The effect of the homogenization process on the viscoelastic properties of processed cheese sauce with furcellaran addition

Vendula Kurova[1], Richardos Nikolaos Salek[1], Nela Svajdova[1], Robert Gal[1], Frantisek Bunka[2]

[1]Department of Food Technology
Tomas Bata University in Zlin
nam. T.G. Masaryka 5555, 760 01 Zlin
[2]Food Research Laboratory, Department of Logistics
University of Defence
Kounicova 65, 662 10 Brno
CZECH REPUBLIC

v_kurova@utb.cz

Abstract: The present work examined the impact of the homogenization (two- and one-stage) and various furcellaran levels (0.25; 0.50; 0.75 and 1.00% w/w) addition on the viscoelastic properties of the processed cheese sauce (PCS), whereas the measurement was carried out 24 hours after the PCS manufacture. The gradual increase of furcellaran concentration significantly affected the viscoelastic properties which was indicated by an increase in the storage modulus (G´) and loss modulus (G´´). Homogenization elevated the complex modulus (G^*) values of the PCS produced with relatively low-furcellaran content (0.25% w/w), indicating an increase in the stiffness of the samples. However, the PCS samples with greater furcellaran levels were less rigid with the application of homogenization and increasing homogenization degree.

Key Words: casein-based structure, processing parameters, hydrocolloids, rheology, viscoelasticity

INTRODUCTION

Processed cheese sauce (**PCS**) could be described as novel dairy product characterized by various benefits, such as a relatively long-shelf life, low price (in comparison to other cheese products), simple use and a possibility of an addition of health-promoting components. However, there are not known any standards or legislative regulations that restrict PCS raw material composition. Therefore, a wide spectrum of ingredients [e.g. natural cheese, processed cheese (**PC**), cheese powder, milk and whey powders, butter, vegetable fats] and food additives [e.g. emulsifying salts (**ES**), hydrocolloids, flavor enhancers] could be applied to the PCS in order to obtain a smooth and stable product. Likewise, the production protocols of different PCS types could vary. Generally, the manufacture could be described as continuous mixing and stirring of the ingredients at elevated temperatures (85–110 °C) under a partial vacuum until a desired homogeneous emulsion-based product is formed (Shalaby et al. 2017, Salek et al. 2019, Szafrańska and Sołowiej 2020).

Moreover, homogenization can be included in the production process of PCS as an optional step, which can affect its functional properties (as a processing parameter), such as consistency, stability, smoothness, flavor and color (Szafrańska and Sołowiej 2020). The principle of PCS homogenization is to exposed the hot molten mass to higher pressure (usually 5 to 20 MPa) in order to promote the formation of a finer fat emulsion. Moreover, for dairy products with a relatively high dry matter content (compared to milk; such as PC or PCS), the two-stage homogenization could be applied. In addition, the application of homogenization can prevent occurrence of coarse particles (e.g. lumps of proteins or undissolved ES) and ensures further mixing of the individual components of the developed melt. On the other hand, the inclusion of the homogenization to the production process is a relatively expensive matter (Lopez et al. 2015, Mohammadi and Fadaei 2018).

Furthermore, hydrocolloids are a wide group of the long chain polymers (proteins and polysaccharides) which are commonly applied in the food industry as thickening, gelling, stabilizing or emulsifying agents (Saha and Bhattacharya 2010). Furcellaran is an anionic sulphated galactan (obtained from red algae *Furcellaria lumbricalis*), which is ordinarily considered as a κ-carrageenan type. The basic structure of furcellaran and κ-carrageenan consists of repeating units of galactose and 3,6-anhydrogalactose units (sulphated and non-sulphated), which are joined by alternating α-(1,3) and β-(1,4) glycosidic links. However, the main difference lies in the lower sulphate content of furcellaran (one sulfate group per three to four monomeric units) (Imeson 2009, Robal et al. 2017).

