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Preparation and characterization of novel oxidized cellulose acetate methyl esters

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ABSTRACT

In this paper, we report the preparation of oxidized cellulose acetate methyl esters (OCAM) from OCA (OC14A: carboxylic acid content 10.6% (w/w), degree of acetyl group substitution: 1.89; OC21A: carboxylic acid content 15.7% (w/w), degree of acetyl group substitution: 1.70) by treatment with methanol at room temperature using 4-dimethylaminopyridine (DMAP) as a catalyst and dicyclohexylcarbodiimide (DCC) as a coupling agent. The new polymers were characterized by Fourier-transform infrared (FT-IR) and ^{1}H and ^{13}C nuclear magnetic resonance spectroscopies, carboxylic acid content determination, moisture sorption isotherms, intrinsic viscosity, and powder X-ray diffractometry. The new polymers are amorphous powders. It is practically insoluble in water but show solubility in a range of organic solvents.

1. Introduction

Recently, considerable interest has been focused on the use of carboxyl-functionalized cellulose (6-carboxycellulose – commonly referred to as oxidized cellulose (OC)) as a drug carrier. Oxidized cellulose containing 3–25% carboxylic acid content is biodegradable and biocompatible (Dimitrijevich, Tatarko, & Gracy, 1990). Currently, OC containing 16–24% free carboxylic acid groups is used in humans as a hemostatic agent and as a post-surgical adhesion barrier (Stillwell, Marks, Sferstein, & Wiseman, 1997). Studies show that OC also possesses antibacterial (Abaev, Kaputskii, Adarchenko, & Sobeshchukh, 1986), antitumor (Tokunaga & Naruse, 1998), immunostimulant (Otterlei, Espvik, Skjak-Braek, & Smidsrod, 1992), and wound healing properties (Finn, Schow, & Schneiderman, 1992; Pollack & Bouwsma, 1992). Owing to the presence of carboxyl groups, it also serves as an immobilizing matrix for a variety of amine drugs (Dol'berg et al., 1974; Zimatkina, Yurkshtovich, Zimatkin, & Kaputsky, 1996), for enzymes (Alinovskaya, Yurkshtovich, & Kaputskii, 1989; Alinovskaya, Kaputskii, Yurkshtovich, Talapin, & Stel'makh, 1988), and for proteins (Kumar & Deshpande, 2001). Despite these properties, OC has found very little use in pharmaceutical preparations. This is because OC is practically insoluble in water and common organic solvents and, hence, offers little or no formulation flexibility. To overcome the solubility problem, we recently prepared oxidized cellulose acetates (carboxylic acid content 18.1%; acetyl group degree of substitution 1.1–2.2) (OCA), from OC containing 20% carboxylic acid content (0.47 mmol/g) (Kumar & Yang, 2002a). The new polymers show solubility in a range of organic solvents (hexane 2.7 mg/ml; toluene 2.63 mg/ml; ethyl ether 2.82 mg/ml; ethyl acetate 18.05 mg/ml; chloroform 3.47 mg/ml; and methanol 11.71 mg/ml (Yang, 2005). However, because of the high free carboxylic acid groups, they hydrate and eventually dissolve at physiologic pH and in aqueous alkaline solutions. This limits their use in the design and development of long term sustained release formulations.

To resolve this problem, in this paper, the methyl ester of OCA (OCAM) has been prepared by reacting OCA with methanol using DCC/DMAP as coupling agent and catalyst in room temperature. The hypothesis was that the substitution of carboxylic acid group in OCA by an ester group leads to a decrease in hydrophilicity and consequently increased solubility in organic solubility. DCC/DMAP coupling method provides a mild reaction condition which prevents degradation of OC during reaction. Compared to H_2SO_4 method (Mark & Siggin, 1945), it is more suitable for polysaccharides. In this study, oxidized celluloses with 14% and 21% carboxylic acid content (w/w) have been used as the starting materials and their corresponding acetate methyl esters have been prepared. The resulting methyl esters show good solubility in methylene dichloride and chloroform with improved hydrophobic properties

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compared to their starting material. The resulting OCAMs have been characterized using FT-IR, ^{1}H NMR, ^{13}C NMR, PXRD, and VTI, etc. technologies.

2. Experimental

2.1. Materials

Oxidized celluloses (OC) containing 14% and 21% carboxylic acid content (hereinafter abbreviated as OC21 and OC14, respectively) were prepared from cotton linters (grade 10-270; Southern Cellulose Products, Inc., Chattanooga, TN) by treatment with a mixture of H_3PO_4–HNO_3/$NaNO_2$ at room temperature, according to the procedure reported by Kumar and Yang (Kumar & Yang, 2002b). 4-N,N-dimethylaminopyridine (DMAP) and dicyclohexylcarbodiimide (DCC) were from Aldrich (St. Louis, MO) and used as catalysts. All other chemicals were purchased from Fisher Scientific Co. (Fair Lawn, NJ) and used as received.

