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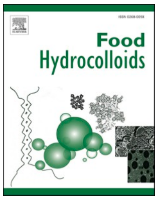

Effect of addition of human saliva on steady and viscoelastic rheological properties of some commercial dysphagia-oriented products

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ABSTRACT

Three commercial thickened fluids were rheologically characterized before and after addition of unstimulated human saliva to improve the further development of better products in dysphagia management by taking into account the dynamic process of bolus flow and the effect of saliva. Instant purées (vegetables and beef (VB), vegetables and codfish (VC) and chicken with rice and carrots (CR)) were prepared and mixed with water or unstimulated saliva from five healthy individuals. Steady and dynamic rheological properties were evaluated, and composition of saliva from five donors was determined. Control purées had shear-thinning behaviour and showed a liquid-structured character with different viscoelastic parameters. All the water samples showed significant differences in the steady and viscoelastic parameters although not so notable as those produced by saliva addition. Thereby, addition of saliva produced a remarkable change in: viscosity (at 0.1, 1, 10 and 50 s^{-1}), consistency index (K) and flow behaviour (n), and, in the conformational structure (decrease of maximum stress amplitude (σ_{max}) and maximum complex modulus (G^*) and increase in loss factor (tan δ) of all the three purées, especially in CR. VC and CR purées showed an increase in degree of structural deformability (higher γ_{max}). High variability was found in the saliva composition, specifically in α-amylase activity, which might affect the rheological behaviour of these commercial products. Therefore, structural changes produced by saliva addition should take into account to design safer dysphagia products although this inter-individual effect should be studied with a larger number of individuals to obtain more relevant conclusions.

1. Introduction

The term dysphagia refers to abnormal swallowing of foods and/or liquids due to neurological diseases, various forms of cancer (e.g., head and neck; tongue) or stroke (Longeman, 2007), and it affects people of all ages, from the newborn to the elderly. Dysphagia is commonly managed by prescribing texture-controlled diets that seek to modify the consistency of foods and/or drinks in order to change the rate at which food is transported through the pharynx and thus reduce the risk of aspiration (Quinchia et al., 2011). Lack of coordination between clinical practice and rheological studies is one of the important issues for treatment of dysphagia (Zargaraan et al., 2013).

The most available dysphagia products are: powdered thickeners that have to be added to a food matrix (commonly fluids, such as milk, water and juices) and pre-thickened foodstuffs that are ready to use. Thickened fluids are complex dispersions of gums and starches which provided thickened boluses lowering transit speeds during swallowing process, and therefore, reducing the risk of aspiration (Turcanu et al., 2018). In the well-known National Dysphagia Diet (NDD) classification, the four levels that refer to fluids are based on shear viscosities measured at a single shear rate (50 s^{-1}) and at a temperature of 25 °C. These measurement conditions were selected by the National Dysphagia Diet Task Force (NDDTF, 2002) without any scientific evidence or rationale, although a wide range of shear rates, ranging from 5 to 1000 s^{-1}, is feasible during swallowing (Gallegos et al., 2012; Salinas-Vázquez et al., 2014). The NDDTF (2002) did not take into account the fact that food bolus flow is a dynamic process that depends on the force applied (Gallegos et al., 2017). On the other hand, viscoelasticity balance in terms of increased elastic component and cohesiveness of masticated food is crucial for safe and easy swallowing (Ishihara, Nakauma,

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Funami, & Odake, 2011). Most of the available information on rheological properties of ready-to-eat dysphagia-oriented products is only focused on viscosity, whereas elasticity is hardly mentioned (Ishihara et al., 2011; Sopade et al., 2008). Some authors (Moret-Tatay et al., 2015; Sukkar, Maggi, Travalca Cupillo, & Ruggiero, 2018; Zargaraan et al., 2013) have pointed out the importance of studying viscoelastic and extensional properties of thickened fluids in the swallowing process in order to improve understanding of the mechanical behaviour of these products and the interactions between their major molecules. Recently, there is some research focused on extensional deformations of bolus which could be correlated to cohesiveness during the oral processing (Hadde & Chen, 2019; Nishinari et al., 2019; Sukkar et al., 2018; Turcanu et al., 2018). Consequently, a cohesive bolus will fracture less during the pharyngeal phase of the swallowing, decreasing the risk of aspiration. Cohesiveness shows the strength of the intermolecular attraction of the fluid and how they are held together.

Moreover, little information is available related to the study of the dynamic rheological properties of dysphagia products mixed with human saliva (Hanson et al., 2012; Lee et al., 2016; Vallons et al., 2015).

Saliva plays an essential role in bolus safety because it increases bolus cohesiveness and affects its viscoelastic properties (Moret-Tatay et al., 2015). However, there has been little research on the effect of saliva on dysphagia-oriented products, with the exception of a few studies dealing with thickened drinks (Hansonet al., 2012; Turcanu et al., 2018) and commercial food thickeners (Lee et al., 2016; Moret-Tatay et al., 2015). When food is chewed and swallowed it is always mixed with saliva, which contains α-amylase, responsible for the early breakdown of starch components. Some authors (Chen, 2009; Ferry et al., 2004) have reported that when foods are in contact with saliva (or α-amylase) their viscosity may be reduced by more than half in less than 10 s, especially in the case of dysphagia products that contain starch as the main thickener. This significant decrease in viscosity can affect the risk of aspiration by the patient. Therefore, it is critical to characterize dysphagia products in terms of their resistance to a hydrolysis reaction with saliva for dysphagia management (Gallegos et al., 2017; Wang, Li, Özkan, & Li, 2009).

It is important to note that the pattern of human saliva varies with the individual. In fact, Criado et al. (2019) found very large inter-individual differences in saliva viscosity. They reported that human salivary flow, viscosity at 50 s^{-1} and consistency index (K) were parameters that were highly dependent on the individual. A further consideration is that the rheological properties of saliva depend on the level of dysphagia of the patient. In fact, Sukkar et al. (2018) pointed out the need to perform a rheological classification of foods adapted to each patient phenotype, based on the degree of the disease.

Therefore, the aim of this work was to characterize steady and viscoelastic rheological properties of three commercial dysphagia products before and after mixing with the unstimulated saliva of five healthy individuals as the first step towards developing more suitable food products for dysphagia patients.

2. Materials and methods

2.1. Materials

Three commercial thickened fluids belonging to the brand Resource (Nestlé Health Science, Epalinges, Switzerland) that are used for patients with dysphagia were studied. Specifically, they were three instant purées which are eaten as main dish (Resource vegetables and beef (VB), vegetables and codfish (VC), and chicken with rice and carrots (CR)).

All these purées are presented in the form of coloured powder that can easily be dissolved in hot water, but without specifying the water temperature. VB purée consists of meat, vegetables, rice, milk proteins, soy lecithin and celery, and it may contain egg and wheat. VC purée consists of fish, vegetables, rice, milk proteins, soy lecithin and fish, and it may contain egg, wheat, celery, crustaceans and molluscs. In turn, CR purée consists of chicken, carrots, rice and celery, and it may contain milk, egg and wheat.

2.2. Sample preparation

The manufacturers' instructions were followed to reconstitute the purée products. The amount of powder and water was calculated from the amounts recommended on the packages to produce 50 g of a specific purée. For this purpose, the purée samples were always prepared with 10.1 g of powder and 39.9 mL of hot water (85 °C).

First, hot water at 85 °C was initially poured into a 100-mL beaker. Then, the powder was slowly poured and stirred into the water until it was completely dissolved and the mixture was additionally stirred for 2 min in a magnetic stirring device at 600 rpm. Afterwards, the sample was always placed in a water bath at 37 °C for a maximum time of 30 min. The first portion of each sample was measured after 2 min at 37 °C, whereas the last portion of the same sample was measured after as much as 30 min. Samples measured between 2 and 30 min were briefly stirred again for 10 s at 200 rpm to minimize any effects of settling. The manufacturer recommends allowing a few minutes for the purée to reach the desired texture, without further specification.

2.3. Saliva collection

Fresh unstimulated saliva was collected in the morning on various days from 5 healthy volunteers with ages ranging from 22 to 47 years old, recruited from the Institute of Food Science, Technology and Nutrition (ICTAN-CSIC). For 1 h before saliva collection the volunteers were not allowed to smoke, drink or eat. They were instructed to brush their teeth and vigorously rinse their mouths with tap water. The subjects were told to avoid swallowing during the saliva collection process. Unstimulated saliva was spat out directly into a sterile tube as many times as the donors wanted for 5 min. Saliva flow was calculated from the weight of saliva, assuming that 1 g was equal to 1 mL Öztürk et al. (2012). One part of the saliva from each individual was used to carry out the pH measurements and the analysis of saliva composition and another part was used to perform the rheological measurements. For the rheological analysis, the saliva was always used within 1 h of collection, and it was stored at 5 °C. Before use, the collected saliva was first gently mixed in a vortex for 5 s and then rested for 30 s before the rheological measurements. For the composition analysis, the saliva samples were stored at −80 °C.

