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Oral processing, texture and mouthfeel: From rheology to tribology and beyond ☆

Jason R. Stokes [a,b,*], Michael W. Boehm [a], Stefan K. Baier [c]

[a] School of Chemical Engineering, The University of Queensland, Brisbane 4072, Queensland, Australia
[b] ARC Centre of Excellence of Plant Cell Walls, The University of Queensland, Brisbane 4072, Queensland, Australia
[c] PepsiCo Long Term Research, 3 Skyline Dr., Hawthorne, NY 10532, USA

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ABSTRACT

Texture and mouthfeel arising from the consumption of food and beverages are critical to consumer choice and acceptability. While the food structure design rules for many existing products have been well established, although not necessarily understood, the current drive to produce healthy consumer acceptable food and beverages is pushing products into a formulation space whereby these design rules no longer apply. Both subtle and large scale alterations to formulations can result in significant changes in texture and mouthfeel, even when measurable texture-related quantities such as rheology are the same. However, we are only able to predict sensations at the initial stages of consumption from knowledge of material properties of intact food.

Research is now on going to develop strategies to capture the dynamic aspects of oral processing, including: from a sensory perspective, the recent development of Temporal Dominance Sensation; from a material science perspective, development of new in vitro techniques in thin film rheology and tribology as well as consideration of the multifaceted effect of saliva. While in vivo, ex vivo, imitative and empirical approaches to studying oral processing are very insightful, they either do not lend themselves to routine use or are too complex to be able to ascertain the mechanism for an observed behaviour or correlation with sensory. For these reasons, we consider that fundamental in vitro techniques are vital for rational design of food, provided they are designed appropriately to capture the important physics taking place during oral processing. We map the oral breakdown trajectory through 6 stages and suggest a dynamic multi-scale approach to capture underlying physics. The ultimate goal is to use fundamental insights and techniques to design new food and beverages that are healthy yet acceptable to consumers.

1. Introduction

Both natural and processed foods contain hierarchical structures and multiples phase, ranging in length scale from the nanoscopic to the macroscopic. These structures are present to provide certain functionality such as nutritional value and texture control or to aid processing and shelf-stability. Rheology is used as an essential design tool in engineering food as it is important to processing, shelf stability and sensory perception, including texture and mouthfeel, and it can probe the overall structure as well as the interplay between individual colloidal components. There is extensive knowledge on the complex relationships between rheology and the dominant underlying structure of foods and beverages, and a good enough understanding exists to re-design different types of foods to have largely the same rheological features [1,2]. Therefore, it is possible to design food rationally to meet rheological criteria and for meeting specific nutritional requirements; for instance, the role of hydrocolloids in nutrition and digestion is covered elsewhere in this issue [3]. However, foods created in this rational way still fail to meet consumer expectations: consumers are let down by the overall sensory experience, which is strongly influenced by the food and beverages' organoleptic properties. We address here consideration of in vitro strategies that provide insights into oral processing and, when coupled to in vivo studies, will better enable rational design of foods and beverages.

Texture and mouthfeel play pivotal roles in product acceptability, and except for the point at which food enters the mouth (e.g., first bite of solids, initial thickness of liquids), we cannot currently predict these percepts using fundamental rheological properties of the food and beverage [4••] or through measurements derived from imitative or empirical techniques such as "texture profile analysis" (TPA) using a texture analyser [5,6•]. Consequently, replicating foods with healthier formulations has proven difficult, and important questions arise as to what role ingredients like fat play that makes it so desired in food and renders the texture of

* Corresponding author at: School of Chemical Engineering, The University of Queensland, Brisbane 4072, Queensland, Australia. Tel.: +61 7 336 54361; fax: +61 7 336 54199.
E-mail address: jason.stokes@uq.edu.au (J.R. Stokes).

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products more acceptable [7]. Similarly in beverages, when basic tastants such as bulk sweeteners (e.g., high fructose corn syrup) are substituted with alternative sweeteners (e.g., aspartame), even if apparent sweetness level is the same, the perceived mouthfeel is substantially altered [8,9]. New insights are needed into the physical drivers for texture and mouthfeel if food manufacturers are going to be in a position to rationally design food with an enhanced nutritional profile that is also acceptable to consumers.

Food Oral Processing involves comminuting solid food to small particle sizes, mixing with saliva, and forming a bolus that is then swallowed and transferred to the stomach [4••,10]; the first book on the subject has recently been published [11••]. Regardless of the initial state of food, it undergoes a conversion to a form that is rheologically suitable for swallowing in a highly sophisticated dynamic process [12,13••]. The organoleptic properties of food, including texture perception, should depend on the constantly changing status of the food during oral processing [14] as well as the changing status of the salivary film coating oral surfaces and saliva itself [11••,15•,16•]. Utilising knowledge of oral processing in the rational design of foods is challenging and relevant in vitro measurement techniques are needed that provide mechanistic insights into texture/mouthfeel and can be used in food structure design, but these also require validation using in vivo studies and sensory science.