2.2. Preparation of oxidized cellulose acetates

OC (100 g) was soaked in 500 ml of distilled water for 12 h and then dehydrated with 500 ml of glacial acetic acid. The treated OC was added to 1000 ml of a mixture of glacial acetic acid, acetic anhydride and sulfuric acid (1:1:0.002, v/v/w) at room temperature. The reaction mixture was stirred at 30 °C for 24 h. The resulting clear solution was cooled to room temperature and then poured into 1000 ml diethyl ether, which had been previously cooled in an ice-water bath. The white solid that formed was filtered, washed with distilled water to a constant pH (between 4 and 5), and finally dried under vacuum (127 mmHg) at 50 °C.

The yield of OCA was calculated according to Eq. (1):

$$\%\,\text{Yield} = \frac{\text{Weight of the product}}{\text{Theoretical weight of the product}} \times 100 \quad (1)$$

The theoretical weight of the product was calculated from the relationship presented below:

$$\text{Theoretical weight of OCA} = \frac{\text{Weight of OC}}{173.0} \times (173.0 + \text{DS} \times 42) \quad (2)$$

where 173.0 is the average molecular weight of the anhydroglucose ring in OC and 42 is the molecular weight of the acetyl group.

2.3. Preparation of methyl ester of OCA (OCAM)

To prepare OC21AM, oxidized cellulose acetate prepared from OC21 (OC21A; 30 g), dried over P_2O_5 for 24 h, and DMAP (4.8 g) were dissolved in a 1:1 (v/v) mixture of CH_2Cl_2:CH_3OH (300 ml). DCC (30 g) was dissolved separately in the same solvent mixture (300 ml) and added drop-wise into the OCA solution over a period of 1 h. The mixture was stirred at room temperature for 48 h. The reaction mixture was sampled at 2, 6, 18, and 48 h time intervals and the resulting OCAM products were purified. To purify OC21AM, the excess solvent from the mixture was removed under reduced pressure. The residue obtained was washed with 3 × 20 ml of hexane, dissolved in a minimum volume of methylene dichloride, and then filtered. The excess methylene dichloride was removed under reduced pressure and then hexane was added to precipitate the polymer. The latter was washed with 3 × 20 ml methanol. The resulting pale yellow product was dried in a vacuum oven at 50 °C under 127 mmHg for 12 h.

To prepare OC14AM, oxidized cellulose acetate prepared from OC14 (OC14A; 20 g), dried over P_2O_5 for 24 h, and DMAP (1.3 g) were dissolved in a 1:1 (v/v) mixture of CH_2Cl_2:CH_3OH (300 ml). DCC (13 g) was dissolved separately in the same solvent mixture (300 ml) and added drop-wise into the OCA solution over a period of 1 h. The mixture was stirred at room temperature for 6 h, and then purified using the same method above as OC21AM.

The yield of OCAM was calculated according to Eq. (3):

$$\%\,\text{Yield} = \frac{\text{Weight of the product}}{\text{Theoretical weight of the product}} \times 100 \quad (3)$$

The theoretical weight of the product was calculated using Eq. (4):

$$\text{Theoretical weight of OCAM} = \frac{\text{Weight of OCA}}{(173.0 + \text{DS}_{\text{acetyl}} \times 42)} \times (173.0 + \text{DS}_{\text{acetyl}} \times 42 + \text{DS}_{\text{methyl}} \times \text{MW}) \quad (4)$$

where DS is the degree of substitution of acetyl and methyl group. 173.0 is the average molecular weight of the anhydroglucose ring in OC, 42 is the molecular weight of the acetyl group, and MW is the molecular weight of methyl group.

2.4. Characterization of oxidized cellulose esters

2.4.1. Proton and carbon-13 nuclear magnetic resonance (^{1}H and ^{13}C NMR)

OCAs (about 10 mg), which was previously dried over P_2O_5 for 48 h, was dissolved in 1.0 ml of DMSO-d_6. The ^{1}H and ^{13}C NMR spectra were collected on a Bruker MSL-360 NMR spectrometer. DMSO-d_6 served as an internal reference (^{1}H = 2.49 ppm). Their ^{13}C NMR spectra of samples were measured using either dimethylsulfoxide-d_6 (DMSO-d_6) as a solvent on a Bruker MSL-360 NMR spectrometer. The peak of DMSO-d_6 served as an internal reference (^{13}C = 49.5 ppm). The chemical shift values reported were automatically calibrated with an accuracy of ±0.001 ppm.

OCAMs (about 10 mg), which was previously dried over P_2O_5 for 48 h, was dissolved in 1.0 ml of chloroform-d. The ^{1}H and ^{13}C NMR spectra were collected on a Bruker MSL-360 NMR spectrometer. Tetramethylsilane (TMS) served as an internal reference (^{1}H = 0.00 ppm) from ^{1}H NMR spectra. And, the solvent peak of chloroform-d (^{13}C = 77.23 ppm) served as the internal reference for ^{13}C NMR spectra. The chemical shift values reported were automatically calibrated with an accuracy of ±0.001 ppm.

