SALIVA MATTERS: REVIEWING THE ROLE OF SALIVA IN THE RHEOLOGY AND TRIBOLOGY
OF LIQUID AND SEMISOLID FOODS. RELATION TO IN-MOUTH PERCEPTION

Laura LAGUNA, Susana FISZMAN* and Amparo TARREGA

Instituto de Agroquímica y Tecnología de Alimentos (IATA-CSIC)

Catedrático Agustín Escardino, 7, Valencia. Spain

*Corresponding author, email: sfiszman@iata.csic.es

Abstract

In recent years, the dynamic aspects of the oral perception of food have increasingly been taken into account in food texture characterization. At the same time, the experimental settings of instrumental measurements have also been emulating “oral contexts” more closely. The aspects related to in-mouth handling that have been incorporated into food studies include using saliva as a key material. Semisolid (or liquid) food does not usually need mastication but undergoes more subtle processes involving the tongue and palate, among other buccal structures, in which saliva is omnipresent. Creaminess, mouthfeel and astringency are central sensory sensations for which oral handling and consequently, saliva is pivotal. The present review examines the experimental considerations involved in using saliva in the rheology and tribology of liquid and semisolid foods. It also analyses some instrumental parameters that have been related to sensory attributes of liquid and semisolid foods.

Keywords: rheology; tribology; saliva; oral processing, semisolid; texture perception

26 Highlights

- 27 • Instrumental texture-related measurements are getting closer to oral contexts
- 28 • Saliva performs multiple functions and is central to every in-mouth food process
- 29 • It is difficult to obtain uniform saliva samples; experimental considerations might be
- 30 borne in mind
- 31 • Rheology & tribology with saliva aid grasp of liquid & semisolid texture perception

32

1. Introduction

Oral processing has become an essential facet of the study and interpretation of food texture perception. Since Hutchings and Lillford's (1988) breakdown path model proposal, recently revisited by Boehm, Yakubov, Stokes, and Baier (2020), research has focused on capturing the dynamic essence of oral perception. Saliva is an ever-present material in any action exerted on any and every food material while it is in the mouth. For this reason, saliva has lately been used as an important element to bring instrumental measurements closer to an "oral context" in food bolus characterization and especially to relate them to sensory perception. However, even when saliva is incorporated into the measurements there is no single, ideal technique for decoding the complex, multisided process of texture perception during oral processing (Sethupathy, Mose, & Anandharamakrishnan, 2020). Over the last decade, the use of saliva in a number of instrumental techniques has gained ground. The present work reviews how saliva intervenes in several aspects of the oral perception of food and the current use of saliva in several of these techniques.

1.1 Saliva in the Food Science research context

Saliva is a physiological fluid with multiple roles. Saliva is essential for the conservation of good oral and mucosal health (Chaudhury, Shirlaw, Pramanik, Carpenter, & Proctor, 2015). One of its most important roles is helping to lubricate and protect the surfaces of the oral cavity. Saliva also appears to contribute to pellicle formation (Odanaka et al., 2020). Pellicle is the biofilm that covers the surface of tooth enamel and other exposed buccal surfaces; it is formed by an organic, proteinaceous material that protects teeth from abrasion and chemically induced erosion (Zimmermann et al., 2019). Pellicles are unique among other biological lubricants in being very resistant to wear and showing low friction coefficients (Boyd et al., 2020). Saliva also contributes to building up a fluid film that covers food to facilitate bolus formation, swallowing and clearance (Spirk et al., 2019). Loss or impairment of salivary function is associated with orodental diseases, speech impairment and dysphagia (Chaudhury et al., 2015).

Both interface and bulk rheological properties of saliva are responsible for most of the above-mentioned properties and are due to the presence of large, heavily glycosylated mucins. According to a recent review (Sarkar, Xu, & Lee, 2019), up to now the complex protein structure of saliva, which has specific characteristics, has made it very difficult to reproduce these properties of human saliva in full. The particular chemistry of these proteins is associated with spinnability, which is one of saliva's main rheological features. Saliva shares this property with other biological fluids such as mucus (Wagner, Wheeler, & Ribbeck, 2018). It is precisely these complex biophysical properties which make it so difficult to obtain artificial fluids that mimic human saliva. Impairment or loss of its extensibility property would hinder the adhesion of saliva to surfaces within the mouth, leading to oral dryness or xerostomia (Vijay, Inui, Dodds, Proctor, & Carpenter, 2015). Saliva unfailingly intervenes in any oral food processing and actively participates in food perception. A recent review of the different mechanisms of food-saliva interactions in oral processing (Mosca & Chen, 2017) classified and analysed them as 1) surface coating and clustering, 2) colloidal interactions, 3) complexation, 4) enzymatic interactions, and 5) participation in chemosensory perception. The first interaction, *coating and clustering*, refers to covering, moistening and gathering together the solid food particles that will form a bolus. This function of saliva is of primary importance for solid foods but much less so for the oral processing of liquid and semisolid foods, which normally have a high water content, although saliva could modify or at least have an effect on the rheological behaviour of these kinds of food whilst they are in the mouth. On the other hand, as for any kind of food, it is worth taking the lubrication/ friction features of the food-saliva system into account in the transportation step of oral processing, which, in turn, could be linked to their sensory perception (Wang, Wang, & Chen, 2021). The way a semisolid is tasted involves forces generated during compression and/or shearing and/or squeezing between tongue and palate (Nishinari, Ishihara, Hori, & Fang, 2020), making the lubrication/ friction aspects of oral processing particularly important.

90 *Colloidal interactions* of saliva with food mainly encompass a number of emulsion
91 destabilization mechanisms, such as flocculation, coalescence, etc. These phenomena all
92 lead to loss of the initial physical structure of the semisolid food, which greatly affects its
93 sensory perception (Fuhremann, Kalisvaart, Sala, Scholten, & Stieger, 2019). These authors
94 found that physical measurements of an emulsion made in the presence of saliva correlate
95 better with sensory data than when saliva is absent. Emulsions are very varied, complex
96 systems that use different types of emulsifiers (protein-or starch-based) to prevent
97 instability, creating, in turn, different kinds of interactions with saliva and subsequent in-
98 mouth behaviours (Karthik, Ettelaie, & Chen, 2019).

99 The third interaction, *complexation*, principally refers to the binding of some specific
100 salivary proteins to polyphenols such as those present in wine or green tea. Acidic and
101 basic proline-rich proteins (25-42% proline residues) and P-B peptide seem to be the most
102 active toward tannins depending on the protein size, structure and charge (Guerreiro et
103 al., 2020). This interaction leads to astringent sensations. In-mouth astringency is related
104 to sensations of roughness and dryness that are typically perceived when consuming
105 unripe fruits. It has been extensively studied because it is an important, naturally
106 occurring sensory feature of a number of food items, such as red wine, green and black
107 tea and red fruits, among others. Some cationic compounds, such as high isoelectric point
108 proteins and multivalent metal salts, are also astringent. Zimmermann et al. (2019) stated
109 that past studies of the mechanism leading to an astringent oral sensation had focused on
110 interactions between astringent agents and proteins present during the bulk saliva phase
111 and had not established a clear correlation between protein precipitation and astringency
112 perception. Instead, these authors suggested that perceived astringency is the effect of
113 molecular interactions between food components at the pellicle level (loss of dental
114 lubrication) which alter its thickness, roughness and charge; these changes would depend
115 on the kind of astringent (polyphenols, or cationic substances) and would be governed by
116 hydrogen bonding, hydrophobicity and entropic effects.

117 *Enzymatic interactions* are due to the presence of enzymes in saliva, mainly corresponding
118 to alpha-amylase. This enzyme initiates the hydrolysis of starch (digestion) in the mouth. A

number of semisolid foods contain naturally occurring starch (such as vegetable purees) or contain starch added as a thickener. The extent of such a digestive phase is the subject of much research, especially, of course, on rich-starch foods such as bread or rice. However, the full physiological connotations of amylase in saliva continue to intrigue investigators (Butterworth, Warren, & Ellis, 2011). The contact time of salivary amylase and food starch is generally short and the acidic pH of gastric fluid mostly stops the amylolytic activity after swallowing; the greater part of the starch in the body is digested by pancreatic amylase, which is secreted into the duodenal tract (Peyrot des Gachons & Breslin, 2016). Nevertheless, it has been demonstrated that some starch hydrolysis activity could take place in the mouth in a few seconds, especially in individuals with higher salivary amylase levels and activity, who show a faster and more significant decrease in perception of the oral viscosity of starch (Mandel, Peyrot des Gachons, Plank, Alarcon, & Breslin, 2010). Recent studies have shown that subjects with high levels of salivary amylase could be related to lower preferences for refined carbohydrates (Tarragon, Stein, & Meyer, 2018) and the ability to taste glucose oligomers (average degree of polymerization 7-14) without any other sensory cues (Lapis, Penner, & Lim, 2016), with a potential effect on their ulterior eating behaviour.

Chemosensory perception is the fifth and last of the above-mentioned interactions between food and saliva. Saliva has a basic role of dissolving and delivering tastants to the taste receptors on the taste buds (Lamy, Rodrigues, Louro, & Capela e Silva, 2017) and a number of studies have shown that taste perception of certain compounds is related more to tastant concentration in saliva than to that in the corresponding food system (Canon & Neyraud, 2017). In addition, some components of saliva develop molecular interactions that in turn can be modulated by flavour stimuli (Muñoz-Gonzalez, Feron, & Canon, 2018). In direct or indirect ways, these five kinds of interactions (alone or combined) are part of the process of texture perception in liquid and semisolid foods, making the role of saliva pivotal. A further complexity is that saliva does not show a unique composition (Pedersen, Sorensen, Proctor, & Carpenter, 2018) and variation in both its composition and flow rate is an important factor in relation to all the types of interactions and functions described

above. Some of the main factors responsible for inter- and intra-individual differences are the degree of hydration of the body and nutritional and health status, among others. The differences affect not only the saliva's composition and flow rate but also its buffering capacity, which in turn modulates flavour perception.

1.2 Instrumental characterization of the viscosity of liquid and semisolid foods and its correlation with thickness: the beginnings

Over the last 50 years, research on in-mouth perception of thickened fluids has covered a large number of facets. While oral processing of solid foods involves a complex dynamics of food breakdown and bolus formation and handling from the first bite until swallowing, liquid and semisolid foods like yogurt, soup, custard, dressings, etc. undergo more subtle, less severe in-mouth actions. Ingestion of liquid foods only needs transportation from the front to the back of the mouth (Chen, 2009), but more viscous to semisolid foods need some palatal reduction before the bolus is transported to the back of the mouth (Derks, De Wijk, De Graaf, & Stieger, 2016), with the participation of tongue movements. These impose a kind of shear regime on these foods in the mouth. Consequently, it is not surprising that instrumental measurements of viscosity in these kinds of food were first correlated with sensory attributes such as oral viscosity and thickness.

