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Additional Information

Use of chia seed mucilage as a texturing agent: effect on instrumental and sensory properties of texture-modified soups

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Abstract

This work aimed to evaluate colour, texture, flow, and viscoelastic properties of texture-modified chicken and vegetables soups for dysphagic people, as well as their characteristics during simulated oral processing. The use of chia seed mucilage (CSM) as an alternative texturing agent for dysphagia, the influence of temperature, the effect of saliva during the simulated oral processing of samples, and the sensory acceptance of samples were also studied. Modified starch (MS), guar gum (GG), and CSM were used to modify samples texture at two consistency levels: honey-like and pudding-like consistencies. MS and CSM soups presented higher elasticity and resistance to deformation than GG samples, being considered safer to swallow by dysphagic patients. Addition of saliva caused remarkable changes in samples' consistency, adhesiveness, and apparent viscosity. Moreover, the use of CSM did not modify the swallowing properties of samples. These results confirm the feasibility of using CSM as a novel texturing agent for dysphagia management, and represent an advance in developing dysphagia-oriented products by tailoring their textural, rheological, viscoelastic, and sensory characteristics, as well as their properties during the oral processing.

Keywords: dysphagia-oriented products; hydrocolloids; rheology; oral processing; sensory evaluation; saliva

1. Introduction

Texture-modified foods are mainly prescribed for oropharyngeal dysphagia (OD) management. OD is the most frequent and severe stage of dysphagia caused during food transfer from the oral cavity to the esophagus (Vieira et al., 2021). The consequences of dysphagia are related to reduce oral intake and malnutrition, dehydration, aspiration, and aspiration pneumonia (Andersen, Beck, Kjaersgaard, Hansen, & Poulsen, 2013).

A technique commonly employed to enhance safe swallowing in dysphagic patients is the modification of bolus viscosity by using texturing agents, which can be classified into two categories: starch-based and gum-based hydrocolloids (Sharma, Kristo, Corredig, & Duizer, 2017; Vieira et al., 2021). Nevertheless, the use of plant-based hydrocolloids has attracted the interest of both academia and food industry. Vieira et al. (2021) proposed the soluble part of the flaxseed gum as a promising hydrocolloid for dysphagic patients due to its excellent thickening capability and nutritional properties. Yousefi and Ako (2020) evaluated the use of *Lepidium perfoliatum* seed gum as emerging texturing agent for dysphagia management due to its good water retention capability, high viscosity, texture modification, and product stability. Furthermore, chia seeds (*Salvia hispanica* L.) produce a fibre-rich mucilaginous gel in contact with water with excellent viscosity and water retention capacity (Ribes, Peña, Fuentes, Talens, & Barat, 2021). These characteristics make chia seed mucilage (CSM) a favourable candidate for food applications as texturing agent, but its use in the design of dysphagia-oriented products has not been investigated.

Texture-modified foods are classified according to the recommendations of National Dysphagia Diet Task Force (NDDTF, 2002) guideline. It defines products' consistencies based on their viscosity, which is determined at a shear rate of 50 s^{-1} and at 25 ºC, as follows: nectar-like consistency (51-350 mPa·s); honey-like consistency (351-1750 mPa·s); and pudding-like consistency (>1750 mPa·s). On the contrary, International Dysphagia Diet Standardisation Initiative

(IDDSI, 2019) framework uses a visual scale, instead of viscosity, to classify the liquids employed in dysphagia management (Ong, Steele, & Duizer, 2018), which is based on the flow rate of the products. The IDDSI classifies the products as thin (level 0 = the product flows like water), slightly thick (level 1 = the product is slightly thicker than water), mildly thick (level 2 = the product flows off a spoon), moderately thick (level 3 = the product does not maintain the shape on a spoon), and extremely thick (level 4 = the product keeps the shape on a spoon). However, a complete analysis of products' texture, flow, viscoelastic, and sensory properties, along with their characteristics during the oral processing should be conducted to develop dysphagia-oriented products since their behaviour cannot be completely elucidated by a metric. In the last years, the necessity of studying the viscoelastic properties of these type of products has been increased, given that not only the viscosity or consistency, but also elasticity and other rheological parameters play an important role in the swallowing process (Moret-Tatay, Rodríguez-García, Marti-Bonmartí, Hernando, & Hernández, 2015; Herranz, Criado, Pozo-Bayón, & Álvarez, 2021; Wei, Guo, Li, Ma, & Zhang, 2021). Dynamic spectra obtained by small amplitude oscillatory shear test also provide relevant information of the internal structure of foods (Moret-Tatay et al., 2015). Besides, the use of instrumental methods to simulate the food oral processing has attracted the interest of researchers since they can provide a valuable insight for a better understanding of the oral processing (Kim, Oh, Kim, & Lee, 2019). However, although some authors evaluated the rheological and viscoelastic characteristics of texture-modified water, carrot purees, and pea creams (Sharma et al., 2017; Talens et al., 2021; Vieira et al., 2021), no studies reporting the rheological, viscoelastic, and sensory properties of texture-modified chicken and vegetables soups, also including their characteristics during the oral processing, have been found.

