

# Developing a homogeneous texture dish by combining solid and liquid foodstuff matrices

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## ABSTRACT

A dish with a uniform texture was developed for people with a poor oral health problem: dysphagia. Its texture and color were studied, along with its consumption and cold storage with reheating. The dish was constituted by softening carrot and integrated into thickened soup. Carrot was softened by applying enzymes via freeze-thaw impregnation (FI). Soup was thickened by guar gum. The results indicate both components achieved a similar texture. Firmness and cohesiveness increased significantly as temperature dropped. Judges were unable to detect the presence or absence of carrot in the dish by a sensorial compression assay, but could detect color changes. These outcomes were also verified by a digital image analysis. The results demonstrate the feasibility of using FI treatment combined with enzymes to soften vegetables and subsequently incorporating them into thickened liquid foodstuff to develop safe, sensory-accepted and texture-modified products for specific populations.

## 1. Introduction

The prevalence of chewing or swallowing disorders is rapidly increasing because the world's population is aging due to longer life expectancy and a declining birth rate, which is an important social issue (Aguilera & Park, 2016). Of such disorders, dysphagia is probably the most important. It affects the ability to swallow, which makes safe-swallowable boluses difficult to form (Cichero, 2013). It can occur because of neurological, muscular and structural pathologies (Díaz et al., 2021), and currently affects about 50% of the residents in care facilities for the elderly and close to 8% of the world's population (Dick, Bhandari, Dong, & Prakash, 2020; Talens, Castells, Verdú, Barat, & Grau, 2021; Zarim, Zainul, Abidin, & Ariffin, 2021). Dysphagia disorders have been recently found in children as a consequence of SARS-CoV-2 (Halfpenny et al., 2021). Dysphagia provokes unbalanced diets, vitamin or mineral deficiencies, and malnutrition because it tends to suppress the intake of products that cause discomfort or difficulties while eating. This is the case of fruit and vegetables (Sheiham & Steele, 2001), which are often removed from diet by dysphagic people because they find them hard to prepare, chew or swallow (Roininen, Fillion, Kilcast, & Lähteenmäki, 2004).

Hence the importance of highlighting that texture-modified (TM) foods are usually prescribed to dysphagics to prevent health risks

(Zarim, Zainul, Abidin, & Ariffin, 2021). Solid products are normally puréed, minced, chopped, mashed or softened. Liquid products are thickened with hydrocolloids to enhance safe swallowing for dysphagic patients by modifying bolus viscosity (Cichero, 2016; Suebsaen, Sukstitt, Kanha, & Laokuldilok, 2019; Park & Yoo, 2020). With this procedure, a safe cheap uniform texture can be obtained by cooking food products altogether, mincing and then adding a hydrocolloid to obtain the desired texture. Unfortunately, these products may not be appetizing for some consumers (Park & Lee, 2020), which decreases food volume intake and, therefore, also increases malnutrition. So obtaining a uniform texture for a dish in which products are usually identified as "solid" (e.g., carrot, meat), have the same soft texture as soup, but appear solid, could be a solution.

In order to increase the softness of vegetable tissues like carrots, which are extremely relevant in the food world thanks to their numerous benefits and being an important source of fiber, carotenoids (especially  $\beta$ -carotenes) and essential nutrients (Elik, Yanik, & Göğüş, 2020), an easy strategy is to use high temperature or extensive cooking (overcooking). Despite this procedure being easy to apply, as previously mentioned, it entails disadvantages like loss of vitamins and flavors, and organoleptic alterations in color and sweetness (Achir et al., 2016). But the main drawback is that it generates texture gradients because, to reach high softness levels in innermost areas, outermost ones are usually

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destroyed, which is why they must be minced. One way of softening solid foodstuff, without disturbing its organoleptic characteristics, is by enzyme impregnation using freeze-thaw infusion (FI). FI is an impregnation technique that can create TM foods without disturbing the original product shape because it permits a substance to be rapidly impregnated into a food matrix (Nakatsu et al., 2012, 2014; Park & Lee, 2020; Sakamoto, Shibata, & Ishihara, 2006; Shibata et al., 2010). Moreover, commercial enzymes with methylsterase and polygalacturonase activities have been applied to degrade the polymers of vegetable cell walls by breaking down their cellular integrity and softening their texture (Eom et al., 2018). Several studies have been conducted to soften solids or thicken liquids for people with oral deficiencies (Gallego, Barat, Grau, & Talens, 2022), but no studies have combined solid and liquid foodstuff matrices by homogenizing their mechanical properties. This outcome could imply making considerable progress in the design of nutritionally balanced TM foods for dysphagics with improved organoleptic characteristics. The main challenge of this strategy is to both completely homogenize texture and reduce the risk of choking when a bolus forms that can be swallowed (Alcalde, Ricote, & Rodríguez, 2020; Saitoh et al., 2007; Suebsaen et al., 2019). In addition, TM foods can fulfill both functions by increasing a patient's appetite to eat a dish and its nutritional value because it is submitted to less heat treatment.

However, one of the problems of combining two components or more in a single texture is their stability during service and consumption because of temperature change. This is an important aspect for hospitals and geriatric centers where many menus must be prepared and sometimes could be reheated after storage and the components' texture evolution could not be the same. This means that dish components have to remain stable to keep safe the dish. It is well-known that some gels increase firmness with prolonged storage, but carrots could also be affected by these effects (Yang, Dai, Huang, & Sombatgamwilai, 2020). Color is another interesting parameter to study in foods like carrots because it can be affected by changes in temperature during consumption, cold storage or reheating. This attribute plays an important role in food choice and consumption for influencing taste thresholds, food preferences, pleasantness, and acceptability (Spence, 2015). In carrots, color is specifically associated with the number of pigments and, therefore, with the presence of antioxidants, among others (Camorani et al., 2014; Park & Lee, 2020). Besides, it strongly impacts consumer expectations of sensory and functional properties, including freshness and nutritional value (Schifferstein, Wehrle, & Carbon, 2019).