2.4. Physico-chemical saliva analysis

2.4.1. pH values

A pH-meter (Schott Instruments GmbH, Mainz, Germany) was used to measure the pH of the saliva from the various donors.

2.4.2. Total protein content

The Pierce BCA Protein Assay Kit (Pierce Thermo Scientific, Illinois, USA) was used to measure the total protein content (TPC), with bovine serum albumin as the calibration standard.

2.4.3. α-Amylase activity

The α-Amylase Saliva Assay (IBL International GmbH, Hamburg, Germany) was used to determine the α-amylase concentration, based on the variation of the intensity of colour produced, which is proportional to the α-amylase activity. The α-amylase measurement was performed at room temperature (25 °C).

All the saliva measurements were carried out at least three times.

2.5. Rheological properties

Rheological measurements were carried out with a rotational Kinexus pro rheometer (Malvern Instruments Ltd., UK) equipped with

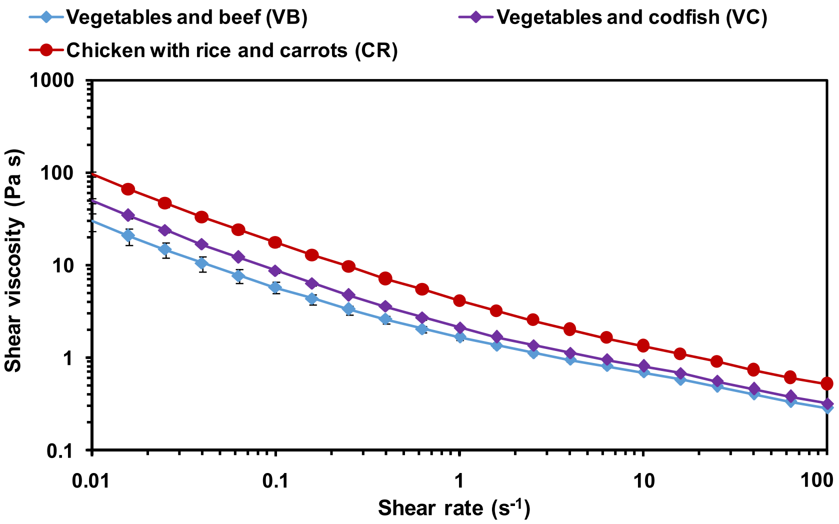

Fig. 1. Apparent viscosity changes versus shear rate of three Resource instant purées (vegetables and beef (VB), vegetables and codfish (VC) and chicken with rice and carrots (CR)). T = 37 °C. Mean values of seven measurements ± standard deviations.

rSpaces of software and a Peltier Plate cartridge in the lower plate for temperature control (resolution to 0.01 °C). A plate-plate measuring geometry of 40 mm (1 mm gap) was used. The rheological tests were performed directly on the three commercial thickened fluids and also on their mixtures with fresh unstimulated human saliva and with water.

Seven different batches of each purée were prepared for rheological measurements: control samples (C), saliva samples (S1, S2, S3, S4 and S5) and water samples (W). The C samples simply corresponded to reconstituted product; the S1–S5 samples and W samples corresponded to 20 g of control sample gently mixed with 1 mL of fresh human saliva from the five volunteers or tap water, respectively, and were rested for 30 s before rheological measurement in a water bath at 37 °C. Therefore, the batches of products mixed with fresh human saliva or water corresponded to a product:saliva or product:water ratio of 20:1. The 20:1 ratio was chosen in order to correspond to a short retention time of these semi-solid products in the mouth, the incorporation of a small amount of saliva. The freshly reconstituted products were mixed with either saliva or water in order to determine whether the effect found after mixing with saliva was associated with the specific composition of the saliva (pH, TPC, α-amylase activity) or only with a dilution effect.

In this study, the instant puréed products were measured at 37 °C, which is between room temperature and the typical serving temperature (35–70 °C), and which is also the human body temperature. In all conscience, this temperature (37 °C) does not coincide with the temperature used by the NDDTF 2002 (25 °C), but we considered it is a more realistic temperature to determine the viscoelastic characteristics of the purées as they are expected to be consumed in a warmer serving temperature.

The samples were rested for 5 min at 37 °C prior to measurements for sample relaxation and temperature equilibration.

All the rheological measurements were performed in triplicate, and the results are expressed as mean ($n = 3$) ± standard deviation.

2.5.1. Steady shear rheological measurements

In order to study viscous flow behaviour, flow curves were obtained as a function of shear rate ranging from 100 to 0.01 s^{-1}. Integration time at each respective shear rate was 20 s. Data from the flow curves of C and W samples were fitted to the Ostwald de Waele or power law fit model ($\eta = K\dot{\gamma}^{n-1}$), where K (Pa s) is the consistency index (corresponding to viscosity at 1 s^{-1}) and n is the flow behaviour index. The saliva (S) samples did not fit the power law model. For the dietary management of dysphagia patients, NDDTF guidelines propose objective viscosity borders and ranges for thickened liquids or food boluses (thin, nectar, honey and spoon-thick). However, classification and ranges are based on shear viscosities measured at 50 s^{-1} at 25 °C as mentioned above. Therefore, it was decided not to use this classification in this study, obtaining the viscosities at 0.1, 1, 10, 50 s^{-1}, K and n from flow curves and compared.

Table 1
Effect of food matrix on the steady shear and the SAOS rheological properties for Resource instant purées.

	Resource instant purées		
Rheological parameter	Vegetables and beef (VB)	Vegetables and codfish (VC)	Chicken with rice and carrots (CR)
Steady-state			
$\eta_{0.1}$ (Pa s)	5.72 ± 0.822c	8.75 ± 0.407 b	17.3 ± 1.01a
η_1 (Pa s)	1.66 ± 0.131c	2.10 ± 0.071 b	4.09 ± 0.224a
η_{10} (Pa s)	0.691 ± 0.029c	0.802 ± 0.024 b	1.33 ± 0.052a
η_{50} (Pa s)	0.402 ± 0.007c	0.454 ± 0.011 b	0.734 ± 0.019a
K (Pa s^n)	2.07 ± 0.195c	2.75 ± 0.081 b	5.04 ± 0.247a
n (−)	0.515 ± 0.026a	0.464 ± 0.008 b	0.437 ± 0.006 b
R^2(Power law)	0.981 ± 0.001	0.981 ± 0.001	0.988 ± 0.001
SAOS measurements			
σ_{max} (Pa)	0.334 ± 0.002 b	0.336 ± 0.001 b	1.02 ± 0.001a
γ_{max} (%)	0.767 ± 0.100a,b	0.891 ± 0.065a	0.684 ± 0.063 b
G^* (Pa)	44.0 ± 5.42 b	37.8 ± 2.70 b	150 ± 13.6a
tan δ(−)	0.351 ± 0.023 b	0.431 ± 0.026a	0.288 ± 0.018c
G' (Pa) at 1 Hz	48.2 ± 8.19c	66.0 ± 0.361 b	128 ± 3.27a
G'' (Pa) at 1 Hz	13.2 ± 2.22 b	16.6 ± 0.700 b	30.5 ± 0.435a
G^* (Pa) at 1 Hz	50.0 ± 8.49c	68.1 ± 0.530 b	132 ± 3.27a
tan δ (−) at 1 Hz	0.273 ± 0.008a	0.252 ± 0.009 b	0.238 ± 0.003c
G'_0 (Pa $s^{n'}$)	47.2 ± 5.39c	66.4 ± 3.70 b	131 ± 4.98a
n' (−)	0.246 ± 0.016a	0.231 ± 0.058a	0.151 ± 0.026 b
R^2 (Power law)	0.977 ± 0.013	0.964 ± 0.012	0.985 ± 0.007
G''_0 (Pa $s^{n''}$)	13.7 ± 0.417c	19.4 ± 0.815 b	33.7 ± 0.619a
n'' (−)	0.267 ± 0.004a	0.234 ± 0.005 b	0.241 ± 0.008 b
R^2 (Power law	0.957 ± 0.020	0.937 ± 0.028	0.932 ± 0.017

Mean values ± standard deviation.
a–c Effect of powder type on Resource instant purées. For each rheological property, mean values without the same letter in the same row are significantly different ($p < 0.05$). $\eta_{0.1}$, η_1, η_{10} and η_{50}, apparent viscosities at shear rates 0.1, 1, 10 and 50 s^{-1}; K and n, consistency index and flow behaviour index from power law fits; R^2, determination coefficient of power law fits; σ_{max}: maximum stress amplitude; γ_{max}: maximum strain amplitude; G^*: maximum complex modulus; tan δ, maximum loss factor ($=G'/G''$) limiting the linear viscoelastic (LVE) range; G', storage modulus at 1 Hz; G'', loss modulus at 1 Hz; G^*, complex modulus at 1 Hz; tan δ, loss factor at 1 Hz; G'_0, G''_0, $n'$and n'', regression coefficients relating G' and $G''$with frequency (f) in Hz; G'_0 and G''_0 correspond to G' and G'' values at 1 Hz.