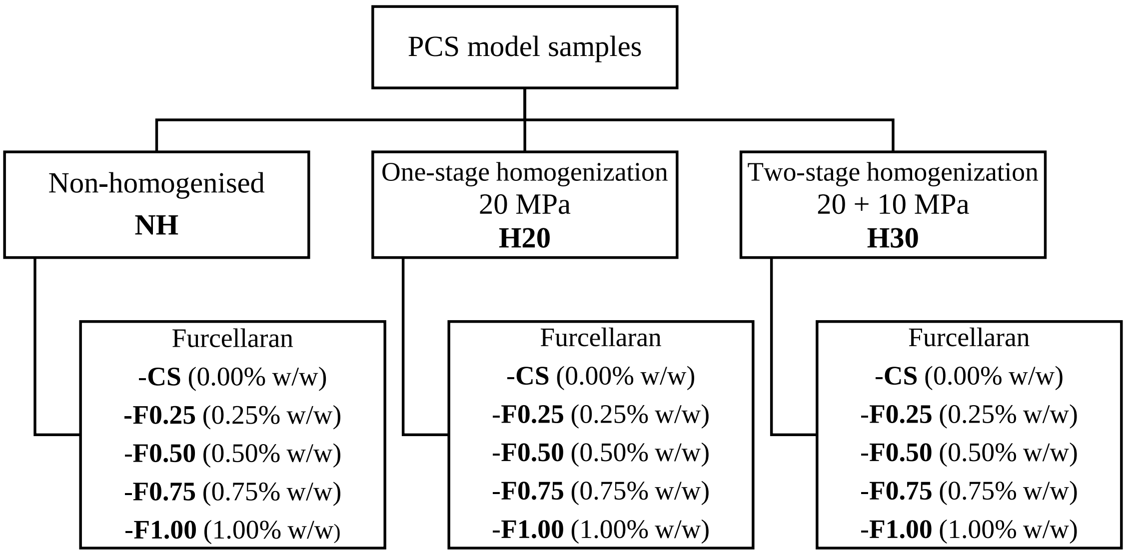
However, in the literature, there is a lack of information of homogenization impact on the PC and PCS properties. This study was focused on the evaluation of the impact of homogenization on the viscoelastic PCS properties manufactured with different furcellaran levels (0.25–1.00% w/w). In addition, a second objective was to describe the effect of one- and two-stage homogenization on the PCS viscoelastic behavior.

MATERIAL AND METHODS

Manufacture and materials

The model PCS samples were prepared with 0.25; 0.50; 0.75 and 1.00% w/w furcellaran and 2.27% w/w ES addition, whereas all model samples were designed to have a dry matter (**DM**) content 30% w/w and fat in dry matter (**FDM**) content 66% w/w. After PCS manufacture, the hot molten mass was divided into three groups; the (i) of which was not subjected to homogenization (**NH**); the (ii) was subjected to one-stage homogenization (20 MPa; **H20**); and the (iii) was subjected to two-stage homogenization (20 MPa/10 MPa; **H30**). Moreover, control samples were produced (**CS**; without furcellaran addition). For the PCS preparation, the following ingredients were utilized: Edam cheese (AGRICOL s.r.o., Czech Republic; DM 50% w/w, FDM 30% w/w, 7 week maturity); butter (Sachsenmilch Leppersdorf, GmbH, Germany; DM 84% w/w, fat content 82% w/w); ES [Fosfa a.s., Czech Republic; Na_2HPO_4, NaH_2PO_4, $Na_4P_2O_7$ and sodium salt of polyphosphate (number of phosphate units ≈ 20), in a ratio of 2.6:3.0:2.2:2.2)] furcellaran (Estgel 1000; Est-Agar AS, Estonia); a mixture of monoacylglycerols and diacylglycerols (Brenntag CR s.r.o., Czech Republic) and water. The device Stephan UMC-5 (Stephan Machinery GmbH, Germany) with an indirect heating system was employed for the PCS manufacture, whereas the PCS was melted for 1 minute at 90 °C (total melting time was 12 min) at 3000 rpm. For PCS samples homogenization [at two homogenization regimes; (i) one stage: 20 MPa; and (ii) two-stage 20 MPa and 10 MPa, respectively] the PandaPLUS (GEA Niro Soavi, Italy) was used. For greater clarity, the scheme of the produced samples is shown in Figure 1. Thereafter, the hot PCS molten mass was transferred into polypropylene pots, which was closed with aluminum lids. The model samples were cooled down and stored for 24 hours at 6 ± 2 °C. The PCS model samples were produced in triplicate.

Figure 1 Overview of the composition of PCS samples manufactured



Basic chemical analysis

The basic chemical analysis consisted of the determination of DM content and pH of the PCS samples. The DM content was determined according to ISO 5534 (2004). For pH measurement (at 22 ± 2 °C), a puncture pen-type pH meter pHSpear (Eutech Instruments, Malaysia) with a glass tip electrode was used. All the measurements were performed at least three times for each model sample (n = 9; 3 repetitions × 3 batches).

