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Axial Compression Properties of Calcium Caseinate Gels[1]

ABSTRACT

The wide range of physicochemical and functional properties of caseins and caseinates, as well as their bland flavor, make them an excellent protein source for the creation of formulated foods, either as novel or imitative products. The gelation properties of these highly nutritive proteins were investigated to determine their potential for the creation or imitation of high value products such as kamaboko, a surimi product. Instrumental texture profile analyses and stress-strain relationships were evaluated to determine the textural responses of caseinate gels with various additives. The addition of sodium hexametaphosphate (.5%, wt/wt) was effective in creating firm, elastic gels that more closely resembled many of the textural properties of kamaboko. The addition of κ-carrageenan with the phosphate markedly improved gel cohesiveness, springiness, water holding, and foldability. The elasticity and recoverable energy of these gels were also improved, but these gels were not as elastic as kamaboko.

(**Key words**: texture, kamaboko, surimi, gels, rheology)

Abbreviation key: **CaCNT** = calcium caseinate, **ITPA** = instrumental texture profile analyses.

INTRODUCTION

The emphasis on the production of fabricated foods has increased the demand for highly purified food-grade proteins, commonly referred to as functional proteins (3). Proteins from various sources have been evaluated for their functionality, but milk and soy proteins are by far the most important sources (1).

Casein, the major protein component of cow's milk, and its caseinate derivatives have physicochemical and nutritive properties that make them a useful protein source in a variety of formulated foods (17). Functionally, the effect of the addition of casein on the food system is the enhancement of texture, body, fat emulsification, and water-holding. Their utility is further enhanced by the bland nature of their products. High concentrations of caseins have exceptional water-holding capacity and are viscous and soluble in neutral or alkaline conditions (6). These functional properties have given rise to a number of applications for caseins in foods that include coffee creamers, confectionery, extruded snacks, cheese analogs, and meat products (18).

Milk proteins gel when they are subjected to specific treatment, such as acid treatment (12), heat treatment (13), aging (10), and rennet treatment (2). Casein is the component involved in each of these gels. The most prominent example, the rennet-induced gels, is the basis of the manufacture of most cheese varieties. Hayes et al. (5) report on the creation of gels from calcium caseinate (CaCNT) dispersions at concentrations >15% when heated to 50 to 60°C. However, these gels are reversible and liquify slowly on cooling. Sodium caseinate forms a gel when it is treated with rennet (25). For the most part, the studies of the utilization of gelation and other functional properties of caseins and caseinates have been limited to their use as additives to some other food component as a binding, thickening, or emulsifying agent. Except for use in cheese and yogurt (depending on the definition of a gel), few uses are identified for casein as a solid, viscoelastic gel. The acceptance of such a gel depends largely on the value of the final product for which the gels are used. High value products, such as candied fruit slices and seafood analogs among others, offer an outlet for the utilization of the gelation capability of this protein while providing nutritional enhancement.

Burgess and Coton (1) reported the creation of gels from skim milk curd by the addition of $CaCl_2$ and autoclaving. The resultant gels contained 30 to 40% solids of which the major portion was protein. The meatlike chunks were considered to have a structure too close and homogeneous to simulate the structure of meat.

The structure of caseinate gels can be altered significantly by the use of polysaccharide additives. Polysaccharides are often used as additives to food systems to enhance structure by thickening and stabilization. Potato starch, because of its high water sorption characteristics, is an effective additive for increasing the rigidity of surimi gels (9).

Carrageenans have been used extensively in a wide range of thickener, suspension, and gelation applications to food systems (19). Carrageenans are frequently added to dairy products, such as ice cream, custards, or chocolate milk to improve viscosity. Moderately high concentrations of κ-carrageenan cause casein to gel (4).