The first attempt to take "oral conditions" into account in instrumental measurements was by paying attention to the ranges of shear stress and shear rate to which liquid and viscous food are submitted in the mouth. Several pioneering studies by Prof. Sherman's research team studied instrumental test situations that were close to the mechanical conditions for fluid food during oral processing. These authors correlated such situations with the oral viscosity perceived by a sensory panel for syrup, treacle, condensed milk, tomato juice, salad cream, lemon curd, tomato ketchup, and yogurt (Shama & Sherman, 1973). They concluded that the viscosity evaluated in the mouth involved a wide range of shear rates (10 to 1000 s^{-1}) depending on the flow characteristics of the food. A "spreading coefficient" was also mentioned as an additional factor to be considered, since not all foods spread over the tongue and hard palate spontaneously. Some years later Cutler,

Morris, and Taylor (1983) found good correlation between perceived viscosity and instrumental values measured at 10 s^{-1} in a wide range of viscous foods, but not for samples showing pronounced shear thinning with very high apparent viscosity at low rates of shear. In more recent years, a number of studies have evaluated the oral viscosity and thickness of many thickeners (alone or combined), especially in relation to the development of easy-to-swallow food for the elderly and for dysphagia (Yamagata, Izumi, Egashira, Miyamoto, & Kayashita, 2012; Ong, Steele, & Duizer, 2018), but the experimental conditions for instrumental measurement still pose questions.

The parallel development and application of small amplitude dynamic techniques and models has made it possible to study and characterize the viscoelastic behaviour of a number of polymer solutions and semisolid foods (Elliott & Ganz, 1977; Ferry, 1980). In 1993, Stanley and Taylor stated that some viscoelastic parameters of semisolid foods would be correlated to the oral perception of viscosity, thickness, stickiness and sliminess; however, according to these authors “there is still much speculation as to what forces actually operate in the mouth.”

The above papers date from the late 1970s and 1980s and are cited just as examples. Ever since then, rheological techniques have been widely used to characterize the behaviour of thickened fluids in relation to their sensory perception. In addition, the evolution of rheology and its instrumentation has never ceased to gather pace.

1.3 Instrumental characterization of oral sensations other than thickness

The sensory perception of thickened food is normally described by a number of other key attributes such as creaminess, smoothness, mouthfeel, or roughness, among others. Stimuli associated with their perception are not easy to identify; one of the main reasons is that they do not appear individually and give rise to an isolated sensation. The aforementioned attributes are textural characteristics that develop complex perceptual interplays and have created a huge body of research. According to Szczesniak (2002), texture perception does not allow atomistic or elemental analysis of the stimulus and obliges interconnectedness. In addition, the occurrence of one stimulus may influence

evaluation of the perception of another. The action of saliva during liquid and semisolid food consumption will be as much a result of covering the food material as of mixing with it. Consequently, unique rheological and lubricant properties of saliva will have an impact (not measurable instrumentally) on the perception of sensations such as creaminess and mouthfeel.

In the last two decades, sensory science has experienced an enormous expansion encompassing more and more consumer-based profiling techniques (Varela & Ares, 2014). A number of emergent sensory techniques that make sensory characterization of food easier and more reliable have now become established (Ares & Varela, 2018). Especially interesting is the Temporal Dominance of Sensations technique, which accounts for the evolution of the food's sensory features over the consumption and oral processing time (see Fiszman & Tarrega, 2018 for a review).

At this point, it is obvious that instrumental techniques other than rheology should play a part in the development of a framework for the study of perceptions of thickened food. Measurement of some composition- and structure-related factors of the food, such as the amount of fat, fat droplet size and distribution, stability factors, microstructural features of the food systems, particle size and distribution and fibre type and content, just to give a few examples, complements the rheology results and aids interpretation of their relationships with sensory perception.

With the emergence, development and availability of multivariate data analysis and models that examine patterns in complex sets of data, crossing results from rheology, composition, structure and sensory perception opens up a wide range of possibilities for food behaviour analysis with increasingly user-friendly statistical programs (Lê & Worch, 2014).

Creaminess

Food creaminess has been extensively studied, probably because of its important role in the acceptability of a number of food items such as dressings, ice cream, yogurt, mayonnaise and sauces, among others. In a recent study (Kim & Vickers, 2020), *creamy*

was scored as one of the most liked attributes from a list of 106 terms describing food texture. The proposed mechanisms of perception of this multimodal (visual, olfactory, gustatory, and tactile) sensory attribute have been reviewed recently (Upadhyay, Aktar, & Chen, 2020). A (not exhaustive) list of descriptors that consumers relate to creaminess includes thick, smooth, mouth-coating, melting, soft, sticky, fatty, oily, unctuous, greasy, not dry, not rough, not powdery, soft, velvety, and fatty after-feel. Although it is widely known that some odour and taste cues modulate the perception of creaminess, texture sensations might be more important for consumers. According to a study using the Word Association technique, the consumers mentioned texture attributes more than twice as frequently as flavour attributes (Antmann, Ares, Salvador, Varela, & Fiszman, 2011). The amount and diversity of sensory terms involved in consumer descriptions of creaminess warrant some reflection, in that each food category possesses salient creaminess-related sensory characteristics that are not the same as for other food categories. For example, the creamy sensation expected of chocolate melted in the mouth is probably not the same as that of ice cream melted in the mouth. Evidently, the compositions of the two boluses are not the same, neither is the modulation that flavour-related factors can exert. This could indicate that each food category has its own sensory universe and studies seeking instrumental/ sensory correlations might be confined to single categories. Creamy textures can be achieved in the total absence of dairy cream or fat as long as the expected sensations are present in the given food.

Mouthfeel

Mouthfeel, like creaminess, is a sensory attribute that lacks a widely accepted definition, but consumers know what it is and how to evaluate it in different beverages and in food. Some sensory descriptors associated with mouthfeel are richness, fullness, oiliness, silkiness, density, unctuousity, and body. Interestingly, both creaminess and mouthfeel require similar oral handling of the food product: no mastication but oral rubbing movements between the tongue and palate and a certain time of retention in the oral cavity. In red wine, for example, mouthfeel or “body” is a very important sensory attribute

(Laguna, Bartolome, & Moreno-Arribas, 2017; Laguna, Sarkar, et al., 2017) that forms part of its identity. Mouthfeel is an important sensory parameter that has been investigated in relation to food-saliva interaction for many foods. Some examples are carbonated water (Vladescu et al., 2020), beer (Langenaeken, De Schutter, & Courtin, 2020), red wine (Laguna, Alvarez, Simone, Moreno-Arribas, & Bartolome, 2019), and chocolate (Hamada, Terianne, Brown, Hopfer, & Ziegler, 2020).

1.4. New approaches to instrumental characterization at oral interfaces

In more recent years, a resurgence of observing “oral conditions” in the instrumental assessment of food properties has been detected. In the late 1990s, tribology appeared as a new, complementary technique for studying liquid and semisolid food perception-related properties. Giasson, Israelachvili, and Yoshizawa (1997) reported a notable absence of tribology studies in food at the end of the 20th century; these authors highlighted the importance of the interfacial properties of food materials confined between two surfaces in motion relative to each other. In these conditions, very thin films (at microscopic or even molecular level) are formed and adhesion, friction and lubrication at the interface can be studied. Since then, systems that attempt to represent the tongue/palate contact have been investigated under different conditions (Ranc, Elkhyat, et al., 2006) and tribology studies of food materials (Dresselhuis, de Hoog, Stuart, & van Aken, 2008), especially emulsions, have gained considerable momentum. According to the latter authors it is impossible to disregard the role of salivary mucin glycoproteins in adhesion and friction between surfaces. The hydrocolloids normally added as thickeners in semisolid foods have been shown to have different lubrication properties depending on their structure (Garrec & Norton, 2012).

A large part of the current liquid and semisolid food research relating instrumental parameters to oral perception uses a combination of rheological and tribology techniques, and most incorporate saliva effects in order to acquire the whole picture. The present paper reviews the role of saliva in the instrumental characterization of liquid and

semisolid food, where the recent incorporation of this element has improved the correlation with sensory perception.

2. Considerations for using saliva in instrumental measurements

In instrumental studies with saliva, researchers need to take decisions regarding the type and amount of saliva. Both human and artificial saliva can be used in instrumental measurements. A number of studies have reported on the effect on saliva composition of circadian rhythm, several forms of stimulation, the duration of sampling, and eating and smoking (Savinov & Anisimov, 2020). Human saliva can be collected under stimulated or unstimulated conditions, which can lead to differences in saliva lubrication properties (Chen & Engelen, 2012; Francis, Hector, & Proctor, 2000). Stimulated saliva (mainly from the parotid gland) is normally obtained from a donor who chews a non-soluble chewable material (oral paraffin, taste-free base gum, Parafilm®, etc.) for a period of time that normally varies from 5 to 15 min; during mastication of this material, saliva is produced and collected by expectoration. To obtain unstimulated saliva (mainly from the sublingual and submandibular glands), nothing is placed inside the oral cavity and saliva drips naturally by drooling from the mouth. After collection, saliva samples are normally centrifuged to remove suspended particles (oral debris); only a few studies have used untreated whole saliva in instrumental experiments. Saliva samples are normally used within 1-3 h of being collected or are stored at -80 °C until needed and warmed to 25 °C before the experiment. Most instrumental studies use stimulated saliva, probably because these conditions produce a larger amount of saliva. Unstimulated and stimulated saliva have been shown to differ in their concentration of proteins and mucin and their buffering capacity, and some differences have also been found for α -amylase amount and activity (Yang et al., 2015). For these reasons, a single saliva donor does not represent the average of the naturally-occurring differences between healthy individuals and over the day, and neither does pooled saliva from a small number of subjects (Muñoz-González, Brulé, Feron, & Canon, 2019); this point could raise experimental concerns and lead to limitations. In addition, the properties (lubrication, flow behaviour, rheology) and

composition (protein, enzyme content) of the human saliva used are usually not reported in the literature, making it more difficult to compare results among studies.

Saliva composition in a given subject also varies depending on the gland of origin. Saliva is mainly secreted by the bilateral major salivary glands (parotid, submandibular and sublingual) and comprises whole saliva (stimulated and unstimulated) and residual mucosal saliva retained on oral surfaces (Proctor, 2016). The different main salivary glands produce saliva with different mucin contents; however, a basal level of saliva with mucins is produced at all times (Chaudhury, Proctor, Karlsson, Carpenter, & Flowers, 2016).

