# Physicochemical Characteristics and Functional Properties of Various Commercial Chitin and Chitosan Products

Young In Cho,[†] Hong Kyoon No,*[,†] and Samuel P. Meyers[‡]

Department of Food Science and Technology, Catholic University of Taegu-Hyosung, Hayang 712-702, South Korea, and Department of Food Science, Louisiana State University, Baton Rouge, Louisiana 70803

Physicochemical characteristics and functional properties of five commercially available chitins and five chitosans were investigated. Physicochemical characteristics (nitrogen, ash, degree of deacetylation, bulk density, and viscosity) differed with products. In functional properties, dye binding capacity differed depending on the products, although average binding capacity (63%) of chitosans was higher than that (54%) of chitins. Water binding capacity ranged from 381 to 673% for chitins and from 458 to 805% for chitosans. Fat binding capacities of chitins were mostly similar (316−320%) except for one product (563%), whereas chitosans showed dissimilar binding capacities from 314 to 535%. However, significant correlations were observed between water binding capacity and bulk density ($r = -0.89$, $P < 0.01$) and between fat binding capacity and viscosity ($r = 0.72$, $P < 0.05$) of chitin products. Both water and fat binding capacity of chitosan products were significantly correlated positively with ash ($r = 0.81$, 0.80) and negatively with bulk density ($r = -0.98$, $-0.95$). Emulsifying capacity of egg yolk increased by addition of chitosan compared with the control. No differences in emulsifying capacity of chitosan products were observed at each concentration tested.

**Keywords:** *Chitin; chitosan; physicochemical characteristics; functional properties*

## INTRODUCTION

Natural, nontoxic, biopolymers chitin and chitosan are now widely produced commercially from crab and shrimp waste shells. During the past few decades, chitin and chitosan have attracted significant interest in view of varied proposed novel applications. Use of these two functional polymers, especially chitosan, is noted over a broad range of scientific areas, including use in biomedical, food, and various chemical industries (Knorr, 1984; Muzzarelli, 1977).

Crustacean shell waste consists mainly of 30−40% protein, 30−50% calcium carbonate, and 20−30% chitin (Johnson and Peniston, 1982). These proportions vary with species and with season (Green and Mattick, 1979). Thus, the particular method of chitin and chitosan preparation can vary with sources to meet compositional differences. Similarly, the physicochemical characteristics of chitin and chitosan differ with crustacean species and preparation methods (Brine and Austin, 1981). Several studies (Brine and Austin, 1981; Shimahara et al., 1984; Wu and Bough, 1978) have clearly demonstrated that specific characteristics of these products, that is, molecular weight and degree of deacetylation (DD), vary with process conditions.

The physicochemical characteristics of chitin and chitosan influence their functional properties, which differ with crustacean species and preparation methods. More recent studies (Ahn and Lee, 1992; Byun et al., 1992; Lee et al., 1995) have revealed notable variability in the dye, water, and fat binding capacities of various chitins, chitosans, and their derivatives prepared in the laboratory from crustacean shell wastes. However, few attempts have been made to compare such functional properties with those of commercially available chitin and chitosan products. No et al. (1996) investigated dye binding capacity of two commercial chitin products and two dyes (FD&C Red No. 3 and Yellow No. 5) and reported different dye binding capacities for the two chitin products examined, even with the same dye. Therefore, it is evident that the functional properties of chitin and chitosan products should be carefully monitored to effectively utilize chitinous products for particular usages.

The objectives of the present research were to compare functional properties of various selected commercially available chitin and chitosan products and to determine the relationship between functional properties and physicochemical substrate characteristics.

## EXPERIMENTAL PROCEDURES

**Materials.** Five chitins (designated 1−5) and five chitosans (designated 6−10) used were commercially available products from Keumho Chemical Co. (Seoul, Korea; 1, 6), Sigma Chemical Co. (St. Louis, MO; 2, 7), Pronova Biopolymer (Raymond, WA; 3, 5, 8, 10), Chungmu Co. (Chungmu, Korea; 4), and DuPont (Wilmington, DE; 9). Chitosan from DuPont was provided by the courtesy of Dr. Portier at Louisiana State University. The other chitin and chitosan products were purchased from, or kindly provided by, the companies. Brief information for the products is as follows: chitin 3, unbleached; chitin 5 and chitosan 10, from shrimp shell; the others, bleached and from crab shell.

