

Influence of Secondary Homogenisation and Final Thermal Treatment on the Evolution of the Rheological Properties of Model Puddings for Dysphagia Nutritional Support

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Management of dysphagia is commonly done by the prescription of texture-controlled products (i.e. puddings). This research deals with the influence of different processing variables (i.e. final thermal treatment, and secondary homogenization step) on the evolution of the rheological properties and microstructural characteristics of a MODEL pudding, with similar composition to that of commercially available products for dysphagia nutritional support, during storage at different temperatures. From the experimental results obtained, it is apparent that pudding ageing favours the development of protein aggregates, mainly at high storage temperature. These results correlate fairly well with the evolution of the linear viscoelasticity functions during ageing at different storage temperatures. A longer final thermal treatment benefits the development (and density) of the above-mentioned aggregates, as well as an increase in pudding mean particle size and in the linear viscoelasticity functions. Finally, an increase in the number of steps during pudding secondary homogenization produces a decrease in mean particle size and an increase in the values of the linear viscoelasticity functions.

1. Introduction

Dysphagia or abnormal swallowing disorders is one of the serious complications from several diseases, such as cancer (e.g. head and neck, tongue), stroke, Parkinson, as well as neurological diseases (Logeman, 2007). Dysphagia induces aspiration and secondary pneumonia, compromising patient's life (Ozaki et al., 2010). The nutritional dietary management for dysphagic patients drives the need for designing oral nutritional supplements, ONS, with controlled rheological properties to allow a safe swallow (Quinchia et al., 2010; Strowd et al., 2008). This last is not an easy task if the product has to meet both functions, due to the complex relationship between formulation and process variables and their impact in the final product rheological properties. The need for a more comprehensive rheological data on ready-to-use ONS for dysphagic patients

has been recently the focus of different research groups in this field (Ekberg et al., 2009; Gallegos et al., 2009).

In previous studies from our group, Quinchia et al. (2010) focused on the characterization of the rheological behaviour, as a function of ageing, of a new ready-to-serve dysphagia diet food with spoon-like consistency (pudding). Linear (small amplitude oscillatory shear) and non-linear (steady-state flow and relaxation) material functions were measured as a function of product shelf life at different storage temperatures. It was concluded that both linear viscoelasticity moduli and viscosities of the commercial pudding studied increase with ageing, showing maximum values for samples stored at 40°C. However, the differences in mean particle diameter were not large enough to explain the significant increase in the rheological functions found during storage at high temperature. Protein aggregation enhancement in the continuous phase could explain the experimental results obtained.

Taking into account these results, this work focuses on the influence that some processing variables, such as final thermal treatment and secondary homogenization step, exert on the evolution of the rheological properties and microstructural characteristics of a MODEL pudding, with similar composition to that of commercially available products for dysphagia nutritional support, during storage at different temperatures.

2. Experimental

2.1. Formulation

The model formulation studied corresponds to the composition of commercial puddings manufactured by Fresenius Kabi Deutschland GmbH (Germany). The ingredients list is: water (59% wt), milk protein (11.6% wt), vegetable oils (6.7% wt), premix components (22.6% wt; sucrose, maltodextrin, inulin (from chicory), thickeners (E1442, E407), flavourings, potassium citrate, sodium chloride, sodium citrate, vitamin C, magnesium oxide, magnesium citrate, iron pyrophosphate, zinc sulphate, niacin, manganese chloride, pantothenic acid, vitamin E, copper sulphate, vitamin B2, vitamin B6, sodium fluoride, vitamin B1, β -carotene, vitamin A, folic acid, potassium iodide, chromium chloride, sodium selenite, sodium molybdate, vitamin K, biotin, vitamin D3 and vitamin B12), and emulsifiers (0.1% wt; soya lecithin, E471). Samples have been stored at different temperatures: 25°C, 4°C, and 40°C. Ageing studies were performed up to two months. No more precise information can be given, due to confidentiality issues.

2.2. Pudding Manufacture: Processing Variables Studied

The standard pudding manufacture includes primary and secondary homogenisation (rotor-stator and high pressure homogenisation/microfluidisation) and final thermal treatment. From previous research, it was considered necessary to perform an in-depth study on the influence that the number of secondary homogenization steps (M-110L Microfluidiser Processor (USA), 1-2 steps), and the final thermal treatment characteristics (Autoclave Steam Steriliser, model RAYPA AES-12 (Germany), at 120°C for 15 or 35 min) exert on the microstructure and rheology of enteral puddings for dysphagia nutritional support. With this aim, different samples were manufactured with various processing conditions (see Table 1).