In this study, we have established a method for creating firm, irreversible gels from CaCNT. These gels, created using a high shear dispersion technique, followed by heating to 90°C and then cooling, showed a wide variety of rheological attributes, depending on additives used. These rheological parameters indicate the potential for using casein formulations as a gel food. The creation of a formulated food to emulate a target product requires exhaustive evaluation and comparison. This study does not include this all-inclusive evaluation. The objective of this paper is to evaluate the potential of CaCNT formulations to create gels that rheologically resemble kamaboko.

MATERIALS AND METHODS

Ingredients

Commercial CaCNT (Alanate® 310; New Zealand Milk Products, Inc., Petaluma, CA, 89.8% protein, 4.1% ash, 4.5% water, 1.1% fat, and .1% lactose) was used to prepare all gels. The carrageenans, Gelcarin® FF489E κ-carrageenan A (formulation includes potassium carbonate, sodium carbonate, and calcium sulfate), Gelcarin® 911 κ-carrageenan B (formulation includes dextrin), and Gelcarin® GP359 ι-carrageenan, were obtained from FMC (Philadelphia, PA). Unmodified, food-grade potato and wheat starches were obtained from AVEBE America Inc. (Princeton, NJ) and Manildra Milling Corp. (Shawnee Mission, KS), respectively. Phosphate was added to all noncontrol samples at .5% (wt/wt) using FMC Glass H sodium hexametaphosphate. Kamaboko loaves (Hana Brand, Rhee Bros., Inc., Columbia, MD) used for our studies were the Itatsuki variety from Alaska Pollock and purchased locally.

Gel Preparation

Specific solids contents (25, 35, and 45%) were used for all formulations. Carrageenans were added at 1, 2, 3, and 4% (wt/wt). The ratios for the κ-carrageenan B and ι-carrageenan mixture were 1:1, 3:1, 5:1, and 7:1. The KCl was added at a 5% (wt/wt) level. The use of various additives was compensated by reduced CaCNT in the formulation. Dispersions of CaCNT were prepared by mixing the protein powder and the various additives with crushed ice. The mixing method used is described by Strange and Konstance (20) and provides for rapid and uniform dispersion, utilizing a Cuisinart (Stamford, CT) food processor (750-ml bowl capacity) equipped with a stainless steel blade rotating at 1790 rpm. All samples were mixed for 10 min. Samples were removed from the food processor and spooned into twirl bags. The CaCNT mixtures were compacted into the bags before sealing and placing in a 90°C water bath. Samples were heated for 1 h, creating a uniformly viscous sol, removed from the bath, and allowed to gel under refrigerated conditions. Samples were stored in the refrigerator for 12 to 48 h before rheological analysis.

Sample Preparation

Sample gels, in loaf form, were removed from the bags and sliced to the desired height (15 mm) using a parallel wire slicer. Cylindrical samples were extracted from the slices using a 15-mm number 11 cork borer. To minimize deformation during slicing and extraction, all sampling was at 4°C. Four samples were extracted from each gel. Length to diameter ratios >.95 were used for all analyses. Samples were rejected when major flaws were detected (air pockets on surface) or when deviation from upright cylinder geometry occurred.

Rheological Analysis

Instrumental texture profile analyses (ITPA), double compression, were used to determine rheological responses, using an Instron Universal Testing Machine (model 4201; Canton, MA) with 5.6-cm lucite plates. Each formulation was sampled in quadruplicate and statistically evaluated. Coefficients of variation for all replicate runs were established. The mean coefficient of variation for replicates for all parameters evaluated was 5.39%; chewiness exhibited the highest coefficient of variation at 9.23%. Instron control was maintained using Series XII Cyclic Test application program. A 500-N load cell was used for all analyses, and samples were compressed to 50% of their original height at a constant rate of 50 mm/min. All samples were tested at 25°C. Stress-strain data was derived from the force deformation data (Instron output) using the following equations:

$$\text{Hencky strain} = \ln [h_o/(h_o - \Delta h)] \quad [1]$$

and

$$\text{True stress } (\text{Pa} \times 10^{-3}) = F_t/A_o \times [(h_o - \Delta h)/h_o] \quad [2]$$

where h_o = original height of sample in millimeters, Δh = change in height in millimeters, F_t = compressive force in Newtons at time t, and A_o = original cross-sectional area in square millimeters (16).

