Structure and functional performance of gigartinacean kappa–iota hybrid carrageenan and solieriacean kappa–iota carrageenan blends

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Abstract

Hybrids of kappa and iota carrageenans, known as kappa-2 carrageenan, of contrasting phycological origin and type of hybridization were compared chemically and functionally. Nuclear magnetic resonance spectrometry showed gigartinacean kappa-2 (hybridization was known to be a co-occurrence of kappa and iota structures in a chain) to contain 45\% iota and 55\% kappa, very similar to a 3:3 kappa:iota hand-made blend of solieriacean origin (hybridization was that kappa and iota occurring as separate chains). Gel permeation chromatographic data, however, demonstrated the gigartinacean extract to possess lower molecular weight compared to the solieriacean extracts, a hint to the variability in the origin of the two hybrid carrageenans. As texturing agents in water and milk systems, gigartinacean kappa-2 was found to produce inferior gels compared to its hand-made counterpart. However, both hybrids were found to exhibit similar functional performance as viscosity-enhancing/stabilizing agent in hot-processed chocolate milk preparations, and analogous utility as viscosity build-up agent in cold-processed chocolate milk. A hand-made solieriacean kappa–iota blend can have the same properties as a gigartinacean kappa-2, but it depends on the actual application which blend performs comparable to kappa-2.

Keywords: Algal polysaccharide; Carrageenan; Gigartinaceae; Kappa-2 carrageenan; Solieriaceae

1. Introduction

Carrageenans are hydrocolloids of phycological origin and are built on a disaccharide backbone of alternating 3-linked \(\beta\)-D-galactopyranose (G) and 4-linked \(\alpha\)-D-galactopyranose (D). Several types of carrageenans were recognized in accordance to the position of sulfation (S) and the cyclization of the D units to form an anhydro ring (A). Carrageenan nomenclature traditionally employs the Greek alphabet to designate the idealized disaccharide backbone, however a more versatile binomial version incorporating the substitution pattern of each galactosyl residue was established recently (Knutsen, Myśliwiec, Larsen, \& User, 1994). Industrially important representatives include the gelling kappa (G4S-DA) and iota (G4S-DA2S), as well as the non-gelling lambda (G2S-D2S6S) (Fig. 1). The major sources of kappa and iota carrageenans are the solieriacean genera Kappaphycus and Eucheuma, whereas lambda carrageenan is commercially extracted mainly from sporophytes of various seaweeds belonging to the family Gigartinaceae. The hydrocolloid extract from Kappaphycus is almost pure kappa carrageenan with minimal amounts of iota, while Eucheuma extract is pure iota carrageenan (Villanueva \& Montaño, 2003). These two gelling extracts differ in the textural properties of their hydrogel, i.e. kappa gel is relatively brittle and hard while the iota gel is flexible and soft. Their textural behavior, however, could be tamed by the polysacharide concentration in gel preparation, fortification with counterions (alkali metal ions, of varying concentrations) and by blending carrageenan types, as well as with other polysaccharides like galactomannans, in various proportions.

An innovation in carrageenan food applications is the advent of 'kappa-2' carrageenan (synonyms: weak kappa, weak gelling kappa, kappa/iota hybrid; sensu Bixler, 1996; Bixler, Jander, \& Falschau, 2001). Kappa-2 carrageenan was recently introduced commercially by Shemberg Corporation (Cebu, Philippines) and was especially developed for use as a gelling and binding agent in various
dairy applications (as stated in Shemberg product description 2000-014GP for Benlacta CKL-91R). Chemically, kappa-2 differs from kappa by being hybridized with iota, with an arbitrary criterion ranging from 20 to 45–50% sulfation at C(O)2 of the 4-linked anhydrogalactose residues (Bixler, 1996; Bixler et al., 2001), tantamount to the iota molar concentration (equivalent to 77:23 to 50:50–45:55 kappa:iota weight proportion). Sources of this hybrid carrageenan are primarily the temperate gigartinacean gametophytes (see ‘Stancioff Diagram’ in Bixler (1996) and Bixler et al. (2001) for a listing). Since gigartinacean seaweeds biosynthesize different carrageenan types in their two alternating life stages (but see Estevéz, Ciancia, & Cerezo, 2002), additional procedure is employed in the extraction of kappa-2 from a raw material bulk of a mixture of gametophytes and tetrasporophytes, where phase segregation is a laborious and not totally efficient step prior to extraction for carrageenan type distinction in an industrial scale. A suitable process for the fractionation of the gelling kappa–iota hybrid and the non-gelling lambda is detailed in Falshaw, Bixler, and Johndro (2001).

