Biodegradation of Cellulose Acetate by *Neisseria sicca*

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Bacteria capable of assimilating cellulose acetate, strains SB and SC, were isolated from soil on a medium containing cellulose acetate as a carbon source, and identified as *Neisseria sicca*. Both strains degraded cellulose acetate membrane filters (degree of substitution, DS, mixture of 2.8 and 2.0) and textiles (DS, 2.34) in a medium containing cellulose acetate (DS, 2.34) or its oligomer, but were not able to degrade these materials in a medium containing cellulose octacetate. Biodegradation of cellulose acetate (DS, 1.81 and 2.34) on the basis of biochemical oxygen demand reached 51 and 40% in the culture of *N. sicca* SB and 60 and 45% in the culture of *N. sicca* SC within 20 days. A decrease in the acetyl content of degraded cellulose acetate films and powder was confirmed by infrared and nuclear magnetic resonance analyses. After 10-day cultivation of *N. sicca* SB and SC, the number-average molecular weight of residual cellulose acetate decreased by 9 and 5%, respectively. Activities of enzymes that released acetic acid and produced reducing sugars from cellulose acetate were present in the culture supernatant. Reactivity of enzymes for cellulose acetate (DS, 1.81) was higher than that for cellulose acetate (DS, 2.34).

Key words: cellulose acetate; biodegradation; *Neisseria sicca*; esterase; cellulase

Natural polymers, such as starch, cellulose, and proteins, are completely degraded by enzymes from microorganisms, such as amylases, cellulases, and proteases, in the environment and the degradation products are metabolized in the cells. On the other hand, almost all synthetic polymers are extremely persistent in the environment and remain as environmental pollutants. Synthetic polymers with molecular weights of more than ten thousand that have been reported to be degraded by enzymatic catalyzed processes of microorganisms include poly(ethylene glycol) (PEG), polyester, and poly(vinyl alcohol) (PVA). Some aliphatic polyesters are degraded by lipases from microorganisms that catalyze the hydrolysis of triglycerides. PEG and PVA are degraded by the enzymes that recognize the intrinsic structures in polymer molecules. These enzymes also act on some compounds with low molecular weight and the same structural units, while the natural substances for these enzymes are not known. Natural polymers and the synthetic polymers mentioned above are used as components of biodegradable plastics. The development of biodegradable polymers requires research on the mechanisms of enzymatic degradation of the polymers to be sure of the assimilability of degradation products in the environment.

Cellulose is one of the most abundant and renewable natural resources and is degraded by many microorganisms in the environment. Cellulose derivatives, such as various cellulose esters and nitrates, are widely used in industry. Cellulose acetate is the most important organic ester because of its broad applications, such as fibers, plastics, films, and membranes. Biodegradation of cellulose acetate was reported by some workers. Reese† has reported that a few cellulolytic microorganisms such as *Pestalotiopsis westerdijkii* QM 381 produced cellulbiose octaacetatease, which deacetylated cellulbiose octaacetate (CBOA) and water-soluble cellulose acetate (DS, 0.76). Cantor and Mechalas have shown that cellulose acetate reverse-osmosis membranes (DS, 2.5) suffered losses in permeability due to microbial attack, and that cellulose triacetate (DS, 2.8) membranes were recalcitrant to microbial attack. Recently, it has been reported that cellulose acetate films (DC, 1.7 and 2.5) were degraded by *Pseudomonas paucimobilis* and in mixed cultures such as activated sludge. While the biodegradability of cellulose acetates with various DS values has been demonstrated by these reports, the degradation mechanism and degrading enzyme system are not clear.

This paper is described isolation of cellulose acetate-degrading microorganisms, biodegradability of the polymer, and analyses of enzyme-treated cellulose acetate. Furthermore, enzymes involved in the cellulose acetate degradation are described.

Materials and Methods

Materials. CA54 (combined acetic acid, CAA, 54%; degree of polymerization, DP, about 190), CA54 oligomer (DP, about 35), and CA54 textiles were obtained from Teijin Ltd. CA45 (CAA, 45.6%), CA28 (CAA, 27.9%), and ο-cellulose octoacetate were obtained from Nacalai Tesque, Inc. Cellulose acetate membrane filters (diameter 47 mm, pore size 0.8 μm) were obtained from Toyo Roshi Kaisha, Ltd. Surfactant Prysurf A210G was obtained from Dai-ichi Kogyo Seiyaku Co., Ltd. All other chemicals were of the highest purity commercially available.