The use of Hencky strain for large deformations is appropriate for most food applications (15); true stress represents an adjustment of engineering stress (F_t/A_o) to account for cross-sectional area expansion of the deformed specimen (16).

ITPA Parameters

The ITPA parameters, determined from the force-deformation curve shown in Figure 1, were hardness (the force, in Newtons, necessary to achieve a 50% compression, F_{max}); cohesiveness (A_3/A_1, where A_3 is the area under the force-deformation curve for the compression cycle of the second bite and A_1 is the corresponding area for the first bite); gumminess (product of hardness and cohesiveness, in Newtons); springiness (DD_2 the height, in millimeters, of the sample recovery during the time that elapsed between the end of the first bite and the start of the second bite); chewiness (the product of gumminess and springiness, in Newton-millimeters); degree of elasticity (DU_1/DD_1), the ratio of the time (or trace distance) for which the force in the sample recovering from deformation is recorded during unloading, to that to which the sample is subjected during deformation (first bite); recoverable energy (A_2/A_1), the ratio of the energy recovered during the first bite decompression cycle to that applied during the first bite compression cycle); and adhesive force (F_{adh}), the negative force, in Newtons, resulting from product adhesion to the Instron plate, bite 1.

Other Measurements

Water-holding capacity (or syneresis) was determined by subjecting a 5-mm slice of the gel to a 500-g static force for approximately 30 min. Syneresis is presented as the ratio of the

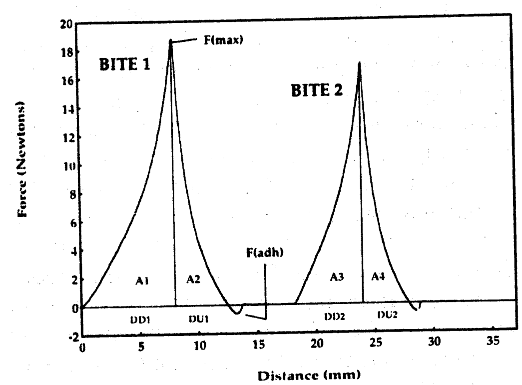

Figure 1. Force deformation curve for caseinate gels. Description of texture profile parameters: F_{max} = hardness, A_n = area under curve, DU_1/DD_1 = degree of elasticity, DD_2 = springiness, A_3/A_1 = cohesiveness, A_2/A_1 = recoverable energy, F_{adh} = adhesive force.

amount of water expressed to the total weight of the sample. The fold test, used in evaluating surimi products (21), evaluates the resilience of the gel by observing the tendency for cracking of gel slices (50 mm long by 5 mm thick), folded twice. Scoring is as follows: AA, double fold, no crack; A, single fold, no crack; B, single fold, partial crack; C, single fold, total crack; and D, single fold, total break.

Data were subjected to ANOVA. Differences were considered to be significant at $P < .05$.

RESULTS

CaCNT Gels with Phosphate

Konstance and Strange (8) observed a significant increase in the viscosity of CaCNT solutions when phosphate was added. Phosphate binds Ca and creates linkages that improve the gel matrix. Parker and Dalgleish (11) indicated that the binding of Ca^{2+} to residues in a phosphate cluster could be strongly dependent on the extent of prior binding of Ca^{2+} in the region of that molecule. The use of the Glass H hexametaphosphate increases the available phosphate residues and improves this binding.

