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Note

Microwave-accelerated methylation of starch

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Abstract—A novel microwave-accelerated method for methylating soluble starch is described. Soluble starch could be fully methylated in 72% yield within 4.66 min using iodomethane and 30% potassium hydroxide under microwave irradiation. The completely methylated starch thus obtained was hydrolyzed with 60% HCO_2H for 1.5 min under 80% MW power, followed by 0.05 M H_2SO_4 for 2.0 min under 100% MW power. The partially methylated monosaccharides were separated by preparative paper chromatography and identified by their melting points and optical rotations.

Keywords: Starch soluble; Irradiation microwave; Iodomethane; Methylation

Conventionally starch can be methylated[1] by the dimethyl sulfate (DMS)-alkali procedure of Haworth to provide solubility in *N*,*N*-dimethylformamide and then by Kuhn methylation with silver oxide and iodomethane. Amylose and amylopectin can also be methylated directly in liquid ammonia with sodium and iodomethane, but native starch granules require some form of pretreatment. The Freudenberg and Boppel method[1] involves dissolution of the starch in a mixture of liquid ammonia, sodium, and iodomethane in which the ammonia must be removed after completing the methylation. Methylation[2] of starch is also reported in DMSO using the lithium methylsulfinyl carbanion and iodomethane (a modification of the Hakomori method), which requires stirring for long periods and sonication. Microwave (MW) irradiation[3] as an efficient source of thermal energy is becoming a standard technique in various fields of chemistry including carbohydrate chemistry. Microwave-assisted selective and unselective protection and deprotection of hydroxyl functionalities of carbohydrates and many other aspects of carbohydrate chemistry have been reviewed by Corsaro et al.[4] Hydrolyses of starch[5] and plant seed gums,[6] synthesis of alkyl glycosides,[7] graft copolymerization[8] of acrylic acid with starch, graft copolymerization of acrylonitrile,[9] and acrylamide[10] with guar gum have been recently reported. Our group has reported a modification of Haworth's method where complete methylation of guar gum could be done under microwave irradiation using dimethyl sulfate in aqueous alkali.[11] The methylation could be completed in a very short reaction time under milder conditions, but with the disadvantage of SO_2 evolution during the reaction. In the present study complete methylation of starch was undertaken (Scheme 1) to avoid SO_2 evolution, and iodomethane instead of dimethyl sulfate was used as methylating agent. Complete methylation of the soluble starch could be achieved under MW irradiation without using any catalyst or an inert atmosphere. Starch was fully methylated[12] with iodomethane and 30% aqueous potassium hydroxide under MW irradiation. An IR spectrum of the methylated product obtained after 3 min exposure showed a small peak in the –OH region, indicating that methylation is incomplete at this stage. The O–H stretching peak completely disappeared after 4.66 min exposure, indicating that complete methylation requires 4.66 min exposure (Fig. 1). The fully methylated product had no absorption in the IR (Fig. 1) at 3600–3400 cm^{-1},

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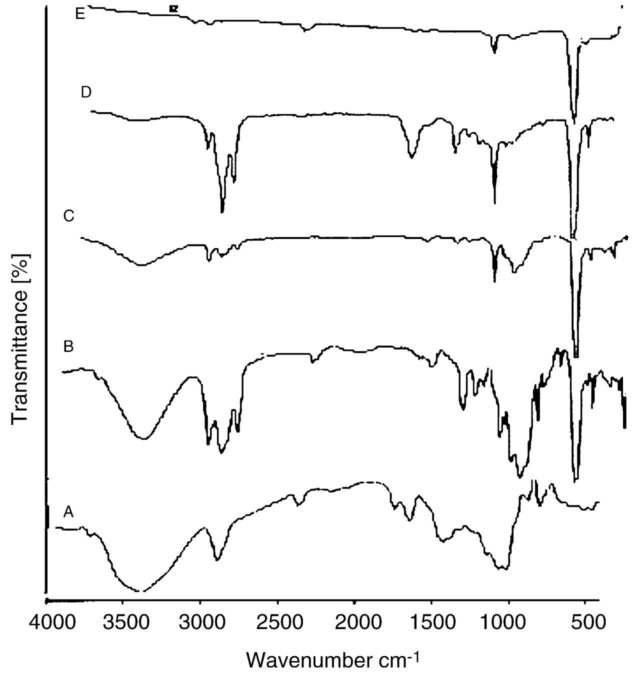


Figure 1. FTIR spectra of (A) soluble starch; (B) hydrolyzate of completely methylated soluble starch; (C) partially methylated starch recovered after 2nd addition; (D) partially methylated starch obtained after 3rd addition; (E) fully methylated starch after 4th addition.