Artificial, model or simulated saliva refers to a fluid that mimics the ion content of saliva (sodium, potassium, calcium, chloride, magnesium, bicarbonate, and phosphate are electrolytes commonly present), with the addition of amylase (porcine, for instance) and mucins (normally porcine or bovine). Although the rheological properties of artificial saliva are normally far from those of human saliva, it is stable, reproducible, and comparable among studies. Artificial saliva has also been used where strict control and adjustment of the amylase activity level is necessary for oral digestion studies (Chung, Degner, & McClements, 2012). A few studies have used lyophilized human saliva (Turcanu et al., 2018). Several recipes for artificial or simulated saliva have been published for medical and dental research, but fewer in the food science context. A harmonized INFOGEST protocol for performing *in-vitro* static digestion studies recommended the electrolyte concentration to be used in a simulated salivary fluid (oral phase of digestion) that optionally incorporates human alpha amylase for starchy foods (Minekus et al, 2014); this protocol has recently been revised (Brodkorb et al., 2019). However, the latter recipe does not incorporate mucins, probably because they are not important for the digestive process strictly speaking, although they are very important for studying food texture perception-related features.

The bulk and interfacial performance of human and model saliva have been reviewed recently (Sarkar, Xu, & Lee, 2019), including the changes that pooled human saliva undergoes after frozen storage; one of these changes is the precipitation of Ca²⁺-induced

salivary protein aggregates which in turn would change some colloidal and mechanical properties of thawed saliva.

3. Use of saliva in rheological measurements of semisolid food

3.1 Experimental conditions

Both human and artificial saliva have been used to measure rheological properties of semi-solid foods under oral conditions. In most studies, human saliva is collected from volunteer donors (only one or pooled from several) either at rest (such as in Yuan, Ritzoulis, and Chen, 2018) or under stimulation (such as in Herranz, Criado, Pozo-Bayon, and Alvarez, 2021). Saliva from different volunteers has been used separately to study the impact of inter-individual differences in saliva on the rheological behaviour of food products (Drago et al., 2011).

The amount of saliva added and mixed with the product when measuring its rheological behaviour also varies among studies. The product:saliva ratios have ranged from 1:1 in emulsions and polysaccharide solutions (Fuhrmann, et al., 2019; Yuan et al., 2018) to 100:0.5 in a study on thickened beverages (Hanson, Cox, Kaliviotis, & Smith, 2012). However, intermediate ratios are more usual in experimental rheology. Ratios of 10:1 and 12:1 have been used in studies on dairy systems (Drago et al, 2011; Prinz, Janssen,& de Wijk, 2007; Laguna et al., 2021), thickened beverages (Turcanu et al., 2018) and vegetable purees (Laguna, Manickam, Arancibia, & Tarrega, 2020). Higher proportions of saliva, such as 5:1 and 4:1, have been used in studies with hydrocolloid suspensions (Chung et al., 2012; Choi, Mitchell, Gaddipati, Hill, & Wolf, 2014), carrot puree (Sharma, Pico, Martinez, & Duizer, 2020) and yoghurts (Morell, Fiszman, Varela, & Hernando, 2015). Unfortunately, the food:saliva ratios in most of these studies are far from realistic and no mention is made of how they were selected.; a few mention experimental conditions taken from previous literature, but without clear criteria. The above-mentioned rheological studies on liquid and semisolid food using saliva have certainly aided in proving some effects of saliva, but due to this lack of reality the magnitude of such an effect could be

misestimated. In general, the factors that determine the amount of saliva incorporated into boli are sip/bite volume (or weight) ingested and in-mouth residence time, in addition, of course, to food characteristics; so it would seem quite feasible to calculate ratios nearer to actual oral conditions by performing some preliminary tests. A number of studies have determined the saliva content of boli, but most have used solid foods (model dairy products, Drago et al., 2011; cooked meat, Pematilleke, Kaur, Adhikari, & Torley, 2020; sausages, de Lavergne, Derks, Ketel, de Wijk, & Stieger, 2015; bread, Jourden et al., 2016). Investigations of saliva incorporation into liquid and semisolid food boli are scarcer.

3.2 Approaches to studying the impact of saliva on rheological properties in relation to sensory perception

Different types of rheological studies, such as shear (flow behaviour and viscoelasticity), compression or extensional rheometry, include saliva to emulate oral conditions and oral handling in relation to food perception. Different approaches and procedures are followed depending on the aim of the studies.

Monitoring the changes in the rheological properties of a food product over time after adding and mixing in saliva is one of the most frequent approaches in studies that relate rheology to sensory perception.

Prinz et al. (2007) developed an apparatus for *in vitro* simulation of saliva oral mixing; these authors measured changes in the viscosity (torque) of semisolid products for 30 s. Similarly, Janssen, Terpstra, de Wijk, and Prinz (2007) used a rheometer coupled to a “structure breakdown cell” that consisted of a helical rotating vane that mixed the added saliva with the sample (custards) while registering torque (at 200 rpm) for 60 s. Later, Chung et al. (2012) also proposed a new cell to measure rheological changes in semisolids under simulated “mastication” conditions using a combination of compression and shear forces in the presence of saliva. More recently, “starch pasting cells” from rapid viscoanalysers and rheometers have been used in a similar fashion to monitor changes in the apparent viscosity of purees, custard and rice flour pastes, among others, after saliva

addition. The samples are sheared at constant rate (10 s^{-1}) and the evolution of the viscosity is registered over a period of time (normally from 60 to 120 s (Kim, Oh, Kim, & Lee, 2019); Laguna, et al., 2020; Laguna et al., 2021). These latter studies obtained the curves representing the decrease in viscosity or torque values over time. This decay is attributed to the structural breakdown caused by shearing and the enzymatic attack (starch hydrolysis), but also to a dilution effect due to saliva addition. For this reason, the curves with saliva were compared with curves obtained after adding water. As an example, Figure 1 shows the comparison between viscosity-time curves for two different starch-based dairy systems when mixed with water or with saliva. Working with commercial custards (Janssen et al., 2007), the viscosity-time curves after addition of saliva, after addition of water, and without any addition were obtained. The rate of breakdown (slope between 0.1 and 5 s) and the total breakdown (torque difference between the start and end points) values varied between custard samples, indicating different breakdown patterns. In addition, the enzymatic breakdown effect was separated from the effects attributed to dilution and mechanical breakdown by subtracting the data obtained in the different experimental scenarios. All these parameters, together with the initial rheological properties of custards (flow and viscoelasticity), were used to analyse the relationships with the texture profile of custards evaluated by a trained panel using the Quantitative Descriptive Analysis technique. Partial Least Squares regression and Pearson correlation coefficients were used to determine the impact of the initial rheological parameters and mechanical and saliva-induced breakdown for each specific texture attribute. The results showed that some texture sensations such as creaminess would be understood better through combining structural breakdown and conventional rheological parameters. Thickness and melting sensations were mainly related to mechanical and enzyme-induced breakdown, whereas fattiness, roughness, and stickiness were mainly related to enzyme-induced breakdown parameters.

A second-order structural kinetic equation has been used to model the curves of viscosity decay over time of vegetable purees thickened with different hydrocolloids (Laguna et al., 2020). This study observed large differences in structure breakdown patterns between

purees, associated with the type of thickener employed (starch, carboxymethylcellulose, xanthan, and carrageenan). These patterns were quantified using three parameters: initial viscosity when just saliva is added, the rate of breakdown, and the viscosity at equilibrium (related to the structure remaining after the “oral digestion”). Multi Factorial Analysis was used to establish relationships between puree mouthfeel sensations (evaluated by untrained assessors using Flash Profiling) and oral breakdown parameters. The results showed that initial viscosity was related to the thickness sensation dimension while the viscosity at equilibrium was related to the smoothness+roughness dimension. Purees with low viscosity at equilibrium were described as “rough, lumpy, and fibrous” and purees with high viscosity at equilibrium as “smooth and creamy”. The same approach was used to study the sensation of grittiness elicited by two types of resistant starch (different particle size) added to custards thickened with several hydrocolloids (Laguna et. al., 2021); relations were established taking into account the custard matrix characteristics and its “oral” breakdown. Differences in viscosity at equilibrium explained the differences in grittiness perception between samples: systems containing xanthan (with higher viscosity at equilibrium) were perceived as less gritty, confirming the role in in-mouth perception of the structure remaining after oral processing.

Another approach is to study and compare the rheological properties of food products before and after addition of saliva followed by a rest period (to allow enzymatic action); the incubation time varies among studies (ranging from 5 to 60 min or undefined). This approach has been applied to study different rheological behaviours: flow behaviour, viscoelasticity, compression, and extensional rheometry. Comparison of the flow behaviour of milkshakes before and after exposure to saliva showed a decrease in the viscosity and pseudoplasticity of milkshakes after incubation with saliva; these decreases were much higher for starch-based milkshakes than for those containing carrageenan or guar gum (Morell et al., 2014). The decrease in viscosity was related to creaminess perception, as starch-based milkshakes with higher oral breakdown were described as “fondant”, “melting” or “disappearing”.

The flow behaviour and viscoelastic properties of emulsions stabilized by different combinations of emulsifiers (gelatine/whey protein and gelatine/diacetyl tartaric acid of mono and diglycerides), with and without the addition of saliva, have been compared by Fuhrmann et al. (2019). They obtained consistency index values by fitting flow curves to the Ostwald de Waele model and critical strain values from viscoelastic measurements. The impact of saliva was very different depending on the size and charge of the oil droplets in the emulsions studied. They further analysed correlations between rheological parameters and sensory attributes evaluated by the Rate-All-That-Apply (RATA) method. Thickness and creaminess perceptions of emulsions correlated better with rheological properties measured without added saliva than with those obtained with the addition of saliva, confirming that thickness is related to the perception of initial properties of semisolid foods, not to its oral breakdown.

The flow behaviour and viscoelastic parameters of pureed carrots have also been determined after saliva (or water) addition to relate them to the dynamics of the perceived thickness of purees during oral processing, evaluated by Progressive Profiling (Sharma et al., 2020). According to these authors, oral thickness decreased continuously over the time of consumption at a rate that did not depend much on the amount of starch in the puree but was related more to a dilution effect (progressive incorporation of saliva) than to salivary starch hydrolysis.

