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Dynamic texture perception and oral processing of semi-solid food gels: Part 2: Impact of breakdown behaviour on bolus properties and dynamic texture perception

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ABSTRACT

Food texture perception depends on food structure and oral processing behaviour. The aim of this study was to explain dynamic texture perception of emulsion-filled, semi-solid gels by properties of the boli formed during three stages of oral processing. Texture perception of emulsion-filled gels varying in fracture stress and strain was found to be a dynamic process. Specific texture attributes were perceived as dominant sensations in the beginning (firm), middle (moist, refreshing, elastic, sticky) and end of oral processing (grainy, melting, creamy). In the beginning of oral processing mechanical properties of the boli, such as first penetration peak force and flowability, were correlated to sensory firmness. In the middle of oral processing, correlations between boli properties and texture perception were more complex. Perception of moist and refreshing was related to mechanical properties of the boli, such as flowability, rather than to the amount of saliva incorporated into the boli. Perception of elastic and sticky was related to the mechanical bolus properties resilience and adhesiveness. In the end of oral processing, emulsion-filled gels were perceived either as creamy or grainy. Gels perceived as creamy revealed a high bolus flowability while gels perceived as grainy consisted of boli with a high number of broken down particles. We conclude that bolus formation and changes in the properties of the bolus underlay the changes in texture perception during oral processing.

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1. Introduction

Food oral processing is an essential process contributing to sensory perception of food, especially to perception of texture (Chen, 2009). As food is broken down during mastication, its properties constantly change leading to variations of texture perception in time. The main phenomena contributing to dynamic texture perception are the reduction in degree of structure and increase in degree of lubrication of foods. Those two processes contribute to the formation of a safely ready to swallow food bolus (Hutchings & Lillford, 1988). Bolus properties depend on the physical and chemical properties of food and the physiological characteristics of the mastication process (Foster et al., 2011). Understanding bolus formation through *in vivo* studies has been suggested to increase understanding of dynamic texture perception (Wilkinson, Dijksterhuis, & Minekus, 2000).

A wide range of methodologies is nowadays available to characterise the physical and chemical properties of food boli. The structural breakdown of boli has been studied by particle size analyses with methods, such as sieving (Guo, Ye, Lad, Dalgleish, & Singh, 2013; Peyron et al., 2011) and image analysis (Chen, Niharika, Zhenyu, & Takahiro, 2013; Hutchings et al., 2011; Mosca, Van de Velde, Bult, Van Boekel, & Stieger, 2012). Depending on the consistency and rheological properties of boli which vary largely between different foods, various instrumental texture characterization methods have been applied including modified Texture Profile Analysis (TPA) of cereal boli (Peyron et al., 2011), oscillatory small deformation rheology of bread boli (Le Bleis, Chaunier, Della Valle, Panouille, & Reguerre, 2013), force-displacement mechanical testing of model cheese boli (Drago et al., 2011) and shear rheology of meat boli (Yven, Culioli, &

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Mioche, 2005). The methodology chosen depends on the physical properties of the boli, mainly its homogeneity and cohesiveness which can vary strongly between foods depending on the level of mastication. Information that could be related to lubricational properties of food boli was obtained by quantifying saliva and dry matter content of boli (Loret et al., 2011). Release of oil from the boli during mastication was quantified (Guo et al., 2013). The lubricational properties of boli were determined using tribological measurements on soft, semi-solid foods, such as custard desserts (de Wijk, Prinz, & Janssen, 2006; de Wijk, Terpstra, Janssen, & Prinz, 2006). Tribological measurements are unlikely to be applicable to boli containing inhomogeneous, solid particles. The diversity of tests used to characterize the breakdown and lubricational properties demonstrates the need to adapt the characterization method to the specific properties of the bolus, which can differ considerably between foods depending on degree of breakdown.

Bolus properties have been extensively studied, especially at the end point of oral processing to understand the mechanisms that trigger swallowing (Chen & Lolivret, 2011; James et al., 2011; Loret et al., 2011; Peyron et al., 2011). In addition, taste and aroma perception in relation to bolus properties (de Loubens et al., 2010; Mosca, Van de Velde, Bult, Van Boekel, & Stieger, 2010) have been investigated. Correlations between bolus properties and taste and aroma release were difficult to obtain (Tarrega, Yven, Semon, & Salles, 2011). Oral processing behaviour including muscle activity and jaw movements during mastication have been related to texture perception of gels (Çakır et al., 2012). Çakır et al. observed that sensory firmness was correlated to muscle activity at first bite. Sensory attributes perceived during chew down were related to jaw opening velocity and cycle duration of the first five chewing cycles. Jaw movement amplitudes of the later chewing cycles were related to after-feel sensory attributes. Despite the importance of understanding dynamic sensory perception through bolus properties throughout an entire mastication cycle, only few studies have related bolus properties to dynamic texture perception. Seo, Hwang, Han, and Kim (2007) identified two sensory cues, slipperiness and compliance, which were linked to bolus rheological properties at swallowing point. Cereal boli properties at intermediate mastication times were measured together with sensory hardness, stickiness and dryness in order to identify the sensory triggers of swallowing (Peyron et al., 2011). It was found that sensory hardness decreased together with mechanical hardness of the boli. Using a more dynamic approach, dynamic sensory perception determined by temporal dominance of sensation (TDS) was compared recently to mechanical and rheological bolus properties (Young, Cheong, Hedderley, Morgenstern, & James, 2013). Changes in bolus properties were found to be a possible cause contributing to changes in dominance of sensation of texture attributes during mastication.

