# Innovation in plant-based cheese development: controlling texture using twin-screw extrusion and rheological analysis

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## Introduction

Market demand for vegan alternatives to meat and dairy products is driven by consumers' concerns regarding sustainability, health, and animal welfare, along with other considerations like price and product quality. Vegan cheese, a plant-based alternative to traditional dairy cheese, is designed to replicate the taste, texture, and melting properties of cheese without using any animal products. Vegan cheese comes in many forms, similar to dairy cheese. These include soft cheeses (like cream cheese and ricotta), semi-soft cheeses (like mozzarella and brie), and hard cheeses (like cheddar and parmesan). There are also vegan cheese spreads, slices, and shreds available. The texture of vegan cheese is modulated by choosing the right ingredients. To this effect, a variety of plant-based ingredients, including nuts (such as cashews, almonds, and macadamias), seeds (like sunflower or pumpkin seeds), starches, soy, coconut oil, and nutritional yeast, are responsible for recreating dairy cheese properties.[1]

Vegan cheese can be used in much the same way as dairy cheese. It can be melted on pizzas, used in sandwiches, added to pasta dishes, or enjoyed on its own as part of a cheese platter. Vegan cheese products are also suitable for those who are lactose intolerant, allergic to dairy, or following a vegan diet. Additionally, producing vegan cheese generally has a lower environmental impact compared to dairy cheese. It requires fewer resources like water and land and generates fewer greenhouse gas emissions. However, producing vegan cheese with characteristics that are similar to conventional cheese is challenging due to the complexity of developing comparable structure and composition when using plant-derived components. The production of vegan cheese is usually conducted in a batch mixer, where all ingredients are added and mixed for some minutes. Although this process is simple, it brings some limitations regarding the maximum viscosity of the mixture. This could pose a problem when working with starches and proteins, hence limiting the feasibility of some recipes.[1]

Twin-screw extrusion offers a modular and flexible method to produce vegan cheese. This process has two primary advantages over batch mixing. During twin-screw extrusion, all dry ingredients (starches, proteins, nuts, and seeds) are mixed in a simple setup. Additionally, the oil/fat phase can be added along the barrel without the necessity of preparing an emulsion. The rotation of the screws brings sufficient energy to emulsify and disperse the oil/fat phase into the starch/protein mixture. As an added benefit, twin-screw extruders are typically much more compact than batch mixing setups, which allows for a reduction in occupied floor space. Other advantages of twin-screw extrusion include lower energy consumption, greater control over the transformation of raw materials to obtain the desired material properties, and the ability to apply different temperature zones during processing to adapt to the different gelation temperatures.

In this application note, we aim to showcase the production of vegan cheese with different textures (soft, medium, and hard) using a Thermo Scientific™ Process™ 16 Twin-Screw Extruder. Beyond production, we will show how the gel and melting properties of the extruded cheese can be assessed via rheometry with a Thermo Scientific™ HAAKE™ MARS™ iQ Air Rheometer. How easily a material melts, or the meltability of a material—in this case, vegan cheese—is linked to heat transfer within the cheese. The extent of the melting process is dominated by the rheological properties of the material. Therefore, storage modulus is a perfect indicator of the gel strength, and the phase angle displays the point of phase transition from solid-like to viscous-like behavior upon heating. [2]

## Extrusion trials

For the extrusion trials, a Process 16 Twin Screw Extruder was used. The experimental setup is depicted in Figure 1.


**Figure 1. Trial setup for vegan cheese production.**

For this application note, a mixture of starches and salt were chosen as the gelling matrix, and palm fat was selected as the disperse phase. A citric acid solution was also added to process to aid the gelling of starch and to enhance the flavor of the samples.

The twin screw extruder was equipped with two peristaltic pumps, for water/acid and palm fat dosing in the 3rd and 5th ports, respectively. The powder was fed into the main feeding port with a gravimetric twin-screw feeder, equipped with a concave screw to ensure consistent material flow into the extruder. The total throughput was set to 2 kg/h, including powder, citric acid, and palm fat feeding. However, the exact amount of powder and liquids changed depending on the formulation.

