How microscopy and physical analysis are used to optimise food texture and accelerate product development

White Paper

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Abstract

Creating an appealing texture remains one of the biggest challenges when developing and reformulating certain food products. Navigating this complex area requires a detailed understanding of the structural properties and physical composition of formulations. Here we explain why using both microstructure and physical analysis techniques can help to achieve successful product outcomes.

Contents

Introduction

Texture is one of the most important factors when it comes to the enjoyment of food. Alongside appearance and taste, texture plays a critical role in the purchasing decision. However, it is arguably the most complex attribute to get right.

Texture is the response of tactile senses to physical stimuli but can also relate to the sounds emitted as the food is chewed[1,2,3]. As such, it encompasses many different sensorial qualities and is evaluated at every touch point. Consumer perception starts from the moment the product is first handled and continues through consumption, which itself is not a static state. The texture of food evolves from the first bite, through the chewing action and final breakdown; the beginning is a completely different experience to the end.

To complicate matters further, the words commonly used to describe the texture of food are often fluid and imprecise. A 'hard' apple, for example, is not the same as 'hard' cheese. At the same time, sustainable ingredients, healthier, free-from and plant-based alternatives have brought new challenges for product developers tasked with creating appealing textures.

Understanding how a product will behave during manufacture, distribution, and storage is therefore vital. Analytical methods to characterise both the physical composition and microstructural properties of food systems enable microstructure to be visualised and texture to be quantified. Used effectively, these tools can measure relevant textural attributes during product development, formulation, and troubleshooting, or simply for quality control.

Characterising texture

Given that texture is such a multi-parametric attribute, developing an effective analytical strategy requires an understanding of the mechanics of deformation and fracture throughout the chewing process. The main phases and how they relate to instrumental analysis are shown in Figure 1.

In the early stages – first bite and initial chewing action – mechanics are generally used to address fundamental questions such as: How much force does it take to compress the product? Does it spring back? At which point does it break?

As the product breaks down and a bolus starts to form, attention moves to the level of lubrication in the mouth and the impact on texture. For example, is the desired creamy sensation being reduced due to the presence of insoluble protein particles taking water out of the mouth? Tribological measurements are used to quantify the interaction of the food with the surface of the mouth, measuring friction and lubrication.

The latter stages of bolus formation and residue are all about measuring how things flow. So, this is when rheology comes into play to access levels of viscosity and softness.

In addition, microscopy can be used to explore food microstructures and enhance product development. This detailed visual analysis can help explain why, for example, a product's texture is not meeting expectations. Microscopy helps us to understand the size and location of individual ingredients which will impact flavour release and texture in the mouth.

