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ABSTRACT

The aim of the work was to compare K-carrageenan and i-carrageenan (in concentrations 0.025-0.150 g/100 g) application to cream desserts (dry matter content 44 g/100 g and fat content 38.5 g/100 g) and evaluate their viscoelastic properties and sensory quality. Sample properties were monitored during 28 d (6 ± 2 °C). During storage a slight decrease in the pH of the samples was monitored. Furthermore, the increasing addition of k- and i-carrageenan resulted in complex modulus (G*) and gel strength (Af) values increase ($P < 0.05$). In all samples, regardless of the type and concentration of carrageenan, a significant increase in the values of firmness was observed during storage. In general, the G* and Af were higher in the samples with K-carrageenan compared to products to which i-carrageenan was applied ($P < 0.05$). Moreover, all samples were characterised as homogenous and no water release and no off-flavour ($P > 0.05$) were detected. The suggested concentration of both tested carrageenans in order to obtain products with desired properties lies in the range of 0.050-0.125 g/100 g.

Keywords: Cream dessert, carrageenan, rheology, gel strength, sensory analysis

1. Introduction

Cream desserts (sometimes also labelled as "cream cheese") are dairy products with rheological/textural and organoleptic characteristics derived from the famous Italian cheese "Mascarpone". Furthermore, traditional Mascarpone is manufactured by heating standardised cream in the presence of an acid (usually citric acid, acetic, tartaric or lactic acid), until a precipitate forms after several min (in a temperature range of 75-90 °C). In addition, the casein micelles (or fractions thereof) and serum proteins present within the developed matrix associate with fat droplet membranes (which are lipoprotein in nature). Moreover, "Mascarpone-like" dairy products (including cream desserts) are usually produced by heating a mixture of high-fat in content cream with dairy powders (e.g. skim milk powder, whey powder, caseinates, milk protein concentrates, milk protein isolates) and selected hydrocolloids. Hence, the resultant dairy products, unlike traditional Mascarpone, present a neutral pH **(Hinrichs, 2004; Lopez, 2011; McSweeney et al., 2017)**.

Furthermore, carrageenans belong to the group of anionic linear sulphated galactans. The structure of carrageenans is based on the carabiose disaccharide composed of β-D-galactopyranose and 3,6-anhydro-a D-galactopyranose building blocks linked by a β-(1-4) bond. Additionally, for the production of Mascarpone-like products it is possible to use two types of carrageenans (k- and i-carrageenan). Particularly, k -carrageenan contains one sulphate group in the basic unit of carabiose, and in the case of i-carrageenan are present two sulphate groups **(Matignon et al., 2014; Singh et al., 2003; Spagnuolo et al., 2005)**. Furthermore, k- and i-carrageenan can occur in an aqueous medium (depending on temperature), in two states. Therefore, the latter states are the ordered helical structure (helix) and the disordered state. In addition, the transition temperature from the helical structure to the disordered state in the aqueous medium is usually in the range of 35-55 °C and depends on a number of parameters (including the type of carrageenan and the proportion and concentration of ions) (**Bourriot et al., 1999**; Langendorff et al., 1999; **Spagnulo et al., 2005)**.

Interactions between carrageenans and milk proteins are studied in depth. In particular, k- and i-carrageenans can form aggregates with milk proteins through positively charged segments of milk proteins and negatively charged carrageenans **(Garnier et al., 2003; Kovacová et al., 2010; Langendorff et al., 2000)**. However, according to **Lynch and Mulvihill (1996)**, interactions might also occur between carrageenan and β-casein and aS-caseins, in the presence of calcium ions and phosphorus ester-bonded on the seryl residues of the individual casein fractions. Additioanlly, in dairy systems might occur extensive interactions of anionic linear hydrocolloids, enhancing their ability forming aggregates with casein fractions and serum proteins **(Borreani et al., 2016)**. The interactions among carrageenans and milk proteins also depend on whether the temperature of the system is below or above the transition temperature from the helical structure to the disordered state. The adsorption of k- and i-carrageenan on casein micelles occurs only at temperatures lower than the transition temperature (at which both k- and i-carrageenan are in the helical state). Furthermore, the concentration of applied carrageenan and the properties of the environment (ionic strength, presence individual ions) are also important factors. According to **Klojdova et al. (2018)** application of carrageenans in Mascarpone-like products could enhance emulsion stability (over time) by preventing the aggregation of fat globules resulting.

Although Mascarpone-like products are applied in a wide range of confectionery and bakery products and salads, the available information in the scientific literature is scare. Additionally, these products can vary in terms of consistency and the application of carrageenans could lead to final products with versatile rheological and organoleptic properties. Moreover, various regions and cultures might have divergent expectations to the desirable consistency of Mascarpone-like products. The present work was undertaken under the objective to compare the effect of k- and i-carrageenan (in concentrations ranging from 0.025 to 0.150 g/100 g) application in cream desserts and evaluate their viscoelastic properties and sensory quality during a 28-d storage period (at 6 ± 2 °C).

2. Material and methods

2.1. Cream desserts manufacture

The Stephan UMC-5 (Stephan Machinery GmbH, Hameln, Germany) apparatus was applied for the production of the model samples of cream desserts (dry matter content of 44 g/100 g and fat content of 38.5 g/100 g). The raw materials utilized in all cream dessert samples formulation were: 3000 g of high-fat cream (dry matter content of 42 g/100 g and fat content of 40 g/100 g; Lacrum Velke Mezirící Ltd., Velké Mezirící, Czech Republic) and 120 g milk protein concentrate (KUK BOHEMIA, Ltd., Prague, Czech Republic). Furthermore, K-carrageenan (CAS Number 11114-20-8, EC Number 234-350-2, MDL number MFCD00151514; SigmaAldrich, Ltd., Prague, Czech Republic) and i-carrageenan (CAS Number 9062-07-1, EC Number 232-949-3, MDL number MFCD00151512; SigmaAldrich, Ltd., Prague, Czech Republic) were added separately at concentrations of 0.025; 0.050; 0.075; 0.100; 0.125 and 0.150 g/100 g.

