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Instrumental Texture Parameters and Solvation Characteristics of Mixed Casein Gels[1]

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ABSTRACT

Caseins exhibit a wide range of physicochemical and functional properties that make them an excellent source of protein for the creation of formulated foods, either as novel or imitative products. Their ability to gel suggests their potential use in highly valued imitative products, such as Kamaboko, a surimi product. However, gelation and the resultant textural properties can be enhanced by various factors, especially the ionic strength of the mixtures and the addition of noncasein proteins. Instrumental texture profile analyses of gels made from mixtures of casein with chicken egg albumin, whey protein concentrate, rennet, and calcium ion were evaluated as well as the solvation characteristics of these protein systems. Of the factors that alter functionality, protein type and Ca^{2+} concentration contributed most significantly. Whey protein concentrate added to the casein resulted in weaker gels that failed when subjected to 50% compression, but casein gels made with added egg albumin were firm and elastic. The addition of rennet was effective in improving the elasticity of the gels made with casein and egg albumin. The observed improvements in functionality did not lend themselves to the creation of surimi-like products with the formulations studied but suggest the potential for rheological emulation of these products with additional formulation.

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[1]Mention of brand or firm names does not constitute an endorsement by the USDA over others of a similar nature not mentioned.

(**Key words**: texture, casein, gels, rheology)

Abbreviation key: **CC** = concentration of Ca^{2+}, **CN** = casein, **EA** = chicken egg albumin, **PC** = protein concentration, **WPC** = whey protein concentrate.

INTRODUCTION

Many proteins form gels. The structural matrix provided by gels can hold water and various food ingredients. This entrapment is useful in many food applications for the development of new or imitative products. Casein (CN), the major protein component of cow milk, has physicochemical and nutritive properties that make it a useful protein source in a variety of formulated foods (24). The functionality of CN as an additive in many food systems allows for the enhancement of texture, body, fat emulsification, and water binding. The bland nature of this protein further enhances its utility. High concentrations of CN have exceptional water-binding capacity and are viscous and soluble in neutral or alkaline conditions (9). Although much is known about the chemistry of milk components, fundamental data on the physical properties that govern functionality, particularly in the presence of other food components, are still somewhat limited, and this lack of information limits the potential use of milk ingredients in the food processing industry (11). The gelation of milk proteins has been established, under conditions of acid (17), heat (18), aging (15), and enzyme treatments (6), and CN generally is the component involved (16). The study of the utilization of induced CN gelation mostly addresses its use as an additive as a binding, thickening, or emulsifying agent. Its viscoelasticity as the major food ingredient has been studied in yogurt and cheese products. Alone and in combination with relatively low concentrations of polysaccharides

and other proteins, CN is capable of gelation and produces gels that have utility in the creation of novel or imitative foods with a wide variety of rheological and textural properties. The acceptance of such a gel depends largely on the final product for which the gels are used and the properties of these products, such as gel strength, hardness, adhesiveness, cohesiveness, and elasticity, which are usually evaluated subjectively, need to be quantified (10). Highly valued products, such as seafood analogs, make use of the gelation capability of CN and also provide nutritional enhancement. This use is of special interest and serves as an incentive for development of alternative sources for surimi production, especially when the reduction in the supply of Alaska pollack, the predominant source of protein in surimi production, is considered (2).

A previous study (13) showed the potential for use of polysaccharides with CN to create gels that exhibited rheological properties similar to those of Kamaboko, a surimi product. Although these studies indicated that CN gels can have properties similar to those of Kamaboko (13), such as water binding, gel hardness, and cohesiveness, the high elasticity characteristic of surimi products was not duplicated.

The interaction of two or more proteins in a complex food system can exhibit incompatibility, which interferes with the formation of a firm gel matrix; however, the interaction between proteins often synergistically enhances formation of the gels and their textural properties. Chang-Lee et al. (3) determined that hardness and elasticity of surimi gels from Pacific whiting were significantly increased by the addition of chicken egg albumin (EA) and whey protein concentrate (WPC) at 1 to 3% (wt/wt) as a result of a sulfhydryl-disulfide interchange. However, surimi gels from red hake were weakened when EA was added in similar amounts. Lee and Kim (14) concluded that the EA did not have a composite reinforcing effect and that gel strength was reduced because the EA interfered with the formation of a gel matrix. In the cheese-making process, interaction between WPC (β-lactoglobulin) and κ-CN, as a result of heat treatment, profoundly affected the characteristics of CN gel structure (21). The addition of salts, specifically $CaCl_2$, affects the textural attributes of many protein gels, especially ionic strength. Many factors that affect the textural properties of food gels also affect their water-binding properties, and an analysis of these properties is important in textural evaluation. Heat-induced gelation is an important functional property of both EA and WPC (7). Their contribution as additives to CN and the determination of the effects of the interactions between proteins are rheologically important in the formulation of foods.