The impact of saliva in elongational rheology has mainly been studied in thickened beverages used for dysphagia, as a way to predict their oral performance. Extensional rheometers register changes in the diameter of the filament formed when a given sample is subjected to uniaxial elongation over time, as a measure of its elastic behaviour. A study of the effect of saliva on the elongational properties of xanthan gum and carboxymethyl cellulose solutions (Choi et al., 2014) found that mixing with saliva increased the filament break-up times for both hydrocolloid solutions, although the effect was greater for xanthan gum. Turcanu et al. (2018) proposed monitoring the axial forces in extensional tests to characterise the elongational properties of highly thickened beverages (NDD level

pudding); addition of saliva showed a large decrease in the axial elongational forces of starch-based dysphagia thickeners but not of those containing gums.

Changes in the flow behaviour of thickened beverages before and after contact with saliva for increasing times (sampling every 6 min over a period of 60 min) have also been measured (Hanson et al., 2012), revealing the sizeable impact of saliva action depending on the pH of the beverage. With pH values higher than 5.5, viscosity rapidly fell to less than 1% of the initial value, with pH values in the range of 4 to 5 the thinning effect was slowed and with $\text{pH} < 4$, viscosity was not reduced after saliva addition.

Penetration experiments have also been performed to measure the resistance to displacement of a probe (TA-XT2 Texture Analyser) in three beverages thickened with five different thickeners (Vallons, Helmens, & Oudhuis, 2015). The change in compression force after saliva or water addition varied considerably among samples, depending on the initial beverage (water, coffee or milk) and the thickener type (starch-or gum-based).

To measure the difference in “real” oral breakdown, Vallons, Oudhuis, Helmens, and Kistemaker (2015) measured the viscosity of water samples thickened with several commercial dysphagia products. The samples were measured after being spat out. Trained subjects were instructed to move their tongues at a given speed by rolling them from under the teeth to the palate and back. After 10/20 s the bolus was spat into a cup containing acid to inactivate the salivary amylase and stored.

4. Use of saliva in tribology measurements of liquid and semisolid food

The word tribology comes from the Greek word “tribos”, which means rubbing; tribology is the science that studies the interaction of two solid surfaces in relative motion (Persson, 2014). Tribology is considered an ancient science, especially in engineering. However, the use of tribology in food science is still quite new: the first work on food tribology dates from the 1990s. Since then, the number of published works regarding food and tribology has increased greatly (Figure 2) because tribology is particularly relevant when trying to

relate instrumental measurements of food/oral surface interaction at an interface level (Figure 3) to in-mouth perceived sensations.

4.1 Experimental conditions

Unlike rheology, food tribology is still under development. Consequently, it would be of interest to review the equipment (including soft contact surfaces), experimental setting and approaches to measuring the friction/lubrication properties of liquid and semisolid foods, together with the use of saliva in these kinds of instrumental arrangements (Table 1).

4.1.1 Tribology equipment

The equipment used is fundamental in tribology experiments since the measurement results are equipment-dependent. The friction coefficient is not a physical property of a given material but a system property at interfacial level. The Surface Force Apparatus used in the initial published works in food tribology enabled monitoring of the distancing of two interacting surfaces and of the friction force whilst sliding under a load (Giasson et al., 1997). To calculate friction coefficients, the results were plotted as kinetic friction force versus applied load (see equation 1).

$$\mu = F_k/L \quad (\text{eq. 1})$$

where μ is the friction coefficient, F_k is the friction force and L is the applied load.

This method allowed these authors to differentiate the friction caused in mayonnaise samples with different fat contents. Samples of chocolate with different fat and sugar contents could also be differentiated by their friction coefficient using the same approach (Luengo, Tsuchiya, Heuberger, & Israelachvili, 1997). For the first time, factors influencing the physical sensation that food would induce at the food-mouth interface during consumption were measured.

Some years later, Prinz and Lucas (2000) were the first to measure tannins-saliva interaction with a Boothroyd friction tester, based on the hypothesis that astringency

would be a tactile sensation related to an increase in the friction coefficient of the oral mucosa due to lower salivary lubrication. This equipment was attached by a rubber band to a universal testing machine (Lloyd LRX, Fareham, UK) normally used to test fracture strength. The friction coefficient was calculated from forces generated by switching the motor clockwise and then anti-clockwise, following equation 2.

$$\mu = \pi \log(F_1/F_2) \quad (\text{eq. 2})$$

where μ is the coefficient of friction and F_1 and F_2 are the load with the motor rotating clockwise and anti-clockwise, respectively.

These were pioneering works in food tribology. A similar device to the Boothroyd friction tester that was later developed (de Wijk & Prinz, 2005) related the effect of fat on the texture properties of vanilla custard desserts to lubricant properties and subsequently to friction.

Today, it is possible to perform well-controlled studies in more realistic frameworks. The most important advances have been to mimic oral conditions not only by adding saliva but also by using tribo-pairs with surface properties nearer to those of the oral cavity surfaces and controlled temperature (Rudge, Scholten, & Dijksman, 2019).

Two main types of equipment, the Mini Traction Machine (MTM Tribometer, PCS Instruments) and tribology fixtures attached to a rheometer, are currently used in food tribology research. The MTM measures the friction between different surfaces, with or without a lubricant, for a wide range of load force, rolling and sliding conditions at controlled temperatures. This machine has a cell with a rotating plate and a rotating ball where the food sample (Newtonian or non-Newtonian) is placed. The temperature is easily controlled during the whole experiment as the cell is hermetically closed, which also avoids potential drying out of the sample.

Rheometers are also quite often used in tribology research and some specific fixtures (rotating ball on three fixed plates, ring on plate, double-ball-on-plate, plate on three balls, etc.) have been designed for attachment to the main machine. It is worth noting that

572 rheometers only work in sliding mode (not rolling/sliding), so the results obtained cannot
573 be compared with those of the MTM (Shewan, Pradal, & Stokes, 2020).

574 Another proposed type of equipment is a texture analyser (TA-XT2, SMS, UK), placed
575 horizontally (Chen, Liu, & Prakash, 2014) (i.e. lying in one side), working with a tribometer
576 platform built to measure lubrication properties. This equipment has been used in a
577 number of studies by the same research team but is not in widespread use. The
578 temperature is controlled by a water bath or Peltier plate, but sample drying cannot be
579 controlled.

581 *4.1.2 Contact surfaces*

582 Tribology, as a matter of friction between surfaces, shows results that depend on the
583 materials where the friction takes place. In food studies, mimicking the surfaces of the
584 oral cavity requires soft contact materials. Pig tongue tissue was one of the first
585 approaches (Dresselhuis, et al., 2008; Ranc, Elkhyat, et al., 2006), but it was found that pig
586 tongues show individual differences, the dead tissue degrades fast and availability is not
587 unlimited; in addition, it was found that the roughness of a pig tongue is different from
588 that of a human. Non-biological, soft, reproducible materials such as silicone (Ranc,
589 Servais, Chauvy, Debaud, & Mischler, 2006), tetrafluorethylene and zirconia (Lee,
590 Heuberger, Rousset, & Spencer, 2004) have been investigated. Several of these materials
591 have been moulded to obtain different, well defined topographical patterns. Nowadays,
592 surgical tape (stuck to probes for rheometers) and polydimethyl siloxane (PDMS) (for
593 MTM) are extensively used to provide an adequate representation of the roughness of
594 oral surfaces. Surgical tape was first proposed by Nguyen, Nguyen, Bhandari, and Prakash
595 (2016) for use in a ring-on-plate probe attached to a rheometer; this tape (3M Transpore
596 Surgical Tape 1527-2) is hydrophobic, very easy to replace between experiments, and
597 normally presents no visible wear or material adhesion, so after cleaning it can be re-used
598 for several more samples. PDMS is the most common material for the ball and plate used
599 in the MTM; it is also hydrophobic, can adsorb saliva and is believed to bear a close
600 resemblance to human oral surfaces because of its elastomeric nature (Bongaerts,

Fourtouni, & Stokes, 2007). Recently, a 3D printed PDMS surface that imitates several features of the human tongue surface has been reported (Andablo-Reyes et al., 2020); the advantages of this material are that it not only mimics the wettability, roughness, and deformation of oral surfaces but also incorporates the topography of the tongue (papilla density). Although more results with this new material for food tribology applications are still to be seen, it seems highly promising.

4.1.3 Addition of saliva

Despite the key role of saliva in oral processing, so far the number of tribology studies that have incorporated saliva (human or artificial) into their measurements has been limited (Figure 2). Saliva in tribology studies is normally added at a ratio of 1:1 food:saliva (Table 1) although other proportions (ranging from 4:1 to 10:1) have been used. In fact, as tribology studies seek to mimic oral conditions, depending on some food properties such as consistency and viscosity, and on the individual's physiology, the food:saliva proportion in the bolus might change. To the best of the present authors' knowledge, no studies have compiled these differences. As commented above for rheology measurements, preliminary tests to determine the content of saliva incorporated into liquid and semisolid foodboli under normal eating conditions would contribute results to assist in choosing more realistic food:saliva ratios for tribology measurements. In some in-mouth lubrication studies, it is important to ensure that enough saliva is present to account for the phenomena taking place; for example, enough salivary proteins that will interact with food components such as wine tannins in astringency studies. Nonetheless, making the reasons for choosing a given food:saliva ratio clear in each study is to be encouraged. Also, researchers currently agree in mixing the food with the saliva before performing the experiment, and creating a dynamic system in which saliva is added progressively remains to be addressed.

4.2 Approaches for studying the impact of saliva on tribology properties in relation to sensory perception

Results generated in tribology experiments provide information about the lubricant properties of a given material. They are normally presented in Stribeck curves which represent the friction coefficient as a function of the entrainment speed, which is also considered as the shear stress intensity acting across the contact zone (Selway, Chan, & Stokes, 2017). The curves, initially defined for hard surfaces, show the frictional variation over the entire range of lubrication, including the hydrodynamic, mixed and boundary lubrication regimes which represent three different friction contexts. These authors warned that for soft contact tribology measurements, where lubrication regimes are less well-defined, caution should be taken in the interpretation of these terms. As oral surfaces under sliding conditions move from hard enamel to soft tissues and oral lubrication and lubricant (saliva) do not have a unique composition and can wet, stick or slip at the surface, the analysis and interpretation of the experiments are not straightforward (for a recent review see Sarkar, Andablo-Reyes, Bryant, Dowson, & Neville, 2019). It is important to bear in mind that Stribeck curves were defined for Newtonian lubricants, but most food products are not Newtonian; some examples of tribology of non-Newtonian fluids are yoghurts (Joyner, Pernell, & Daubert, 2014) and sauces (Ruan, Yang, Zeng, & Qi, 2019). Rudge et al. (2019) analysed several examples of deviations from standard Stribeck curves in food tribology, and even examined two extensions of Stribeck curves which include additional regimes and frictional zones. Before using tribology techniques, delving into their basic concepts is highly recommended, especially if they are to be applied to materials and experimental conditions (non-Newtonian fluids and soft materials) that are far from those on which they are founded.

