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Preparation and rheological properties of a dairy dessert based on whey protein/potato starch

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Abstract

Gels were prepared by heating different mixtures of whey protein concentrates (WPC) potatoes and ι-carrageenan. The influence of these ingredients on the strength of the obtained gels was investigated. The rheological properties of these gels were also measured during cooling from 90 to 10 °C at variable frequencies and strains. Analysis of variance showed a highly significant ($P < 0.0001$) relationship between the concentrations of the different ingredients and the gel strength. The storage modulus (G') was generally higher than the loss modulus (G'') at different temperatures. Generally, the log (G') and log (G'') increased with the increase in the applied frequency, which suggested a weak gel entanglement network. Desserts were also prepared using 4% WPC and 3% potato starch (PS), 0.1% ι-carrageenan, 10% sucrose, 3% milk fat and 3% cocoa powder, by heating at 100, 110 or 120 °C for 30 min, packaged hot and stored for 28 days at room temperature (20 ± 5 °C). Samples of fresh and stored desserts were taken at 0, 7, 14, 21, 28 days of storage and their gel strengths were measured. Also, the effect of heat treatment during preparation on G', G'' and phase angle (δ) of the different desserts was followed. The effects of the heating time and temperature on the gel strength and rheological properties were relatively small.
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Keywords: Gel strength; ι-Carrageenan; Storage modulus; Loss modulus; Phase angle

1. Introduction

Whey proteins have many functional properties, which allow their use in a variety of foods to improve texture, flavour and colour and to increase protein content. One of the most important functional properties of whey proteins is their ability to form heat-induced gels (Mleko, 1996). Application of whey protein concentrate (WPC) in foods requires extensive knowledge of their gelling properties, and of their interaction with other components found in food systems (Tang, McCarthy, & Munro, 1995). In recent years, studies on the interactions between proteins and polysaccharides have received much attention. Electrostatic interaction between acidified potato starch (PS) and α-casein was reported (Takeushi, 1969). A milk-based system, containing corn starch, was used by Ling (1984) to elucidate the role of β-lactoglobulin in milk gelation. Rheological methods have often been used to follow the swelling, solubilization and gelation of different starches (Evans & Haisman, 1979). Penetration tests have been widely used to measure gel firmness of skim milk gel (Kalab, Voisey, & Emmons, 1971) and WPC gels (Schmidt and Illingworth, 1978). The penetration test is easy to perform and quickly provides information for quality control purposes in the dairy industry. Non-destructive dynamic shear tests have been applied extensively to the study of whey protein gelation (Tang, McCarthy, & Munro, 1993, 1995).

The use of whey protein preparations in milk desserts has several impacts on the functional and nutritional attributes of the final product. However, their use in milk desserts needs more thorough investigation in order to find the optimum combinations with other ingredients. The affect of heat treatment on the different

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ingredients used in dairy desserts has been the subject of several studies (Goff & Jordan, 1984; Jana, 1994; Mleko, 1997; Mottar, 1982, 1984). However, little has been cited in the literature concerning the formulation of desserts containing whey proteins.

This work deals with the changes in the rheological properties of PS, WPC and ι-carrageenan during heat treatments, in order to study the effects of heating and storage on the rheological properties of a dairy desserts based on these ingredients.

2. Materials and methods

2.1. Materials

Potato starch (24% amylose and 76% amylopectin), was purchased from SIGMA (St. Louis, MO, USA), WPC from Laiterie Triballat (Noyal-Sur- Vilaine, France) and ι-carrageenan from (Sanofi Bio-Industries, France). Sugar and cocoa powder were from the market. Fresh pasteurised cream (35% fat) was used as a source of milk fat in the dessert.

2.2. Preparation of gels

Variable concentrations of WPC (3%, 4% and 5%), PS (2%, 3%, 4% and 5%) and ι-carrageenan (0.1%, 0.2% and 0.3%) were used for preparing gels. Two hundred millilitres from each of the previous combinations were stirred to form a homogeneous solution. The solution was heated at 95 °C for 15 min, under a constant shear rate of 600 s-1 in a coaxial cylinder viscometer, type Rheomot-108E (Contrives, Switzerland). The gels was divided into two parts; the first was used to measure the rheological properties, namely, G', G'' and phase angle (δ) during cooling from 90 to 10 °C. The second part was packaged while hot (90 °C) in polypropylene tubes, 22 mm diameter, cooled to 20 ± 1 °C and kept overnight at the same temperature.

