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RESEARCH PAPER

Physical Properties and Molecular Behavior of Chitosan Films

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ABSTRACT

Chitosan films, varying in molecular weight and degree of deacetylation, were prepared by a casting technique using acetic acid as a dissolving vehicle. The physicochemical properties of the films were characterized. Both molecular weight and degree of deacetylation affected the film properties. Powder X-ray diffraction patterns and differential scanning calorimetry thermograms of all chitosan films indicated their amorphous state to partially crystalline state with thermal degradation temperature lower than 280–300°C. The increase in molecular weight of chitosan would increase the tensile strength and elongation as well as moisture absorption of the films, whereas the increase in degree of deacetylation of chitosan would either increase or decrease the tensile strength of the films depending on its molecular weight. Moreover, the higher the degree of deacetylation of chitosan the more brittle and the less moisture absorption the films became. All chitosan films were soluble in HCl–KCl buffer (pH 1.2), normal saline, and distilled water. They swelled in phosphate buffer (pH 7.4), and cross-linking between chitosan and phosphate anions might occur. Finally, transmission infrared and ^{13}*C-NMR spectra supported that chitosan films prepared by using acetic acid as a dissolving were chitosonium acetate films.*

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INTRODUCTION

Chitosan is a cationic natural biopolymer produced by alkaline *N*-deacetylation of chitin, the most abundant natural polymer after cellulose. It becomes an interesting material in pharmaceutical application, especially as a film-former due to its biodegradability, biocompatibility, and low toxicity (1). It can be an easily formed film by a casting technique (2–6). In the pharmaceutical field, many studies on permeation of drug through chitosan films were performed (2,4–8). Drug-loaded chitosan films were also prepared, and most investigations were focused on drug-release studies (3,9–11). Many studies reported that the physicochemical properties of polymer films (i.e., mechanical properties, water uptake and additive content of the films, molecular weight of polymer, drug concentration in films, type of polymer, swelling property, and drug-polymer interaction) affected the drug release from the matrix film systems as well as the drug permeation through the films (12–18). The drug permeation through chitosan films as well as the drug release from chitosan matrix films also depended on the properties of the films (3,5–9,19,20).

To date, not much attention has been given to the study of the effect of chitosan properties, such as molecular weight and degree of deacetylation, on the film characteristics. The chitosan film characteristics varied from one report to another. This may be attributable to the difference in sources of chitin used to produce chitosan, chitosan properties, types of solvent used, and methods of film preparation in which the films were or were not subsequently treated with NaOH solution (21–28). This investigation therefore aimed to study the influence of molecular weight as well as degree of deacetylation on the characteristics of chitosan films prepared by using acetic acid as a dissolving vehicle without being subsequently treated with sodium hydroxide solution. The film properties, such as, morphology, mechanical strength, moisture sorption behavior, swelling property, and molecular behavior of chitosan molecules in the films, that were essential for pharmaceutical dosage form design, especially for coating technology and transdermal drug delivery, were studied.

MATERIALS AND METHODS

Materials

Four types of chitosan derived from crab shell chitin varying in molecular weight (MW) and degree of deacetylation (% DD), that is, very low-viscosity grade (VL type, MW 50,000–60,000) with 82% DD; very low-viscosity grade (VL type, MW 50,000–60,000) with 100% DD; high-viscosity grade (H type, MW 800,000–1,000,000) with 80–85% DD; and high-viscosity grade (H type, MW 600,000–800,000) with 100% DD, were gifts from Dainichiseika Colors and Chemicals Manufacturing. Co. Ltd., Japan. The H-type chitosan is a high-viscosity grade (1000–2000 cps, 0.5wt.-% in 0.5wt.-% acetic acid solution at 20°C) in which the VL-type chitosan is a very low-viscosity grade (5 ± 1 cps, 1wt.-% in 1wt.-% acetic acid solution at 20°C) (data obtained from the manufacturer). All other chemicals were of reagent grade.

Preparation of Chitosan Films

Chitosan was dissolved in 1vol.-% acetic acid solution to obtain 1wt.-% solution. Fifteen grams of chitosan acidic solution were then cast in a dish with a diameter of 43.5 mm and dried at 60°C for 7–9 h.

Morphology Study

Morphology of chitosan films was observed under a scanning electron microscope (model JSM 4510, Jeol, Japan). The samples were attached to the slab surfaces with double-sided adhesive tapes and then coated with gold to a thickness of approximately 30 nm under vacuum to make the samples conductive. Scanning electron photomicrographs were taken at 2000 × magnification.

Powder X-Ray Diffraction Study

Powder X-ray diffraction patterns of chitosan powders and films were measured using X-ray diffractometer (model JDX-3530, Jeol, Japan) with Ni-filtered Cu radiation generated at 30 kV and 30 mA as the X-ray source.

Differential Scanning Calorimetry (DSC)

DSC thermograms of chitosan powders and films were measured using a differential scanning calorimeter (model DSC7, Perkin-Elmer, Norwalk, CT). The samples of 2–4 mg were accurately weighed into solid aluminum pans without seals. The measurements were obtained at a heating rate of 10°C/min under nitrogen purge.

Thermogravimetric Analysis (TGA)

TGA thermograms of chitosan powders and films were measured using a thermogravimetric analyzer (model TGA7, Perkin-Elmer). The sample size of 5–10 mg was weighed into an aluminum pan. The measurements were obtained at 30–340°C at a heating rate of 10°C/min under nitrogen purge.

Tensile Strength Measurement

Tensile strength of chitosan films was measured by using a tensile tester (model 4502, Instron Corp., Canton, MA) under the ASTM standard D882-88 (29). A maximum load of 100 N was used. The samples were cut to 1- × 10-cm pieces. The thickness of the films was measured using a micrometer. Five determinations were made for each sample ($n = 5$). The tensile stress was plotted against the percent of elongation to give a stress–strain curve, and the ultimate tensile strength as well as the percent of elongation at break was reported.

Moisture Sorption Study

Chitosan films were placed inside a desiccator containing saturated solutions of sodium dichromate (54% RH), sodium chloride (75% RH), potassium chloride (84% RH), potassium nitrate (93% RH), and distilled water (100% RH) and stored at 25°C. The weight gain of the films was recorded at predertermibned time intervals over at least 72 h and calculated as the percentage of moisture sorption. The measurement was made in triplicate.

Swelling Property of Chitosan Films

A chitosan film (circular; diameter, 1.6–1.8 cm; thickness, 70–90 μm)was immersed in a medium (distilled water, normal saline, pH 7.4 phosphate buffer and pH 1.2 HCl–KCl buffer) for at least 4 h. Increases in diameter and thickness were measured under microscope (model CHS, Olympus, Japan) and calculated as volume increases. The swelling index was calculated from the volume increase obtained from three determinations, as follows:

$$\text{Swelling index} = (V_2 - V_1)/V_1 \tag{1}$$

where V_1 and V_2 are the volumes of the film before and after immersion in the media, respectively.