The aim of this paper is to develop a safe and homogeneous texture dish by combining solid and liquid foodstuff matrices for people with poor oral health to enhance their appetite with attractive shapes. To this end, the influence of temperature drop, from which the dish is served, and the effect of subsequent reheating after cold storing were also evaluated.

## 2. Materials and methods

### 2.1. Materials

The carrots (*Daucus carota*) and chicken and vegetable soup ingredients used in our experiments were purchased at a local supermarket (Valencia, Spain). A metallic core bore and a slice cutter (Slice Cutter MS 4570, Orbegozo, Murcia, Spain) were used to prepare carrot cylinders (10 mm thick, 25 mm in diameter). They were enzyme-treated to be later added to soup, which was prepared and thickened to the same texture as carrots. The aim of adding carrots was to make the dish more appetizing. The chicken and vegetable soup was prepared traditionally, but following the methodology described by Ribes, Grau, and Talens (2022). After cooking, liquid was filtered, transferred to plastic containers and frozen until used. A hydrocolloid was employed to thicken soup and to achieve similar mechanical properties to those contained in carrots. Guar gum (GG) (EPSA, Valencia, Spain) was selected in line with

different studies to underline its thickening effect (Dick et al., 2020; Hedayati et al., 2021; Merino, Gómez, Marín-Arroyo, Beriain, & Ibañez, 2020), and also because it is odorless and tasteless (Gupta, Saurabh, Variyar, & Sharma, 2015; Kapoor et al., 2020).

### 2.2. Experimental procedure

The study was performed in two stages (Fig. 1). The first stage involved obtaining a dish with one same texture. For this purpose, carrots were enzyme-treated until the highest softness level was reached, but without disturbing their original shape. The soup with the same texture as carrots was prepared by employing GG.

In Stage 2, once the textures of both dish parts were equal, the influence of temperature and cold storage time with reheating was evaluated on the dish's texture and color. To this end, instrumental and sensory measurements were taken. For the sensory visual evaluation and instrumental color analysis, a plate containing three carrots on thickened soup was designed and evaluated at 55 °C, 37 °C and 25 °C immediately after being prepared (0 h) and after 24 h of cold storage (5 °C). To do so, dishes were reheated in a water bath (70 °C) and cooled until the above-mentioned temperatures were reached, which were selected according to Ribes, Estarriaga, Grau, and Talens (2021). Selection was based on consumption temperature because a dish is usually served at around 55 °C and then cooled down to room temperature during consumption. Measurement times 0 h and 24 h of cold storage with reheating were selected to study the texture and color thermostability of the designed dish based on the research carried out by Merino et al. (2020), Pematilleke, Kaur, Rai Wai, Adhikari, and Torley (2021) and Yang et al. (2020).

### 2.3. FI carrot treatment and soup thickening

Carrots were labeled and stored in a freezer at -20 °C. To avoid loss of water by sublimation, samples were wrapped in transparent plastic and left in the freezer for a maximum of 10 days. The frozen samples were thawed at 20 °C for 5 h. The methodology followed to soften carrots was selected according to Park and Lee (2020) and Eom et al. (2018), but with slight modifications. Briefly, samples were immersed in a 400 mL solution containing 0.5% commercial enzyme complex (Enozym Vintage; Agrovin, Ciudad Real, Spain), with polygalacturonase (PG) activity (546 IU/g), pectinmethylsterase (PME) activity (7.3 IU/g), and pectinlyse (PL) activity (2.8 IU/g). The enzyme solution was left at a neutral pH (ca. 6.5 pH) to avoid changes in the final product taste. Next carrots were submitted to vacuum treatment, which consisted of placing the enzyme solution with the immersed samples inside a beaker, followed by the application of vacuum pulses. The achieved pressure conditions were 85 kPa for 5 min and then atmospheric pressure was restored for 1.5 min. Processing was repeated in duplicate to improve the impregnation effect according to preliminary studies. After vacuum treatment, samples were removed from the enzyme solution and placed in an oven at 36 °C for 7, 15, 17, and 22 h. The enzyme action time was the variable used to increase carrot softness. After the oven treatment, carrots were steamed for 5 min to inhibit any enzyme reaction. It is noteworthy that the heat treatment time was estimated from a heat penetration study carried out by measuring the temperature in the center of samples until these measurements exceeded 90 °C. The aim of this process was to achieve an internal temperature of 85 °C because: PME is inactivated after remaining between 57 °C and 65 °C for a couple of minutes (Anthon, Sekine, Watanabe, & Barrett, 2002); PG is almost completely inactivated (up to 86% of its enzyme activity) when temperatures between 55 and 70 °C are reached (Fachin et al., 2003).

Solutions of soup at different GG concentrations (3.5, 4, 4.2, 4.5, and 5%, w/v) were prepared by adding and stirring GG into soup at 70 °C. The thickening action of GG in soup was evaluated at room temperature to obtain the GG concentration to prepare thickened soup with the same texture as the softest carrot (4.2% GG).