Microorganisms and culture conditions. The organisms used in this study were *Neisseria sicca* SB and SC, isolated from soil. These were grown in a cellulose acetate medium (CA medium) which contained 0.1% KH₂PO₄, 0.1% K₂HPO₄, 0.2% NH₄NO₃, 0.05% NaCl, 0.05% MgSO₄·7H₂O, 0.005% Prysurf A210G, 0.1% peptone, 0.05% yeast extract, and 1.0% agar.

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Abbreviations: DS, degree of substitution; PEG, poly(ethylene glycol); PVA, poly(vinyl alcohol); CBOA, cellulbiose octaacetate; CA, cellulose acetate; IR, infrared; NMR, nuclear magnetic resonance; CAA, combined acetic acid; DP, degree of polymerization; Mₙ, number-average molecular weight; Mₚ, weight-average molecular weight; GPC, gel permeation chromatography.
cellulose acetate powder, pH 7.0. Cellulose acetate as the carbon source were CA54 (CS, 2.34), CA45 (DS, 1.81), and CA28 (DS, 0.94). For solid medium, CA agar slants and plates, CA medium contained 1.0% CA45 as the carbon source and 1.5% agar. Each strain was maintained on a CA agar slant. Cultures were prepared by transferring cells from a CA agar slant to 50 ml of CA medium in 500-ml shaking flasks. CA45 and CA28 were used for isolation of cellulose acetate-degrading microorganisms. Cultures were incubated for several days at 27°C with reciprocal shaking. A 50 ml of CA medium and cells from the slants were inoculated into the media. After 10 days of cultivation, the films and CA54 used as the carbon source were washed extensively with distilled water and dried in a desiccator at room temperature. Recording of the infrared (IR) spectra of films was done with a JASCO Jasco Micro FT-IR spectrophotometer.

Enrichment and isolation. The media for enrichment cultures were CA medium and poor CA medium, which was the same as CA medium except for 0.02% peptone and 1.25% yeast extract, containing CA45 or CA28 as the carbon source. Enrichment cultures were incubated in 10 ml of CA medium with reciprocal shaking at 27°C. After 14 days of cultivation, 0.5 ml of each culture was transferred to 10 ml of CA medium and the cultures were incubated under the same conditions. This procedure was repeated four times, and then 1.0 ml of each culture was transferred to 10 ml of poor CA medium. The cultures were incubated under the same conditions, after which 0.5 ml of each culture was transferred to 10 ml of poor CA medium and the cultures were incubated for another 14 days under the same conditions. After the cultivation in poor CA medium, each culture was spread on a CA agar plate. Distinct colonies formed were picked and isolated on pure culture on a CA agar plate. To confirm the ability of cellulose acetate degradation, the colonies were cultivated in CA medium with added textiles (10 x 35 mm) made of CA45 and cellulose acetate membrane filters (DS, mixture of 2.8 and 2.0).

Enzyme assays. Cellulose acetate-degrading activity was assayed in a reaction mixture containing 50 mm phosphate buffer, pH 7.0, 1.0% cellulose acetate, and enzyme solution in a total volume of 1.0 ml. In using insoluble cellulose acetate as the substrate, Pholus A2101G was added to the reaction mixture at a concentration of 0.005%. The reaction was started by adding the enzyme solution and then the mixture was incubated at 40°C for an appropriate time. The reducing sugar produced was measured by the 3,5-dimethylphenol method with glucose as a standard. Cellulose acetate esterase activity was assayed in the same reaction mixture and under conditions as in the assay of cellulose acetate-degrading activity. The acetic acid released was measured by the 1-ethyl-3-(3-dimethylaminopropyl)carbodiimide hydrochloride method.\(^1\)

