Food Hydrocolloids 63 (2017) 67–76

Contents lists available at ScienceDirect

Food Hydrocolloids

journal homepage: www.elsevier.com/locate/foodhyd

Investigation of oral gels breakdown using image analysis

Carole Tournier [a, *], Marine Devezeaux de Lavergne [b, c], Fred van de Velde [b, d], Markus Stieger [b, c], Christian Salles [a], Dominique Bertrand [e]

[a] Centre des Sciences du Goût et de l'Alimentation, CNRS, INRA, Univ. Bourgogne Franche-Comté, F-21000, Dijon, France
[b] TI Food and Nutrition, P.O. Box 557, 6700 AN, Wageningen, The Netherlands
[c] Wageningen University, Agrotechnology and Food Sciences Group, P.O. Box 8129, 6700 EV, Netherlands
[d] NIZO Food Research BV, P.O. Box 20, 6710 BA, Ede, The Netherlands
[e] data_frame, 25 rue Stendhal, 44300, Nantes, France

ARTICLE INFO

Article history:
Received 7 June 2016
Received in revised form
13 July 2016
Accepted 27 July 2016
Available online 30 July 2016

Keywords:
Emulsion-filled gels
Food bolus
Mastication
Image texture analysis
Mathematical morphology

ABSTRACT

Characterizing the dynamics of food oral breakdown is of interest to understand the temporal perception of food products. The present work aimed at studying the possible contribution of artificial vision for studying bolus formation. Four emulsion-filled gels were prepared from two concentrations of agar and gelatin. By combining two different layers of these gels, four samples of homogeneous composition and 6 samples of heterogeneous composition were prepared. The layers were colored independently in order to study their breakdown and mixing during oral processing. Images of spat out boluses were collected at different stages of the chewing process and studied by different image analysis methods: gray-level histograms, histogram of shape area, mathematical morphology and gray level co-occurrence matrix. Methods were compared for their ability in discriminating boluses as function of homogeneous gel composition and mastication time. Three methods were found to be relevant and mathematical morphology provided the best results. Using this method, we further analyzed the impact of heterogeneous gels composition on the evolution of boluses properties. Results showed that when two gel layers of different composition were combined, the agar layer dominated bolus properties and that the presence of gelatin impacted the dynamics of gel breakdown. The results were in agreement with results obtained previously when characterizing the physical properties of the boluses. This study showed that artificial vision provides reliable tools for evaluating the dynamics of bolus formation, which is complementary to the methods commonly used in literature while avoiding extensive manipulation of boluses.

1. Introduction

Food oral processing corresponds to the transformation of a food product into a bolus that can be swallowed. Under the joint actions of mastication and salivation, the food is comminuted into particles which are lubricated and agglomerated together to form a cohesive bolus (Hutchings & Lillford, 1988). The dynamic of oral food transformation and the resulting bolus properties are known to depend both on the nature of the food, such as its wateriness, hardness or level of fat and on individual's characteristics: dental status, salivary flow rates, chewing behavior. The characterization of bolus properties is of interest as it can help understanding the dynamic of texture perception (Devezeaux de Lavergne et al., 2016; Panouillé, Saint-Eve, Déléris, Le Bleis, & Souchon, 2014; Young, Cheong, Hedderley, Morgenstern, & James, 2013) and of the release of flavor components in the oral cavity (Feron et al., 2014; Tournier, Grass, Septier, Bertrand, & Salles, 2014; Salles et al., 2011).

Several studies have aimed at characterizing bolus properties and the methods used depend on the nature of the food. Boluses obtained from hard and brittle products have been characterized by their particles size distribution, as measured by sieving, image analysis of isolated particles, laser diffraction, optical scanning (Lucas & Luke, 1983; Mishellany, Woda, Labas, & Peyron, 2006; Mowlana & Heath, 1993; Peyron, Mishellany, & Woda, 2004; van der Bilt, van der Glas, Mowlana, & Heath, 1993). The quantity of saliva taken up by the bolus is usually determined by drying (Le Bleis, Chaunier, Della Valle, Panouillé, & Réguerre, 2013; Loret

* Corresponding author. INRA, UMR CSGA, 17 rue Sully, BP 86510, 21065, Dijon Cedex, France.
E-mail address: carole.tournier@dijon.inra.fr (C. Tournier).

http://dx.doi.org/10.1016/j.foodhyd.2016.07.037
0268-005X/

et al., 2011; Tournier et al., 2014). Finally, boluses rheological properties have been determined using compression test, texture profile analysis, penetration tests, capillary rheometry, back extrusion (Devezeaux de Lavergne et al., 2016; Le Bleis et al., 2013; Peyron et al., 2011; Young et al., 2013; Yven et al., 2012).

In the case of totally or partly soft foods, it is difficult to have a description of the evolution of food in the mouth, because the concept of individual particles is not clear and the bolus texture is not always homogeneous. For this reason, it is convenient to examine the possible utilization of other analytical techniques, such as artificial vision. Indeed few studies evidenced that image texture analysis (such as the Gray-Level Co-occurrence Matrix method) was a relevant method to characterize bolus formation (Arvisenet et al., 2008; Devezeaux de Lavergne et al., 2016; Tournier, Grass, Zope, Salles, & Bertrand, 2012). This kind of method presents the advantage to avoid extensive manipulation of boluses (analysis is made on the images of the entire collected bolus), to allow analyzing important quantity of data in a short time (through automated data processing) and does not require supplementary material (no need to collect multiple spit out to have sufficient material).