Fourier Transform Infrared (FTIR) Spectroscopy

Transmission infrared spectra of chitosan powders and films were measured using a Fourier transform infrared spectrophotometer (model Magna-IR system 750, Nicolet Biomedical Inc., Madison, WI). The powders were measured using the KBr method, and the films were directly measured for FTIR spectra.

Nuclear Magnetic Resonance (NMR) Spectroscopy

^{13}C-NMR spectra of chitosan powder and chitosan films were measured using high-resolution solid-state ^{13}C NMR spectrometer (model DPX 300, Bruker, Switzerland). The spectra were recorded with the cross-polarization magic angle spinning (CP-MAS) method at 75.46 MHz using a Bruker z-32DR ^{13}C-MAS probe. The contact time for cross-polarization was 1 ms. The 90° pulse width at 5 ms and repetition time was 4 s. ^{13}C chemical shifts were calibrated using adamantane (29.5 ppm from tetramethylsilane).

RESULTS AND DISCUSSION

Morphology of Chitosan Films

All chitosan films were clear and colorless to pale yellow. The films, especially those prepared from lower-molecular-weight chitosan (VL type), became dark yellow after storage for a few weeks. The average thickness of the films ranged from 70 to 90 μm. The scanning electron photomicrographs of all films exhibited the smooth surface without pores (Fig. 1). The scratches in films were attributable to the nonsmooth surface of the cast dishes.

Powder X-Ray Diffraction Study

Powder X-ray diffraction patterns of all chitosan powders showed diffraction peaks at approximately 10° (2θ) and 20° (2θ) (Fig. 2). All types of chitosan powders were of crystalline state. It was noted that the diffraction peaks at approximately 10° (2θ) of both VL-100% DD and H-100% DD chitosan were 10.68° (2θ) and 10.96° (2θ), respectively whereas those of VL-82% DD and H-80–85% DD chitosan were 9.84° (2θ) and 9.56° (2θ), respectively. This indicated that the diffraction peak at approximately 10° (2θ) of higher deacetylated chitosan appeared at a slightly higher diffraction angle. It was known that the functional group substituted at the α carbon atom of chitosan molecules with 100% DD was only an amino group, whereas that of lower degree of deacetylation was either an amino group or an acetylamide group. The polymer chains substituted with amino groups, which were smaller, would be packed more densely than those substituted with acetylamide groups, which might cause some steric effects. The difference in molecular structure of chitosan molecules leading to such arrangements seemed to have an effect on

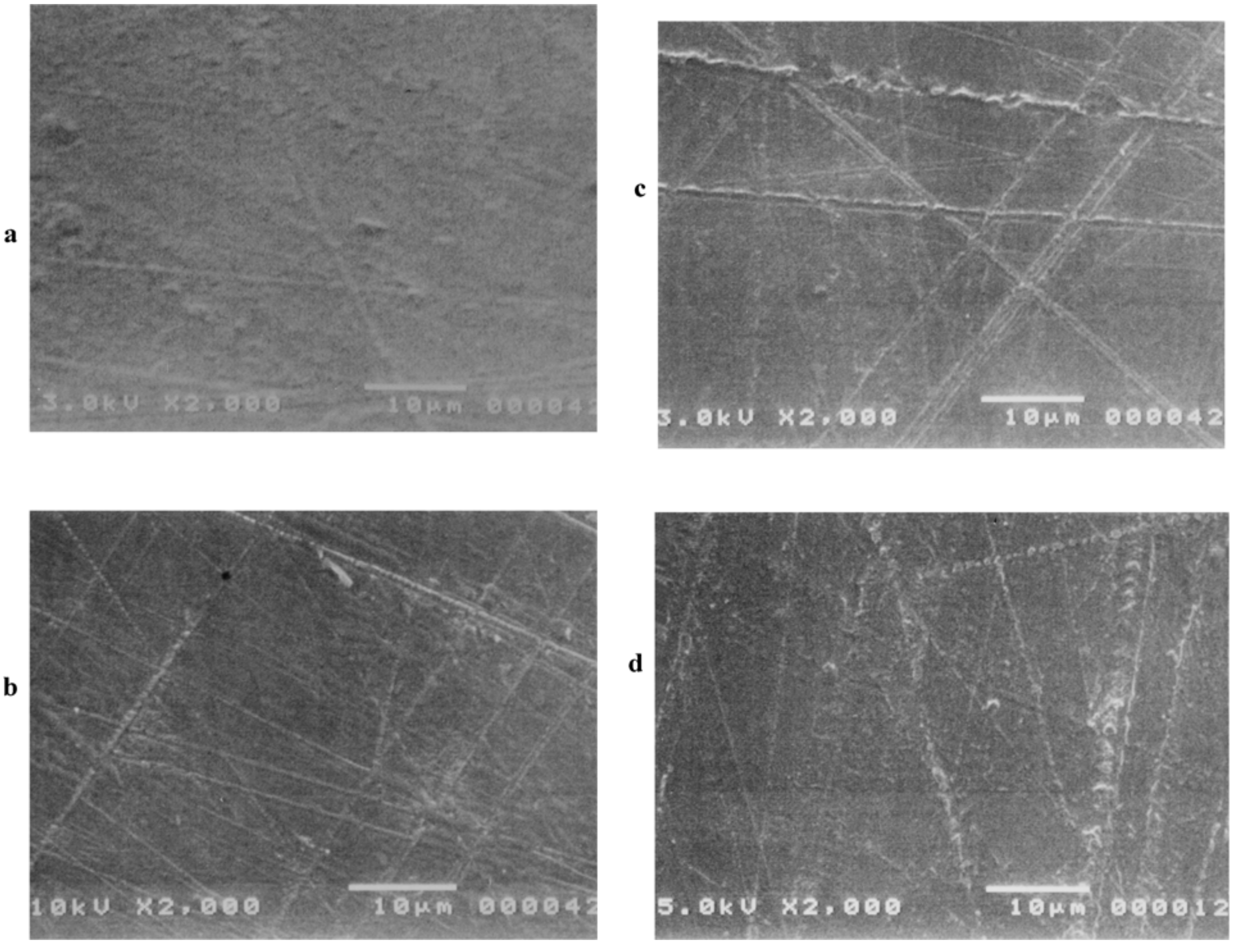

Figure 1. Scanning electron photomicrographs of chitosan films prepared from chitosan of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

X-ray diffraction of these crystalline molecules at approximately 10° (2θ).

