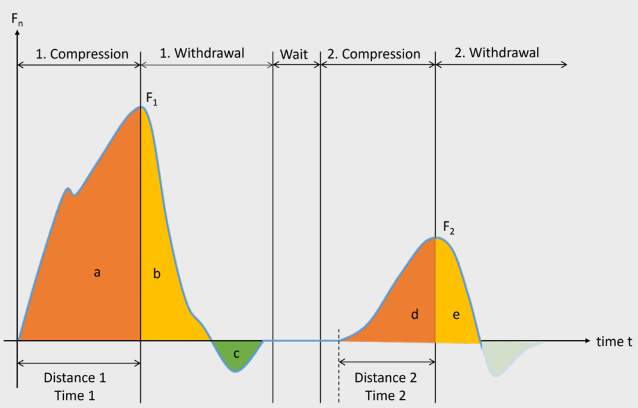

Figure 2: Implementation and evaluation of the two-bite test.

Hardness / N	Maximum in the first compression curve (F_1)	
Cohesiveness / - or %	Tendency of a product to cohere or stick together	$\left(\frac{d+e}{a+b}\right)$
Springiness / - or %	Percentage of product's recovery to its original height	$\left(\frac{time\ 2}{time\ 1}\right)$
Gumminess / N	For semi-solid products (Hardness * Cohesiveness)	
Chewiness / N	For solid products (Gumminess * Springiness)	
Resilience / - or %	Ratio of the energy of both peaks	$\left(\frac{a}{b}\right)$

Table 1: Evaluated and calculated TPA parameters.

To investigate the influence of deformation on the TPA characteristics, the experiment was conducted at a constant speed of 0.1 mm/s. The deformation was varied from 10 to 60 % for the sausage and from 10 to 50 % for the vegetarian substitute. To investigate the influence of velocity on the TPA characteristics, the velocity was varied from 0.5 to 5 mm/s at a constant deformation of 30 %.

Oscillation

After loading the sample on the bottom plate, the upper plate was moved downwards onto the sample with reduced lift speed until an axial force of F_N = 1 N was detected. This axial force is maintained throughout the whole measurement.

To get a general idea about the viscoelastic properties of both products, amplitude sweeps at 20 °C were performed over a stress range from τ = 1 Pa and 10^4 Pa at a frequency of f = 1 Hz. The frequency-dependent behavior was examined between f = 0.01 and 100 Hz. During this measurement, the rheometer applied a constant stress with $\tau_{0,\ sausage}$ = 10 or $\tau_{0,\ veg\ substitute}$ = 30 Pa.

Results

TPA—Influence of deformation

At Δh = 10 % (Figure 3 a), F_N increases and decreases continuously for both products. At Δh = 50 % (Figure 3 b), there is a defined peak for the sausage in the first compression (red curve), which can be equated with the first bursting of the sausage skin. This phenomenon cannot be observed for the vegetarian alternative. The recorded force F_n shows a continuously increasing and decreasing slope during compression and withdrawal (blue curves).