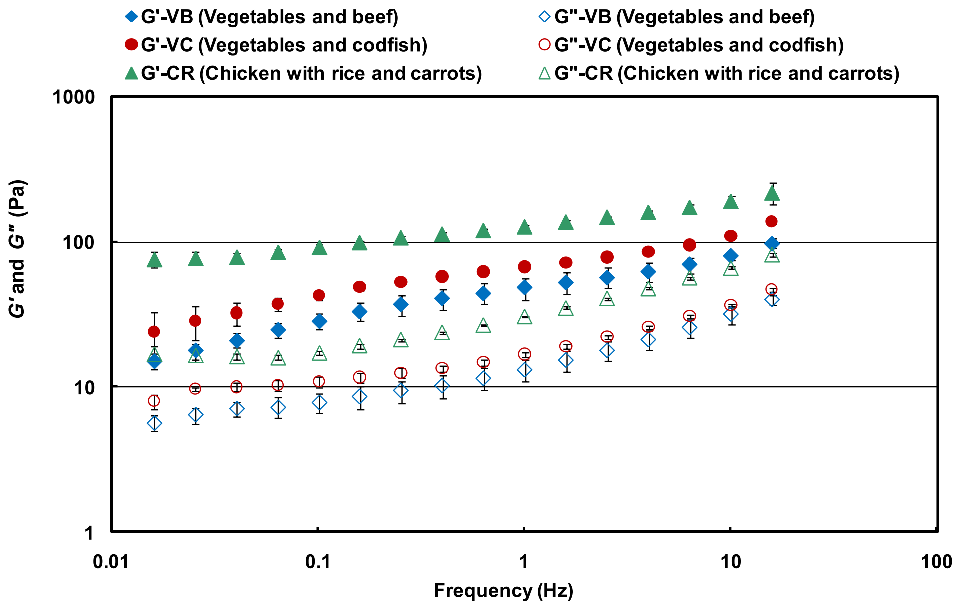

Fig. 2. Mechanical spectra of vegetables and beef (VB), vegetables and codfish (VC) and chicken with rice and carrots (CR) purées. T = 37 °C. Closed symbols: *G*′, open symbols: *G*″. Mean values of seven measurements ± standard deviations.

2.5.2. Small-amplitude oscillatory shear (SAOS) measurements

To determine the linear viscoelastic (LVE) range, stress sweeps were run at 1 Hz with the shear stress (σ) of the input signal varying from 0.1 to 100 Pa for C and W samples, and from 0.01 to 10 Pa for S samples. Then, frequency sweeps were run, subjecting the samples to a stress that varied harmonically with time at variable frequencies from 0.016 to 16 Hz. Periods at each frequency ranged between 110 and 11 s for lower and higher frequencies, respectively. The strain amplitude was set at $\gamma = 0.2\%$ for C and W samples and at $\gamma = 0.1\%$ for S samples, within the LVE region (previously determined from stress sweeps).

2.6. Statistical analysis

One-way analysis of variance was carried out with the SPSS computer program (SPSS Inc., Chicago, IL, USA), and differences between pairs of means were evaluated by the Tukey test, using a 95% confidence interval.

3. Results and discussion

3.1. Rheological characterization of control dysphagia-oriented products

3.1.1. Steady-state measurements

Fig. 1 shows the viscous flow behaviour of the three instant purées. It can be seen that there was a clear trend of pseudoplasticity (shear-thinning behaviour) and all the samples showed a non-Newtonian flow, which is more suitable for patients with dysphagia because this type of fluid can slow down the swallowing process and make it possible to swallow a small amount of bolus (Meng et al., 2005). Table 1 provides the results obtained from the steady shear measurements for the three C samples. The values at a shear rate of 50 s^{-1} showed that the three purées exhibited different consistencies, with CR presenting higher consistency than VB and VC (Fig. 1). Cutler et al. (1983) reported that shear rate at 50 s^{-1} is not feasible for dysphagic patients or older people more fragile because they were not able to develop this high rate. They proposed lower shear rates more specific for shear thinning products. In detail, the shear rate at 0.1, 1 and 10 s^{-1} were also chosen to compare the viscosity among these shear thinning products. Payne et al. (2011) characterized rheologically two instant thickening agents and three pre-thickened commercial beverages (orange and apple juice-based) for dysphagia patients. They highlighted the importance of measure the viscosity at low shear rates as a transient increase in apparent viscosity of the bolus is accompanied with the decrease in shear rate associated with the swallowing process (Meng et al., 2005). As it can be observed in Table 1, the three instant purées showed an important increase in viscosity as the shear rate decreased. This was also reported by Payne et al. (2011).

On the other hand, the flow behaviour index, *n*, and the consistency index, *K*, of the three purées studied differed significantly, depending on the thickener composition. At all the shear rates selected, CR purée yielded *K* and viscosity values that were nearly 2-fold higher than those of the other two instant purées. However, this purée also had a lower *n* value, indicating higher pseudoplastic behaviour, although there were no significant differences between the flow index value of this instant purée and that of the VC one. The degree of shear-thinning behaviour is closely related to the safety of swallowing thickened products (Gallegos et al., 2017). It has been said that the viscosity of a thickened product with a low flow index decreases to quite low values as the shear rate increases (e.g. in the pharynx), and this may increase the risk of aspiration in dysphagia patients (Gallegos et al., 2012). On the other hand, a thickened product with a higher flow index, such as VB, could remain relatively viscous at high shear rates, and thus may facilitate a safe swallowing process. However, in this study, VB purée had significantly lower *K* and viscosity values, both at high shear rates (10 and 50 s^{-1}) and at lower shear rates (0.1 and 1 s^{-1}) than the other two Resource instant purées studied.

In nectar-like products (51–350 mPa s or 0.051–0.350 Pa s), such as cocoa drink, a positive correlation between safe and easy swallowing and consistency index and apparent viscosity was also reported by Zargaraan et al. (2015), as higher viscosities reduce the speed of bolus flow. The authors just cited also stated that reporting single-point viscosity could be too simplistic for describing oropharyngeal swallowing. In this context, the consistency index, corresponding to viscosity at 1 s^{-1}, obtained from steady-state shear rate tests, may be used as a reference parameter. Cho and Yoo (2015) used this parameter to compare four commercial instant xanthan gum-based thickeners in five media (orange juice, apple juice, grape juice, whole milk and a sports drink). The *n*, *K* and η_{50} values for the three instant purées studied here are quite similar to those obtained by those authors for cold thickened whole milk with the four commercial thickeners containing xanthan gum. However, it is worth pointing out that in all these mentioned studies the viscosity measurements were done at 25 °C.

3.1.2. SAOS measurements

Table 1 also shows the rheological parameters of the three purées within the limits of the LVE range. Critical (maximum) shear stress ($\sigma_{\max}$) and strain ($\gamma_{\max}$) amplitudes, complex modulus (G^*) and loss factor (tan δ) were used to limit the LVE range. Critical $\sigma_{\max}$ and $\gamma_{\max}$ values can be taken as measurements of rheological stability (Mezger, 2011). It is thought that these viscoelastic parameters could be more suitable parameters to characterize dysphagia products than those obtained from viscosity measurements (like consistency or viscosity at different shear rates) because they allow measuring the shear rate dependence of the product without destroying the sample (Payne et al., 2011). Thus, they provided the sample behaviour closer way to physiological conditions. In this sense, G^* provides the resistance to deformation while $\sigma_{\max}$ contributes the structural stability, $\gamma_{\max}$ provides structural deformability and tan δ supplies the elasticity degree. Therefore, all these parameters were used to compare the three instant purées providing the overall structure of the products. They were obtained by defining the range of tolerable deviation as 10% (Campo-Deaño & Tovar, 2009). Results showed that, among the three instant purées, CR had a more rigid matrix (higher G^*) with higher structural stability (higher $\sigma_{\max}$) and degree of elasticity (lower tan δ) than the other two instant purée samples, while VC showed the highest degree of structural deformability (higher $\gamma_{\max}$) but the lowest elasticity (highest tan δ) (Mezger, 2011). Thus, CR instant purée showed a different viscoelastic behaviour compared to VB and VC. These differences in the rheological behaviour could influence the swallowing process (Nström, Qazi, Bülow, Ekberg, & Stading, 2015). These authors proved that dysphagic patients perceived swallowing easier for thinning fluids with increased elasticity (the form of so-called Boger fluids). Therefore, CR control would be safer to swallow because of its high elasticity degree and it is more resistant to deformation as shown by its high structural stability unlike it had a lower flow index (n) than VB. Therefore, a better control of the rheological properties over a broader range of deformation it would be more beneficial in dysphagia management.