Saliva is also essential in bolus safety as it increases bolus cohesiveness and affects its viscoelastic properties, but its impact during consumption of dysphagia-oriented products has been scarcely investigated (Herranz et al., 2021). During the oral processing, foods are mixed with saliva that contains α-amylase, which is responsible of the starch breakdown. This could favour the sudden decrease in the oral viscosity, especially in starch-based products, increasing the risk of aspiration in dysphagic patients (Sharma, Pico, Martinez, & Duizer, 2020).

Hence the aim of this work was to evaluate the colour, texture, flow, and viscoelastic properties of different texture-modified chicken and vegetable soups for people with swallowing disorders, as well as their characteristics during the simulated oral processing. The possibility of using CSM as a potential texturing agent for dysphagia treatment compared to starch or guar gum, the influence of temperature on the structural changes of samples, the effect of saliva during the simulated oral processing of samples, and the sensory acceptance of the texture-modified chicken and vegetables soups were also investigated.

2. Materials and Methods

2.1 Materials

Chicken breasts (Lidl Supermercados S.A.U, Murcia, Spain), carrots (Anecoop S. Coop, Valencia, Spain), onions (Cebollas Consuay, S. L., Valencia, Spain), green beans (Packalia, S.L., Sevilla, Spain), and sodium chloride (Sal Bueno, S.L., Xirivella, Spain) were purchased from a local supermarket to prepare the chicken and vegetables soup. To modify the texture of the soups, three different hydrocolloids or texturing agents were employed: Modified starch (Nutavant®, MS), guar gum (GG), and chia seed mucilage (CSM). MS, a commonly starch based thickener used in dysphagia treatments, was purchased from a local pharmacy. GG was provided by EPSA (Valencia, Spain), and CSM was extracted from commercial chia seeds (Pedon S.P.A, Molvena, Italy). For artificial saliva preparation, porcine stomach mucin Type II and porcine pancreatic α-amylase were supplied by Sigma-Aldrich, Co. Ltd (St. Louis, MO, USA). The use of pancreatic α-amylase was based on previous studies on food oral processing (Torres, Yamada, Rigby, Kawano, & Sarkar, 2019).

2.2 Mucilage extraction from chia seeds

The CSM was extracted following the methodology described by Ribes et al. (2021), with minor modifications. Briefly, chia seeds were incorporated to distilled water (ratio 3:30, w/w) and stirred for 3 h at 60 °C in an electrical food processor (Thermomix TM 31, Vorwerk M.S.L, Spain). This mixture was centrifuged at 10,000 rpm for 10 min at 20 °C (Centrifuge 5804 R, Eppendorf AG, Hamburg, Germany). The supernatant was removed and freeze-dried (LyoQuest-55, Telstar, Terrassa, Spain) for 48 h and kept in sealed plastic vessels at room temperature until its use.

2.3 Chicken and vegetable soup preparation

The chicken and vegetable soup was prepared by cooking (100 ºC, 50 min) the following ingredients, cut into small pieces, in an electrical food processor (Thermomix TM 31, Vorwerk M.S.L, Spain): chicken breast (15%, w/w), carrot (12%, w/w), onion (5%, w/w), green beans (3.5%, w/w), olive oil (4%, w/w), sodium chloride (3%, w/w), and water (57.5%, w/w). After cooking, the chicken and vegetables pieces were removed, and the liquid was filtered and transferred to plastic containers. Each texture-modified soup was obtained by adding and mixing the different hydrocolloids (MS, GG and CSM) at 70 ºC with a magnetic stirrer, until ensuring their total dispersion. Concentrations (%, w/w) of each hydrocolloid used to prepare the samples, as well as their apparent viscosities (η_{app}) measured at 25 ºC with a shear rate of 50 s^{-1} (NDDTF, 2002), are shown in Table 1. On this basis, the texture-modified chicken and vegetables soups were classified as honey-like (1405±68 mPa·s) or pudding-like consistencies (2360±44 mPa·s). All samples were prepared 24 h before testing and stored at 4 °C until analysed at 37 ºC. This temperature was selected to mimic the oral conditions (Laguna, Farrell, Bryant, Morina, & Sarkar, 2017). Two independent batches were prepared for all the samples.

2.4 Artificial saliva preparation

The artificial saliva was prepared according to the standardised INFOGEST method (Minekus et al., 2014), with minor changes. Simulated salivary fluid, containing porcine stomach mucin Type II (3 g/L) and porcine pancreatic α-amylase (75 U/mL), was mixed with the samples in a ratio 1:1 (v/w).

2.5 Colour and texture characterisation

Colour parameters (L*, a*, and b*) of texture-modified chicken and vegetables soups were measured by using a spectrocolorimeter (CM-3600d, Minolta Co., Tokyo, Japan) with an observer 10º and illuminant D65. For avoiding sample's translucency, the measurements were taken by using a white and a black background. The infinite reflectance (R∞) of the samples was obtained by applying the Kubelka–Munk theory. Chroma (C_{ab}*), hue (h_{ab}*), and colour variations (ΔE*) of the texture-modified soups compared to the control were calculated by using Eq. (1), (2), and (3), respectively:

$$C_{ab} * = ((a^*)^2 + (b^*)^2)^{0.5} \quad (1)$$

$$h_{ab} * = arctg\ (b^*/a^*) \quad (2)$$

$$\Delta E^* = ((\Delta L^*)^2 + (\Delta a^*)^2 + (\Delta b^*)^2)^{0.5} \quad (3)$$

Texture of each sample was determined by conducting a back extrusion test in a TA.XT2 Texture Analyser (Stable Micro Systems, Godalming, UK). The samples were transferred to a measuring container and filled up to 40 mm of height. A cylindrical probe of 35 mm of diameter was employed to press the samples to a depth of 12 mm, with a test speed of 2 mm/s. The force *vs* distance plot generated was used to obtain the maximum force, which is related to the firmness of the sample, and area under the curve, which is related to the consistency of the sample (Yang, Dai, Huang, & Sombtngamwilai, 2020; Gallego, Arnal, Barat, & Talens, 2021).