2.3. Rheological Characterization

Small amplitude oscillatory shear (SAOS) tests, inside the linear viscoelasticity region, were carried out with a controlled-stress rheometer (Modular Advanced Rheometer System MARS, HAAKE, Thermo-Scientific, Germany), in a frequency range comprised between 0.068 and 100 rad/s, using a serrated plate-and-plate geometry (35 mm diameter, 1 mm gap). All the samples tested had the same recent past thermal and mechanical history. All the rheological tests were carried out at 25°C.

Table 1: Processing characteristics for the different samples studied.

Sample	Thermal Treatment	Secondary Homogenizer	Homogenization Steps
1	Short	Microfluidiser	1
2	Long	Microfluidiser	1
3	Short	Microfluidiser	2
4	Long	Microfluidiser	2

2.4. Particle Size Distribution and Optical Microscopy Characterization

Particle size distribution (PSD) measurements were made by using laser light-scattering equipment (MALVERN Mastersizer Hydro 2000MU, UK). The morphological characterization of pudding samples was carried out by means of optical microscopy using an Olympus microscope, BX51 model (Japan), equipped with a digital camera and thermostatic circulator. Micrographs were obtained at 25°C.

2.5. Statistical Analysis

A two-way ANOVA with interactions analysis was applied to study the effect the different variables on the rheology and particle size distribution of the pudding samples studied. The significance level was set at 95%.

3. Results and Discussion

3.1. Linear Viscoelasticity Properties

Figure 1 shows the frequency dependence of the linear viscoelasticity functions, G' and G'' for two selected pudding sample (samples 3 and 4, stored at 40°C). As can be observed, this dependence is always qualitatively similar, typical of weak-gel materials (G' larger than G''). In this sense, the results obtained mainly correspond to the plateau region of the mechanical spectrum, characterized by a relatively low slope of G' versus frequency.

An increase in ageing time yield larger values of the linear viscoelasticity functions. However, the storage temperature has a remarkable effect on both the values of the linear viscoelasticity functions and their dependence on ageing. Aiming to quantify its dependence on pudding ageing, a power-law equation has been used to describe the evolution of the storage modulus, G' , with frequency:

$$G' = G'_1 \omega^m \quad (1)$$

where G' , and m are fitting parameters.

The power law index (m) does not significantly change (mean value 0.11 ± 0.01) with ageing time nor storage temperature. In addition, processing conditions do not have any significant influence. However, there is a slight tendency to show minimum values for most of pudding samples stored at 40°C , fact that would indicate a slightly more developed and complex pudding microstructure.

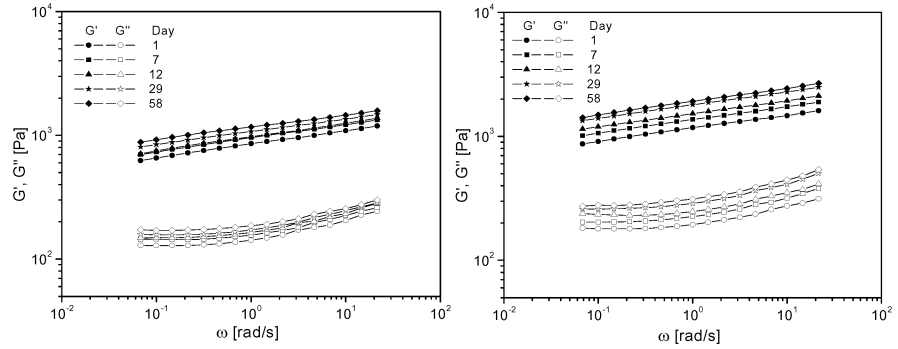


Figure 1: Frequency sweep tests: Evolution of the linear viscoelasticity functions (G' and G'') with frequency, as a function of ageing, for pudding samples stored at 40°C : samples 3 (left) and 4 (right).

On the other hand, the values of G'_1 , related to the storage modulus at 1 rad/s, increase with ageing time (see Figure 2), although this increase is more significant when pudding samples are stored at high temperature (40°C).

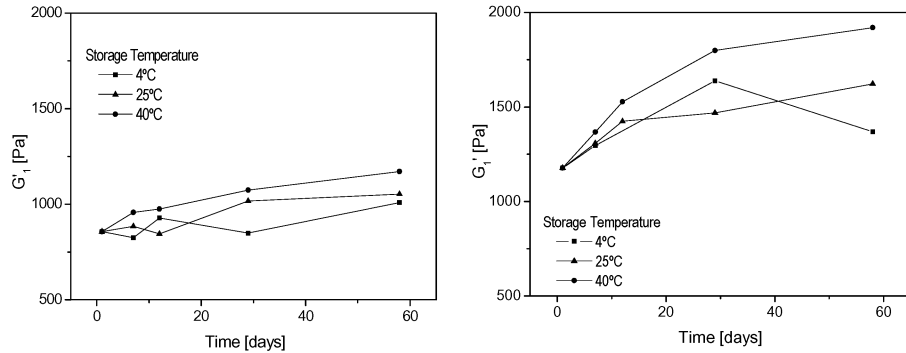


Figure 2: Evolution of G'_1 with sample ageing, at different storage temperatures: samples 3 (left) and 4 (right).