The mechanical spectra of the instant purée samples are shown in Fig. 2. All these dysphagia-oriented products had storage modulus (G') greater than loss modulus (G''), and showed a structured liquid character given its considerable frequency dependence for both moduli in the whole frequency range studied (Nishinari, 2009; Ross-Murphy, 2008). The three instant purées (Fig. 2) had similar patterns but VB and VC purées had lower moduli values than the CR one. These results are in accordance with the ones obtained from the flow curves in which CR showed the highest consistency and viscosity values at both low and high rates.

Note that for CR purée the G' values were above 100 Pa at high frequencies (1–100 Hz) but below 100 Pa at low frequencies (0.01–1 Hz), and for VB and the VC purées they were below 100 Pa. In general, for all the purée products, the G'' values were below 100 Pa but still well above 10 Pa. This result is in accordance with the results of a study performed by Moret-Tatat et al. (2015) because the G' and G'' values are between the values obtained by those authors for two Resource thickeners dissolved in water.

In all the control products the frequency dependence of G' and G'' corresponded to straight lines in the log-log plots and therefore, G'_0 (f) and G''_0 (f) could be fitted to power law equations:

$$G' = G'_0 f^{n'}$$

$$G'' = G''_0 f^{n''}$$

where G'_0 and G''_0 are storage and loss moduli at 1 Hz, respectively, and n' and n'' (both dimensionless) denote the frequency (f) dependence expressed in Hz of the two moduli. The results obtained for all the products are also shown in Table 1. The CR purée showed significantly higher G'_0 and G''_0 and lower n' values than the other two instant purées. Moreover, both CR and VC purées had significantly ($p < 0.05$) lower n'' values than that of VB one. Therefore, CR purée behaved like a stronger gel because of the lower frequency dependence of its two viscoelastic moduli.

Table 2
Physico-chemical properties of the five unstimulated salivas.

Saliva samples	Flow (mL/min)	pH	TPC (mg/L)	α-amylase (U/mL)
1	0.542 ± 0.001a	7.11 ± 0.010	618 ± 48.7c	65.8 ± 2.47 b
2	0.337 ± 0.001 b	6.79 ± 0.005	914 ± 67.8 b	85.3 ± 6.99a
3	0.355 ± 0.001 b	7.01 ± 0.005	1913 ± 4.06a	88.8 ± 4.93a
4	0.302 ± 0.001 b	6.60 ± 0.005	524 ± 35.2 d	23.5 ± 0.162c
5	0.524 ± 0.001a	7.16 ± 0.010	1855 ± 95.6a	58.6 ± 2.81 b
Average	0.412 ± 0.001	6.93 ± 0.007	1165 ± 50.3	64.4 ± 3.47

Mean values ± standard deviation.
Values followed by the same letter within each physico-chemical property indicate no significant differences ($p < 0.05$).

On the other hand, the G'_0 values for VB and VC instant purées were between those reported by Moret-Tatay et al. (2015) for dysphagia-oriented thickened beverages. In contrast, the authors just cited reported much lower n' values than those obtained in this study. However, the n' values obtained in the present study matched the ones observed in an earlier study on Ferni (an Iranian dessert used as a dysphagia-oriented food product), for which the values of n' ranged between 0.18 and 0.24 (Zargaraan et al., 2015).

3.2. Effect of addition of human saliva to dysphagia-oriented products

3.2.1. Physico-chemical composition of saliva

Table 2 shows the values for some physic-chemical parameters of the saliva collected from the five individuals, together with average values. The pH values of the saliva samples from the five individuals were quite similar (average value 6.93 ± 0.007). These values are in agreement with those reported as normal values in previous studies (Ferry et al., 2004; Humphrey & Williamson, 2001). However, there were significant differences between the unstimulated flow rate values of the participants. The values ranged between 0.302 and 0.524 mL/min and thus, in general, they were lower than others previously reported under unstimulated conditions (0.64 ± 0.40 mL/min) (Neyraud et al., 2012). These differences in saliva flow rates might be associated with genetic factors, gender or age, among other things (Criado et al., 2019; Fischer et al., 1994; Guinard et al., 1997; Neyraud et al., 2012). Moreover, inter-individual variability was also found in total protein content (TPC) and α-amylase but no individual pattern could be defined, which could be due to the relatively low number of individuals used in this study. Individuals 3 and 5 showed the highest protein content while individual 4 showed the lowest protein content and α-amylase activity. These results show high variability in the saliva composition, especially in α-amylase activity, which might have affected the rheological behaviour when the saliva was mixed with the commercial products used for patients with dysphagia.

3.3. Rheological properties of control samples with added saliva or water

3.3.1. Steady-state measurements

With regard to the effect of the addition of human saliva, in general, as can be seen in Fig. 3, all the instant purées followed a similar pattern,

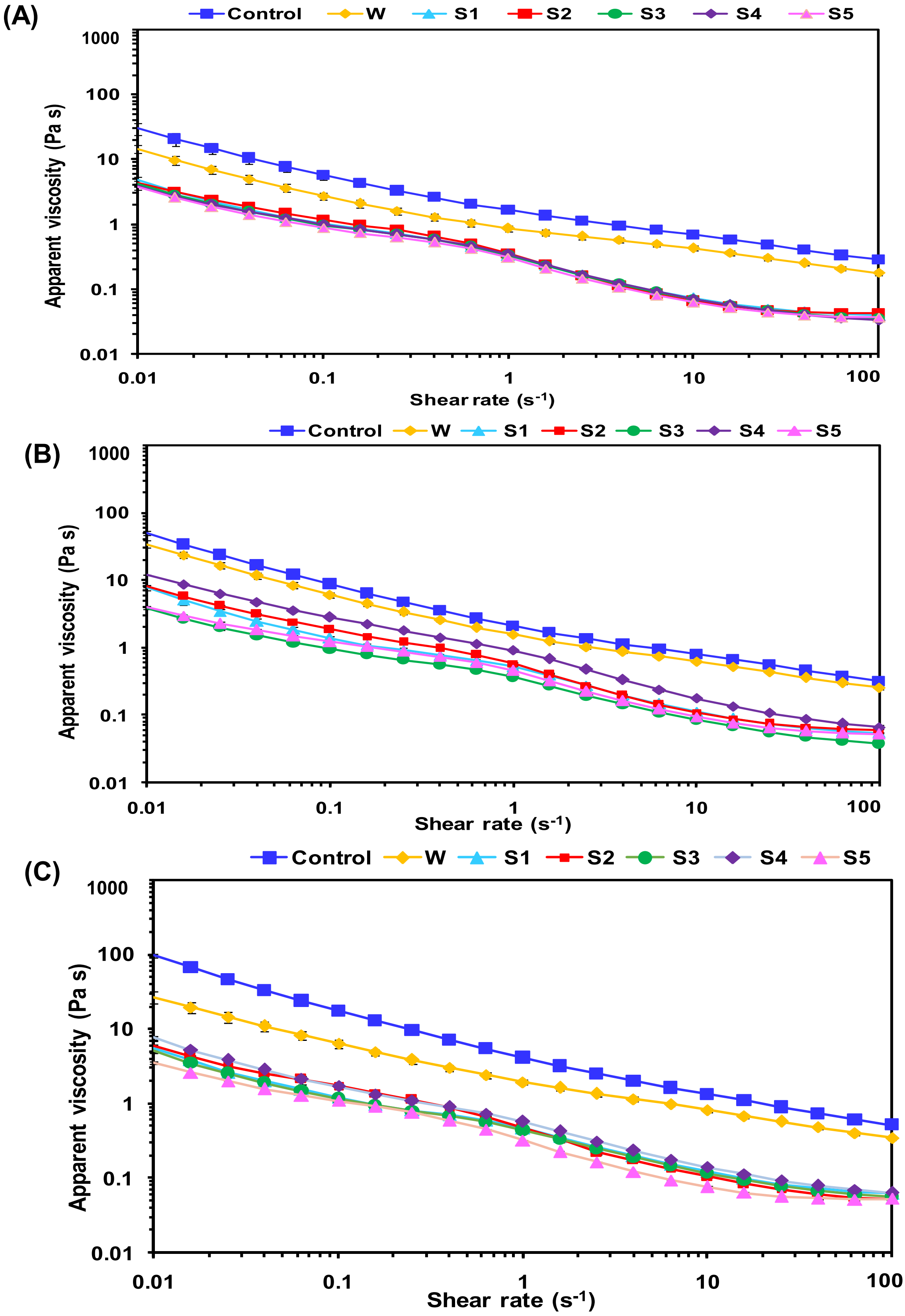

Fig. 3. Viscous flow behaviour of the three Resource instant purées mixed with water (W) and unstimulated saliva from five healthy individuals (S1–S5) at a ratio of 20:1; (A) vegetables and beef (VB) purée; (B) vegetables and codfish (VC) purée; (C); and chicken with rice and carrots (CR) purée. T = 37 °C. Mean values of seven measurements ± standard deviations.