2.4.2. Fourier-transform infrared (FT-IR) spectroscopy

To collect FT-IR spectra of OC esters, each sample (~2 mg) was ground and mixed with dry KBr (~400 mg, dried at 105 °C for 2 h before use) with an agate mortar and pestle. The ground sample was scraped from the sides of the mortar with a microspatula. The triturated sample was then compressed into a flat-faced disk using a one-half inch diameter punch and die with a pair of wenches. The disk should be transparent. The pressure and dwell time were adjusted to obtain a transparent disc in case that disc was opaque. The spectra were obtained on a Nicolet 210 FT-IR spectrophotometer (Nicolet Instrument Corp, Madison, WI), equipped with Omnic data processing software (Nicolet Instrument Corp, Madison, WI). Spectra were recorded over the range of 650–4000 cm^{-1}. The number of scans was 100 and the resolution was 8 cm^{-1}.

2.4.3. Carboxylic acid contents of OCA and OCAM

OCA or OCAM (~200 mg) were accurately weighed and put in a 250 ml Erlenmeyer flask. Acetone (50 ml) was added, and the mixture was sonicated until a clear solution was obtained. To the resulting solution, phenolphthalein test solution (1 ml) was added. The mixture was then titrated with 0.1 N NaOH. The carboxylic acid content (w/w) in the sample was calculated according to Eq. (5):

$$\text{Carboxylic acid content}\,(\%) = \frac{4.5 \times V}{\text{Sample weight}} \times 100 \quad (5)$$

where V is the volume of the 0.1 N NaOH solution consumed by the sample and 4.5 is the product of normality of sodium hydroxide

solution (0.1 N) and the molecular weight of the carboxylic acid group (45 g/mole).

2.4.4. Degree of substitution (DS) of acetyl group

The DS of acetyl group in OCA was determined by the unit peak ratio of acetyl methyl protons versus glucose/glucuronic ring protons, which is shown in Eq. (6):

$$\mathrm{DS} = \frac{\text{Peak area of methyl protons } (\delta 1.5\text{–}2.3 \text{ ppm})/3}{\text{Peak area of glucose/glucuronic ring protons } (\delta 3.5\text{–}6.0 \text{ ppm})/\mathrm{H}} \quad (6)$$

where 3 and H correspond to the total number of methyl protons and glucuronic acid/glucose ring protons, respectively. The values of H for OC21A and OC14A are 5.5 and 5.9, respectively. The water signal of DMSO-d_6 at about δ 3.3 ppm was separated from the proton signals of glucuronic acid/glucose ring by line fitting function of Nuts Software (Acorn NMR Inc., Livermore, CA).

2.4.5. Degree of substitution of methyl group

The degree of substitution of methyl group in OCAM ester as a function of the reaction time was determined by ^{1}H NMR. The spectra were collected on a Bruker MSL-360 NMR spectrometer using conditions described above. The degree of methyl group substitution was calculated using Eq. (7):

$$\text{DS of methyl group} = \frac{[(\text{Peak area}(3.48\text{–}5.24 \text{ ppm}))/(\text{Peak area}(4.79\text{–}5.24 \text{ ppm}))] - A}{3} \quad (7)$$

where the peak area between the region from δ 3.48 to δ 5.24 ppm is due to methyl protons on C-6 and the backbone protons (the proton number = $A + \mathrm{DS}_{\mathrm{methyl}} \times 3$, $\mathrm{DS}_{\mathrm{methyl}}$ = degree of substitution of methyl group). The peak area between 4.79 and 5.24 ppm is due to the proton on C-3 (one proton). These two peak areas were separated from the other signals by line fitting function using Nuts Software (Acorn NMR Inc., Livermore, CA) and accurately determined. A is the average number of protons on one repeating unit, and A equals to 5.5 and 5.9 for OC14 and OC21, respectively.

2.4.6. Average-viscosity molecular weight

OCA was determined in acetone at 20.0 ± 0.1 °C and OCAM was in chloroform at 25.0 ± 0.1 °C. Briefly, 10 ml of OCA solution (conc. 0.2–0.8%, w/v) or OCA-methyl ester solution (conc. 0.05–0.6%, w/v) were transferred into the lower bulb of an Ostwald capillary viscometer (size: 100) and then equilibrated in a water bath that had been set at 20 or 25 °C, for 5 min. The equilibrated solution was drawn into the upper bulb (above the upper mark) by suction and then allowed to flow freely. The efflux time for the solvent (t_0) was measured in the same manner using the same viscometer. The viscosity average molecular weight (M_v) of OCA and OCAM were estimated using the Mark-Houwink equation: $[\eta] = KM_v^{\alpha}$, where K and α are constants for a given polymer–solvent combination at a given temperature. The K and α values of cellulose acetate (CA) in acetone at 20.0 ± 0.2 °C are 2.31×10^{-5} dl/g and 1.0, respectively, while in chloroform at 25 °C the corresponding values are 0.69×10^{-5} dl/g and 1.02 (Klemm, Philipp, Heinze, Heinze, & Wagenknecht, 1998).

2.4.7. Powder X-ray diffraction

The PXRD measurements were conducted between 5° and 40° 2θ using a Siemens Model D5000 X-ray diffractometer (Siemens Energy & Automation, Inc., Madison, WI), which irradiated the sample with monochromatic Cu K_α X-rays (40 kV, 30 mA, $K_{\alpha1}$ = 1.54060 Å, $K_{\alpha2}$ = 1.54438 Å). The step width was 0.020° 2θ and the time constant was 0.5 s. Each sample powder was filled in a standard X-ray sample holder and covered with a glass slide to lightly press the surface until a flat and smooth surface was obtained. The sample was then placed on the diffractometer to obtain the diffraction pattern. The X-ray data were processed by Diffrac$^{\mathrm{Plus}}$ diffraction software (EVA, Version 2.0, Siemens Energy and Automation, Inc., Madison, WI).