A major issue on kappa-2 is the nature of kappa/iota hybridization, as a number of schemes are possible. Hybridization can either be in the form of a hybrid chain or copolymer (i.e. both kappa and iota structures occurring on the same chain with both structures either distributed singly or in short blocks in a random fashion or as long sequence in a preponderantly kappa chain) or as a mixture of kappa and iota chains (Rocha et al., 1989). Due to the difficulty in sequence elucidation of a hybrid chain or a copolymer and the fact that this type of hybrid can only be synthesized in vivo, account on the physical behavior of its aqueous solutions and hydrogels can be hinged on the deviation from the behavior of a physical mixture of kappa and iota of identical analytical chemical results as the copolymer, that is realized only if the two hybrid types do exhibit different gel properties. As an example, the gel properties in milk or in water of Gigartina stellata extract will be quite different from an analytically equal mixture of Eucheuma denticulatum (formerly known as Eucheuma spinosum) iota carrageenan and Kappaphycus alvarezi (formerly known as Eucheuma cottonii) kappa carrageenan (Stancioff, 1981). In a recent investigation of the performance of gigartinacean kappa-2, assumed to be a copolymer, in quality control tests and in simulated dairy applications, it was found out that it has distinct properties from the other hydrocolloidal fractions derived from the same seaweed source (Bixler et al., 2001; Falshaw, Bixler, & Johndro, 2003). A new evidence based on coil-to-helix and temperature dependence of viscosity measurements revealed that gigartinacean kappa-2 carrageenans are indeed copolymers or hybrid chains containing both kappa and iota structures (van de Velde, Peppelman, Rollema, & Tromp, 2001). Despite the discovery, the other side of the coin, i.e. kappa-2 being a physical mixture of kappa and iota, is still of interest especially on a functional or application perspective, due to the ease of extraction of solieriacean kappa and iota carrageenans compared to that of a gigartinacean kappa–iota hybrid carrageenan. Also, new textural features may be offered by such hybridization, hence expanding the application spectrum of these phycocolloids. The natural occurrence of mixture-of-chains type of hybridization was found in K. alvarezi carrageenan, though with very low iota levels, as elucidated through enzymatic degradation and potassium chloride fractionation experiments (Rocha et al., 1989).

In this work, the case of kappa-2 carrageenan being simply a blend of kappa and iota carrageenans is being investigated. First, the analytical distinction of gigartinacean kappa-2 from a solieriacean kappa–iota physical mixture is featured. Then the performance of the hybrid carrageenans as gelling agent in aqueous, in the presence of different counterions, and milk systems and as viscosity-enhancing/stabilizing agent in simulated dairy formulations is compared. Of particular interest is to know whether simply hand mixing or blending ‘pure’ kappa and iota carrageenans of solieriacean origin, i.e. in appropriate proportion, can produce a carrageenan formula whose functions in food systems approximate that of the kappa-2 carrageenan of gigartinacean origin. In most of the discussions, we are bound to the expectation that gigartinacean kappa-2, being a hybrid of kappa and iota carrageenans, exhibits gel and solution characteristics intermediate to that of pure kappa and pure iota.