Dynamic oscillatory rheology

Viscoelastic properties of PCS model samples were determined by a dynamic oscillatory shear rheometer Rheostress 1 (Haake, Germany) with plate-plate geometry (35 mm diameter, 1 mm gap). The storage modulus (**G´**; Pa; describing the elastic response) and the loss modulus (**G´´**; Pa; describing the viscous response) were measured. Moreover, complex modulus (G^*; Pa) and tangent of phase shift angle (**tanδ**; unitless) were calculated according to the equation (i) and (ii), respectively. All measurements were performed in the oscillation frequency range of 0.1–10.0 Hz (at 20.0 ± 0.1 °C). The shear stress amplitude (20 Pa) was within the linear viscoelastic region. The presented data are the mean value from three measurements of each PCS sample (n = 9). Moreover, the reference frequency of 1 Hz was chosen for tan δ and G^* data presentation.

(i) $$G^* = \sqrt{(G')^2 + (G'')^2}$$

(ii) $$\tan\delta = G''/G'$$

Statistical analysis

For the evaluation of data obtained, Kruskal-Wallis and Wilcoxon tests were used (the selected significance level was 0.05).

RESULTS AND DISCUSSION

Evaluation of basic chemical analysis of the PCS samples

The DM content of all the model PCS samples ranged from 30.56 to 31.04% w/w, which met the specified requirements and assured the comparability of the PCS samples ($P \geq 0.05$). Furthermore, the pH values of model samples were in the range of 5.95–6.11. The growing furcellaran concentration (0.25–1.00% w/w) slightly increased the pH values of PCS samples; nevertheless, the changes were not significant ($P \geq 0.05$). Likewise, the effect of homogenization (and homogenization regime; H20, H30) was not demonstrated as well, the pH values were equal or slightly higher ($P \geq 0.05$) than those of NH samples (with the same furcellaran concentration).

Viscoelastic properties of the PCS samples

The G´ and G´´ development of the PCS samples tested (which varied in the furcellaran levels and homogenization regimes used) concerning the frequency (0.1−10.0 Hz) is presented in Figure 2. Generally, in the all model PCS samples tested, the elastic component of behavior predominated over the viscous response (G´ > G´´; in the whole range of tested frequencies); the PCS structure thus corresponds to a solid type structure rather than liquid and could be described as gel (Cunha et al. 2013).

Furthermore, the elevated concentration of furcellaran (0.25; 0.50; 0.75 and 1.00% w/w) progressively increased ($P \leq 0.05$; regardless the homogenization regime) the G´ and G´´ values in the whole range of frequency observed (0.1–10.0 Hz; Figure 2), which indicates the growing PCS rigidity. Moreover, according to Černíková et al. (2008), the creation of a denser network structure within the PCS matrix has occurred due to the more intense interaction between the chains of the hydrocolloid. The G´ and G´´ values of the homogenized (both H20 and H30) CS and samples produced with relatively low furcellaran addition (0.25% w/w) were significantly ($P < 0.05$) higher in comparison with the NH samples. If compared the homogenized (H20 and H30) products with each other, the higher ($P \leq 0.05$) G´ and G´´ curves were observed in case of those which was two-stage-homogenized ($P \leq 0.05$; at constant furcellaran levels). The latter phenomena can be explained by the reduction of particles (especially fat globules) during homogenization and also by the formation of a more intensive protein network (by the proteins newly covered the reduced fat droplets surface;

Mohammadi and Fadaei 2018). However, for PCS samples produced with relatively higher furcellaran content (0.50; 0.75 and 1.00% w/w), the opposite trend was observed; the G´ and G´´ values of homogenized (both H20 and H30) samples were even lower ($P < 0.05$) than those made without homogenization (NH). In terms of comparing different types of homogenization, the lowest values ($P < 0.05$) were measured after two-stage homogenization for those PCS (compared to H20). Furthermore, in the case of samples with 0.50% furcellaran content, the G´ and G´´ values were comparable in the range of measured frequencies (0.1 – 10.0 Hz; $P \geq 0.5$) for H30 samples and lower ($P \leq 0.05$) for H20 samples.