2.3. Dynamic viscoelastic measurements

The gels were transferred to the preheated (90 °C) cone and plate device of a Carri-Med rheometer (Rheo, UK). The cone had a diameter of 6 cm with a 4° angle. To avoid evaporation, the cone was covered with paraffin oil. The rheological properties namely storage modulus (G'), loss modulus (G'') and phase angle (δ) of the gels were monitored during cooling from 90 to 10 °C at a rate of 1 °C/min, a strain below 0.01 mm and a frequency of 0.5 Hz. The temperature during rheological measurements was carefully controlled within the range between 90 and 10 °C (±0.2 °C).

Also, the rheological properties gels were measured at 25 °C at variable frequencies.

2.4. Penetration test

The gel strength was determined by the cone penetrometric method using a traction – compression type instrument DY30 (Admel Lhamargy, France) at a constant speed of 2.00 mm/s using polyamide cone with cone angle of 20°. The maximal penetration depth was set to 25 mm. An autotrac programme was used for the data acquisition. All the measurements were made on ten replicate gels for each treatment.

2.5. Statistical analysis

Analysis of variance and general linear modelling (SAS, 1990) were carried out on the data obtained.

2.6. Preparation of dairy dessert

A laboratory-built controlled heating system was used for the preparation of desserts. This system consisted of a double-jacket 1 l stainless steel pressure-tight vessel placed over a magnetic stirrer for continuous mixing during heating. This vessel was connected to a circulating oil bath which was controlled by a computer programme for the selection of the heating conditions.The ingredients were mixed thoroughly in the determined water quantity using a blender, transferred to the heating vessel, and the heating time calculated when temperature reached the chosen value. The desserts were then packaged while hot (90 °C) in polypropylene tubes, 22 mm diameter, under almost sterile conditions. The products were stored at room temperature; firmness of the product was measured after 1, 7, 14, 21 and 28 days of storage.

3. Results and discussion

3.1. Effect of variable ingredients on the gel strength

The results (Table 1) indicate linear relations between the Concentration of WPC, PS, ι-carrageenan and the gel strength. Analysis of variance showed a highly significant ($P < 0.0001$) relationship between the concentration of the used ingredients and the gel strength. These relationship were found to follow the equation:

$$\text{logstress(Pa)} = 2.314 + 0.076 \ast \text{WPC\%} + 0.133 \ast \text{PS\%} + 0.554 \ast \log(\text{IC})\%.$$

The present results suggest that the contributions of the different constituents to the gel strength were additive, with minimal interaction between the ingredients. The results are in line with those reported by Mauhrbeck and Eliasson (1991) who found that, in a milk

Table 1
Table changes in log stress (Pa) of whey protein concentrate (WPC)-, potato starch (PS)-based gels as a function of PS, WPC and ι-carrageenan contents

	Potato starch (%)			
ι-Carrageenan (%)	2	3	4	5
WPC 3%				
0.1	2.253	2.386	2.519	2.652
0.2	2.420	2.553	2.686	2.819
0.3	2.518	2.651	2.784	2.917
WPC 4%				
0.1	2.329	2.462	2.595	2.728
0.2	2.496	2.629	2.762	2.895
0.3	2.594	2.727	2.859	2.993
WPC 5%				
0.1	2.405	2.538	2.671	2.804
0.2	2.572	2.705	2.838	2.971
0.3	2.669	2.803	2.936	3.069
WPC 6%				
0.1	2.481	2.614	2.747	2.880
0.2	2.648	2.781	2.914	3.047
0.3	2.746	2.879	3.012	3.145

protein/PS system, the starch network was formed before that of the protein, and that the leaking out of amylose from the starch granules might be hindered by the aggregating protein molecules.

Ranking the contributions of the different ingredients to the strength of WPC/PS gels on a weight basis, ι-carrageenan showed the greatest effect, followed by PS and WPC, which showed the smallest effect. The relationship between ι-carrageenan concentration and the gel strength was not linear, being more pronounced at low ι-carrageenan contents. A similar relationship was reported by Descamps, Langeuin, and Combs (1986). There is no simple explanation for the dramatic effect of ι-carrageenan on the gel strength of WPC/PS gels. Also, during gelation, the volume of the aqueous phase accessible to the ι-carrageenan was reduced, giving rise to an increase in its concentration within the continuous phase and giving rise to a dramatic increase in viscosity. Similar results were reported for galactomannans in mixed gels with starch (Alloncle, Lefebvre, Llamas, & Doublier, 1989) these being located within the continuous phase of the starch gel.