For the manufacture of the samples, all applied ingredients were added into the Stephan UMC-5 apparatus. Thereafter, the vessel of the equipment was sealed and a vacuum of approx. 0.02 MPa was set. The model samples of cream desserts were manufactured at 3000 rpm with a target temperature of 80 °C and a holding time of 1 min. The total production time was in the range of 5-6 min, regardless of the applied carrageenan type and concentration. Thereupon, the products were poured into cylindrical polypropylene containers (diameter 72 mm; height 35 mm) and sealed with a plastic lid. Packed samples were cooled and stored under refrigeration conditions (6 ± 2 °C) for a period of 28 d until analyses were performed. All analyses were performed on the 1st, 7th, 14th, 21st and 28th d of storage. The model samples with each carrageenan type (n = 2) addition at each concentration (n = 6) were produced three times (n = 3) according to the production protocol presented above. Thus, 36 batches (2 types of carrageenan x 6 concentrations of carrageenan x 3 repetitions; n = 36) of cream desserts were produced in total. During chemical and viscoelastic properties determination, each container was tested in triplicate (9 containers X 3 repetitions = 9 analyses; n = 27).

2.2. Chemical analysis

Dry matter content, fat content and crude protein content (crude protein) were analysed according to ISO 5534:2004 **(ISO, 2004a)**, ISO 1735:2004 **(ISO, 2004b)** and ISO 8968-1:2014 **(ISO, 2014)**. The pH was measured with a pH meter with a glass probe (pH Spear, Eutech Instruments, Oakton, Malaysia) directly in the sample.

2.3. Rheological analysis

Dynamic oscillation rheometry was performed on a RheoStress 1 rheometer (Thermo Haake, Bremen, Germany) equipped with a 35 mm diameter plate-to-plate geometry. The measurement was performed at 20.0 ± 0.1 ° C and a gap of 1 mm was used. The amplitude of shear stress (2.0 Pa) was selected in the linear region of viscoelasticity. The exposed edge of the parallel-plates geometry was covered with a thin layer of silicone oil in order to prevent sample dehydration. During the measurement the storage (G’; Pa) and loss (Gé Pa) moduli were determined as a function of frequency f (0.1-10.0 Hz). The above-mentioned moduli were used for complex modulus of elasticity (G*; Pa) calculation according to equation **(1) (Eq. (1)**):

$$G^* = \sqrt{(G')^2 + (G'')^2} \quad (1)$$

Moreover, the phase shift angle (δ; °) was calculated as the arcus tangent of the G"/G’ ratio. For the evaluation of the samples viscoelastic properties the Winter’ s critical gel theory was implemented.

According to equation **(2) (Eq. (2)**), the complex modulus of elasticity can be expressed as follows (**Winter & Chambon, 1986**):

$$G^*(\omega) = A_F \mathrm{n}\omega^{\frac{1}{z}} \qquad (2)$$

where AF (Pa-$s^{1/z}$) is the gel strength, ro is the frequency (Hz) and z (unitless) corresponds to the interaction factor.

2.4. Sensory analysis

The sensory analysis was performed by a panel of 24 selected assessors (experts) trained according to ISO 8586:2012 **(ISO, 2012)**. The assessors were between 24 and 49 years old (18 women and 6 men). For the evaluation of the organoleptic properties, cream dessert samples were served in cylindrical polypropylene containers (coded with 3-digit numbers). The tested samples were served in randomized order (to avoid positional bias) and at controlled temperature (20 ± 2 °C). The sensory analysis was realized in a laboratory equipped with sensory booths (under normal light condition) in accordance to ISO 8586:2007 (2007). Moreover, in order to avoid carry-over effects water was provided for mouth rinsing between the samples evaluation. A 5 min break was taken after each sample to avoid palate fatigue. The cream dessert samples were evaluated using 7-point scales for the following sensory traits: homogeneity (1—completely homogeneous; 4—moderate homogeneity; 7—completely inhomogeneous), drainage of water (1—no free water; 4—moderate amount of free water; 7—excessive amount of free water), hardness (1 —very soft; 4—moderate hardness; 7—very hard) and off-flavour (1—negligible, 4—moderate, 7—excessive).

2.5. Statistical analysis

The obtained results were analysed by non-parametrical analysis of variance of Kruskall-Wallis and Wilcoxon tests (Unistat® 6.5 software; Unistat, London, UK), where the significance level was 0.05. Correlation analysis was performed using Spearman's correlation coefficient.

3. Results and discussion

3.1. Chemical analysis

Dry matter content, fat content and crude protein content were insignificantly different in all tested batches, regardless of the storage time ($P > 0.05$) and ranged in the intervals of 43.79-44.12 g/100 g, 38.22-38.67 g/100 g and 5.12-5.39 g/100 g, respectively. Similar values of dry matter, fat and protein content for individual samples are important for their comparability and for drawing relevant conclusions about the tested factors **(Lee & Klostermeyer, 2001; Piska & Štětina, 2004; Salek et al., 2020)**. The pH values of cream desserts on the 1st d ranged from 6.56 to 6.61, regardless of the type and concentration of the utilized carrageenan ($P > 0.05$). During the 28-d storage period, a slight and gradual decrease in the pH values was observed (data not shown). Moreover, on each d of analysis (7, 14, 21 and 28) the pH values of the tested samples did not differ significantly from each other ($P > 0.05$). In addition, stable pH values are also important for samples comparability. Thus, the pH could affect the charges on caseins and serum proteins as well as lipoprotein membranes of the fat globules **(Marchessau, Gastaldi, Lagaude &)**.

3.2. Rheological analysis

The results of the rheological analysis of the cream desserts are shown in Tables **1 and 2** and **Figs. 1-4**. In particular, Tables 1 and 2 present the values of complex modulus of elasticity (G*; Pa), the phase shift angle (δ; °), the gel strength (AF; Pa^ $s^{1/z}$) and the interaction factor (z; unitless) expressed for the reference frequency of 1 Hz. The latter reference value was previously used by **Černíková et al. (2008), Piska and Štětina (2004)** and **Salek et al. (2020)**. From the obtained results it could be reported that with the increasing addition of k- and i-carra-geenan, the complex modulus of elasticity (G*) and the strength of the gel (AF) increased, indicating an increase in the firmness of the tested cream dessert samples. On the contrary, the monitored decreasing values of the phase shift angle (δ) could provide information that the increase in the stiffness of the product was accompanied by an increase in the proportion of the elastic component over the viscous. On the same token, the resulting structure of the tested samples came “closer1’ to the ideally elastic behaviour. Furthermore, the latter statement could also be depicted by the course of the frequency dependence of the elastic and loss moduli (**Figs. 1-4**). In addition, the above-mentioned observations could be supported by the interaction factor values increase, indicating a multiple rise in the mutually interacting units (biopolymers—proteins and polysaccharides) in the monitored network structure. Moreover, the applied carrageenans, casein and serum proteins (derived mainly from the utilized milk protein concentrate) as well as components of the lipoprotein membrane, could be “enriched” with bonded casein micelles (or fractions) and serum proteins (**Borreani et al., 2016; Lopez, 2011; Matignon et al., 2014**). In addition, two types of three-dimensional structure formation can occur during the carrageenan-casein micelle interactions (**Arltoft et al., 2007; Langendorff et al., 1999**). Based on the latter statement, a limit concentration of carrageenan for the formation of a certain type of three-dimensional network might exist. In particular, if the applied carrageenan level is considered to be below the limit, then the carrageenan only adsorbs on the surface of the casein micelles forming an “interlayer” (bridges) between individual micelles. On the contrary, if the carrageenan level is considered to be above the limit, in addition to bridges, carrageenan can form a three-dimensional structure from its own chains. In general, the above-mentioned carrageenan limit level is considered to be 0.2 g/100 g.

