Intramolecular glycosylation approach toward constructing macrocyclic structure of resin glycosides

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Abstract: Oligosaccharide containing macrolides of resin glycosides were effectively constructed by MeOTf promoted intramolecular glycosylation of dodecyl thioglycosyl donors. Synthesis of a key disaccharide intermediate of tricolorin A and total synthesis of tricolorin F were successfully achieved by this approach.

Key words: resin glycoside, macrolide, tricolorin, dodecyl thioglycoside, intramolecular glycosylation

Resin glycosides are glycolipids of plant origin are one of the constituents of the Convolvulaceae (morning glory family), some of which has been used as traditional folk medicines.1 Recently, various resin glycosides with unique biological effects such as antibacterial,2 antifungal,3 cytotoxic,4 and plant growth controlling activities5 are isolated from leaves and roots of these plants. They are consisted of several deoxygenated monosaccharides and hydroxy fatty acids as an aglycon moiety. Most of the bioactive resin glycosides have unusual macrolidic structures, in which the aglycon carboxyl group is intramolecularly esterified with one of the sugar hydroxy groups. The unique structure and bioactivity attract attention of synthetic chemists.6 Synthetic studies so far reported on resin glycosides revealed that construction of the macrolide structure is a crucial step, which was conventionally carried out by intramolecular esterification between the aglycon carboxylic acid and a sugar hydroxy group under high dilution conditions.7 Recently, Fürstner developed an alternative approach employing ring closure metathesis (RCM) for this cyclization, which was applied to synthesis of various resin glycosides.8 In contrast to these two approaches, the oligosaccharide-containing macrocidic structure would be constructed by intramolecular glycosylation. In our previous studies on cycloglycan synthesis, we recognized the usefulness of thioglycosyl donors for intramolecular glycosylation.9 In this communication, we describe a model reaction of intramolecular glycosylation and application
of this concept to synthesis of tricolorin A and F\textsuperscript{10} having tetra- and tri-saccharide structures, respectively.

Applicability of intramolecular glycosylation toward a model disaccharide 6RS was first investigated employing our recently developed odorless dodecyl thioglycosides\textsuperscript{11} as glycosyl donors as depicted in Scheme 1. The key intermediate 5RS that has both glycosyl donor and acceptor functions was prepared by glycosylation and esterification of racemic methyl 11-jalapionate\textsuperscript{6a} 1RS with two dodecyl thioglycosides 2 and 4. The first glycosylation was conducted with 1RS and the quinovoside 2 using MeOTf\textsuperscript{12} as a promoter, giving the β-glycoside 3RS in 85% yield. After saponification of 3RS, the resulting acid was esterified with 4 to give 5RS in 69% yield.\textsuperscript{14} The precursor 5RS was subjected to intramolecular glycosylation under the conditions summarized in Table 1. Comparison with two promoters, NIST\textsuperscript{13}OH and MeOTf (entries 2 and 5), showed that the former reaction gave 6RS\textsuperscript{14} in slightly higher yield with an almost same ratio of the diastereomer. Although increasing the substrate concentration resulted in rapid consumption of 5RS and production of various polar products, almost same yield (27-35%) of the desired S-isomer 6S was obtained. These results suggest that the R-isomer of 5RS easily undergoes intermolecular glycosylation to afford polymeric compounds. The best results were obtained at the substrate concentration of 2.2 mM with 10 mol equiv promoter, giving 6RS in 69% yield with a diastereomer ratio of R/S = 52 : 48. For structural elucidation of the products, the corresponding S-isomer 6S was synthesized from 1S.

Encouraged by these successful results of the model experiments, we next examined the synthesis of a disaccharide constituent of tricolorin A. As shown in Scheme 2, the D-fucosyl donor 7 was first coupled with enantiomERICALLY pure aglycon\textsuperscript{7a} 1S using MeOTf as a promoter giving 8 in 81%, which was subsequently saponified and condensed with the glucosyl donor 11. Although we chose trichloroethoxycarbonyl (Troc) group as a temporary protective group of 11, its migration during the condensation reaction resulted in low isolated yield of 12.\textsuperscript{14} The key intermediate 12 thus obtained was subjected to similar MeOTf promoted intramolecular glycosylation in CH\textsubscript{2}Cl\textsubscript{2} at a substrate concentration of 2.1 mM, giving the macrolide\textsuperscript{14} 13 in 67% isolated yield. The coupling constant (7.6 Hz) between H-1′ and 2′ suggested that the anomic configuration of newly formed glycosidic bond was β.