3.2. Effect of ingredients on the rheological properties of the gels

3.2.1. Effect of whey protein concentrate

The rheological behaviour of gels containing 3%, 4% and 5% whey protein concentrate, 3% PS and 0.1% ι-carrageenan was measured during cooling from 90 to 10 °C. Fig. 1 shows the changes in storage modulus (G'), loss modulus (G''), and phase angle (δ) of these gels as a function of temperature. The storage modulus (G'),

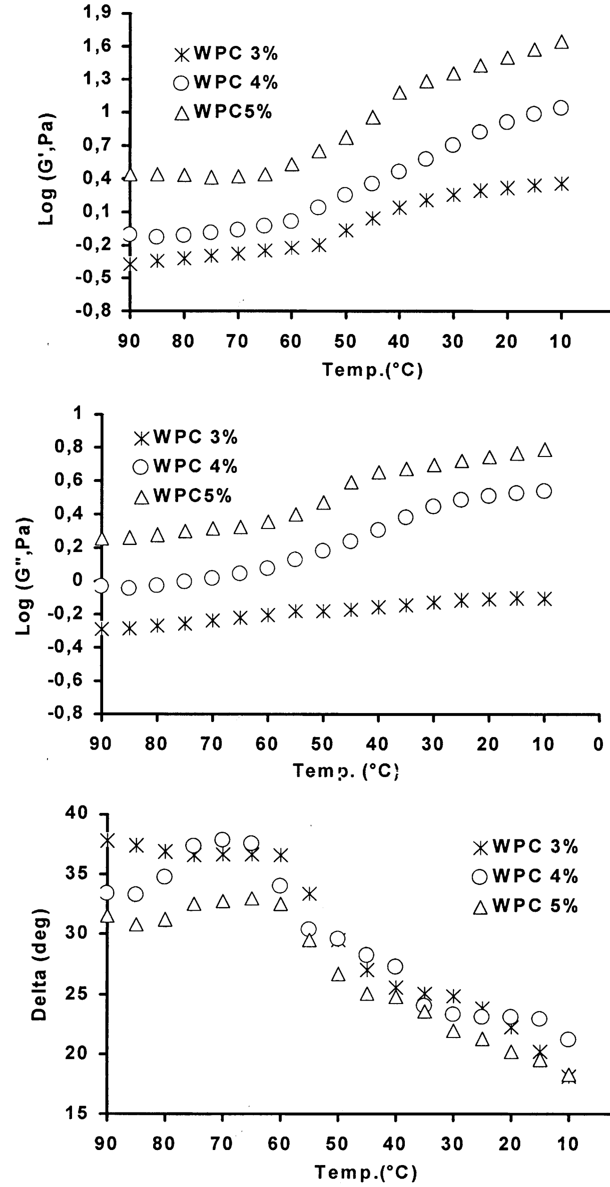

Fig. 1. Changes in log storage modulus (G'), loss modulus (G'') and phase angle (δ) cooling from 90 to 10 °C for PS (3%), ι-carrageenan (0.1%) with whey concentrate at 3%, 4% or 5%.

which represents the elastic component, increased after the first transition at 75–65 °C, on further decrease in temperature, until 25 °C, and then remained almost unchanged until 10 °C. The loss modulus (G''), which represents the viscous component, showed almost the same pattern of changes as the storage modulus (G'). An increase in loss modulus (G'') upon cooling was previously noted for β-lactoglobulin (Foegeding et al., 1992; Paulsson, Dejmek, & van Vliet, 1990), ovalbumin and soybean isolate gels (VanKleef, Boskamp, & Tempel, 1978). Several researchers (Beveridge & Timbers, 1985; Breton-Dollet, Korolczuk, Doublier, & Maingonnat, 1995) have reported higher storage modulus (G') than loss modulus (G'') for starch and WPC gels and mixed starch/WPC gels, in agreement with the present results. This behaviour can be attributed to the cross-linkage formations by disulfide bonds and hydrophobic interactions. The increase in rigidity during cooling is due to contributions from physical interactions, especially hydrogen bonding (Chen, Dickinson, Langton, & Hermansson, 2000).

As the phase angle approaches (0°), very little energy is lost as heat and the gel become more elastic (Tang and Paulsson, 1995). For gels containing 3%, 4% and 5% WPC, phase angle was low (about 30°–37°) at 90 °C and decreased to 5°–15° at 10 °C. These values indicate a high elastic component of the WPC gels the probably associated with gelation of whey proteins in presence of starch and ι-carrageenan. The low phase angle values (all <90°) were also noted for β-lactoglobulin gels. From a rheological point of view, the gels at 90 °C can be considered as structured systems, as the loss angle δ was below 40°.