The objectives of this study were 1) to evaluate the effects of added WPC and EA with various concentrations of Ca^{2+} (CC) on functional properties, specifically the texture profile parameters and the solvation characteristics, of CN gels formed in the presence of heat and 2) to determine the suitability of the proteins, rennet, and CC as additives for utilization of CN as surimi-like analogs.

MATERIALS AND METHODS

Preparation of Protein Solids (Controls)

Samples (~38.5 g) of unflavored Kamaboko loaves, made from Alaskan Pollack and purchased locally, were finely diced for the solvation studies and centrifuged (Beckman L8-70 ultracentrifuge; Beckman Instruments, Inc., Fullerton, CA) using an SW-28 rotor at 83,500 $\times g$ for 30 min at 37°C. The CN was prepared from fresh raw skim milk by acid precipitation (with 1*N* HCl to pH 4.6), filtered, and stored frozen until needed. The WPC was Calpro-75 (Calpro Ingredients, Corona, CA; average composition: 75% protein, 4.0% moisture, 3.0% ash, 7.0% fat, and 11.0% lactose). The EA was Sigma 1 (crude, grade II; from Sigma Chemical Co., St. Louis, MO). Anhydrous $CaCl_2$ was reagent grade.

Mixtures of CN and Protein

Three stock solutions of the individual proteins were prepared in sufficient quantity to replicate preparation and analysis three times. Thawed CN was resuspended in a minimum of water and adjusted to pH 7.0 with 50% NaOH for a stock solution containing 20% protein. Aliquots were diluted to 7.5, 10, and 12.5% for controls. Dilutions of 5% also were prepared to be mixed with solutions of EA and WPC. The 20% stocks were prepared, as described, for

EA and WPC; aliquots were diluted to 10 and 15%. Sample solutions were prepared by mixing 5% solutions of CN, 1:1 (vol/vol), with EA or WPC (10, 15, and 20%) for the final concentrations of 2.5% CN:5% EA or WPC; 2.5% CN:7.5% EA or WPC; and 2.5% CN:10% EA or WPC. Each mixture was divided into three 80-ml flasks; sufficient 1 *M* $CaCl_2$ was slowly added to the 80-ml aliquots during stirring for final concentrations of 10, 20, and 40 m*M* Ca^{2+} and stirred for about 5 min. Then, 1.6 ml of 1:500 diluted commercial rennet (Ch. Hansen's Lab., Inc., Milwaukee, WI) was pipetted into each solution of a second experimental sample set, stirred at a moderate speed for 1 min at 25°C, and allowed to set for 30 min. Both sets were heated in a water bath at 80°C for 30 min, briefly chilled, observed, centrifuged at 37°C for 30 min as described, decanted, and drained inverted for 5 min, and the solids were refrigerated until preparation for texture analysis.

Solvation

Protein samples, prepared as indicated, were centrifuged for 30 min at 37°C, and the supernatant was decanted. The samples were allowed to drain inverted for 5 min, and the centrifuged tubes then were cut off 2 to 3 mm above the protein pellet. The portion of the tube containing wet solids was weighed (w_1) and then lyophilized for 20 h, and the dry weight was recorded (w_2). The solids were then carefully removed from the tube and weighed (w_3); solvation, expressed in grams of water per gram of dry solids, was calculated using $(w_1 - w_2)/w_3$ (25).