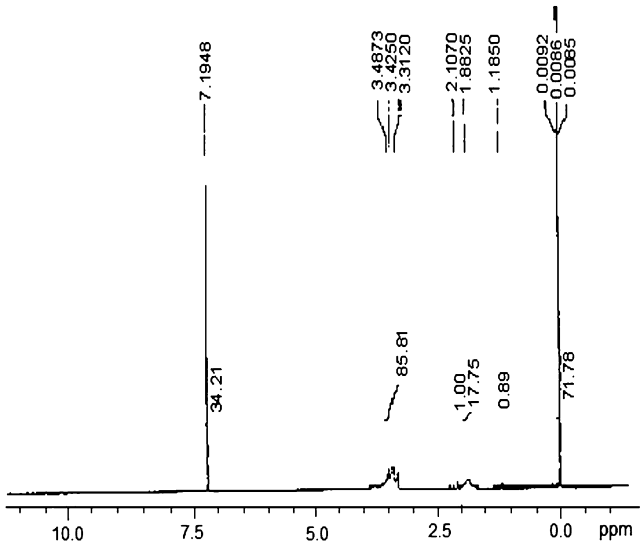
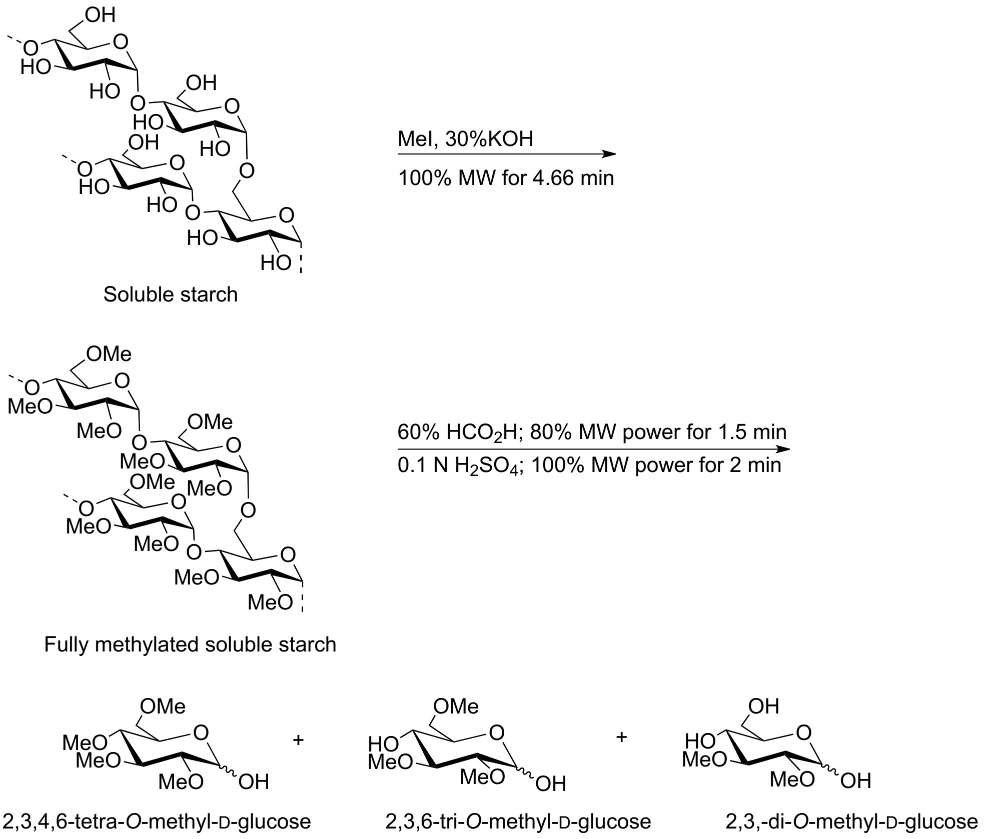


Figure 2. ^{1}H NMR of fully methylated soluble starch.

while the starch originally had a broad peak at 3440 cm^{-1} due to the –OH stretching. The ^{1}H NMR spectrum in CDCl$_3$ (Fig. 2) showed strong, sharp, three-proton singlets between peaks at δ 3.31 and 3.48



Scheme 1. Methylation and hydrolysis of soluble starch under MW irradiation.

for the –OCH_3 groups besides the other usual peaks (Scheme 1).

The fully methylated starch was hydrolyzed in 3.5 min using MW irradiation, using 60% HCO_2H, followed by 0.1 N H_2SO_4.