Table 1 Complex modulus (G; kPa) of PCS samples with different furcellaran levels) subjected to different homogenization regimes measured at reference frequency of 1 Hz*

Homogenization regime	G^* (kPa)[1]				
	Furcellaran concentration (% w/w)				
	0	0.25	0.50	0.75	1.00
NH	0.60 ± 0.02^{Aa}	1.32 ± 0.05^{Ba}	3.74 ± 0.01^{Cb}	7.64 ± 0.08^{Dc}	12.77 ± 0.11^{Ec}
H20	1.24 ± 0.03^{Ab}	2.26 ± 0.10^{Bb}	3.38 ± 0.04^{Ca}	6.00 ± 0.01^{Db}	8.55 ± 0.07^{Eb}
H30	1.32 ± 0.02^{Ab}	2.79 ± 0.02^{Bc}	3.78 ± 0.04^{Cb}	5.56 ± 0.03^{Da}	7.60 ± 0.02^{Ea}

Legend: NH – non-homogenized, H20 – one-stage homogenization; H30 – two-stage homogenization; [1]results are given as the mean ± standard deviation; $^{A–E}$ distinct superscripts in the row indicate the significant difference ($P < 0.05$); $^{a–c}$ distinct superscripts in the column indicate the significant difference ($P < 0.05$)

The G^* (Table 1) and tan δ (Table 2; for a reference frequency of 1 Hz) data were in an accordance with the above-mentioned trends. The increasing furcellaran content (0.25–1.00% w/w) and homogenization applied (H20 and H30; for CS and F0.25 samples) led to the increase ($P < 0.05$) in G^* and the decrease ($P \geq 0.05$, statistically insignificant) in tan δ, whereas, the greatest G^*values were observed ($P \leq 0.05$) for two-homogenized samples. Nevertheless, G^* of the homogenized (H20 and H30) products with relatively higher furcellaran concertation (0.75 and 1.00% w/w) declined ($P > 0.05$) in NH samples comparison (at a constant furcellaran level). The development of G^* for F0.50 samples were dependant on homogenization type (see Table 1). However, the differences in tan δ values were not significant ($P \geq 0.05$; Table 2). Thus, changes in the viscoelastic properties of PCS due to homogenization were affected by the concentration of furcellaran, which may be due to the disruption of the furcellaran chains (occurring in the greater quantities) by the homogenization pressure, and thus possible less effective impact on the ability to form a gel and increase the PCS firmness.

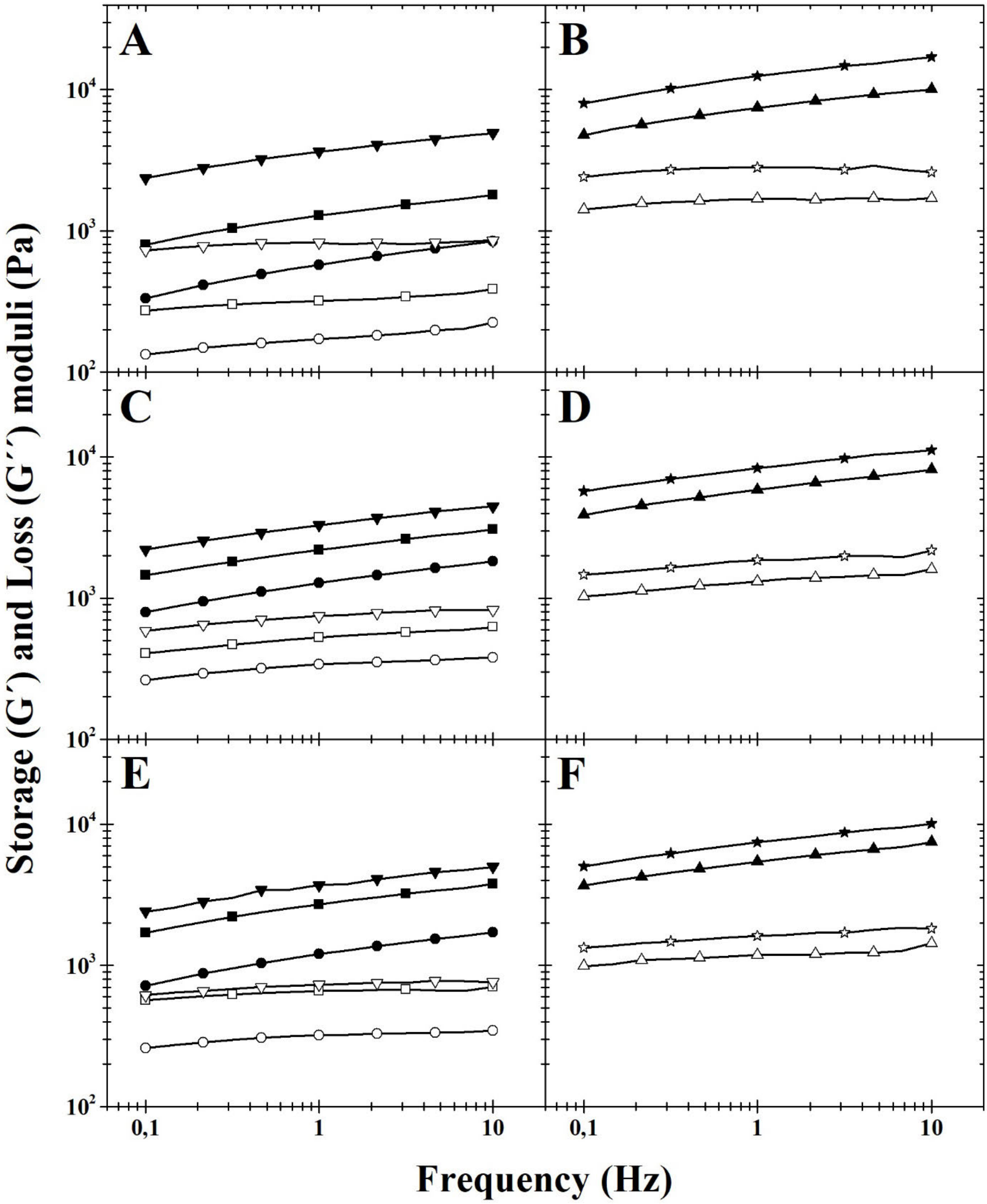
These findings provide a better insight of the use of various homogenization regimes in PCS manufacture. Moreover, applications of furcellaran (permitted to be used as a food additive in the European Union under the code E407 together with carrageenans) to dairy products in order to control their properties was described, since application of this carrageenan type has not yet been discussed in the available literature.