Table 2, shows the relationship between log frequency and storage modulus (G') and loss modulus (G'') for gels containing 3%, 4% and 5% WPC, 3% PS and 0.1% ι-carrageenan. The storage modulus (G') of the gels increased slightly but linearly with increase in frequency; the slopes of these relationships were nearly the same for gels of different protein contents. The same was also observed for the relationships between log frequency and loss modulus (G''). However, these relationships were almost linear and their slopes increased with the decrease in WPC in the gels. The relationships between applied frequency and the rheological parameters were almost linear and increased with increase in frequency. The loss modulus (G'') was lower than the storage modulus, which means that gels mainly retained elasticity.

3.2.2. Effect of potato starch concentration

Fig. 2, shows the changes in the storage modulus (G'), loss modulus (G''), and phase angle (δ) of gels containing 3%, 4% and 5% PS, 4% WPC and 0.1% ι-carrageenan as a function of temperature.

Table 2
Changes in the storage modulus (G') and loss modulus (G'') for gels containing 3%, 4% and 5% whey protein concentrate at different frequencies

log (frequency, rad/s)	log (G')			log (G'')		
	WPC (%)					
	3	4	5	3	4	5
−1.10	0.265	0.937	1.331	−0.764	0.027	0.342
−0.72	0.281	0.959	1.348	−0.659	0.090	0.379
−0.48	0.298	0.980	1.367	−0.560	0.162	0.429
−0.23	0.318	1,000	1.383	−0.450	0.243	0.489
0.13	0.354	1.040	1.412	−0.288	0.376	0.594
0.37	0.376	1.077	1.433	−0.156	0.477	0.704
0.61	0.397	1.119	1.481	−0.045	0.575	0.747
0.86	0.386	1.176	1.481	0.088	0.676	0.838
1.10	0.302	1.263	1.505	0.254	0.786	0.937

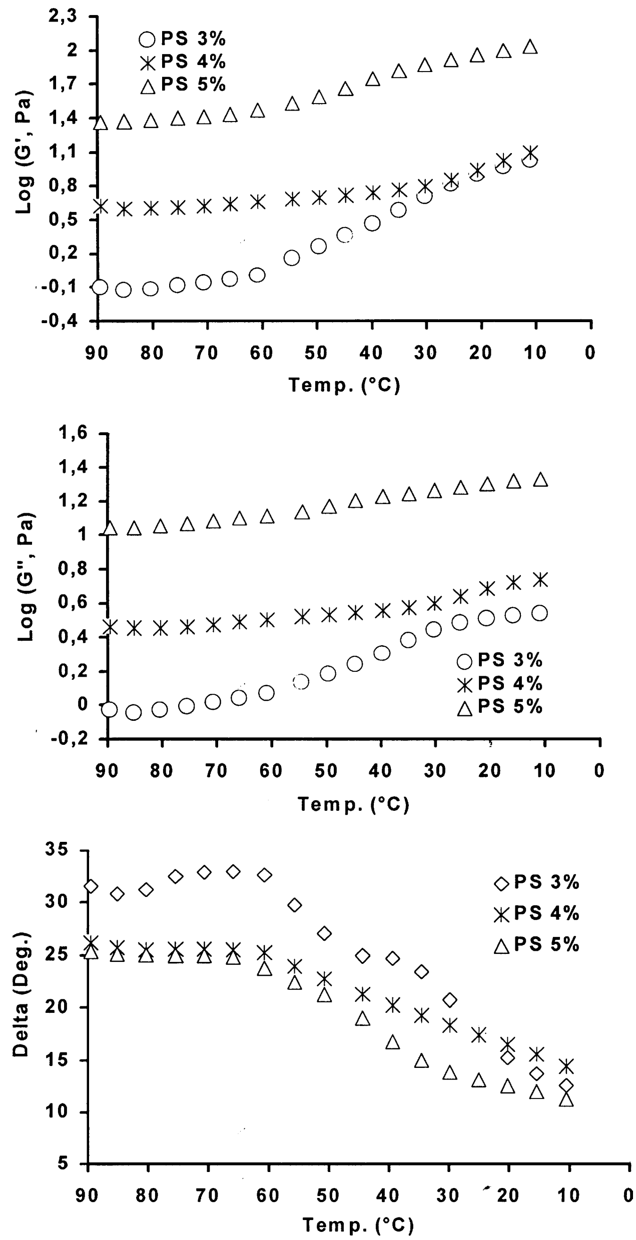

Fig. 2. Changes in log storage modulus (G'), loss modulus (G'') and phase angle (δ) during cooling from 90 to 10 °C for WPC (4%) PS (3%), ι-carrageenan (0.1%) with PS at 3%, 4% or 5%.