To obtain a uniform size product, all chitinous samples were ground separately through a Wiley mill (model 4, Thomas Scientific, Swedesboro, NJ); sifted with 40- (0.425 mm), 60- (0.250 mm), 80- (0.180 mm), and 100-mesh (0.150 mm) sieves; placed in opaque plastic bottles; and stored at ambient

* Author to whom correspondence should be addressed (telephone 82 53-850-3219; fax 82 53-850-3252; e-mail hkno@cuth.cataegu.ac.kr).

[†] Catholic University of Taegu-Hyosung.

[‡] Louisiana State University.

S0021-8561(97)01047-9 CCC: $15.00 
Published on Web 08/20/1998

**Table 1. Characteristics[a] of Various Chitin and Chitosan Products**

| product | N (%) | ash (%) | DD[b] (%) | bulk density (g/mL) | viscosity[c] (cP) |
|---|---|---|---|---|---|
| chitin | | | | | |
| 1 | 5.97 ± 0.11[a] | 0.4 ± 0.0[a] | 17.1 ± 0.1[a] | 0.36 ± 0.00[d] | 700 ± 17[c] |
| 2 | 6.21 ± 0.06[a] | 2.0 ± 0.2[b] | 19.6 ± 1.1[b] | 0.38 ± 0.01[d] | 4 ± 3[a] |
| 3 | 7.01 ± 0.04[b] | 1.8 ± 0.4[b] | 19.6 ± 0.1[b] | 0.33 ± 0.01[c] | 18 ± 3[a] |
| 4 | 6.31 ± 0.56[a] | 0.3 ± 0.1[a] | 19.5 ± 0.8[b] | 0.21 ± 0.01[a] | 1152 ± 11[d] |
| 5 | 6.52 ± 0.01[ab] | 0.5 ± 0.0[a] | 19.9 ± 1.6[b] | 0.26 ± 0.01[b] | 610 ± 14[b] |
| chitosan | | | | | |
| 6 | 7.13 ± 0.00[a] | 0.3 ± 0.1[a] | 90.6 ± 0.0[d] | 0.26 ± 0.02[b] | 120 ± 3[b] |
| 7 | 7.16 ± 0.03[a] | 0.2 ± 0.1[a] | 89.9 ± 1.1[d] | 0.38 ± 0.01[c] | 444 ± 6[c] |
| 8 | 7.14 ± 0.08[a] | 1.0 ± 0.2[b] | 83.0 ± 0.0[b] | 0.28 ± 0.00[b] | 1928 ± 11[e] |
| 9 | 6.91 ± 0.28[a] | 0.2 ± 0.1[a] | 72.5 ± 0.0[a] | 0.38 ± 0.01[c] | 72 ± 3[a] |
| 10 | 7.00 ± 0.05[a] | 1.7 ± 0.3[c] | 86.9 ± 1.1[c] | 0.20 ± 0.01[a] | 768 ± 8[d] |

[a] Mean ± standard deviation of duplicate determinations, on a dry basis. Means with different superscripts within a column indicate significant differences ($P < 0.05$). [b] DD, degree of deacetylation. [c] Viscosity was measured with 0.25% chitin solution in DMAc/5% LiCl and 1% chitosan solution in 1% acetic acid, respectively.

temperature. Ground chitin and chitosan of 0.180−0.150 mm size were used throughout this research to obtain reproducible and consistent results. Prior to binding and emulsifying studies, these samples were dried at 105 °C for 2 h.

The dye used for evaluation of dye binding capacity was FD&C Red No. 40 (disodium salt of 6-hydroxy-5-[(2-methoxy-5-methyl-4-sulfophenyl)azo]-2-naphthalenesulfonic acid). Commercially available refined soybean oil was used for fat binding and emulsifying capacity studies.