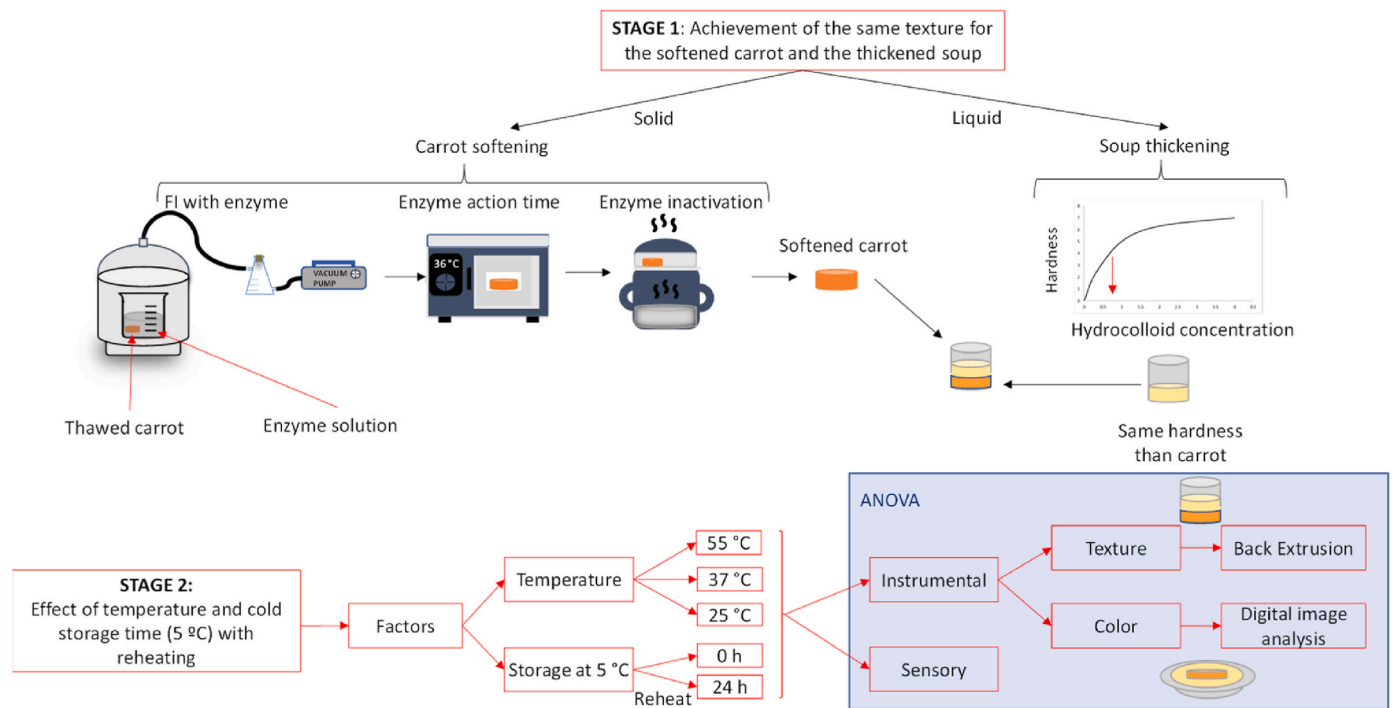


Fig. 1. Scheme of the experimental procedure.

#### 2.4. Texture analysis

Samples' texture was characterized by a back extrusion assay as described by several authors, but with slight modifications (Ibañez, Gómez, Merino, & Beriain, 2019; Merino et al., 2020; Yang et al., 2020). Measurements were taken by a TA-TX2 texture analyzer (Stable Micro Systems, Surrey, UK), equipped with a 25 kg load cell. In the first study stage, only the softened carrot (10 mm thick, 25 mm in diameter) and the thickened soup (10 mm thick) samples were characterized. Then in Stage 2, the above-mentioned samples and the dish (20 mm of thickened soup (4.2% GG) with one softened carrot sample) were analyzed under their respective temperature and cold storage time conditions. To this end, samples were placed in a methacrylate cell (28 mm diameter, 50 mm high) and were back-extruded by a cylindrical back extrusion disc (20 mm in diameter) until 90% deformation at a test probe speed of 2.00 mm/s. Maximum force ( $F_{max}$ ) and minimum force ( $F_{min}$ ) to extrude, as well as their ratio ( $F_{min}/F_{max}$ ), were reported using the Exponent software (Stable Micro Systems Ltd., version 6.1.11.0). Many authors have identified  $F_{max}$  as firmness and  $F_{min}$  as cohesiveness (Angioloni & Collar, 2009; Yang et al., 2020). In this study, however,  $F_{min}$  was also related to adhesiveness because it coincides with the force needed to separate the compression disc and the sample.  $F_{min}/F_{max}$  were expressed as the stickiness to firmness ratio, as proposed by Merino et al. (2020). Each analysis was run in quintuplicate.

#### 2.5. Image analysis

Two different image analyses were carried out. The first was used to evaluate the texture back extrusion test, and the second to evaluate the dish's visual appearance by analyzing the color of the entire dish and soup and carrots separately.

##### 2.5.1. Image analysis of the back extrusion test

The interactions between both product phases (softened carrot and thickened soup) during the extrusion test were explored by an image analysis. Texture measurements were recorded on video by a camera (Logitech C922 Pro Stream Webcam) and were imported to the ImageJ

software. Ten dish samples were used at 25 °C and 0 h.

##### 2.5.2. Dish color analysis

The color and possible visual changes in the dish were explored by a digital image analysis in the  $L^*a^*b^*$  color space. This color model is widely used because it comes very close to human perception. To obtain representative information from all the samples, color was evaluated by a digital image analysis (Lee, Baek, Kim, & Seo, 2019). The digital images of samples were captured in the RGB model inside a dark cabin with standard lighting. Any potential effects of the different room conditions were eliminated, such as lighting, position and angle of the camera (Lee et al., 2019; Verdú, Pérez, Barat, & Grau, 2019). Images were taken by a camera (Logitech C922 Pro Stream Webcam) at 55 °C, 37 °C and 25 °C, and at 0 h and 24 h of cold storage with reheating. Carrots and the thickened soup were placed on a white plate, which contained three cylindrical softened carrots immersed in 30 mL of thickened soup (4.2% GG). Images were imported to the ImageJ software and were converted into the  $L^*a^*b^*$  color space. The  $L^*a^*b^*$  parameters and  $\Delta E^*$  were calculated. The effect of temperature and cold storage time with reheating were studied on the dish. To evaluate which components could bring about possible changes in dish color, only the area that represented soup or carrot was analyzed.

#### 2.6. Sensory evaluation of the dish

Sensory analysis of the dish, including texture and visual appearance evaluations, was carried on as a first approximation. Both parameters are important for people who have problems swallowing. Texture needs to be safe and visual appearance must increase people's appetite to eat meals. The panel was made up of 22 non expert and untrained panelists (4 men, 18 women) who had no swallowing issues. The obtained information can be useful since healthy people may be more demanding in their visual appreciation because they have a greater range of foods to select. On the other hand, the texture information should not be different given the testing method employed. The visual evaluation of each sample was done by image inspection on a PC screen. It was carried out on a single screen to ensure the same conditions for all the

evaluations. The evaluated digital images were the same as those evaluated by the image analysis. Plates and carrots were located in the same position to focus on any possible visual differences generated by thickening agent and carrots (Fig. 2). Five replicates of each dish were evaluated depending on temperature and time.