Preparation of enzymes. After 7 days of cultivation in 50 ml of CA medium containing CA54, culture supernatant and cells were obtained by centrifugation (10,000 x g, 10 min, 4°C) of the culture. The culture supernatant was salted out by adding ammonium sulfate to 60% saturation. The resulting precipitate was collected by centrifugation (10,000 x g, 10 min, 4°C) and dissolved in 10 mm phosphate buffer, pH 7.0. The solution was dialyzed against the buffer overnight at 4°C. After centrifugation (10,000 x g, 10 min, 4°C) of dialyze, the supernatant was used as a crude enzyme preparation from the culture supernatant. Cells were washed twice with 10 mm phosphate buffer, pH 7.0, and resuspended in the buffer containing 5 mm 2-mercaptoethanol. The cells were disrupted by a sonic oscillator (9 kHz, 180 W) for 5 minutes at 4°C and centrifuged at 16,000 x g for 20 minutes at 4°C. The supernatant was used as the cell-free extract. Protein was measured by the method of Lowry et al.\(^1\) with bovine serum albumin as a standard.

Biodegradation assay. Biodegradation experiments were done with a Okura OM3001 coulometer used in the MTTI method\(^1\) which is based on an electrochemical process to measure the oxygen demand of microorganisms. Cultivations were done in 500-ml flasks containing 300 ml of CA medium and 600 mg of CA45 or CA45 at 30°C with stirring. Each flask was inoculated with 1.0 ml of the suspension of cells, an optical density of about 0.5 at 600 nm, from CA agar slants.

Analysis of cellulose acetate yarn. After the isolated microorganisms were incubated in 50 ml of CA medium for 10 days with reciprocal shaking at 27°C, remaining cellulose acetate textiles were taken out and washed extensively. Absorbance of water, Tensile strength of the cellulose acetate yarns was analyzed with a Tensilon UTM-HI-20 (Orient Co., Ltd) by the method of JIS L1015.\(^1\) The yarns were 75 denier and consisted of 20 filaments. The length of yarns was 35 mm.

**Analytical methods.** Cellulose acetate films were made by casting CA45 dissolved in acetone with a concentration of 12.5%. Thickness of the films was 80 to 100 μm. The films (2 x 5 cm) were added to the shaking flasks containing 50 ml of CA medium and cells from the slants were inoculated into the media. After 10 days of cultivation, the films and CA54 used as the carbon source were washed extensively with distilled water and dried in a desiccator at room temperature. Recording of the infrared (IR) spectra of films was done with a JASCO Jasco Micro FT-IR spectrophotometer.

**Results**

Isolation and identification of cellulose acetate-degrading microorganisms

The bacteria capable of assimilating cellulose acetate were isolated from soil samples. Two bacteria, strains SC and SF, were isolated from cultures in CA medium containing CA45 and six bacteria, strains D, G, SB, SI, SM, and SQ, were isolated from cultures in CA medium containing CA28. Degradation of cellulose acetate membrane filters and textiles by the isolated bacteria was examined. Each strain was cultivated in CA medium containing CA54, CA54 oligomer, or CBOA as the carbon source. In the culture with CA54 or CA54 oligomer, strains SB and SC degraded the membrane filters to pieces and the other strains slightly degraded them. The degradation of the filters in the culture with CBOA was scarcely observed. For degradation of cellulose acetate textiles by the isolated bacteria, similar results were obtained. The strength of remaining cellulose acetate yarns is shown in Table I. Strength retention of

| Table I. Tensile Strength of Cellulose Acetate Yarns after Microbial Degradation in CA Media Containing Various Carbon Sources |
|---------------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| Strain                          | Strength (g)    | Strength retention (%) |
| CA54                           | 94.6            | 95.1            | 91.4            | 100             | 100             |
| CA54 Oligomer                   | 57.3            | 35.9            | 94.1            | 60.6            | 37.7            | 103             |
| CBOA                           | 89.4            | 88.2            | 98.2            | 94.5            | 92.7            | 107             |
| Oligomer                        | 87.0            | 93.6            | 93.5            | 92.0            | 98.4            | 102             |
| Absorption                     | 94.7            | 91.6            | 90.4            | 89.5            | 96.3            | 98.9            |
| Acetate                        | 46.4            | 41.1            | 89.4            | 49.0            | 43.2            | 97.8            |
| D                              | 89.7            | 94.3            | 79.3            | 97.0            | 99.2            | 106             |
| G                              | 91.8            | 94.3            | 79.3            | 97.0            | 99.2            | 106             |
| SM                             | 89.7            | 92.7            | 86.5            | 94.5            | 97.5            | 94.6            |
| SQ                             | 87.8            | 87.9            | 82.8            | 83.2            | 92.4            | 90.6            |

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yarns degraded in CA medium containing CA54 or CA54 oligomer was 49.0% and 43.2% in the culture of strain SB and 60.6% and 37.7% in the culture of strain SC, respectively.