This review will consider oral processing and texture/mouthfeel with particular emphasis on developing in vitro strategies to capture the dynamic nature of oral processing and the changing status of food during consumption, as well as the underlying physics/mechanics taking place during this process.

2. The multi-dimensional and dynamic nature of texture and mouthfeel

Food texture is regarded as a multidimensional sensory property that is influenced by the food's structure, rheology and surface properties; this has been recently reviewed by Kravchuk et al. [17]. As defined by the International Standards Organisation (ISO, 1994), texture is "*all the mechanical, geometrical and surface attributes of a product perceptible by means of mechanical, tactile, and, where appropriate, visual and auditory receptors*". Mouthfeel is a term often used to refer to the tactile aspects of texture perception during consumption, as defined by Guinard and Mazzucchelli [18•] who state that mouthfeel encompasses all of the "*tactile (feel) properties perceived from the time at which solid, semi-solid or liquid foods or beverages are placed in the mouth until they are swallowed.*" Following consumption, the mouth still senses residue and after effects resulting from the consumed food, such as astringency and mouthcoating; a*fter-feel* is a term commonly used to describe these mechanical sensations that are also inherently part of texture perception. Hence, texture is not just about rheology, but texture also encompasses tactile mechano-sensations associated with the contact between the food, food residue and human oral surfaces [17].

These accepted definitions of texture highlight its truly multi-dimensional nature and emphasise that it is not a simple food property that can be measured instrumentally [17]. Regardless, a considerable amount of effort has been expended to do just this using imitative mechanical tests and rheology, as covered in the next section. However, these endeavours rarely consider contributions to texture from structural and surface properties, and they are also unable to consider cross-modal influences from the different senses. Tactile mechano-sensation plays a major role in the perception of texture and mouthfeel, yet this is unlikely to be captured through rheology measurements; of closer relevance is measurement techniques in tribology, which considers the forces associated with interacting surfaces in relative motion (covered later in this review). In addition, what is often not considered or quantified in both sensory and mechanical measurements is that food undergoes a major transformation upon entering the mouth, so exactly what structural, mechanical and surface properties of the food and the food bolus are relevant to the perception at any particular time point is open for debate. Fig. 1 depicts the transition in film thickness of fluid-like foods or beverages between oral surface as they are consumed, indicating it goes from a rheology-dominant deformation process to one where tribology (surface properties) dominates.

Sensory profiling traditionally involves a descriptive approach and quantification of intensity after eating [19]. Time–intensity (T–I) studies were introduced to account for the dynamics of perception [20], but the main constraint is that evaluation is limited to one or two attributes at a time [21]. Temporal Dominance Sensation (TDS) has been recently introduced as a viable technique to capture the multidimensionality of the perceptual space over time [21–23••]; it involves assessment of the most intense (dominant) percept at any particular time and scoring the intensity (refer to Fig. 3). The challenge with this approach has been in analysing data collectively from different panellists, especially when the attributes are not highly distinguishable or interrelated. In a recent study on brittle cereals, TDS was used to identify the dominant textural attributes with time during mastication [14], which we believe is a promising approach for directly linking the changing status of food and its interaction with saliva during oral processing. Future studies need to focus on mapping the temporal sensory process to relevant physical properties measured in vitro, which will assist in developing suitable in vitro methodologies for rational food design that accounts for texture and mouthfeel.

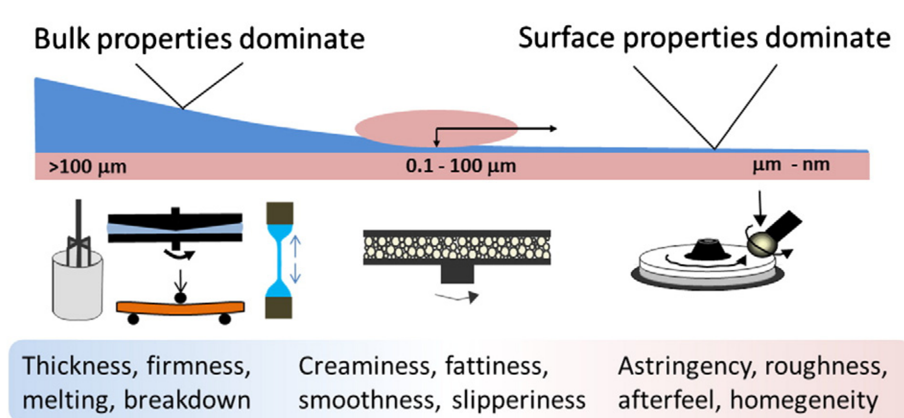

Fig. 1. Depiction of the transition in film thickness of fluid-like (and soft) foods or beverages between oral surfaces as they are consumed, indicating it goes from a rheology-dominant deformation process to where tribology (surface properties) dominates. Also shown is an indicator of the types of techniques that could be used to study the multiscale deformations, and where typical textural mouthfeel attributes may lie.