2.4.8. Solubility in organic solvents

The solubility of OCA and OCAM was determined in hexane, toluene, ethyl ether, methylene dichloride, ethyl acetate and methanol. In a typical experiment, the sample was added in excess to 3.0 ml of the test solvent. The mixture was shaken at room temperature on a shaker (Burrell, wrist-action shaker, Burrell Corp., Pittsburgh, PA) for 48 h. The sample was then centrifuged for 5 min at 7000 r.p.m. The supernatant (1.0 ml) was transferred into a tarred weighing dish. The solvent in the supernatant was allowed to evaporate at room temperature. The residue obtained was dried under vacuum (~127 mmHg) at 50 °C for 12 h. After cooling to room temperature, the weight of the residue was determined by subtracting the weight of the dish from the weight of the empty dish containing residue. The solubility was expressed in milligrams per milliliter (mg/ml).

2.4.9. Vapor sorption analysis

The moisture sorption isotherms of the samples were obtained using a SGA-100 Symmetric Vapor Sorption Analyzer (EdgeTech, Milford, MA). About 10 mg of sample was put into the VTI sample pan and accurately weighed. The VTI instrument was calibrated using a 20.0 mg weight before each measurement. The samples were dried at 60 °C prior to use, and the heating rate was 5 °C/min. The relative humidity (RH%) was increased slowly with a criterion of 0.01% weight change within 5 min. The sorption isotherms of samples were determined at 25.0 °C. The RH steps were 10%, 20%, 30%, 40%, 50%, 60%, 70%, 80%, 90%, and 95%.

3. Results and discussion

3.1. Preparation of OCAM

The preparation of OCA was achieved by reacting OC with a mixture of Ac_2O/HOAc in the presence of H_2SO_4 as a catalyst, following the procedure reported earlier (Kumar & Yang, 2002a, 2002b). In this research, the methyl ester of OCA was successfully prepared by reacting OCA with methanol in present of DCC/DMAP as coupling agent and catalyst at room temperature. This reaction was performed in a mild reaction condition which prevents degradation of OC during reaction, where DMAP performed as a catalyst. Due to presence of DMAP, the reaction solution was in a brown color. Since water molecules can have a competing side-reaction with DCC, anhydrous solvent and pre-dried starting materials should be used in the process. The resulting by-product from DCC, dicyclohexyl urea, has a low solubility in reaction mixture and precipitated as needle shape crystals. To purify OCAM product, the reaction solvent was removed first by reduced pressure, and followed by triple wash with hexane to remove DCC residuals. Then, the solid mixture was dissolved in methylene dichloride and filtered with normal filter paper to remove the by-product of DCC. Then, methylene dichloride was removed under vacuum. The resulting solid residual was then washed with methanol to move DMAP residuals. The final OCAM product was dried under vacuum to remove methanol and resulted pale yellow product.

This reaction has been performed at 2, 6, 18, and 48 h time durations. The reaction mixture was taken out from the reactor and purified according to the method described above. Their corresponding ^{1}H and ^{13}C NMR spectra have been measured and are shown in Figs. 2 and 3. The degree of substitution (DS) of methyl