A compression assay was also run to determine if panelists detected sensory texture differences between both components of the developed dish. To this end, covered plastic jars (36 mm in diameter, 65 mm high) were employed to avoid visual influences for panelists. Here two sample types were used for each temperature and cold storage time: one with the soft carrot and thickened soup (4.2% GG) and the other to be used as a control and contained the thickened soup (4.2% GG). Panelists tested the different samples by using a cylindrical compression tube (5 mm in diameter), and by penetrating each sample and indicating the detection of two phases or textures whenever applicable. All the samples were labeled with codes formed by three randomized numbers, and were stored in a thermostatic bath until the analysis temperature was reached (55 °C, 37 °C, or 25 °C).

### 2.7. Statistical analysis

Factors enzyme action time, temperature and cold storage time were studied by a multifactorial ANOVA for the texture, color, and sensory analysis. When a significant effect ( $P < 0.05$ ) was observed, the average was compared by Fisher's least significant difference (LSD). The employed software was Statgraphics Centurion XVII.II, version 17.2.04.

## 3. Results and discussion

### 3.1. Stage 1: achieving the same texture for softened carrot and thickened soup

The first step was to find out the minimum firmness of softened carrots without disturbing their original shape. Carrot firmness was evaluated and plotted in relation to the enzyme reaction time at 36 °C (Fig. 3A).

As expected, carrot firmness decreased during the enzyme reaction time. This was because plant cell wall degradation was caused by enzyme activity when penetrating foodstuff (Park & Lee, 2020). The plant cell wall is composed of approximately 35% pectin, 30% cellulose, 30% hemicellulose and 5% protein for dicotyledonous plants. To study texture evolution, pectin plays an important role as the main compound and forms a matrix along with hemicellulose where cellulose microfibrils are embedded, and plays a crucial role in structural and texture aspects (Bermejo-Prada et al., 2014). This process mainly involves PME and PG

enzymes, which degrade pectin from the cell wall. While PME de-esterifies pectin by producing methanol and peptic acid with a lower degree of esterification, PG catalyzes the hydrolytic excision of glycosidic bonds  $\alpha$ -D-(1-4) in peptic acid (Fachin et al., 2003).

Fig. 3A shows an exponential reduction of carrot firmness where, after 15 h of treatment, statistically significant differences disappeared ( $P < 0.05$ ) as indicated by the LSD intervals. Moreover, after 15 h of sample treatment, they were difficult to handle because structure had considerably deteriorated. Therefore, a 15-h enzyme reaction time was selected to modify carrot texture and 4.4 N of firmness was accomplished. According to the International Dysphagia Diet Standardization Initiative (IDDSI), and its testing methods for classifying foods (IDDSI, 2019), the obtained carrots were classified at level 4: "purée". They can be eaten with a spoon, are smooth without lumps, and are not sticky. Food can also be eaten with a fork because it does not fall through prongs. Fork prongs make a clear pattern on the surface.

In order to thicken soup and reach these firmness scores, the required GG concentration was calculated by a calibration curve (Equation (1)), which was obtained after measuring soup firmness at different GG concentrations (Fig. 3B), which was established at 4.2%.

$$y = 2.0717x - 4.1357 \quad (1)$$

$$x = \text{GG concentration (\%)}$$

$$y = \text{Fmax (N)}$$

### 3.2. Stage 2: effect of temperature and cold storage time (5 °C) with reheating

Once the textures of both dish parts had been equalized, the temperature and cold storage time effects were evaluated on the dish's texture and color thermostability.

#### 3.2.1. Texture

Variance in the texture parameters was studied to know the role of each factor (temperature and time) and to determine the significance of their main effects by a multifactorial ANOVA. The thickened soup, softened carrot and dish were independently studied for this purpose (Fig. 4).

According to the classification of Ibañez et al. (2019), all the samples had suitable firmness values for dysphagic populations because they all obtained scores between 4.6 N and 2.7 N (Fig. 4A). These authors classified foods for dysphagic people into three extrusion force levels: soft (4.1 N), medium (7.8 N) and hard (23.5 N). According to this classification, all products can be classified as soft and medium levels.