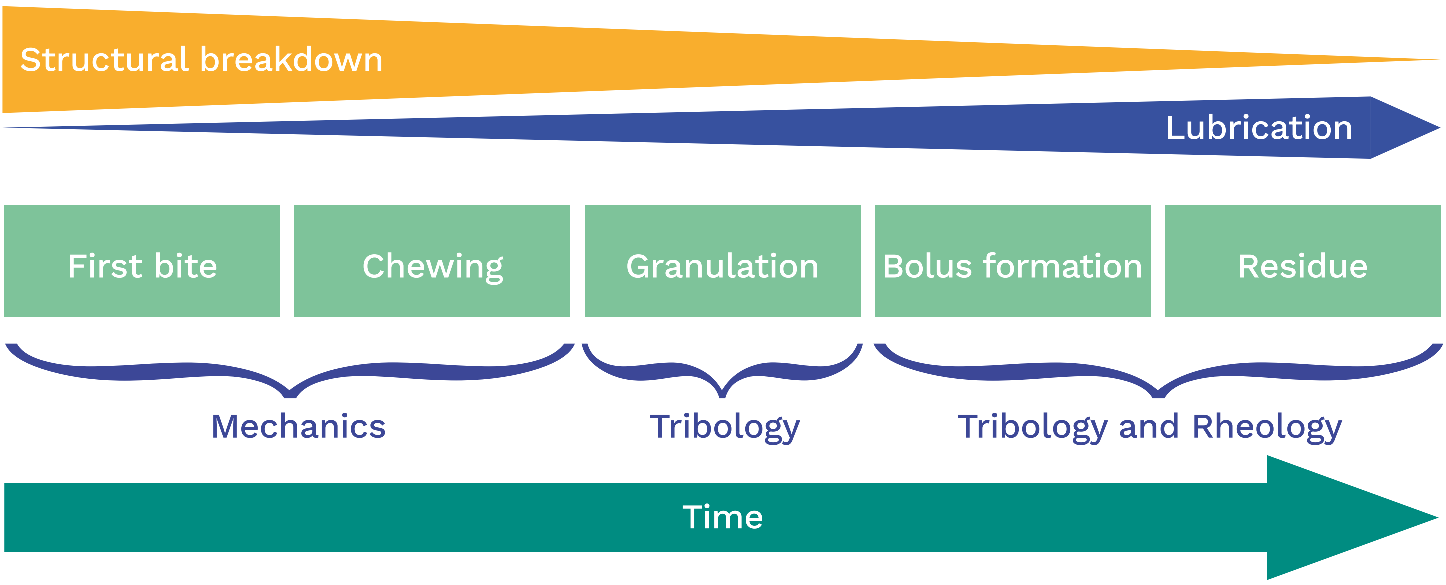

Figure 1: A schematic of the relation between the chewing process and instrumental methods.

Creating a framework

In order to know which textural attributes to measure, they must first be prioritised according to consumer preference. A clearly defined lexicon can then be defined and referred to throughout the development process.

This may involve investment in sensory analysis with a trained panel of sensory experts. Although widely regarded as the gold standard, it is also a costly and time-consuming option which may preclude it from many product development plans.

An effective alternative is to use existing products as benchmarks for the desired texture. By identifying positive attributes, it is possible to map and define what 'good' looks like, make comparisons, or identify what is lacking. It is also useful to identify characteristics that the consumer dislikes so that these can be avoided. This is about understanding, articulating, and measuring the key textural features that make a product stand out. With this framework in place, product developers can then build a product structure that aligns with the defined textural experience.

A useful starting point is Texture Profile Analysis (TPA). Commonly used to characterise the fracture behaviour (mechanics) of solid and semi-solid foods when subjected to axial pressure that causes deformation, this technique can be used to evaluate several physical attributes in a single measurement (Figure 2).

TPA attribute	Definition
Fracturability	Force at first significant break in curve
Hardness	Peak force during first compression cycle
Cohesiveness	Ratio of positive force area during second compression to that during first compression (A2/A1)
Springiness	Ratio of the height at the end of the second compression to that of the end of the first compression (d2/d1)
Gumminess (semi-solids only)	Hardness × cohesiveness
Chewiness (solids only)	Hardness × cohesiveness × springiness

Figure 2: Key physical attributes measured by Texture Profile Analysis.

Rheological studies are key for emulsions, foams, and liquids, as well as semi-solid products such as jelly. These techniques quantify the relationship between deformation and the resulting rheological properties such as flow behaviour, viscosity, elasticity, and recovery[4].

It is also important to think in terms of the product composition or, more specifically, ingredient functionality. The size, distribution, and composition of a product's constituent parts, as well as the adhesion between them, need to be considered, visualised, and measured using relevant microscopy techniques. A well-designed series of experiments can then be carried out to investigate how ingredients behave under different processing conditions, with the resulting data used to identify key drivers of quality and consumer preference.

Analysis in action

In practical terms, developing the desired product texture demands an integrated analytical strategy that considers the process, the composition, and how the two interact. Here we explain how different techniques can be used to evaluate the influence of these critical factors on the textural characteristics of products in three different categories. In all cases, benchmarking provides valuable insights that product developers can then use to build and improve textural structure.

Plant-based sausage

Traditional fermented sausages contain considerable amounts of fat and connective tissue that are minced and mixed with salt, before being fermented and dried. This gives them a distinctive granular appearance and texture that needs to be replicated in vegan alternatives to secure consumer acceptance. Therefore, being able to analytically characterise the attributes of a meat-based fermented sausage and compare them against those of a new concept containing plant-based protein sources is an extremely useful exercise.

For example, both products may have the same visual appeal but differ in terms of their textural performance. Various microscopy techniques can be used to explore the reasons why and one of the most widely used in this context is light microscopy.

Figure 3 highlights a fermented meat based sausage (left) and plant-based vegan alternative (right). The vegetarian sausage was similar in visual appearance to the meat-based product but staining with iodine revealed that the white lumps that resembled fat, were starch based, which was distributed throughout the whole sausage. The meat product has a dense protein network in which lumps of fat are dispersed (Figure 3). In addition, the vegan concept has a much higher amount of starch, while the meat product has much higher levels of protein (Figure 4).