Previously, it was found that texture perception at the beginning of oral processing of emulsion-filled, semi-solid gels depended on fracture properties of the gels (Devezeaux de Lavergne, van Delft, van de Velde, van Boekel, & Stieger, 2015). The fracture properties influenced perception of texture attributes at later stages of oral processing. Analysing bolus formation and properties is likely to help understanding the link between initial mechanical and structural properties of food, properties of the bolus and dynamic texture perception.

The physical-chemical and sensory properties determined using Qualitative Descriptive Analysis (QDA), TDS and progressive profiling of emulsion-filled gels varying in fracture stress (high/low), fracture strain (high/low) and interactions between oil droplets and gel matrix (bound/unbound) were described previously by Devezeaux de Lavergne et al. (2015). Changes in texture perception during mastication could be quantified using sensory trajectories which were obtained from TDS measurements (Lenfant, Loret, Pineau, Hartmann, & Martin, 2009). Fig. 1 shows the sensory trajectories of the emulsion-filled, semi-solid emulsion-filled gels together with selected images of expectorated boli. Three phases of oral processing were identified based on the appearance of dominant sensations: beginning (dominant sensation is firm), middle (dominant sensations are moist, refreshing, elastic and sticky) and end phase of oral processing (dominant sensations are grainy, melting and creamy). We hypothesize that the dominant texture attributes perceived during each phase of oral processing are linked to physical and chemical bolus properties. In the present study, we analyse the relationships between the physical-chemical bolus properties and texture perception following the order of appearance of the texture attribute as dominant sensation in time. In the beginning of oral processing, all gels were perceived mainly as firm. In the middle of oral processing, gels were perceived elastic, sticky, moist and refreshing, and in the end of oral processing, as creamy, melting and grainy. The aim of this present study is to explain dynamic texture perception of emulsion-filled, semi-solid gels by properties of the boli formed during three stages of oral processing. Saliva content, mechanical properties, fat release and fragment size and shape were analysed in food boli obtained at different oral processing times. The physical-chemical data was correlated with dynamic texture perception.

2. Materials and methods

2.1. Samples

Emulsion-filled agar/gelatin gels were prepared following the protocol described by Devezeaux de Lavergne et al., 2015. The details of the preparation procedure and characterization of gels including sensory characterization (QDA, progressive profiling, TDS), uniaxial compression test and oil release have been described previously (Devezeaux de Lavergne et al., 2015) and are not summarized here. All sensory data can be found in detail in Devezeaux de Lavergne et al., 2015. In the present study, the previously published sensory data is compared to and correlated with additional data of bolus properties. The full factorial experimental design of gels varying in fracture stress (high/low), fracture strain (high/low) and oil binding to the matrix (bound/unbound) is summarized in Table 1 together with the corresponding sample names.

2.2. Bolus collection

A panel consisting of 10 Dutch women all of whom have previously participated in the QDA and TDS sensory study of the gels (Devezeaux de Lavergne et al., 2015) was selected. All subject had a healthy dentition. The average age of the panel was 54.9 ± 13.8 years. Five sessions of 1.5 h were organised to collect boli from gels, boli from each session were used for a specific analysis. Two boli collections sessions were needed to obtain sufficient volumes of boli to perform the Two Cycle Penetration Tests (TCTP). Between 18 and 22 h after gel preparation, gels were cut into cylindrical pieces of 26.4 mm diameter and 10 mm height. Boli from gels were collected after mastication for 5, 10, 15 and 20 s from n = 10 panellists. In each spit out sessions, 32 gel samples corresponding to a single piece of gel for each gel type and spitting time, were served per panellists except for the TCPT test (128 pieces were served over 2 sessions). Samples were presented in a randomized order between gel samples but spitting times were always kept from longer to shorter time per gel type. Time points correspond to 25, 50, 75 and 100% of the maximum oral processing time of the gels reported by Devezeaux de Lavergne et al., 2015. At the desired time points,

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