The storage modulus (G') increased after the first transition at 70–60 °C, and further decrease in temperature until 10 °C, which was more clear for the gel containing 3% potato starch. The loss modulus (G''), showed an almost similar pattern; with phase angles (δ) below 35°, gels can be considered as structured systems at 90 °C. During cooling to 10 °C phase angle (δ) decreased to about 14°, 12° and 11° for gels containing 3%, 4% and 5% PS. Mauhrbeck and Eliasson (1991), reported that the phase angle (δ) of the PS gels gradually

Table 3
Changes in the storage modulus (G') and loss modulus (G'') for gels containing 3%, 4% or 5% potato starch at different frequencies

log (frequency, rad/s)	log (G')			log (G'')		
	Potato starch (%)					
	3	4	5	3	4	5
−1.10	0.937	1.022	1.932	0.027	0.259	1.019
−0.72	0.959	1.056	1.953	0.090	0.332	1.056
−0.48	0.980	1.086	1.974	0.163	0.408	1.098
−0.23	1.003	1.121	1.995	0.243	0.488	1.145
0.13	1.044	1.175	2.028	0.376	0.613	1.225
0.37	1.077	1.214	2.052	0.477	0.703	1.289
0.61	1.119	1.256	2.077	0.575	0.789	1.352
0.86	1.176	1.299	2.104	0.676	0.877	1.418
1.10	1.263	1.340	2.131	0.786	0.972	1.491

decreased with time, indicating a build-up of the structure.

The changes in the phase angle (δ) of gels during cooling indicate that all the gels retained the gel structure even at the temperature of 90 °C (phase angle 40°). This can be attributed to the resistance of the PS to shearing and heating conditions during the preparation of the gel. The same results were reported by Breton-Dollet et al. (1995) and Beveridge and Timbers (1985). Beveridge, Jones, and Tung (1984) reported that the increase in the storage modulus (G') after cooling can be attributed to formation of multiple hydrogen bonds since these are favoured by lower temperature.

The relationships between the rheological parameters and applied frequency were almost linear, increasing with increase in frequency (Table 3). but the gel containing 5% PS, showed higher values than the gel containing 3% or 4% PS.

3.2.3. Effect of ι-carrageenan concentration

Addition of 0.1%, 0.2%, 0.3% ι-carrageenan, to gels containing 4% WPC and 3% PS increased storage modulus (G') and loss modulus (G'') during cooling to 10 °C. The role of ι-carrageenan was more apparent at about 40 °C. The gels at 90 °C can be considered as structured systems, as their phase angles (δ) were below 40°. During cooling to 10 °C, the phase angles decreased to about 12°, 11° and 9° for gels containing 0.1%, 0.2%, −0.3% ι-carrageenan, respectively, (Fig. 3). The relationships between the rheological parameters and applied frequency were almost linear and increased with increase in frequency (Table 4).

The foregoing results revealed that the storage modulus (G') values were almost one order of magnitude higher than the loss modulus (G''). In all studied gels, the storage modulus (G') and loss modulus (G'') generally increased with increase in the applied frequency, which suggests a weak gel entanglement network (Clark & Ross-Murphy, 1987). Changing the concentration of the different ingredients did not alter the frequency-dependence of the rheological properties.