Some tribology experiments using saliva that have related the results to sensory perception are summarized in Table 1, along with the sensory technique employed. Tribology has been used to understand creaminess perception in mayonnaise (de Wijk & Prinz, 2005), in dairy products (de Wijk, Prinz, & Janssen, 2006; Laguna, Farrell, Bryant, Morina, & Sarkar, 2017) and in hydrocolloid mixtures (Zhu, Bhandari, & Prakash, 2020), as well as other fat-related sensations in emulsions (Dresselhuis et al., 2007, Fuhrman et al. 2019) and milk gels Joyner et al., 2014). Tribology also seems to be useful for

understanding astringency sensations, which have been associated with a depletion of the lubricating oral salivary film (Wang, Olarte-Mantilla, Smith, Stokes, & Smyth, 2020). Several food matrices have been investigated from this angle, such as wines (Brossard, Cai, Osorio, Bordeu, & Chen, 2017; Laguna, Sarkar, et al., 2017; Wang et al., 2020), yoghurts (Morell, Chen & Fiszman, 2017) and tea (Chong et al., 2019). From a sensory point of view, it has been reported that behaviour in the boundary and mixed lubrication regimes provides cues to understanding the oral processing phenomenon related to perception (Dresselhuis et al., 2008). Prakash (2017) stated that in the hydrodynamic regime, food is able to fully separate the surfaces so sensory thickness is perceived in this regime and relates to the viscosity of the food, whereas in the boundary regime, lubrication depends on the ability of the food to form a static film on oral moving surfaces that come into asperity contact, related to sensory perception of astringency and slipperiness. A recent systematic review (Sarkar & Krop, 2019) stated that in the mixed regime, frictional behaviour could be associated to not only with fat-related sensations (smoothness) but also with non-fat ones like pastiness and stickiness. Several sensory techniques have been coupled with tribology measurements to relate semisolid food properties at an interface level to the perception of specific attributes (Table 1). Some of these techniques, such as TDS, evaluate the evolution of some perceived attributes in relation to time of consumption and afterfeelings.

5. Conclusion and future perspectives

The present review highlights the effort made by researchers to bring instrumental measurements of liquid and semisolid food perception closer to an “oral context”. For this, the use of saliva has been shown to play a key role. Rheology and tribology measurements made with the addition of saliva contribute to the understanding of the many-sided performance of saliva in texture perception. Food tribology in particular is still under development and its potential has yet to be calibrated. The present review reveals the undoubtedly great influence of saliva in instrumental results, where the findings aid the analysis and interpretation of how food is processed in the mouth. The multiplicity of

tasks that saliva can perform both at bulk and interfacial levels and the complexity in obtaining “ideal” saliva to be used in instrumental measurements make its use challenging. Amount/proportion, mixing with food protocol, temperature, pH and electrolyte environment, origin, storage conditions and composition, among others, are factors still under discussion. There is probably no golden solution for all these questions. The most honest and coherent way to perform experiments is to think of the aim and the food system to be analysed. It is essential to perform parallel sensory tests to relate instrumental results to perception. Recommended methods include those performed by consumers and techniques that account for the dynamic, temporal evolution of food in the oral cavity. The use of multivariate statistical techniques that integrate sets of data from several approaches could be useful. Food texture is a sensory property, as Alina Szczesniak shrewdly reminded us in 2002. Rational, engineering approaches are important but should not lose sight of the real, whole picture. The undoubtedly complex nature of oral functionality and saliva's role therein confront us with major challenges. The sense-making principle should govern experiment planning, starting with a well-founded and well-defined initial hypothesis and considering different (sometimes partial) ways of looking at the problems. Interconnecting data from different techniques will lead us to create a clearer roadmap.

Declaration of competing interests

The authors declare no competing financial interests.

Acknowledgments

The authors are grateful for research funding from the Spanish Ministry of Science and Innovation (PID2019-107723RB-C21) and the Generalitat Valenciana (Project Prometeo 2017/1 89). Author L. L. thanks the Ramon y Cajal program for her contract (RYC2019-027350-I). They also wish to thank Mary Georgina Hardinge for English language editing assistance.

717 Funding

718 This research did not receive any specific grant from funding agencies in the public,
719 commercial, or non-for-profit sectors.

720

721 Declarations of interest

722 None

723

724 References

725 Andablo-Reyes, E., Bryant, M., Neville, A., Hyde, P., Sarkar, R., Francis, M., & Sarkar, A.

726 (2020). 3D Biomimetic Tongue-Emulating Surfaces for Tribological Applications. ACS

727 Applied Materials & Interfaces, 12(44), 49371-49385.

728 <https://doi.org/10.1021/acsami.0c12925>.

729 Antmann, G., Ares., G., Salvador, A., Varela, P., & Fiszman, S. (2011). Exploring and

730 Explaining Creaminess Perception: Consumers' Underlying Concepts. Journal of Sensory

731 Studies, 26, 40-47. <https://doi.org/10.1111/j.1745-459X.2010.00319.x>.

732 Arancibia, C., Agudelo, A., Fiszman, S., & Tárrega, A. (2017). Hydrocolloids modulate the

733 structure breakdown of starch-based systems under oral conditions. Poster session

734 presentation at the INFOGEST 2017, Rennes, France.

735 Ares, G. & Varela, P. (2018). Methods in Consumer Research, Volume 2: Alternative

736 Approaches and Special Applications . Woodhead Publishing.

737 <https://doi.org/10.1016/C2015-0-06109-3>.

738 Boehm, M. W., Yakubov, G. E., Stokes, J. R.. & Baier, S. K. (2020). The role of saliva in oral

739 processing: Reconsidering the breakdown path paradigm. Journal of Texture Studies,

740 51, 67-77, <https://doi.org/10.1111/jtxs.12411>.

741 Bongaerts, J. H. H., Fourtouni, K., & Stokes, J. R. (2007). Soft-tribology: lubrication in a

742 compliant PDMS–PDMS contact. Tribology International, 40, 1531-1542.

743 <https://doi.org/10.1016/j.triboint.2007.01.007>.

744 Boyd, H., Gonzalez-Martinez, J. F., Welbourn, R. J. L., Gutfreund, P., Klechikov, A.,

745 Robertsson, C., Wickstrom, C., Arnebrant, T., Barker, R., & Sotres, J. (2020). A

746 comparison between the structures of reconstituted salivary pellicles and oral mucin
 747 (MUC5B) films. *Journal of Colloid and Interface Science*, 190, Article e110938.
 748 <https://doi.org/10.1016/j.jcis.2020.10.124>.
 749 Brodkorb, A., Egger, L., Alminger, M., Alvito, P., Assuncao, R., Ballance, S., et al. (2019).
 750 INFOGEST static in vitro simulation of gastrointestinal food digestion. *Nature Protocols*,
 751 14, 991-1014. <https://doi.org/10.1038/s41596-018-0119-1>.
 752 Brossard, N., Cai, H., Osorio, F., Bordeu, E., & Chen, J. (2016). 'Oral' Tribological Study on
 753 the Astringency Sensation of Red Wines. *Journal of Texture Studies*, 47, 392–402.
 754 <https://doi.org/10.1111/jtxs.12184>.
 755 Butterworth, P. J., Warren, F. J., & Ellis, P. R. (2011). Human alpha-amylase and starch
 756 digestion: An interesting marriage. *Starch-Starke*, 63, 395-405. [https://doi.org/](https://doi.org/10.1002/star.201000150)
 757 10.1002/star.201000150.
 758 Canon, F. & Neyraud, E. (2017). Interactions between saliva and flavour compounds. In: E.
 759 Guichard, C. Salles, M. Morzel, & A-M. Le Bon (Eds.), *Flavour: From Food to Perception*.
 760 John Wiley & Sons, Ltd. <https://doi.org/10.1002/9781118929384.ch12>.
 761 Chaudhury, N. M. A., Proctor, G. B., Karlsson, N. G., Carpenter, G. H., & Flowers, S. A.
 762 (2016). Reduced Mucin-7 (Muc7) Sialylation and Altered Saliva Rheology in Sjogren's
 763 Syndrome Associated Oral Dryness. *Molecular & Cellular Proteomics*, 15, 1048-1059.
 764 <https://doi.org/10.1074/mcp.M115.052993>.
 765 Chaudhury, N. M. A., Shirlaw, P., Pramanik, R., Carpenter, G. H., & Proctor, G. B. (2015).
 766 Changes in Saliva Rheological Properties and Mucin Glycosylation in Dry Mouth. *Journal*
 767 *of Dental Research*, 94, 1660-1667. <https://doi.org/10.1177/0022034515609070>.
 768 Chen, J. (2009). Food oral processing - A review. *Food Hydrocolloids*, 23, 1-25.
 769 <https://doi.org/10.1016/j.foodhyd.2007.11.013>.
 770 Chen, J. & Engelen, L. (2012). *Food Oral Processing: Fundamentals of Eating and Sensory*
 771 *Perception*. John Wiley & Sons.
 772 Chen, J., Liu, Z. & Prakash, S. (2014). Lubrication Studies of Fluid Food Using a Simple
 773 Experimental Set Up. *Food Hydrocolloids*, 42, 100–105.
 774 <https://doi.org/10.1016/j.foodhyd.2014.01.003>.

775 Choi, H., Mitchell, J. R., Gaddipati, S. R. , Hill, S. E. , & Wolf, B. (2014). Shear rheology and
 776 filament stretching behaviour of xanthan gum and carboxymethyl cellulose solution in
 777 presence of saliva. *Food Hydrocolloids*, 40, 71–75.
 778 <https://doi.org/10.1016/j.foodhyd.2014.01.029>.

779 Chong, P. H., Chen, J., Yin, D., Upadhyay, R., Mo, L., & Han, L. (2019). ‘Oral’ Tribology Study
 780 on Saliva-Tea Compound Mixtures: Correlation between Sweet Aftertaste (Huigan)
 781 Perception and Friction Coefficient. *Food Research International*, 125, Article e108642.
 782 <https://doi.org/10.1016/j.foodres.2019.108642>.