Rheological Analysis

Cylindrical samples of gels, 10 mm in diameter, were removed directly from the test tubes, using a number 7 cork borer. Direct removal of samples from the tubes, because of the structural support and confinement of the gels, improved the cylinder geometry. The cylinders were then cut to a 10-mm height. Kamaboko samples were prepared and analyzed as by Konstance (12). The loaves were sliced to a 10-mm height using a parallel wire slicer. Cylindrical samples were removed from the resultant slices using a number 7 cork borer. All samples were prepared at 4°C to minimize deformation during slicing and extraction. Each formulation was sampled and analyzed in triplicate. Instrumental texture profile analyses involving double compression were used to determine rheological responses in an Instron Universal Testing machine (model 4201; Instron Corp., Canton, MA) provided with 5.6-cm Lucite plates. Instron control was maintained using the Cyclic Foam Compression software with a personal computer (model 86B Hewlett Packard; Hewlett Packard Co., Boise, ID). A 500-N load cell was used for all analyses, and samples were compressed to 50% of their original height at a rate of 50 mm/min. All samples were tested at 25°C.

Texture Profile Parameters

The instrumental texture profile parameters determined from the force-deformation curve (Figure 1) included hardness, cohesiveness, gumminess, springiness, chewiness, and degree of elasticity. Statistical analyses were performed using the general linear models procedure and ANOVA of SAS (20). Separation of means was at $P = .05$.

RESULTS AND DISCUSSION

General Gel Characteristics

All gels created with the mixtures of CN and protein were opaque, which indicated an aggregated dispersion type of gel formation that is characteristic of globular proteins. The

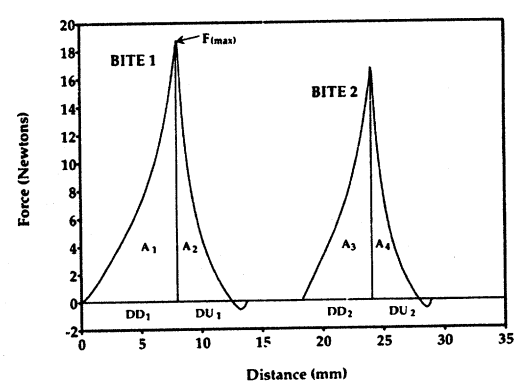

Figure 1. Typical force-deformation curve. Description of texture profile parameters: F_{max} = hardness, A_n = area under curve, DU_1/DD_1 = degree of elasticity, DD_2 = springiness, A_3/A_1 = cohesiveness, bite 1 = first compression, and bite 2 = second compression.

TABLE 1. Solvation characteristics of protein gels containing 2.5% casein and other proteins.

Protein[1] addition	Total protein concentration	Solvation of protein					
		Calcium ion concentration					
		No rennet			Rennet		
		10 m*M*	20 m*M*	40 m*M*	10 m*M*	20 m*M*	40 m*M*
	(%)	water in protein (g/g)					
CN	5	3.48^{c}	3.17^{de}	2.18^{jk}	3.30^{d}	2.91^{ef}	1.51^{st}
EA	5	3.14^{dc}	2.58^{g}	1.90^{mn}	2.47^{ghi}	1.98^{lm}	1.73^{opqr}
WPC	5	2.49^{ghi}	1.90^{mn}	1.68^{qr}	2.05^{klm}	1.57^{rst}	1.37^{u}
CN	7.5	3.67^{b}	2.91^{ef}	2.37^{hi}	4.00^{a}	3.14^{de}	2.77^{f}
EA	7.5	2.88^{ef}	2.47^{ghi}	1.93^{mn}	2.78^{f}	2.10^{kl}	1.78^{nopq}
WPC	7.5	2.56^{g}	1.87^{no}	1.71^{opqr}	2.18^{jk}	1.47^{tu}	1.38^{u}
CN	10	3.27^{d}	2.90^{ef}	2.33^{ij}	3.85^{a}	3.49^{c}	3.02^{e}
EA	10	3.17^{de}	2.50^{gh}	1.98^{lm}	2.76^{f}	2.16^{k}	1.80^{nop}
WPC	10	2.10^{kl}	1.97^{lm}	1.78^{nopq}	2.42^{ghi}	1.65^{qrs}	1.33^{u}
Kamaboko	. . .	2.07^{klm}					

[a–u]Means with same superscripts did not differ ($P > .05$). Standard error of mean = .05.

[1]CN = Casein, EA = chicken egg albumin, WPC = whey protein concentrate.

randomness of aggregation determines the relatively high concentration required for gelation (19). Casein and CN formulations produced very weak gels, primarily because of the heat stability of the casein, which is attributable to the lack of a secondary and tertiary structures (8). Because of the lack of a solid-like structure, texture profile analyses of these gels were not conducted. The CN and EA and the CN and WPC formulations did, however, result in firm gels.

