Food Research International 170 (2023) 112975

Contents lists available at ScienceDirect

Food Research International

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

Comparison between the use of hydrocolloids (xanthan gum) and high-pressure processing to obtain a texture-modified puree for dysphagia

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ARTICLE INFO

Keywords:
Dysphagia
Plant proteins
High pressure processing
Hydrocolloids
Rheology
Emerging technologies

ABSTRACT

Enriched lentil protein vegetable purees (10% zucchini, 10% carrots, 2.5% extra virgin olive oil and 21.8% lentil protein concentrate) suitable for people with dysphagia were developed with 0.8% xanthan gum (XG) or 600 MPa/5 min high pressure processing (HPP) treatment with the aim of comparing their rheological and textural properties. Selection of the appropriate XG % and HPP conditions was made by performing initial pilot trials. Purees showed a good nutritional profile (12% protein, 3.4% fiber, 100 Kcal/100 g), being adequate for people with dysphagia. Microbiological testing of HPP treated purees indicated that it has a good shelf-life under refrigerated conditions 14 days). Both types of purees showed a gel-like character (tan delta 0.161–0.222) and higher firmness, consistency and cohesiveness than control samples. Comparing XG and HPP samples at time 0, HPP treated purees showed the highest stiffness (G′), the lowest deformability capacity (yield $strain_{LVR}$) and the lowest structural stability (yield $stress_{LVR}$). With storage, HPP treatment samples showed significant increases in all rheological and textural parameters. These results confirm the suitability of HPP as an alternative technology to hydrocolloids for the obtained dysphagia dishes.

1. Introduction

Oropharyngeal dysphagia is the most prevalent and severe type of dysphagia among elderly, and the number of people diagnosed with this has been on the rise. This condition is commonly caused by neurological or structural disorders, that help in bolus movement, and is defined by the difficulty or incapability to transfer the food bolus from the oral cavity to the stomach (Rofes et al., 2011). The pandemic caused by Coronavirus disease 2019 (COVID-19) had also a negative impact on the health of the hospitalized patients, causing an increase in the prevalence of oropharyngeal dysphagia (being a common complication in patients who received intubation or mechanical ventilation) and malnutrition (Martin–Martinez et al., 2021).

Texture-modified foods made using hydrocolloids such as gums or starches is the most common compensatory technique for dysphagia management, which has been used extensively with the purpose of avoiding aspiration or chocking in affected patients (Schmidt, Komeroski, Steernburgo & de Oliveira, 2021; Pematilleke, Kaur, Adhikari, & Torley, 2022; Raheem, Carrascosa, Ramos, Saraiva, & Raposo, 2021). Among the most used hydrocolloids for preparing dysphagia dishes, xanthan gum (XG) can be highlighted due to its good rheological and functional stability, and its better therapeutic effects in terms of pharyngeal residue when compared with modified starch thickeners (Dick, Bhandari, Dong, & Prakash, 2020; Giura, Urtasun, Ansorena, & Astiasarán, 2022; Vilardell, Rofes, Arreola, Speyer, & Clavé, 2016; Xing et al., 2022). Since dysphagia can also lead to malnutrition, proteins are key macronutrients when designing special foods for dysphagia patients. Nowadays, the consumption of plant protein such as lentil, pea, soybeans, chickpeas and faba bean proteins is increasing worldwide, since they are a good alternative to animal proteins, mostly due to their lower environmental impact and their relatively lower cost of production (Cosson, Oliveira-Correia, Descamps, Saint-Eve & Souchon, 2022; Mulla, Subramanian, & Dar, 2022; Willett et al., 2019). Nevertheless, even though plant proteins have been used over the last few years as a more sustainable alternative to animal proteins, their techno-functional properties need to be improved (Astiasaran, Giura, & Ansorena, 2022; Queirós, Saraiva, & da Silva, 2018).

High pressure processing (HPP) has been widely used as a non-thermal technology for food preservation. Moreover, various studies have shown that the application of high pressure modifies the proteińs

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https://doi.org/10.1016/j.foodres.2023.112975
Received 7 March 2023; Received in revised form 10 May 2023; Accepted 13 May 2023
Available online 15 May 2023

structure, affecting their techno-functional properties (Ahmed, Al-Ruwaih, Mulla, & Rahman, 2018; Cadesky, Walkling-Ribeiro, Kriner, Karwe, & Moraru, 2017; Garcia-Mora, Peñas, Frias, Gomez, & Martinez-Villaluenga, 2015; Lee et al., 2018; Sim, Karwe, & Moraru, 2019). The solubility of proteins is often reduced by HPP, but their surface hydrophobicity is increased, exposing sulfhydryl groups, which promote aggregation or gelation or improve the protein capacity to stabilize emulsions/foams (Queirós et al., 2018). In the last years, HPP has been used as a possible treatment to change the texture of ingredients and get texture modified products (TMP) (Giura, Urtasun, Astiasaran, & Ansorena, 2023; Maksimenko, Lyude, & Nishiumi, 2020; Tokifuji, Matsushima, Hachisuka, & Yoshioka, 2013; Yoshioka, Yamamoto, Matsushima, & Hachisuka, 2016). To our knowledge, there are no comparative studies between the use of HPP treatment and the addition of a hydrocolloid on the rheological and textural properties of a food designed for people with dysphagia.

The aim of this work was to evaluate the effect of HPP as an alternative technology to the use of xanthan gum for the preparation of lentil protein enriched vegetable purees with a suitable texture for dysphagia management. Initial trials were conducted to optimize the amount of protein and xanthan gum to be used, and the HPP conditions to be applied to the puree preparations. Rheological and textural properties of the developed products were analyzed. Also, the evolution of those properties during the shelf-life of HPP treated samples was assessed. Moreover, the nutritional profile of the purees was determined.