Table 3
Effect of unstimulated saliva (S1–S5) and water (W) on the steady shear rheological properties for Resource instant vegetables and beef (VB) and vegetables and codfish (VC) purées.

	K (Pa s^n)	n (−)	R^2	$\eta_{0.1}$ (Pa s)	η_1 (Pa s)	η_{10} (Pa s)	η_{50} (Pa s)
Vegetables and beef (VB)							
C	2.07 ± 0.195^{a}	0.515 ± 0.026^{b}	0.981 ± 0.001	5.72 ± 0.822^{a}	1.66 ± 0.131^{a}	0.691 ± 0.029^{a}	0.402 ± 0.007^{a}
W	1.12 ± 0.122^{b}	0.554 ± 0.009^{a}	0.972 ± 0.002	2.70 ± 0.342^{b}	0.866 ± 0.086^{b}	0.427 ± 0.039^{b}	0.252 ± 0.019^{b}
S1	$0.312 \pm 0.018^{c}_{A,B}$	$0.460 \pm 0.002^{c}_{A}$	0.989 ± 0.001	$1.01 \pm 0.024^{c}_{A,B}$	$0.326 \pm 0.026^{c}_{A}$	$0.073 \pm 0.024^{c}_{A}$	$0.049 \pm 0.003^{c,d}_{A,B}$
S2	$0.320 \pm 0.004^{c}_{A}$	$0.453 \pm 0.020^{c}_{A}$	0.983 ± 0.003	$1.17 \pm 0.085^{c}_{A}$	0.349 ± 0.012^{cA}	$0.065 \pm 0.003^{c}_{A,B}$	$0.051 \pm 0.0001^{c}_{A}$
S3	$0.298 \pm 0.014^{c}_{A,B}$	$0.462 \pm 0.003^{c}_{A}$	0.991 ± 0.001	$0.969 \pm 0.038^{c}_{A,B}$	$0.331 \pm 0.019^{c}_{A}$	$0.070 \pm 0.004^{c}_{A,B}$	$0.045 \pm 0.002^{d,e}_{B,C}$
S4	$0.297 \pm 0.026^{c}_{A,B}$	$0.461 \pm 0.002^{c}_{A}$	0.992 ± 0.001	$1.00 \pm 0.131^{c}_{A,B}$	$0.345 \pm 0.041^{c}_{A}$	$0.071 \pm 0.005^{c}_{A,B}$	$0.043 \pm 0.002^{e}_{C}$
S5	$0.272 \pm 0.016^{c}_{B}$	$0.470 \pm 0.010^{c}_{A}$	0.987 ± 0.001	$0.873 \pm 0.075^{c}_{B}$	$0.303 \pm 0.013^{c}_{A}$	$0.062 \pm 0.002^{c}_{B}$	$0.045 \pm 0.001^{d,e}_{B,C}$
Average S	0.300 ± 0.018	0.461 ± 0.006	0.987 ± 0.001	0.873 ± 0.075	0.303 ± 0.013	0.062 ± 0.002	0.045 ± 0.001
Vegetables and codfish (VC)							
C	2.75 ± 0.081^{a}	$0.464 \pm 0.008^{b,c}$	0.981 ± 0.001	8.75 ± 0.407^{a}	2.10 ± 0.071^{a}	0.802 ± 0.024^{a}	0.454 ± 0.011^{a}
W	2.03 ± 0.136^{b}	$0.483 \pm 0.010^{a,b}$	0.979 ± 0.001	6.04 ± 0.584^{b}	1.57 ± 0.061^{b}	0.626 ± 0.023^{b}	0.361 ± 0.013^{b}
S1	$0.464 \pm 0.030^{d,e}_{C}$	$0.459 \pm 0.010^{c}_{B}$	0.990 ± 0.001	$1.38 \pm 0.108^{e,f}_{C}$	$0.524 \pm 0.026^{d,e}_{B,C}$	$0.112 \pm 0.005^{d}_{B}$	$0.070 \pm 0.020^{d,e}_{BC}$
S2	$0.524 \pm 0.080^{d}_{B}$	$0.432 \pm 0.007^{d}_{C}$	0.989 ± 0.002	$1.86 \pm 0.036^{d}_{B}$	$0.585 \pm 0.032^{d}_{B}$	$0.110 \pm 0.002^{d}_{B,C}$	$0.075 \pm 0.004^{c,d}_{B}$
S3	$0.318 \pm 0.014^{e}_{E}$	$0.491 \pm 0.003^{b}_{A}$	0.994 ± 0.001	$0.951 \pm 0.044^{f}_{D}$	$0.372 \pm 0.021^{f}_{D}$	0.085 ± 0.004^{dD}	$0.050 \pm 0.002^{e}_{D}$
S4	$0.780 \pm 0.031^{c}_{A}$	$0.421 \pm 0.006^{d}_{C}$	0.996 ± 0.001	$2.81 \pm 0.047^{c}_{A}$	$0.910 \pm 0.039^{c}_{A}$	$0.177 \pm 0.009^{c}_{A}$	$0.091 \pm 0.005^{c}_{A}$
S5	$0.385 \pm 0.017^{d,e}_{D}$	$0.499 \pm 0.002^{a}_{A}$	0.989 ± 0.001	$1.24 \pm 0.034^{e,f}_{C}$	$0.458 \pm 0.029^{e,f}_{C}$	$0.095 \pm 0.007^{d}_{C,D}$	$0.065 \pm 0.003^{d,e}_{C}$
Average S	0.494 ± 0.178	0.460 ± 0.035	0.992 ± 0.003	1.65 ± 0.730	0.570 ± 0.206	0.116 ± 0.036	0.070 ± 0.015

Mean values ± standard deviation.

a–eFor each type of product, different small letters indicate significant differences ($p < 0.05$) among rheological properties of control (C), water (W) and saliva (S1–S5) samples.

A–EFor each type of purée, different capital letters indicate significant differences ($p < 0.05$) among the rheological properties of the S1–S5 saliva samples from the 5 volunteers. K and n, consistency index and flow behaviour index from power law fits; R2, determination coefficient of power law fits; η0.1, η1, η10 and η50, apparent viscosities at shear rates 0.1, 1, 10 and 50 s−1.

Average S: average of S1, S2, S3, S4 and S5 samples.

Table 4
Effect of unstimulated saliva (S1–S5) and water (W) on the steady shear rheological properties for Resource instant chicken with rice and carrots (CR) purée.