2. Materials and methods

2.1. Materials

Carrageenans used are commercial products of Shemberg Corporation (Cebu, Philippines). Kappa
NaNO₃, 0.45 μm-filtered) was eluted with 0.1 M NaNO₃ at (26–28 °C). Carrageenan solution (0.1%, w/v in 0.1 M NaNO₃) was filtered through gel permeation chromatography (GPC) in an Ultrahydrogel™ Linear (7.8 × 300 mm²) column (Waters Associates Inc., Milford, MA). The effluent was monitored by a Shimadzu RID-10A refractometer (Shimadzu Corporation, Kyoto, Japan). Poly(ethylene oxide) standards (Polymer Standards Service GmbH, Mainz, Germany) were used for calibration. Number and weight average molecular weights were calculated using the formula presented in Cooper (1989).

2.3. Textural studies

Water gels were prepared by first dispersing carrageenan powder (1.5%, w/w) with, or without, salt (0.5%, w/w) in water. Dissolution was done by boiling the dispersion in a microwave oven. Water lost through evaporation was then replenished. The hot solution (35 g) was poured in 50 ml beaker, covered with aluminum foil and the gel was allowed to set at room temperature (ca. 28 °C) for 20 h.

Milk gels were prepared by subjecting in a water bath (80 °C) a dispersion of carrageenan powder (0.25%, w/v) in cold milk. The dispersion was then swirled gently every 5 min for a period of 30 min. The solution was cooled down to 60 °C; poured into 50 ml beaker and covered with aluminum foil. The gel was allowed to set in a refrigerator (4 °C) for 20 h.

Textural measurements were conducted using a texture analyser (model TA-XT2i, Stable Micro Systems, Surrey, UK). The plunger has a crosshead diameter of 1.27 cm and a descent rate of 0.5 cm s⁻¹. Gel strength (g cm⁻²) was obtained by dividing the force (g) at gel rupture by the crosshead area of the plunger (1.27 cm²). Other textural parameters were obtained as described in Whyte, Englar, and Hosford (1981): deformation (mm), the total distance penetrated by the probe into the gel prior to rupture; cohesiveness (g), the force required to deform the gel matrix a distance of 2 mm; and flexibility (mm g⁻¹), the distance traveled per unit load by the surface of the gel prior to rupture.

2.4. Dairy product simulation tests

The following milk formulation tests were patterned after Bixler et al. (2001) with minor modifications.

2.4.1. Cold processed milk viscosity build-up

Cocoa powder (7%, w/v) and carrageenan powder (0.1%, w/v) were dispersed in cold milk and stirred using a magnetic stirrer (model Cimarec 2, Barnstead/Thermolyne, Dubuque, IA), which was set at speed 5. Stirring was maintained in a water bath (10 °C) and the viscosity was measured at 4, 8, 15, and 30 min intervals using a viscometer (model 98936, Cole Parmer, Vernon Hills, IL).

2.4.2. Hot processed chocolate milk viscosity

Chocolate milk slurry was prepared mixing cocoa (3%, w/v), sugar (6%, w/v), carrageenan powder (0.03%, w/v), and milk (57%, w/v) with or without salt (0.5%, w/w) and dispersed in a water bath (80 °C) for 20 h. The dispersion was then swirled gently every 5 min for a period of 30 min. The solution was cooled down to 60 °C, poured into 50 ml beaker and covered with aluminum foil. The gel was allowed to set in a refrigerator (4 °C) for 20 h.
and cold milk. The slurry was heated to 80 °C in a water bath for 30 min with periodic swirling. The hot chocolate milk was homogenized in a blender (model 8890-48F, Sunbeam-Oster, Bay Springs, MS) for 1 min, cooled in an ice bath, and then refrigerated (4 °C) for 20 h. The viscosity of the chocolate milk preparation was determined immediately after retrieval from the refrigerator using the Cole Parmer viscometer.

Control formulations, in which no carrageenan was incorporated, were also run for comparison.