The CaCNT gels, with .5% (wt/wt) added phosphate and without added phosphate, were analyzed as control samples at solids contents of 25, 35, and 45%. Table 1 shows the results of the rheological analyses and other parameters of these samples and of the target material, kamaboko (7). Both hardness and degree of elasticity of the CaCNT gels increased with increased solids content and the addition of phosphate, but cohesiveness appeared to be dependent only on the added phosphate. Syneresis improved significantly at caseinate concentrations >25%. Comparison with the kamaboko target material showed that hardness, cohesiveness, and water-holding could be duplicated with the CaCNT gel with added phosphate at 35 and 45% solids. The degree of elasticity of the gels with added phosphate and at solids content >25% significantly increased ($P < .05$), but these gels were not as elastic as the kamaboko gels. All subsequent evaluations with the polysaccharide additives used a 35% solids concentration with .5% added phosphate. Adjustments were made to the CaCNT content of the gels to allow this concentration of solids to be maintained.

Starches

The gelatinization properties of starches are well known. Starches should increase gel strength and elasticity through a composite reinforcing effect and water-binding. Starch granule size is thought to be important to the textural effect produced in a protein gel (23). As the starch granules imbibe water, they swell and fill interstitial spaces of the gel network, thus adding to the rigidity. Because modified starches have better granule structure, they were used in the CaCNT formulations. The greater the water-holding capacity and viscosity of the starch, the greater is its gel strengthening effect. Both potato and wheat starch are considered to be advantageous in creating strong and elastic gels and were added at 2.5 and 5%.

The evaluation of the textural parameters of CaCNT gels made with added starch is shown in Table 2. The gels were compared with both kamaboko and control samples. Sample hardness, gumminess, springiness, and degree of elasticity were effectively unaltered by the addition of starch; however, the cohesiveness, chewiness, and recoverable energy of the starch and CaCNT gels were significantly reduced. In every aspect of the texture profile analysis, starch was ineffective in providing textural modifications that emulated the target material.

The stress-strain curves for the CaCNT gels and the CaCNT-starch mixtures are shown in Figure 2. The sigmoid shape of each curve is indicative of a gel that is predominantly yielding (concave downward portion) in the Hencky strain range of .1 to .4 and a predominantly compressible material (concave upward portion) with Hencky strain range of .4 to .7). The addition of 2.5% (wt/wt) potato and wheat starch, 5% (wt/wt) potato starch, and phosphate resulted in an increase in the Apparent Young's Modulus (the slope of the initial linear portion of the stress-strain relationship) compared with that of the control sample. The elastic limits of these gels (the point at which deviation from initial linearity occurs) was increased by a factor of 2 to 2.5. The gels made with 5% (wt/wt) wheat starch were less firm

TABLE 1. Texture parameters of calcium caseinate gels, with and without phosphate, at various solids concentrations.

Solid	Without phosphate				With phosphate			
	Hardness	Elasticity	Cohesiveness	Syneresis	Hardness	Elasticity	Cohesiveness	Syneresis
(%)	(N)			(g/g)	(N)			(g/g)
25	7.67[c]	.413[c]	.655[b]	7.70[a]	13.24[c]	.456[c]	.680[b]	6.80[a]
35	10.18[b]	.42[c]	.661[b]	1.01[c]	17.10[b]	.574[b]	.732[a]	1.01[c]
45	20.34[a]	.472[b]	.659[b]	.91[c]	29.13[a]	.576[b]	.699[b]	1.19[c]
Kamaboko	18.53[a]	.795[a]	.752[a]	1.99[b]	18.53[b]	.759[a]	.752[a]	1.99[b]

[a,b,c]Superscripts that are the same within a parameter category indicate no significant difference as determined by ANOVA ($P > .05$).

TABLE 2. Effect of starches on texture parameters of calcium caseinate gels with phosphate.

	Hardness	Cohesiveness	Gumminess	Elasticity	Springiness	Chewiness	Adhesion	Recoverable energy
	(N)		(N)		(mm)	(N-mm)	(N)	
Control[1]	17.10[a]	.73[a]	12.53[a]	.57[b]	5.97[b]	74.41[a]	.18[c]	.48[c]
2.5% Starch								
Potato	12.49[a]	.68[b]	8.47[b]	.52[b]	5.51[b]	46.45[b]	.25[b]	.38[d]
Wheat	17.70[a]	.72[ab]	12.72[a]	.59[b]	5.62[b]	55.01[b]	.29[b]	.54[b]
5% Starch								
Potato	15.91[a]	.65[b]	10.28[ab]	.50[c]	4.82[c]	49.41[b]	.34[b]	.37[d]
Wheat	15.59[a]	.70[b]	10.85[ab]	.54[b]	5.55[b]	59.39[b]	.39[a]	.38[d]
Kamaboko	18.53[a]	.75[a]	11.05[a]	.80[a]	6.77[a]	74.80[a]	.10[d]	.66[a]