Our attention next focused on the synthesis of a trisaccharidic resin glycoside, tricolorin F,\textsuperscript{10} having a 21 membered ring. The D-fucosyl acceptor 9, which was prepared by Zemplén de-O-benzyolation of 8, underwent MeOTf promoted glycosylation with the donor 14 to give the disaccharide 15 in 83% yield. In order to transform into the substrate 19 for
intramolecular glycosylation, the ester functions in 15 were hydrolyzed with aq. NaOH. Subsequently, the resulting carboxylic acid 16 was to be coupled with the thioquinovoside 17. Stoichiometric reaction between 16 and 17 gave a complex mixture containing the desired 19 only in 9% yield probably due to polymerization. This problem was overcome by use of excess alcohol 17 (5 mol equiv) to give 18 in 72% yield. In its $^1$H NMR spectrum, a signal assignable to H-2 of the quinovose residue was observed at lower magnetic field of $\delta$ 4.95 as a triplet ($J = 9.6$ Hz), suggesting that the hydroxy group at this position was esterified. The next intramolecular glycosylation of 18 using similar MeOTf method found to proceed smoothly in CH$_2$Cl$_2$ at the substrate concentration of 1.8 mM, giving known fully protected derivative 19* of tricolorin F in 70% yield. Its structure was confirmed mainly by NMR spectroscopy; $^1$H-1” and H-2” were observed at doublet ($J = 10.8$ Hz) and $\delta$ 5.01, respectively, showed that newly formed $\beta$-D-quinovosyl linkage and the 1”, 2”-macrolide structure. It was noteworthy that H-1 and H-1’ observed at $\delta$ 5.06 and 4.42 as broad doublets probably due to the constrained structure of its trisaccharide containing macrolide structure. Finally global deprotection of 19 was successfully attained by a two-step procedure involving hydrolysis of the acetal group with 3% HCl/methanol and catalytic hydrogenolysis of the O-benzyl groups over Pd/C in MeOH, giving tricolorin F 20* in almost quantitative yield.

In conclusion we have succeeded in synthesis of the macrolidic structures of resin glycosides through novel intramolecular glycosylation approach. Combination with macrolactonization and RCM, the new methodology would provide various synthetic analogues useful for a systematic survey of the biological functions of resin glycosides.

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References and Notes

All new compounds had satisfactory data for elemental analysis or high resolution mass spectrum. Selected physical data.

