Silylated Chitin: A New Organosoluble Precursor for Facile Modifications and Film Casting

Keisuke Kurita,* Masaaki Hirakawa, and Yasuhiro Nishiyama
Department of Industrial Chemistry, Faculty of Engineering, Seikei University, Musashino, Tokyo 180-8633

(Received April 5, 1999; CL-990254)

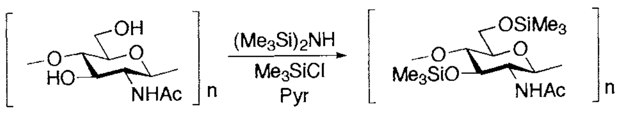
Trimethylsilylation of chitin and some properties of the product have been examined. Full substitution could be achieved on β-chitin under appropriate conditions. The high solubility along with easy desilylation enabled simple preparation of chitin films. Furthermore, the silylated chitin exhibited high reactivity and thus proved to be a convenient organosoluble precursor for facile modifications of this intractable biomass resource.

Much attention is being paid to chitin because of the unique biological activities ascribable to the presence of acetamide groups at C-2 instead of hydroxy groups of cellulose. Chitin is therefore highly expected to be a specialty biomaterial useful in various fields including medicine, cosmetics, and food.[1,2] However, it still remains an unutilized biomass resource due to the lack of solubility and poor chemical reactivity.

The ordinary chitin is of the α-form,[3] and the chemistry of chitin has been developed primarily with this form. Another form, β-chitin,[4] is also available, though in a smaller quantity, and may be important as an alternative chitin. One of the possible approaches to new applications of chitin is to construct sophisticated molecular environments through controlled chemical modifications. Although the reactions of chitin are usually encountered by severe problems associated with the intractable nature, some organosoluble precursors have been found useful for preparing the derivatives with well-defined structures.[5-7]

In order to develop solubility in organic solvents, it is necessary to prevent strong intermolecular forces of chitin as exemplified by the introduction of tosyl[5] or phthaloyl groups.[6,7] Silylation of chitin may be another way for effective solubilization, while retaining the reactivity of hydroxy functionalities, and we have been examining the possibility of quantitative introduction of trimethylsilyl groups into chitin. The product is a novel type of derivative possibly characterized by some favorable properties: high solubility in organic solvents, considerable reactivity, and easy regeneration of chitin structure. Silylated chitin is therefore expected to be important as an organosoluble derivative, which will be useful for further controlled manipulations as well as film casting. Here we report about the trimethylsilylation behavior of α- and β-chitins and some characteristic properties of the resulting silylated chitin.

Prior to trimethylsilylation, free amino groups (10-15%) present in chitin as isolated were selectively acetylated to give structurally uniform chitin (**1**)[8] for excluding the possible N-silylation. Trimethylsilylation of chitin was once reported with hexamethyldisilazane in *N,N*-dimethylformamide at 70 °C to result in partial substitution (degree of substitution (ds) 0.6) under the conditions where cellulose gave a fully substituted product (ds 3.0),[9] supporting the poor reactivity of chitin. The reaction was thus examined in pyridine with a mixture of hexamethyldisilazane and chlorotrimethylsilane on α- and β-chitins to establish a procedure for full substitution. The product was isolated in methanol and identified by elemental analysis and IR spectroscopy.[10] As summarized in Table 1, the silylation occurred rather sluggishly with both α- and β-chitins at room temperature.



1 **2**

Table 1. Trimethylsilylation of α- and β-chitins[a]

Chitin	Temperature /°C	Time /h	ds[b]
α-chitin	r. t.	24	0.16
α-chitin	70	48	1.45
β-chitin	r. t.	24	0.16
β-chitin	70	24	2.00

[a]With hexamethyldisilazane and chlorotrimethylsilane (10 equiv each to the pyranose units). [b]Degree of substitution calculated from the C/N value of elemental analysis.