2. Material and methods

2.1. Ingredients

Zucchini, carrots, and extra virgin olive oil were purchased from local supermarkets (Calahorra, La Rioja, Spain). Lentil protein concentrate 55 (LP), (protein content: 55 g/100 g) was purchased from AGT Foods (Regina, SK, Canada). The xanthan gum (XG) was bought from Dayelet (Barcelona, Spain).

2.2. Preparation of samples

2.2.1. Protein model solutions

For the protein-XG solutions, different lentil protein (LP) contents to provide 10, 12 or 15% protein were dissolved in water and mixed with appropriate concentrations of XG (0.3–1%) in order to obtain a pudding-like texture. They were stored for 24 h at 4 °C before analysis.

Protein solutions for the HPP treatment were prepared by dissolving different LP concentrations (to provide 10, 12 and 15% of protein) in water. The samples were packed in 250 mL polypropylene transparent (PP) plastic bags and submitted to the corresponding HPP treatment. The treated solutions were stored for 24 h at 4 °C before analysis. Water solutions of LP with the corresponding protein concentrations (10, 12 and 15 %) were used as control.

2.2.2. Puree preparation

Control formulation was: 21.82% lentil protein concentrate, 10% zucchini, 10% peeled carrots, 55.68% water, and 2.5% extra virgin olive oil. For purees with hydrocolloid, the 0.8% of XG was added as a replacement from water content while maintaining the proportions of protein, vegetables and olive oil. Purees for HPP treatment had the same formulation as the control.

Entire vegetables were boiled for 30 min (vegetable and water at 1:2 proportion) in a cooking pot and the cooking water was stored. Then, they were pureed at speed 7 (over 4400 rpm) for 3 min using a Thermomix® (TM5, Vorwerk Spain M.S.L., S.C., Madrid, Spain) in order to obtain a homogeneous puree. Separately, the protein and the cooking water were mixed at speed 7 for 5 min using a Thermomix. Then the puree and the extra virgin olive oil and the hydrocolloid (in XG formulation) were incorporated and also mixed for 5 min at speed 7.

Three batches of every type of puree sample (control, those with XG and those treated with HPP) were prepared and stored at 4 °C for 24 h before testing. Samples with XG spoiled after 3 days of storage, whereas samples with HPP treatment were stable and analyzed after 14 days of storage at 4 °C.

2.3. Nutritional composition of the puree

The Regulation 1169/2011 of the European Parliament was used to determine the nutritional composition of control sample following the methods used by (Giura et al., 2023). Proteins were analyzed by Kjeldhal method (AOAC, 2000a), fats by Soxhlet(AOAC, 2000b), ash and fiber were determined by gravimetric method (AOAC, 2000c) and (AOAC, 2000d), respectively. To determine the moisture content the microwave drying method (AOAC, 2000e) was employed. Carbohydrates were calculated by difference.

2.4. HPP treatment

HPP treatment was applied using a 10 L HPP unit (Idus HPP Systems S.L.U., Noain, Navarra, Spain) at a temperature of 8 °C. The protein solutions samples were treated using two conditions: 250 MPa for 15 min or 600 MPa for 5 min. These conditions have been shown to modify rheological and textural parameters of vegetal and animal (Cadesky et al., 2017; Hall & Moraru, 2021; Sim et al., 2019).In the case of puree samples only the selected condition (600 MPa/5 min) was applied.

2.5. IDDSI measurements

The IDDSI Method (International Dysphagia Diet Standardization Initiative) was used as a useful and easy method to preselect the optimal concentrations of protein solutions and XG in order to confirm the suitability of the textural characteristics for dysphagia. A syringe with a length of 61.5 mm from the zero line to the 10 mL line was used to measure the gravity flow test's results (for levels 0 to 4) in order to determine the liquid's flow category, and a metal fork and a spoon were used for levels 3 to 7 (IDDSI, 2019).

2.6. Rheological properties

The rheological measurements were performed with a discovery HR-1 Hybrid Rheometer (TA Instruments Ltd., New Castle, DW, USA) equipped with a peltier in order to maintain the temperature. The geometry used in this experiment was the concentric cylinder. After loading, the samples were released during 10 min for the control and XG samples and for 30 min for the HPP treated samples in order to recover their structure from the stress produced during sample loading and geometry lowering and to equilibrate the temperature. All rheological measurements were made at 40 °C in order to simulate the temperature of the products when they are consumed (Giura et al., 2022; Hadde, Nicholson, & Cichero, 2015).

2.6.1. Viscosity

A continuous shear rate ramp from 0.001 to 400 s^{-1} was performed and the corresponding change in viscosity was recorded. Apparent viscosity value at shear rate of 50 s^{-1} was selected for comparison among the protein solutions and the vegetables purees samples.

2.6.2. Viscoelastic properties

An amplitude sweep test within strain range from 0.01% to 400% and at a frequency of 1 Hz was used to determine the linear viscoelastic region (LVR) of puree samples, following the method used by Giura et al. (2022). The value at which the G′ value deviated 5% from the plateau value (according to the standards ISO 6721–10 and EN/DIN EN 14770) was taken as the limit of LVR. The following parameters were obtained: the storage modulus (G'_{LVR}, Pa), represented by the mean of the G′

values on the LVR; the yield $strain_{LVR}$ (%) and the corresponding yield $stress_{LVR}$ (Pa), considered as the values of the shear strain and shear stress, respectively, at the limit of the LVR region. The flow point (Pa) which gives information about the breakdown of the internal structure, was taken as the value of the crossover point where $G' = G''$ (Mezger, 2020).