Table 1 Values of the complex modulus (Ga; Pa), phase shift (δ; °), gel strength (AF; Pa*$s^{1/z}$) and interaction factor (z; dimensionless) of the model cream dessert samples produced with K-carrageenan (concentrations in the range of 0.025-0.150 g/100 g) and stored during a 28 d period (at 6 ± 2 °C). The results are expressed as mean ± standard deviation (n = 27).a.

Concentration	Storage time	G^a	δ	A_F	z
g/100 g)	(days)	(Pa)	(°)	(Pa·$s^{1/z}$)	(–)
0.025	1	14.3 ± 0.7 ^{a}A	45.7 ± 2.6 ^{a}A	12.0 ± 0.7 ^{a}A	1.27 ± 0.06 ^{a}A
	7	62.4 ± 3.6 ^{b}A	33.9 ± 1.5 ^{b}A	64.2 ± 3.2 ^{b}A	2.47 ± 0.13 ^{b}A
	14	109.6 ± 5.1 ^{c}A	28.1 ± 1.6 ^{c}A	112.2 ± 5.5 ^{c}A	3.31 ± 0.15 ^{c}A
	21	127.8 ± 6.3 ^{d}A	27.6 ± 1.1 ^{c}A	131.1 ± 7.1 ^{d}A	3.42 ± 0.19 ^{c}A
	28	737.6 ± 35.2 ^{e}A	18.8 ± 0.9 ^{d}A	736.8 ± 41.9 ^{e}A	4.95 ± 0.23 ^{d}A
0.050	1	213.7 ± 9.8 ^{a}B	23.5 ± 1.1 ^{a}B	216.7 ± 8.9 ^{a}B	5.24 ± 0.28 ^{a}B
	7	465.7 ± 22.2 ^{b}B	17.1 ± 0.8 ^{b}B	466.6 ± 23.6 ^{b}B	6.27 ± 0.29 ^{b}B
	14	501.2 ± 27.4 ^{c}B	16.9 ± 0.8^{b,c}B	503.4 ± 26.6 ^{c}B	6.35 ± 0.34^{b,c}B
	21	617.3 ± 27.3 ^{d}B	16.6 ± 1.1 ^{c}B	615.8 ± 29.2 ^{d}B	6.62 ± 0.31 ^{c}B
	28	1113.9 ± 53.6 ^{e}B	15.8 ± 0.8 ^{d}B	1091.8 ± 62.1 ^{e}B	7.09 ± 0.41 ^{d}B
0.075	1	381.4 ± 22.2 ^{a}C	17.7 ± 0.8 ^{a}C	384.3 ± 17.3 ^{a}C	6.69 ± 0.31 ^{a}C
	7	1140.8 ± 61.7 ^{b}C	14.6 ± 0.8 ^{b}C	1142.2 ± 59.6 ^{b}C	7.46 ± 0.38 ^{b}C
	14	1306.1 ± 59.1 ^{c}C	14.1 ± 0.6^{b,c}C	1300.5 ± 65.1 ^{c}C	7.63 ± 0.42^{b,c}C
	21	1397.4 ± 74.8 ^{c}C	13.9 ± 0.7^{c,d}C	1388.7 ± 70.4 ^{c}C	7.70 ± 0.38^{c,d}C
	28	2583.9 ± 104.5 ^{d}C	13.6 ± 0.6 ^{d}C	2537.3 ± 123.9 ^{d}C	7.93 ± 0.32 ^{d}C
0.100	1	755.6 ± 45.2 ^{a}D	14.5 ± 0.9 ^{a}D	756.9 ± 41.7 ^{a}D	7.84 ± 0.42 ^{a}D
	7	1354.3 ± 72.9 ^{b}D	13.6 ± 0.7 ^{b}D	1352.2 ± 58.0 ^{b}D	8.18 ± 0.43 ^{a}D
	14	1417.9 ± 79.6 ^{b}D	13.6 ± 0.5 ^{b}D	1411.5 ± 70.2 ^{b}D	8.67 ± 0.46 ^{b}D
	21	1902.5 ± 86.9 ^{c}D	13.6 ± 0.6 ^{b}C,D	1893.5 ± 72.3 ^{c}D	8.85 ± 0.37^{b,c}D
	28	4747.2 ± 234.2 ^{d}D	12.7 ± 0.7 ^{c}D	4664.3 ± 256.4 ^{d}D	9.04 ± 0.39 ^{c}D
0.125	1	1243.6 ± 63.1 ^{a}E	14.5 ± 0.6 ^{a}D	1215.9 ± 51.3 ^{a}E	8.35 ± 0.38 ^{a}E
	7	2088.7 ± 96.5 ^{b}E	13.4 ± 0.7 ^{b}D	2095.8 ± 109.5 ^{b}E	9.02 ± 0.48 ^{b}E
	14	2458.5 ± 124.4 ^{c}E	13.1 ± 0.5^{b,c}D	2457.7 ± 106.5 ^{c}E	9.11 ± 0.45^{b,c}E
	21	2529.7 ± 144.6 ^{c}E	13.0 ± 0.6 ^{c}E	2510.5 ± 109.8 ^{c}E	9.36 ± 0.48 ^{c}E
	28	5401.0 ± 234.7 ^{d}E	12.4 ± 0.6 ^{d}D	5265.8 ± 252.4 ^{d}E	9.80 ± 0.48 ^{d}E
0.150	1	1696.6 ± 72.4 ^{a}F	12.8 ± 0.7 ^{a}E	1688.8 ± 75.2 ^{a}F	8.60 ± 0.43 ^{a}E
	7	3388.8 ± 151.4 ^{b}F	12.3 ± 0.5 ^{b}E	3368.5 ± 150.1 ^{b}F	9.62 ± 0.49 ^{b}F
	14	4202.3 ± 218.7 ^{c}F	12.2 ± 0.5^{b,c}E	4173.9 ± 210.9 ^{c}F	9.68 ± 0.46 ^{b}F
	21	6471.1 ± 319.7 ^{d}F	11.9 ± 0.6^{c,d}F	6410.7 ± 293.2 ^{d}F	10.29 ± 0.48 ^{c}F
	28	7805.2 ± 466.3 ^{e}F	11.4 ± 0.6 ^{d}E	7683.1 ± 389.1 ^{e}F	10.62 ± 0.49 ^{d}F

[a]The means within a column (the difference between the storage time) followed by different superscript letters differ ($P < 0.05$); the samples manufactured using a different K-carrageenan concentrations were evaluated independently. The means within a column (the difference between the concentration of K-carrageenan used) followed by different capital letters differ ($P < 0.05$); the samples stored in different times were evaluated independently.