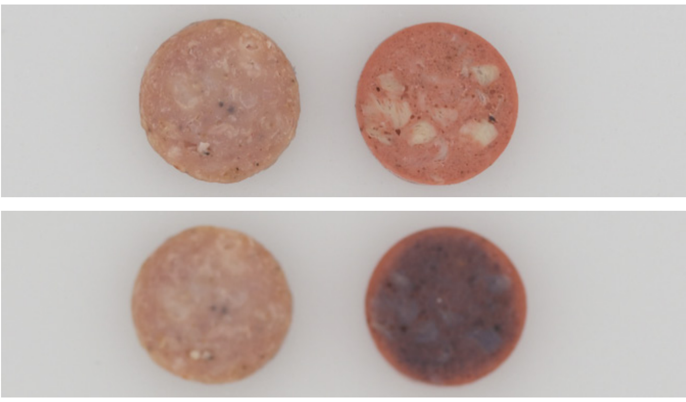

Figure 3: Fermented meat based sausage (left) and vegan alternative (right), stained with iodine to reveal the presence of starch.

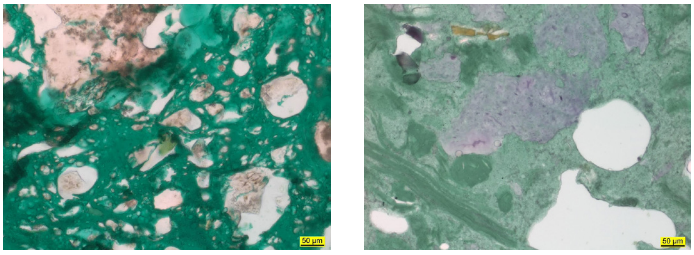

Figure 4: Fermented meat based sausage (left) and vegan alternative (right). The meat based sausage has a much higher level of protein (stained green) and the vegan alternative (right) has a higher amount of starch (blue-black).

Confocal laser scanning micrographs provide further important information about the distribution of protein and fat, which are both crucial to succulence and chewing. These results show that the fat in the vegan product is present as an emulsion (mainly as small fat droplets) and typically located within the gelled protein phase of the product. In the fermented meat sausage, the fat is present in much larger regions throughout the protein.

The meat-based sausage (left) and vegetarian alternative (right) can be observed in Figure 5 with the protein being coloured red and fat green.

Textural profile analysis (TPA) also adds to the overall understanding by measuring some of the key mechanical attributes commonly used to describe fermented meat sausages, such as cutting and compression. Reviewed together, this analysis shows that the fermented meat-based sausage is firmer, less cohesive, and chewier than the plant based vegan alternative; providing a framework of key textural characteristics that need to be improved in order for the new concept to meet consumer expectations.

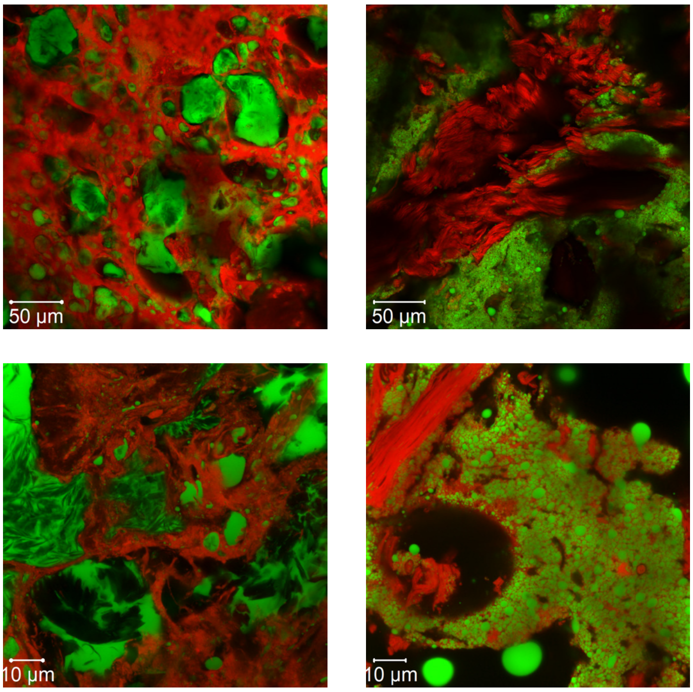

Figure 5: Confocal laser scanning micrographs of meat based sausage (left) and vegan alternative (right).