	K (Pa s^n)	n (−)	R^2	$\eta_{0.1}$ (Pa s)	η_1 (Pa s)	η_{10} (Pa s)	η_{50} (Pa s)
Chicken with rice and carrots (CR)							
C	5.04 ± 0.247^{a}	0.437 ± 0.006^{e}	0.988 ± 0.001	17.3 ± 1.01^{a}	$4.01 \pm 0.224a$	1.33 ± 0.052^{a}	0.734 ± 0.019^{a}
W	2.34 ± 0.02^{b}	0.540 ± 0.018^{a}	0.988 ± 0.001	6.33 ± 0.719^{b}	1.94 ± 0.169^{b}	0.817 ± 0.049^{b}	0.540 ± 0.018^{b}
S1	$0.434 \pm 0.004^{c}_{B,C}$	$0.508 \pm 0.013^{a,b}_{A}$	0.991 ± 0.001	$1.20 \pm 0.028^{c}_{B}$	$0.467 \pm 0.004^{c}_{B}$	$0.121 \pm 0.003^{c}_{B}$	$0.079 \pm 0.002^{c}_{B}$
S2	$0.452 \pm 0.021^{c}_{B}$	$0.452 \pm 0.019^{d,e}_{D}$	0.990 ± 0.001	$1.72 \pm 0.181^{c}_{A}$	$0.472 \pm 0.003^{c}_{B}$	$0.105 \pm 0.001^{c}_{C}$	$0.067 \pm 0.0005^{c}_{D}$
S3	$0.411 \pm 0.006^{c}_{C}$	$0.507 \pm 0.003^{a,b}_{A}$	0.993 ± 0.001	$1.16 \pm 0.008^{c}_{B}$	$0.442 \pm 0.017^{c}_{C}$	$0.116 \pm 0.001^{c}_{B}$	$0.073 \pm 0.003^{c}_{C}$
S4	$0.538 \pm 0.010^{c}_{A}$	$0.473 \pm 0.012^{c,d}_{B,C}$	0.995 ± 0.001	$1.69 \pm 0.068^{c}_{A}$	$0.569 \pm 0.005^{c}_{A}$	$0.139 \pm 0.002^{c}_{A}$	$0.083 \pm 0.002^{c}_{A}$
S5	$0.319 \pm 0.004^{c}_{A}$	$0.497 \pm 0.003^{b,c}_{A,B}$	0.981 ± 0.001	$1.08 \pm 0.008^{c}_{B}$	$0.320 \pm 0.004^{c}_{D}$	$0.076 \pm 0.002^{c}_{D}$	$0.063 \pm 0.001^{c}_{E}$
Average S	0.431 ± 0.079	0.487 ± 0.024	0.990 ± 0.005	1.37 ± 0.309	0.454 ± 0.089	0.111 ± 0.024	0.073 ± 0.009

Mean values ± standard deviation.

[a–e]For each type of product, different small letters indicate significant differences ($p < 0.05$) among rheological properties of control (C), water (W) and saliva (S1–S5) samples.

[A–E] For each type of purée, different capital letters indicate significant differences ($p < 0.05$) among the rheological properties of the S1–S5 saliva samples from the 5 volunteers. K and n, consistency index and flow behaviour index from power law fits; R^2, determination coefficient of power law fits; $\eta_{0.1}$, η_1, η_{10} and η_{50}, apparent viscosities at shear rates 0.1, 1, 10 and 50 s^{-1}.

Average S: average of S1, S2, S3, S4 and S5 samples.

with all the water (W) and saliva samples (S1–S5) showing flow curves with typical shear-thinning behaviour ($n < 1$), as observed for the control (C) samples. However, all the saliva flow curves were very close, showing a very notable decrease in viscosity with respect to the C samples in the entire range of shear rates studied. The addition of water did not produce as remarkable a reduction of viscosity as the addition of saliva, with flow curves much closer to those of the C samples. However, the values of the consistency index (K) and apparent viscosities at 0.1, 1, 10 and 50 s^{-1} were significantly lower ($p < 0.05$) than those of their respective controls for all the W samples (Tables 3 and 4). For example, the viscosity values at 10 and 50 s^{-1} of the W samples showed decreases of 21.9% and 20.5% in VC, of 37.5% and 38.6% in VB (Table 3), and of 38.6% and 26.4% in CR purée (Table 4), respectively.

The addition of saliva produced a more significant ($p < 0.05$) decrease of the K value and the viscosity values at shear rates of 0.1, 1, 10 and 50 s^{-1}, with additional significant differences ($p < 0.05$) among the various saliva samples (Tables 3 and 4). In general, the values ofη_{10} and η_{50}, decreased in comparison with their respective original values (C samples) by percentages of around 91% and 88.4% in VB, 85.5% and 83.7% in VC, 91.6% and 90.1% in CR (average value of S1–S5), respectively. Therefore, the highest percentages of decrease of all the steady rheological parameters in the products with added saliva were observed in CR purée (Table 4). These results are also in accordance with those obtained by other authors in starch-thickened drinks used for dysphagia patients, with a reduction of around 99–99.9% of initial viscosity (η_{50}) by the addition of small quantities of saliva to thickened water in less than 10 min (Hanson et al., 2012; Lee et al., 2016). Note that in all these studies the η_{50} was measured at 25 °C while our measurements were carried out at 37 °C. Moreover, these results demonstrate the fundamental role of the α-amylase enzyme, which hydrolyses starch, breaking down its complex structure (Dokic et al., 2004; Turcanu et al., 2018), even at this small proportion (20:1), and irrespective of the dilution effect caused by the incorporation of additional liquid.

On the other hand, the flow index (n) increased significantly in the W samples of the three instant purées, in accordance with the expected dilution effect produced by the water. However, in general, addition of saliva (average value of S1–S5) produced a reduction of the n value in VB purée (Table 3) and an increase in CR one (Table 4). Therefore, it

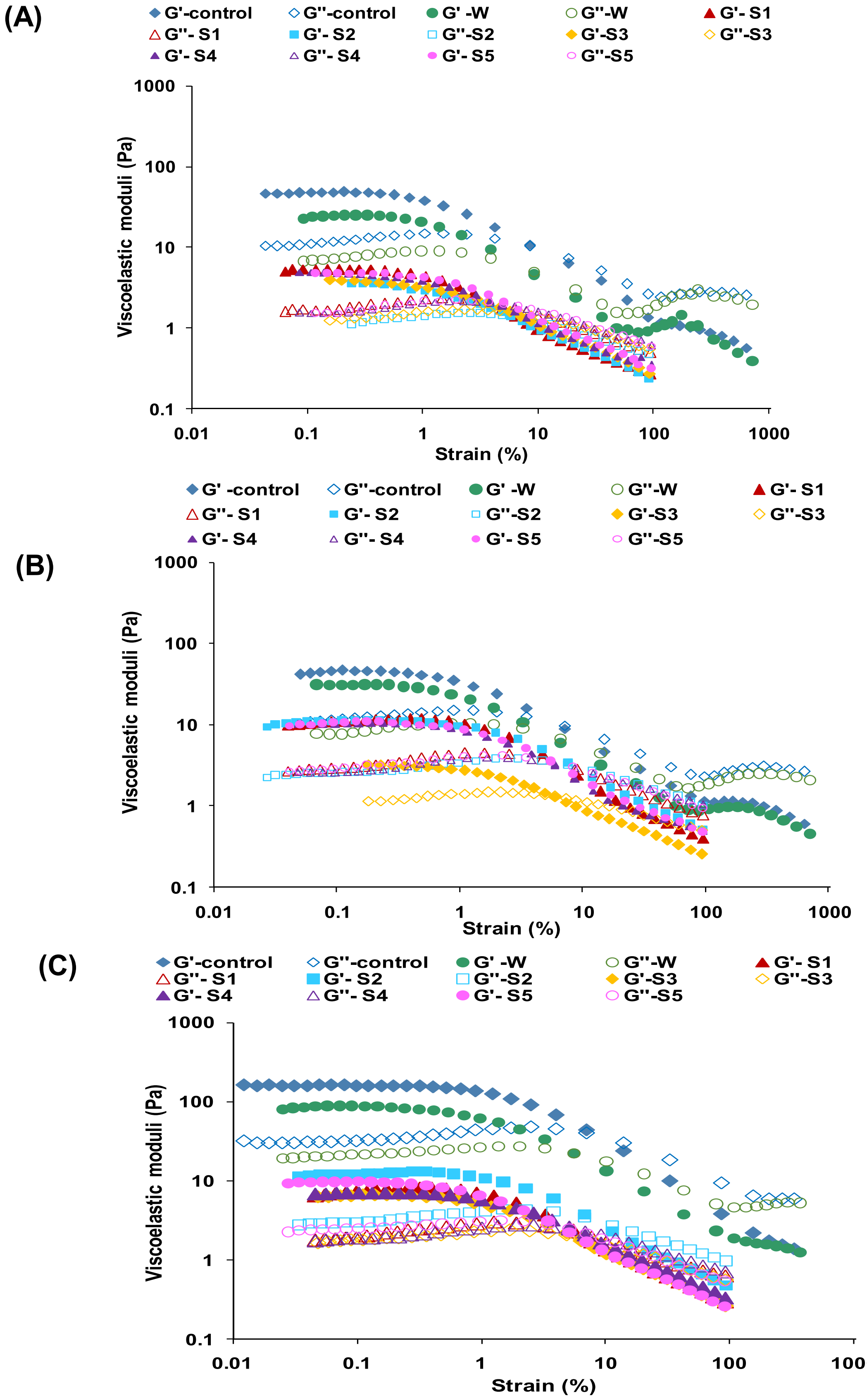

Fig. 4. G' (closed symbols) and G'' (open symbols) of three Resource instant purées mixed with water (W) and unstimulated saliva from five healthy individuals (S1–S5) at a ratio of 20:1 as a function of strain at a frequency of 1 Hz; (A) vegetables and beef (VB) purée; (B) vegetables and codfish (VC) purée; and (C) chicken with rice and carrots (CR) purée. T = 37 °C. Mean values of seven measurements ± standard deviations.