When processing chitosan powders into films, the halo diffraction pattern was observed, indicating an amorphous state of the films (Fig. 3). However, the crystalline peaks at approximately 10° (2θ) and 18° (2θ) were observed in low intensity and could be hardly observed in the film prepared from chitosan VL-82%DD. Ogawa et al. (24) reported the crystallinity of chitosan membranes that were prepared in the aqueous acetic acid solution and subsequently treated with sodium hydroxide. They reported that the diffraction peaks at approximately 10° (2θ) and 15° (2θ) were attributed to the hydrated and anhydrous crystals, respectively. They found that the ratio of the amount of anhydrous crystals increased when the lower-molecular-weight chitosan was used in the membrane preparation, whereas the amount of hydrated crystals increased with an increase of the molecular weight of chitosan. In our study, chiotsan films were not treated with soduim hydroxide as in Ogawa's study. It was found that the hydrated crystal peak at approximately 10° (2θ) of the films prepared from H-type chitosan was higher than those prepared from VL-type chitosan. In addition, the intensity of the hydrated crystal at approximately 18° (2θ) was very low. It might be concluded that all chitosan films were in amorphous state to partially crystalline state.

Thermal Behavior of Chitosan Films

As shown in Figure 4, DSC thermograms of all chitosan powders exhibited the broad endothermic peaks attributable to water loss at approximately 35–160°C and the exothermic decomposition peaks at onset at 280–300°C. These changes corresponded to the weight loss in TGA

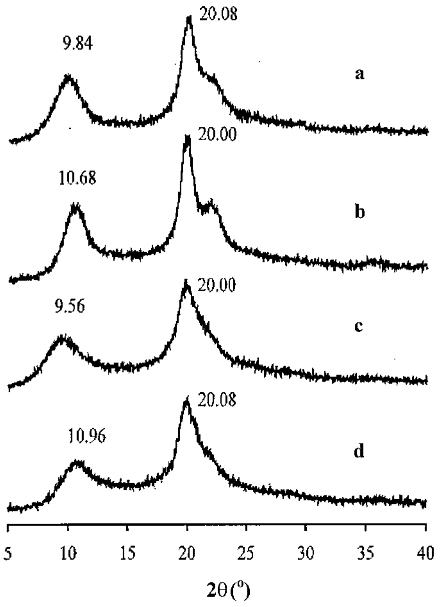

Figure 2. X-ray diffraction patterns of chitosan powder of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

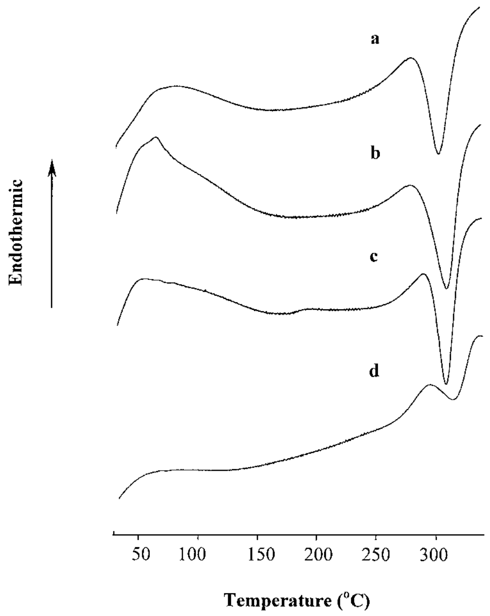

Figure 4. DSC thermograms of chitosan powders of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

thermograms as illustrated in Figure 5. The change in weight loss at a lower temperature was attributed to dehydration of water, and the change at higher temperature was attributed to polymer decomposition. DSC and TGA thermograms of chitosan films are shown in Figures 6 and 7, respectively. The broad endothermic peaks attributable to water loss followed by exothermic decomposition peaks were observed. In TGA thermograms, two steps of weight

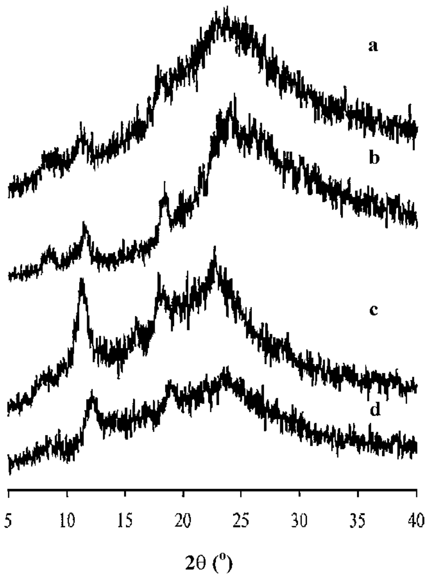

Figure 3. X-ray diffraction patterns of chitosan films prepared from chitosan of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

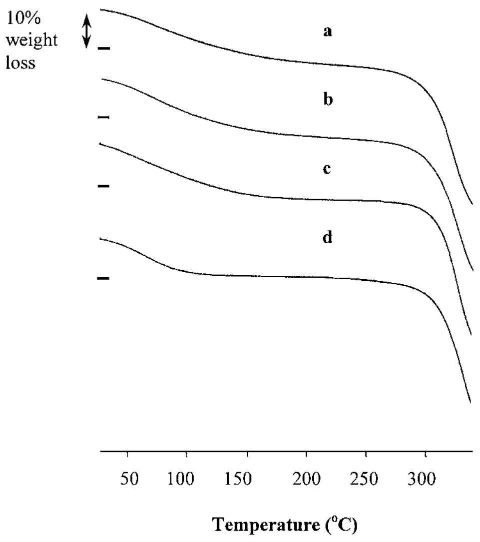

Figure 5. TGA thermograms of chitosan powders of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

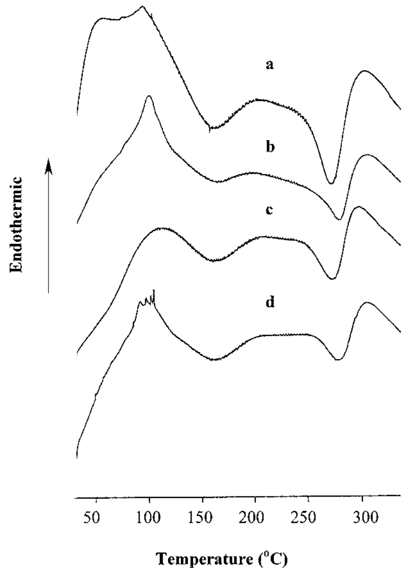

Figure 6. DSC thermograms of chitosan films prepared from chitosan of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

Table 1.

Ultimate Tensile Strength (UTS) and percent of Elongation at Break of Chitosan Films Prepared from Chitosan of Different Grades

Type of Chitosan Films	UTS (MPa)[a]	% Elongation at Break[a]
VL-82% DD	45.07 ± 3.10	9.34 ± 1.13
VL-100% DD	36.77 ± 2.48	4.79 ± 1.17
H-80-85% DD	52.93 ± 6.44	23.82 ± 4.11
H-100% DD	61.76 ± 5.14	18.25 ± 6.08

[a] All values were mean ± SD of five samples.

loss were observed, which were in agreement with DSC results. It was noted that thermal degradation of the films took place at a lower temperature than those of chitosan powders. Lim and Wan (28) reported the exothermal decomposition peaks of chitosan flakes and films, without reporting their molecular weights, at 315 and 290°C, respectively, and the water loss near 100°C, which are in good agreement with the results obtained in our study.