**Preparation of Dye Solution.** Dye solution was prepared by dissolving dye in deionized water at a concentration of 100 or 500 mg/L. For the standard curve determination, the maximum absorbance of the aqueous dye solutions containing 2.5−20 mg of dye/L was measured with a spectrophotometer (Shimadzu UV-160A, Shimadzu Co., Tokyo, Japan) using deionized water as a blank. The absorbances measured were reduced by the nondye background absorption.

**Dye Binding Capacity.** Dyeing of chitin and chitosan was achieved by shaking 0.2 g of chitin or chitosan and 10 mL of aqueous dye solution (containing 5 mg of dye) in horizontally positioned screw-capped test tubes at 20 °C for 1 h using a shaking water bath (80 rpm). For evaluation of the effect of temperature, 0.2 g of chitin or chitosan was treated with 10 mL of aqueous dye solution (containing 1 mg of dye) at 20 and 80 °C, respectively. After settling of the dyed chitin or chitosan particles, the supernatant was withdrawn with a pipet and filtered through a glass filtering Gooch crucible (1G-3) using a glass microfiber filter paper (Whatman, 47 mm). The dyed chitin or chitosan was then repeatedly washed with deionized water and filtered until the filtrate was clear. The dye concentration of the combined filtrate was determined spectrophotometrically. The amount of dye bound to chitin or chitosan was determined by calculating differences in concentrations between the initial dye solution and the combined filtrate. Dye binding capacity (DBC) was expressed as milligrams of dye per gram of chitin or chitosan or percent adsorption.

**Water and Fat Binding Capacity.** Water (WBC) and fat binding capacity (FBC) of chitin and chitosan were measured using a modified method of Wang and Kinsella (1976). Water or fat absorption was initially carried out by weighing a centrifuge tube containing 0.5 g of sample, adding 10 mL of water or soybean oil, and mixing on a vortex mixer for 1 min to disperse the sample. The contents were left at ambient temperature for 30 min with shaking for 5 s every 10 min and centrifuged at 3200 rpm for 25 min. After the supernatant was decanted, the tube was weighed again. WBC and FBC were calculated as follows: WBC (%) = [water bound (g)/sample weight (g)] × 100; FBC (%) = [fat bound (g)/sample weight (g)] × 100.

**Emulsifying Capacity.** The effect of chitosan on the emulsifying capacity of egg yolk was determined by modifying the method of Borton et al. (1968). Initially chitosan was dissolved in vinegar (apple vinegar, total acidity = 6.5−7.0%) at concentrations of 0 (control), 0.1, 0.3, and 0.5%. Emulsion was prepared by blending 9 g of egg yolk, 12 mL of soybean oil, and 6 mL of vinegar (containing chitosan) using a homogenizer (Nissei AM-12, Tokyo, Japan) at 15000 rpm for 2 min. One gram of the resultant emulsion was taken and blended with 9 mL of 0.1 M NaCl. To this was added soybean oil at a speed of 1 mL/s while stirring until the emulsion broke. Emulsifying capacity was expressed as milliliters of soybean oil added per gram of egg yolk.

**Proximate Analyses.** Nitrogen was determined using a Buchi Auto Analyzer (Basle, Switzerland). Ash was calculated according to standard methods (AOAC, 1990).

**Degree of Deacetylation (DD).** The DD of chitin was established using an IR spectrophotometer (Polaris FT-IR, Mattson Co., Madison, WI) as described by Sannan et al. (1978). The DD of chitosan was determined according to a colloid titration method (Kim, 1996) using N/1200 potassium polyvinyl sulfate (PVSK; esterification degree = 93.2%; Wako Pure Chemical Ind., Osaka, Japan).

**Viscosity.** Viscosities of chitin and chitosan samples were determined with a Brookfield viscometer, model RVT (Brookfield Engineering Laboratories, Inc., Stoughton, MA). Chitin solution was prepared in *N*,*N*-dimethylacetamide (DMAc) containing 5% lithium chloride (5% LiCl) at a 0.25% concentration. Chitosan solution was prepared in 1% acetic acid at a 1% concentration. Measurements were made in duplicate using a No. 5 spindle at 50 rpm on solutions at 20 °C with values reported in centipoise units.