**Compound 5RS:** $^1$H NMR (300 MHz, CDCl$_3$): $\delta = 8.02$ (2H, CH$_{arom}$), 5.45 (t, 1H, J$_{3',4'} = 9.4$ Hz, H-3'), 5.19 (t, 1H, J$_{2',3'} = 9.8$ Hz, H-2'), 4.97 (m, 6H, PhCH$_2$), 4.57 (d, 1H, J$_{1',2'} = 10.0$ Hz, H-1'), 4.25 (d, 1H, J$_{1,2} = 7.1$ Hz, H-1), 3.61 (m, 4H, H-2, 3, 5', OCH$_3$), 3.41 (m, 2H, H-5, 4'), 3.20 (t, 1H, J$_{4,5} = 8.6$ Hz, H-4), 2.69 (m, 2H, SCH$_2$), 2.26 (s, 1H, OH), 2.09 (t, 2H, J = 7.3 Hz, CH$_3$COO), 1.57 (m, 56H, H-6, 6', 22 × CH$_2$, 2 × CH$_3$). Although 5R and 5S were not distinguished by both $^1$H and $^{13}$C NMR spectra, the diastereomer ratio of almost 1:1 was deduced by careful HPTLC (Merck) analysis on silica gel using hexane-EtOAc (2:1).
Compound 6R: [α]_D +13.3 (c 1.05, CHCl_3). \(^1\)H NMR (300 MHz, CDCl_3): δ = 7.907.19 (m, 20 H, CH_3), 5.41 (t, 1 H, J_3′, 4′ = 8.6 Hz, H-3′), 5.23 (t, 1 H, J_2′, 3′ = 7.7 Hz, H-2′), 5.14 (d, 1 H, J_1′, 2′ = 7.7 Hz, H-1′), 4.754.48 (m, 6 H, PhCH_2), 4.39 (d, 1 H, J_1, 2 = 7.7 Hz, H-1), 3.853.76 (m, 2 H, H-2, OCH), 3.533.45 (m, 1 H, H-5′), 3.42 (t, 1 H, J_4′, 5′ = 9.2 Hz, H-4′), 3.41 (t, 1 H, J_3, 4 = 8.5 Hz, H-3), 3.293.22 (m, 1 H, H-5), 3.11 (t, 1 H, J_4, 5 = 9.1 Hz, H-4), 2.292.08 (m, 2 H, CH_2COO), 1.671.21 (m, 30 H, H-6, 6′, 12 × CH_2), 0.88 (t, 3 H, J = 6.7 Hz, CH_3CH_3). \(^1\)C NMR (75.5 MHz, CDCl_3): δ = 172.4, 165.4, 138.5, 138.1, 133.4, 130.2, 130.1, 129.0, 128.8, 128.4, 128.4, 128.2, 128.0, 99.6, 95.6, 86.4, 84.4, 82.9, 81.0, 76.2, 75.8, 75.6, 75.4, 74.9, 71.2, 71.1, 34.9, 34.5, 34.5, 32.6, 31.2, 29.4, 28.3, 28.0, 27.9, 26.9, 23.1, 18.5, 18.4, 14.6. HRMS (FAB): m/z calcd for C_{58}H_{72}O_{11} [M + Na]^+: 943.4995; found: 943.4995.

Compound 6S: [α]_D +25.6 (c 0.20, CHCl_3). \(^1\)H NMR (300 MHz, CDCl_3): δ = 7.927.17 (m, 20 H, CH_3), 5.42 (t, 1 H, J_3′, 4′ = 8.6 Hz, H-3′), 5.23 (t, 1 H, J_2′, 3′ = 8.3 Hz, H-2′), 5.07 (d, 1 H, J_1′, 2′ = 7.6 Hz, H-1′), 4.754.46 (m, 6 H, PhCH_2), 4.24 (d, 1 H, J_1, 2 = 7.8 Hz, H-1), 3.82 (dd, 1 H, J = 8.0 Hz, J_2, 3 = 9.3 Hz, H-2), 3.533.46 (m, 2 H, H-5′, OCH_3), 3.40 (t, 1 H, J_4′, 5′ = 9.2 Hz, H-4′), 3.40 (t, 1 H, J_3, 4 = 8.4 Hz, H-3), 3.313.26 (m, 1 H, H-5), 3.11 (t, 1 H, J_4, 5 = 9.2 Hz, H-4), 2.19 (s, 2 H, CH_2COO), 1.591.22 (m, 30 H, H-6, 6′, 12 × CH_2), 0.89 (t, 3 H, J_1, 2 = 6.4 Hz, CH_2CH_3). \(^1\)C NMR (75.5 MHz, CDCl_3): δ = 172.4, 165.5, 138.5, 138.2, 133.4, 130.2, 129.0, 128.9, 128.8, 128.4, 128.3, 128.3, 128.0, 102.3, 99.5, 86.1, 84.1, 83.2, 82.2, 76.5, 75.8, 75.6, 75.5, 75.1, 71.5, 70.9, 35.3, 35.0, 34.6, 32.5, 31.6, 29.8, 28.4, 28.1, 27.3, 25.7, 25.4, 23.4, 23.1, 18.4, 14.6. HRMS (FAB): m/z calcd for C_{58}H_{72}O_{11} [M + Na]^+: 943.4995; found: 943.4995.