Table 5
Effect of unstimulated saliva (S1–S5) and water (W) on the parameters of LVE from stress sweeps for Resource instant vegetables and beef (VB) and vegetables and codfish (VC) purées.

Samples	$\sigma_{\max}$ (Pa)	$\gamma_{\max}$ (%)	G^* (Pa)	tan δ (−)
Vegetables and beef (VB)				
C	0.334 ± 0.002^{a}	0.767 ± 0.010$^{b\text{-}d}$	44.0 ± 5.42^{a}	0.351 ± 0.023^{c}
W	0.221 ± 0.001^{b}	0.985 ± 0.039^{b,c}	22.4 ± 0.825^{b}	0.437 ± 0.025^{b,c}
S1	0.051 ± 0.003$^{d}_{B}$	1.06 ± 0.227$^{b}_{B}$	4.92 ± 0.691$^{c}_{A}$	0.537 ± 0.052$^{a,}_{A,B}$
S2	0.027 ± 0.0001$_{C}$	0.820 ± 0.057$^{b,c}_{B,C}$	3.31 ± 0.244$^{c}_{C}$	0.460 ± 0.046$^{a\text{-}c}_{A\text{-}C}$
S3	0.026 ± 0.001$^{e}_{C}$	0.696 ± 0.082$^{c,d}_{C,D}$	3.72 ± 0.277$^{c}_{B,C}$	0.437 ± 0.013$^{b,c}_{B,C}$
S4	0.022 ± 0.002$^{e}_{C}$	0.472 ± 0.098$^{d}_{D}$	4.64 ± 0.483$^{c}_{A,B}$	0.409 ± 0.040$^{c}_{C}$
S5	0.066 ± 0.002$^{c}_{A}$	1.43 ± 0.024$^{a}_{A}$	4.46 ± 0.010$^{c}_{A,B}$	0.562 ± 0.041$^{a}_{A}$
Average S	0.038.±0.002	0.896 ± 0.366	4.21 ± 0.673	0.481 ± 0.066
Vegetables and codfish (VC)				
C	0.336 ± 0.001^{a}	0.891 ± 0.065^{b,c}	37.8 ± 2.70^{a}	0.431 ± 0.026^{a,b,c}
W	0.172 ± 0.001^{b}	0.612 ± 0.040^{c}	28.2 ± 1.70^{b}	0.382 ± 0.013^{c}
S1	0.158 ± 0.001$^{c}_{A}$	1.57 ± 0.046$^{a}_{A,B}$	10.0 ± 0.205$^{c}_{A}$	0.511 ± 0.031$^{a,b}_{A}$
S2	0.165 ± 0.006$^{b,c}_{A}$	1.93 ± 0.324$^{a}_{A}$	8.76 ± 1.18$^{c}_{A}$	0.480 ± 0.029$^{a\text{-}c}_{A}$
S3	0.033 ± 0.001$^{f}_{D}$	1.08 ± 0.109$^{B,C}_{b}$	3.07 ± 0.238$^{B}_{d}$	0.522 ± 0.006$^{A}_{a}$
S4	0.081 ± 0.002$^{e}_{C}$	0.841 ± 0.099$^{b,c}_{C}$	9.74 ± 0.031$^{c}_{A}$	0.411 ± 0.025$^{b,c}_{A}$
S5	0.102 ± 0.003$^{d}_{B}$	1.09 ± 0.200$^{b}_{B,C}$	9.57 ± 1.48$^{c}_{A}$	0.481 ± 0.080$^{a\text{-}c}_{A}$
Average S	0.108 ± 0.055	1.30 ± 0.439	8.24 ± 2.92	0.481 ± 0.043

Mean values ± standard deviation.
[a–e] For each type of product, different small letters indicate significant differences ($p < 0.05$).
Among rheological properties of control (C), water (W) and saliva (S1–S5) samples.
[A–D] For each type of purée, different capital letters indicate significant differences ($p < 0.05$) among the rheological properties of the S1–S5 saliva samples from the 5 volunteers.
Average S: average of S1, S2, S3, S4 and S5 samples.

seems that CR purée would be safer to swallow than the other purée products.

With regard to the individual effect of the saliva from the various donors, significant differences were found between the rheological properties of the various S samples (S1–S5) for each type of product, but without a fixed tendency. It is worth mentioning that sample S4 had the highest *K* and viscosity values of all the products, except VB purée (Tables 3 and 4). However, S4 also had the lowest values of total protein content (TPC) and α-amylase activity (Table 2). This means that the saliva composition might affect the rheological behaviour of these dysphagia-oriented products. Therefore, dysphagia products might behave in different ways during pharyngeal transit, depending on the composition of the saliva of each individual. However, to confirm this statement, a larger number of subjects would be needed, in order to obtain greater variability of saliva composition. In fact, Criado et al. 2019 recently demonstrated a relationship between saliva viscosity and some protein and esterase activity of saliva. In that study, the authors found that the saliva with the highest TPC and total esterase activity was also the most viscous saliva. Note the fact that saliva was unstimulated, and therefore, the products were tested unaltered, mixed with water or with unstimulated human saliva. The stimulation could affect both the mucin and the α-amylase concentration, and as a consequence the overall rheological behaviour of saliva (Turcanu et al., 2015).

Table 6
Effect of unstimulated saliva (S1–S5) and water (W) on the parameters of LVE from stress sweeps.

Samples	$\sigma_{\max}$ (Pa)	$\gamma_{\max}$ (%)	G* (Pa)	tan δ (−)
Chicken with rice and carrots (CR)				
C	1.02 ± 0.001^{a}	0.684 ± 0.063^{c,d}	150 ± 13.6^{a}	0.288 ± 0.018^{d}
W	0.411 ± 0.002^{b}	0.549 ± 0.089^{c,d}	76.1 ± 11.0^{b}	0.344 ± 0.030^{c,d}
S1	0.116 ± 0.004$^{d}_{B}$	1.95 ± 0.280$^{a}_{A}$	6.03 ± 0.649$^{c}_{B,C}$	0.566 ± 0.015$^{a}_{A}$
S2	0.158 ± 0.004$^{c}_{A}$	1.53 ± 0.220$^{a,b}_{A,B}$	10.5 ± 1.28$^{c}_{A}$	0.455 ± 0.053$^{b}_{B}$
S3	0.034 ± 0.006$^{e}_{C}$	0.871 ± 0.095$^{c,d}_{C}$	5.70 ± 0.412$^{c}_{C}$	0.429 ± 0.023$^{b,c}_{B,C}$
S4	0.060 ± 0.005$^{e}_{C}$	1.01 ± 0.301$^{b,c}_{B,C}$	6.14 ± 1.63$^{c}_{B,C}$	0.455 ± 0.039$^{b}_{B}$
S5	0.042 ± 0.001$^{e}_{C}$	0.494 ± 0.032$^{d}_{C}$	8.61 ± 0.454$^{c}_{A,B}$	0.348 ± 0.034$^{c,d}_{C}$
Average S	0.082 ± 0.053	1.17 ± 0.572	7.40 ± 2.10	0.450 ± 0.078

Mean values ± standard deviation.
[a–e]For each type of product, different small letters indicate significant differences ($p < 0.05$).
Among rheological properties of control (C), water (W) and saliva (S1–S5) samples.
[A–D] For each type of purée, different capital letters indicate significant differences ($p < 0.05$) among the rheological properties of the S1–S5 saliva samples from the 5 volunteers.
Average S: average of S1, S2, S3, S4 and S5 samples.

3.3.2. SAOS measurements

Fig. 4 shows the linear viscoelastic (LVE) range spectra from stress sweeps of C, W and S1–S5 for each type of purée, where storage modulus (G') and viscous modulus (G'') are represented as a function of the strain applied. For all the samples, G' was higher than G'', showing a structured-liquid character in the whole LVE range, although both viscoelastic moduli were considerably lower in all the S samples. CR purée presented the most extended LVE range for both C and W samples which means that this sample has a more stable network. In particular, for the C and W samples, the LVE limit was at strains below 1.0%. In the case of the S1–S5 samples, there was high variability in the maximum strain values ($\gamma_{\max}$), which were between 0.47 and 1.43% for VB, 0.84–1.43% for VC, and 0.49–1.95% for CR.