Frequency sweep tests from 0.1 to 10 Hz were performed at a constant strain within the LVR (obtained for each sample from the amplitude sweep tests) and storage modulus (G′, Pa), loss modulus (G″, Pa) and loss tangent (tan δ, G″/G′, dimensionless) were recorded.

2.7. Textural properties

Textural properties were evaluated using a texture analyzer (TA. XT2i Plus Texture Analyzer, Stable Micro Systems, Texture Technologies Corporation, Scarsdale, NY, USA). A back extrusion test was performed using a back-extrusion disc (A/BE40, 40 mm diameter). Each sample was loaded in a 60 mm diameter container which was filled 75% from its height and the disc was plunged into the sample at the following settings: 1 mm/s test speed, 1 mm/s pre-speed, 10 mm/s post-speed, distance 20 mm and return distance 85 mm. The parameters obtained were: firmness (N), consistency (N.s), cohesiveness (N), and viscosity index (N. s).

2.8. pH, microbiological analysis and color stability

pH was measured using a pH-metro Crison micropH2000. The microbiological analysis were carried out according to certified methods (AENOR, 2008). All samples were analyzed at time 0, and HPP samples were also analyzed after 14 days of storage (at 4 °C). In the case of XG samples, as they seemed to be spoiled, the microbiological analysis was done after 3 days of storage. The mesophilic anaerobes and aerobes were determined by plating the suspensions on liver agar and incubated at 37°C for 48 h (anaerobes) and at 30°C for 72 h (aerobes); *Salmonella* spp. and *Listeria monocytogenes* were analyzed by VIDAS immunoanalyzer. For *Salmonella spp*. samples were plated with buffered peptone water and incubated at 41.5 °C for 18–24 h. Samples for *Listeria monocytogenes* were plated with LMX broth and incubated at 37 °C for 26–30 h (Giura et al., 2023). All measurements were made in triplicate.

The color of the samples was measured using a colorimeter (CR-5, Konica Minolta Sensing Inc., Tokyo, Japan) with D65 as illuminant and 10° observer angle as a reference system. The results were expressed using CIEL*a*b*. Chroma (C*) and hue angle (h°) were also determined.

2.9. Statistical analyses

Statistical analyses were performed by using the STATA 15 program (Stata Corp LLC, TX, USA). One-way analysis of variance (ANOVA) was performed to evaluate statistical significance ($p \le 0.05$) among all formulations followed by a post hoc test Tukey to detect statistically significant differences between the samples. Every parameter (nutritional composition, rheological, texture, microbiological and color) were analyzed in triplicate and the results are expressed as mean ± standard deviation.

3. Results and discussion

3.1. Pre-selection of the hydrocolloid concentration and HPP treatment conditions

Before the preparation of protein enriched vegetable purees, a previous experimental study was carried out in order to preselect the most adequate protein amount, XG concentration and HPP treatment conditions. Different amounts of lentil protein (LP) that supplied 10, 12 or 15% protein were solved in water. Some formulations were added with XG (0.3–1%) and the others were treated under two different HPP conditions (250 MPa/15 min, 600 MPa/5min). IDDSI tests and viscosities were measured in all samples, including the control ones (without XG and HPP treatments) in order to choose the best combinations. Table 1 shows the results obtained in this experiment.

The criteria used for selecting the optimum conditions were: a level 4 for IDDSI test and a pudding-like viscosity (>1750 cP, according to National Dysphagia Diet Task Force, (NDD, 2002). Control samples at 10, 12 and 15 % of protein resulted in 0, 2 and 2 IDDSI levels, and viscosity values of 39, 109.2 and 386.5 mPa.s, respectively. When XG was added to the protein solutions the consistency and viscosity of the samples increased, being the increment higher as the protein concentration increased, as it could be expected. Due to their functional and textural properties proteins and polysaccharides have an important role in food development. Moreover, when both of them are mixed they interact and create systems with better functional properties compared to pure protein or pure polysaccharide (Bi et al., 2018). IDDSI level 4 was achieved with XG concentrations of 1% in 10% LP samples, 0.8% in 12% LP samples and 0.5%/0.8% in 15% LP samples. In every case, the viscosity values were > 1750 mPa s.

HPP usually leads to an increase in water holding capacity (WHC) of proteins, which may positively impact the textural attributes of many protein-rich food commodities (Queirós et al., 2018). Our results showed that HPP treatments modified the consistency and viscosity of samples. With 250 MPa/15 min treatments, the respective viscosity values were 100, 342.5 and 595.2 mPa s. for samples with 10, 12 and 15 % LP, respectively and in none of these samples the 4 IDDSI level was reached. Sim et al. (2019), analyzing the structural modifications of different pea protein concentrates as a consequence of HPP treatments observed that pressures above 350 MPa induced protein denaturation and subsequent gel structure formation.

With 600 MPa/5 min treatments the viscosities were much higher, reaching values of 293.3, 1173.1 and 3070.4 mPa s. for 10, 12 and 15% LP samples. Only in the case of 15% LP the 4th level IDDSI was achieved. Garcia-Mora et al. (2015) observed no effect on lentil protein solubility when 100–300 MPa were applied, but pressure levels of 400–500 MPa significantly reduced their solubility, which could explain the increase of viscosity. Using 12% of lentil protein and the same treatment (600

Table 1
IDDSI parameters and apparent viscosity at 50 s^{-1} shear rate for the control, XG and HPP-treated protein solutions measured at 40 °C.