Table 2 Values of the complex modulus (Ga; Pa), phase shift (5; °), gel strength (AF; Pa^s$^{1/z}$) and interaction factor (z; dimensionless) of the model cream dessert samples produced with i-carrageenan (concentrations in the range of 0.025-0.150 g/100 g) and stored during a 28 d period (at 6 ± 2 °C). The results are expressed as mean ± standard deviation (n = 27).a.

Concentration (g/100 g)	Storage time (days)	G^{a} (Pa)	δ (°)	A_F ($Pa \cdot s^{1/z}$)	z (–)
0.025	1	2.4 ± 0.1 ^{a}A	62.7 ± 3.4 ^{a}A	3.5 ± 0.2 ^{a}A	1.23 ± 0.06 ^{a}A
	7	3.7 ± 0.2 ^{b}A	60.8 ± 2.7^{a,b}A	3.8 ± 0.2 ^{a}A	1.33 ± 0.07 ^{a}A
	14	4.1 ± 0.2 ^{c}A	58.9 ± 3.1 ^{b}A	4.8 ± 0.2 ^{b}A	1.47 ± 0.07 ^{b}A
	21	12.2 ± 0.7 ^{d}A	53.4 ± 3.1 ^{c}A	13.8 ± 0.7 ^{c}A	2.34 ± 0.12 ^{c}A
	28	27.9 ± 1.4 ^{e}A	40.3 ± 1.5 ^{d}A	25.2 ± 1.2 ^{d}A	2.69 ± 0.16 ^{d}A
0.050	1	111.2 ± 5.6 ^{a}B	21.4 ± 1.1 ^{a}B	113.7 ± 5.9 ^{a}B	4.28 ± 0.24 ^{a}B
	7	359.9 ± 15.8 ^{b}B	16.9 ± 1.0 ^{b}B	364.7 ± 16.5 ^{b}B	5.42 ± 0.28^{a,b}B
	14	390.1 ± 22.1 ^{c}B	16.1 ± 0.8^{b,c}B	395.8 ± 22.9 ^{c}B	5.71 ± 0.28 ^{b}B
	21	1049.4 ± 41.6 ^{d}B	15.8 ± 0.8 ^{c}B	1052.3 ± 48.2 ^{d}B	6.19 ± 0.27 ^{c}B
	28	1597.7 ± 86.8 ^{e}B	14.5 ± 0.7 ^{d}B	1612.8 ± 81.7 ^{e}B	6.81 ± 0.36 ^{d}B
0.075	1	684.5 ± 35.1 ^{a}C	14.1 ± 0.7 ^{a}C	694.4 ± 34.3 ^{a}C	6.40 ± 0.27 ^{a}C
	7	1043.4 ± 57.5 ^{b}C	12.9 ± 0.7 ^{b}C	1063.1 ± 55.3 ^{b}C	7.01 ± 0.36 ^{b}C
	14	1396.3 ± 70.8 ^{c}C	13.0 ± 0.7 ^{b}C	1403.9 ± 57.1 ^{c}C	7.26 ± 0.36^{b,c}C
	21	1963.1 ± 112.1 ^{d}C	12.7 ± 0.7^{b,c}C	1970.1 ± 92.1 ^{d}C	7.42 ± 0.35^{c,d}C
	28	1987.9 ± 104.3 ^{d}C	12.5 ± 0.6 ^{c}C	1990.1 ± 101.8 ^{d}C	7.69 ± 0.39 ^{d}C
0.100	1	1205.9 ± 49.2 ^{a}D	12.2 ± 0.6 ^{a}D	1226.1 ± 64.4 ^{a}D	7.56 ± 0.39 ^{a}D
	7	1712.1 ± 84.6 ^{b}D	11.5 ± 0.4 ^{b}D	1732.6 ± 81.3 ^{b}D	7.92 ± 0.41^{a,b}D
	14	2232.7 ± 97.5 ^{c}D	11.4 ± 0.6 ^{b}D	2254.9 ± 106.9 ^{c}D	8.22 ± 0.34^{b,c}D
	21	2771.2 ± 136.3 ^{d}D	11.2 ± 0.5^{b,c}D	2781.2 ± 167.4 ^{d}D	8.61 ± 0.44^{c,d}D
	28	2985.7 ± 118.4 ^{e}D	11.1 ± 0.6 ^{c}D	2982.4 ± 139.9 ^{e}D	8.98 ± 0.54 ^{d}D
0.125	1	2184.5 ± 93.1 ^{a}E	11.9 ± 0.6 ^{a}D,E	2201.8 ± 105.2 ^{a}E	7.78 ± 0.37 ^{a}D,E
	7	3812.5 ± 206.4 ^{b}E	11.2 ± 0.6 ^{b}D	3834.4 ± 175.9 ^{b}E	8.56 ± 0.39 ^{b}E
	14	4027.9 ± 212.3 ^{b}E	10.9 ± 0.6 ^{c}D,E	4045.9 ± 238.5 ^{c}E	8.83 ± 0.48^{b,c}E
	21	4617.4 ± 245.7 ^{c}E	10.5 ± 0.4^{c,d}E	4646.5 ± 229.2 ^{d}E	9.21 ± 0.49^{c,d}E
	28	4857.6 ± 208.9 ^{c}E	10.4 ± 0.5 ^{d}E	4839.1 ± 248.4 ^{d}E	9.43 ± 0.47 ^{d}E
0.150	1	3138.7 ± 151.9 ^{a}F	11.5 ± 0.5 ^{a}E	3091.1 ± 160.3 ^{a}F	7.99 ± 0.34 ^{a}E
	7	4378.1 ± 192.7 ^{b}F	10.7 ± 0.5 ^{b}E	4393.5 ± 223.2 ^{b}F	8.81 ± 0.39 ^{b}E
	14	4506.2 ± 213.5 ^{b}F	10.6 ± 0.6 ^{b}E	4501.5 ± 234.3 ^{b}F	9.28 ± 0.51^{b,c}E
	21	4955.9 ± 240.2 ^{c}F	10.4 ± 0.5^{b,c}E	4982.2 ± 197.9 ^{c}F	9.46 ± 0.51^{c,d}E
	28	5409.6 ± 274.6 ^{d}F	10.1 ± 0.5 ^{c}E	5420.1 ± 255.1 ^{d}F	9.96 ± 0.52 ^{d}E