All the tests were conducted at 37 ºC in duplicate. The samples were introduced in a water bath for 30 min before performing the tests.

2.6 Flow and viscoelastic measurements

A rotational controlled-stress Kinexus Pro+Rheometer (Malvern Instruments Ltd., MA, USA), with a Peltier heating system for temperature control, was used to perform the flow and viscoelastic measurements of each texture-modified chicken and vegetables soups. Assays were run at 37 ºC by means of using the PLC61/PU40 parallel-plate geometry with a 1 mm gap. For structure recovery, samples were allowed to stand for 120 s prior to be analysed. All the measurements were done in duplicate.

2.6.1 Flow rheological properties

To evaluate the steady-shear flow behaviour of the texture-modified chicken and vegetables soups, flow curves were obtained as a function of the shear rate, ranging from 0.1 to 100 s^{-1} for 300 s. The flow curves were fitted to the power-law model. The consistency coefficient (K) and flow behaviour index (n) were calculated as described by Talens et al. (2021). The correlation coefficient R^2 was employed to confirm the goodness-of-fit of the model.

2.6.2 Viscoelastic properties

Non-linear and linear viscoelastic assays were used to characterise the viscoelastic properties of the texture-modified chicken and vegetables soups. A large amplitude oscillatory shear test (LAOS) was run to delimit the linear viscoelastic region (LVR) and to evaluate the non-linear viscoelastic properties of the samples. Stress sweep test was performed within a stress range from 0.1 to 100 Pa at 1 Hz. From this assay, the variations in elastic (G') and viscous modulus (G"), the elastic modulus value at LVR (G'_{LVR}), and the stress value at LVR ($Stress_{LVR}$) were presented.

A small amplitude oscillatory shear test (SAOS) was used to characterise the linear viscoelastic properties of the texture-modified chicken and vegetables soups. A frequency sweep test was conducted at 1 Pa (in the LVR) to cover a 0.1-10 Hz frequency range. The viscoelastic parameters including elastic modulus (G'), viscous modulus (G''), complex modulus (G*), the complex viscosity (η*), and loss tangent (Tan δ) were obtained from the rheometer software (rSpace for Kinexus). To evaluate the influence of the temperature on the structural changes of the texture-modified chicken and vegetables soups, temperature sweep tests were performed from 20 ºC to 80 ºC at a heating rate of 5 ºC/min, within the LVR, and at a frequency of 1 Hz. To avoid water evaporation from the samples, silicone oil was incorporated on the outside of the plates and the samples' cover provided by the instrument was placed over the samples.

2.7 Simulated oral processing conditions: combining squeezing flow and shear force tests

The squeezing flow and shear force tests were combined to simulate certain aspects of the oral processing, and the assays were conducted as described by Chung, Olson, Degner, and McClements (2013). The rotational Kinexus Pro+Rheometer (Malvern Instruments Ltd., MA, USA), with a Peltier heating system and a PLC61/PU40 parallel-plate geometry, was employed. The samples were compressed, sheared, and decompressed for ten cycles to mimic the movement of the tongue and palate during consumption. The tests were carried out at 37 ºC in presence and absence of artificial saliva (food:artificial saliva ratio, 1:1) to determine its impact during the simulated oral processing of samples. To elucidate the effect of the α-amylase on those samples containing starch (MS), the tests were also conducted in presence of distilled water (food:distilled water ratio, 1:1) for these samples.

2.8. Sensory evaluation

The sensory evaluation of the texture-modified chicken and vegetables soups was made by a panel of 38 assessors (23 women and 15 men) aged between 21 and 74 years old. They were recruited following the UNE-ISO 8586:2012 general guideline (ISO, 2012). Sensory evaluations were made by considering the IFST Guidelines for Ethical and Professional Practices for the

Sensory Analysis of Foods (Institute of Food Science and Technology, 2020). Every assessor gave written consent before conducting the sensory evaluation. Testing was performed by using a 9-point numeric response scale (UNE-ISO 4121:2003, ISO, 2003) to evaluate the intensity perception of colour, oral consistency, oral adhesiveness, oral residue, and swallowing attributes. The panellists tested six different samples (three hydrocolloids: MS, GG, and CSM; two consistencies: honey-like and pudding-like) and the sensory analysis was carried out 24 h after preparing the samples, which were stored at 4 °C. The texture-modified chicken and vegetables soups were presented to the assessors at 37 ºC in a plastic cup coded with three arbitrary digits, and they were asked to drink water between samples to avoid aftertaste.

2.9 Statistical analysis

The data obtained from all the analyses were evaluated by a one-way ANOVA to study differences among samples, within the same consistency level. The least significance procedure (LSD) was employed to evaluate for differences between averages at the 5% level of significance. Results were statistically processed by the Statgraphics Centurion XVI software. The correlation between instrumental and sensory data was derived by means of using Pearson Product Moment Correlation Coefficient.