**Bulk Density.** Bulk density of chitin and chitosan was determined following procedures described by Wang and Kinsella (1976) and Anderson et al. (1978). One gram of chitin or chitosan sample (80−100 mesh particle size) was placed in a 15-mL tapered graduated centrifuge tube, vibrated on a vortex mixer for 1 min, and packed by gently tapping the tube on the benchtop 10 times. The volume of the sample was recorded. The procedure was repeated two times for each sample, and the bulk density was computed as grams per milliliter of the sample.

**Statistical Analysis.** All experiments were carried out in duplicate and average values or means ± standard deviations reported. Mean separation and significance for correlation were analyzed using the SPSS (Statistical Package for Social Sciences, SPSS Inc.) software package.

## RESULTS AND DISCUSSION

**Characteristics of Chitin and Chitosan Products.** The physicochemical characteristics of various chitin and chitosan products were determined, and the results are shown in Table 1. The nitrogen content ranged from 5.97 to 7.01% for chitins and from 6.91 to 7.16% for chitosans on a dry basis. However, no significant differences ($P > 0.05$) in nitrogen content

**Table 2. Comparison of DBC before and after Washing of the Dyed Chitin or Chitosan[a] with Deionized Water**

| product | DBC (mg of dye/g of product) | |
|---|---|---|
| | before washing | after washing |
| chitin 2 | 18.6 (74.4%)[b] | 11.1 (44.4%) |
| chitosan 7 | 12.7 (50.8%) | 8.8 (35.2%) |

[a] Dyeing of chitin and chitosan was achieved by shaking 0.2 g of dry chitin or chitosan and 10 mL of aqueous dye solution (containing 5 mg of dye) at 20 °C for 1 h. [b] Average percent adsorption of duplicate determinations.

were observed among chitosan products. The ash contents were different with various products. DD was <20% for chitins and >80% for chitosans except for chitosan 9, which had a DD of 72.5%. Bulk density of chitin and chitosan products was in the range of 0.20−0.38 g/mL, showing up to 1.9 times difference in porosity. Chitin 5 and chitosan 10 from shrimp generally were more porous than crab chitins and chitosans, as reported by Shahidi and Synowiecki (1991). Viscosity differed with products. In chitins 2 and 3, some residual ash may have affected their solubility, consequently contributing to lower viscosity. Particularly, chitin 2 showed almost no viscosity due to little dissolution in DMAc/5% LiCl as observed previously by No et al. (1996). The decreased viscosity of chitosan 9 may be due to its lower molecular weight compared with those of other chitosan products.

The above results clearly demonstrate that critical physicochemical characteristics of chitin and chitosan differ with products. Therefore, it is expected that functional properties may differ.

**Effect of Washing on Dye Binding Capacity.** To compare whether there is any difference in DBC before and after washing of the dyed chitin or chitosan with deionized water, binding capacity was determined using chitin 2 and chitosan 7.

As seen in Table 2, there were considerable differences in the results. DBC was reduced ~30% for chitin and ~16% for chitosan, respectively, after the dyed chitin or chitosan was washed. These results indicate that the DBC of chitin or chitosan could be overestimated by calculating directly from the supernatant after the dyed chitin or chitosan was centrifuged, as done by previous workers (Ahn and Lee, 1992; Byun et al., 1992; Knorr, 1983; Lee et al., 1995), because some dyes may exist unbound between particles and in particle interspaces (Dwivedi and Agrawal, 1994). Therefore, washing of the dyed chitin or chitosan was applied to subsequent dye binding studies.

**Dye Binding Capacity.** DBCs of various chitin and chitosan products were compared, and the results are given in Table 3. Marked differences in binding capacity were observed among products. Chitins and chitosans showed DBC (as percent adsorption) of from 6.8 to 100% and from 35.2 to 85.6%, respectively, at 5 mg of dye concentration/0.2 g of sample. The considerably lower DBC of chitin 3 compared with other chitin products may be due to the product being unbleached.