[a] The means within a column (the difference between the storage time) followed by different superscript letters differ ($P < 0.05$); the samples manufactured using a different i-carrageenan concentrations were evaluated independently. The means within a column (the difference between the concentration of i-carrageenan used) followed by different capital letters differ ($P < 0.05$); the samples stored in different times were evaluated independently.

Moreover, according to **Bourriot et al. (1999)** there is also a minimum concentration of carrageenan in order to achieve the formation of a stable dairy gel. In particular, the above-mentioned minimum concentration was 0.018 g/100 g. Additionally, the existence of a minimum effective carrageenan concentration in order to increase product firmness was presented by **Černíková et al. (2008)** and **Gustaw and Mleko (2007)**. In general, it could be assumed that in cream desserts, carrageenans are probably absorbed on the surface of milk proteins, or on the surface of the fat droplets, resulting in the development of an "interlayer" between the above-mentioned particles with significantly less intense to form a three-dimensional structure deriving from the polysaccharide chains **(Arltoft et al., 2007; Langendorff et al., 1999, 2000)**.

Moreover, the applied concentration of 0.025 g/100 g of k- and i-carrageenan led to the formation of a very weakly interconnected structure of cream dessert (**Tables 1 and 2; Figs. 1 and 3** - parts A). Hence, by utilizing the latter concentration, it is possible to obtain a homogeneous product, presenting a viscous-like behaviour (based on the values of the phase shift angle; $\delta > 45°$). , this statement could also be supported by the low values of the interaction factor z, indicating a small number of interacting units (biopolymers) within the examined matrix. In particular, this phenomenon was observed for samples with K-carrageenan addition on the 1st d of storage and for samples with i-carrageenan addition up to the 21st d of storage. According to **Bourriot et al. (1999)** and **Černíková et al. (2008)** the limiting effective concentration of carrageenans for the formation of dairy gels was reported to be lower than 0.018 g/100 g and 0.050 g/100 g, respectively. Nevertheless, with respect to the obtained results it could be reported that the actual effective limiting concentration of k- and i-carrageenan depends on the properties of the tested dairy matrix (applied ingredients and processing parameters).

In general, a significant increase in the firmness of the cream desserts was observed over the 28-d storage period, based on an increase in the values of complex modulus of elasticity (G*) and gel strength (AF) (P < 0.05; **Figs. 1-4; Tables 1 and 2**), regardless of the carrageenan type and concentration. Furthermore, the character of the gel also changed during storage. In particular, with the progress of the storage time the proportion of the elastic modulus over the loss modulus increased and a significant decrease in the values of the phase shift angle (δ) was also observed (P < 0.05). In addition, a possible explanation of the latter phenomenon could be found in the increase in the intensity of network interconnection, which can be depicted by the significant increase in the values of the interaction factor z during storage (P < 0.05). Additionally, a change in the milk fat polymorphism and thus, in the ratios between a-, β'- and β-crystalline form may also have contributed to the increasing values of firmness of the cream desserts during the 28 d of storage. Furthermore, at temperatures below 10 ° Č, milk fat can crystallise and with prolonged storage time, the proportion of p-form might increase, leading to an increase in the stiffness of the matrix **(Bylund, 1995; Sato & Ueno, 2011)**.

From the obtained results (**Tables 1 and 2**), it could be reported that higher values of the complex modulus (G*) and gel strength (AF) were recorded for cream desserts with K-carrageenan addition compared to products in which i-carrageenan was utilized (P < 0.05). Moreover, the values of the phase shift angle (5) indicate a more intense predominance of the elastic modulus over the loss modulus for samples with K-carra-geenan addition compared to those in which i-carrageenan was applied (P < 0.05). Generally, the phenomena mentioned above were identified for all applied hydrocolloids concentrations during the storage period. However, there is no available scientific literal source providing direct information about the effect of k- and i-carrageenan addition in cream desserts and/or dairy products with a similar composition and pH values.