[a,b,c,d]Superscripts that are the same within a parameter category indicate no significant difference ($P > .05$).

[1]Control sample is gel from calcium caseinate with phosphate added.

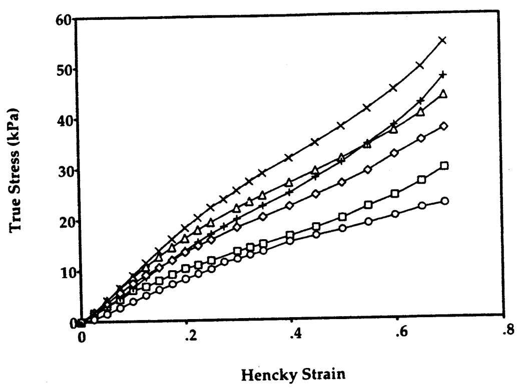

Figure 2. Stress-strain relationship for calcium caseinate (CaCNT) gels with starch added. Control (□), CaCNT with .5% phosphate (+), potato starch at –2.5% (◊) or 5% (△), or wheat starch at 2.5% (×) or 5% (○).

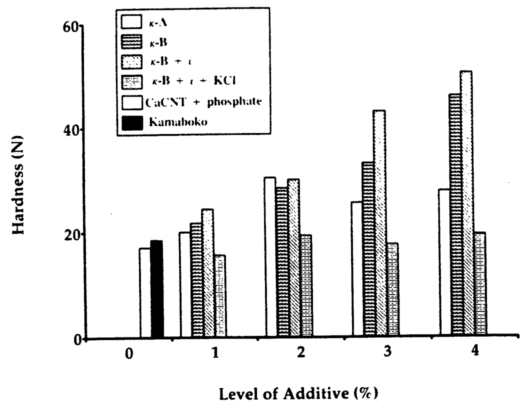

Figure 3. Hardness of calcium caseinate (CaCNT) gels with added phosphate and carrageenan. κ-A = Gelcarin® FF489E κ-carrageenan A; κ-B = Gelcarin® 911 κ-carrageenan B; and ι = Gelcarin® GP359 ι-carrageenan.

and less elastic, possibly indicating an extensive swelling of the starch granules (23) and a disruptive effect on the gel matrix. Although the stress-strain curves showed firmer gels with the addition of starch, the textural modifications that are considered to be advantageous in creating a surimi-like product were not evident.

Carrageenans

Carrageenans, especially κ-carrageenan, are frequently added to dairy products to increase viscosity (3). Moderately high concentrations of κ-carrageenan cause casein to gel as a result of electrostatic interactions between the caseins and carrageenan. Stanley (19) noted that salts lower the viscosity of carrageenan solutions by reducing electrostatic repulsion among the sulfate groups. However, at high enough salt concentrations, κ-carrageenan solutions may gel, particularly for the cations K^+ and Ca^{2+}, which strongly induce gelation (24). At temperatures above the gel melting point, however, Ca^{2+} lowers viscosity. Carrageenans behave like casein in that they require heat to bring them into solution or dispersion, and they gel upon cooling. The commercially important interaction of carrageenans with milk proteins is an example of the electrostatic interaction that can occur between the negatively charged carrageenans and the positively charged sites on proteins. Binding occurs between carrageenan and κ-casein at the point at which they interact to form a complex. Binding with other caseins is weaker.

The textural parameters of the CaCNT-carrageenan gels are shown in Figures 3 through 7 and Table 3. Data for the control and kamaboko gels are also presented for comparison.