Solvation

The water binding of protein gels is influenced by the factors that control texture (26). Data for the solvation characteristics of the protein gels are shown in Table 1. An inverse relationship between solvation and CC was evident (Figure 2) for each of the protein samples, which agrees with the observations of Creamer and Waugh (5). At lower CC, binding of Ca^{2+} decreases, and the solvation increases. Behavior was similar for WPC (22) and EA (23) gels. Competitive binding generally occurs among water, salt, and AA side groups. At higher salt concentrations, interactions of water and salt may predominate, yielding a "dehydrated" protein. Interactions among proteins and ionic strength appear to affect the water binding of the protein samples more than protein concentration (PC), as evidenced by the relatively small changes in solvation resulting from the PC. Degree of solvation was greatest in the CN and CN samples, intermediate in CN and EA, and least in CN and WPC for each CC, within a given total PC. Because WPC is compact, an improvement in water binding was expected (4); however, heating, the presence of fat in the WPC (1), and the interaction with the CN resulted in a reduction in solvation. Rennet reduced solvation for the mixtures of CN and EA and CN and WPC but increased solvation for the CN and CN samples at the higher PC.

Using multiple regression analysis, relationships for CC and solvation (S) were as follows.

CN and EA (without rennet):

$$S = 4.395 - .089\ CC \quad (R = .941;\ P < .05). \qquad [1]$$

CN and WPC (without rennet):

$$S = 2.765 - .069\ CC \quad (R = .800;\ P < .05). \qquad [2]$$

CN and EA (with rennet):

$$S = 2.485 - .093\ CC + .002\ CC^2 \quad (R = .949;\ P < .05). \qquad [3]$$

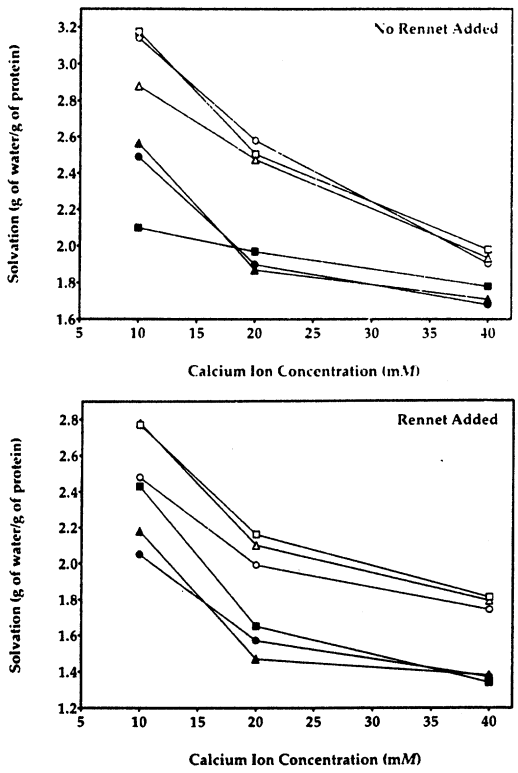

Figure 2. Effect of Ca^{2+} concentration on solvation of casein gels with protein additives and with or without rennet. Chicken egg albumin, 5% (○), 7.5% (△), and 10% (□); whey protein concentrate, 5% (●), 7.5% (▲), and 10% (■).

CN and WPC (with rennet):

$$S = 3.045 - .102\ CC + .002\ CC^2 \quad (R = .714;\ P < .05), \qquad [4]$$

where S is in grams of water per gram of dry solids, and CC is millimolar. Regression analysis established that PC at the amounts used had no significant effect on the solvation characteristics, regardless of rennet treatment.

Textural Parameters

The textural parameters for the protein gels without rennet are shown for CN and EA and CN and WPC in Tables 2 and 3 and with rennet in Tables 4 and 5. The gels containing CN were not analyzed because of severe slumping. The gels with added EA were compressed to 50% of their original height without any evidence of yield; the CN and WPC gels, without rennet, all failed under this strain. The yield strain increased directly with CC. Failure was visually observed and graphically represented by a break in the force-deformation curves. The addition of rennet appears to have reduced the brittleness of the CN and WPC gels at the lower concentrations of whey protein. The differences in the texture profiles analysis responses of the gels with the addition of rennet may be due to major structural differences in the microstructure. Differences in the textural parameters between gels with and without rennet were apparent throughout. The effects of centrifugation and solvation on the textural properties was analyzed using an analysis of covariance (20) with solvation as the covariant. The result was a small increase in hardness only (R = .577). Little or no effect was seen in other textural parameters.