3. Results and discussion

3.1. Structural analysis

Iota carrageenan differs from kappa carrageenan by the presence of sulfate hemiesters at C(0)2 of its DA units, hence contains higher sulfate content. Sulfate analysis revealed GK-2 to contain sulfate almost similar to those of iota carrageenan (0:6) and the blends high with iota proportion (1:5 and 2:4) with levels between 25 and 27%. Monosulfated kappa carrageenan (6:0) contained 19% sulfate. On the other hand, lambda carrageenan had higher sulfate level (329%) than its gelling counterparts, disclosing its tri-sulfated disaccharide repeating structure.

FT-IR spectral analysis results (Fig. 2) showed GK-2 to possess sulfate ester at C(0)2 of the DA units. The quantity of which is comparable to those of the 3:3 and 2:4 blends, as determined from the apparent intensity of the signal at 805 cm⁻¹, being attributable to such sulfation (Anderson et al., 1968). It was noteworthy that pure kappa (6:0) possessed a detectable level of 2-sulfation, which is suggestive of a minor hybridization with iota carrageenan. This was also observed in previous reports on Kappaphycus carrageenan as elucidated using various spectroscopic techniques (Aguilan et al., 2003; Bellion, Brigand, Prume, Welti, & Bociek, 1983; Mendoza, Montaño, Gonzon-Fortes, & Villanueva, 2002; Rochas et al., 1989; Santos, 1989; van de Velde et al., 2001; Villanueva & Montaño, 2003). Other carrageenan structural functionalities that were elucidated in the FT-IR spectra include sulfate ester at C(0)4 of the G units (850 cm⁻¹), 3,6-anhydrogalactose (930 cm⁻¹) and total sulfate (1250 cm⁻¹) (marked signals in Fig. 2). It was also notable that signals at 830 and 820 cm⁻¹ are absent in the GK-2 FT-IR spectrum, indicating the lack of the diagnostic lambda carrageenan sulfations at C(0)2 of G and D units and at C(0)6 of D units. This observation demonstrates the efficiency of the fractionation procedure during processing, i.e. in separating lambda from the kappa/iota (GK-2) fraction. Furthermore, no signal at 820 cm⁻¹ was detected in all the gelling carrageenan samples analyzed, showing that no precursor units (mu and nu carrageenans), bearing labile sulfate ester at C(0)6 of D units, are present and signifies the effective alkali-modification procedure (conversion of precursor units to 3,6-anhydrogalactose) during processing. The high levels of sodium, potassium or calcium in these samples, as detected from atomic absorbance spectroscopy (Section 2.1), evidenced the strong alkali treatment.

Carbon and proton NMR spectra of the different carrageenans (Figs. 3 and 4, respectively) consistently showed GK-2 to be composed of around 45% iota and 55% kappa (on the weight basis), and is almost equivalent to the solieriaceous 3:3 kappa/iota blend. This GK-2 composition was calculated from the relative carbon peak heights and from the integrated area under the carbon peaks (data not shown) of α-anomeric signals in the presence/absence of adjacent C(0)2 sulfate substitution (marked resonances in Figs. 3 and 4). The observed resonances in all spectra were confirmatory of kappa and iota carrageenan structures, i.e. in reference to chemical shifts reported by Usov and Shashkov (1985). As found out in the FT-IR analysis, no biological precursors were detected in the NMR analysis.

It was evident that a hand-made mixture of kappa and iota carrageenans can mimic GK-2 carrageenan analytically. However, there is slight ambiguity in its exact composition using different techniques employed as

![FT-IR spectra of solieriacean kappa/iota blends and gigartinacean kappa-2 carrageenan (GK-2). See text for signal attributions.](image-url)
shown above. It is believed that NMR spectroscopy, being the most powerful technique for red algal polysaccharide analysis (Usov, 1984; Usov, Yarotsky, & Shkadov, 1980; van de Velde, Knutsen, Usov, Rellena, & Cerozo, 2002), is the most reliable of these analytical techniques, hence disclosing a GK-2 kappa:iota composition almost similar to a 3:3 kappa:iota blend. Such composition is within the specification set for kappa-2 carrageenan (Section 1).