Plant-based yogurt

Yogurt, just like any other emulsion, is not a homogenous mixture of individual molecules but rather a complex structural hierarchy of colloidal particles, semi-liquid fat droplets, and a continuous aqueous phase rich in minerals, all held together by proteins and/or hydrocolloid biopolymers within a viscoelastic matrix. Changing the fat droplet size, interfacial material or the continuity and strength of the protein network can therefore have a big impact on textural properties.

So, when it comes to developing a plant-based Greek-style yogurt, studying these features using a range of relevant analytical techniques and comparing them against a dairy product is a critical part of the process.

Confocal laser scanning microscopy (CLSM), for instance, is a powerful technique that uses stains to label fat and protein within a subsurface region of a product. Here (Figure 6), it shows that the protein in the dairy product is well distributed and interconnected into a network and the aqueous spaces were small. By contrast, the plant-based version has clusters of small fat and protein plus large, discrete protein-rich particles.

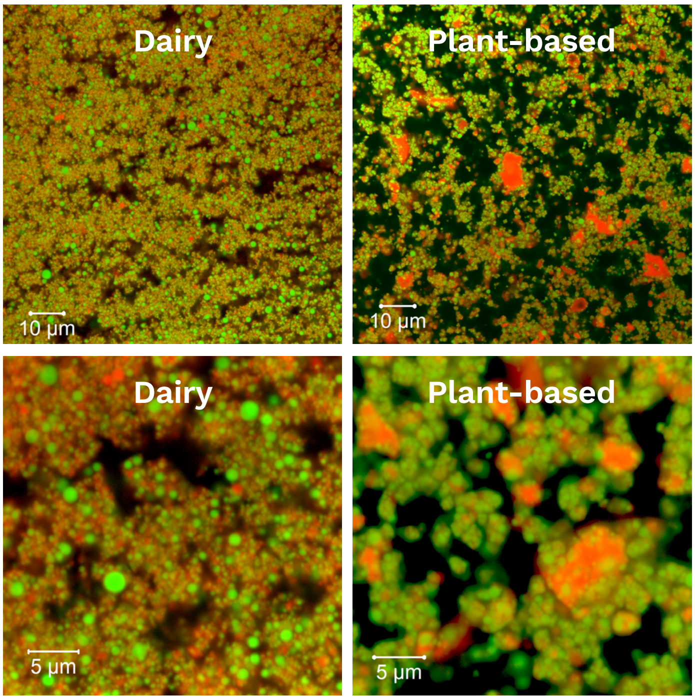

Figure 6: Microstructure of a dairy and plant-based Greek yogurt; protein (red) and fat (green).

Figure 7 is a colour coded map showing the chemical distribution of major ingredients in the plant-based Greek yogurt using confocal Raman microsocopy. As well as the fat and protein, this map shows major components that could not be visualised by confocal laser scanning microsocopy, the starch and serum phases. The serum phase is where the hydrocolloid (often polysaccharides such as Pectin or Guar gum) will be present. It is important to ensure the hydrocolloid has fully and evenly dispersed into the serum phase, otherwise the product will not perform as expected.

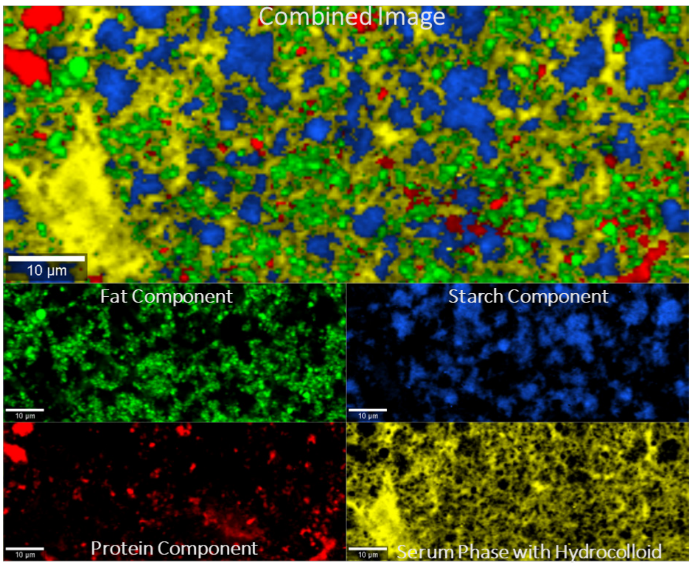

Figure 7: Colour coded map showing the chemical distribution of major ingredients in the plant-based Greek yogurt using confocal Raman microscopy.