Earlier, Giles et al. (1958) reported that the acetamide groups of chitin are the adsorptive groups for sulfonated azo dyes. In the present study, the DD values (Table 1) of chitins 2−5 were not significantly different from each other. However, these chitins revealed considerable variations in DBC.

According to Lee et al. (1995), chitosan with 78% DD had >4 times higher DBC than did chitin using Red No. 40. Similarly, Ahn and Lee (1992) found higher DBC for chitosan than for chitin. However, the present data clearly demonstrate that the DBC of chitinous polymers differs considerably depending on the products, although the average binding capacity (63%) of chitosans was higher than that (54%) of chitins.

**Table 3. DBC, WBC, and FBC of Various Chitin and Chitosan Products**

| product | DBC[a,b] (%) | WBC[a] (%) | FBC[a] (%) |
|---|---|---|---|
| chitin | | | |
| 1 | $94.4 \pm 0.6^{d}$ | $407 \pm 42^{a}$ | $320 \pm 33^{a}$ |
| 2 | $44.4 \pm 5.6^{c}$ | $381 \pm 12^{a}$ | $319 \pm 4^{a}$ |
| 3 | $6.8 \pm 0.5^{a}$ | $555 \pm 43^{b}$ | $320 \pm 51^{a}$ |
| 4 | $100.0 \pm 0.0^{d}$ | $559 \pm 24^{b}$ | $563 \pm 1^{b}$ |
| 5 | $25.2 \pm 0.1^{b}$ | $673 \pm 14^{c}$ | $316 \pm 34^{a}$ |
| chitosan | | | |
| 6 | $80.0 \pm 1.8^{d}$ | $671 \pm 37^{b}$ | $446 \pm 24^{b}$ |
| 7 | $35.2 \pm 1.7^{a}$ | $458 \pm 12^{a}$ | $314 \pm 6^{a}$ |
| 8 | $40.8 \pm 0.6^{b}$ | $662 \pm 16^{b}$ | $444 \pm 24^{b}$ |
| 9 | $85.6 \pm 1.4^{e}$ | $506 \pm 43^{a}$ | $344 \pm 7^{a}$ |
| 10 | $72.8 \pm 0.8^{c}$ | $805 \pm 6^{c}$ | $535 \pm 9^{c}$ |

[a] Mean ± standard deviation of duplicate determinations. Means with different superscripts within a column indicate significant differences ($P < 0.05$). [b] At 5 mg of dye concentration/0.2 g of sample.

**Table 4. Effect of Temperatures on DBC of Various Chitin and Chitosan Products**

| product | DBC[a] (% adsorption) | |
|---|---|---|
| | 20 °C | 80 °C |
| chitin | | |
| 1 | $100 \pm 0$ | $100 \pm 0$ |
| 2 | $87 \pm 0$ | $89 \pm 5$ |
| 3 | $20 \pm 0^{a}$ | $33 \pm 0^{b}$ |
| 5 | $67 \pm 2$ | $66 \pm 2$ |
| chitosan | | |
| 6 | $100 \pm 0$ | $100 \pm 0$ |
| 7 | $93 \pm 1^{a}$ | $88 \pm 1^{b}$ |
| 8 | $84 \pm 1$ | $75 \pm 3$ |
| 10 | $100 \pm 0$ | $99 \pm 0$ |

[a] Mean ± standard deviation of duplicate determinations at 1 mg of dye concentration/0.2 g of sample. Means with different superscripts within a row indicate significant differences ($P < 0.05$).

The effects of temperature on DBC were evaluated with four respective chitins and chitosans using 1 mg of dye concentration/0.2 g of sample. Results (Table 4) showed comparable binding capacities at both temperatures of 20 and 80 °C except for chitin 3 and chitosan 7, which exhibited increased and decreased binding capacities, respectively, at the higher temperature. No definite conclusions on the effect of temperature can be drawn from the present results. Differences in DBC between Tables 3 and 4, even with the same chitin or chitosan products, were due to different dye concentrations applied. Percent adsorption of dye to chitin or chitosan generally increases with decreasing dye concentrations (No et al., 1996).