One important aspect of the structure of the polymers under study that was not reflected in the above chemical analysis is the degree of polymerization or the molecular weight. GPC revealed variable molecular weights of the solieriaceous and the gigartinaaceous carrageenans samples (Fig. 5). $M_n$ and $M_w$ values of 517 and 1742 kDa, respectively, were obtained for solieriaceous kappa carrageenan.
carrageenan; 674 and 3123 kDa for iota carrageenan; and 237 and 1132 kDa for GK-2. These results clearly detect the variability in the source of the carrageenans, but do not implicate a generality in the source-carrageenan molecular weight relationship due to limited samples investigated. Despite the low molecular weight of GK-2, it is beyond the critical value of 180 kDa in which below this value, the elastic modulus is said to be dependent to the molecular weight, i.e. for kappa carrageenan (Rochas, Rinaudo, & Landry, 1990). Furthermore, a minimum molecular weight of 40 kDa was predicted to obtain a "macroscopic" gel at 1% kappa carrageenan concentration in 0.1 M KCl (Rochas et al., 1990). These accounts would eliminate the possibility of molecular weight confounding the effect of hybridization to the rheology and functional performance of the carrageenans being compared.

3.2. Textural profile of water and milk carrageenan gels

Textural attributes of water gels of the carrageenans, with and without counterion fortification, are shown in Fig. 6. Gel strength and cohesiveness of the GK-2 fell within the values demonstrated by the solierian kappa-iota blends that are quite close to the iota end-member. These observations were not expected in consideration of the results from the compositional analysis of GK-2 (i.e. equal to or slightly less than 50% iota concentration) if a physical-mixture type of hybridization is sought after. Furthermore, GK-2 consistently exhibited low gel deformation values in the different counterionic environments compared to the hand-made blends of kappa and iota. These gel deformation results showed the inconsistent feature of GK-2 with respect to those of the carrageenan blends of solierian origin. On the contrary, flexibility of GK-2 gel was similar to those of blends close to the kappa end-member including the blend possessing the same analytical composition (i.e. the 3:3 kappa:iota blend). The unsalted gels, however, showed an extreme behavior with flexibility being remarkably enhanced by iota carrageenan, i.e. in separate chains, and letting GK-2 gel to approximate the rigidity of pure kappa.

The milk reactivity of different hand-made blends of kappa and iota carrageenan and GK-2 was demonstrated by the formation of gels despite the employment of carrageenan concentrations (i.e. 0.25%) that do not produce gels on mere aqueous system. This unique property of gelling carrageenans was particularly attributed to the electrostatic interaction of the carrageenans with kappa casein in milk (Snoeren, Payens, Jeunink, & Both, 1975). However, the role of calcium ions in milk (Xu, Stanley, Goff, Davidson, & Le Magnier, 1992), carrageenan-carrageenan interactions (Drohan, Tziboula, McNulty, & Horne, 1997; Langendorff, Cucuier, Michon, Launay, Parker, & de Kruif, 2000) and phase separation (Bourriot, Garnier, & Dublier, 1999; Langendorff, Cucuier, Launay, & Parker, 1997) were recognized recently. The textural profiles of the milk gels are shown in Fig. 7. The trend in milk gel strength of the kappa-iota physical mixtures is comparable to the results of Puvanenthiran, Goddard, and Augustin (2000). GK-2 was not in agreement with the kappa:iota physical mixture of the same analytical results (3:3) in terms of milk gel strength and deformation, but to some extent in terms of cohesiveness and flexibility. The more interesting of these results is the unusually low milk gel strength obtained for GK-2, even lower than pure iota. This result is consistent though with the water gels, despite the contribution of other mechanisms, aside from carrageenan-carrageenan interaction as in water gelation, governing milk gelation. This is in contrary to what had