3. Results and Discussion

3.1 Colour and texture characterisation

Colour attribute plays an important role in food choice and consumption since it influences taste thresholds, food preference, pleasantness, and acceptability (Spence, 2015). Table 2 summarises the colour attributes (L^*, C_{ab}^*, h_{ab}^*) and colour variations (ΔE^*) of the texture-modified chicken and vegetables soups compared to the control (chicken and vegetables soup without any hydrocolloid added) at 37 ºC. Slightly lower L^* values were observed in case of MS and GG samples presenting the honey-like consistency compared to the control, while the soups prepared with CSM exhibited the lowest L* values. For the pudding-like consistency, significantly ($p < 0.05$) lower L* values were observed in case of CSM samples in comparison with the control, whereas significantly ($p < 0.05$) higher L* values were perceived for MS samples. Moreover, greater C_{ab}* values were noted in case of all texture-modified chicken and vegetables soups compared to the control, being this effect more noticeable for MS and CSM pudding samples. The incorporation of hydrocolloids could improve the C_{ab}* of soups probably due to their capacity to increase the stability of samples by reducing the movement and precipitation of the soup coloured substances (Nwaokoro & Akanbi, 2015). The lowest h_{ab}* values and highest colour differences (ΔE*) were observed for those samples prepared with CSM, which exceed the just noticeable difference (Baldevbhai & Anand, 2012). The presence of natural pigments or tannic substances from the tegument of chia seeds could explain the results obtained during the colour characterisation of samples (Koocheki, Taherian, Razavi, & Bostan, 2009).

Texture is also an important factor since it defines the eating experience and affects the preference of consumers for foods (Yang, Li, Li, Sun, & Guo, 2020). Table 2 presents the texture parameters of the different texture-modified chicken and vegetables soups at 37 ºC. Significant differences ($p < 0.05$) were observed among samples prepared with the different texturing agents, regardless of their consistency. Furthermore, greater area and maximum force values were noticed when using higher hydrocolloid concentrations. Samples manufactured with CSM exhibited the highest area and maximum force values, and consequently, the greatest consistency and firmness. The lowest area and maximum force values were shown by those texture-modified chicken and vegetables soups prepared with MS as texturing agent. The greater consistency and firmness observed by GG and CSM samples at both consistency levels could be ascribed to: i) an intermolecular chain entanglement provoked by the interaction of water molecules with the GG galactose chains (Thombare, Jha, Mishra, & Siddiqui, 2016); and ii) the capacity of swollen CSM particles to act as fillers, diminishing the matrix movement and increasing products' consistency and firmness (Ribes et al., 2021).

3.2 Flow and viscoelastic measurements

3.2.1 Flow rheological properties

Table 3 shows the data of the rheological parameters from the steady flow behaviour test of the texture-modified chicken and vegetable soups. A marked increase in samples' viscosity was observed in products containing greater hydrocolloids amounts. The η_{app} at 50 s^{-1} of the samples presenting the honey-like consistency ranged from 1183±16 mPa·s to 1343±11 mPa·s; whereas for the pudding-like consistency the η_{app} at 50 s^{-1} values of samples were between 1902±24 mPa·s and 2311±118 mPa·s. It could be attributed to higher total solids content, which decrease the intermolecular movement caused by hydrodynamic forces and the formation of a hydrocolloid network (Alpizar-Reyes et al., 2018). Similar results were reported by Vieira et al. (2021) regarding the use of rising amounts of flax-seed gum as alternative thickener for dysphagic patients.

The flow behaviour index (n) indicates the rheological nature of the fluid. As the fluid approaches Newtonian behaviour, the n value was close to 1 (Kaur & Kaler, 2008). Noteworthy that the non-Newtonian fluids ($n < 1$) are favourable for a swallowing process with a reduced risk of aspiration, by giving the neuromuscular system a longer reflex response time to close the epiglottis (Nakauma, Ishihara, Funami, & Nishinari, 2011; Nishinari, Turcanu, Nakauma, & Fang, 2019). The n values went below 1 in all the tested samples, indicating their pseudoplastic behaviour. In spite of the consistency level achieved, GG sample exhibited the lowest n value; meanwhile higher n values were reported for those soups containing MS and CSM as texturing agents. Furthermore, the n values became lower when using higher hydrocolloid amounts, indicating that the shear thinning behaviour is enhanced at higher polymer concentrations. This behaviour was also observed by

Talens et al. (2021) and Wei, Guo, Li, Ma, and Zhang (2021) when using different thickeners for dysphagia management in pea creams and water, respectively.

Concerning the consistency coefficient (K), the highest K values were observed for all the GG samples, and non-significant ($p > 0.05$) differences were reported between MS and CSM samples at both consistency levels. The greater K values observed in case of GG samples could be attributed to multiple intermolecular chain entanglements due to the interaction of water molecules with the GG galactose chains as previously commented (Thombare et al., 2016). Moreover, an increase in samples' consistency was observed when using higher hydrocolloid amounts, probably due to the capacity of hydrocolloids to increase the stability of samples as a consequence of greater intermolecular interactions in their continuous phase (Ma & Barbosa-Cánovas, 1995; Alpizar-Reyes et al., 2018). These results fall in line with those reported by Talens et al. (2021) in thickened pea creams for dysphagic patients.