At the same time, oscillatory rheology (Figure 8) shows that both the dairy and plant-based products are gels in which the elastic (solid-like) behaviour dominates. However, the plant-based product is stiffer, has a higher elastic modulus than the dairy product, and requires more strain to break.

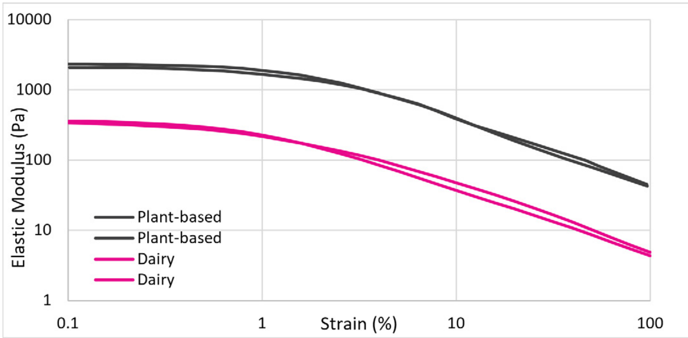

Figure 8: Results of rheological analysis.

Texture analysis can provide a large deformation measurement more representative of how products would behave as eaten. In this example, the initial part of the curve relates to the stiffness of the unbroken gel, the change of gradient shows that some structural reorganisation is occurring and the steep drop in force indicates that the structure has broken and the force value after this point is related to viscosity (Figure 9).

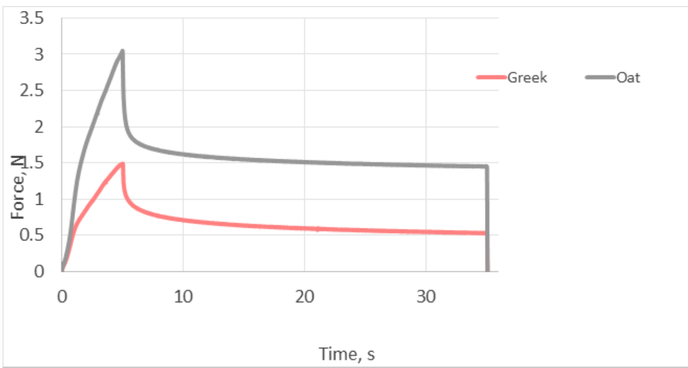

Figure 9: Texture analysis of dairy Greek yogurt and plant-based alternative.

Taken together, the various methods provide an understanding of the structure and enable the product developer to make informed choices of ingredients and process conditions needed to match the target textural experience.

Gluten-free muffin

The air in muffins contributes to the lightness that consumers expect. During manufacturing, air is entrapped as the batter is beaten and a foam forms. Surface active components present in flour and eggs, or added as emulsifiers, reduce the energy required to form bubbles and so help with aeration within the mixture.

These bubbles rise to the surface during baking but are impeded by the viscosity of the batter. As the temperature increases, viscosity decreases. However, as proteins start to coagulate and starch gelatinises, rigid networks form that not only stabilise the structure, but also determine the firmness and springiness that consumers expect.

Changing to a gluten-free formulation will impact these vital textural characteristics, so it is important to benchmark new concepts against a standard muffin. In this example (Figure 10), quantifying the degree of aeration is investigated by measuring total volume by X-ray microtomography which produces a 3D density map to non-destructively image the internal structure of the muffin.

Image analysis was performed on a volume of interest to segment the air phase and measure the size of the air bubbles. The size distribution was plotted, and the distribution of the bubbles was visualised using pseudo colours. When comparing the standard muffin to the gluten-free muffin, the latter had a coarser structure with larger air spaces. In comparison, the standard muffin had smaller air spaces. This technique can also be used to identify distribution of chocolate chips throughout the muffins.

In addition, TPA provides important mechanical information about the extent to which the cell wall deforms when force is applied. This double compression test shows that the standard product is firmer and chewier than the gluten-free alternative, while the gluten-free muffin is slightly adhesive (Figure 11). Results that can also be verified against sensory evaluation.