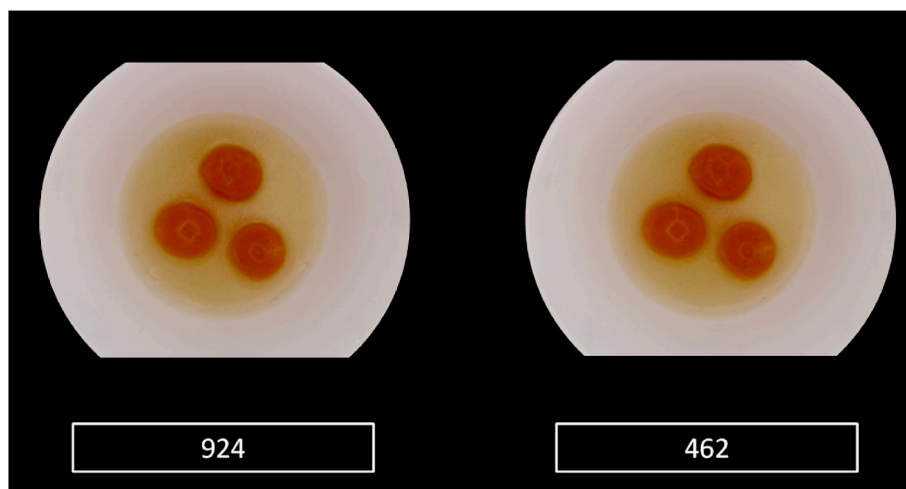
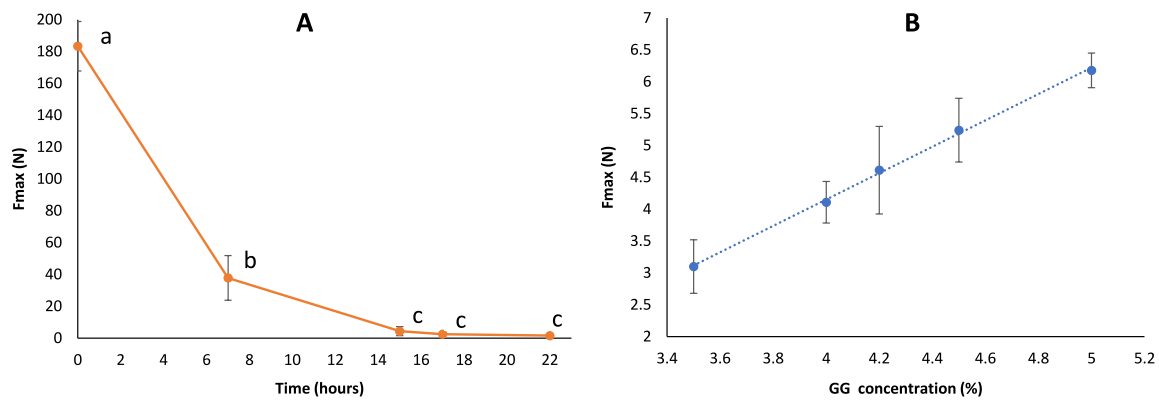
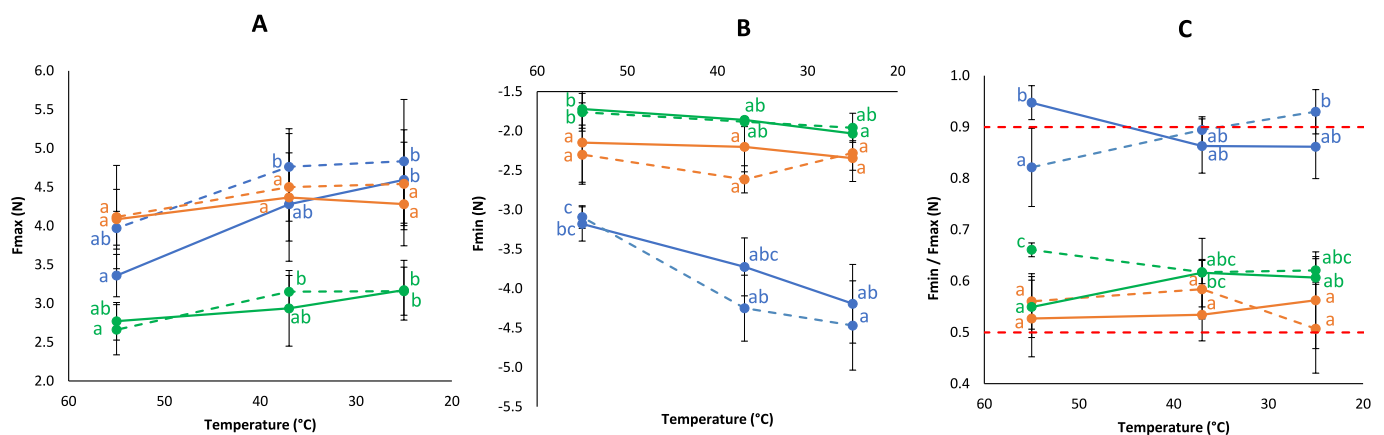


Fig. 2. Example of the images evaluated by panelists during the visual evaluation.



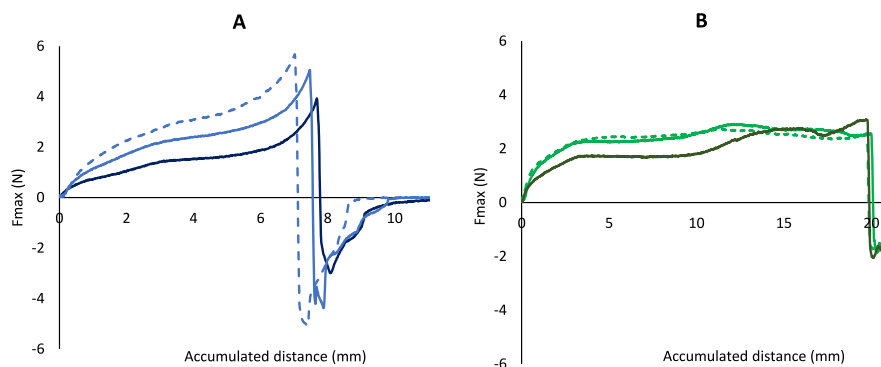
**Fig. 3.** A) Change in the carrots' maximum force (N) as a function of enzyme reaction time. B) Effect of the GG concentration (%) on maximum force (N) of the soup. Bars mark the standard deviation of Fmax. Different letters indicate significant differences at  $\alpha = 0.05$  by Fisher's tests.



**Fig. 4.** Evolution of Fmax (A) and Fmin (B) and its ratio (C) as function of temperature at 0 h (continuous line) and 24 h (dashed line) to softened carrots (orange lines), thickened soup (blue lines), and dish (green lines) with standard deviation. Red dashed lines in Fig. 4C indicate the suitable range of Fmin/Fmax for dysphagic population (Merino et al., 2020). Different letters within the same color, indicate significant differences at  $\alpha = 0.05$  by Fisher's tests. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

These scores are similar to those observed in Stage 1. Temperature had a significant effect on the firmness of the thickened soup with carrot and the thickened soup ( $P < 0.05$ ). Nevertheless, this effect was not significant on carrot firmness ( $P > 0.05$ ). As expected, thickened soup firmness increased as temperature dropped. Similar results have been

observed by Ribes et al. (2021) when investigating the effect of temperature on the firmness of different sauces formulated with GG by the back extrusion test. This fact is due to the low melting point of hydrocolloids because high temperatures can weaken their intermolecular chain entanglement to reduce firmness (Merino et al., 2020).