Furthermore, the constant power-law index values obtained and the evolution of the elastic modulus during sample storage seem to indicate that ageing, at a constant storage temperature, does not modify the overall microstructural pattern of pudding. In this sense, ageing would mainly influence the level of interactions among macromolecular components. Thus, G' and G'' versus frequency master curves can be achieved by applying an empirical superposition method, by means of vertical shifting of the single curves obtained after different ageing times (and constant storage temperature). The shift factor, a_t , (which obviously evolves with ageing) has the same values for both linear viscoelasticity functions. In other words, material relative elasticity does not significantly change during pudding ageing. The shift factor significantly evolves with ageing time, exhibiting very similar values for pudding samples stored at low and room temperature. On the contrary, the lowest values generally correspond to the samples stored at high temperature (40°C).

Finally, it is worth remarking that a short final thermal processing and two secondary homogenization steps in the microfluidiser yield lower values of G'_1 , although do not significantly influence the power-law index, m .

3.2. Pudding Microstructure

Pudding microstructure has been characterized by using two different techniques: droplet size distribution tests and optical microscopy techniques.

Pudding particle size distributions are mostly unimodal, although, in some cases, a bimodal distribution is observed, typical of complex puddings manufactured at lab-scale, and related to a certain lack of homogeneity in the bulk sample, which vanishes at larger process scales. However, bimodal distributions can also be shown as a consequence of the formation of protein aggregates. As a general tendency, larger particles are obtained during pudding ageing at high storage temperature.

On the other hand, the light microscope micrographs obtained clearly show that some kind of aggregates develop at high storage temperature after a certain period of ageing.

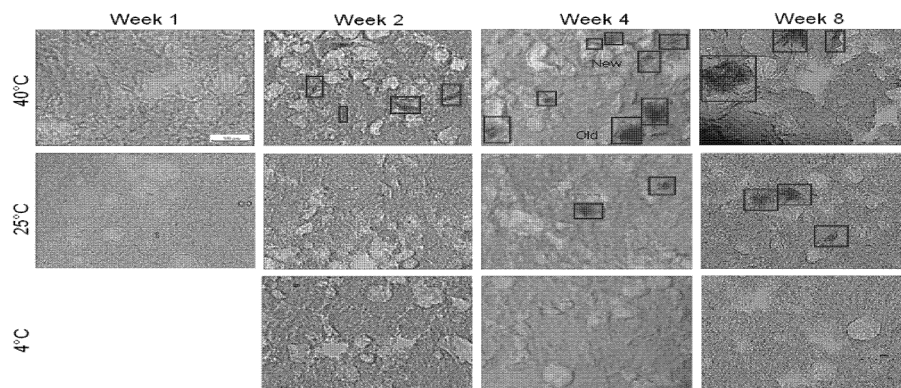


Figure 3: Light microscope micrographs for pudding sample 3, as a function of ageing and storage temperature.

4. Concluding Remarks

In general, storage at 40°C favours a tendency to larger mean particle diameters. This correlates with an apparent increase in size and density of aggregates, as the optical microscopy micrographs obtained demonstrate (see Figure 3).

Pudding ageing favours a tendency to larger mean particle diameters, which also correlates with an apparent increase in size and density of aggregates (see Figure 3).

These results correlate fairly well with the evolution of the linear viscoelasticity functions with ageing and storage temperature. In this sense, both variables induce a significant increase in the values of the storage and loss moduli of the pudding samples studied.

A longer final thermal treatment favours an increase in mean particle size diameter. The optical microscopy micrographs also show an apparent increase in size and density of aggregates. This yields a significant increase in the values of the linear viscoelasticity functions of the pudding samples studied.

An increase in the number of steps during pudding secondary homogenization produces a decrease in the values of the mean particle diameters, though it also seems to slightly favour the development of aggregates during ageing for samples submitted to a long final thermal treatment (mainly at high storage temperature). As a result, an increase in the values of the linear viscoelasticity is noticed, which is dampened after ageing at high temperature for samples submitted to a long final thermal treatment.

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