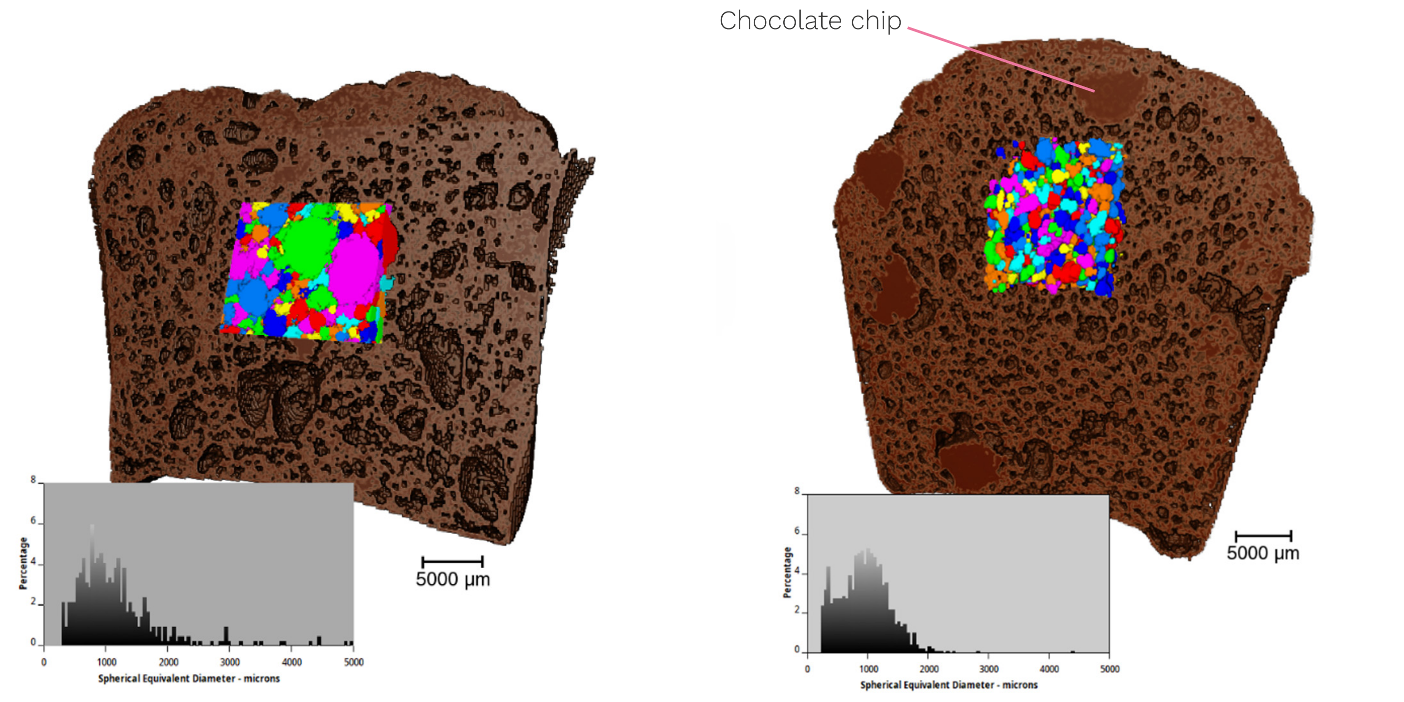

Figure 10: Gluten-free muffin (left) and standard muffin (right).