Hardness. As seen in Figure 3, all gels exhibited hardness greater than that of the control and kamaboko gels. The addition of KCl had the effect opposite to that expected. These gels were less firm, and hardness remained essentially the same, regardless of concentration of the κ- and ι-carrageenan additives. Increases in gel hardness with concentration of the κ- and ι-carrageenans were otherwise significant ($P < .05$). Gels with added κ-carrageenan A showed increased hardness at 2% concentration, and then hardness values reached a plateau. The addition of 1% κ-carrageenan A most closely emulated the target material.

Cohesiveness. Cohesiveness is a measure of the material-binding properties or strength of the internal bonds. Figure 4 shows that, for all gels except those with added KCl, cohesiveness values were comparable with those for the kamaboko and control samples. The addition of 2% κ-carrageenan A significantly increased product cohesiveness, and, in fact, the resultant gel was more cohesive than the kamaboko gel.

TABLE 3. Effect of carrageenans and KCl on texture parameters of calcium caseinate (CaCNT) gels.

	Syneresis				Foldability				Adhesiveness				Recover energy			
	1%	2%	3%	4%	1%	2%	3%	4%	1%	2%	3%	4%	1%	2%	3%	4%
CaCNT plus κ-carrageenan A[1]	.89[c]	.91[c]	1.93[a]	1.48[a]	AA	AA	A	A	.44[a]	.27[b]	.15[c]	.21[c]	.43[d]	.52[b]	.53[b]	.52[b]
CaCNT plus κ-carrageenan B	1.46[b]	1.36[b]	1.20[c]	1.26[c]	AA	A+	A+	A	.34[b]	.35[b]	.37[a]	.35[b]	.40[d]	.39[d]	.40[d]	.41[d]
CaCNT plus κ-carrageenan B plus ι-carrageenan	1.34[b]	1.22[c]	1.32[c]	1.34[bc]	A	A	A	A	.29[b]	.28[b]	.21[c]	.21[c]	.46[c]	.42[d]	.44[c]	.45[c]
CaCNT plus κ-carrageenan B plus ι-carrageenan plus KCl	.99[c]	.97[c]	1.47[b]	1.26[c]	A	A	A	A	.19[c]	.21[c]	.19[c]	.16[c]	.41[d]	.41[d]	.35[e]	.33[f]
CaCNT			1.01[c]				A				.18[c]				.48[c]	
Kamaboko			1.99[a]				AA				.10[c]				.66[a]	

[a,b,c,d,e,f]Superscripts that are the same within a parameter category indicate no significant difference ($P > .05$).

[1]Control sample is gel from CaCN with phosphate added.

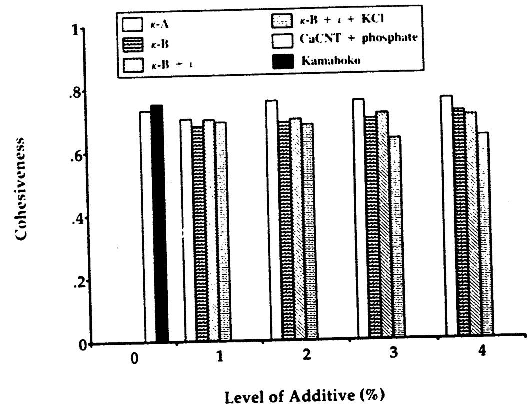

Figure 4. Cohesiveness of calcium caseinate (CaCNT) gels with added phosphate and carrageenan. κ-A = Gelcarin® FF489E κ-carrageenan A; κ-B = Gelcarin® 911 κ-carrageenan B; and ι = Gelcarin® GP359 ι-carrageenan.

Cohesiveness for all additives showed no significant difference at $P = .01$. The addition of ι-carrageenan to the κ-carrageenan B did not appreciably change the cohesiveness, regardless of the concentration added.