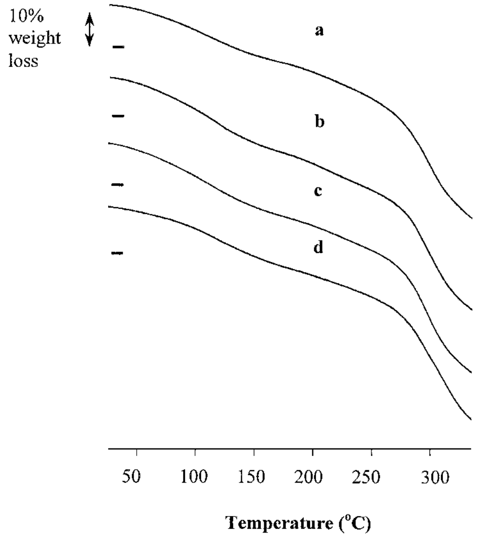

Figure 7. TGA thermograms of chitosan films prepared from chitosan of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

Mechanical Strength of Chitosan Films

The stress–strain plot of various chitosan films are illustrated in Figure 8. The ultimate tensile strength (UTS) and the elongation at break are summarized in Table 1. The results were compared statistically at 95% confident interval using ANOVA. The UTS and percent of elongation at break of the films prepared from H-type chitosan were significantly higher than those prepared from VL-type chitosan ($p < 0.05$), demonstrating that the mechanical strength of the film increased with an increase in the molecular weight of chitosan. This might be attributable to an entanglement network forming during film formation of higher-molecular-weight chitosan. This result was in

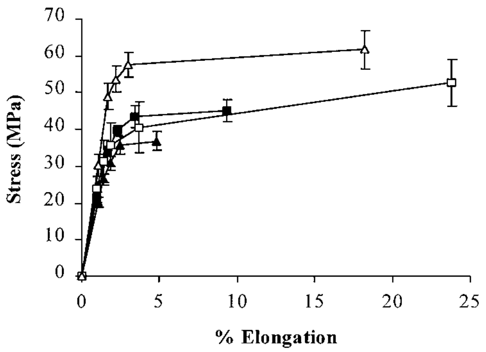

Figure 8. Stress and elongation curves for chitosan films prepared from chitosan of different grades: (■) VL-82% DD, (▲) VL-100% DD, (□) H-80–85% DD, and (△) H-100% DD. Data represented mean ± SD of five determinations ($n = 5$).

good agreement with results from Chen and Hwa's study (27). They found that the tensile strength of chitosan films prepared from chitosan with 90% DD increased with the increasing molecular weight of chitosan. In the case of H-type chitosan films, the films with 100% DD had a higher mechanical strength than did the films with 80–85% DD ($p < 0.05$). The effect of the higher degree of deacetylation of chitosan molecules on the increased mechanical strength of films could be explained by the denser packing of the polymer chains substituted with small amino groups, resulting in higher interchain attraction that therefore resulted in higher mechanical strength. The inverse effect of the degree of deacetylation of chitosan on the mechanical strength of the film was observed in the films prepared from VL-type chitosan. It might be attributable to the fact that the very low-molecular-weight polymer did not have sufficient entanglement network to form films. The effect of the degree of deacetylation on the brittleness of the films was also observed. An increase in the degree of deacetylation would decrease the percent of elongation at break, resulting in the more brittleness of the films. There was inconsistency of findings on the effect of the degree of deacetylation on the mechanical strength of chitosan films. Mima et al. (22) and Chen and Lin (26) investigated the tensile strength of chitosan films that were prepared in the aqueous acetic acid solution and subsequently treated in sodium hydroxide. In Mima's study, they used chitosan with the weight average molecular weight of approximately 5×10^5, whereas there was no report concerning molecular weight of chitosan used in Chen's study. They found that the tensile strength of chitosan films in wet state increased markedly with increasing degree of deacetylation of chitosan molecules, whereas, the dry film did not show a corresponding significant increase in the tensile strength. Blair et al. (23) found that the tensile strength and elongation of the films (in dry state) prepared from chitosan [molecular weight determined from solution viscosity $(M_v) = 0.44 \times 10^5 - 2.54 \times 10^5$] derived from chitin of prawn shells and crab shells would decrease with prolonged treatment in alkaline solutions and with increased degree of deacetylation. The result obtained in the study of the films prepared from VL-type chitosan was similar to that reported by Blair et al (23). It might be concluded that the effect of the degree of deacetylation of chitosan on mechanical strength of the film was related to the molecular weight of chitosan. As the degree of deacetylation increased, the mechanical strength of the high-molecular-weight (H-type) chitosan film increased, whereas that of the low-molecular-weight (VL-type) chitosan films decreased.

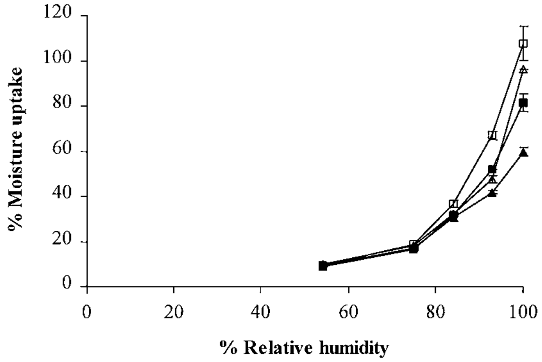

Figure 9. Moisture sorption isotherms of chitosan films prepared from chitosan of different grades at different % RH and 25°C: (■) VL-82% DD, (▲) VL-100% DD, (□) H-80–85% DD, and (△) H-100% DD. Data represented mean ± SD of three determinations ($n = 3$).

Moisture Sorption Isotherms of Chitosan Films

The moisture sorption isotherms of various chitosan films showed an increase in moisture sorption with an increase in relative humidity (Fig. 9). The H-type chitosan provided the films that could absorb more moisture at higher humidity (ANOVA, $p < 0.05$). Moreover, it was observed that the H-type chitosan could uptake more moisture at a higher rate than could the VL-type chitosan films (data not shown). The effect of the degree of deacetylation on moisture absorption was also observed. At the same range of molecular weight, the films with a lower degree of deacetylation could absorb more moisture at >84% RH

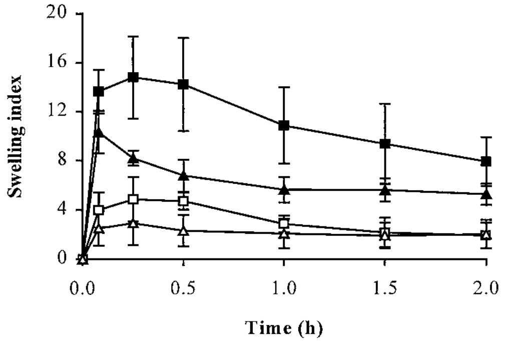

Figure 10. Swelling index of chitosan films prepared from chitosan of different grades in pH 7.4 phosphate buffer: (■) VL-82% DD, (▲) VL-100% DD, (□) H-80–85% DD, and, (△) H-100% DD. Data represented mean ± SD of three determinations ($n = 3$).