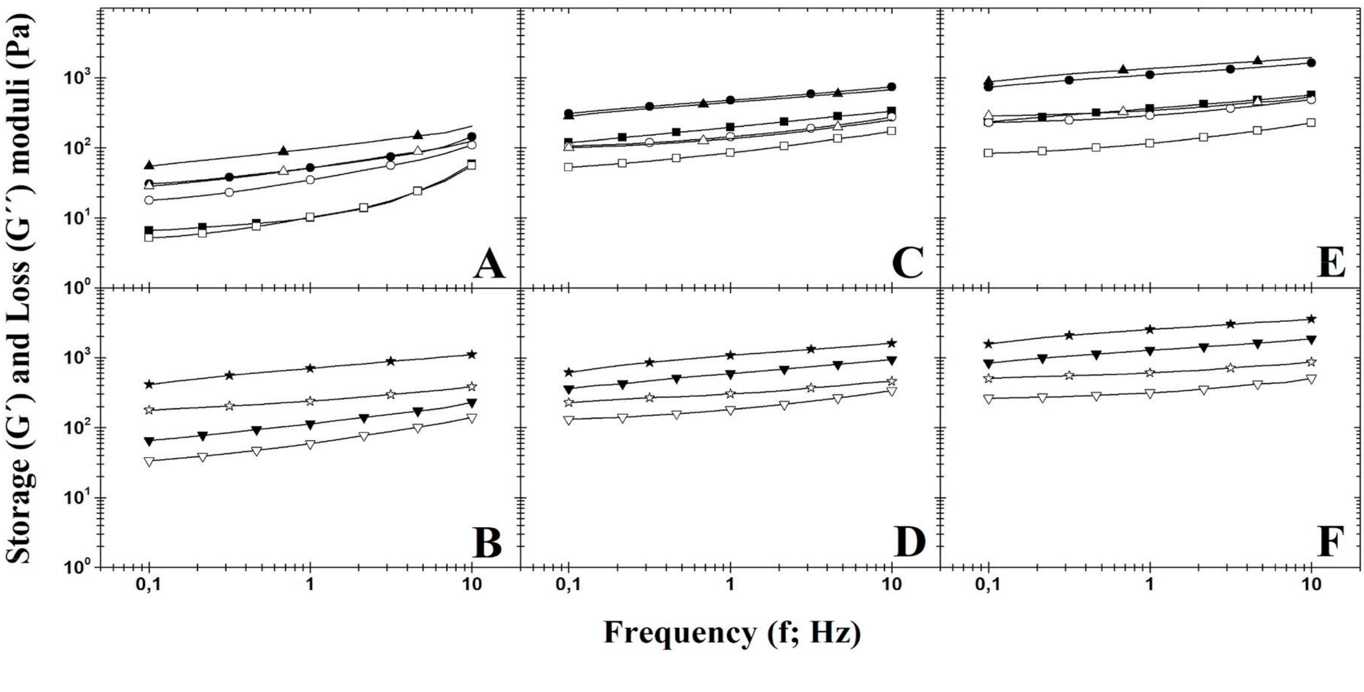

Fig. 1. Dependence of the elastic (G'; full symbols; Pa) and the loss (G"; open symbols; Pa) moduli of the cream dessert samples manufactured with k -carrageenan in the concentrations of 0.025 (parts A and B), 0.050 (parts C and D) and 0.075 g/100 g (parts E, F) on the frequency (f; in the range of 0.1-10.0 Hz) during 28 d of storage (at 6 ± 2 °C); d 1 (parts A, C and E; ■□), d 7 (parts A, C and E; •x), d 14 (parts A, C and E; ±A), d 21 (parts B, D and F; ▼▽) and d 28 (parts B, D and F; ^^) (n = 27).

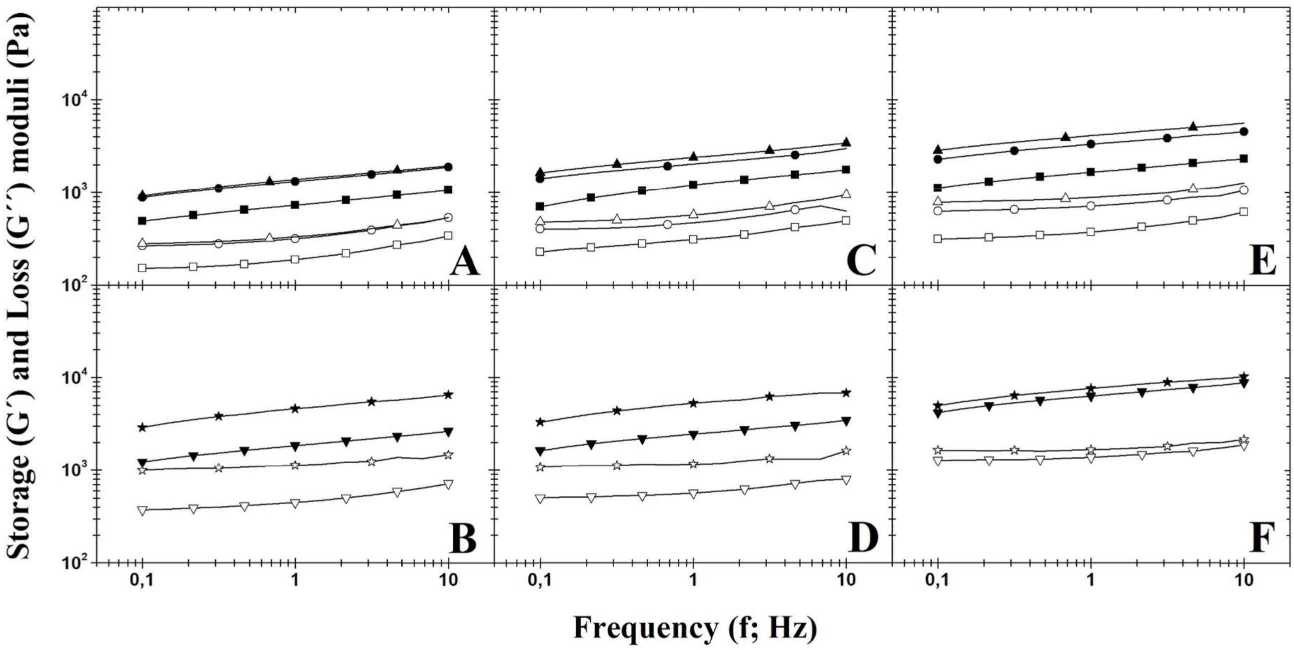

Fig. 2. Dependence of the elastic (G'; full symbols; Pa) and the loss (G"; open symbols; Pa) moduli of the cream dessert samples manufactured with k -carrageenan in the concentrations of 0.100 (parts A and B), 0.125 (parts C and D) and 0.150 g/100 g (parts E, F) on the frequency (f; in the range of 0.1-10.0 Hz) during 28 d of storage (at 6 ± 2 °C); d 1 (parts A, C and E; ■□), d 7 (parts A, C and E; •x), d 14 (parts A, C and E; ±A), d 21 (parts B, D and F; ▼▽) and d 28 (parts B, D and F; ^^) (n = 27).

The results of this study could be compared with those previously reported by **Černíková et al. (2008)**. However, the latter authors examined processed cheese and reported an opposite effect. Hence, it could be hypothesised that a possible explanation might lie in differences in the representation of ions in both tested dairy matrices. In addition, the gel-strength ability of both carrageenan strongly depends on the presence of cations neutralising the negatively charged sulphate groups. In particular, K-carrageenan is influenced by the presence of potassium ions, whereas i-carrageenan is affected by the presence of calcium ions **(Nickerson et al., 2004; Ribeiro et al., 2004; Vega et al., 2005)**. With regard to the applied raw materials for the production of cream desserts herein and processed cheeses (according to Černíková et al., 2008) and taking into consideration the content of potassium and calcium ions in these raw materials, it could be assumed that the ratio of potassium and calcium ions might be approx. 1: 0.8-1.2 for cream desserts and 1: 6-8 for processed cheeses (in the presence of sodium phosphate-based emulsifying salts), respectively **(Lucan et al., 2020; Reykdal et al., 2011)**. Therefore, it could be suggested that i-carrageenan is a more effective thickening agent in processed cheese, due to the higher concentration of calcium ions. On the other hand, K-carrageenan may be a more effective thickening agent in cream desserts, in which the relative amount of potassium ions is comparable to calcium ions.