Gumminess. Gumminess is defined as the energy required to disintegrate a semisolid food product to a state ready for swallowing (22). The instrument measures it as a product of hardness and cohesiveness. Because the cohesiveness showed only minor deviations among the gels, the gumminess response was essentially the same as that for hardness. All samples except those with added KCl were equal to or greater than both the control and kamaboko gels. Gels containing κ-carrageenan A at the 1% level most closely emulated the target material.

Degree of Elasticity. The degree of elasticity accounts for both the rate and extent of recovery of a viscoelastic material (14). The elasticity of kamaboko is its most distinctive textural characteristic. Comparisons of the elasticity of the CaCNT carrageenan gels are shown in Figure 5. Degree of elasticity increased as the concentration of κ-carrageenan A increased. The most significant improvement in elasticity was achieved at the 3 to 4% level. The elasticity of the gels with κ-carrageenan B with and without ι-carrageenan was essentially the same, regardless of concentration. Gels with ι-carrageenan were more

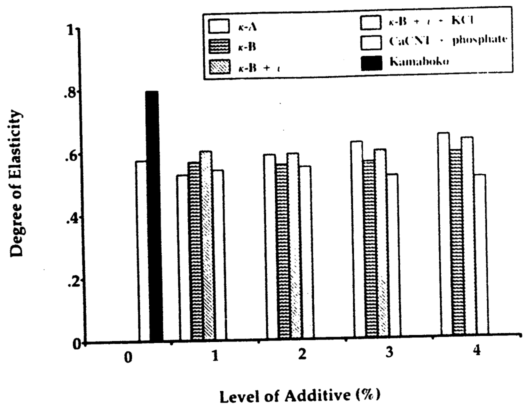

Figure 5. Degree of elasticity of calcium caseinate (CaCNT) gels with added phosphate and carrageenan. κ-A = Gelcarin® FF489E κ-carrageenan A; κ-B = Gelcarin® 911 κ-carrageenan B; and ι = Gelcarin® GP359 ι-carrageenan.

elastic than those with κ-carrageenan B alone. The addition of KCl reduced product elasticity in all cases. None of the gels were as elastic as the kamaboko, and only κ-carrageenan A at addition of 3 to 4% significantly improved the elasticity compared with that of the control gel ($P < .05$).

Springiness. Springiness of the CaCNT-carrageenan mixtures is shown in Figure 6. The additions of both κ-carrageenans and the κ- and ι-carrageenan combination at the 2 to 3% level were effective in significantly improving the springiness of the gels. These gels were also as springy as the target material. Addition of KCl resulted in gels that showed little or no change in springiness from that of the control sample.

Chewiness. Chewiness is defined, for sensory analysis, as the energy required to masticate a solid food product to a state ready for swallowing, and chewiness is the product of gumminess and springiness. Data for chewiness are shown in Figure 7. The relative differences in the chewiness were similar to those for hardness. Because of the improvement in springiness, however, gels with additives at concentrations >1% were significantly chewier than the control and kamaboko gels. The addition of KCl reduced chewiness at all concentrations.

Syneresis. All samples studied showed better water-holding characteristics than the kamaboko. However, increases in concentration of the carrageenans did increase syneresis (Table 3).

Foldability. All samples also performed well when subjected to the fold test and exhibited the most resilient body after the addition of κ-carrageenan A (Table 3).

Adhesive Force. Although differences were significant for the adhesive forces for the CaCNT-carrageenan gels, which were, in fact, slightly more sticky than the kamaboko, all gels performed well in adhesive force (Table 3).

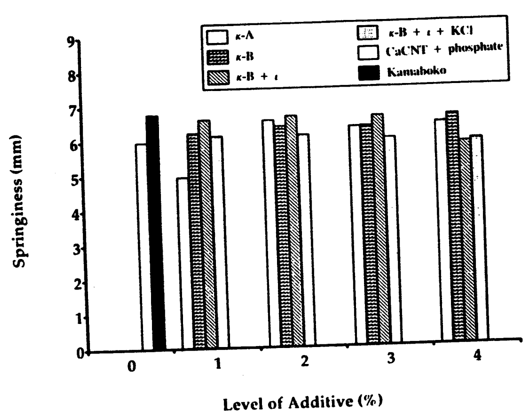

Figure 6. Springiness of calcium caseinate (CaCNT) gels with added phosphate and carrageenan. κ-A = Gelcarin® FF489E κ-carrageenan A; κ-B = Gelcarin® 911 κ-carrageenan B; and ι = Gelcarin® GP359 ι-carrageenan.