Samples	IDDSI Flow Test (ml)	*IDDSI Level*	*Viscosity* (mPa s)
LP 10%			
Control (LP 10%)	0	0	39 ± 4.4
LP10%+ XG 0.3%	8.5	3	498.4 ± 40
LP10%+ XG 0.5%	8.5	3	779.3 ± 5.5
LP10%+ XG 0.8%	9	3	1375.7 ± 21.2
LP10%+ XG 1%	10	4	1827.2 ± 8.7
LP10%+ 600 MPa/5 min	7	2	293.3 ± 13.8
LP10%+ 250 MPa/ 15 min	6	2	99.7 ± 2.1
LP 12%			
Control (LP 12%)	6	2	109.2 ± 11.4
LP12%+ XG 0.3%	8	3	674.6 ± 49.7
LP12%+ XG 0.5%	9	3	1164.7 ± 25.6
LP12%+ XG 0.8%	10	4	1847.2 ± 36.2
LP12%+ 600 MPa/5 min	9	3	1173.1 ± 164.1
LP12%+ 250 MPa/ 15 min	7	2	342.5 ± 12.7
LP 15%			
Control (LP 15%)	8	2	386.5 ± 43.6
LP15%+ XG 0.3%	9	3	1445.2 ± 101.8
LP15%+ XG 0.5%	10	4	3804.9 ± 381.9
LP15%+ XG 0.8%	10	4	3887.2 ± 71.5
LP15%+ 600 MPa/5 min	10	4	3070.4 ± 210.5
LP15%+ 250 MPa/ 15 min	8.5	3	595.2 ± 52.3

Data are presented as mean ± standard deviation of three independent experiments.
Lentil protein (LP), xanthan gum (XG).

MPa/5 min), (Sim, Hua, & Henry, 2020) obtained plant protein gels with similar texture to dairy products opening new alternatives for the production of plant based yogurts with a suitable texture and a high nutritional value.

3.2. Purees formulation and composition

Taking into account these previous experiments, a 15% protein content was firstly chosen for the formulations of protein enriched vegetable purees. In the case of the use of hydrocolloids, 0.8% of XG was used as thickener and in the case of HPP treatment, 600 MPa/ 5 min conditions were applied.

However, the textures of the obtained dishes were clearly too thick and rheological measurements in concentric cylinders at 40 °C were not possible. This lack of extrapolation of the model systems to the developed dishes was probably due to the fact that the vegetables used in the pureed formulations supply polymers (basically carbohydrates and fibers) that contributed to the consistency of the new food matrix and interact with the proteins, as it has been pointed out before. Similar findings were reported in HPP treated pea protein-starch mixtures, where the starch presence increased the gel strength of the resulting products (Sim & Moraru, 2020). So, it was necessary to decrease the protein content to a 12%. The final percentage of each ingredient in the purees is shown in Table S1 (Supplementary material). The thickener amount and the HPP conditions were maintained. The visual appearance of the three different puree samples (control, those with XG and those treated with HPP) after 24 h at 4 °C is show in Figure S1 (Supplementary material).

Once the formulation of the puree was fixed, the nutritional composition was evaluated (Table S2, Supplementary material). The formulations showed a good protein level (12%), enough to be claimed as "high protein content" (Regulation 1924/2006 EC), with a 3.4% fat from olive oil and a significant amount of fiber (3.4%), enough to be claimed as "high fiber content" (Regulation 1924/2006 EC, n.d.). As XG is a soluble dietary fiber with proven health benefits so its presence in the formulation should increase the total amount of fiber of the products (Alshammari et al., 2021; Nagasawa et al., 2022). Vegetables have a high antioxidant capacity because of their significant amount of phenolic compounds (Reyes, Villarreal, & Cisneros-Zevallos, 2007) so their incorporation in a 20% in the product preparation seems to be a good strategy to supply this type of compounds. Therefore, from the nutritional point of view, the dish seemed to be very adequate for people with dysphagia showing protein deficiency and/or obesity problems.

The rheological and textural properties of the developed purees were analyzed in order to assess the potential differences between the use of the hydrocolloid and the HPP treatment. When HPP was applied the analysis were carried out not only at time 0 but also after 14 days of refrigerated storage (which was their estimated shelf-life). XG samples were not analyzed during storage, as they were rapidly spoiled (above limits for microbiological counts at 3 days of refrigerated storage).

3.3. Rheological properties

3.3.1. Viscosity

Fig. 1 shows change in the viscosity with the shear rate change from 0.001 to 400 s^{-1}. A clear shear thinning behavior with the viscosity decreasing when increasing the shear rate can be observed for every analyzed sample. Fig. 2 shows the viscosities of all samples at shear rate 50 s^{-1}. At time 0 the highest viscosity (3651.5 mPa.s.) corresponded to samples thickened with 0.8 XG, although samples treated with HPP also reached a high viscosity (2234.4 mPa.s) as compared to control samples. Moreover, in these HPP treated samples, the viscosity increased with the storage time, reaching values of 4077.8 mPa.s. at 14 days of storage. This fact may be attributed to the retrogradation of the starch present in the samplés composition during the storage (Peñaflor et al., 2017). It has been described that tapioca starch gels formed by 600 MPa HPP treatment became stiffer during their storage at 4 °C, possibly due to starch–starch and/or starch/ water interactions that result in higher viscosity (Vittadini, Carini, Chiavaro, Rovere, & Barbanti, 2008). Zarim et al. (2021) studying the shelf life stability of texture-modified chicken rendang also reported that samples containing modified corn starch exhibit an increase in flow and viscoelastic properties during storage.