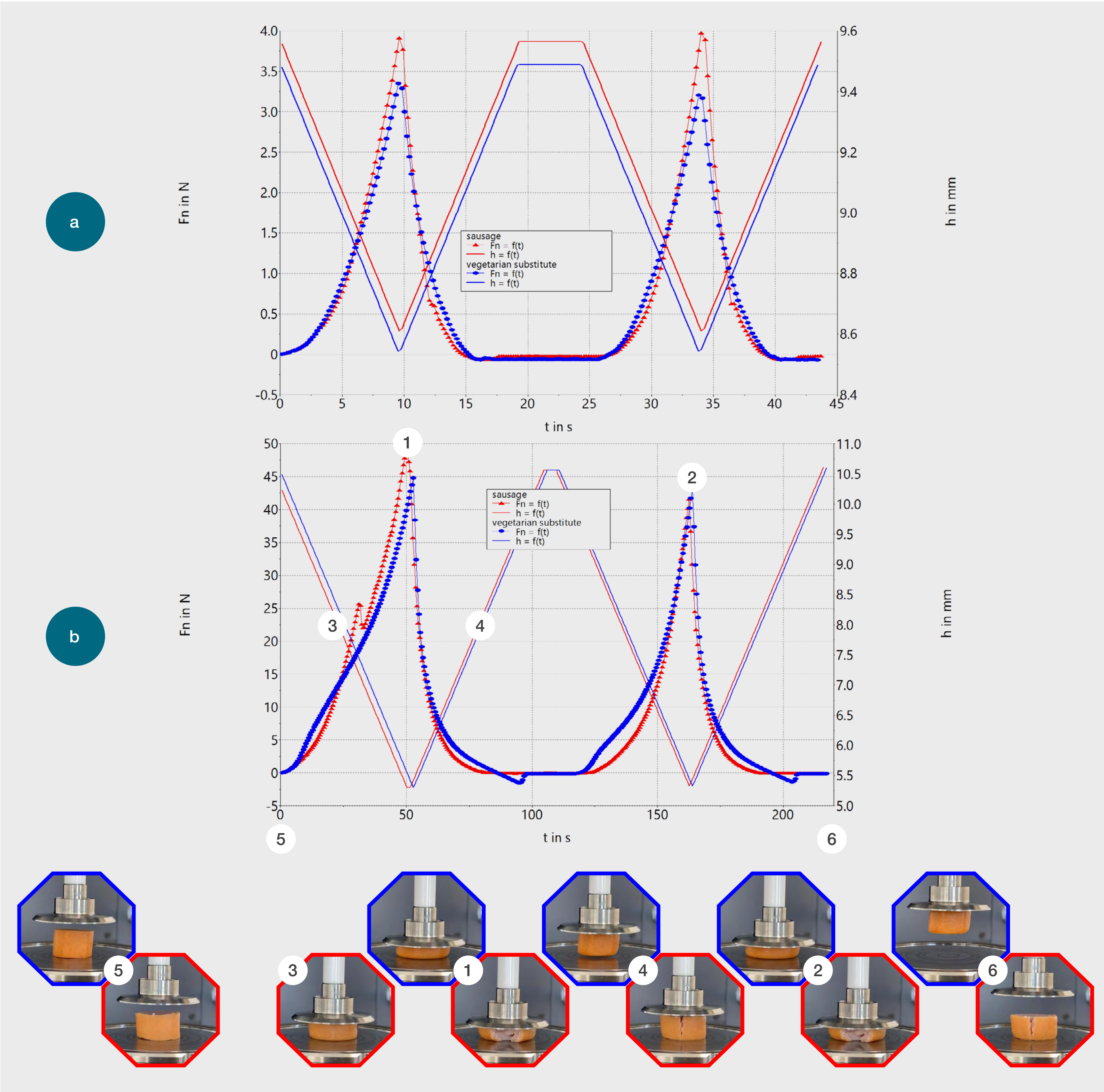

Figure 3: Two-bite test: comparison of the sausage with the vegetarian substitute at a constant velocity of 0,1 mm/s and different deformations of a) Δh = 10 %, b) Δh = 50 %.

Figure 4 shows the dependency of the TPA parameters on the maximum deformation for the sausage (filled symbols and lines) and the vegetarian substitute (open symbols and dotted lines). The same tendencies can be seen for both products until Δh = 50 %: hardness, gumminess and chewiness increase (Figure 4a), cohesiveness and resilience decrease, and springiness slightly increases (Figure 4b). Also, the absolute values are very similar for both products.

The skin of the sausage bursts from Δh = 50 % deformation, which could be seen from a peak maximum of F_N in segment 1 as described above. It can also be seen in a kink in the curve of gumminess and chewiness in Figure 4a: both quantities slightly decrease above Δh = 50 %.

With the vegetarian substitute more than a maximum deformation of Δh = 50 % is not possible, since at even higher deformation the maximum normal force of the rheometer at F_N = 50 N is exceeded. This could be because the vegetarian substitute is more homogeneous and its skin is more elastic, as it does not crack.

TPA—Influence of velocity

The TPA characteristics hardness, gumminess, and chewiness in Figure 5a show no dependence on velocity. The TPA characteristics cohesiveness and springiness in Figure 5b are independent of the velocity, too. Only the resilience increases with increasing velocity (Figure 5b). The respective absolute values are almost identical for the sausage and the vegetarian substitute.