Hardness

Gel hardness (F_{max}), as a function of CC, is shown in Figure 3. For the CN and EA gels without rennet, hardness was greatest at the highest ionic strength and was dependent solely on CC. The relationship that was developed for these conditions using a multiple linear regression analysis showed a very high correlation coefficient (R = .971; $P < .05$) and little or no contribution from protein type or PC;

$$F_{max} = -6.05 + 2.41\ CC - .027\ CC^2. \qquad [5]$$

The CN and WPC gels showed more dependence on PC and the statistical interaction between PC and CC. The relationship between hardness and the gel-forming parameters for these gels also showed a high degree of correlation (R = .943):

$$F_{max} = -105.43 + 3.39\ PC + .91\ CC + .09\ PC \times CC - 2.02\ PC^2 - .02\ CC^2. \qquad [6]$$

The addition of rennet to the CN and EA mixture resulted in firmer gels at the maximal CC, and the relationship was similar to that of

TABLE 2. Texture profile parameters of kamaboko and of gels with 2.5% casein (CN) and chicken egg albumin (EA) but no rennet.

Ca^{2+} Concentration	Protein type	Protein concentration	Hardness	Cohesiveness[2]	Gumminess[3]	Springiness[4]	Chewiness[5]	Degree of elasticity	Yield[1] strain
(m*M*)		(g/100 g)	(N)		(N)	(mm)	(N·mm)		(%)
10	EA	5	13.3[d]	.602[bc]	8.0[c]	3.93[bc]	31.6[c]	.533[c]	NF
20	EA	5	29.6[b]	.598[bc]	17.7[cd]	3.97[b]	70.2[b]	.598[b]	NF
40	EA	5	43.0[a]	.638[b]	27.4[a]	4.00[b]	109.7[a]	.590[bc]	NF
10	EA	7.5	15.6[d]	.615[bc]	9.6[e]	3.65[c]	35.0[c]	.575[bc]	NF
20	EA	7.5	24.1[c]	.609[bc]	14.7[d]	3.93[bc]	57.7[b]	.609[b]	NF
40	EA	7.5	44.4[a]	.605[bc]	26.9[a]	4.10[b]	110.2[a]	.594[b]	NF
10	EA	10	14.2[d]	.511[c]	7.3[e]	3.88[bc]	28.3[c]	.584[bc]	NF
20	EA	10	32.4[b]	.601[bc]	19.5[bc]	3.87[bc]	75.3[b]	.631[b]	NF
40	EA	10	41.8[a]	.595[bc]	24.9[ab]	4.03[b]	100.4[a]	.621[b]	NF
Kamaboko			5.9[e]	.752[a]	4.5[e]	4.60[a]	30.1[c]	.800[a]	NF
SEM			1.6	.03	1.5	.09	6.4	.02	

[a,b,c,d,e]Means with the same superscript within a parameter category did not differ ($P > .05$).
[1]Yield strain expressed in engineering strain (% of compression) at failure, where NF = no failure.
[2]Cohesiveness = Ratio of peak areas of bite 2 and bite 1.
[3]Gumminess = Hardness × cohesiveness.
[4]Springiness = Measure of sample recovery.
[5]Chewiness = Gumminess × springiness.

TABLE 3. Texture profile parameters of gels with 2.5% casein (CN) and whey protein concentrate (WPC) but no rennet.