The extruder features a horizontally split barrel with a removable top half and a length-to-diameter ratio of 40 L/D. The barrel is divided into 8 zones: one cooled feed zone and seven separate heating zones (5 L/D each) to manage temperature profiles. The die used for this application was a rod die with a nozzle diameter of 3 mm. The extruder screw speed was set to 400 rpm and temperatures to tbarrel2-8 = 85 °C, and tdie_adapter = 85 °C.

The extruded samples were collected at the nozzle in beakers and were immediately stored at 4 °C overnight to allow the starch gel to set and the palm oil to solidify. The three different formulations are depicted in Figure 2.


**Figure 2. Starch-based vegan cheese with different textures, produced via extrusion.**

## Rheological characterization

The rheological tests were performed using a HAAKE MARS iQ Air Rheometer equipped with a Peltier temperature module for cone-plate or parallel-plate geometries. 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.

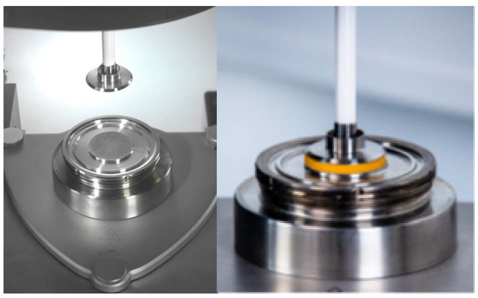

**Figure 3. Experimental setup for rheological characterization.**

To get a general idea about the properties of all vegan cheeses, amplitude sweeps at 20 °C were performed over a strain stress range from 1 to 1000 Pa 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. The results of all amplitude sweeps at 20 °C show some differences in the hardness of all products (Figure 4), with the formulation tailored for hard cheese analogue having a higher storage modulus than the other two samples. The plateau value of storage modulus in the LVR for all samples was calculated at $1.413\times10^5$, $7.650\times10^4$, and $3.273\times10^4$ Pa for the hard, medium, and soft recipes, respectively. This result indicates that the formulation plays an important role in texture development, since the extrusion conditions were the same for all three formulations.

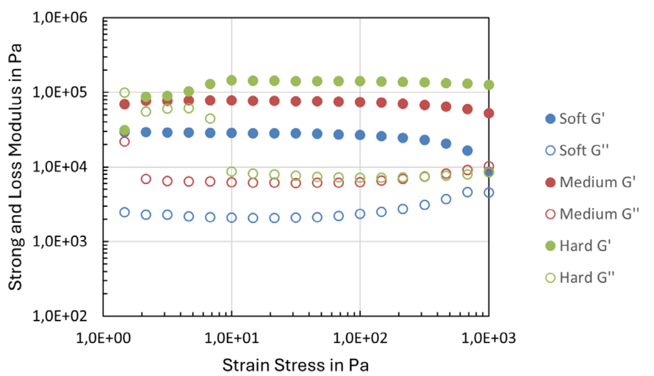


**Figure 4. Amplitude test of extruded vegan cheeses measured at 20 °C and 1 Hz with a plate-plate geometry.**

Besides hardness, another important characteristic for vegan cheese is its ability to melt in a similar manner to conventional dairy cheese. To assess the meltability of the produced samples, temperature sweeps at low deformation stress and frequency were conducted. The aim was to compare all three textures and determine whether they behave differently when melted, either being runny (less viscous) or elastic.

The results of the temperature sweeps show the behaviors of the three products over a wider temperature range from 30 °C to 100 °C. At 30 °C, the vegan cheeses had viscosities of 12,272.77, 14,174.87, and 18,511.3 Pa·s for the soft, medium, and hard textures, respectively. The viscosity curves are found in Figure 5. With increasing temperature, as expected, the viscosity of all samples dropped continuously. However, the slopes of the curves showed significant differences. The samples with soft texture had a flatter slope compared to the other two samples. Hard and medium textures showed similar curves and reached similar viscosity values at 100 °C. It would then be expected that these two samples have similar melting properties when used on bread or in pizza.