Taxonomic characteristics of strains SB and SC are shown in Table II. The bacteria had the closest resemblance each other except for assimilation of mannitol. According to "Bergey's Manual of Systematic Bacteriology," Vol. 1,19 both bacteria were identified as Neisseria sicca and named

Table II. Taxonomic Characteristics of Cellulose Acetate-degrading Bacteria

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>Strain SB</th>
<th>Strain SC</th>
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<tbody>
<tr>
<td>Shape</td>
<td>Short rod</td>
<td>Short rod</td>
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<tr>
<td>Flagella</td>
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<td>-</td>
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<tr>
<td>Spore</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Gram stain</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Color of colony</td>
<td>Whitish</td>
<td>Whitish</td>
</tr>
<tr>
<td>Catalase</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Oxidase</td>
<td>+</td>
<td>+</td>
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<tr>
<td>OF test</td>
<td>Oxidative</td>
<td>Oxidative</td>
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<tr>
<td>VP test</td>
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<td>MR test</td>
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<td>±</td>
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<tr>
<td>Nitrate reduction</td>
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<tr>
<td>Urease</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Acid production from:</td>
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</tr>
<tr>
<td>Glucose</td>
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<tr>
<td>Lactose</td>
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<td>+</td>
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<td>Maltose</td>
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<tr>
<td>Mannitol</td>
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<tr>
<td>Galactose</td>
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<tr>
<td>Xylose</td>
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<tr>
<td>Sucrose</td>
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<tr>
<td>Hydrolysis of:</td>
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<tr>
<td>Esculin</td>
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<td>+</td>
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<tr>
<td>Arginine</td>
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<td>-</td>
</tr>
<tr>
<td>Gelatin liquefaction</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Utilization of citrate</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

* +, positive; ±, weak; −, negative.

Neisseria sicca SB and SC.

Biodegradation of cellulose acetate

To confirm the assimilability of cellulose acetate by N. sicca SB and SC, the number of living cells was examined during growth of both strains in CA media (Fig. 1). The number of living cells of N. sicca SB cultivated in CA media was over 10 times higher than that in a control culture without cellulose acetate. The number of living cells with CA45 was more than that with CA54. N. sicca SB reached the stationary phase at about 6 days with CA45 and about 4 days with CA54. On the other hand, the number of living cells in the control culture gradually decreased after 2 days of cultivation. Growth curve of N. sicca SC was similar to that of N. sicca SB. The course of the biodegradation activity of both strains was examined with cellulose acetate membrane filters in CA medium containing CA54. The membrane filters were slightly degraded at 5 days in both cultures and were broken into small pieces at 10 days (Fig. 1).

Biodegradation experiments were done in CA media with the apparatus for measuring biochemical oxygen demand over a 20-day period (Fig. 2). Biodegradability of CA45 and CA54 on the basis of biochemical oxygen demand reached 51 and 40% in the culture of N. sicca SB and 60 and 45% in the culture of N. sicca SC within 20 days, respectively. Biodegradability of CA45 by both strains was higher than that of CA54. In the biodegradation of CA45, a lag period of 6 to 7 days in both cultures was observed and after that the biodegradation rate rapidly increased. In the biodegradation of CA54, there was also a longer lag period of 9 days in the culture of N. sicca SC. On the other hand, there was no lag period in the culture of N. sicca SB.

Structural changes in degraded cellulose acetate

Various analyses were done with cellulose acetate degraded by N. sicca SB and SC. The ratios of absorption

Fig. 1. Growth Curves of N. sicca SB and SC.