In the frame of a previous work (Devezeaux de Lavergne et al., 2016), we have built up a large collection of images of food model systems (bi-colored gels) boluses, which can be used for testing the efficacy of image analysis to better understand bolus formation. Various emulsion-filled gels varying in mechanical properties were prepared and their oral breakdown was characterized. Important differences were observed in boluses properties (particle size and rheological properties) as a function of mastication time and initial mechanical properties of the gels. In the present complementary study, we first aimed at testing several methods of image analysis applied to this image collection of boluses. In a second step, using the most appropriate image analysis method we have described the influence of the compositions of the gels on boluses and their evolution as a function of mastication time.

2. Material and methods

2.1. Samples

Samples used in this study were emulsion-filled gels of homogeneous or heterogeneous composition. The details of the materials and preparation procedure have been fully described previously (Devezeaux de Lavergne et al., 2016). A short summary is provided here.

Two emulsion-filled gels made of 1 wt% or 2 wt% agar, referred as LA (Low agar), HA (High agar) respectively, and two emulsion-filled gels made of 2.5 wt% and 5.5 wt% gelatin, referred as LG (Low gelatin) and HG (High gelatin) respectively, were prepared. They were composed of distilled water, 20 wt% sunflower oil, 10 wt % sucrose and 0.03 wt% vanilla flavour. These gels varying in composition presented different mechanical properties as measured by uniaxial compression (Devezeaux de Lavergne et al., 2016). They initially showed a white color. In order to enable color distinction, a black version of each gel was prepared with carbon black addition. White and black gel layers were prepared in cylindrical pieces of 5 mm height and 26 mm diameter. Two emulsion-filled gel layers, one black and one white, were placed on top of each other to obtain layered gels of 10 mm height and 26 mm diameter, corresponding to a mouthful (Fig. 1). The color of the layer was coded by capital letter for white gels and regular letters for black ones. Combining gel layers yielded in 10 layered gels (Table 1): 4 of homogeneous composition (LGlg, HGhg, LAla, HAha) and 6 with heterogeneous composition (LAha, LGhg, LGla, LGha, HGla, HGha).

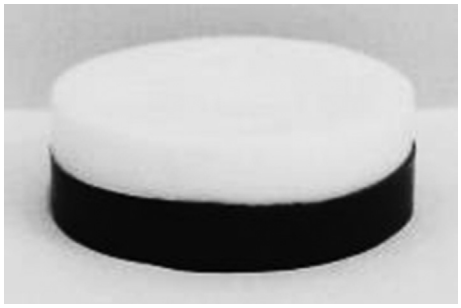

Fig. 1. Gel sample (composed of two layers, a white (no colorant added) and black layer (carbon black added)).

Table 1
Names and composition of emulsion-filled gels.

Gel name[a]	2.5% gelatin	5.5% gelatin	1% agar	2% agar
LGlg	W b			
HGhg		W b		
LAla			W b	
HAha				W b
LAha			W	b
LGhg	W	b		
LGla	W		b	
LGha	W			b
HGla		W	b	
HGha		W		b

[a] Upper-case letters in gels name refer to the composition of the white layer; W: composition of the white layer, b: composition of the black layer.

2.2. Image acquisition

The work reported here was part of our previous study (Devezeaux de Lavergne et al., 2016). Ten women (50.0 ± 13.6 years old) participated in a session of 1-hour duration. They were asked to chew the 10 gels samples and to expectorate the bolus after 7, 14 and 20 s. These times corresponded, respectively to 33, 66 and 100% of the average time required by the panelists to form a bolus ready for swallowing. This time was evaluated by averaging the individual mastication times determined from preliminary experiments. Panelists had previously participated in similar studies and were therefore trained to this procedure. During a session per panelist, 30 boluses (10 gels × 3 masticatory times) were collected. The entire bolus collection thus eventually included 300 boluses.

The bolus collection and image acquisition were adapted from (Tournier et al., 2012). Gel boluses were collected directly in the lid of a glass Petri dish (60 mm diameter) and flattened by slightly pushing with the bottom part of the dish container. Images were acquired on a red background with an IEEE 1394 C-Mount multi-megapixel camera equipped with CDD sensors (Oscar F-810C, Allied Vision Technologies, Stadtroda, Germany) and fitted with a KOWA lens (35 mm). The camera was positioned at a distance of 15 cm from the sample, which was lightened using a light/stand combination system (RS1, Kaiser Fototechnik, Buchen, Germany). The angle between the camera lens and the lighting source axis was around 45°. This set-up made it possible to capture a surface of 36 × 36 mm digitized to 820 × 820 pixels. Four images (2 from above and 2 from below the glass Petri dish) were acquired for each bolus.

2.3. Image analysis

A total of 1200 images (10 panelists × 10 gels × 3 chewing times × 4 images) were collected in this experiment. For some