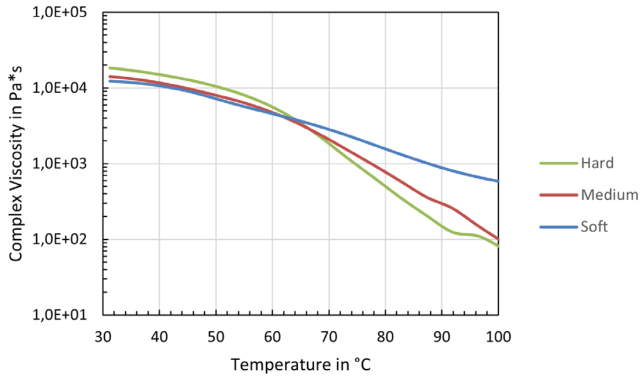


**Figure 5. Viscosity curves of all produced samples over the temperature, measured at 1 Pa and 1 Hz with a plate-plate geometry.**

The melting point of a sample can be assessed by looking at the phase angle δ. When this value equals 45°, the state transition from solid-like to liquid-like begins. The changes in the phase angle of all investigated samples are found in Figure 6. It is clear from the results that none of the produced textures really melt, as none of the phase angles of the samples reached 45°, remaining in the solid-like state. However, both the medium and hard textures show similar behavior, following the trend seen in Figure 4.

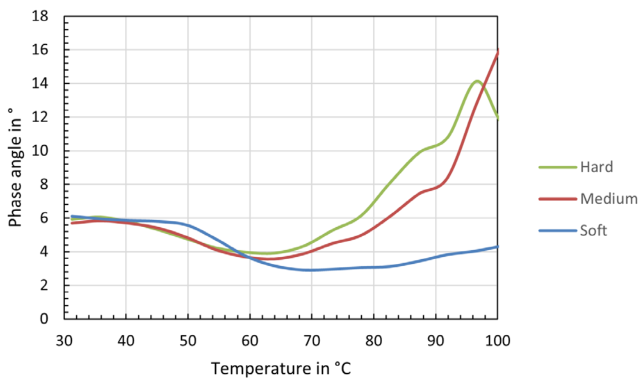


**Figure 6. Phase angle of extruded cheese over the temperature, measured at 1 Pa and 1 Hz with a plate-plate geometry.**

On the one hand, the δ-values of the soft vegan cheese remained almost constant up to 50 °C until they started to decrease down to 3°. With further increases in temperature, δ slightly increased and reached nearly 5° at 100 °C, becoming an even more elastic gel. On the other hand, the δ-values of the medium and hard textures decreased more quickly, reaching their minimum at around 60 °C. However, above 60 °C, the phase angle increased steeply but did not reach the melting point. Compared to dairy products, the curves are quite different. At higher temperatures, dairy cheese melts and behaves like a liquid. All vegan products, on the other hand, did not melt but became an even more elastic gel. This difference explains the observation of vegan consumers that some vegan cheese alternatives still do not meet the melting properties that dairy cheese displays.

## Conclusions

Vegan cheese, traditionally made with a batch mixer, can be produced with Process 16 Twin Screw Extruder. The experimental setup included a mixture of starches and salt as the gelling matrix, with palm fat as the disperse phase, where all ingredients were mixed and cooked in a single equipment.

Rheological tests were performed using a HAAKE MARS iQ Air Rheometer with a parallel-plate geometry to adapt to the cheese slices' thickness. Amplitude sweeps at 20 °C showed differences in hardness among the three formulations, with the hard cheese analogue having the highest storage modulus.

The phase angle δ was used to assess the melting point, indicating that none of the vegan cheeses truly melted, as their phase angles did not reach 45°. Instead, they became more elastic gels at higher temperatures. This behavior contrasts with dairy cheese, which melts and behaves like a liquid at higher temperatures. The results highlight that while the extrusion conditions were consistent, the formulation significantly influenced the texture and rheological properties of the vegan cheese.

### Literature

1. Pandey, R., Kumari, S., Khetra, Y. (2025). Vegan Cheeses. In: Mansha Rafiq, S. (eds) Technological Advances and Trends in Cheese Making. Springer, Cham. https://doi.org/10.1007/978-3-031-94476-5_14
2. Lyu, Z., Sala, G., Scholten, E. (2023). Melting properties of vegan cheese: Effect of emulsion and protein addition on the thermal behaviour of starch gels. Food Hydrocolloids, Volume 144, 108917, ISSN 0268-005X, https://doi.org/10.1016/j.foodhyd.2023.108917.

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