The reaction temperature was then raised to 70 °C, as suggested from the successful silylation of cellulose[9] and amylose,[11] but the ds of the product isolated in methanol was similar to that obtained at room temperature, implying the possible desilylation in the isolation procedure. Detailed studies for practical isolation of the product revealed that a combination of acetone as an extraction solvent and dioxane or water as a precipitation solvent was suitable in terms of purity of the product, simplicity of the isolation process, and reproducibility. The ds of the isolated product from α-chitin was 1.45 in 48 h reaction. β-Chitin exhibited much higher reactivity as anticipated, and actually a homogeneous solution resulted as the reaction proceeded. As included in Table 1, fully substituted chitin (**2**, ds 2.00) could be obtained in this manner from β-chitin as a colorless fibrous material; yield 85-90%.

This high reactivity of β-chitin is reasonably attributable to the weaker intermolecular forces.[3,4] Such a reactivity difference between the two forms is in good accordance with our previous results in some reactions including deacetylation,[12] triphenylmethylation (tritylation),[8] and main chain hydrolysis.[13] β-Chitin has thus proved to be an advantageous starting material for a wide variety of chemical modifications because of the somewhat high accessibility to reactants compared to the rather inert nature of α-chitin.

The silylated product, **2**, was readily soluble even in acetone, which does not dissolve tosyl-chitin and phthaloyl-chitosan, in addition to pyridine. The high solubility in acetone enabled facile film preparation. Casting of an acetone solution of **2** on a glass plate followed by evaporation afforded films, whose silyl groups were removed easily with aqueous acetic acid at room temperature to regenerate the chitin structure. As a result, transparent chitin films could be obtained in a simple manner.

Compound **2** was then evaluated as an organosoluble precursor for modification reactions. As a typical example, tritylation was first conducted, which is indispensable for the protection of C-6 primary hydroxy groups and hence for regioselective modifications.[7] Although no tritylation was observed with β-chitin in pyridine, the reaction took place efficiently to give the product (**3**) when **2** was used instead. As shown in Table 2, the ds reached 0.90 readily; yield 80-85%.[10]

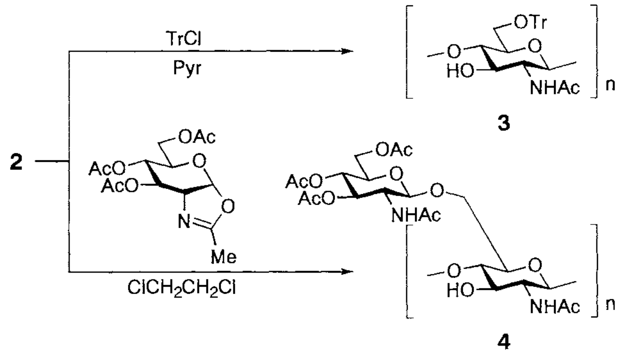


Table 2. Modifications of β-chitin and silylated β-chitin (**2**)

Reagent	Chitin	Temperature /°C	Time /h	ds[a]
TrCl[b]	β-chitin	90	24	0
TrCl[b]	silylated β-chitin	90	24	0.90
oxazoline[c]	β-chitin	80	72	0.05
oxazoline[c]	silylated β-chitin	80	48	0.47

[a]Degree of substitution calculated from the C/N value of elemental analysis. [b]Trityl chloride (10 equiv). [c]Peracetylated oxazoline from D-glucosamine[17] (5 equiv).

Glycosylation of chitin is another interesting modification in view of the rapidly increasing importance of branched polysaccharides owing to their distinctive pharmacological activities.[14-16] The reaction of **2** was thus examined with an oxazoline from D-glucosamine to prepare a branched chitin (**4**) under the conditions similar to those for the glycosylation of a phthaloyl-chitosan derivative with the oxazoline.[17] The results in Table 2 indicate a smooth reaction in 1,2-dichloroethane in the presence of 10-camphorsulfonic acid as the catalyst, the yield of **4** being 75-85%.[10] Branched chitins could be prepared recently by a procedure consisting of many steps of meticulous reactions,[17,18] but the present process is much superior in simplicity and overall yield.