Growth of N. sicca SB (A) and SC (B) was monitored by measuring living cells on nutrient agar plates. Both strains were cultivated in cellulose acetate media without cellulose acetate (●) and with CA45 (▲) or CA54 (▼) as the carbon source. Biodegradation activities of N. sicca SB (C) and SC (D) are shown as the degree of breakdown of cellulose acetate membrane filters in a CA medium containing CA54.
at 1730 and 1210 cm\(^{-1}\) to that of 1030 cm\(^{-1}\) in the degraded films were 78.8 and 95.0\% for \textit{N. sicca} SB and 71.6 and 92.2\% for \textit{N. sicca} SC, respectively (Table III). The integral of peaks at 1.9-2.1 ppm, which is attributable to acetyl groups, in \(^1\)H-NMR spectra of the degraded CA54 decreased to 85.1\% for \textit{N. sicca} SB and 89.5\% for \textit{N. sicca} SC.

The changes of molecular weight of CA54 in both cultures are also shown in Table III. In the number-average molecular weight (\(M_n\)) of the remaining polymer, only 9 and 5\% of the initial molecular weight in both cultures at 10 days reduced. The polymer had almost the same molecular weight distribution as that of the control, although the value for \textit{N. sicca} SB slightly increased. Low-molecular-weight fragments in the remaining polymers were not detected by GPC analyses (Fig. 3).

\textbf{Enzymes involved in cellulose acetate degradation}

To examine the enzymatic degradation mechanism of cellulose acetate, culture supernatant and cell-free extract from \textit{N. sicca} SB and SC were put into reaction solutions containing cellulose acetate with different DS values as the substrate. As shown in Table IV, activities of enzymes which release acetic acid and produce reducing sugars were mainly localized in the culture supernatant of both strains. The amount of acetic acid released from CA45 was 21 and 19 times for \textit{N. sicca} SB and SC higher than that from CA54. Using CBOA as the substrate, whose all hydroxyl groups were acetylated, the amount of released acetic acid was as same as that from CA45. Reducing sugars were produced from CA45 and CBOA and were not from CA54, because of its low degradability.

\textbf{Discussion}

The hydrolysis of cellulose involves 1,4-\(\beta\)-\(\delta\)-glucan glucanohydrolase (EC 3.2.1.4), 1,4-\(\beta\)-\(\delta\)-glucan cellobiohydrolase (EC 3.2.1.91), and \(\beta\)-glucosidase (EC 3.2.1.21). These enzymes are the major components of cellulolytic systems produced by microorganisms such as fungi and bacteria.\(^5,20,21\) Cellulose acetate is a good possibility because of its plastic-like characteristics and cellulose being its main component.\(^9\) Although the biodegradability of cellulose acetate in mixed cultures such as activated sludge,\(^10-13\) by some unidentified bacteria\(^9\) and by \textit{Pseudomonas paucimobilis}\(^9\) has been reported, the mechanism of biodegradation of cellulose acetate in enzymatic level has not been elucidated.

We isolated bacteria, strains SB and SC, capable of assimilating cellulose acetate from soil and identified as \textit{Neisseria sicca}. Both strains degraded cellulose acetate textiles and membrane filters in CA medium containing CA54 or CA54 oligomer as the carbon source, and these

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig2.png}
\caption{Biodegradability of Cellulose Acetates by \textit{N. sicca} SB and SC. Biodegradability of CA45 (\(\bullet\)) and CA54 (\(\Delta\)) by \textit{N. sicca} SB (A) or SC (B) was calculated from the oxygen demand of the microorganisms. The details were described in Materials and Methods.}
\end{figure}

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{fig3.png}
\caption{GPC Profiles of CA54 and Degraded CA54 in Low-molecular-weight Region. A, control CA54; B, CA54 degraded by \textit{N. sicca} SB; C, CA54 degraded by \textit{N. sicca} SC. A horizontal bar represents the molecular weight region of 62 to 8000.}
\end{figure}

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|c|}
\hline
 \textbf{Strain} & \textbf{\(\frac{A_{1330}}{A_{1030}}\)} & \textbf{\(\frac{A_{1210}}{A_{1030}}\)} & \textbf{Integral}^b & \textbf{\(M'_n\)} & \textbf{\(M'_w\)} & \textbf{\(\frac{M_w}{M_n}\) reduction}^d \\
\hline
Control & 0.883 & 1.00 & 45.6 & 32,200 & 92,300 & 2.87 & 100 \\
\textit{N. sicca} SB & 0.696 & 0.950 & 38.8 & 29,200 & 89,600 & 3.07 & 9.31 \\
\textit{N. sicca} SC & 0.632 & 0.922 & 40.8 & 30,600 & 89,600 & 2.93 & 4.97 \\
\hline
\end{tabular}
\caption{Changes in the Acetyl Content and the Molecular Weight of CA54 before and after Biodegradation}
\end{table}