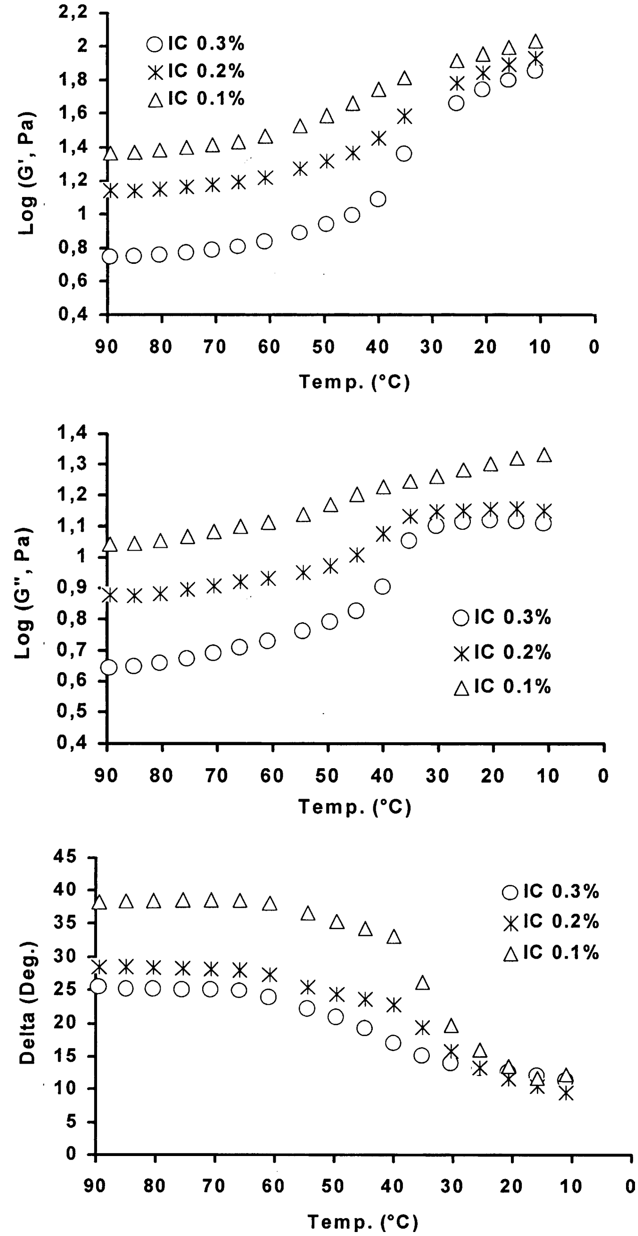

Fig. 3. Changes in log storage modulus (G'), loss modulus (G'') and phase angle (δ) during cooling from 90 to 10 °C for WPC 4%, PS with ι-carrageenan (0.1%, 0.2% or 0.3%).

3.3. Whey protein/potato starch desserts

3.3.1. Changes in gel strength

Table 5 shows the effect of heating temperature and duration on log stress of desserts containing 3% PS, 4% WPC, 3% milk fat, 10% sucrose and 3% chocolate. The effect of heating conditions on these desserts was generally small. Regression analysis showed that the relationship between log stress of the desserts and heating

Table 4
Changes in the storage modulus (G') and loss modulus (G'') for gels containing 0.1%, 0.2% or 0.3% ι-carrageenan at different frequencies

log (frequency, rad/s)	log (G')			log(G'')		
	IC (%)					
	0.10	0.20	0.30	0.10	0.20	0.30
−1.10	1.919	1:872	1.786	1.005	0.842	0.743
−0.72	1.953	1.904	1.819	1.056	0.883	0.796
−0.48	1.974	1.924	1.836	1.098	0.944	0.841
−0.23	1.995	1.940	1.853	1.145	0.964	0.893
0.13	2.028	1.964	1.879	1.225	1.039	0.982
0.37	2.052	1.982	1.898	1.289	1.093	1.040
0.61	2.077	2.001	1.919	1.289	1.155	1.111
0.86	2.104	2.022	1.946	1.352	1.224	1.188
1.10	2.131	2.044	1.981	1.491	1.299	1.273

Table 5
Changes in log stress (Pa) of whey protein concentrate/potato starch desserts as a function of heating and storage period

Heating temperature (°C)	Storage period (days)				
	Fresh	7	14	21	28
100	2.137	2.138	2.138	2.139	2.140
110	2.094	2.095	2.095	2.096	2.097
120	2.051	2.052	2.052	2.053	2.054

temperature and duration can be expressed in the following equation:

log stress (Pa) = INT + A*TEMP + B*TIME

Intercept = 2.567; Temperature (°C) = −0.0043; Time (min) = 0.0001.

3.3.2. Rheological properties of whey protein dessert

At 90 °C, dessert prepared at 110 °C showed the highest (0.988 Pa) storage modulus (G') while that prepared at 100 °C, showed the lowest (0.328 Pa) (Fig. 4). During cooling, the storage modulus (G') of dessert prepared at 110 °C slowly increased between 90 and 70 °C, then rapidly from 70 to 40 °C and then continued to increase reaching its maximum at 10 °C. For dessert prepared at 120 °C, the storage modulus (G') increased almost linearly during cooling from 90 to 10 °C, while that prepared at 120 °C, showed a trend in between those prepared at 100 and 110 °C. The loss modulus (G''), showed an almost similar pattern (Fig. 4). The phase angle (δ) at 90 °C of desserts prepared at 110 °C was much less than those prepared at 100 and 120 °C. In all desserts, the phase angles (δ) were slightly changed between 90 and 40 °C, then rapidly decreased until 10 °C. The decreases in phase angle (δ) of dessert prepared at 100 °C during cooling were more pronounced than that prepared at 120 °C (Fig. 4).