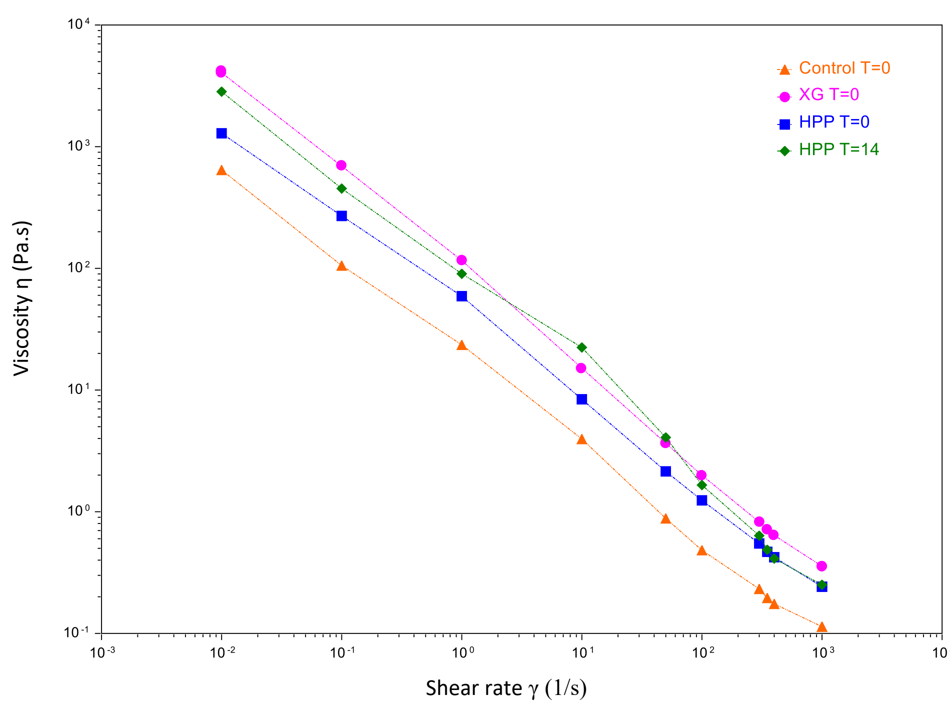

Fig. 1. Viscosity curves for the control puree (Control T = 0) and XG puree (XG T = 0) at time 0 and HPP treated puree at T = 0 and T = 14 Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

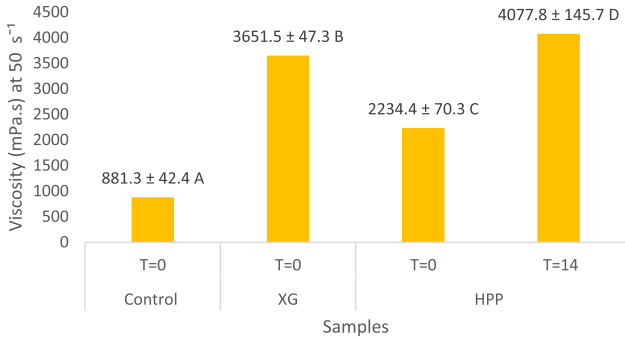

Fig. 2. Viscosity values for the control (T = 0), XG (T = 0), HPP (T = 0) and HPP (T = 14) puree samples at 50 s^{-1}. Different capital letters next to the values indicate significant differences ($P < 0.05$) among samples based on the post hoc Tukey test. Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

3.3.2. Viscoelastic properties

Fig. 3 shows the amplitude sweep curves for G′ (storage modulus) of control, XG and HPP treated samples at time 0 and HPP treated sample at time 14 days. G′ decreased with the increasing strain for all the formulations. HPP treated samples at time 0 and at time 14 days showed the highest G′ values at low strain %, but they had the shortest LVR (Linear Viscoelastic Region), whereas samples with XG showed the larger LVR. Owing to the short LVR, these results indicate that the HPP treatment imparted a brittle texture to the purees and the xanthan imparted a more elastic texture (Ozel & Oztop, 2023).

Fig. 4 (a-d) shows the values for G'_{LVR}, yield $strain_{LVR}$, yield $stress_{LVR}$, and flow point, respectively. G′ provides information about the material stiffness, yield $strain_{LVR}$ gives information about the structural deformability, while yield $stress_{LVR}$ can be taken as an indicator of rheological stability (Mezger, 2020). Comparing XG and HPP samples at time 0, HPP treated purees showed the highest stiffness and the lowest deformability capacity and structural stability. Ribes et al. (2022), comparing different thickeners in texture-modified chicken and vegetable soups found that those prepared with guar gum and chia seed mucilage had better structural stability (higher yield $stress_{LVR}$) than samples containing modified starch which authors attributed to the presence of large polymeric molecules. With storage, changes were observed in HPP treatment samples with significant increases in stiffness (G′), rheological stability (yield $stress_{LVR}$) and deformability capacity (yield $strain_{LVR}$). Regarding the flow point (breakdown of the internal structure) HPP treated samples showed higher values than samples with XG and the control ones, with increasing values during storage. However, in a previous work, cocoa desserts enriched with casein and with a similar HPP treatment showed a decrease on G'_{LVR}, yield $strain_{LVR}$ yield $stress_{LVR}$, and flow point with storage time (Giura et al., 2023). These opposite results point out the relevance of the food matrix in the rheological behavior during the shelf-life of HPP treated foods.