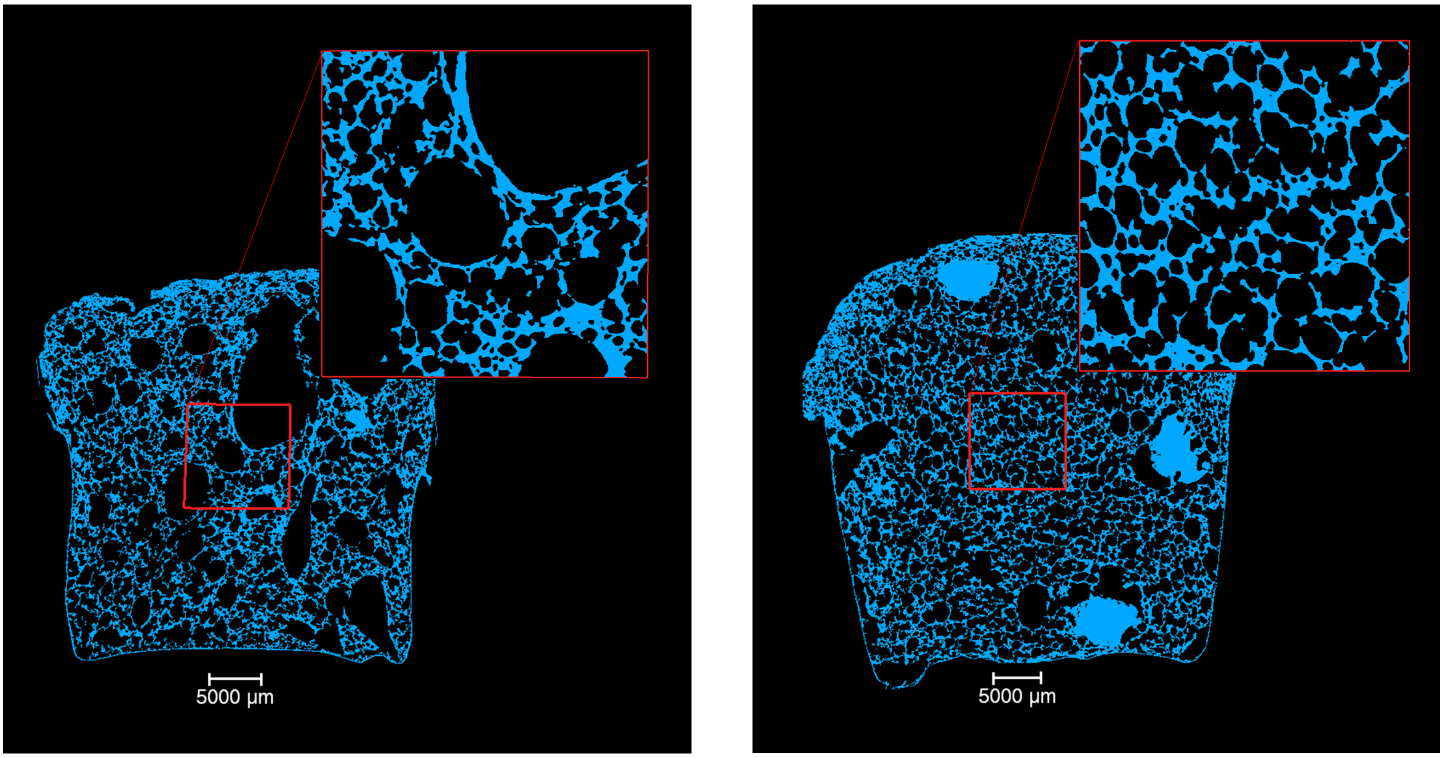

Figure 11: Gluten-free muffin (left) and standard muffin (right).

Attribute	Standard	Gluten-free
Firmness (g)	325.3 ± 21.5	140.7 ± 25.8
Adhesiveness (g.s)	-0.30 ± 0.10	-29.10 ± 17.09
Cohesion (-)	0.427 ± 0.028	0.431 ± 0.013
Springiness (%)	62.4 ± 7.2	70.7 ± 7.4
Chewiness (-)	86.3 ± 7.5	43.1 ± 10.1

Figure 12: Results of force-deformation trace analysis.

Conclusion

Food systems are complex, where the interaction between many different components during manufacture and consumption contribute to overall textural performance. Using microscopy alongside physical analytical techniques provides valuable information that not only helps to optimise formulations, but also accelerates the product development process.

Rather than trying to address numerous aspects, prioritising and measuring two or three parameters through product benchmarking is key. With this framework of defined references in place, product developers can collaborate with the analytical team to make informed decisions, such as which prototypes to take forward, and ultimately find the product 'sweet spot'; where everything works in harmony to create the most desirable eating experience.

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An internationally recognised food microstructure expert, Mark was awarded Food and Drink Federation Scientist of the Year in 2021 and has published over 100 scientific papers during his distinguished career. He is a fellow of the Institute for Food Science and Technology and the Royal Microscopical Society.