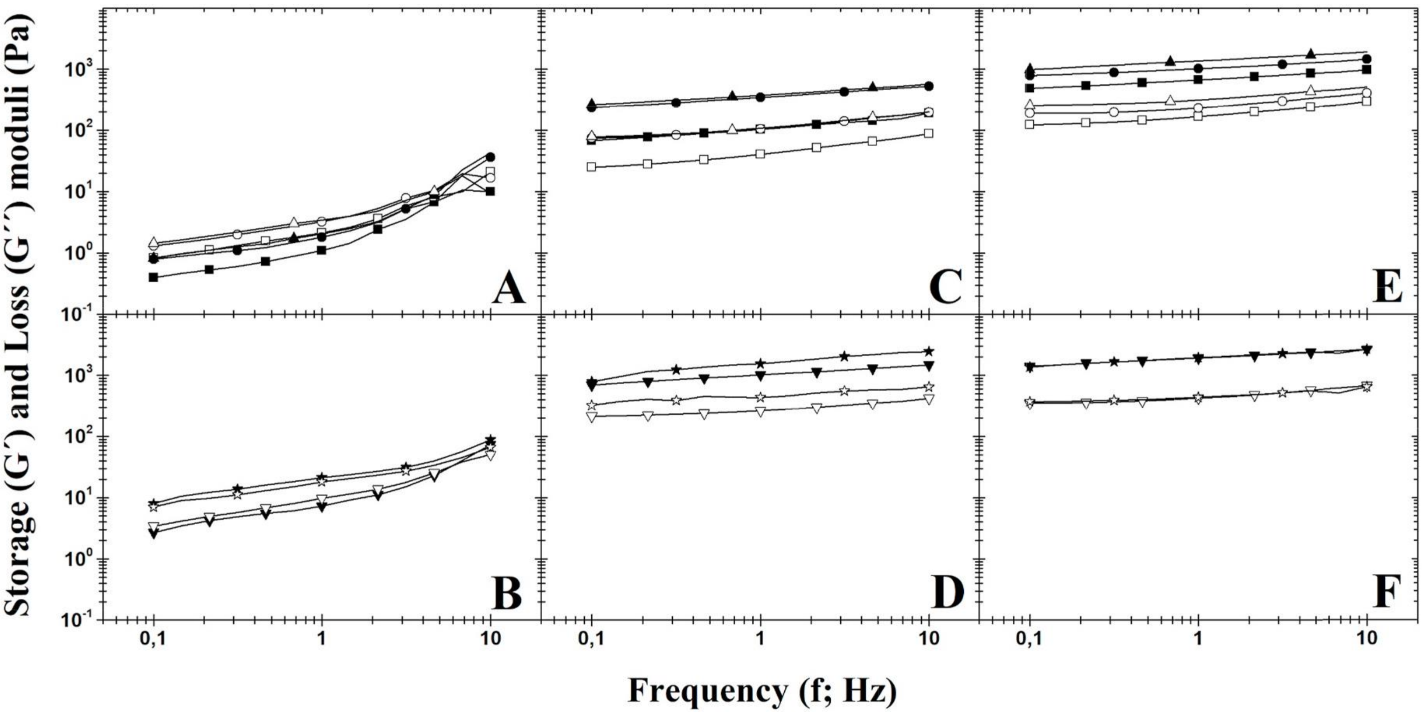

Fig. 3. Dependence of the elastic (G'; full symbols; Pa) and the loss (G"; open symbols; Pa) moduli of the cream dessert samples manufactured with i-carrageenan in the concentrations of 0.025 (parts A and B), 0.050 (parts C and D) and 0.075 g/100 g (parts E, F) on the frequency (f; in the range of 0.1-10.0 Hz) during 28 d of storage at (6 ± 2 °C); d 1 (parts A, C and E; ■□), d 7 (parts A, C and E; •x), d 14 (parts A, C and E; ±A), d 21 (parts B, D and F; ▼▽) and d 28 (parts B, D and F; ^^) (n = 27).