Table 2 Tangent of phase shift angle (tan δ; unitless) of PCS samples with different furcellaran levels subjected to different homogenization regimes measured at reference frequency of 1 Hz

Homogenization regime	tan δ[1]				
	Furcellaran concentration (% w/w)				
	0	0.25	0.50	0.75	1.00
NH	0.30 ± 0.01^{Aa}	0.25 ± 0.01^{Ba}	0.23 ± 0.02^{Ba}	0.23 ± 0.03^{Ba}	0.23 ± 0.02^{Ba}
H20	0.26 ± 0.04^{Aa}	0.24 ± 0.03^{Aa}	0.23 ± 0.02^{Aa}	0.22 ± 0.04^{Aa}	0.22 ± 0.03^{Aa}
H30	0.27 ± 0.03^{Aa}	0.24 ± 0.04^{Aa}	0.24 ± 0.04^{Aa}	0.22 ± 0.02^{Aa}	0.22 ± 0.03^{Aa}

Legend: NH – non-homogenized, H20 – one-stage homogenization; H30 – two-stage homogenization; [1]results are given as the mean ± standard deviation; $^{A–E}$ distinct superscripts in the row indicate the significant difference ($P < 0.05$); $^{a–c}$ distinct superscripts in the column indicate the significant difference ($P < 0.05$)

Figure 2 Development of the storage (G´, Pa; full symbols) and loss (G´´, Pa; open symbols) modulus in a relation to the frequency (0.1–10.0 Hz) of PCS samples manufactured with various levels of furcellaran (control sample – ●○; 0.25% w/w – ■□; 0.50% w/w – ▼▽ in parts A, C and E; and 0.75% w/w – ▲△; 1.00% w/w – ★☆in parts B, D and F). Produced with no homogenization applied (parts A, B) and with one-stage (20 MPa; parts B, C); and two-stage (20/10 MPa; parts E, F) homogenization applied.



CONCLUSION

The various homogenization regimes affected the viscoelastic properties of PCS depending on the furcellaran content. The greatest influence was observed for the increasing addition of furcellaran

(0.25–1.00% w/w), which significantly increased the stiffness of all PCS samples. However, the homogenization process was only suitable for effectively increasing of furcellaran-free or low-content (0.25% w/w) samples firmness. In this case, two-stage homogenization was the most effective. On the other hand, at higher furcellaran concertation (0.50; 0.75 and 1.00% w/w), the effect of homogenization on the increase of PCS rigidity was not observed. The PCS showed lower firmness in the following order: two-stage homogenized < one-stage homogenized < non-homogenized. Nevertheless, further analyzes will be necessary in the future to understand the processes within the homogenization of processed cheese sauce and processed cheese.

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