Ca^{2+} Concentration	Protein type	Protein concentration	Hardness	Cohesiveness[2]	Gumminess[3]	Springiness[4]	Chewiness[5]	Degree of elasticity	Yield[1] strain
(m*M*)		(g/100 g)	(N)		(N)	(mm)	(N·mm)		(%)
10	WPC	5	8.8[d]	.417[a]	3.7[d]	3.93[a]	14.4[d]	.552[b]	40.7
20	WPC	5	14.9[cd]	.537[a]	8.0[cd]	4.05[a]	32.4[cd]	.613[a]	45.0
40	WPC	5	18.6[bc]	.627[a]	11.7[bcd]	4.32[a]	50.3[bcd]	.614[a]	45.7
10	WPC	7.5	20.6[bc]	.677[a]	14.0[bc]	4.25[a]	59.4[bc]	.664[a]	43.2
20	WPC	7.5	36.2[a]	.461[a]	16.7[b]	4.15[a]	69.2[b]	.648[a]	44.8
40	WPC	7.5	40.4[a]	.656[a]	26.5[a]	4.12[a]	109.1[a]	.649[a]	49.3
10	WPC	10	15.1[bc]	.342[a]	5.2[cd]	3.97[a]	20.5[d]	.660[a]	41.2
20	WPC	10	23.1[b]	.490[a]	11.4[bcd]	4.03[a]	45.8[bcd]	.642[a]	46.9
40	WPC	10	38.6[a]	.458[a]	17.7[b]	4.05[a]	71.7[b]	.647[a]	46.5
SEM			2.3	.09	2.6	.13	10.9	.02	

[a,b,c,d,e]Means with the same superscript within a parameter category did not differ ($P > .05$).
[1]Yield strain expressed in engineering strain (% of compression) at failure, where NF = no failure.
[2]Cohesiveness = Ratio of peak areas of bite 2 and bite 1.
[3]Gumminess = Hardness × cohesiveness.
[4]Springiness = Measure of sample recovery.
[5]Chewiness = Gumminess × springiness.

TABLE 4. Texture profile parameters of gels with 2.5% casein (CN), chicken egg albumin (EA), and rennet.

Ca^{2+} Concentration	Protein type	Protein concentration	Hardness	Cohesiveness[2]	Gumminess[3]	Springiness[4]	Chewiness[5]	Degree of elasticity	Yield[1] strain
(m*M*)		(g/100 g)	(N)		(N)	(mm)	(N·mm)		(%)
10	EA	5	14.0[d]	.422[b]	6.1[e]	3.87[a]	23.5[e]	.554[c]	NF
20	EA	5	40.96[b]	.578[a]	23.7[c]	3.88[a]	91.9[c]	.583[abc]	NF
40	EA	5	54.6[a]	.585[a]	32.0[ab]	3.85[a]	123.0[b]	.602[abc]	NF
10	EA	7.5	15.6[d]	.368[b]	5.7[e]	3.95[a]	22.7[e]	.575[bc]	NF
20	EA	7.5	40.8[b]	.584[a]	23.9[c]	4.03[a]	96.3[c]	.620[ab]	NF
40	EA	7.5	51.5[a]	.586[a]	30.2[b]	4.05[a]	122.3[b]	.615[ab]	NF
10	EA	10	25.7[c]	.445[b]	11.5[d]	3.95[a]	45.2[d]	.602[abc]	NF
20	NE	10	39.3[b]	.566[a]	22.3[c]	3.93[a]	87.7[c]	.612[ab]	NF
40	EA	10	57.7[a]	.607[a]	35.0[a]	4.25[a]	148.8[a]	.630[a]	NF
SEM			2.1	.04	1.3	.09	5.1	.02	

[a,b,c,d,e]Means with the same superscript within a parameter category did not differ ($P > .05$).
[1]Yield strain expressed in engineering strain (% of compression) at failure, where NF = no failure.
[2]Cohesiveness = Ratio of peak areas of bite 2 and bite 1.
[3]Gumminess = Hardness × cohesiveness.
[4]Springiness = Measure of sample recovery.
[5]Chewiness = Gumminess × springiness.

TABLE 5. Texture profile parameters of gels with 2.5% casein (CN), whey protein concentrate (WPC), and rennet.