**Fig. 5.** Back extrusion curves of the thickened soup (A) and the dish (B) at 55 °C (dark blue/green lines), 37 °C (pale blue/green lines), and 25 °C (pale blue/green dashed lines) at 24 h of cold storage time with reheating. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

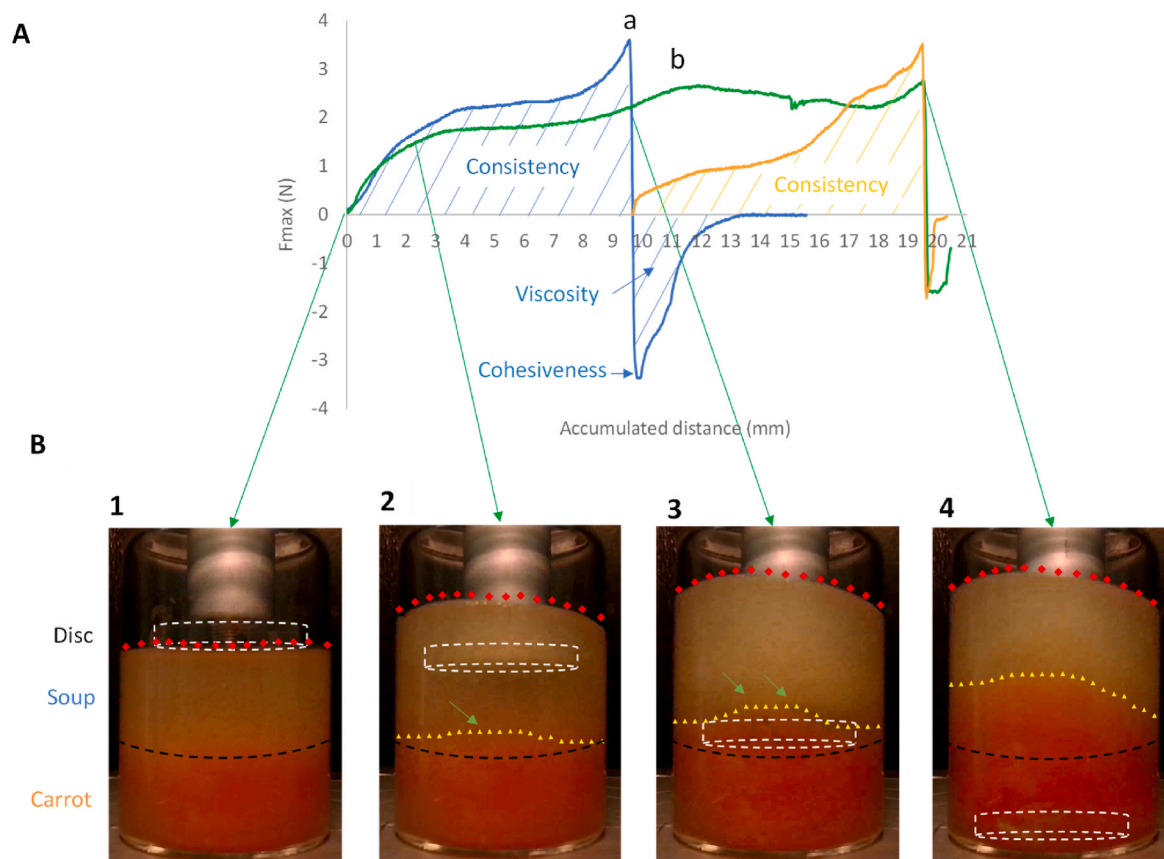


Specifically on this hydrocolloid and at high temperatures, water molecules attach to galactose side chains, which form an entanglement of intermolecular chains, lose their order, disturb conformation and, hence, generate reduced viscosity (Thombare, Jha, Mishra, & Siddiqui, 2016). Thus as temperature lowered, these bonds were consolidated, which increased their firmness because of a higher degree of molecular order. This behavior is shown in Fig. 5A, and indicates the back extrusion curves of the thickened soup at 55 °C (dark blue lines), 37 °C (light blue lines), and 25 °C (light blue dashed lines) after a 24-h cold storage time at 5 °C and reheating. The  $F_{max}$  for the thickened soup at 55 °C was 3.8 N, and was 4.8 and 5.6 N respectively at 37 °C and 25 °C.

Conversely, the combined storage time-reheating effect was not significant on firmness ( $P > 0.05$ ). These results agree with those observed by Yang et al. (2020) and Merino et al. (2020) when evaluating the texture thermostability of gums during storage. Although this effect had no statistical ( $P > 0.05$ ) effect on firmness, a slight increase in the thickened soup firmness took place with storage time. This fact suggests that thickened soup firmness could increase with a longer storage time, as observed in the above-mentioned studies, as a result of a higher degree of molecular order. Reinforcing intermolecular chain entanglement means that even when reheated and having returned to high temperatures, thickened soup did not return to its original firmness at time 0 h, and a higher degree of molecular order remained. Thus when reheating thickened soup after cold storage, its firmness values were higher than at time 0 h. The differences observed between the soup at 0 h and after 24 h of cold storage with reheating were more marked at 55 °C, but lowered as temperatures dropped. This scenario suggests that thickened soup with cold storage acquires stabler firmness because it was less affected by the temperature effect.

For firmness, temperature had a significant effect ( $P < 0.05$ ) for the thickened soup cohesiveness values (Fig. 4B), but not for the softened carrot and the dish. Values rose as temperature dropped due to the higher degree of molecular order and viscosity, as previously mentioned. Although no significant difference ( $P > 0.05$ ) was observed for the cold storage time at 5 °C, higher cohesiveness values were obtained for soup after 24 h of storage. The higher degree of molecular order is shown in Fig. 5A. The accumulated time to reach  $F_{max}$  was 7.5 s for soup at 55 °C, and 7.4 and 7 s at 37 °C and 25 °C, respectively. As observed with the firmness data, the thickened soup viscosity value rose because of the increased water molecule order in the galactose side chains after cold storage. It is worth considering that viscosity is defined by the negative region under the curve (Angioloni & Collar, 2009; Yang et al., 2020). Therefore, cohesiveness increased as viscosity did (Fig. 5A).