The effect of temperature on the adsorption of dyes to chitin may differ depending on the dyes used (McKay et al., 1982; Dwivedi and Agrawal, 1994). According to McKay et al. (1982), the decrease in adsorption capacity of dye with increasing temperature is due to the enhanced magnitude of the reverse (or desorption) step in the mechanism as the temperature increases. On the other hand, the increase in adsorption capacity of dye with increasing temperature is due to an increase in dye mobility and a temperature-induced swelling effect

**Table 5. Correlation (*r*) between Binding Capacities and Physicochemical Characteristics of Chitins and Chitosans**

| | | physicochemical characteristics | | | | |
|---|---|---|---|---|---|---|
| product | binding capacity (%) | N (%) | ash[a] (%) | DD[a] (%) | bulk density[a] (g/mL) | viscosity[a] (cP) |
| chitin | DBC | −0.71 | −0.55 | −0.52 | −0.23 | 0.27 |
| | WBC | 0.37 | −0.33 | 0.38 | −0.89** | 0.29 |
| | FBC | 0.09 | −0.39 | 0.33 | −0.33 | 0.72* |
| chitosan | DBC | −0.53 | 0.02 | −0.38 | −0.22 | −0.62 |
| | WBC | 0.02 | 0.81* | 0.28 | −0.98** | 0.34 |
| | FBC | −0.09 | 0.80* | 0.28 | −0.95** | 0.35 |
| chitin + chitosan | DBC | −0.34 | −0.39 | 0.10 | −0.22 | −0.10 |
| | WBC | 0.45 | 0.08 | 0.44 | −0.88** | 0.35 |
| | FBC | 0.22 | −0.01 | 0.29 | −0.61* | 0.51* |

[a] *$P < 0.05$, **$P < 0.01$.

within the internal structure of the chitin, allowing the large dye ions to penetrate into the particles. However, a certain dye was found to be unaffected by change in temperature.

**Water and Fat Binding Capacity.** WBC and FBC of chitins and chitosans were measured, and the results are shown in Table 3. WBC differed with products, ranging from 381 to 673% for chitins and from 458 to 805% for chitosans. The average WBC (515%) of five chitins was lower than that (620%) of five chitosans. The present results support those of previous workers (Knorr, 1982; Ahn and Lee, 1992; Byun et al., 1992; Chang et al., 1994) in that chitosan has a higher WBC than chitin. However, the reported binding capacity values were different from each other. Knorr (1982) noted that differences in water binding properties between chitin and chitosan possibly were due to dissimilarities in crystallinity, the amount of salt forming groups, and the residual protein content of the products.

FBC of chitins were mostly similar (316−320%) except for chitin 4 (563%), whereas chitosans showed dissimilar binding capacities ranging from 314 to 535%. The average FBC (368%) of five chitins was somewhat lower than that (417%) of five chitosans. In contrast, other workers (Knorr, 1982; Ahn and Lee, 1992; Byun et al., 1992) found that chitin had higher FBC than chitosan. Similar FBC values between chitin and chitosan were observed by Lee et al. (1995). It is apparent from these conflicting results that chitin can or cannot have higher FBC than chitosan depending on the products used in the study.

**Correlation between Binding Capacities and Physicochemical Characteristics.** Results of correlations between binding capacities and physicochemical characteristics of chitin and chitosan products are shown in Table 5. For chitin products, significant correlations were observed between WBC and bulk density ($r = -0.89$, $P < 0.01$) and between FBC and viscosity ($r = 0.72$, $P < 0.05$). For chitosan products, both WBC and FBC were significantly correlated positively with ash ($r = 0.81$, 0.80) and negatively with bulk density ($r = -0.98$, $-0.95$). A negative correlation between WBC and bulk density of chitin and chitosan also was observed by Chang et al. (1994).

Correlations analyzed with pooled products irrespective of chitin and chitosan products consistently did not show similar trends with those analyzed with respective chitin or chitosan products. However, a significant correlation ($r = -0.88$, $P < 0.01$) between WBC and bulk density with pooled products was observed as in respective chitin and chitosan products. FBC was significantly ($P < 0.05$) correlated negatively with bulk density ($r = -0.61$) and positively with viscosity ($r = 0.51$).