The principal viscoelastic parameters ($\sigma_{\max}$, $\gamma_{\max}$, G^* and tan δ), defining the LVE range, were also examined in the W and S samples as compared with the C ones (Tables 5 and 6). As can be seen, there was a significant dilution effect when water was added, while the addition of saliva produced an almost complete breakdown of the conformational structure in each type of product. Specifically, the addition of saliva (average S) produced a notable reduction of $\sigma_{\max}$ and G^* and an increase of loss factor (tan δ) in comparison with their control counterparts. Moreover, an increase in structural flexibility (higher $\gamma_{\max}$) was observed in VC and CR purées. This means that saliva addition produces physical changes in the products' networks making them less resistant to deformation and preparing them for a safer swallowing. Moreover, CR purée showed the highest percentages of reduction of $\sigma_{\max}$ and G^*: 88.5% and 90.4%, respectively. These results are in accordance with those obtained in the steady measurements in which a decrease of viscosity was observed, as shown by the remarkable decrease of their *K* and η_{10} and η_{50} parameters, probably caused by the effect of α-amylase. Therefore, these different changes in the structural conformation of the products by saliva addition should be taken into account in the formulations of oriented-dysphagia products.

Fig. 5 shows the values of the elastic and viscous moduli values derived from the frequency sweeps at 1 Hz for C, W and S1–S5 samples

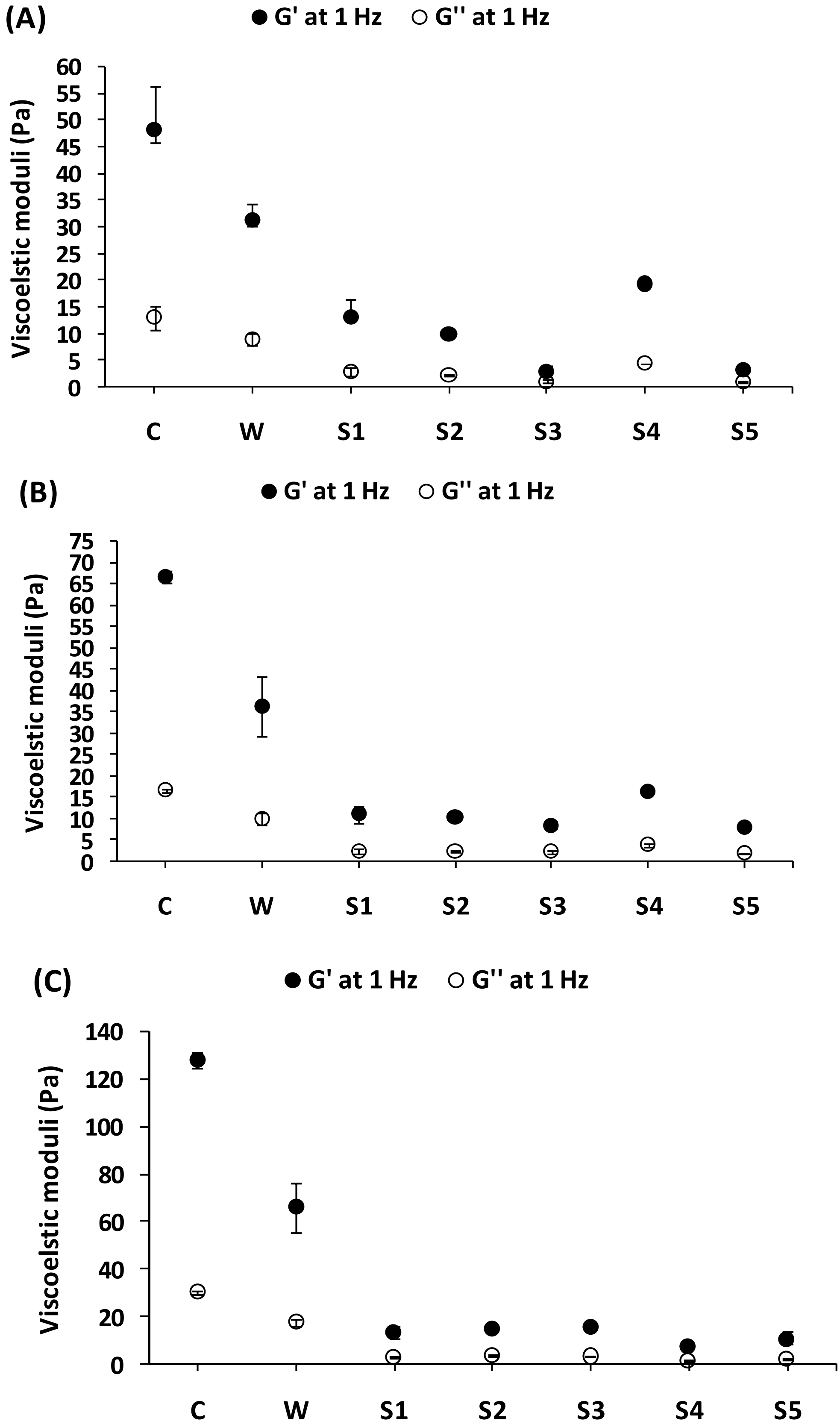

Fig. 5. *G′* (closed symbols) and *G″* (open symbols) of three Resource instant purées mixed at 1 Hz mixed with water (W) and unstimulated saliva from five healthy individuals (S1–S5) at a ratio of 20:1; (A) vegetables and beef (VB) purée; (B) vegetables and codfish (VC) purée; and (C) chicken with rice and carrots (CR) purée. T = 37 °C. Mean values of seven measurements ± standard deviations.

for the three purée products. It can be seen that G' was higher than G'' in all samples for each product, and both moduli were decreased significantly by the addition of saliva. The decrease was particularly large in CR purée. In the water samples both viscoelastic moduli also decreased, but they kept their structured-liquid character. These results are in accordance with those previously observed in the stress sweep and steady tests and highlight the important effect of saliva on the viscoelastic behaviour of dysphagia-oriented products.

4. Conclusions

This study demonstrates the importance of characterizing both the steady and the viscoelastic rheological properties of commercial dysphagia-oriented products mixed with unstimulated human saliva. It has been proved that saliva produces remarkable changes in the structure of these products as evidenced by steady and viscoelastic rheological parameters, which are related to the design of dysphagia products to avoid the risk of aspiration during swallowing. Before the addition of saliva, all the commercial products studied showed shear-thinning behaviour and behaved as structured-liquid systems. However, CR purée showed higher consistency and viscosities at both low and higher shear rates than VB and VC ones. The three instant purées also showed different viscoelastic behaviour. It seems that CR purée has a network with more resistance to deformation as indicated by its high elasticity degree (tan δ), rigidity (G^*) and structural stability ($\sigma_{\max}$), which make it a more adequate product for a safer swallowing.

The addition of unstimulated saliva produced a remarkable decrease of viscosity (η_{10} and η_{50} and K values) and a loss of conformational structure (lower $\sigma_{\max}$ and G^* values and higher tan δ) in all the products, but especially in CR purée because of its higher starch content, which was probably associated with the salivary α-amylase activity.

On the other hand, high compositional variability was observed between the unstimulated saliva samples collected from the five individuals, giving rise to different changes in the viscoelastic properties when they were added to the same product or matrix.

The results obtained in this work reflect the importance of considering not only the matrix (composition of the purée product) but also the differences in personal salivary patterns when designing dysphagia-oriented products, since they might both affect the structure of the bolus and therefore, the safety of the swallowing process.

Additionally, in future studies it will be necessary to increase the number of saliva donors and consider the role of other enzymatic activities of saliva, such as proteolytic and lipolytic activities, which might also modify the viscoelastic properties of the products, in order to obtain more relevant conclusions.

CRediT authorship contribution statement

Beatriz Herranz: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing - original draft, Writing - review & editing, Visualization. **Celia Criado:** Investigation, Formal analysis, Writing - original draft. **María Ángeles Pozo-Bayón:** Conceptualization, Methodology, Validation, Formal analysis, Writing - original draft, Writing - review & editing. **María Dolores Álvarez:** Conceptualization, Methodology, Validation, Formal analysis, Writing - original draft, Writing - review & editing, Visualization.

Declaration of competing interest

We declare that this work has not been published elsewhere and is not under consideration by another journal. The manuscript is approved by all authors to be submitted to Food Hydrocolloids. The authors have no conflicts of interest to declare.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodhyd.2020.106403.

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