It is important to consider that lower firmness and cohesiveness values were observed for the dish compared to the softened carrot and thickened soup individually. This could be attributed to the interaction that occurred between the two dish components (soup and carrot). Fig. 6 shows an explicative scheme that compares the back extrusion test curves (Fig. 6A) and the images (Fig. 6B) obtained while testing. To compare the back extrusion curves of the dish to those obtained for soup or carrot, the two lasts were sequenced, and the distance covered by the disc was expressed as accumulated. For that, first the soup data were plotted and then those from carrot. When the back extrusion disc penetrated soup (Figs. 6B–2), carrot started to break up (yellow dashed line with a green arrow), which increased with disc penetration (Figs. 6B–3), and maximum breaking occurred when the disc arrived at the end (Figs. 6B–4). Thus carrot could act as a damper by diminishing



**Fig. 6.** A) Comparative scheme of representative force-time back extrusion curves between the dish and the thickened soup and the softened carrot measured independently at 25 °C at 24 h. Carrot (orange line); thickened soup (blue line), and dish (green line). B) Images captured at different moments of the back extrusion test. Disc (white dashed line); Soup with carrot (red dashed line); Focal point (black line); unstructured carrot (yellow dashed line). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

firmness because the thickened soup with the disc pressure was displaced through the methacrylate cell. Consequently, when the disc came into contact with carrot, part of carrot was already destroyed by the pressure previously generated by soup. So carrot was less resistant when penetrated by the disc. The mechanical stress absorbed by soup was transmitted to carrot. Due to its softer consistency, viscosity and cohesiveness values (Fig. 6A), carrot deformed (unstructured) before the disc reached it. In addition, the destroyed carrot matrix, composed mainly of water and high fiber content, lowered the  $F_{min}$  values of the thickened soup (Abdullah, Aldughpassi, Sidhu, Foudari, & Al-Othman, 2021; Collar, Santos, & Rosell, 2007), with lower  $F_{max}$  values than the same soup alone. This behavior might explain the differences observed in Fig. 6A between the back extrusion result for the dish and those obtained for the thickened soup and carrot separately. From the very beginning, soup firmness increased more quickly than for the soup in the dish, and its maximum value was reached at the end (point “a” in Fig. 6A) with a notorious peak force immediately before the disc stopped, which falls in line with what many authors report (Brusewitz & Yu, 1996; Hoshino, 2020). From this point, a slight increase in the force value was observed for the dish, probably because of the disc and softened carrot coming into contact. However, this value was not maintained because the carrot structure had been destroyed, and it lowered (point “b” in Fig. 6A) and only increased at the end immediately before the disc stopped.

Although the dish was less affected by temperature and the cold storage time effects (lower  $F_{max}$  and  $F_{min}$  values, Fig. 4A and B, respectively), a minor variation was detected because of soup cohesiveness, but not for the changes in carrot. Fig. 5B shows the back extrusion curves of the dish (B) at 55 °C (dark green lines), 37 °C (light green lines), and 25 °C (light green dashed lines) after a 24-h storage time at 5 °C with reheating. For the first 10 mm (corresponding to soup), the firmness values of the dish were lower at 55 °C than at 37 °C and 25 °C because soup cohesiveness increased. However in the section between 11 mm and 20 mm (the section corresponding to carrot), similar values were observed regardless of the analysis temperature, but with a slight drop as temperature lowered. The higher cohesiveness values of soup observed when temperatures lowered could generate higher pressure on carrots, which would favor their breakage and generate less resistance when the disc came into contact with them.

Finally, Fig. 4C shows the stickiness to firmness ratio. Except for the soup at 55 °C with 0 h cold storage and at 25 °C after 24 h, the values of the other samples were between 0.5 and 0.9. According to Merino et al. (2020), foodstuff with scores below 0.5 have excessive rigid textures for dysphagic people. Conversely, scores over 0.9 are stickier for people with eating difficulties. These results suggest that the dish was postulated as being suitable for dysphagic people for a wide temperature range. The designed dish can be cold-stored for 24 h and reheated

without these procedures diminishing its texture properties. By applying the IDDSI classifying method (2019), the dish can be classified as food level 4: “purée”. These data demonstrate that this dysphagic dish can be prepared in advance, which is an advantage over the optimization process in healthcare institutions like hospitals and care homes, or even for consumers at home. In addition, if consumers completely cannot finish a dish, it can be stored under cold conditions overnight and be reheated the next day with no loss of suitable mechanical product properties.

### 3.2.2. Image analysis of the dish

The  $L^*a^*b^*$  parameters of the dish and its components, the thickened soup and softened carrots obtained from the captured images (data not shown) and  $\Delta E^*$ , due to the changes caused by temperature (Fig. 7A) or the refrigeration storage time (Fig. 7B), were calculated. Cooling the dish (temperature effect) had an effect on the samples'  $\Delta E^*$  values (Fig. 7A), which were higher at 55-37 °C, but did not exceed the thresholds at which consumers detect differences in any case (Baldevbhai & Anand, 2012). However, color differences were observed during the cold storage time (Fig. 7B). These differences can be attributed to changes in the luminosity of the thickened soup for its greater cohesiveness after 24 h of cold storage (see Fig. 4 for details), and also to changes in the hue and chroma of carrots because of carotenoid deteriorating owing to cold storage (Soto et al., 2020). Notwithstanding, differences according to temperature were similar, and slightly bigger for carrot at 55 °C (Fig. 7B).

### 3.2.3. Sensory evaluation

The texture and color sensory scores were collected and plotted as shown in Fig. 8. For texture, between 9% and 27% of the panelists detected differences (double texture) when penetrating the cylindrical tube inside the control and the dish samples (Fig. 8A). These results highlight the difficulty for panelists to establish the presence of double textures in all the samples and, therefore, to detect the double texture of the developed dish. For the samples at 55 °C with 0 h of cold storage time, more panelists were able to detect the double texture in soup than in the dish, while the opposite could be stated at 25 °C.