**Table 6. Effects of Various Chitosan Products and Their Concentrations on Emulsifying Capacity of Egg Yolk**

| chitosan product | emulsifying capacity (mL of soybean oil added/g of egg yolk)[a] at chitosan concentration of | | | |
|---|---|---|---|---|
| | 0% (control) | 0.1% | 0.3% | 0.5% |
| 6 | 80.5 ± 1.3 | 82.4 ± 1.0 | 82.4 ± 2.1 | 86.2 ± 1.5 |
| 7 | 80.5 ± 1.3 | 82.0 ± 1.8 | 82.2 ± 1.7 | 86.4 ± 0.4 |
| 8 | 80.5 ± 1.3 | 82.2 ± 1.1 | 82.0 ± 2.1 | 86.6 ± 0.8 |
| 9 | 80.5 ± 1.3 | 82.8 ± 2.9 | 83.5 ± 1.7 | 84.6 ± 1.7 |
| av | 80.5 | 82.3 | 82.5 | 85.9 |

[a] Mean ± standard deviation of duplicate determinations.

**Emulsifying Capacity of Egg Yolk.** The effect of chitosan on the emulsifying capacity of egg yolk was evaluated with four chitosans from crab shell (Table 6). Although chitin and chitosan alone do not produce emulsions (Knorr, 1982), the emulsifying capacity of egg yolk increased with the addition of chitosan compared with the control. Increase in emulsifying capacity (IEC) was more notable with 0.5% chitosan (IEC = 7%) than with 0.1 or 0.3% chitosan (IEC = 2%). However, no notable differences ($P > 0.05$) in emulsifying capacity with chitosan products were observed at each concentration. This suggests the possibility that any chitosan, regardless of physicochemical characteristics, could be utilized to increase the emulsifying capacity of egg yolk in the preparation of foods such as mayonnaise. An increase in the emulsifying capacity of egg yolk with the addition of chitosan also was observed by Lee (1996), who reported that the emulsifying capacity of egg yolk increased ∼10−13% with the addition of 0.1−0.2% chitosan based on egg yolk weight.

In conclusion, this study has clearly demonstrated that both physicochemical characteristics and functional properties, except for emulsifying capacity, of commercially available chitins and chitosans differ with products. Thus, to effectively utilize chitin or chitosan as a functional ingredient, relationships between the functional properties and characteristics of chitin/chitosan products must be constantly monitored for proper quality control. In the current study, limited relevant information on aspects of such relationships was obtained. More extensive investigations are needed for better understanding of the relationships reported in the present research, especially in view of current worldwide interest in commercial utilization of crustacean chitosan.

## LITERATURE CITED

Ahn, C. B.; Lee, E. H. Utilization of chitin prepared from the shellfish crust. 1. Functional properties of chitin, chitosan, and microcrystalline chitin. *Bull. Korean Fish. Soc.* **1992**, *25*, 45−50.

Anderson, C. G.; DePablo, N.; Romo, C. R. Antarctic krill (*Euphausia superba*) as a source of chitin and chitosan. In *Proceedings of the First International Conference on Chitin/Chitosan*; Muzzarelli, R. A. A., Pariser, E. R., Eds.; MIT Sea Grant Program: Cambridge, MA, 1978; pp 54−63.

AOAC. *Official Methods of Analysis*, 15th ed.; Association of Official Analytical Chemists: Arlington, VA, 1990; p 70.

Borton, R. J.; Webb, N. B.; Bratzler, L. J. Emulsifying capacities and emulsion stability of dilute meat slurries from various meat trimmings. *Food Technol.* **1968**, *22*, 506−508.

Brine, C. J.; Austin, P. R. Chitin variability with species and method of preparation. *Comp. Biochem. Physiol.* **1981**, *69B*, 283−286.

Byun, H. G.; Kang, O. J.; Kim, S. K. Syntheses of the derivatives of chitin and chitosan, and their physicochemical properties. *J. Korean Agric. Chem. Soc.* **1992**, *35*, 265−271.

Chang, H. J.; Jeon, D. W.; Lee, S. R. *In vivo* study on the functionality in digestive tract of chitin and chitosan from crab shell. *Korean J. Food Sci. Technol.* **1994**, *26*, 348−354.