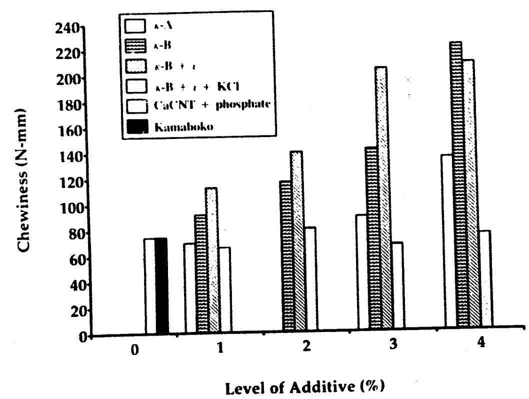

Figure 7. Chewiness of calcium caseinate (CaCNT) gels with added phosphate and carrageenan. κ-A = Gelcarin® FF489E κ-carrageenan A; κ-B = Gelcarin® 911 κ-carrageenan B; and ι = Gelcarin® GP359 ι-carrageenan.

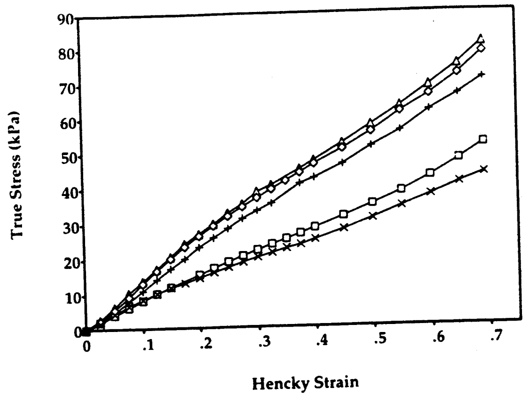

Figure 8. Stress-strain relationship of calcium caseinate (CaCNT) gels with added Gelcarin® FF489E (κ-A) κ-carrageenan A: 1% (□), 2% (+), 3% (◊), 4% (△), or kamaboko (×).

Recoverable Energy. The recoverable energy is a reflection of the gel elasticity. The ability of the CaCNT and CaCNT-carrageenan gels to retain the energy expended upon compression is significantly less than that of the target material. The use of κ-carrageenan A at 2% was effective in significantly increasing recoverable energy ($P < .05$).

Stress-Strain Analysis. Evaluation of the ITPA responses for the gels with added carrageenan indicated that, in all areas, the κ-carrageenan A provided the most significantly improved kamaboko emulation. In Figure 8, the stress-strain relationships for this additive are shown. As can be seen, the 1% κ-carrageenan A behaves similarly to the kamaboko. The deviation of the stress from linearity and the increased sigmoid shape are indicative of the reduced resilience of the CaCNT-κ-carrageenan A gels and implies that the gels are more compressible (less elastic) than the kamaboko.

CONCLUSIONS

The CaCNT gels with varying textural properties can be created. With the addition of phosphate, all textural parameters improved markedly. Although the use of starches may not provide textural properties that are suitable to emulate a product made from surimi, the gels have attributes that may be useful in other food formulations. The use of 1 to 2% of added κ-carrageenan A with the CaCNT gels provides an improvement in gel cohesiveness, springiness, water-holding, and foldability that emulates the target kamaboko material. The degree of elasticity and the recoverable energy of these gels were improved, but not to the extent that they behaved similarly to kamaboko. With additional formulation to improve elasticity, CaCNT gels may be made that will emulate surimi products rheologically.

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