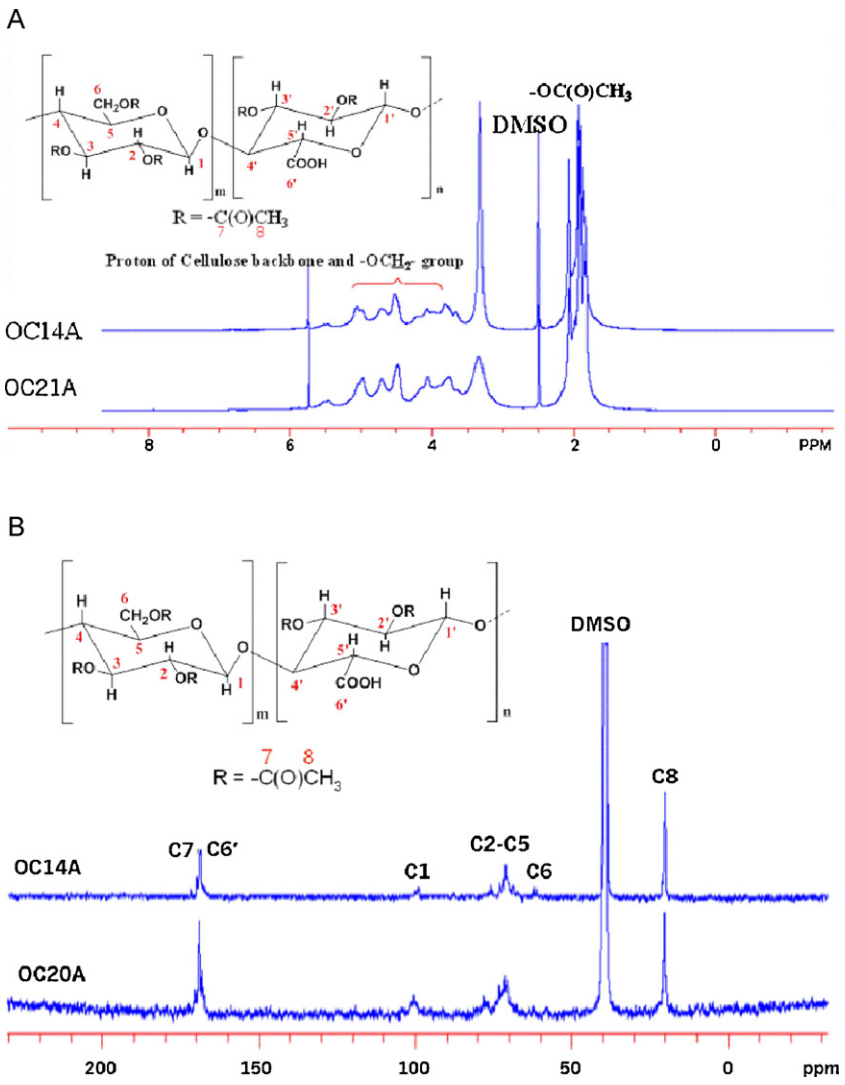

Fig. 1. (A) ^{1}H NMR of OC14A and OC21A (solvent: DMSO-d_6). (B) ^{13}C NMR of OC14A and OC21A (solvent: DMSO-d_6).

group at different time point was calculated using the method shown in Eq. (7). The relationship of degree of methylation with reaction duration is plotted in Fig. 4. As can be seen, the methylation reaction was fast and it was about to finish at first 6 h.

3.2. Characterization of OCAM

The ^{1}H and ^{13}C NMR spectra of the OCA are shown in Fig. 1A and B, respectively. The peaks were assigned on the basis of the chemical shift values reported in the literature for OCA (Yang, 2005) and cellulose acetates (Nunes, Burrows, Bastos, & Gil, 1995). The protons of the acetyl group appear in the region between δ 1.5 and δ 2.3 ppm, whereas those from the cellulose backbone (modified and unmodified anhydroglucose/glucuronic acid rings) occur in the region between δ 3.5 and δ 6.0 ppm. In the ^{13}C NMR spectrum (Fig. 1B), the peaks appearing between the region δ 168 and δ 173 ppm are attributed to the free carboxylic acid (C_6) and acetyl carbonyl (C_7) carbons. The non-oxidized C_6 carbon appears at δ 62 ppm. The peaks appearing at δ 99 and δ 76 ppm in the spectrum are due to C_1 and C_4 carbons, respectively, whereas those in the region between δ 69 and δ 73 ppm are assigned to C_2, C_3, and C_5 carbons. The carbon signal at about 20 ppm is due to CH_3 (acetyl) carbons. From the ^{1}H–^{13}C HQMC NMR spectrum of OCA (Yang, 2005), the proton signals at δ 4.1, 4.5, and 5.0 ppm in the ^{1}H NMR spectrum of OC21A have been assigned to C_5, C_3, and C_2 carbons and those at δ 4.7 and δ 3.8 ppm to C_1 and C_4, respectively.

The ^{1}H and ^{13}C NMR spectra of OCAM prepared using 2, 6, 18, and 48 h of reaction duration are shown in Figs. 2 and 3, respectively. The spectra with peak positions are signed based on the spectral data reported in the literature (Jandura, Kokta, & Riedl, 2000; Tezuka & Tsuchiya, 1995; Zhang & McCormick, 1997). Buchanan and co-workers (Buchanan, Edgar, Hyatt, & Wilson, 1991) studied the NMR spectra of cellulose acetates with low degree of substitution of acetyl groups. The spectra were collected using DMSO-d_6 as the solvent. The peaks of unsubstituted anhydroglucose unit (UAGU) were assigned (Seymour & Johnson, 1978). Cellulose triacetate (CTA) has also been used as the reference to define the assignment of the peaks. The peaks in OCAM spectrum match the peaks in CAT spectrum, besides the proton peak due to —C(O)OCH$_3$ appears at δ ~3.7 ppm, along with the proton signal from the cellulose backbone. There is no δ ~3.7 ppm peak observed in the ^{1}H NMR spectrum of OCA.

A plot depicting the relationship between the degree of methyl group substitution and reaction time is shown in Fig. 4. As can be seen, the methyl group content increased from 0 h to 6 h. After 6 h, there was no significant change in the methyl content of OCAM. In the ^{13}C NMR spectrum of OCAM, the peak at ~52 ppm is due to the methyl carbon of the ester group on C-6. This peak can be seen starting from the spectrum of the 2 h reaction product.