(ANOVA, $p < 0.05$). This finding was in good agreement with the data reported by Blair et al. (23).

Swelling Property of Chitosan Films

The swelling property of chitosan films were different in various media. All films readily dissolved in pH 1.2 HCl–KCl buffer and normal saline. Chitosan molecules formed acetate salts during film formation in aqueous acetic acid solution. Being immersed in an acidic medium and an aqueous solution in the presence of chloride ions, the ionization of protonated amino groups in chitosan molecules occurred, resulting in dissolution of the films. It was also noted that the films became gel like and gradually dissolved into the media. The H-type chitosan films dissolved in both media more slowly than did the VL-type films.

In distilled water, the dissolution of the films was slower than that in an acidic medium and normal saline. The films prepared from VL-type chitosan swelled rapidly and subsequently dissolved, whereas the films prepared from H-type chitosan with 80–85% DD and 100% DD swelled extensively with a swelling index of 1334.6 and 11.63, respectively, after 2-h immersion. Afterward, the films continued swelling then disintegrated into small fragments.

In phosphate buffer (pH 7.4), all chitosan films swelled greatly at an initial period of 15 min and then decreased in volume with increased time (Fig. 10). Although the

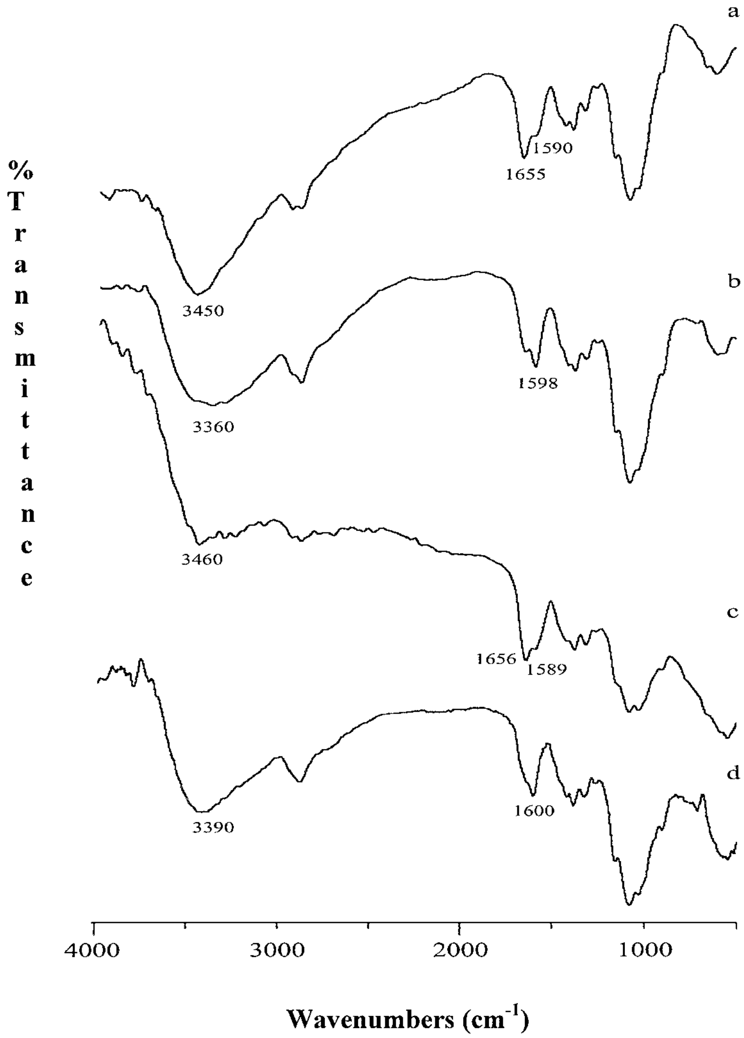

Figure 11. Transmission infrared spectra of chitosan powders of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

volume of the swollen films decreased, the films became denser with color change from colorless to creamy white. Cross-linking between cationic amino groups of chitosan and phosphate anions in the buffer was reported in many studies (30–32), and this might be the reason for a decrease in volume of swollen films. First, the films absorbed water and began to swell, and an amino group of chitosan was simultaneously protonated. Then phosphate anions in the medium penetrated the swollen film to cross-link at quaternary ammonium groups of chitosan molecules. The cross-linking process increased as the time progressed, resulting in the denser films with reduced volumes. The result also demonstrated that VL-type chitosan provided the films with higher swelling ability than did H-type chitosan, and the films prepared from chitosan with 80–85% DD could swell more than those prepared from chitosan with 100% DD (ANOVA, $p < 0.05$).

FTIR Spectroscopy

FTIR spectroscopy was used to give information about the molecular state of chitosan in the cast films. The transmission infrared spectra of all chitosan powders exhibited the broad peaks in a range from 3450 to 3390 cm^{-1} (Fig. 11). The peaks were assigned to an OH stretching, indicating intermolecular hydrogen bonding of chitosan molecules, and they also overlapped in the same region of an NH stretching (33). The C=O stretching (amide I)