Ca^{2+} Concentration	Protein type	Protein concentration	Hardness	Cohesiveness[2]	Gumminess[3]	Springiness[4]	Chewiness[5]	Degree of elasticity	Yield[1] strain
(m*M*)		(g/100 g)	(N)		(N)	(mm)	(N·mm)		(%)
10	WPC	5	21.0[c]	.495[abc]	10.4[c]	3.83[ab]	39.8[c]	.532[b]	NF
20	WPC	5	37.0[ab]	.656[a]	24.3[a]	3.98[ab]	96.8[ab]	.545[b]	NF
40	WPC	5	45.6[a]	.563[ab]	25.7[a]	4.13[ab]	106.0[a]	.592[ab]	NF
10	WPC	7.5	30.4[bc]	.360[bcd]	11.0[c]	4.05[ab]	44.4[c]	.603[ab]	NF
20	WPC	7.5	37.1[ab]	.306[cd]	11.4[c]	3.72[b]	42.2[c]	.609[ab]	NF
40	WPC	7.5	45.2[a]	.480[abcd]	21.3[ab]	3.95[ab]	84.0[ab]	.619[ab]	NF
10	WPC	10	27.7[bc]	.486[abcd]	13.5[bc]	4.25[a]	57.2[bc]	.650[a]	43.0
20	WPC	10	38.0[ab]	.276[d]	10.5[c]	4.12[ab]	43.3[c]	.595[ab]	44.3
40	WPC	10	45.9[a]	.631[a]	29.0[a]	3.87[ab]	112.1[a]	.606[ab]	45.4
SEM			3.5	.06	3.1	.13	13.4	.02	

[a,b,c,d,e]Means with the same superscript within a parameter category did not differ ($P > .05$).
[1]Yield strain expressed in engineering strain (% of compression) at failure, where NF = no failure.
[2]Cohesiveness = Ratio of peak areas of bite 2 and bite 1.
[3]Gumminess = Hardness × cohesiveness.
[4]Springiness = Measure of sample recovery.
[5]Chewiness = Gumminess × springiness.

the equation without rennet for mixtures with a high correlation coefficient (R = .971):

$$F_{max} = -3.06 + 3.94\ CC - .05\ CC^2. \quad [7]$$

Gel hardness did not correlate well (R = .675) with the conditions used for the CN and WPC mixtures with added rennet, and the proposed model equation had no satisfactory fit. The data for hardness for these mixtures showed a coefficient of variation (CV = 23.15%) that was poorer than those for the replicates of the other protein mixtures (no rennet CN and EA, CV = 8.4%; CN and WPC, CV = 12.9%; rennet CN and EA, CV = 9.0%). Ionic bonding plays a complex role in protein gelation, and, although divalent cations such as Ca^{2+} may improve gel strength or hardness, interpretation of the interactions of ions and proteins is difficult in a protein gel system (22).

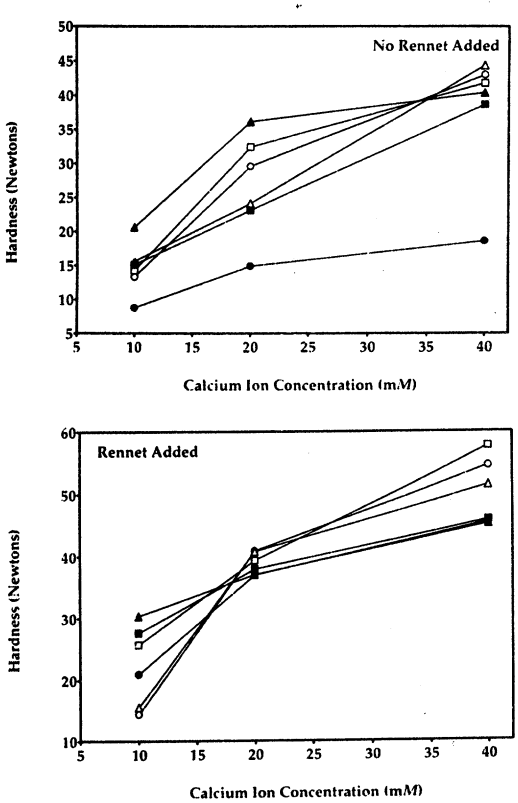

Figure 3. Effect of Ca^{2+} concentration on hardness of casein gels with protein additives, with and without rennet. Chicken egg albumin, 5% (○), 7.5% (△), and 10% (□); whey protein concentrate, 5% (●), 7.5% (▲), and 10% (■).

Cohesiveness and Gumminess

Cohesiveness measures the ability of a material to stick to itself. The failure of the CN and WPC gels makes the cohesiveness values for these gels somewhat questionable. The mean CV of the cohesiveness of the CN and WPC gels were 24 and 22% for gels with and without rennet, respectively, compared with 6.2 and 8.9% for the CN and EA gels. Clearly, cohesiveness, especially at low CC, is reduced by the addition of rennet. Cohesiveness of all CN and EA gels without rennet was equal to or greater than that of gels with rennet. The cohesiveness was affected more by CC in the gels with added rennet. Increased hardness of the rennet gels was the predominant factor in their increased gumminess. Little differences resulted from added PC except at the highest concentration.