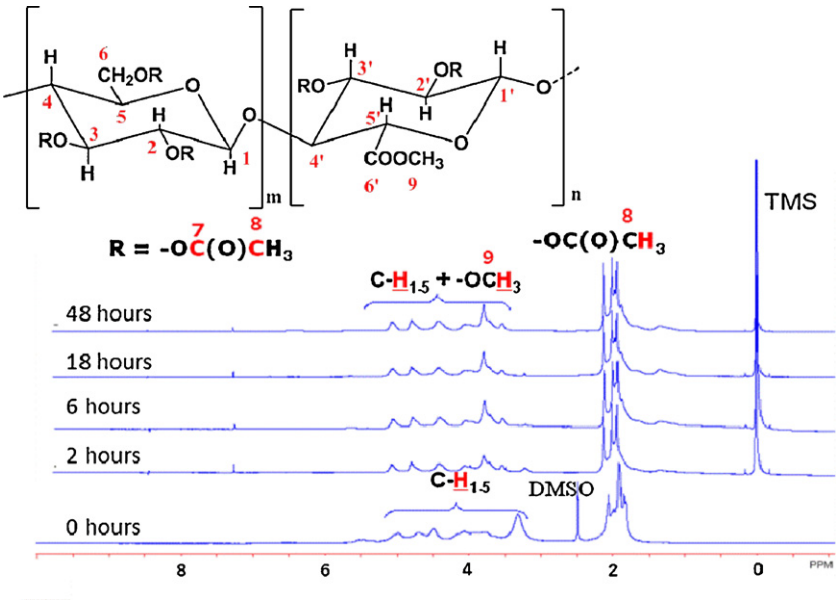

Fig. 2. ^{1}H NMR of spectra OC21A (solvent: DMSO-d_6) and OC21AM (solvent: $CDCl_3$) products prepared using 2, 6, 18, and 48 h of reaction duration.

The intensity of this peak is higher in the spectrum of the 6 h product compared to that present in the spectrum of the 2 h product. No significant increase in the intensity of this peak was observed for products collected after 18 and 48 h of the reaction time. These results suggest that 6 h of reaction time yields the maximum methyl ester group substitution.

The FT-IR spectra of OCAM prepared with 2, 6, 18, and 48 h of reaction duration are compared with that of OCA, used as a starting

Table 1
Yield, carboxylic acid content, DS of acetyl group, DS of methyl group, and average viscosity molecular weight of OCAs and OCAMs.

Sample	Yield (%)	Carboxylic acid content (%, w/w)	DS of acetyl group	DS of methyl group[a]	Average viscosity molecular weight (g/mol)
OC14A	89	10.6	1.9	–	51,340
OC21A	85	15.7	1.7	–	34,606
OC14AM	39	0.94	–	0.46	38,349
OC21AM	37	1.41	–	0.67	27,524

[a] Methyl content refers to the moles of methyl groups per mole of the repeating unit of anhydrous glucose.

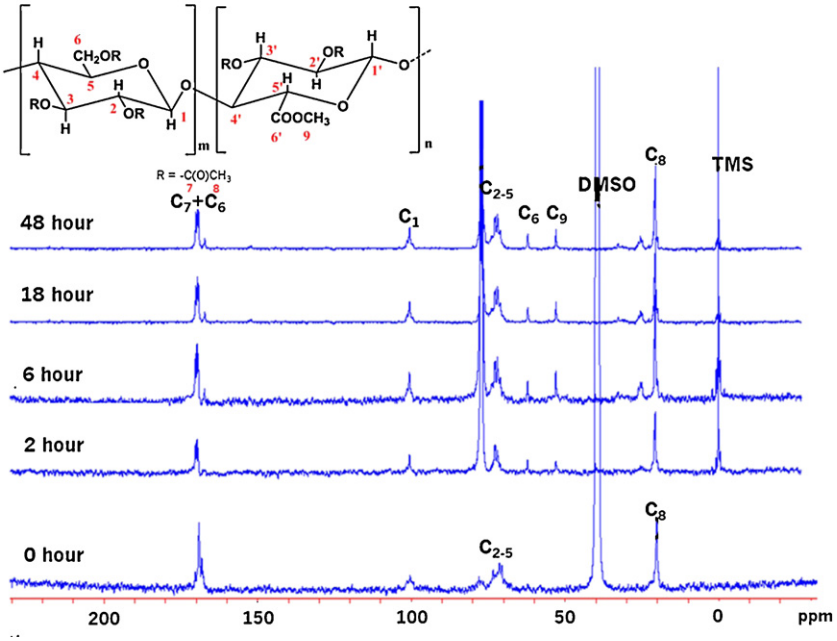

Fig. 3. ^{13}C NMR of spectra OC21A (solvent: DMSO-d_6) and OC21AM (solvent: $CDCl_3$) products prepared using 2, 6, 18, and 48 h of reaction duration.

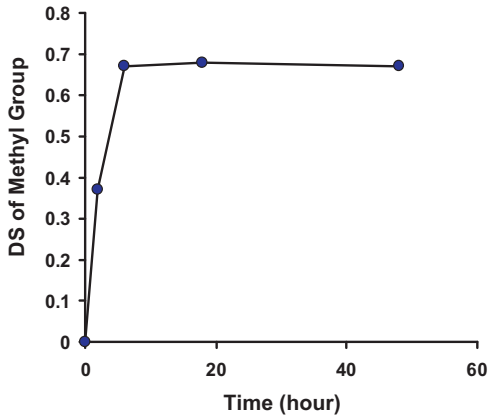

Fig. 4. Relationship of reaction time with degree of substitution (DS) of methyl group of OC21AM.

material, are shown in Fig. 5. Compared to OCA, OCAM products showed a significantly reduced intensity of the ν(O—H) vibration band in the region between 2500 and 3500 cm^{-1}, which belongs to the free carboxylic acid group and hydroxyl groups, with increasing reaction time. Another notable difference is that the ν(C—H) vibration bands, appearing at 2850 and 2950 cm^{-1}, are stronger in intensity in the spectrum of OCAM than that in the spectrum of OCA. The peak at ~2850 cm^{-1}, which appears as a shoulder to the 2950 cm^{-1} peak, is due to the unsymmetric C—H stretching vibration of the methyl group. It is much stronger in intensity in the spectra of OCAM products than in the spectrum of OCA and is attributed to the methyl ester group in OCAM. An unknown peak appeared at ~1519 cm^{-1} in the spectra of OCAM products.