783 Chung, C., Degner, B., & McClements, D.J. (2012). Instrumental mastication assay for
 784 texture assessment of semi-solid foods: Combined cyclic squeezing flow and shear
 785 viscometry. *Food Research International*, 49, 161-169.
 786 <https://doi.org/10.1016/j.foodres.2012.08.024>.

787 Cutler, A. N., Morris, E. R., & Taylor, L. J. (1983). Oral perception of viscosity in fluid foods
 788 and model systems. *Journal of Texture Studies*, 14, 377-395.
 789 <https://doi.org/10.1111/j.1745-4603.1983.tb00357.x>.

790 de Lavergne, M. D., Derks, J. A. M., Ketel, E. C., de Wijk, R. A., & Stieger, M. (2015). Eating
 791 behaviour explains differences between individuals in dynamic texture perception of
 792 sausages. *Food Quality and Preference*, 41, 189-200.
 793 <https://doi.org/10.1016/j.foodqual.2014.12.006>.

794 de Wijk, R. & Prinz, J. F. (2005). The Role of Friction in Perceived Oral Texture. *Food*.
 795 *Quality and Preference*, 16, 121–129. <https://doi.org/10.1016/j.foodqual.2004.03.002>.

796 de Wijk, R A., Prinz, J. F., & Janssen, A. M. (2006). Explaining Perceived Oral Texture of
 797 Starch-Based Custard Desserts from Standard and Novel Instrumental Tests. *Food*
 798 *Hydrocolloids*, 20, 24–34. <https://doi.org/10.1016/j.foodhyd.2005.02.008>.

799 Derks, J. A. M., De Wijk, R. A., De Graaf, C., & Stieger, M. (2016). Influence of Stimulus
 800 Properties and Sensory Task Instructions on Oral Processing Behavior of Liquid Stimuli.
 801 *Journal of Texture Studies*, 47, 49-57. <https://doi.org/10.1111/jtxs.12159>.

802 Drago, S. R., Panouillé, M., Saint-Eve, A., Neyraud, E., Feron, G., & Souchon I. (2011).
803 Relationships between saliva and food bolus properties from model dairy products.
804 Food Hydrocolloids, 25, 659-667. <https://doi.org/10.1016/j.foodhyd.2010.07.024>.
805 Dresselhuis, D. M., de Hoog, E. H. A., Stuart, M. A. C, & van Aken, G. A. (2008). Application
806 of oral tissue in tribology measurements in an emulsion perception context. Food
807 Hydrocolloids, 22, 323-335. <https://doi.org/10.1016/j.foodhyd.2006.12.008>.
808 Dresselhuis, D. M., Klok, H. J., Stuart, M. A. C., de Vries, R. J., van Aken, G. A., & de Hoog,
809 D. G. A. (2007). Tribology of o/w Emulsions Under Mouth-like Conditions: Determinants
810 of Friction. Food Biophysics, 2, 158-171. <https://doi.org/10.1007/s11483-007-9040-9>.
811 Elliott, J. H. & Ganz, A. J. (1977). Salad Dressings—Preliminary Rheological
812 Characterization. Journal of Texture Studies, 8, 359-371.
813 <https://doi.org/10.1111/j.1745-4603.1977.tb01187.x>.
814 Ferry, J. D. (1980). Viscoelastic Properties of Polymers. John Wiley & Sons, Inc.
815 Fiszman, S. & Tarrega, A. (2018). The dynamics of texture perception of hard solid food: A
816 review of the contribution of the temporal dominance of sensations technique. Journal
817 of Texture Studies, 49, 202-212. <https://doi.org/10.1111/jtxs.12273>.
818 Francis, C. A., Hector, M. P., & Proctor, G. B. (2000). Precipitation of Specific Proteins by
819 Freeze-Thawing of Human Saliva. Archives of Oral Biology, 45, 601-606.
820 [https://doi.org/10.1016/S0003-9969\(00\)00026-1](https://doi.org/10.1016/S0003-9969(00)00026-1).
821 Fuhrmann, P. L., Kalisvaart, L. C. M., Sala, G., Scholten, E., & Stieger, M. (2019). Clustering
822 of oil droplets in o/w emulsions enhances perception of oil-related sensory attributes.
823 Food Hydrocolloids, 97, Article e105215.
824 <https://doi.org/10.1016/j.foodhyd.2019.105215>.
825 Garrec, D. A. & Norton, T. (2012). The Influence of Hydrocolloid Hydrodynamics on
826 Lubrication. Food Hydrocolloids, 26, 389-397.
827 <https://doi.org/10.1016/j.foodhyd.2011.02.017>.
828 Giasson, S., Israelachvili, J., & Yoshizawa, H. (1997). Thin film morphology and tribology
829 study of mayonnaise. Journal of Food Science, 62, 640-651.
830 <https://doi.org/10.1111/j.1365-2621.1997.tb15427.x>.

831 Guerreiro, C., Jesus, M., Brandao, E., Mateus, N., de Freitas, V., & Soares, S. (2020).
832 Interaction of a Procyanidin Mixture with Human Saliva and the Variations of Salivary
833 Protein Profiles over a 1-Year Period. *Journal of Agricultural and Food Chemistry*,
834 68(47), 13824–13832. <https://doi.org/10.1021/acs.jafc.0c05722>.

835 Hamada, T. Y., Terianne, Y., Brown, A., Hopfer, H., & Ziegler, G. R. (2020). Flavor and
836 mouthfeel of pseudo-cocoa liquor: Effects of polyphenols, fat content, and training
837 method. *Journal of Sensory Studies*, 35, Article e12541.
838 <https://doi.org/10.1111/joss.12541>.

839 Hanson, B., Cox, B., Kaliviotis, E., & Smith, C. H. (2012). Effects of saliva on starch
840 thickened drinks with acidic and neutral pH. *Dysphagia*, 27, 427-435.
841 <https://doi.org/10.1007/s00455-011-9386-5>.

842 Herranz, B., Criado, C., Pozo-Bayon, M, A., & Alvarez, M. D. (2021). Effect of addition of
843 human saliva on steady and viscoelastic rheological properties of some commercial
844 dysphagia-oriented products. *Food Hydrocolloids*, 111. Article e 106403.
845 <https://doi.org/10.1016/j.foodhyd.2020.106403>.

846 Hutchings, J. B., & Lillford, P. J. (1988). The perception of food texture - the philosophy of
847 the breakdown path. *Journal of Texture Studies*, 19, 103-115.
848 <https://doi.org/10.1111/j.1745-4603.1988.tb00928.x>.

849 Janssen, A. M., Terpstra, M. E. J., de Wijk, R. A., & Prinz J. F. (2007). Relations between
850 rheological properties, saliva-induced structure breakdown and sensory texture
851 attributes of custards. *Journal of Texture Studies*, 38, 42-69.
852 <https://doi.org/10.1111/j.1745-4603.2007.00085.x>.

853 Jourden, S., Panouille, M., Saint-Eve, A., Deleris, I., Forest, D., Lejeune, P., & Souchon, I.
854 (2016). Breakdown pathways during oral processing of different breads: impact of
855 crumb and crust structures. *Food & Function*, 7, 1446-1457.
856 <https://doi.org/10.1039/c5fo01286d>

857 Joyner, H. S., Pernell, C. W., & Daubert, C. R. (2014). Impact of Formulation and Saliva on
858 Acid Milk Gel Friction Behavior. *Journal of Food Science*, 79(5): E867-880.
859 <https://doi.org/10.1111/1750-3841.12439>.

860 Karthik, P., Ettelaie, R., & Chen, J. (2019). Oral behaviour of emulsions stabilized by mixed
861 monolayer. *Food Research International*, 125, Article e108603.
862 <https://doi.org/10.1016/j.foodres.2019.108603>.

863 Kim, Y., Oh, I. K., Kim, H., & Lee, S. (2019). Artificial saliva-induced structural breakdown of
864 rice flour gels under simulated chewing conditions. *Food Science and Biotechnology*, 28,
865 387-393. <https://doi.org/10.1007/s10068-018-0468-0>.

866 Kim, S. & Vickers, Z. (2020). Liking of food textures and its relationship with oral
867 physiological parameters and mouth-behavior groups. *Journal of Texture Studies*, 51,
868 412-425. <https://doi.org/10.1111/jtxs.12504>.

869 Laguna, L., Alvarez, M. D., Simone, E., Moreno-Arribas, M. V., & Bartolome, B. (2019). Oral
870 Wine Texture Perception and Its Correlation with Instrumental Texture Features of
871 Wine-Saliva Mixtures. *Foods*, 8, Article e190. <https://doi.org/10.3390/foods8060190>.

872 Laguna, L., Bartolome, B., & Moreno-Arribas, M. V. (2017). Mouthfeel perception of wine:
873 Oral physiology, components and instrumental characterization. *Trends in Food Science*
874 *& Technology*, 59, 49-59. <https://doi.org/10.1016/j.tifs.2016.10.011>.

875 Laguna, Farrell, G., Bryant, M., Morina, A., & Sarkar, A. (2017). Relating rheology and
876 tribology of commercial dairy colloids to sensory perception. *Food & Function*, 8, 563-
877 573. <https://doi.org/10.1039/c6fo01010e>.

878 Laguna, L., Manickam, I., Arancibia, C., & Tarrega, A. (2020). Viscosity decay of
879 hydrocolloids under oral conditions. *Food Research International*, 136, Article
880 e109300. <https://doi.org/10.1016/j.foodres.2020.109300>.

881 Laguna, L., Rizo, A., Pineda, D., Pérez, S., Gamero, A., & Tárrega, A. (2021). Food matrix
882 impact on oral structure breakdown and sandiness perception of semisolid systems
883 including resistant starch. *Food Hydrocolloids*, 112, Article e106376.
884 <https://doi.org/10.1016/j.foodhyd.2020.106376>.

885 Laguna, L., Sarkar, A., Bryant, M. G., Beadling, A. R., Bartolome, B., Moreno-Arribas, M. V.
886 (2017). Exploring Mouthfeel in Model Wines: Sensory-to-Instrumental Approaches.
887 *Food Research International*, 102, 478-486.
888 <https://doi.org/10.1016/j.foodres.2017.09.009>.

Lamy E. C., Rodrigues, L., Louro, T., & Capela e Silva, F. (2017). The role of saliva in food sensory perception: relevant knowledge to design healthy foods. In: A. Méndez-Vilas (Ed.). *Science within Food: Up-to-date Advances on Research and Educational Ideas*. Formatex Research Center.

Langenaeken, N. A., De Schutter, D. P., & Courtin, C. M. (2020). Arabinoxylan from non-malted cereals can act as mouthfeel contributor in beer. *Carbohydrate Polymers*, 239, Article e116257. <https://doi.org/10.1016/j.carbpol.2020.116257>.