![Fig. 6. Textural profile of water gels of solierian kappa:iota blends and gigartinian kappa-2 carrageenan (GK-2) in different counterions (C: 0.5% KCl; Δ: 0.5% CaCl2; ⊙: 0.25% KCl + 0.25% CaCl2; ◆: no salt added). Bars indicate standard error, n = 3.](image-url)
been said on this unique hybrid that it retained high milk reactivity despite a weaker gel compared to kappa (Bixler et al., 2001). The low GK-2 milk gel strength would give an insight on how incorporation of iota in a predominantly kappa chain (i.e., a copolymer as mentioned above) would affect milk gel formation. Since carrageenan–carrageenan interaction has been implicated to participate in the overall milk gel formation (Drohan et al., 1997; Langendorff et al., 2000), this low milk gel strength can be associated to its likewise low water gel strength. In other words, these observations can be attributable to the ‘impaired’ carrageenan–carrageenan interaction as clearly shown in the water gel character, probably caused by the irregularity of sulfation pattern in the hybrid chain of GK-2.

In general, GK-2 did not produce a gel whose suite of textural behaviors could be exactly comparable to that of a solieriacean kappa–iota blend with similar, or nearly similar, analytical results. The disparity in the type of hybridization shown to have profound influences to the gelling behavior of the carrageenan both in aqueous and milk systems.

To assess if the GK-2 sample studied here is not atypical kappa-2 carrageenan of gigartinacean origin, its milk gel strength value will be compared from those of various gigartinacean extracts as reported by Bixler et al. (2001). The milk gel strength of 0.5% GK-2 was found to be 35 g cm⁻² (Villanueva, Mendoza, Rodriguez, Romero, & Montaño, unpublished data), comparable to those of alkali-modified (HMR processed) whole extracts from gametophytic Gigartina skottsbergii (30 g cm⁻²) and Sarcothalia crispata (43 g cm⁻²). Hence, GK-2 is adjudged to be typical kappa-2 carrageenan. The above values were all within the desired milk gel break force (20–65 g cm⁻²) for hot processed dairy applications (Bixler et al., 2001).

3.3. Dairy product simulations

Using viscosity enhancement to demonstrate the interaction of the different carrageenan blends with milk, dairy product simulations were performed. In the cold-processed chocolate milk formulation, it is apparent that carrageenan systems involving kappa, iota, their hand-made blends, and GK-2 were not successful in promoting thickness of the dairy product. Their products registered viscosities of 6–9 cPs during the whole stirring period of 4–30 min, and are comparable with the control. The lambda-carrageenan-formulated drink exhibited prompt and high viscosity (greater than 200 cPs in the whole stirring period) and generated the desired drink quality. Lambda carrageenan is hence appropriate for such application, and this significant property can be attributed to its quick, full solubility in cold aqueous medium (Glicksman, 1983; Molnar, 1977; Stanley, 1990; Therkelsen, 1993), in contrary to the higher temperatures.
required for dissolution of its gelling counterparts. Alongside to this, the lambda used herein was determined to exhibit high viscosity (293 cP) in aqueous solution at 75 °C (Villanueva, Mendoza, Rodriguez, Romero, & Montaño, unpublished data), thereby the enhanced drink viscosity. Probably, it is noteworthy that the sodium salt of both kappa and iota carrageenans was also reported to exhibit solubility in cold water (Glicksman, 1983; Moirano, 1977; Stanley, 1990; Therkelsen, 1993). However, due to the high concentration of other counterions in milk, especially potassium and calcium (Bixler et al., 2001; Langendorff et al., 1997) and the relatively higher potassium ion concentration in both carrageenan powders (Section 2.1), this character was not elaborated in kappa/iota systems as demonstrated in the results.