3.2.2 Viscoelastic properties

To characterise the non-linear viscoelastic properties of the texture-modified samples and to determine the limits of the linear viscoelastic region (LVR) a stress sweep test was conducted. Figure 1 presents the changes in the elastic modulus (G') and viscous modulus (G") of all the texture-modified chicken and vegetable soups, according to the stress, at 37 ºC. A predominant elastic behaviour (G' > G") was observed throughout the study, which is a common fact in weak viscoelastic systems. After the LVR, G' and G" values of all the samples containing GG and CSM decreased as the stress increased. Nevertheless, texture-modified chicken and vegetable soups prepared with MS show a slight increase in the G" values, which lower again at higher stress levels, regardless of the consistency level. Based on the classification of Hyun, Kim, Ahn, and Lee (2002) for diverse types of modulus behaviour, it can be stated that GG and CSM samples exhibited a stress thinning behaviour, while those soups containing MS reflect weak strain-overshoot behaviour at the beginning of the non-LVR. The increase observed in the G" values of MS samples could indicate the use of higher energy amounts during the deformation process. Thus, microfractures in products structure can be provoked and the friction between the layers in the fracture point causes energy losses in form of heat (Sharma et al., 2017). This behaviour was also reported by Sharma et al. (2017) in texture-modified carrot purees with gellan gum, xanthan gum, pectin, carrageenan, and modified corn starch, and by Talens et al. (2021) in texture-modified pea creams with xanthan gum and GG, among others.

Table 4 summarises the viscoelastic parameters, G'_{LVR} and $Stress_{LVR}$, of the texture-modified chicken and vegetable soups from the stress sweep test performed at 37 ºC. The G'_{LVR} value is linked to the material stiffness (Mezger & Stellrecht, 2000), and the $Stress_{LVR}$ parameter is related to the structural stability of the product (Herranz et al., 2021; Talens et al., 2021). For both consistency levels, the samples manufactured with GG and CSM exhibited the lowest G'_{LVR} values, being considered therefore the least stiff products. Conversely, MS texture-modified chicken and vegetable soup exhibited the greatest stiff structure, with significantly ($p < 0.05$) higher G'_{LVR} values. These results fall in line with those reported by Talens et al. (2021) when investigating the material stiffness of pea creams thickened with MS. Regarding the $Stress_{LVR}$ parameter, significant differences ($p < 0.05$) were observed among samples. In spite of the consistency level achieved, the soups prepared with GG as texturing agent showed the highest $Stress_{LVR}$ values, followed by samples containing CSM and MS. Hence it can be stated that the soups prepared with GG and CSM had better structural stability than samples containing MS. It could be attributed to the presence of large polymeric molecules in GG and CSM samples compared to MS texture-modified chicken and vegetable soups.

To characterise the linear viscoelastic properties of the texture-modified samples a SAOS test was carried out. Figure 2 presents the changes in G', G", and Tan δ values of the texture-modified chicken and vegetables soups at 37 ºC, as a function of the frequency stress applied. Higher G' than

G" values were observed for all the samples at both consistency levels. This outcome indicates the samples' gel behaviour (Talens et al., 2021). Nevertheless, in case of GG samples at both consistency levels and at low frequencies, the G" values predominated over the G' values, indicating a dominance of the liquid-like property (Ahmed, 2021). A similar behaviour was observed for galactomannan solutions, GG dispersions, and blend gum dispersions (Ahmed, 2021; Bourbon et al., 2010; Martín-Alfonso, Cuadri, Berta, & Stading, 2018). It is also important to highlight that this effect is typical of semi-dilute polysaccharides dispersions, which is determined by a physical chain entanglement with a disordered random coil conformation (Ahmed, 2021; Saha & Bhattacharya, 2010).

Tan δ provides information on the balance of the material's viscoelastic modulus (Sharma et al., 2017). Tan δ values above 1 indicate diluted solutions; meanwhile values between 0.1 and 1 denote weak gels (Irani, Razavi, Abdel-Aal, Hucl, & Patterson, 2019). As can be seen in Figure 2 (e and f), the Tan δ values of all the MS and CSM formulations ranged from 0.1 to 0.7, reinforcing the weak gel behaviour, and their Tan δ profile was similar throughout the frequency range evaluated. At low frequency values, the Tan δ values of MS and CSM formulations at both consistency levels were low, but at high frequencies those values increased. However, GG samples exhibited Tan δ values between 0.4 and 1.8. At low frequencies, the GG samples exhibited higher Tan δ values that decreased continuously as the frequency rose. Therefore, the GG texture-modified chicken and vegetables soups are considered diluted solutions at low frequencies, whereas at high frequency values these samples exhibit the weak gel behaviour. Noteworthy that Tan δ can be employed as a rheological factor to distinguish easy-to-swallow bolus for dysphagic patients. A bolus would be considered easy-to-swallow when the Tan δ values fall within the 0.1–1 range (Ishihara, Nakauma, Funami, Odake, & Nishinari, 2011). Based on this, MS and CSM texture-modified chicken and vegetables soups with the honey-like and pudding-like consistencies could be considered safe for swallowing by dysphagic patients.