Lapis, T. J., Penner, M. H., & Lim, J. (2016). Humans Can Taste Glucose Oligomers Independent of the hT1R2/hT1R3 Sweet Taste Receptor. *Chemical Senses*, 41, 755-762. <https://doi.org/10.1093/chemse/bjw088>.

Lê, S. & Worch, T. (2014). *Analyzing Sensory Data with R*. Chapman & Hall. <https://doi.org/10.1201/b17502>.

Lee, S., Heuberger, M., Rousset, P., & Spencer, N. D. (2004). A Tribological Model for Chocolate in the Mouth: General Implications for Slurry-Lubricated Hard/Soft Sliding Counterfaces. *Tribology Letters*, 16, 239-249. <https://doi.org/10.1023/B:TRIL.0000009735.06341.32>.

Luengo, G., Tsuchiya, M., Heuberger, M., & Israelachvili, J. (1997). Thin film rheology and tribology of chocolate. *Journal of Food Science*, 62, 767-772, 812. <https://doi.org/10.1111/j.1365-2621.1997.tb15453.x>.

Mandel, A. L., Peyrot des Gachons, C., Plank, K., Alarcon, S., & Breslin, P. A. S. (2010). Individual Differences in AMY1 Gene Copy Number, Salivary alpha-Amylase Levels, and the Perception of Oral Starch. *Plos One*, 5(10), Article e13352. <https://doi.org/10.1371/journal.pone.0013352>.

Minekus, M., Alminger, M., Alvito, P., Ballance, S., Bohn, T., Bourlieu, C., et al. (2014). A standardised static in vitro digestion method suitable for food - an international consensus. *Food & Function*, 5, 1113–1124. <https://doi.org/10.1039/c3fo60702j>.

Morell, P., Chen, J., & Fiszman, S. (2017). The Role of Starch and Saliva in Tribology Studies and the Sensory Perception of Protein-Added Yogurts. *Food & Function*, 8, 545–553. <https://doi.org/10.1039/c6fo00259e>.

918 Morell, P., Fiszman, S., Varela, P., & Hernando, I. (2014). Hydrocolloids for enhancing
919 satiety: Relating oral digestion to rheology, structure and sensory perception. *Food*
920 *Hydrocolloids*, 41, 343-353. <https://doi.org/10.1016/j.foodhyd.2014.04.038>.

921 Mosca, C., & Chen, J. (2017). Food-saliva interactions: Mechanisms and implications.
922 *Trends in Food Science & Technology*, 66, 125-134.
923 <https://doi.org/10.1016/j.tifs.2017.06.005>.

924 Muñoz-González, C., Brulé, M., Feron, G., & Canon, F. (2019). Does interindividual
925 variability of saliva affect the release and metabolization of aroma compounds ex vivo?
926 The particular case of elderly suffering or not from hyposalivation. *Journal of Texture*
927 *Studies*, 50, 36-44. <https://doi.org/10.1111/jtxs.12382>.

928 Muñoz-Gonzalez, C., Feron, G., & Canon, F. (2018). Main effects of human saliva on
929 flavour perception and the potential contribution to food consumption. *Proceedings of*
930 *the Nutrition Society*, 77(4), 423-431. <https://doi.org/10.1017/S0029665118000113>.

931 Nguyen, P. T. M., Nguyen, T. A. H., Bhandari, B., & Prakash, S. (2016). Comparison of Solid
932 Substrates to Differentiate the Lubrication Property of Dairy Fluids by Tribological
933 Measurement. *Journal of Food Engineering*, 185, 1-8. [https://doi.org/](https://doi.org/10.1016/j.foodhyd.2018.05.043)
934 [10.1016/j.foodhyd.2018.05.043](https://doi.org/10.1016/j.foodhyd.2018.05.043).

935 Nishinari, K., Ishihara, S., Hori, K., & Fang, Y. P. (2020). Tongue-palate squeezing of soft
936 gels in food oral processing. *Trends in Food Science & Technology*, 99, 117-132.
937 <https://doi.org/10.1016/j.tifs.2020.02.023>.

938 Odanaka, H., Obama, T., Sawada, N., Sugano, M., Itabe, H., & Yamamoto, M. (2020).
939 Comparison of protein profiles of the pellicle, gingival crevicular fluid, and saliva:
940 possible origin of pellicle proteins. *Biological Research*, 53(1), Article e3.
941 <https://doi.org/10.1186/s40659-020-0271-2>.

942 Ong, J. J. X., Steele, C. M., & Duizer, L. M. (2016). Challenges to assumptions regarding oral
943 shear rate during oral processing and swallowing based on sensory testing with
944 thickened liquids. *Food Hydrocolloids*, 84, 173-180.
945 <https://doi.org/10.1016/j.foodhyd.2018.05.043>.

946 Pedersen, A. M. L., Sorensen, C. E., Proctor, G. B., & Carpenter, G. H. (2018). Salivary
 947 functions in mastication, taste and textural perception, swallowing and initial digestion.
 948 Oral Diseases, 24, 1399-1416. <https://doi.org/10.1111/odi.12867>.
 949 Pematilleke, N., Kaur, M., Adhikari, B., & Torley, P. (2020). Influence of meat texture on
 950 oral processing and bolus formation. Journal of Food Engineering, 283, Article e110038.
 951 <https://doi.org/10.1016/j.jfoodeng.2020.110038>.
 952 Persson B. N. T. (2014). History of Tribology. In: T. Mang (Ed.) Encyclopedia of Lubricants
 953 and Lubrication. Springer. https://doi.org/10.1007/978-3-642-22647-2_80.
 954 Peyrot des Gachons, C. P. & Breslin, P. A. S. (2016). Salivary Amylase: Digestion and
 955 Metabolic Syndrome. Current Diabetes Reports, 16(10), Article e102.
 956 <https://doi.org/10.1007/s11892-016-0794-7>.
 957 Prakash, S. (2017). From Rheology to Tribology: Applications of Tribology in Studying Food
 958 Oral Processing and Texture Perception. In Advances in Food Rheology and Its
 959 Applications, pp. 65–86. Elsevier. [https://doi.org/10.1016/B978-0-08-100431-9.00004-](https://doi.org/10.1016/B978-0-08-100431-9.00004-8)
 960 8.
 961 Prinz, J. F. & Lucas, P. W. (2000). Saliva Tannin Interactions. Journal of Oral Rehabilitation,
 962 27, 991-994. <https://doi.org/10.1046/j.1365-2842.2000.00578.x>.
 963 Prinz, J. F., Janssen, A. M., & de Wijk, R. A. (2007). In vitro simulation of the oral processing
 964 of semi-solid foods. Food Hydrocolloids, 21, 397-401.
 965 <https://doi.org/10.1016/j.foodhyd.2006.04.009>.
 966 Proctor, G. B. (2016). The physiology of salivary secretion. Periodontology 2000, 70, 11-25.
 967 <https://doi.org/10.1111/prd.12116>.
 968 Ranc, H., Elkhyat, A., Servais, C., Mac-Mary, S., Launay, B., & Humbert, P. (2006). Friction
 969 Coefficient and Wettability of Oral Mucosal Tissue: Changes Induced by a Salivary
 970 Layer. Colloids and Surfaces A: Physicochemical and Engineering Aspects, 276, 155-161.
 971 <https://doi.org/10.1016/j.colsurfa.2005.10.033>.
 972 Ranc, H., Servais, C., Chauvy, P. -F., Debaud, S., & Mischler, S. (2006). Effect of surface
 973 structure on frictional behaviour of a tongue/palate tribology system. Tribology
 974 International, 39, 1518-1526. <https://doi.org/10.1016/j.triboint.2006.01.017>.

975 Ruan, Q. J., Yang, X. Q., Zeng, L. H., & Qi, J. R. (2019). Physical and tribology properties of
976 high internal phase emulsions based on citrus fibers and corn peptides. *Food*
977 *Hydrocolloids*, 95, 53-61. <https://doi.org/10.1016/j.foodhyd.2019.04.014>.

978 Rudge, R. E. D., Scholten, E., & Dijkman, J. A. (2019). Advances and challenges in soft
979 tribology with applications to foods. *Current Opinion in Food Science*, 27, 90-97.
980 <https://doi.org/10.1016/j.cofs.2019.06.011>.

981 Sarkar, A. & Krop, E. M. (2019). Marrying Oral Tribology to Sensory Perception: A
982 Systematic Review. *Current Opinion in Food Science*, 27, 64-73.
983 <https://doi.org/10.1016/j.cofs.2019.05.007>.

984 Sarkar, A., Andablo-Reyes, E., Bryant, M., Dowson, D., & Neville, A. (2019). Lubrication of
985 soft oral surfaces. *Current Opinion in Colloid & Interface Science*, 39, 61-75.
986 <https://doi.org/10.1016/j.cocis.2019.01.008>.

987 Sarkar, A., Xu, F., & Lee, S. (2019). Human saliva and model saliva at bulk to adsorbed
988 phases - similarities and differences. *Advances in Colloid and Interface Science*, 273,
989 Article e102034. <https://doi.org/10.1016/j.cis.2019.102034>.

990 Savinov, S. S. & Anisimov, A. A. (2020). Effect of Conditions for Sampling of Human Saliva
991 on the Results of Determination of Macro- and Micronutrients. *Journal of Analytical*
992 *Chemistry*, 75, 453-458. <https://doi.org/10.1134/S1061934820040139>.

993 Selway, N., Chan, V., & Stokes, J. R. (2017). Influence of fluid viscosity and wetting on
994 multiscale viscoelastic lubrication in soft tribology contacts. *Soft Matter*, 13, 1702-1715.
995 <https://doi.org/10.1039/c6sm02417c>.

996 Sethupathy, P., Moses, J. A., & Anandharamakrishnan, C. (2020). Food Oral Processing and
997 Tribology: Instrumental Approaches and Emerging Applications. *Food Reviews*
998 *International*, <https://doi.org/10.1080/87559129.2019.1710749>.

999 Shama, F. & Sherman, P. (1973). Identification of stimuli controlling the sensory evaluation
1000 of viscosity. II. Oral methods. *Journal of Texture Studies*, 4, 111-118.
1001 <https://doi.org/10.1111/j.1745-4603.1973.tb00657.x>.