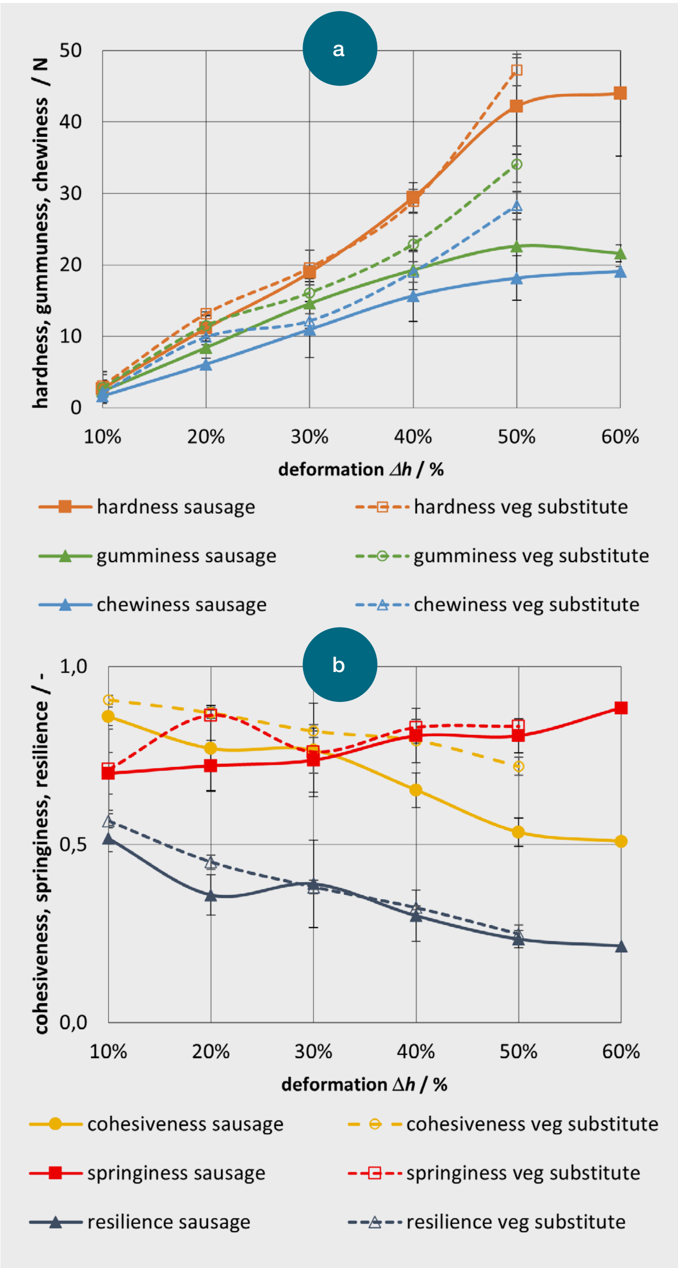

Figure 4: Dependency of the TPA parameters on the deformation at a constant velocity of 0.1 mm/s for the sausage (filled symbols and solid lines) and the vegetarian alternative (open symbols and dotted lines) a) hardness, gumminess and chewiness / N, b) cohesiveness, springiness and resilience / -.