The loss modulus (G'') linearly increased with the increase in the applied frequency. The slopes of these relationships were almost the same in desserts prepared at different temperatures. The storage modulus (G') of desserts prepared at 100 °C seems to be less affected by changing frequency than those prepared at 110 and 120 °C (Table 6). The obtained results show that the effects of the heating time and temperature are relatively small, probably due to multiple interactions between proteins, polysaccharides, fat and minerals which impair the formation of three dimensional networks of whey protein, amylose-amylopectin and carrageenan.

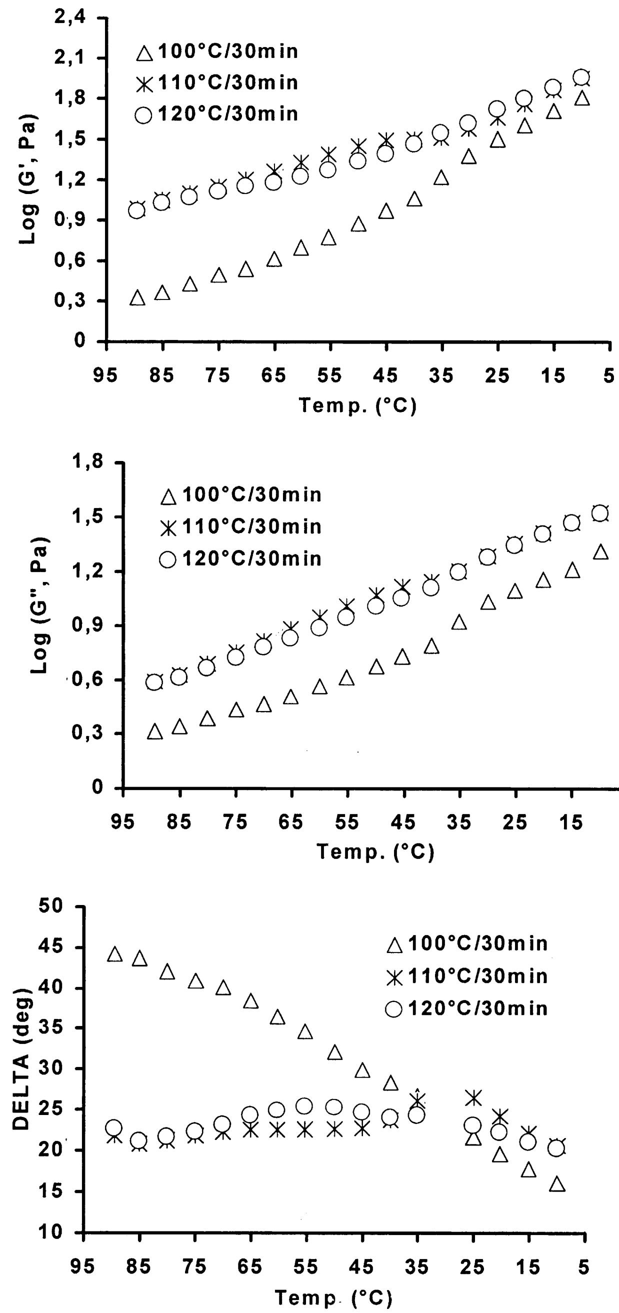

Fig. 4. Changes in log storage modulus (G'), loss modulus (G'') and phase angle (δ) during cooling from 90 to 10 °C for WPC/PS desserts.

Table 6
Changes in log storage modulus (G') and loss modulus (G'') for WPC-, PS-based desserts during heating at different temperatures

log (frequency, rad/s)	log (G')			log (G'')		
	Temperature (°C)					
	100	110	120	100	110	120
−1.10	1.694	1.809	1.792	0.866	1.141	1.158
−0.72	1.734	1.853	1.834	0.925	1.204	1.219
−0.48	1.757	1.882	1.862	0.976	1.255	1.269
−0.23	1.780	1.911	1.890	1.037	1.312	1.324
0.13	1.818	1.958	1.938	1.142	1.409	1.452
0.37	1.847	1.993	1.973	1.208	1.470	1.483
0.61	1.878	2.031	2.011	1.289	1.543	1.555
0.86	1.900	2.070	2.052	1.375	1.619	1.630
1.10	1.848	2.113	2.097	1.464	1.699	1.710

4. Conclusion

For rapid evaluation of the gel strength of large quantities gels and desserts, the penetration test could be a good choice. The gel strength, expressed as log stress, showed linear relationships to the concentrations of WPC and PS used and log concentration of ι-carrageenan. In all gels obtained, the loss modulus (G') was higher than (G''). The types of thickening and gelling agents and their levels determine the dessert rheological dessert properties. Formulation with 4% WPC, 3% PS and 0.1% ι-carrageenan with 10% sucrose, 3% milk fat and 3% chocolate was found to produce products that had acceptable rheological properties and good shelf life.