To better understand the dependency of G' and G" values on frequency and to evaluate the gel properties, ln G' slope (n') *vs* ln frequency plot has been studied (Alvarez, Fuentes, Guerrero, & Canet, 2017). Table 4 presents the gel properties' parameters of the texture-modified chicken and vegetable soups at 37 ºC. The n' values were comprised between 0 and 1, indicating a weak gel behaviour (Irani et al., 2019). Significantly ($p < 0.05$) lower n' values were observed in case of samples prepared with MS and CSM at both consistency levels, indicating lesser frequency-dependence. Moreover, the highest n' value was exhibited by those samples prepared with GG, regardless of their consistency. When using higher hydrocolloid amounts the dependence of G' on frequency seems to be lower. It could be related to the greater water binding capability of the different hydrocolloids employed, which could be caused by higher intermolecular interactions as their concentration rose. Talens et al. (2021) also reported this effect in pea creams thickened with different hydrocolloids.

The viscoelastic properties of the different texture-modified soups from the SAOS test are also shown in Table 4. For comparison purposes, the storage modulus (G'), loss modulus (G"), complex modulus (G*), complex viscosity (η*), and loss tangent (Tan δ) values were considered at a frequency of 1 Hz. An elastic behaviour (G' > G") was noticed for all the samples evaluated, which is a common fact in weak viscoelastic systems. The complex modulus (G*) is a measure of the product stiffness and rigidity (Mezger, 2006). The formulations prepared with MS showed the greatest product stiffness and rigidity, followed by CSM and GG texture-modified chicken and vegetables soups. Furthermore, higher amounts of hydrocolloids conferred significantly ($p < 0.05$) greater stiffness and rigidity to the samples. This fact was more evident when using GG and CSM as texturing agents. The utilisation of larger quantities of polymers could increase product' stiffness and rigidity owing to the strong network structure formed.

The complex viscosity (η*) is a measure of total resistance to flow in relation to the angular frequency (Talens et al., 2021). At both consistency levels, the MS texture-modified chicken and vegetables soup exhibited the highest resistance to flow, followed by CSM and GG samples (Table 4). It is important to mention that greater values were observed in case of samples presenting the pudding-like consistency. Thus, at this level, all the samples confer more resistance to flow, probably due to the strong network structure originated when using larger hydrocolloid amounts. Finally, all the formulations had Tan δ values below 1 at the frequency of 1 Hz, prevailing the elastic properties over the viscous ones. Tan δ values in the range of 0.1-1 have been suggested as safe-swallowing in dysphagic patients (Ishihara et al., 2011). Moreover, Nyström, Qazi, Bülow, Ekberg, & Stading, (2015) proved that dysphagic patients perceived easier to swallow thinning fluids with increased elasticity. Considering that products with high elasticity degree (lower Tan δ values) and resistance to deformation (higher G* values) would be safer to swallow (Herranz et al., 2021), it could be stated that MS and CSM texture-modified chicken and vegetables soups would be more appropriate than GG soups for dysphagic patients.

To evaluate the impact of temperature on the structural changes of the texture-modified chicken and vegetables soups, a temperature sweep test was conducted from 20 ºC to 80 ºC as shown in Figure 3. For MS and GG samples at both consistencies, G' and G'' values slightly decreased during the whole range of temperatures tested. Conversely, both G' and G'' values diminished or kept constant between 20 ºC and 50 ºC for CSM samples at both consistency levels, but after this temperature, the G' and G'' values of CSM samples rose. Hosseini-Parvar, Matia-Merino, Goh, Razavi, and Mortazavi (2010) reported similar results in basil seed gum solutions, and attributed this behaviour to greater intermolecular interactions among hydrocolloids molecules that took place at higher temperatures. Moreover, Tan δ values were particularly variable for all the samples being similar the profile at both consistency levels. GG texture-modified soups showed increasing Tan δ values until 60 ºC were they sharply dropped, CSM samples showed a continuous decreased of their Tan δ values, and for MS samples the results kept quite constant during the whole range of temperatures tested.

3.3 Simulated oral processing conditions: combining squeezing flow and shear force tests

A squeezing flow and shear force tests were combined to assess the oral processing of samples. The compression/decompression motions of the upper plate are used to simulate the upward/downward movement of the tongue against the palate (Terpstra, Janssen, & van der Linden, 2007), whereas the shearing motion of the upper plate (constant shear rate of 10 s^{-1}) is used to mimic the sliding of the tongue against the palate (Chung et al., 2013).

Figure 4 and Figure 5 present, respectively, the maximum positive and negative forces, and η_{app} of all the samples, in presence and absence of artificial saliva, for ten compression-shearing-decompression cycles. To better elucidate the impact of the α-amylase on those samples containing starch (MS) the test was also performed in presence of distilled water (Figures 4-5 e). The maximum positive peak force was taken as a measure of material consistency, whereas the maximum negative force was related to the material adhesiveness. The η_{app} (at 10 s^{-1}) obtained during the fixed gap stage was associated with the tongue sliding against the palate, as above-mentioned.

In absence of artificial saliva, a slight decrease in the maximum and minimum force values were observed for all the samples from the first to second cycles, being more evident in case of all CSM samples and MS sample at the pudding-like consistency (Figure 4). According to Chung et al. (2013) it can be related to the breakdown of the texture-modified soup structure.