Compound 12: [α]_D +7.2 (c 0.76, CHCl_3). \(^1\)H NMR (300 MHz, acetone-d_6): δ = 7.407.25 (m, 10 H, 2 CH_3), 5.40 (t, 1 H, J_3′, 4′ = 8.9 Hz, H-3′), 4.974.57 (m, 6 H, PhCH_2, Cl_3CCH_2), 4.82 (d, 1 H, J_1′, 2′ = 10.0 Hz, H-1′), 4.73 (t, 1 H, J_2′, 3′ = 9.6 Hz, H-2′), 4.22 (d, 1 H, J_1, 2 = 8.1 Hz, H-1), 4.03 (dd, 1 H, J = 2.2 Hz, J_4, 5 = 6.0 Hz, H-4), 4.003.96 (m, 1 H, H-3), 3.91 (dd, 1 H, J = 2.1 Hz, J = 6.5 Hz, H-5), 3.863.75 (m, 4 H, H-4′, 5′, 6′a, 6′b), 3.633.60 (m, 1 H, CHO), 3.35 (t, 1 H, J_2, 3 = 7.6 Hz, H-2), 2.852.65 (m, 2 H, SCH_2), 2.332.20 (m, 2 H, CH_2COO), 1.521.28 (m, 53 H, H-6, C(CH_3)_2, 22 × CH_2), 0.910.86 (m, 6 H, 2 × CH_3). Column chromatography of the mixture gave crude 12 contaminated with small amount of an unknown product in ca. 60% yield and a mixture of 11 its 3-O-Troc derivative. Repeated column chromatography gave pure 12 in 12% yield.

Compound 13: [α]_D +2.1 (c 0.33, CHCl_3). \(^1\)H NMR (300 MHz, acetone-d_6): δ = 7.447.29 (m, 10 H, CH_3), 5.48 (t, 1 H, J_3′, 4′ = 8.6 Hz, H-3′), 5.36 (d, 1 H, J_1′, 2′ = 7.6 Hz, H-1′), 5.084.63 (m, 6 H, PhCH_2, Cl_3CCH_2), 4.57 (dd, 1 H, J = 7.6 Hz, J_2′, 3′ = 8.8 Hz, H-2′), 4.23 (d, 1 H, J_1, 2 = 8.4 Hz, H-1), 4.11 (dd, 1 H, J = 5.3 Hz, J_4, 5 = 7.0 Hz, H-4), 4.05 (dd, 1 H, J = 2.0 Hz, J_3, 4 = 5.3 Hz, H-3), 3.953.84 (m, 5 H, H-2, 5, 4′, 6′a, 6′b), 3.713.65 (m, 1 H, H-5′), 3.553.49 (m, 1 H, CHO), 2.332.00 (m, 2 H, CH_2COO), 1.531.24 (m, 33 H, H-6,
C(CH₃)₂, 12 × CH₂), 0.86 (t, 3 H, J = 6.8 Hz, CH₂CH₃). ¹³C NMR (75.5 MHz, acetone-d₆): δ = 171.8, 153.4, 139.1, 138.8, 128.6, 128.3, 128.2, 128.0, 127.7, 109.6, 101.5, 97.0, 95.3, 81.2, 80.5, 80.2, 77.0, 76.9, 75.5, 75.1, 74.7, 74.5, 73.5, 68.6, 68.3, 35.4, 35.2, 34.5, 32.1, 31.1, 30.1, 29.9, 29.6, 29.3, 29.1, 28.8, 28.6, 28.3, 28.2, 27.9, 27.4, 26.3, 25.4, 25.1, 24.2, 22.8, 16.7, 13.9. HRMS (FAB): m/z calcd for C₄₈H₆₇Cl₃O₁₃ [M + Na]+: 979.3545; found: 979.3542.