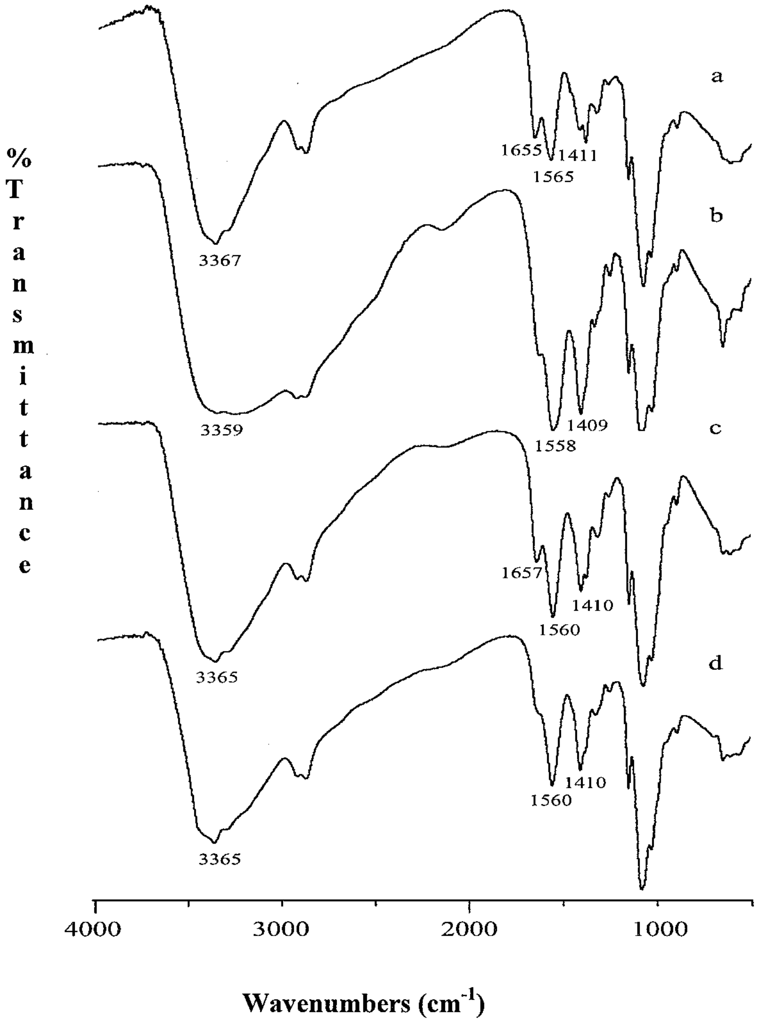

Figure 12. Transmission infrared spectra of chitosan films prepared from chitosan of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

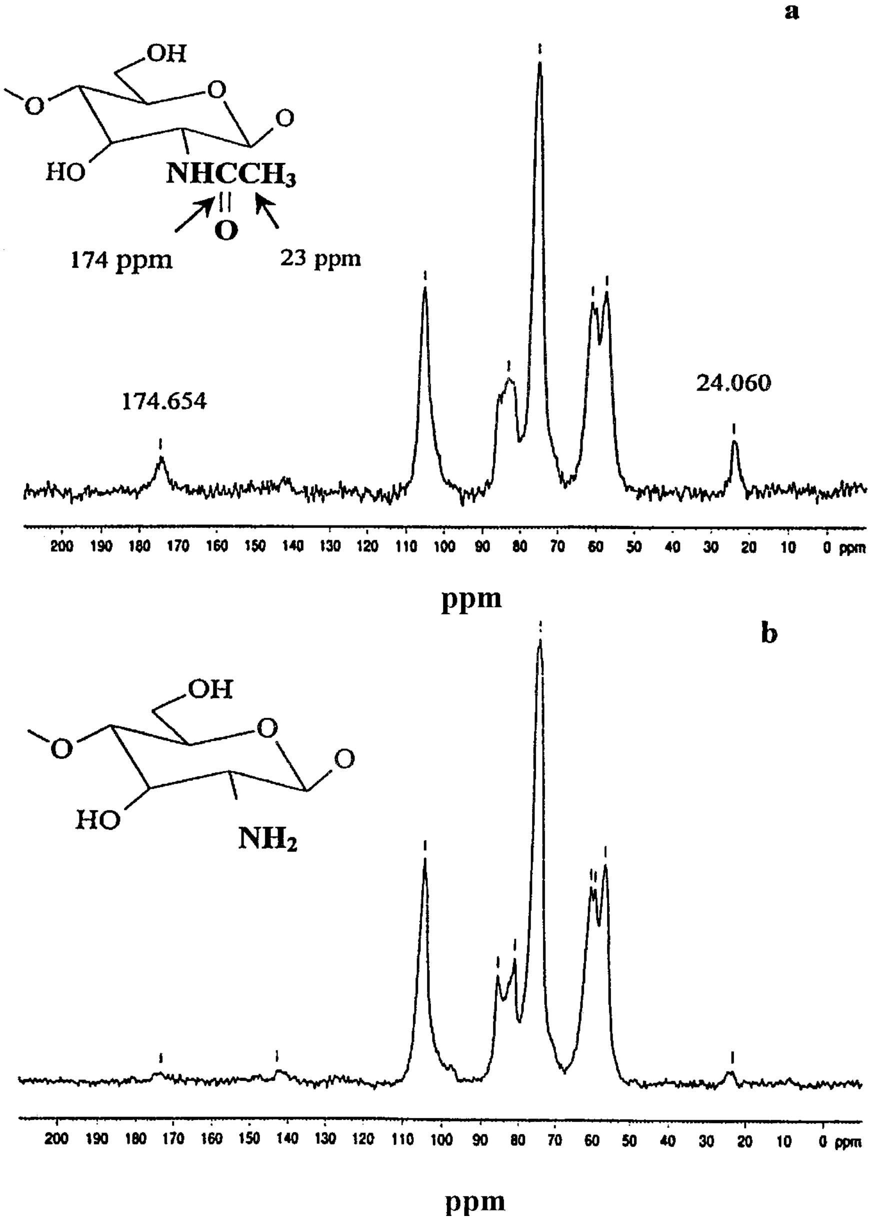

Figure 13. Solid-state ^{13}C NMR spectra of chitosan powders of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

peak near 1655 cm^{-1} and the NH bending (amide II) peak near 1590 cm^{-1} regions were observed only in the spectra of chitosan with a lower degree of deacetylation (VL-82% DD and H-80–85% DD); Fig. 11 a and c. These peaks represented the structure of *N*-aetylglucosamine, which could be found in chitosan with a lower degree of deacetylation (34). Although a peak of NH_2 stretching near 1600 cm^{-1} was obviously observed in the spectra of chitosan with a higher degree of deacetylation (VL-100% DD and H-100% DD; Fig. 11 b and d), the peak associated with an amide II could be observed near 1655 cm^{-1} in the spectra of the film prepared from VL-100% DD chitosan, and it might be claimed that this type of chitosan was not absolutely deacetylated.

In all spectra of chitosan films (Fig. 12), an OH stretching peak was still detected. The peak attribututed to the