At both consistency levels, the texture-modified soups prepared with MS exhibited the lowest consistency value, whereas GG and CSM samples presented higher consistency. It is important to highlight that these results are in accordance with those reported in the back extrusion test (Section 3.1). Furthermore, significant ($p < 0.05$) differences were observed for samples' adhesiveness at the pudding-like consistency. MS sample exhibited the lowest adhesiveness, meanwhile GG and CSM samples presented similar adhesiveness.

In presence of artificial saliva, the maximum and minimum force values significantly ($p < 0.05$) decreased for MS, GG, and CSM samples at both consistency levels due to their dilution. Moreover, to corroborate the effect of the α-amylase on samples containing MS the test was also conducted with distilled water. Figure 4 (e) shows the dilution effect and the impact of the α-amylase on MS samples. Their maximum and minimum force values were lower in presence of artificial saliva than in presence of distilled water, regardless of the consistency level. Thus, the α-amylase present in artificial saliva caused the degradation of this hydrocolloid mainly composed by modified starch.

Regarding the η_{app} (Figure 5), non-significant ($p > 0.05$) differences were observed among samples at the honey-like consistency in absence of artificial saliva. At the pudding-like consistency, the samples formulated with GG and CSM as texturing agents exhibited the highest η_{app} values. When adding artificial saliva to the texture-modified soups, the η_{app} values decreased probably due to the dilution effect. The highest η_{app} values were observed for the CSM texture-modified soups at both consistency levels, followed by GG and MS samples. Thus, the greater tongue sliding against the palate was offered by CSM samples. Moreover, to confirm the action of the α-amylase on MS samples, the assays were also run with distilled water (Figure 5 e). Lower η_{app} values were reported by MS samples mixed with artificial saliva, regardless of the consistency level. The α-amylase causes the starch hydrolysis, breaking down its complex structure and reducing the viscosity of samples (Sharma et al., 2020; Herranz et al., 2021). Since the sudden decrease in oral viscosity is a major safety concern in dysphagia management owing to the risk of aspiration (Sharma et al., 2020), MS texture-modified chicken and vegetable soups would be less appropriate than CSM samples for people with swallowing disorders.

3.4 Sensory evaluation

Figure 6 presents the sensory properties of the texture-modified chicken and vegetables soups prepared with MS, GG, and CSM at both consistency levels. Significant ($p < 0.05$) differences were observed in colour, oral adhesiveness, oral consistency, and oral residue attributes among samples. The samples presenting the lowest scores related to the intensity of the colour attribute were those formulated with CSM at both consistency levels. The greatest scores in oral adhesiveness were shown by CSM soups at the honey-like and pudding-like consistencies, followed by GG and MS samples as observed in the simulated oral processing conditions. Concerning the oral residue attribute, GG samples at both consistency levels presented the highest scores. Furthermore, GG and CSM samples were considered as the most in-mouth consistent by panellist, and non-significant ($p > 0.05$) differences were noted among samples according to the swallowing attribute.

3.5 Correlations of instrumental and sensory data

The interrelationships between instrumental and sensory analysis could help in designing texture-modified food products for people with swallowing difficulties. Table 5 presents the Pearson correlation coefficients of instrumental and sensory measurements.

For the honey-like consistency, a negative correlation was obtained between the instrumental parameter ΔE^* and the colour sensory attribute. It could be attributed to the presence of natural pigments or tannic substances from the tegument of chia seeds (Koocheki et al., 2009), suggesting some formula adjustments to improve the organoleptic characteristics of the final product. Positive correlations were observed between the instrumental measurements of area under the curve and sensory data of the oral consistency and oral adhesiveness. These results suggest that samples with high area under the curve, such as CSM, will be more consistent in the early stages of the oral processing, which is crucial when developing products for dysphagics in order to diminish the risk of aspiration. Nevertheless, these samples will be also more adhesive, which could indicate the necessity of an increased salivary flow at the beginning of the oral processing.

Moreover, a positive correlation was obtained between the instrumental measurement of G'_{LVR} and the sensory attribute of swallowing. This suggests that stiff materials (high G'_{LVR} values), such as

MS, would be more easily swallowed. However, it is important to highlight that the α-amylase present in artificial saliva degrades this hydrocolloid and reduces the viscosity of the soups, which is crucial in dysphagia treatment due to the risk of aspiration (Sharma et al., 2020). Furthermore, Tan δ values correlate negatively with the sensory attributes of swallowing and positively with the oral residue, indicating that samples exhibiting greater Tan δ values will be more difficult to swallow and will require greater salivary flow for the oral cleansing. As previously indicated, Nyström et al. (2015) observed that dysphagic patients perceived easier to swallow thinning fluids with increased elasticity (low Tan δ values). Regarding the maximum positive and negative forces obtained when combining the squeezing flow and shear force tests and in presence of artificial saliva, positive correlations were obtained between these instrumental measurements and the sensory attributes of oral consistency and oral adhesiveness. The results suggest that these parameters will be maintained at the early stages of the oral processing.