\begin{itemize}
\item The recovered films were analyzed by IR spectroscopy.
\item The recovered powder was analyzed by \(^1\)H-NMR spectroscopy. The values were integrated between 1.9 to 2.1 ppm. Integral for 1,1,2,2-tetrachloroethane was assigned a value of 1.0.
\item The recovered powder was analyzed by GPC system.
\item \(M_w\) reduction \((\%) = \frac{M_w(t) - M_w(0)}{M_w(0)} \times 100\). \(M_w(t)\) is \(M_w\) of control. \(M_w(0)\) is \(M_w\) of sample at 10 days of cultivation.
\end{itemize}
degradations occurred at stationary phase of the growth. The degradation of these materials, however, was not observed in the medium supplemented with CBOA instead of cellulose acetate, while the strains could grow in the medium. These facts suggest that enzymes involved in the degradation of cellulose acetate are extracellular and efficiently produced in the medium containing cellulose acetate or its oligomer as the carbon source. CA45 with a lower DS value was a good nutrient and was degraded more rapidly than CA54. Tokiwa and Suzuki\(^{22}\) reported that the susceptibility to hydrolysis of various copolyesters by *Ricinus communis* lipase decreased with increasing rigidity of the copolyester molecule. The higher biodegradability of CA45 seemed to depend on its hydrophilic characteristic and lower crystallinity.\(^{23}\)

Although CA45 as the carbon source was assimilated by *N. sica* SB and SC, \(M_\text{w}/M_\text{n}\) and polydispersity (\(M_\text{w}/M_\text{n}\) ratio) of the remaining CA45 changed only slightly and degradation products with low molecular weight in the polymer were not detected by GPC analyses. Doi et al.\(^{24}\) reported in the enzymatic degradation of poly(3-hydroxybutyrate) and its copolyesters that the weight of remaining polymers decreased and their \(M_\text{w}\) values were almost unchanged, and suggested that polymer erosion proceeds via surface dissolution. It was concluded that the water-insoluble polymers are degraded enzymatically at the surface and the degradation products with low molecular weight are rapidly diffused and metabolized by the bacteria. Especially in the biodegradation of cellulose acetate, degraded cellulose acetate with DS of less than about one is soluble in water and seems to be easily assimilated.

In the biodegradation experiments, a lag period of 6 and 9 days for GA45 and CA45 was observed, after which rapid degradation occurred. The shorter lag period in the biodegradation of CA45 and the decrease in the acetyl content of cellulose acetate with cultivation time indicated that the biodegradation of cellulose acetate needed a preliminary reaction(s) such as deacetylation, which proceeded at the early stage of growth, before significant degradation by hydrolysis of main chain. In fact, enzymes involved in the cellulose acetate degradation were predominantly present in the culture supernatant of *N. sica* SB and SC and were active on CA45, CA54, and CBOA to produce acetic acid and reducing sugars. These facts suggest that cellulose acetate was degraded by the cooperative reactions of esterase(s) and cellulase(s). No papers have appeared describing the degradation of cellulose acetate by enzymes from an isolated bacterium. We showed here the biodegradation of cellulose acetate on the enzymatic level. The \(\beta\)-1,4-linked D-xylopyranosyl residues of the xylan backbone are commonly substituted with acetyl, arabinosyl, and glucuronosyl residues.\(^{25}\) Acetyl xylan esterases (EC 3.1.1.6) which have been reported are assayed with natural water-soluble acetyl xylan as the substrate\(^{25}\) and are not or little active on water-insoluble cellulose acetate.\(^{27,28}\) While whether acetyl xylan esterase and esterase acting on insoluble cellulose acetate are identical is not known, the esterase was tentatively termed cellulose acetate esterase because of its specificity.

Whether these cellulose acetate esterase(s) and cellulase(s) are more active on hydrophilic compounds than the other esterases and cellulases which have been reported is not known. Work is in progress to purify the enzymes involved in cellulose acetate degradation and to examine their substrate specificities.

### References

23. R. T. Bogan and R. J. Brewer, in “Encyclopedia of Polymer Science