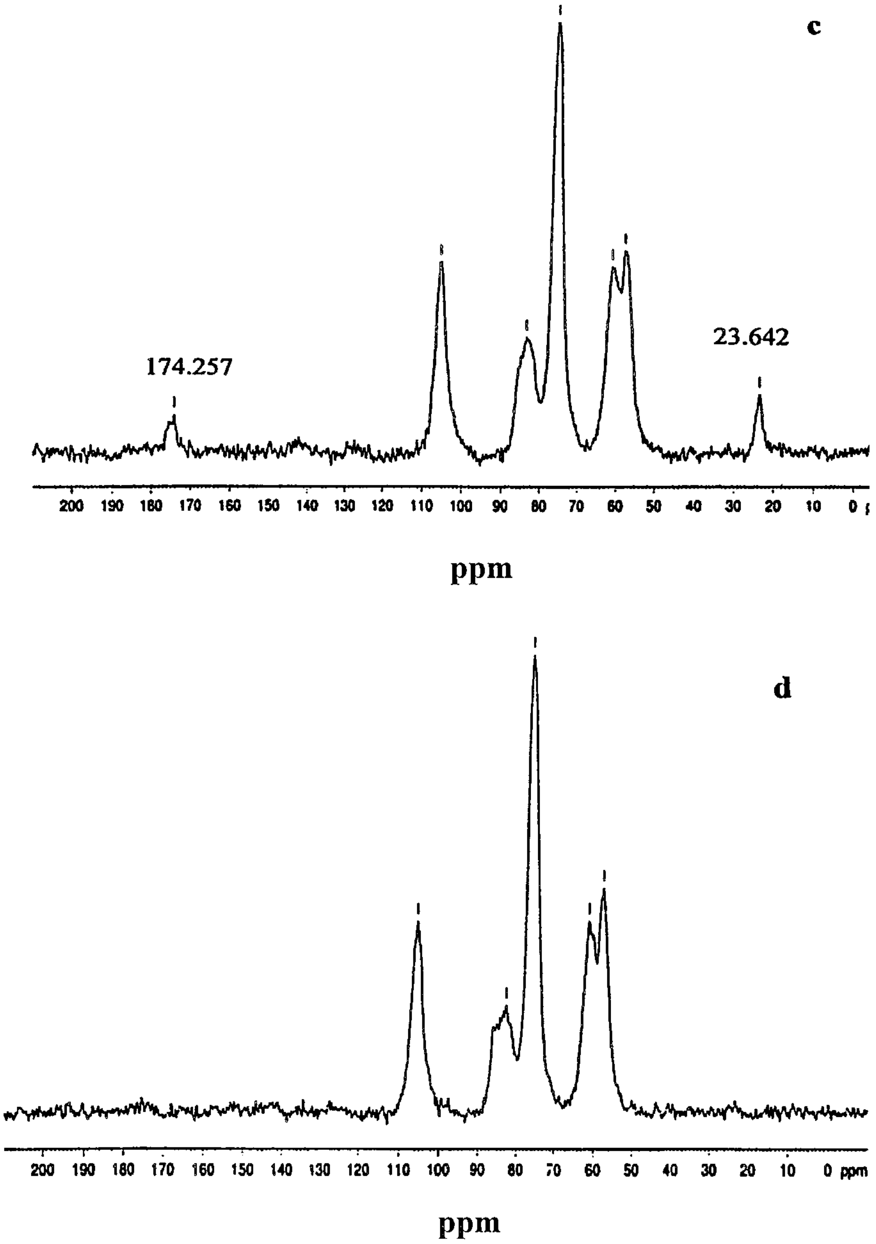

Figure 13. *Continued.*

C—O stretching at 1655 and 1657 cm^{-1} were observed in the films prepared from chitosan with a lower percentage of DD. The strong peak at 1550–1600 cm^{-1} and the weak peak near 1400 cm^{-1} regions in all spectra were attributable to an asymmetric and a symmetric carboxylate anion stretching, respectively. It was indicated that all chitosan films prepared using acetic acid as a dissolving vehicle were chitosonium acetate films.

NMR Spectroscopy

The application of the solid-state NMR method, namely carbon-13 cross-polarization magic angle spinning, was used in the spectral assignment of sugar resonances in chitosan powders and chitosan films. The analyses of ^{13}C-spectra of chitosan powders of varying degree of viscosity and *N*-acetylation are illustrated in Fig. 13.

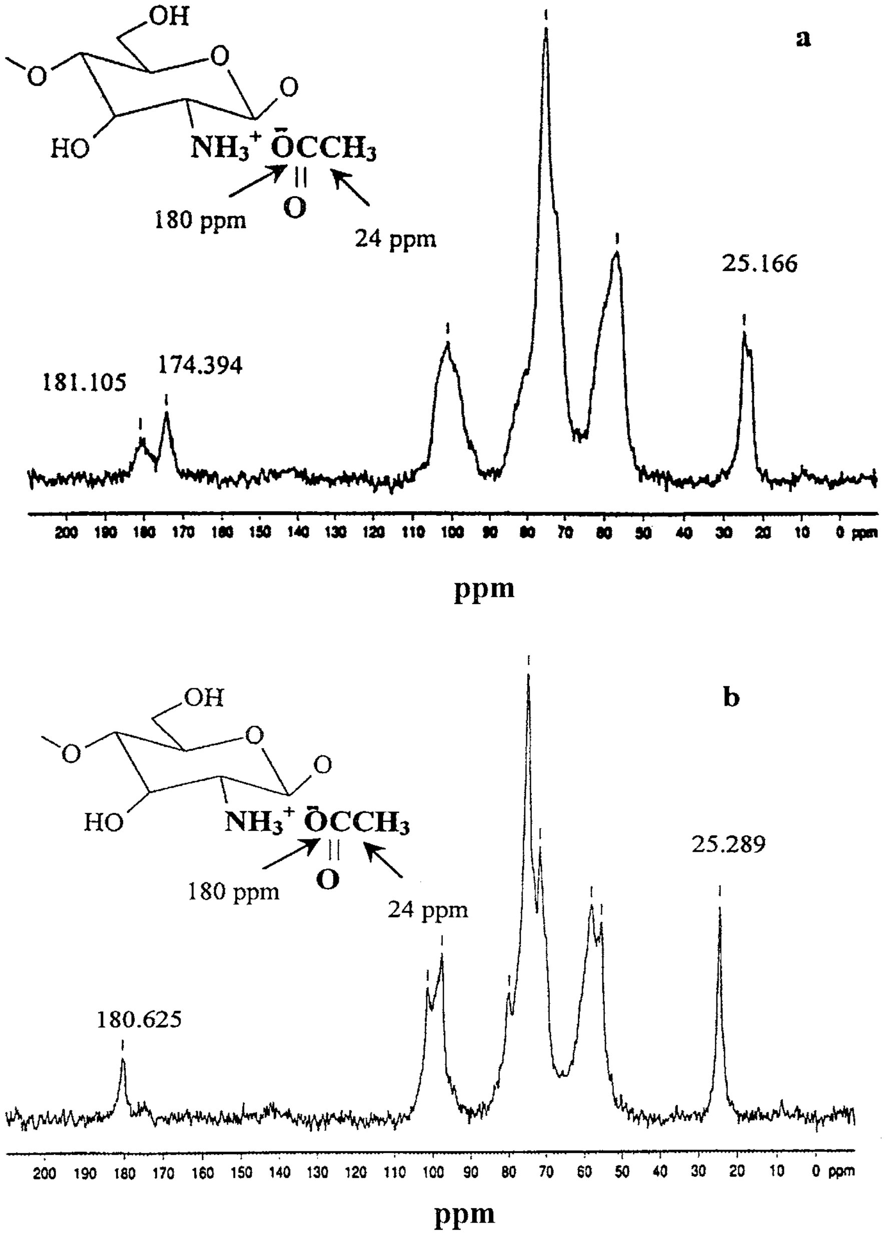

Figure 14. Solid-state ^{13}C NMR spectra of chitosan films prepared from chitosan of different grades: a) VL-82% DD, b) VL-100% DD, c) H-80–85% DD, and d) H-100% DD.