The carboxylic acid residual content of OCAM was determined using traditional titration method. Briefly, the polymer was dissolved in acetone and then titrated with 0.1 N NaOH using phenolphthalein as an indicator. The effect of the solvent on the end point was corrected by a blank titration. The results are presented in Table 1. The lower carboxylic acid contents compared to that of the respective OCA starting polymer is attributed to the presence of methyl ester group, which renders hydrophobicity to the polymer, restricting accessibility of the remaining carboxylic acid groups to hydroxide ions and, consequently, their ionization.

The average viscosity molecular weight of OC14A and OC21A are 51,340 and 34,606, respectively, measured using the method

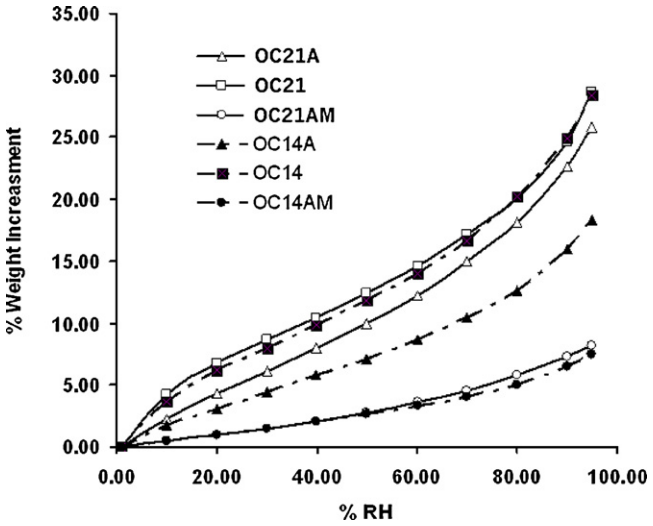

Fig. 6. Moisture sorption isotherms of OCs, OCAs, and OCAMs.

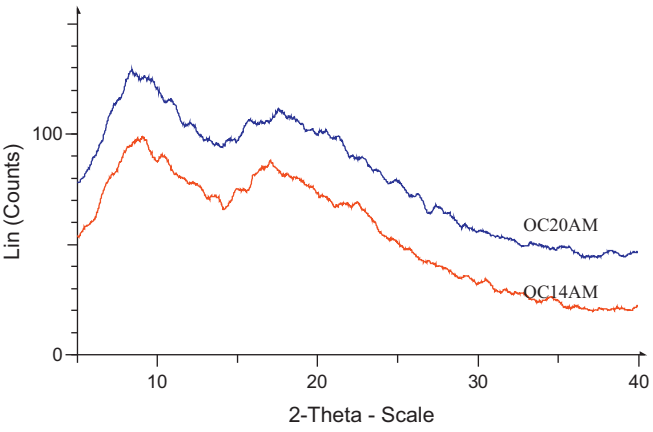

Fig. 7. Powder X-ray diffractograms of OCAMs.

mentioned in experimental section. The lower molecular weight of OC21A compared to OC14A, although their starting materials, OC21 and OC14, had comparable molecular weights (Yang, 2002), suggests that OC21 is more prone to hydrolysis than OC14 during

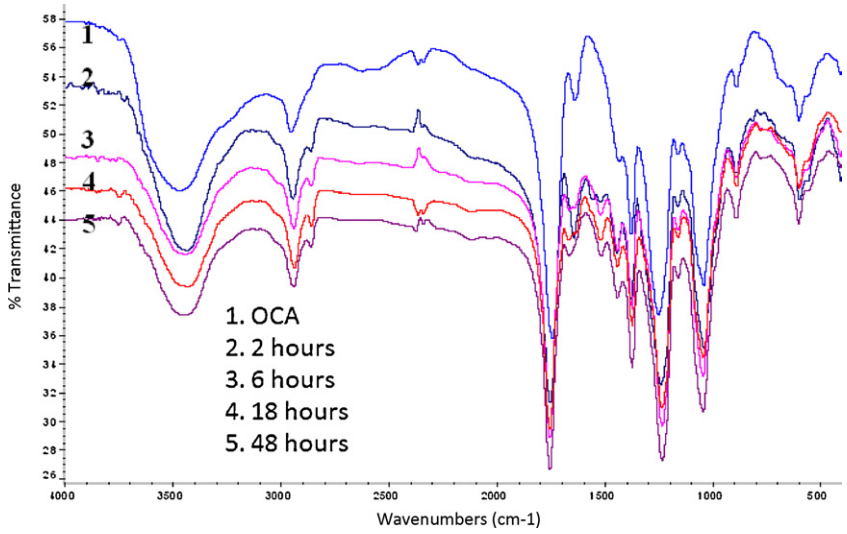

Fig. 5. FT-IR spectra of OC21A and OC21AM prepared with 2, 6, 18, and 48 h of reaction duration.