The above resemblance of GK-2 to the hand-made kappa–iota mixture, of similar analytical results, was also illustrated in the hot-processed chocolate milk formulation test. The viscosity of the drink formulated with GK-2 was comparable to those formulated with the 4:2, 5:1 and 6:0 kappa:iota blends (Fig. 8) or essentially those with high kappa proportions. It almost resembled the blend of similar analytical results (3:3) but of slightly lower viscosity. On the other hand, those blends with high iota contents produced high viscosity drinks, whereas the lambda carrageenan produced a fluid chocolate drink in which observable settling of cocoa powder occurred. The stability of chocolate milk has been attributed to the formation of network structure formed by the interaction of milk protein and protein-covered cocoa particles with a suitable stabilizer, e.g. kappa carrageenan (van den Boomgaard, van Vliet, & van Hooydonk, 1987). Comparable to the various kappa–iota blends, GK-2 produced a stable drink, in which no cocoa settling occurred. Iota carrageenan has been regarded to be functional in this particular application (Moirano, 1977), producing a high viscosity and stable product.

The major finding of the dairy product simulation tests is the comparability of GK-2 to the kappa–iota blends. It was apparent that GK-2 offers no oddness in performance, in reference to the hand-made solieriacean kappa–iota blends, in the dairy applications investigated herein, unlike what had been revealed in the gel tests.

4. Conclusions

Gigartinacean kappa-2 is a special type of carrageenan, which was commercially launched to be of general use for dairy applications. It was particularly acclaimed to exhibit a remarkable reactivity with milk despite its weaker gel compared to kappa (Bixler et al., 2001).

Chemical and spectroscopic analysis demonstrated GK-2 to exhibit identical analytical results as a solieriacean kappa–iota blend, particularly with a 3:3 proportion. It was, however, unraveled from GPC measurements that GK-2 is a different material from a hand-made kappa–iota blend, as it possesses lower molecular weight. This difference could be drawn from the phycological origin of these polysaccharides. It is notable that the recognition of the type of hybrid structures cannot be realized by using chemical and spectroscopic analysis, unless enzymatic degradation and KCl or hydroalcoholic fractionation were performed prior to spectroscopic investigations as had been done in Bellion et al. (1983) and Rochas et al. (1989).

The water and milk gel textural attributes of the GK-2 were observed to vary with that of hand-made kappa–iota hybrid, implying an unusual gelling character. In line with this variability, the type of hybridization in GK-2 is ascertained to be different to that of a mixture of separate kappa and iota chains, therefore GK-2 occurs as a copolymer wherein both kappa and iota structures exist in a chain. This is consistent with what has been previously elucidated (van de Velde et al., 2001). Furthermore, GK-2 was interestingly determined to produce water and milk gels with inferior gel strength compared to a hand-made kappa–iota blend of similar analytical results. This result deviates from the earlier belief that kappa-2 carrageenans retain high milk reactivity despite the weak water gel offered by the hybridization (Bixler et al., 2001).

Dairy product simulation tests showed invariability of GK-2 with the hand-made carrageenan hybrids. Application-wise, the results of this investigation contest the novelty of GK-2 with consideration of its utility as viscosity enhancing or stabilizing agent in hot-processed milk chocolate drinks, as well as its inutility as prompt viscosity builder in cold-processed chocolate milk. But, some other dairy applications should be evaluated.

Finally, the question ‘Can a kappa–iota hybrid of gigartinacean origin be substituted commercially by a hand-made kappa–iota hybrid of solieriacean origin?’
should be answered. We would rather put the reply in terms of the application, if a gelling agent is desired, based on the results, a hand-made hybrid can replace kappa-2 of gigartinaeacean origin, since the latter produces an inferior gel. In the replacement, however, a lowering of the hydrocolloid concentration is necessary to acquire the desired gel texture, particularly strength. But, lowering gum solids concentration could yield an inferior product (Bixler et al., 2001), probably in terms of other attributes, and the product developer should be cautioned accordingly. Whereas, in dairy applications where viscosity enhancement is desired, especially for hot-processed chocolate drink, a hand-made hybrid can substitute a gigartinaeacean kappa-2 since they exhibit quite similar functional performance.

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