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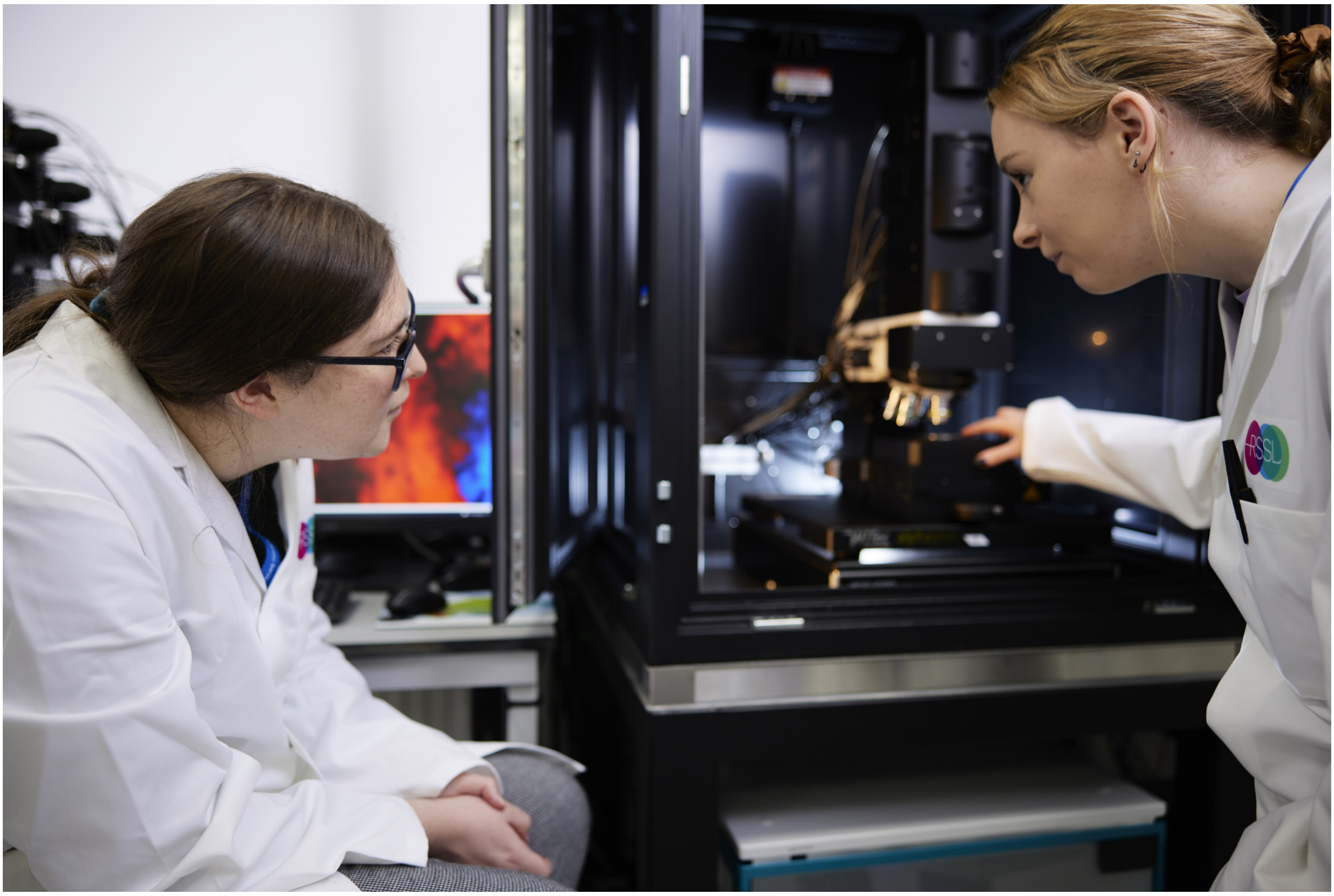
James has extensive experience working with a range of food materials to characterize their micro-structure. James' particular focus is the generation of accurate 3D digital twins with food and packaging based materials, using a range of advanced tools such as X-ray micro-CT and hand held 3D scanning.



Scientists using our new confocal Raman microscope, which adds chemical mapping to our imaging capabilities.

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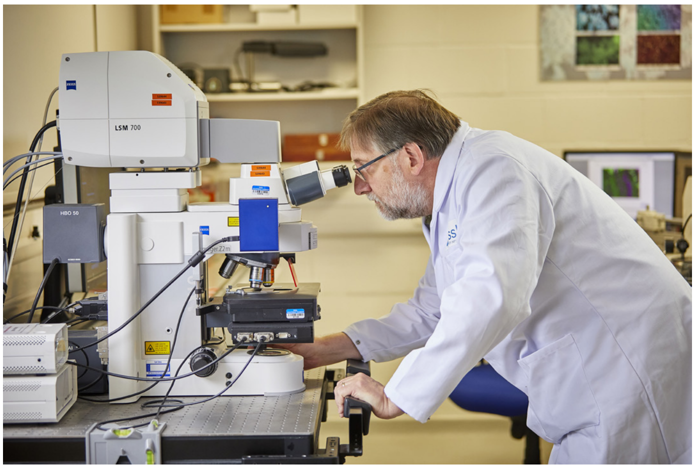

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