Dwivedi, J.; Agrawal, O. P. The formation of chitin-congo red complex. *J. Environ. Biol.* **1994**, *15*, 243−248.

Giles, C. H.; Hassan, A. S. A.; Subramanian, R. V. R. Adsorption at organic surfaces. IV-Adsorption of sulphonated azo dyes by chitin from aqueous solution. *J. Soc. Dyers Colour.* **1958**, *74*, 682−688.

Green, J. H.; Mattick, J. F. Fishery waste management. In *Food Processing Waste Management*; Green, J. H., Kramer, A., Eds.; AVI Publishing: Westport, CT, 1979; pp 202−227.

Johnson, E. L.; Peniston, Q. P. Utilization of shellfish waste for chitin and chitosan production. In *Chemistry and Biochemistry of Marine Food Products*; Martin, R. E., Flick, G. J., Hebard, C. E., Ward, D. R., Eds.; AVI Publishing: Westport, CT, 1982; pp 415−422.

Kim, S. K. Synthetic techniques of chitin and chitosan derivatives and their analytical methods. *Korean J. Chitin Chitosan* **1996**, *1*, 20−47.

Knorr, D. Functional properties of chitin and chitosan. *J. Food Sci.* **1982**, *47*, 593−595.

Knorr, D. Dye binding properties of chitin and chitosan. *J. Food Sci.* **1983**, *48*, 36−37, 41.

Knorr, D. Use of chitinous polymers in food—A challenge for food research and development. *Food Technol.* **1984**, *38*, 85−97.

Lee, S. H. Effect of chitosan on emulsifying capacity of egg yolk. *J. Korean Soc. Food Nutr.* **1996**, *25*, 118−122.

Lee, W. J.; Han, B. K.; Park, I. H.; Park, S. H.; Oh, H. I.; Jo, D. H. Effects of reaction temperature, time and particle size on the physicochemical properties of chitosans. *Korean J. Food Sci. Technol.* **1995**, *27*, 997−1002.

McKay, G.; Blair, H. S.; Gardner, J. R. Adsorption of dyes on chitin. I. Equilibrium studies. *J. Appl. Polym. Sci.* **1982**, *27*, 3043−3057.

Muzzarelli, R. A. A. *Chitin*; Pergamon Press: Oxford, U.K., 1977.

No, H. K.; Cho, Y. I.; Meyers, S. P. Dye binding capacity of commercial chitin products. *J. Agric. Food Chem.* **1996**, *44*, 1939−1942.

Sannan, T.; Kurita, K.; Iwakura, Y. 7. I.r. spectroscopic determination of degree of deacetylation. *Polymer* **1978**, *19*, 458−459.

Shahidi, F.; Synowiecki, J. Isolation and characterization of nutrients and value-added products from snow crab (*Chinoecetes opilio*) and shrimp (*Pandalus borealis*) processing discards. *J. Agric. Food Chem.* **1991**, *39*, 1527−1532.

Shimahara, K.; Takiguchi, Y.; Ohkouchi, K.; Kitamura, K.; Okada, O. Chemical composition and some properties of crustacean chitin prepared by use of proteolytic activity of *Pseudomonas maltophilia* LC102. In *Chitin, Chitosan, and Related Enzymes*; Zikakis, J. P., Ed.; Academic Press: New York, 1984; pp 239−255.

Wang, J. C.; Kinsella, J. E. Functional properties of novel proteins: Alfalfa leaf protein. *J. Food Sci.* **1976**, *41*, 286−292.

Wu, A. C. M.; Bough, W. A. A study of variables in the chitosan manufacturing process in relation to molecular-weight distribution, chemical characteristics and waste-treatment effectiveness. In *Proceedings of the First International Conference on Chitin/Chitosan*; Muzzarelli, R. A. A., Pariser, E. R., Eds.; MIT Sea Grant Program: Cambridge, MA, 1978; pp 88−102.

Received for review December 8, 1997. Revised manuscript received July 6, 1998. Accepted July 8, 1998.

JF971047F