Though starch, being a macromolecule cannot show rotation or migration when exposed to an electric field of microwaves, its hydroxyl groups show localized rotation[13] on an essentially immobile starch molecule. However, such localized rotations[13] cannot correspond instantaneously to the rapidly changing direction of the field, which creates friction that manifests itself as heat resulting in O–H bond breaking. The dielectric heating results in rapid energy transfer from these groups to neighboring molecules (CH_3I and NaOH), as it is not possible to store the energy in a specific part of the molecule. Further MW are also reported to have special effects[14] on lowering of Gibbs free-energy of activation of the reactions. This occurs either through the storage of microwave energy in the vibrational energy of a molecule (enthalpy effect) or by the alignment of molecules (entropy effect). In view of the above two effects, methylation under MW conditions is possible under mild conditions in a very short time.

Thus, under MW irradiation starch can be fully methylated in good yield and thereafter hydrolyzed very efficiently into a mixture of the methylated monosaccharides within a very short reaction time. The hydrolyzates of the methylated starch, methylated conventionally and by the MW method, were co-chromatographed in solvent A. Three methylated monosaccharides, namely 2,3,4,6-tetra-*O*-methyl-D-glucose, 2,3,6-tri-*O*-methyl-D-glucose, and 2,3-di-*O*-methyl-D-glucose were detected. The products were fractionated by paper chromatography on Whatman 3 MM paper (solvent A). The methylated sugars were identified[15] by their mp, optical rotation, R_{TMG}, and by preparing their crystalline derivatives.

1. Experimental

1.1. General

A Kenstar (Model No. MOW 9811, 1200 W) domestic microwave (MW) oven was used for all the experiments. Solutions were concentrated at diminished pressure at 60–62 °C. Paper chromatography was carried out at room temperature with solvent system A, 4:1:5 butanol–ethanol–water;[16] B, 169:47:15 benzene–ethanol–water;[17] and C, 10:1 butanone–water,[18] with detection using aniline hydrogen phthalate. IR spectra were recorded on Bomem ABB FTLA2000 spectrophotometer in $CHCl_3$. ^1H spectra were recorded on Jeol 400 MHz FT NMR in $CDCl_3$. Soluble starch (Qualligen) was used for the study. All the reactions were carried out in open glass vessels.

1.2. Methylation under microwave irradiation[‡]

To a solution of starch (2.0 g in 20 mL of 15% aq KOH), 5 mL of CH_3I and 5 mL of 30% KOH were added in four equal installments. After each addition of the reagents, the reaction mixture was given a 1-min exposure to 100% MW power. The progress of the reaction was monitored by IR spectroscopy. For complete methylation the reaction mixture required an additional exposure of 0.66 min. Thus complete methylation required a total exposure time of 4.66 min. On addition of each installment of the reagents, the pH of the reaction mixture was 13.6, which decreased to pH 7.1 after exposure. Finally the reaction mixture was cooled to room temperature and was thoroughly extracted with $CHCl_3$. The extract was dried over anhyd Na_2SO_4, and the solvent was evaporated under reduced pressure. The methylated product was obtained as a light-yellow powder: yield 1.82 g, (72%); methoxyl[19] (42.4%). An additional methylation reaction did not increase the methoxyl content of the product.

1.3. Hydrolysis of methylated starch using MW irradiation

The methylated starch (250 mg) was dissolved in 25 mL of 60% HCO_2H, and the solution was exposed to 80% MW power for 1.5 min. The solution was then concentrated, and the last traces of HCO_2H were removed under vacuum. The residue was then dissolved in 15 mL of 0.1 N H_2SO_4 and exposed to full MW power for 2.0 min. The hydrolyzate was cooled, neutralized with barium carbonate, filtered, and concentrated under reduced pressure to a light-yellow syrup. The partially methylated monosaccharides were identified by paper chromatography (pc) in solvent A.

GLC of the partially methylated alditol acetates[20] (obtained by the reduction of the hydrolyzate with $NaBH_4$, followed by acetylation) also confirmed the presence of 2,3,4,6-tetra-*O*-methyl-D-glucose, 2,3,6-tri-*O*-methyl-D-glucose, and 2,3-di-*O*-methyl-D-glucose in the hydrolyzate.

Complete methylation and hydrolysis of the fully methylated starch could be successfully achieved under microwave irradiation in very short time. Besides being rapid, the method does not necessitate an inert atmosphere for the methylation.

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[‡] This operation should be conducted in a well-ventilated hood. CH_3I (bp 41–43 °C) is volatile and toxic.

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