Consequently, although silylation was slow with α-chitin, it was found to proceed efficiently with β-chitin. This indicates the importance of β-chitin for overcoming serious drawbacks due to the inherent intractable nature of chitin to developing new applications. The remarkable solubility of fully silylated chitin along with easy removal of the silyl groups has enabled facile preparation of pure chitin films for the first time; the procedure is much simpler than the conventional method using a solvent system consisting of *N*,*N*-dimethylacetamide, *N*-methyl-2-pyrrolidone, and lithium chloride.[19] It is also noteworthy that the silylated chitin exhibited significant reactivity, comparable to that of silylated phthaloyl-chitosan,[17] to allow smooth modifications under mild conditions. These results suggest a high potential of silylated chitin as a versatile organosoluble precursor for controlled manipulations to open a way to advanced functional materials based on this abundant biomass resource.

This work was supported in part by a Grant-in-Aid for Scientific Research (#10650871) from the Ministry of Education, Science, Sports, and Culture of Japan.

References and Notes

1 R. A. A. Muzzarelli, "Chitin," Pergamon, Oxford (1977).
2 G. A. F. Roberts, "Chitin Chemistry," MacMillan, London (1992).
3 M. Minke and J. Blackwell, *J. Mol. Biol.*, **120**, 167 (1978).
4 K. H. Gardner and J. Blackwell, *Biopolymers*, **14**, 1581 (1975).
5 K. Kurita, H. Yoshino, K. Yokota, M. Ando, S. Inoue, S. Ishii, and S. Nishimura, *Macromolecules*, **25**, 3786 (1992).
6 K. Kurita, H. Ichikawa, S. Ishizeki, H. Fujisaki, and Y. Iwakura, *Makromol. Chem.*, **183**, 1161 (1982).
7 S. Nishimura, O. Kohgo, K. Kurita, and H. Kuzuhara, *Macromolecules*, **24**, 4745 (1991).
8 K. Kurita, S. Ishii, K. Tomita, S. Nishimura, and K. Shimoda, *J. Polym. Sci., Part A: Polym. Chem.*, **32**, 1027 (1994).
9 R. E. Harmon, K. K. De, and S. K. Gupta, *Carbohydr. Res.*, **31**, 407 (1973).
10 Elemental analysis data of all the derivatives (**2**, **3**, and **4**) agreed satisfactorily with calculated values. In addition to absorption bands due to chitin, characteristic bands were observed at 1250 and 850 cm^{-1} for $Si-CH_3$ in silylated chitin, at 3058, 760, and 701 cm^{-1} for phenyl groups in tritylated chitin, and at 1745 cm^{-1} for ester groups in branched chitin.
11 D. Horton and J. Lehmann, *Carbohydr. Res.*, **61**, 553 (1978).
12 K. Kurita, K. Tomita, T. Tada, S. Ishii, S. Nishimura, and K. Shimoda, *J. Polym. Sci., Part A: Polym. Chem.*, **31**, 485 (1993).
13 M. Shimojoh, K. Fukushima, and K. Kurita, *Carbohydr. Polym.*, **35**, 223 (1998).
14 G. Chihara, Y. Maeda, and J. Hamuro, *Int. J. Tissus. React.*, **4**, 207 (1982).
15 A. Misaki, K. Kawaguchi, H. Miyaji, H. Nagae, S. Hokkoku, M. Kakuta, and T. Sasaki, *Carbohydr. Res.*, **129**, 209 (1984).
16 K. Matsuzaki, I. Yamamoto, T. Sato, and R. Oshima, *Makromol. Chem.*, **187**, 317 (1986).
17 K. Kurita, T. Kojima, T. Munakata, H. Akao, T. Mori, Y. Nishiyama, and M. Shimojoh, *Chem. Lett.*, **1998**, 317.
18 K. Kurita, K. Shimada, Y. Nishiyama, M. Shimojoh, and S. Nishimura, *Macromolecules*, **31**, 4764 (1998).
19 T. Uragami, Y. Ohsumi, and M. Sugihara, *Polymer*, **22**, 1155 (1981).