Fig. 5 shows the frequency sweep tests of elastic modulus (G′) and viscous modulus (G″). For every frequency, the elastic modulus was higher than the viscous modulus in all samples. These results (G′>G″) are very usual in the rheology of dysphagia designed foods (Dick et al., 2020; Herranz et al., 2021; Suebsaen et al., 2019; Vieira et al., 2021). Table 2 summarizes the values obtained for the parameters related with viscoelastic properties measured at 1 Hz. Although significant differences were found for storage and loss modulus among all samples, tan delta (G″/G′) values were similar for HPP treated samples and control samples (0.161–0.174), while samples with XG showed a bit higher values (0.222). Talens et al. (2021) obtained similar tan delta values (0.207) when using 0.4% XG in tailor pea cream for people with swallowing problems. Tan delta values ranged between 0.1 and 0.4 are indicative of a weak-gel-like character (Ikeda & Nishinari, 2001). Sim et al. (2020) developed high protein plant-based yogurt products (12% protein) using different plant proteins, including lentil protein, getting the gel-like structure with HPP treatments of 600 MPa/5 min. They found that this treatment formed viscoelastic gels with comparable gel strength to commercial dairy products.

3.4. Textural properties

Textural parameters obtained by texture analyzer were suggested to

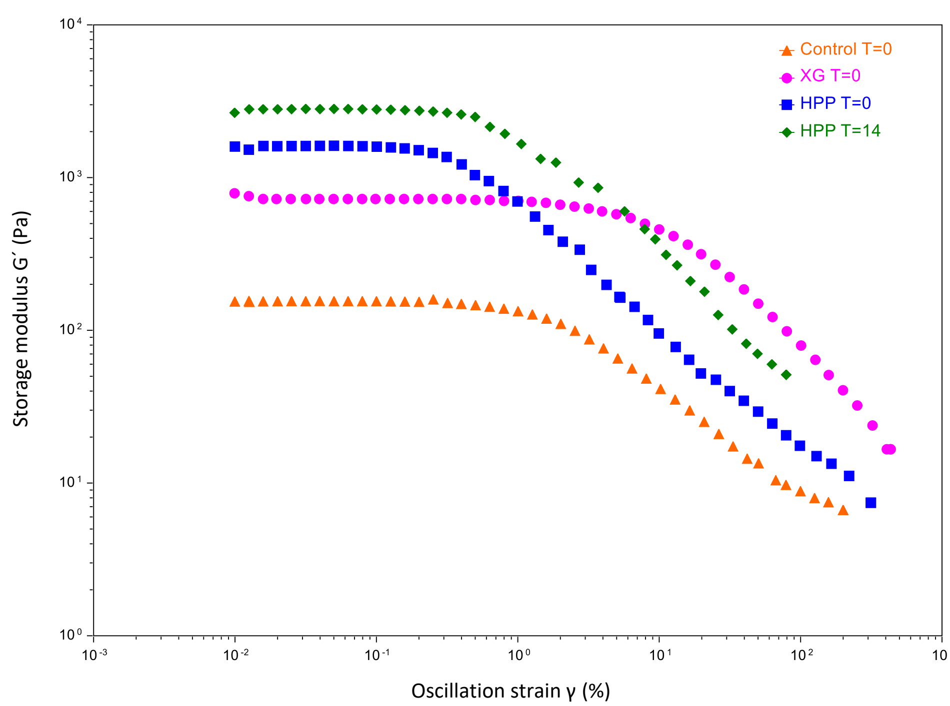

Fig. 3. Amplitude curves of Storage modulus (G′) for the control (T = 0), XG (T = 0), HPP (T = 0) and HPP (T = 14) puree samples Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