References

Alloncle, M. J., Lefebvre, G., Llamas, & Doublier, J. L. (1989). A rheological characterization of cereal starch-galactomannan mixtures. *Cereal Chemistry, 66*, 90.

Beveridge, T., Jones, L., & Tung, M. A. (1984). Progel and gel formation and reversibility of gelation of whey, soybean and albumin protein gels. *Journal of the Agriculture of Food Chemistry, 32*, 307.

Beveridge, T., & Timbers, G. E. (1985). Small amplitude oscillatory testing (SAOT). Instrumentation development and application to coagulation of egg albumen, whey protein concentrate and beef wiener emulsion. *Journal of Texture Studies, 16*, 333.

Breton-Dollet, V., Korolczuk, J., Doublier, J.-H., & Maingonnat, J. F. (1995). Rheological properties of maize starch pastes and gels. *Rheology, 5*, 24.

Chen, J., Dickinson, E., Langton, M., & Hermansson, A.-M. (2000). Mechanical properties and microstructure of heat – set whey protein emulsion gels: Effect of emulsifiers. *Lebensmittel-Wissenschaft Und-Technologie-Food Science and Technology, 33*, 299.

Clark, A. M., & Ross-Murphy, S. B. (1987). Structural and mechanical properties of biopolmer gels. *Advances in Polymer Science, 87*, 57.

Descamps, O., Langeuin, P., & Combs, D. H. (1986). Physical effect of starch/carrageenan interactions in water and milk. *Food Technology, 81*, 88.

Evans, I. D., & Haisman, D. R. (1979). Rheology of gelatinised starch suspensions. *Journal of Texture Studies, 10*, 347.

Goff, D. H., & Jordan, W. K. (1984). Aspartame and polydextrose in a calorie reduced frozen dairy dessert. *Journal of Food Science, 49*, 306.

Kalab, M., Voisey, P. W., & Emmons, D. B. (1971). Heat-induced milk gels. ii. Preparation of gels and measurement of firmness. *Journal of Dairy Science, 54*, 178.

Ling, L.-H. (1984). Effect of heat denaturation of whey proteins on the rheological properties of corn starch-milk systems. *Dissertation Abstracts International, 44*(12).

Mauhrbeck, P., & Eliasson, A.-C. (1991). Rheological properties of protein/starch mixed gels. *Journal of Texture Studies, 22*, 317.

Mleko, S. (1997). Rheological properties of milk and whey protein desserts. *Milchwissenschaft, 52*, 265.

Mleko, S. (1996). Effect of pH on the microstructure and texture of whey protein concentrates and isolate gels. *Polymer Journal of Food Nutrition Science, 5/46*, 33.

Mottar, J. (1982). L'influence sur quelques propriétés physique des desserts lactés UHT à la vanille. *Revue de I'Agriculture n°4, 35*, 2807.

Mottar, J. (1984). La fabrication de desserts lactés à I'aide du procédé UHT indirect et leurs propriétés. *Revue de I'Agriculture n°4, 37*, 1167.

SAS/STAT (1990). User's Guide, Version 6, fourth ed., Vol. 2. SAS Institute Inc., Gary, NC.

Paulsson, M., Dejmek, P., & van Vliet, T. (1990). Rheological properties of heat-induced lactoglobulin gels. *Journal of Dairy Science, 73*, 45.

Takeushi, I. (1969). Interaction between protein and starch. *Cereal Chemistry, 46*, 570.

Tang, Q., McCarthy, O. J, & Munro, P. A. (1993). Oscillatory theological study of the gelation mechanism of whey protein concentrate solutions; effects of physicochemical variables on gel formation. *Journal of Dairy Research, 60*, 543.

Tang, Q., McCarthy, O. J., & Munro, P. A. (1995). Effects of pH on whey protein concentrate gel properties: Comparisons between small deformation (Dynamic) and large deformation (Failure) testing. *Journal of Texture Studies, 26*, 255–272.

VanKleef, F. S. M., Boskamp, J. V., & Tempel, M. (1978). Determination of the number of cross-links in a protein gel from its mechanical and swelling properties. *Biopolymers, 17*, 225.