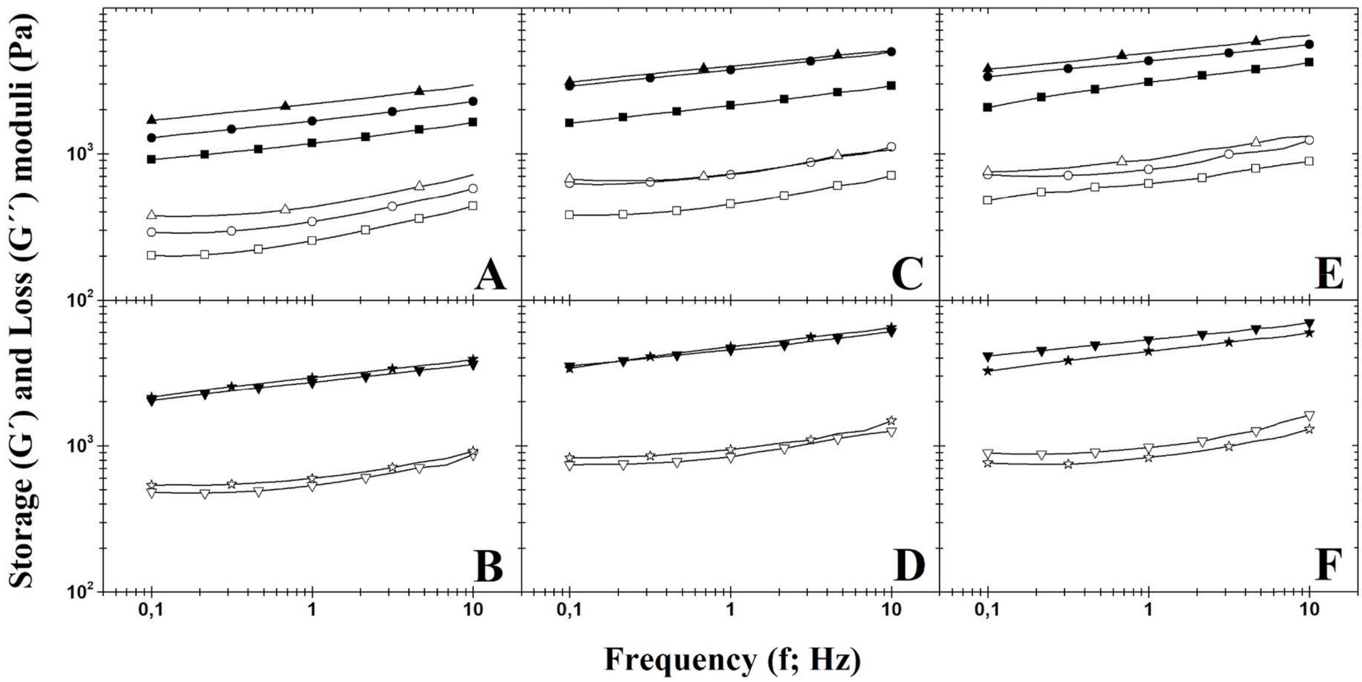

Fig. 4. Dependence of the elastic (G'; full symbols; Pa) and the loss (G"; open symbols; Pa) moduli of the cream dessert samples manufactured with i-carrageenan in the concentrations of 0.100 (parts A and B), 0.125 (parts C and D) and 0.150 g/100 g (parts E, F) on the frequency (f; in the range of 0.1-10.0 Hz) during 28 d of storage at (6 ± 2 °C); d 1 (parts A, C and E; ■□), d 7 (parts A, C and E; •x), d 14 (parts A, C and E; ±A), d 21 (parts B, D and F; ▼▽) and d 28 (parts B, D and F; ^^) (n = 27).

Furthermore, the current hypothesis could be supported by the significantly greater value of the interaction factor reported for cream desserts with K-carrageenan addition compared to samples in which i-carra-geenan was used (P < 0.05; **Tables 1 and 2**).

Finally, with respect to the obtained results it could be stated that the type of carrageenan utilized would depend on desired final cream dessert consistency. Particularly, in cream desserts with a creamy and smooth consistency, heavy body, short texture, presenting a more viscous behaviour, i-carrageenan is recommended. On the other hand, in cream desserts with increased firmness and homogeneous consistency, presenting a more elastic character, K-carrageenan should be the best choice (**Saunders, 2011**).

3.3. Sensory analysis

The tested cream desserts were also evaluated by sensory analysis. In particular, all tested samples were characterized as homogeneous during storage (score 1; P > 0.05), no water release was detected (score 1; P > 0.05), and no off-flavours ware reported either (score 1; P > 0.05). From the comparison of hardness (**Table 3**) it was found that with the increasing concentration of both applied carrageenan types and with the prolonging of the storage time, the firmness of cream desserts increased significantly (P < 0.05).

Table 3 Sensory evaluation results of hardness of the model cream dessert samples produced with k- and i-carrageenan (concentrations in the range of 0.025-0.150 g/100 g) and stored during a 28 d period (at 6 ± 2 °C) evaluated by an expert panel (n = 24). The values were expressed as median[a].

Concentration (g/100 g)[b]	Storage time (days)	κ-carrageenan	ι-carrageenan
0.025	1	1 ^{a}A	1 ^{a}A
	7	2 ^{b}A	1 ^{a}A
	14	2 ^{b}A	1 ^{a}A
	21	3 ^{c}A	1 ^{a}A
	28	3 ^{c}A	2 ^{b}A
0.050	1	3 ^{a}B	3 ^{a}B
	7	3 ^{a}B	3 ^{a}B
	14	3 ^{a}A	3 ^{a}B
	21	4 ^{b}B	4 ^{b}B
	28	4 ^{b}A	4 ^{b}B
0.075	1	3 ^{a}B	3 ^{a}B
	7	4 ^{b}C	4 ^{b}C
	14	4 ^{b}B	4 ^{b}C
	21	5 ^{c}C	5 ^{c}C
	28	5 ^{c}B	5 ^{c}C
0.100	1	4 ^{a}C	4 ^{a}C
	7	4 ^{a}C	4 ^{a}C
	14	5 ^{b}C	5 ^{b}D
	21	5 ^{b}C	5 ^{b}C
	28	5 ^{c}B	5 ^{b}C
0.125	1	5 ^{a}D	5 ^{a}D
	7	6 ^{b}D	6 ^{b}D
	14	6 ^{b}D	6 ^{b}E
	21	7 ^{c}D	6 ^{b}D
	28	7 ^{c}C	6 ^{b}D
0.150	1	5 ^{a}E	5 ^{a}D
	7	6 ^{b}D	6 ^{b}D
	14	6 ^{b}E	6 ^{b}E
	21	7 ^{c}D	6 ^{b}D
	28	7 ^{c}C	6 ^{b}D

[a]The products were evaluated using the following criteria: hardness (using 7-point scale: 1—very soft; 4—moderate hardness; 7—very hard). [b]The values within a column (the difference between the storage time) followed by different superscript letters differ (P < 0.05); the samples manufactured using a different carrageenan concentrations were evaluated independently. The values within a column (the difference between the concentration of carrageenan used) followed by different capital letters differ (P < 0.05); the samples stored in different times were evaluated independently.

Furthermore, the results of hardness determination positively correlate ($P < 0.05$) with the development of the values of the complex modulus (G*), gel strength (AF), interaction factor (z), whereas negatively correlate ($P < 0.05$) with the values of the phase shift angle (δ). Additionally, the samples with K-carrageenan addition were perceived by the sensory assessors as stiffer compared to those in which i-carrageenan was applied. The latter phenomenon was observed in samples in which K-carrageenan was utilized at the highest concentrations (0.125 and 0.150 g/100 g) and were evaluated at the second half of e storage period ($P < 0.05$). Moreover, over the whole storage time the samples with a 0.025 g/100 g concentration of K-carrageenan were characterized as stiffer in comparison to that in which i-carrageenan was added. In general, i-carrageenan cream desserts were by nature more viscous rather than intensely bonded elastic gels. The results obtained by sensory analysis were analogous to those from rheological analysis.

4. Conclusion

The effect of k- and i-carrageenan (in the range of 0.025-0.150 g/ 100 g) addition on cream dessert samples viscoelastic properties and sensory quality during a 28-d storage period (at 6 ± 2 °C) was evaluated. Increasing concentrations of k- and i-carrageenan and increasing storage time, led to an increase in the firmness of the cream desserts. In general, K-carrageenan was evaluated to be a more effective thickening agent than i-carrageenan. From the obtained results, it could be concluded that the suggested concentration of both tested hydrocolloids lies in the range of 0.050-0.125 g/100 g, in order to produce cream desserts with desired rheological and sensory properties. Moreover, a practical benefit of this study, could be considered that for regions where cream desserts with softer consistency are desired, a concentration of k- and i-carrageenan < 0.050 g/100 g could be recommended. On the contrary, for regions where a firmer product is required, it is possible to apply K-carrageenan in concentrations >0.100 g/100 and i-carrageenan in concentrations >0.125 g/100.

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