1002 Sharma, M., Pico, J., Martinez, M. M., & Duizer, L. (2020). The dynamics of starch
 1003 hydrolysis and thickness perception during oral processing. *Food Research*
 1004 *International*, 134, Article e109275. <https://doi.org/10.1016/j.foodres.2020.109275>.
 1005 Shewan, H. M., Pradal, C., & Stokes, J. R. (2020). Tribology and its growing use toward the
 1006 study of food oral processing and sensory perception. *Journal of Texture Studies*, 51, 7-
 1007 22. <https://doi.org/10.1111/jtxs.12452>.
 1008 Spirk, C., Hartl, S., Pritz, E., Gugatschka, M., Kolb-Lenz, D., Leitinger, G., & Roblegg, E.
 1009 (2019). Comprehensive investigation of saliva replacement liquids for the treatment of
 1010 xerostomia. *International Journal of Pharmaceutics*, 571, Article e118759.
 1011 <https://doi.org/10.1016/j.ijpharm.2019.118759>.
 1012 Stanley, N. L. & Taylor, L. J. (1993). Rheological basis of oral characteristics of fluid and
 1013 semi-solid foods: A review. *Acta Psychologica*, 84(October), 79-92.
 1014 [https://doi.org/10.1016/0001-6918\(93\)90074-2](https://doi.org/10.1016/0001-6918(93)90074-2).
 1015 Stokes, J. R., Boehm, M. W., & Baier, S. K. (2013). Oral processing, texture and mouthfeel:
 1016 From rheology to tribology and beyond. *Current Opinion in Colloid & Interface Science*,
 1017 18, 349-359. <https://doi.org/10.1016/j.cocis.2013.04.010>.
 1018 Stribitcaia, E., Krop, E. M., Lewin, R., Holmes, M., & Sarkar, A. (2020). Tribology and
 1019 rheology of bead-layered hydrogels: Influence of bead size on sensory perception. *Food*
 1020 *Hydrocolloids*, 104, Article e105692. <https://doi.org/10.1016/j.foodhyd.2020.105692>
 1021 Szczesniak, A. S. (2002). Texture is a sensory property. *Food Quality and Preference*, 13,
 1022 215-225. [https://doi.org/10.1016/S0950-3293\(01\)00039-8](https://doi.org/10.1016/S0950-3293(01)00039-8).
 1023 Tarragon, E., Stein, J., & Meyer, J. (2018). Basal Levels of Salivary Alpha-Amylase Are
 1024 Associated with Preference for Foods High in Sugar and Anthropometric Markers of
 1025 Cardiovascular Risk. *Behavioral Sciences*, 8(10), Article e94.
 1026 <https://doi.org/10.3390/bs8100094>.
 1027 Turcanu, M., Siegert, N., Secouard, S., Brito-de la Fuente, E., Balan, C., & Gallegos, C.
 1028 (2018). An alternative elongational method to study the effect of saliva on thickened
 1029 fluids for dysphagia nutritional support. *Journal of Food Engineering*, 228, 79-83.
 1030 <https://doi.org/10.1016/j.jfoodeng.2018.02.015>.

1031 Upadhyay, R., Aktar, T., & Chen, J. (2020). Perception of creaminess in foods. *Journal of*
1032 *Texture Studies*, 51, 375-388. <https://doi.org/10.1111/jtxs.12509>.

1033 Vallons, K. J. R., Helmens, H. J., & Oudhuis, A. A. C. M. (2015). Effect of human saliva on
1034 the consistency of thickened drinks for individuals with dysphagia. *International Journal*
1035 *Of Language & Communication Disorders*, 50(2), 165-175.
1036 <https://doi.org/10.1111/1460-6984.12120>.

1037 Vallons, K. J., Oudhuis, L. A., Helmens, H. J., & Kistemaker, C. (2015). The Effect of Oral
1038 Processing on the Viscosity of Thickened Drinks for Patients With Dysphagia. *Annals of*
1039 *Rehabilitation Medicine*, 39,772-777. <https://doi.org/10.5535/arm.2015.39.5.772>.

1040 Varela, P. & Ares, G. (2014). Novel Techniques in Sensory Characterization and Consumer
1041 Profiling. CRC Press. <https://doi.org/10.1201/b16853>.

1042 Vijay, A., Inui, T., Dodds, M., Proctor, G., & Carpenter, G. (2015). Factors that Influence the
1043 Extensional Rheological Property of Saliva. *PLOS ONE* 10, Article e0135792.
1044 <https://doi.org/10.1371/journal.pone.0135792>.

1045 Vladescu, S-C., Bozorgi, S., Hu, S., Baier, S. K., Myant, C., Carpenter, G., & Reddyhoff, T.
1046 (2020). Effects of beverage carbonation on lubrication mechanisms and mouthfeel.
1047 *Journal of colloid and interface science*. <https://doi.org/10.1016/j.jcis.2020.10.079>.

1048 Wagner, C. E., Wheeler, K. M., & Ribbeck, K. (2018). Mucins and Their Role in Shaping the
1049 Functions of Mucus Barriers. *Annual Review of Cell and Developmental Biology*, 34,
1050 189-215. <https://doi.org/10.1146/annurev-cellbio-100617-062818>.

1051 Wang, S., Olarte-Mantilla, S. M., Smith, P. A., Stokes, J. R., & Smyth, H. E. (2020).
1052 Astringency Sub-Qualities Drying and Pucker Are Driven by Tannin and pH—Insights
1053 from Sensory and Tribology of a Model Wine System. *Food Hydrocolloids*, 109, Article
1054 e106109. <https://doi.org/10.1016/j.foodhyd.2020.106109>.

1055 Wang, Q., Wang, X. M., & Chen, J. (2021). A new design of soft texture analyzer tribometer
1056 (STAT) for in vitro oral lubrication study. *Food Hydrocolloids*, 110, Article e106146.
1057 <https://doi.org/10.1016/j.foodhyd.2020.106146>.

Yamagata, Y., Izumi, A., Egashira, F., Miyamoto, K., & Kayashita, J. (2012). Determination of a Suitable Shear Rate for Thickened Liquids Easy for the Elderly to Swallow. *Food Science and Technology Research*, 18, 363-369. <https://doi.org/10.3136/fstr.18.363>.

Yang, Z. M., Chen, L. H., Zhang, M., Lin, J., Zhang, J., Chen, W. W., Yang, X. R. (2015). Age Differences of Salivary Alpha-Amylase Levels of Basal and Acute Responses to Citric Acid Stimulation Between Chinese Children and Adults. *Frontiers in Physiology*, 6, Article e340. <https://doi.org/10.3389/fphys.2015.00340>.

Yuan, B., Ritzoulis, C., & Chen, J. (2018). Extensional and shear rheology of okra hydrocolloid-saliva mixtures. *Food Research International*, 106, 204-212. <https://doi.org/10.1016/j.foodres.2017.12.051>.

Zhu, Y., Bhandari, B., & Prakash, S. (2020). Relating the Tribo-Rheological Properties of Chocolate Flavoured Milk to Temporal Aspects of Texture. *International Dairy Journal*, 110, Article e104794. <https://doi.org/10.1016/j.idairyj.2020.104794>.

Zimmermann, R., Delius, J., Friedrichs, J., Stehl, S., Hoffmann, T., Hannig, C., Rehage, M., Werner, C., & Hannig, M. (2019). Impact of oral astringent stimuli on surface charge and morphology of the protein-rich pellicle at the tooth-saliva interphase. *Colloids and Surfaces B-Biointerfaces*, 174, 451-458. <https://doi.org/10.1016/j.colsurfb.2018.11.028>.

1076 Figure captions

1077 Figure 1. Apparent viscosity decay (at 60 s^{-1}) over time for starch based dairy systems
1078 containing carrageenan (triangles) or CMC (circles) when mixed with water (a) or saliva
1079 (b). Taken from Arancibia, Agudelo, Fiszman, and Tárrega (2017) with permission.

1080 Figure 2. Number of publications per year in peer reviewed manuscripts. “Food &
1081 tribology” (black) and “Food & Tribology & Saliva” (grey)

1082 Figure 3. Diagram of oral processing stages where tribology properties can be key
1083 measurements. Taken from Stokes, Boehm and Baier (2013) with permission.

Table 1. Sensory technique, type of saliva, proportion of food to saliva, tribology equipment and contact surfaces, and load applied in different studies using saliva in tribology measurements

Sensation (sensory test)*	Type of saliva	Proportion of food to saliva**	Tribometer	Contact material	Food	Load force applied	Reference
Creaminess (QDA)	Stimulated human	15% saliva	Friction tester	Rubber and metal	Vanilla custards Mayonnaise	50 N	De Wijk and Prinz, 2005
Creaminess (Triangle)	Artificial	1:1	Mini Traction Machine	PDMS	Milk, yogurts and cheese	2 N	Laguna, Farrell, et al., 2017
& Prinz Powderiness, thickness, creaminess (TDS)	Stimulated human	4:1	Tribology probe (ring on plate) and rheometer	3M Transpore Surgical Tape 1527-2	Hydrocolloids (gelatin, k-carrageenan, low methoxy pectin and curdlan) Casein and whey protein isolate mixtures	2N	Zhu et al., 2020
Fat-related sensations (QDA)	Human	Not reported	Optical tribological configuration (OTC)	PDMS	Oil-in-water emulsions	0.5 N	Dresselhuis et al., 2007
Fat-related sensations (RATA)	Human	1:1	Tribology probe (glass ball-on-three balls) and rheometer	PDMS	Oil-in-water	1.N	Fuhrman et al., 2019
Coating, astringency (QDA)	Stimulated human		Tribology probe (two balls on a plate) and rheometer	Polypropylene balls and whey protein isolate	Acid milk gels	---	Joyner et al., 2014
Particle feel (Discriminating)	Artificial	4:1	Mini Traction Machine	PDMS	Gels with beads	2N	Stribiţcaia et al., 2020
Astringency (Flash profiling)	Stimulated human Artificial	1:4	Texture Analyser (adapted)	Silicon rubber	Yoghurt	0.27 N	Morell et al., 2016
Astringency (QDA)	Artificial	1:1	Mini Traction Machine	PDMS	Model wine	1 N	Laguna, Sarkar, et al., 2017
Astringency (Trained panel)	Human	1:1	Texture Analyser (adapted)	Steel and PDMS	Tannic acid and catechin solution	0.56 N	Brossard et al., 2017
Astringency sub-qualities	Stimulated	10:1	Mini Traction Machine	PDMS	Model wine	1 N	Wang et al., 2020
Hui Gan intensity (QDA)	Unstimulated human	1:1	Texture Analyser (adapted)	Steel and PDMS	Tea	0.56 N	Chong et al., 2019

*QDA: Quantitative Descriptive Analysis; TDS: Temporal Dominance of Sensations; RATA: Rate-All-That-Apply

**As reported by the authors