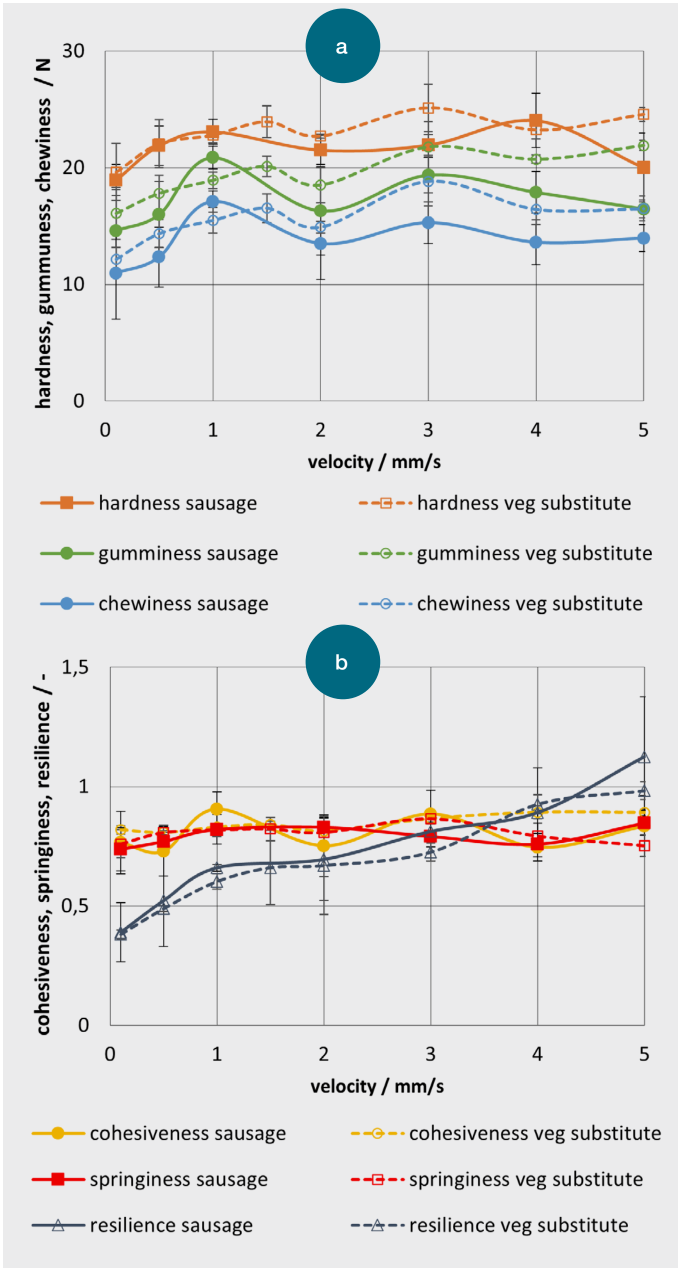

Figure 5: Dependency of the TPA parameters on the velocity at a constant deformation of 30 % for the sausage (filled symbols and solid lines) and the vegetarian alternative (open symbols and dotted lines) a) hardness, gumminess, and chewiness, b) cohesiveness, springiness, and resilience.

Oscillation measurements

From the amplitude sweeps in Figure 6a, it can be seen that the end of the linear viscoelastic range (LVE) is significantly earlier for the sausage (τ = 283 Pa) than for the vegetarian substitute (τ = 890 Pa). In addition, the plateau modulus for the sausage ($G'_{plateau}$ = 1.3*10^5 Pa) is slightly higher than for the vegetarian substitute ($G'_{plateau}$ = 9.3*10^4 Pa). The phase angles in the LVR are identical.

In the frequency sweeps in Figure 6b, G' and G" are parallel and show only a small frequency dependency for both products over the tested range. Typical behavior of gel like materials with high interconnectivity are observed. The moduli of the sausage are slightly higher than those of the vegetarian substitute. The complex viscosity decreases with increasing frequency and is slightly higher for the sausage than for the vegetarian substitute.

Overall, the sausage and the vegetarian substitute behave similarly in the oscillation measurements.

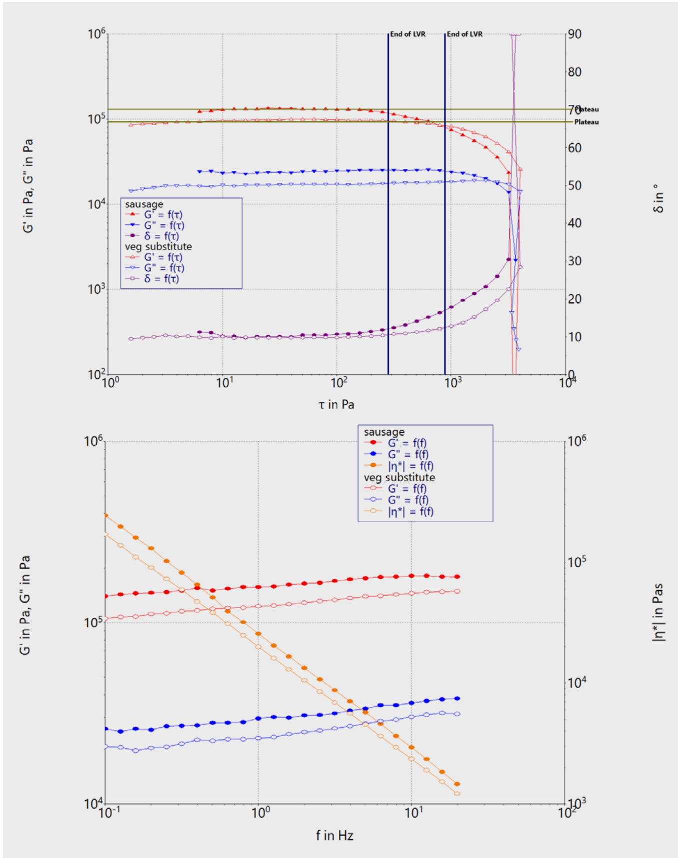

Figure 6: Oscillation measurements: a) amplitude sweep at *f* = 1 Hz, b) frequency sweep at τ = 10 Pa (sausage) or τ = 30 Pa (vegetarian substitute).

Summary

Texture profile analysis (TPA) and typical rheological tests in oscillation mode were performed on sausage and a vegetarian alternative product using a rotational rheometer with normal force capabilities. TPA measurements provide various (practical) information and are an excellent supplement to the classic rheological measurements. Both in the rheological and in the TPA measurements, the investigated sausage and the vegetarian substitute behaved similarly. Only in the texture of the skin, the two products differ slightly since the skin of the sausage is less elastic and cracks under a certain deformation. However, this is the characteristic crack, that a sausage should make when bitten off. This attribute is missing for the vegetarian substitute.

References

1. Fabian Meyer and Klaus Oldörp, "V292—Rheological and textural properties of various food formulations analyzed with a modular rheometer setup" 2019.

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