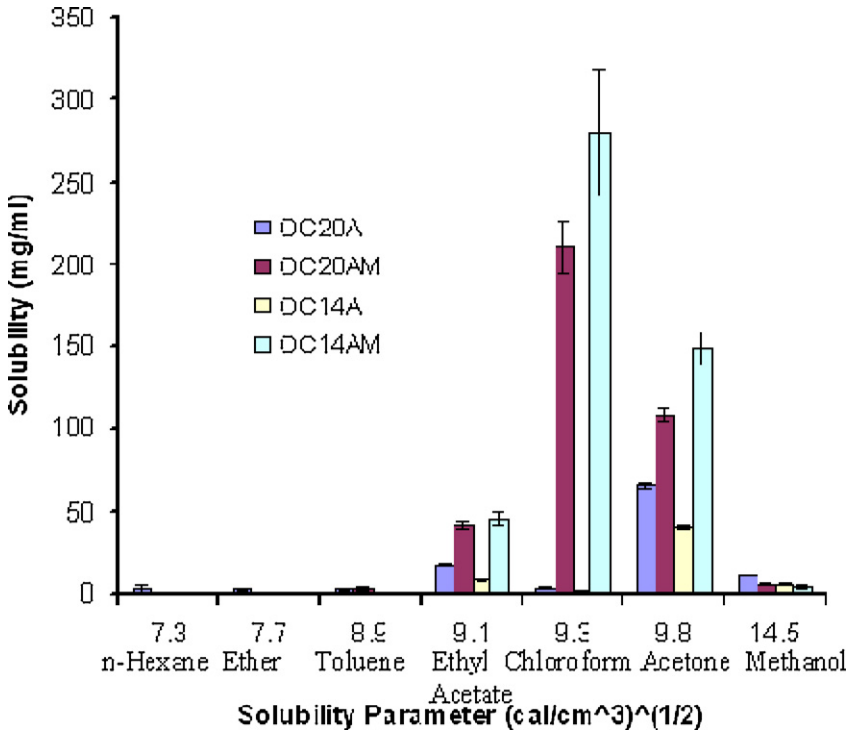

Fig. 8. Solubility of OCAs and OCAMs in organic solvents.

acetylation. The molecular weights of OC14AM and OC20AM, determined using the viscosity method in chloroform, are 38,349 and 27,524, respectively. As can be seen, the molecular weight dropped in methylation reaction using DCC/DMAP as coupling agents. This might be due to the presence of DMAP, used as a catalyst in the reaction, induced the abstraction of hydrogen concomitant with the cleavage of the β-1,4-glucosidic linkage, in hence, the reduction of the molecular weight.

The moisture sorption isotherms of OCAM are compared to its starting materials of OC and OCA and are shown in Fig. 6. OC showed the highest moisture uptake and OCAM the lowest moisture sorption over the whole relative humidity range used in the study. OCA shows significantly less moisture uptake compared to that of OC, and much higher than that displayed by OCAM. As can be seen, the acetylation and methylation process significantly increase hydrophobicity of oxidized cellulose and reduce moisture uptake.

The powder X-ray diffractograms of OCAM are shown in Fig. 7. As can be seen with OC14A and OC20A, OCAM showed two broad diffuse halos, covering the angular range 6–13° 2θ and 14–14° 2θ. These results suggest OCAM to be low crystallinity materials with cellulose II crystal pattern.

The solubility of the OCA and OCAM esters were determined in seven commonly used organic solvents: hexane, diethyl ether, toluene, ethyl acetate, chloroform, acetone, and methanol, and the results are shown in Fig. 8 and plotted against the solubility parameters of these solvents. As can be seen, OCA has the highest solubility in acetone which has a solubility parameter of 9.8, while OCAM showed the highest solubility in chloroform which has a solubility parameter of 9.3. OCA also have a higher solubility in ethyl acetate compared to that in chloroform, and this could be because there esters could have stronger interaction with ethyl acetate molecules by hydrogen bonding than chloroform molecules.

4. Conclusions

Oxidized cellulose acetate methyl ester (OC14AM and OC21AM) was successfully prepared from oxidized cellulose acetate (OCA) using DCC/DMAP as coupling agent and catalyst at room temperature. The viscosity-average molecular weights of these two OCAM polymers were ~38,349 and ~27,524, respectively. Powder X-ray diffraction studies revealed that OCAMs are low crystallinity materials. Although soluble in a wide range of organic solvents, both OC14AM and OC21AM show the highest solubility in chloroform (280 mg/ml and 211 mg/ml, respectively). OC14 and OC21, the starting materials for OC14A and OC21A, respectively, in contrast, are only soluble in aqueous alkaline solutions. The moisture sorption ability decreases significantly with acetylation and methylation of OC. The degradation study results and sustained release effect of these polymers will be reported in the following papers.

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