Springiness and Chewiness

Because the springiness of the CN and EA gels varied over a small range (from 3.65 to 4.25 mm), the resultant chewiness values were similar to those for gumminess; the gels containing unstable rennet showed the greatest chewiness.

Degree of Elasticity

The effect of rennet on the degree of elasticity of the protein gels, as a function of CC, is shown in Figure 4. Gel elasticity, with and without rennet, was dependent on protein type and PC. Without rennet, CN and EA gels showed maximal elasticity at higher CC and 10% added EA. The CN and WPC gels showed maximal elasticity at the higher PC, 10 m*M* Ca^{2+}. These gels were the most elastic of all those evaluated. When rennet was added, the result was an almost linear relationship with both the CN and EA and CN and WPC gels; elasticity was maximal at the highest PC and CC.

Comparison with Kamaboko

The solvation value of the Kamaboko was 2.07 g of water/g of dry solid. The CN and EA gels and the CN and WPC gels exhibited

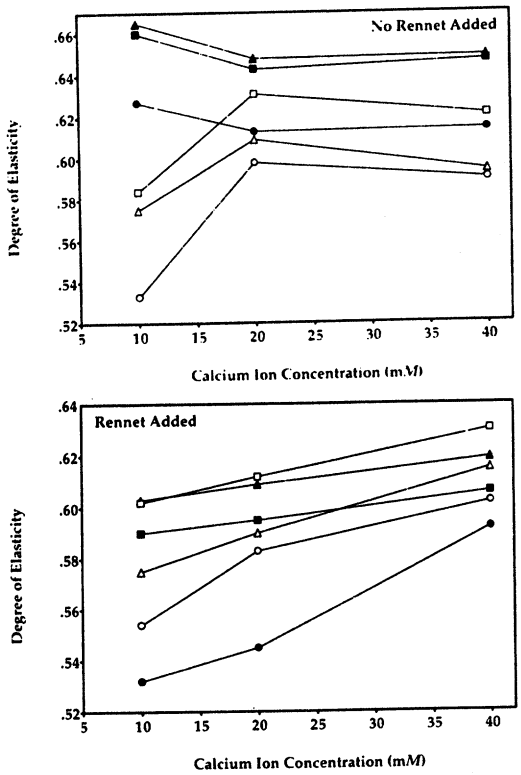

Figure 4. Effect of Ca^{2+} concentration on degree of elasticity of casein (2.5%) gels with protein additives, with and without rennet. Chicken egg albumin 5% (○), 7.5% (△), and 10% (□); whey protein concentrate, 5% (●), 7.5% (▲), and 10% (■).

water-binding characteristics that were as good as or better than those of the Kamaboko (Table 2). However, the CN and WPC gels had a texture that was too brittle for use in a surimi-like food without further formulation with hydrocolloids or polysaccharides. Despite the improved elasticity with 7.5 to 10% added WPC at 10 m*M* Ca^{2+} and without rennet, the tendency to failure and relatively poor cohesiveness appeared to make them unsuitable for this use. The addition of EA to the CN yielded a reasonably firm gel with good elastic and cohesive properties. However, additional formulation would be required to use these mixtures for surimi-like products.

CONCLUSIONS

The addition of proteins, such as EA and WPC, to CN along with Ca^{2+} and rennet significantly altered the functional properties. The CC and the protein type were the major contributors to these changes in functionality. At the amounts studied, PC, although it showed some impact on gel elasticity, played a much smaller role. The addition of rennet to these protein systems reduced water-binding characteristics, as measured by solvation, while significantly increasing the hardness, cohesiveness, and gumminess of the CN and EA gels. The addition of WPC generally weakened gels that yield when subjected to a compressive strain of 50%. The differences in the functionality of the protein systems offer valuable information for their use in surimi-like products. The improvement in gel characteristics, although lacking the elastic nature that characterizes the unique properties of Kamaboko, may, with additional formulation using hydrocolloids or polysaccharides, provide rheological properties that can be used to emulate surimi-like products.

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