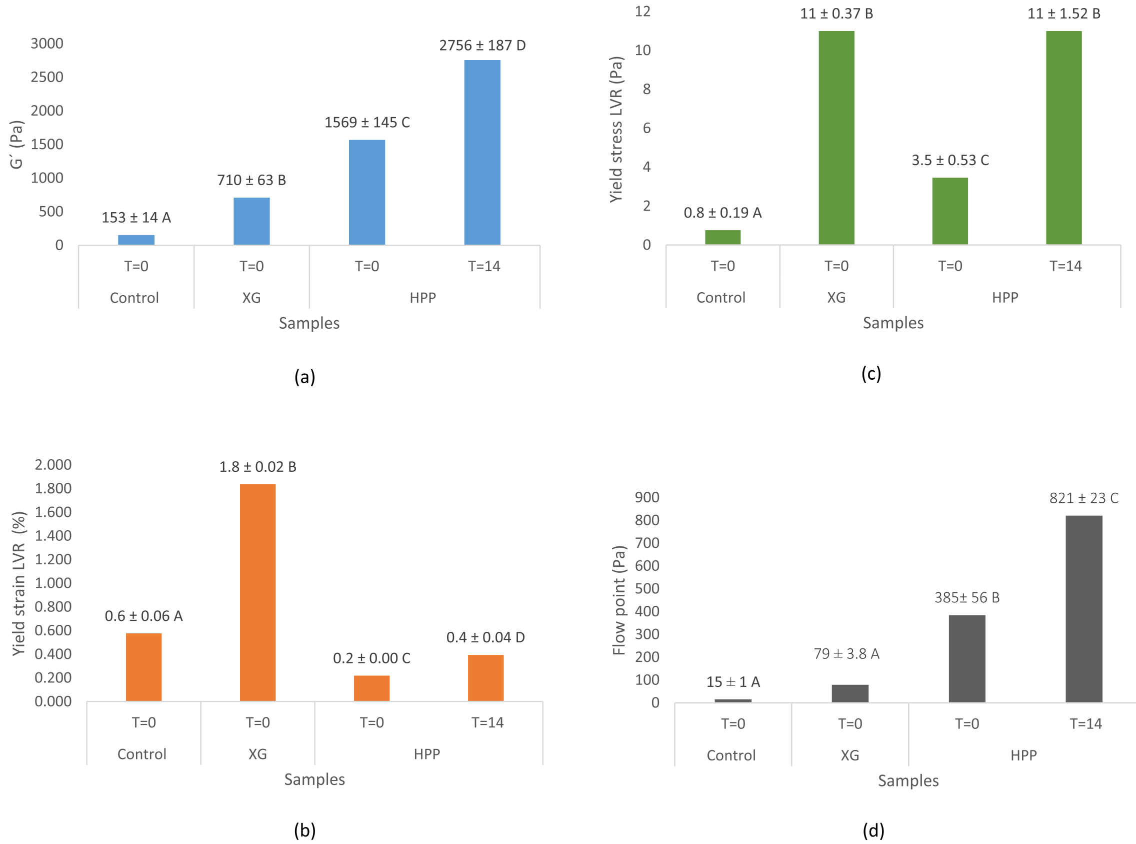

Fig. 4. (a-d) Rheological parameters (G'_{LVR}, yield $strain_{LVR}$ yield $stress_{LVR}$, and flow point) obtained from amplitude sweep tests for the control (T = 0), XG (T = 0), HPP (T = 0) and HPP (T = 14) puree samples. Different capital letters next to the values indicate significant differences ($P < 0.05$) among samples based on the post hoc Tukey test. Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

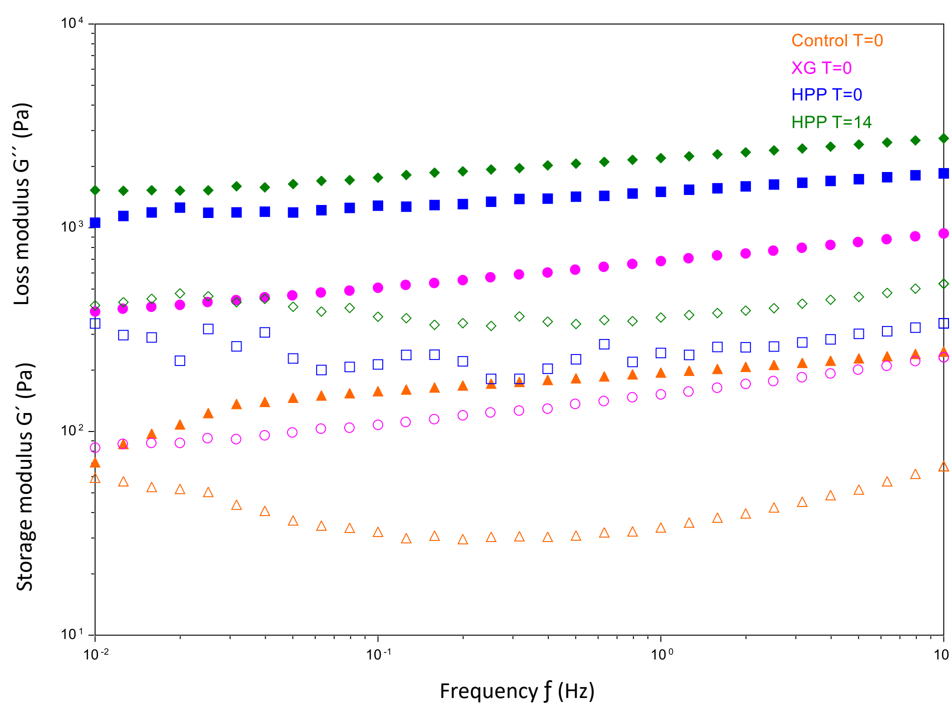

Fig. 5. Frequency sweep curves for the control (T = 0), XG (T = 0), HPP (T = 0) and HPP (T = 14) puree samples. Storage modulus (G′): closed symbols; and loss modulus (G′′): open symbols. Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

Table 2
Viscoelastic parameters obtained from Frequency sweep tests at 1 Hz (Storage modulus, loss modulus, and loss tangent) in puree samples.

Sample	Sampling time	Storage modulus (Pa)	Loss modulus (Pa)	Tan delta
Control	T = 0	194.6 ± 30.3^{A}	33.8 ± 5.6^{A}	0.174 ± 0.005^{A}
XG	T = 0	680.5 ± 13.2^{B}	151.2 ± 2.2^{B}	0.222 ± 0.001^{B}
HPP	T = 0	1501 ± 103.1^{C}	242.8 ± 31.5^{C}	0.161 ± 0.011^{A}
	T = 14	2198.4 ± 353.6^{D}	362.7 ± 56.1^{D}	0.165 ± 0.005^{A}

Note: Data are presented as mean ± standard deviation of three independent experiments. Different capital letters, in the same column, indicate significant differences ($P < 0.05$) among the samples based on the post hoc Tukey test. Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

Table 3
Textural parameters obtained by back extrusion test in puree samples.

Sample	Sampling time	Firmness (N)	Consistency (N.sec)	Cohesiveness (N)	Index of viscosity (N.sec)
Control	T = 0	0.3 ± 0.01^{A}	5.5 ± 0.09^{A}	0.4 ± 0.00^{A}	0.6 ± 0.01^{A}
XG	T = 0	1.6 ± 0.04^{B}	30.3 ± 0.28^{B}	3.3 ± 0.08^{B}	4.3 ± 0.24^{B}
HPP	T = 0	2 ± 0.02^{B}	34.7 ± 0.48^{B}	2.5 ± 0.26^{B}	4.4 ± 0.64^{B}
	T = 14	4.2 ± 0.43^{C}	63.4 ± 4.8^{C}	5.7 ± 0.71^{C}	8.2 ± 0.86^{C}

Note: Data are presented as mean ± standard deviation of three independent experiments. Different capital letters, in the same column, indicate significant differences ($P < 0.05$) among the samples based on the post hoc Tukey test. Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

be important in characterizing dysphagia dishes, since they provide additional rheological parameters to those obtained with the rheometer (Baixauli et al., 2022). Firmness, consistency, cohesiveness values and index of viscosity (Table 3) were much higher in samples with XG and HPP time 0 than in control samples, similar to the results obtained in the rheological analysis. Firmness and consistency are related to stiffness and cohesiveness was suggested to be related with the yield stress (rheological stability) (Ross, Tyler, Borgognone, & Eriksen, 2019).