The assignments of chitosan resonances were according to Saito et al. (35). The sugar resonances at 24 ppm, 50–110 ppm, and 174 ppm in chitosan powders (VL-82% DD, Fig. 13a) were assigned to acetyl carbon, methine/methylene carbons, and amide-carbonyl carbon, respectively. The spectrum of chitosan powders with higher viscosity also showed the same pattern (Fig. 13c). It indicated that the degree of polymerization does not affect the sugar resonances. The resonances of acetyl carbon and carbonyl carbon disappeared in the spectra of chitosan powders with a high degree of *N*-deacetylation, which indicated the presence of glucosamine units or the complete deacetylation of the commercial product used (Fig. 13b and d). The sugar resonances of chitosan

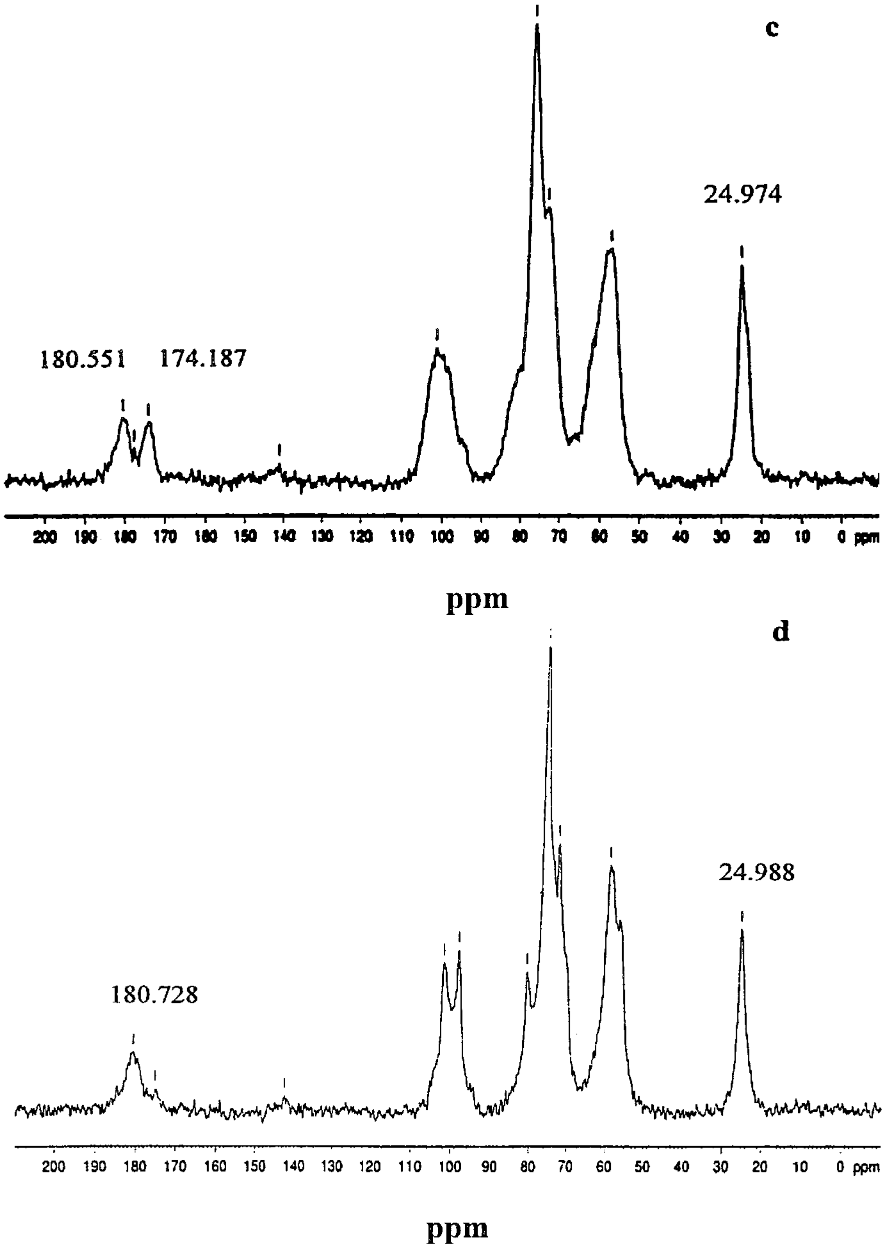

Figure 14. *Continued.*

films with 80–85% DD were relatively broad with an additional resonance of approximately 180 ppm assigned to carbonyl carbon resonance in the films (Fig. 14a and c). The line broadening in the spectra might be attributable to chemical shift dispersion and molecular motion such as exchange among magnetically nonequivalent spins, ^{1}H-^{13}C dipolar coupling (33). The downfield shift might be attributable to the appearance of the electronic deshielding effect of the acetosonium functionality in the chitosan films. The resonances of approximately 25 ppm in the spectra of chitosan films, assigned to the CH_3 carbon, were observed in the spectra of all chitosan films (Fig. 14). It indicated that chitosan films prepared using acetic acid as a dissolving vehicle were in the form of chitosonium acetate (36). However, the resonance of approximately 174 ppm, assigned to amide-carbonyl carbon, was still observed in the spectra of chitosan films with 80–85% DD because of the incomplete deacetylation (Fig. 14a and c).

CONCLUSION

Physicochemical characterization of chitosan films revealed much knowledge about chitosan polymers. Varying chitosan properties of molecular weight and degree of deacetylation would provide the films with various different characteristics. Chitosan films obtained by casting from aqueous acetic acid solution were in amorphous form to partially crystalline form. All chitosan films degraded at temperature $< 280–300^{\circ}C$. Chain entanglement network forming in high-molecular-weight chitosan as well as close packing arrangement of polymer chains with a high degree of deacetylation would affect the characteristics of the film. The increase in molecular weight of chitosan would increase the tensile strength and elongation as well as the moisture absorption of the films, whereas the increase in the degree of deacetylation of chitosan would either increase or decrease the tensile strength of the films depending on the molecular weight. Moreover, the increase in the degree of deacetylation of chitosan also decreased the elongation and moisture absorption of the films. All chitosan films were soluble in pH 1.2 HCl–KCl buffer, normal saline, and distilled water. They swelled in pH 7.4 phosphate buffer, and cross-linking between chitosan and phosphate anions might occur. The transmission infrared and the ^{13}C-NMR spectra supported that chitosan films prepared using acetic acid as a dissolving vehicle were chitosonium acetate films. According to these results, additional study of the development of chitosan films for drug delivery systems especially the matrix film system would be valuable. The incorporation of some drugs, especially an acidic drug, into chitosan films should be investigated because the drug might interact with chitosan molecules at an amino functional group as did the acetate anion. We also plan additional study of the physicochemical characterization of drug-loaded chitosan films with an acidic and a basic model drug as well as of the drug release from such films.

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