Furthermore, panelists were able to see differences (from 68% to 100% samples) in the color of the dish depending on the storage time (Fig. 8B, grey bars). It is important to highlight that the observed differences became smaller as temperature dropped. Thus 100% panelists identified differences at 55 °C between the dishes evaluated at 0 h and 24 h, but the 91% and 68% of them detected differences at 37 °C and 25 °C, respectively. These results correlate with the digital image analysis, in which the storage time effect was significantly observed (Fig. 7B).

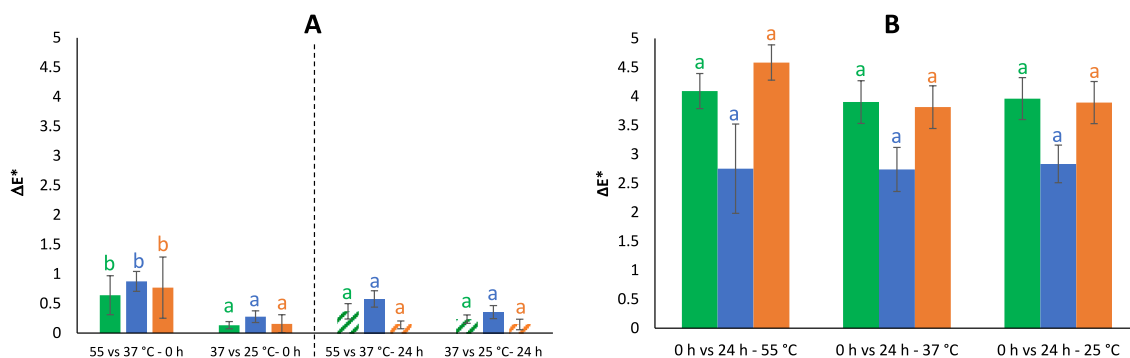
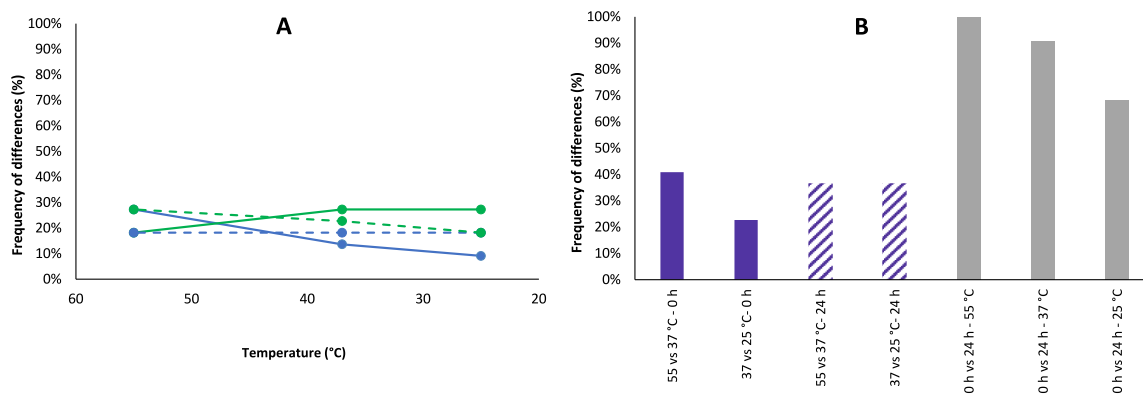


Fig. 7.  $\Delta E^*$  values between different temperatures (temperature effect) (A) and between 0 h and 24 h of cold storage with reheating at 25 °C, 37 °C, and 55 °C (cold storage time effect) (B) for dish (green bars), soup (blue bars) and carrots (orange bars) regions with standard deviation. Different letters within the same color, indicate significant differences at  $\alpha = 0.05$  by Fisher's tests. (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)



**Fig. 8.** Scores of the texture (A) and visual (B) differences detected by panelists. Thickened soup (blue lines); dish (green lines); 0 h (continuous lines); 24 h (dashed lines); Temperature effect (purple bars); Time effect (grey bars). (For interpretation of the references to color in this figure legend, the reader is referred to the Web version of this article.)

Conversely, the temperature effect was more subtle because panelists detected visual changes in 23–40% of the samples (Fig. 8B, purple bars). As cooling did not seem to affect the dish's color (Fig. 7A), the differences observed by these panelists can be attributed to changes in other optical properties, such as changes in samples' gloss or translucency.

#### 4. Conclusions and limitations

A dish's homogeneous texture was successfully designed by unifying the texture of softened carrots and a thickened chicken and vegetable soup. Without disturbing their original shape, the minimum firmness of the softened carrots was 4.4 N, and the thickened soup achieved similar mechanical properties by adding 4.2% GG. With these characteristics, and according to the IDDSI organization, the dish could be classified as level 4: "purée". Nevertheless, the evaluation of the dish's stability while being consumed, and after cold storage and reheating, showed slight changes in texture and color. Consumption temperature affected mainly the firmness and cohesiveness values of the thickened soup, which increased as temperature decreased. Storage with reheating affected mainly the dish's color because of changes in the hue and chroma of carrots, and it also slightly affected soup texture. The results of this study indicate that this method can be employed to develop safe TM foods with a unique texture. This work provides a fundamental basis to start combining solid and liquid foodstuff matrices with a homogeneous texture. However, due to the sensory analysis applied to this work is a first approximation, deeper sensory studies employing panelists with and without swallowing issues are needed which will be accompanied by the nutritional contributions that foods with a "solid appearance" and soft textures can offer to obtain unique texture dishes for the dysphagic population. In addition, the technique will have to be scaled to the industrial environment to optimize process variables and costs.

#### CRediT authorship contribution statement

**Sergio Hernández:** Conceptualization, Methodology, Investigation, Visualization, Writing – original draft. **Susana Ribes:** Conceptualization, Methodology, Investigation, Visualization, Writing – original draft. **Samuel Verdú:** Investigation, Visualization, Writing – original draft. **José M. Barat:** Writing – review & editing. **Pau Talens:** Conceptualization, Methodology, Investigation, Writing – review & editing, Project administration, Funding acquisition. **Raúl Grau:** Conceptualization, Methodology, Investigation, Resources, Writing – original draft, Supervision, Project administration, Funding acquisition.

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