With storage time, all parameters increased in HPP treated samples, which again agree with the increase observed for the rheological parameters. Mechanical cohesiveness is a synonym of the internal binding force that contributes to the formation of a coherent bolus (Ben Tobin et al., 2020) and could have an important role in preventing aspiration (Nishinari, Turcanu, Nakauma, & Fang, 2019). Index of viscosity can be related with the work of cohesion (the higher its value the sample is more resistant to withdraw) and it is related to cohesiveness and consistency of the sample (Syahariza & Yong, 2017).

3.5. pH, microbiological analyses and color stability

All samples showed pH around 6.24 and high moisture content, making them highly susceptible to deterioration. The HPP treatment (600 MPa/5 min) applied to the puree reduced the initial counts of mesophilic aerobic from 6.7 Log CFU/g to < 2.0 Log CFU/g and mesophilic anaerobic from 5.4 Log CFU/g to < 1.6 Log CFU/g. With the storage, the mesophilic aerobes increased up from 2 to 3 Log CFU/g and anaerobic counts were maintained below 2 Log CFU/g after 14 days of storage. *L. monocytogenes* and *Salmonella* spp. were not detected neither before nor after the HPP treatment. These results confirmed that the HPP treated purees were microbiologically safe, at least during 14 days of storage at 4 °C. On the contrary, for the samples containing XG bad appearance and smell were detected after 3 days of storage time. Microbiological analyses confirmed that the mesophilic aerobes were above 7.72 Log CFU/g after 3 days, being discarded due to its microbial instability. Color is a very important factor in the pleasantness and acceptability of food products. Although differences in color were not visually relevant (see Figure S1 Supplementary material), the instrumental color measures gave significant differences in every parameter among samples (Table 4). HPP treatment had a lower effect on color than the use of XG, showing the treated samples quite similar values for every parameter as compared to control samples.

4. Conclusions

The rheological and textural properties of vegetable purees enriched in protein and appropriate for people with dysphagia through the use of thickeners or HPP treatment were compared. HPP treatment (600 MPa/5 min) gave rise to products with a shelf-life of 14 days/4 °C. Differences in the gel structure were observed, being stronger (higher Ǵvalues and firmness) for the formulations submitted to the HPP treatment, especially after the storage period. On the contrary, those prepared with XG showed higher elasticity. In conclusion, HPP treatment and XG are both good strategies for developing dysphagia foods. With the use of HPP it is possible to obtain clean label products with an extended shelf life and, on the other hand, the XG has a reduced cost and is accessible to a large part of the industry. Future works to confirm their suitability for people with dysphagia should be carried out.

Funding

This research was funded by Gobierno de Navarra, DEGLUSEN project (PhD grant: Ayudas para la contratación de doctorandos y doctorandas por empresas, centros de investigación y centros tecnológicos: Doctorados industriales 2020).

CRediT authorship contribution statement

Larisa Giura: Conceptualization, Formal analysis, Data curation, Methodology, Investigation, Writing – original draft, Writing – review & editing. **Leyre Urtasun:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Writing – review & editing. **Diana Ansorena:** Conceptualization, Funding acquisition, Investigation, Resources, Visualization, Supervision, Writing – original draft, Writing – review & editing. **Iciar Astiasaran:** Conceptualization, Funding acquisition, Investigation, Resources, Supervision, Supervision, Writing – original draft, Writing – review & editing.

Table 4
Color (CIEL*a*b*) measurements in puree samples.

Sample	Sampling time	L*	a*	b*	C*	h*
Control	T = 0	71.37 ± 0.06^{A}	4.43 ± 0.07^{A}	37.38 ± 0.26^{A}	37.64 ± 0.25^{A}	83.24 ± 0.14^{A}
XG	T = 0	74.44 ± 0.02^{B}	−0.77 ± 0.01^{B}	26.39 ± 0.01^{B}	26.41 ± 0.01^{B}	91.68 ± 0.02^{B}
HPP	T = 0	71.89 ± 0.11^{C}	3.82 ± 0.08^{C}	36.11 ± 0.08^{C}	36.31 ± 0.09^{C}	83.96 ± 0.11^{C}
	T = 14	72.09 ± 0.03^{D}	5.08 ± 0.02^{D}	35.05 ± 0.07^{D}	35.41 ± 0.07^{D}	81.75 ± 0.02^{D}

Note: Data are presented as mean ± standard deviation of three independent experiments. Different capital letters, in the same column, indicate significant differences ($P < 0.05$) among the samples based on the post hoc Tukey test. Xanthan gum (XG), HPP (high-pressure processing), T = 0 (time 0), T = 14 (time 14 days).

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgments

The authors thank the collaboration of Idus HPP Systems S.L.U for the HPP treatments during the entire experimental design.

Special thanks to Dr. Carlos Alberto Gracia Fernandez for providing technical assistance on the realization of rheological measurements.

Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.foodres.2023.112975.

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