Compound 19: [α]D -20.5 (c 0.064, CHCl₃). ¹H NMR (600 MHz, acetone-d₆): δ = 7.417.20 (m, 25 H, CHarom), 5.06 (d, 1 H, J ₁,₂ = 7.4 Hz, H-1'), 5.01 (s, 1 H, H-1''), 5.01 (t, 1 H, J ₂', ₃' = 4.5 Hz, H-2''), 5.014.61 (m, 10 H, PhCH₂), 4.45 (t, 1 H, J ₃,₄ = 6.3 Hz, H-3), 4.42 (d, 1 H, J ₁,₂ = 6.4 Hz, H-1), 4.12 (dd, 1 H, J = 2.0 Hz, J ₄,₅ = 5.7 Hz, H-4), 3.983.91 (m, 1 H, H-5), 3.94 (t, 1 H, J ₂,₃ = 6.4 Hz, H-2), 3.803.74 (m, 2 H, H-6'a, 6'b), 3.69 (t, 1 H, J ₃',₄' = 7.7 Hz, H-3'), 3.64 (m, 1 H, H-3''), 3.61 (t, 1 H, J ₂',₃' = 7.4 Hz, H-2''), 3.58 (t, 1 H, J ₄',₅' = 7.3 Hz, H-4'), 3.56 (m, 2 H, H-5'', CHO), 3.463.42 (m, 1 H, H-5'), 3.32 (t, 1 H, J ₄',₅'' = 9.1 Hz, H-4''), 2.13 (t, 2 H, J = 7.6 Hz, CH₂COO), 1.700.85 (m, 39 H, H-6, 6'', 12 × CH₂, C(CH₃)₂, CH₂CH₃). ¹³C NMR (75.5 MHz, acetone-d₆): δ = 172.6, 138.9, 138.7, 138.5, 138.3, 129.0, 128.9, 128.8, 128.6, 128.5, 128.3, 128.2, 128.1, 127.9, 127.6, 110.2, 102.9, 100.8, 83.8, 78.7, 77.7, 75.9, 75.8, 75.6, 75.5, 75.4, 74.0, 72.0, 68.8, 36.6, 35.4, 34.5, 32.5, 30.2, 30.1, 29.4, 28.2, 28.1, 28.0, 26.9, 25.5, 23.1, 18.7, 17.3, 14.6. HRMS (FAB): m/z calcd for C₇₂H₉₆O₁₅ [M + H]+: 1199.6672; found: 1199.6640.
Scheme 1

Intramolecular glycosylation toward a model disaccharide 6RS. **Reagents and conditions:** (a) MeOTf, MS 4 Å, CH₂Cl₂, r.t., 1.5 h, 85%; (b) NaOH, THF–EtOH, 50 °C, 7 h; then 4.

Scheme 2

Synthesis of a disaccharide constituent of tricolorin A 13. **Reagents and conditions:** (a) MeOTf, MS 4 Å, CH₂Cl₂, r.t., 1 h, 81%; (b) NaOMe, MeOH,
Scheme 3  Total synthesis of tricolorin F.  Reagents and conditions: (a) MeOTf, MS 4 Å, CH₂Cl₂, r.t., 6 h, 83%; (b) NaOH, THF–EtOH, 50 °C, 4 h, 99%; (c) WSC·HCl, DMAP, CH₂Cl₂, r.t., 24 h, 72%; (d) MeOTf, MS 4 Å, CH₂Cl₂, r.t., 24 h, 70%; (e) i) HCl, MeOH, r.t., 2 h; ii) Pd/C, H₂, MeOH, r.t., 24 h, 99%. 
Table 1
Results of intramolecular glycosylation$^a$

<table>
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<tr>
<th>Entry</th>
<th>Promoter$^b$</th>
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<th>Time</th>
<th>Yield</th>
<th>$R/S$</th>
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<tr>
<td>1</td>
<td>MeOTf (10 equiv)</td>
<td>2.2 mM</td>
<td>19 h</td>
<td>69%</td>
<td>52/48</td>
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<tr>
<td>2</td>
<td>MeOTf (5 equiv)</td>
<td>4.5 mM</td>
<td>13 h</td>
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<td>MeOTf (5 equiv)</td>
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<td>39%</td>
<td>29/71</td>
</tr>
<tr>
<td>4</td>
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<td>35%</td>
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</tr>
<tr>
<td>5</td>
<td>NIS (1.5 equiv)</td>
<td>4.5 mM</td>
<td>13 h</td>
<td>52%</td>
<td>41/59</td>
</tr>
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</table>

$^a$ Reactions were performed in dry CH$_2$Cl$_2$ at r.t. for MeOTf and at −20 °C for NIS.
$^b$ Catalytic amount of TfOH was added together with NIS.
$^c$ Ratio of diastereomer was determined by $^1$H NMR analysis.