In case of the samples presenting the pudding-like consistency, a negative correlation was obtained between the instrumental parameter ΔE* and the colour sensory attribute, as also observed at the honey-like consistency. The presence of natural pigments or tannic substances from the tegument of chia seeds negatively affects the colour perceived by panellists. A positive correlation was obtained between the area under the curve and the oral consistency and oral adhesiveness of the samples. More consistent samples, like CSM, will be perceived as more in-mouth consistent and adhesive. As previously indicated, the maintenance of the oral consistency of the samples plays an important role when designing foods for dysphagics. Moreover, an increased salivary flow could be needed for CSM samples. Negative correlations were observed between the instrumental measurements of G'_{LVR} and G* and the sensory attributes of oral consistency and oral adhesiveness. This suggests that stiff and rigid soups, like MS, will be less consistent and adhesive at the beginning of the oral process, probably due to the α-amylase action that reduces the viscosity of the samples (Sharma et al., 2020), as above-mentioned. Regarding the Tan δ, it correlates negatively with the sensory attribute of swallowing, suggesting that samples with greater Tan δ values will be more difficult to swallow (Nyström et al., 2015). Finally, as occurred in the samples with the honey-like consistency, positive correlations were obtained between the maximum positive and negative forces and the sensory attributes of oral consistency and oral adhesiveness.

4. Conclusions

Texture-modified chicken and vegetables soups present different instrumental and sensory data regardless of their similar apparent viscosity values measured at 25 ºC and at shear rate of 50 s^{-1}.

The viscoelastic evaluation of samples shows that MS and CSM texture-modified chicken and vegetables soups would be more suitable for dysphagic patients since they exhibit high elasticity degree and resistance to deformation. Nonetheless, α-amylase presents in saliva cause the degradation of the texture-modified soup prepared with MS. Given that the rapid reduction in oral viscosity is crucial in dysphagia management due to the risk of aspiration, MS soups would be considered less convenient for people with swallowing disorders than CSM samples. The sensory evaluation shows that using CSM as texturing agent in soups does not modify the swallowing property of samples. Moreover, instrumental and sensory parameters exhibit strong correlations, which plays an important role when designing dysphagia-oriented products. At both consistency levels, Tan δ can be considered a good measure for designing texture-modified foods since its correlation suggests that samples with higher Tan δ values will be more difficult to swallow. Besides for the pudding-like consistency soups, G'_{LVR} and G* values show a strong negative correlation with the oral consistency and oral adhesiveness, being an indicator of the rapid reduction of the MS samples' viscosity during the oral processing.

The present study provides helpful information to develop texture-modified chicken and vegetables soups with desirable instrumental and sensory properties for dysphagia management, and confirms the potential of CSM as a novel texturing agent for dysphagia treatment. Further studies on the lubrication properties of these soups should be conducted, by means of tribological tests, to fully understand their behaviour during swallowing. It would be also interesting to perform the sensory analysis in long-term care centres, and adjustments to CSM formulations should be considered to reduce its impact on product’s colour and sensory acceptance.

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Conflict of interest

None.

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Table captions

Table 1. Concentration (%, w/w) of each hydrocolloid used to prepare the texture-modified soups and their apparent viscosities (η_{app}, mPa·s) measured at 25 ºC with a shear rate of 50 s^{-1}.

Table 2. Colour attributes, colour variations compared to the control, and texture parameters of the different texture-modified soups at 37 ºC.

Table 3. Rheological parameters from the steady flow behaviour test of the different texture-modified soups at 37 ºC.

Table 4. Viscoelastic parameters obtained from the LAOS and SAOS tests, and slope (n') of ln G' *vs* ln frequency performed at 37 ºC.

Table 5. Pearson correlation coefficients of instrumental measurements with sensory attributes.

Figure captions

Figure 1. Changes in elastic modulus, G' (a and c), and viscous modulus, G'' (b and d), with the stress applied. Curves are representative runs. Modified starch (MS), guar gum (GG), and chia seed mucilage (CSM).

Figure 2. Changes in elastic modulus, G' (a and b), viscous modulus, G'' (c and d), and loss tangent, Tan δ (c and d), of the different texture-modified chicken and vegetables soups at 37 ºC, as a function of the frequency stress applied. Curves are representative runs. Modified starch (MS), guar gum (GG), and chia seed mucilage (CSM).

Figure 3. Temperature sweep of the different texture-modified chicken and vegetables soups from 20 ºC to 80 ºC: changes in elastic modulus, G' (a and b), viscous modulus, G'' (c and d), and loss tangent, Tan δ (e and f). Curves are representative runs. Modified starch (MS), guar gum (GG), and chia seed mucilage (CSM).

Figure 4. Maximum positive (consistency) and negative forces (adhesiveness) of the texture-modified chicken and vegetables soups during 10 compression-shearing-decompression cycles: a) Honey-like consistency without saliva; b) Pudding like consistency without saliva; c) Honey-like consistency with saliva; d) Pudding like consistency with saliva; and e) MS samples with saliva and dilution effect (DE). Modified starch (MS), guar gum (GG), and chia seed mucilage (CSM). Values are the average of two independent experiments.

Figure 5. Apparent viscosity (η_{app} at 10 s^{-1}) changes of the texture-modified chicken and vegetables soups during 10 compression-shearing-decompression cycles: a) Honey-like consistency without saliva; b) Pudding like consistency without saliva; c) Honey-like consistency with saliva; d) Pudding like consistency with saliva; and e) MS samples with saliva and dilution effect (DE). Modified starch (MS), guar gum (GG), and chia seed mucilage (CSM). Values are the average of two independent experiments.

Figure 6. Average score of the attributes tested in texture-modified chicken and vegetables soups with honey-like and pudding-like consistencies. *Indicates significant differences among samples ($p < 0.05$) (n = 38). Modified starch (MS), guar gum (GG), and chia seed mucilage (CSM).