chromatographed on a silica gel column with benzene–hexane as an eluent to afford 0.285 g (54%) of 8[18] as a colorless oil: IR 1740, 1640, 1260, 1230 cm^{-1}; ^1H NMR ($CDCl_3$) δ 7.50 (br d, J = 1.8 Hz, 1 H), 7.45 (s, 1 H), 6.75 (d, J = 3.6 Hz, 1 H), 6.50 (dd, J = 1.8, 3.6 Hz, 1 H), 4.40 (q, J = 7.2 Hz, 2 H), 4.27 (q, J = 7.2 Hz, 2 H), 1.36 (t, J = 7.2 Hz, 3 H), 1.30 (t, J = 7.2 Hz, 3 H).

A titanium tetrachloride catalyzed reaction of **1b** with furan in dichloromethane at 0 °C at atmospheric pressure also afforded 8 in 35% yield.

Yb(fod)$_3$ as a Catalyst. To a solution of 0.502 g (2.2 mmol) of **1b** and 0.07 g (10.4 mmol) of furan in dichloromethane was added 0.024 g of tris(6,6,7,7,8,8,8-heptafluoro-2,2-dimethyl-3,5-octanedionato)ytterbium (Yb(fod)$_3$). The solution was pressurized to 1.0 GPa for 5 days. Working up of the reaction mixture as mentioned above gave 0.203 g (39%) of 8.

Thermal Retro Diels–Alder Reactions of 2b. A solution containing *endo*-**2b** (66.9 mg; 0.224 mmol) and *exo*-**2b** (29.7 mg; 0.1 mmol) in 1.0 mL of benzene-d_6 was sealed in an NMR tube, and the tube was immersed in a constant temperature bath maintained at 71.2 °C. The reactions were monitored by a 100-MHz NMR spectrometer. The decomposition rates of *endo*-**2b** and *exo*-**2b** were calculated by the intensity change of the acetoxy methyl signals of the reactants and **1b**, and the ring hydrogens of furan as well. The reactions were found to be very clean, and no other product signals were detected.

Lewis Acid Catalyzed Retro Diels–Alder Reactions of *endo*-2b. ZnI$_2$ as a Catalyst. A solution of *endo*-**2b** (59.5 mg; 0.2 mmol) and zinc iodide (75.7 mg; 0.2 mmol) in 5 mL of tetrahydrofuran was stirred for 5 min at 20 °C. The solution was evaporated, and to the residue was added 10 mL of benzene. Then the mixture was washed with saturated aqueous sodium hydrogen carbonate and water, and the organic layer was dried over sodium sulfate. After removal of the solvent under reduced pressure, 31.9 mg (69%) of **1b** was obtained as a colorless oil.

Yb(fod)$_3$ as a Catalyst. A solution of *endo*-**2b** (59.5 mg; 0.2 mmol) and Yb(fod)$_3$ (20.3 mg; 0.19 mmol) in 5 mL of tetrahydrofuran was stirred for 30 min at 20 °C. Working up of the reaction mixture as described above afforded 32.8 mg (71%) of **1b** as the sole product.

Acknowledgment. We are indebted to Dr. M. Hashimoto, the Department of Chemistry, Kobe University, for X-ray crystallography. This work was supported by a Grant-in-Aid for Scientific Research (No. 60430008) from the Ministry of Education, Science and Culture of Japan.

(18) Bogatskaya, L. G.; Kamalov, G. L.; Lukyanenko, N. G.; Samitov, Yu. Yu.; Kuehne, T. *Zh. Org. Khim.* **1977**, *13*, 1072.

Highly Stereoselective Total Synthesis of β-Ribofuranosylmalonate

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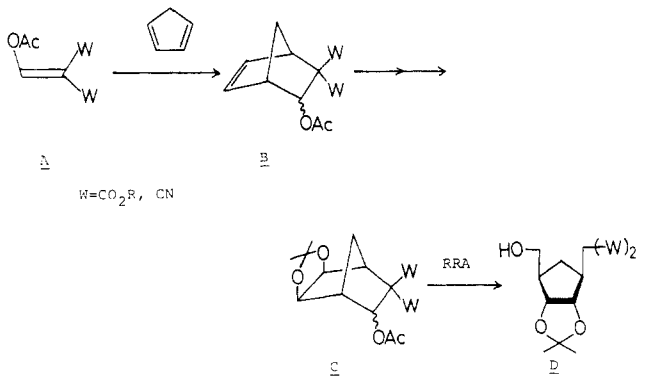
β-Ribofuranosylmalonates, prospective synthons for a variety of C-nucleosides, have been synthesized stereoselectively through the high-pressure Diels–Alder reaction of furan with dialkyl (acetoxymethylene)malonate, followed by reductive retrograde aldol C–C bond fission of the diol derived from the adduct.

Previously, we have established a facile method for the synthesis of the carbocyclic analogues D (Scheme I) of β-ribofuranosylmalonate and demonstrated their usefulness by their conversion to a variety of carbocyclic analogues of C-nucleosides (e.g., carbocyclic pyrimidine C-nucleosides[1] and carbocyclic oxazinomycins[2]). Although our method follows the general strategy for the construction of the bicyclo[2.2.1]heptene framework B using the Diels–Alder reaction of cyclopentadiene with acrylate derivatives,[3,4] the novelty of this method is the use of 3-acetoxyacrylate derivatives having a strong electron-withdrawing substituent at the 2-position (A: W = CO_2R, CN), which permits not only ready access of the cycloadduct B but also stereoselective cleavage of the C–C bond

Scheme I[a]



[a] RRA: reductive retrograde aldol reaction (K_2CO_3–$NaBH_4$–MeOH, room temperature).

of the dihydroxylated derivative C by reductive retrograde aldol reaction. We hereafter term this reaction as the RRA reaction.

Recently, we have found that the use of di-*l*-menthyl (acetoxymethylene)malonate (A: W = CO_2-*l*-menthyl) in the titanium tetrachloride catalyzed Diels–Alder reaction affords the corresponding adduct (chiral B) in high diastereomeric excess (de, ≥90%) and hence accomplished

(1) (a) Katagiri, N.; Haneda, T.; Kaneko, C. *Chem. Pharm. Bull.* **1986**, *34*, 4875. (b) Katagiri, N.; Haneda, T.; Tomizawa, S.; Kaneko, C. *Nucleic Acids Symp. Ser.* **1986**, *17*, 1.

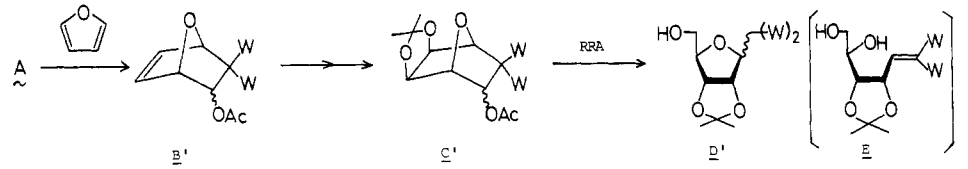
(2) Katagiri, N.; Tomura, M.; Haneda, T.; Kaneko, C. *J. Chem. Soc., Chem. Commun.* **1987**, 1422.

(3) (a) Just, G.; Reader, G.; Faure, B. C. *Can. J. Chem.* **1976**, *54*, 849. (b) Just, G.; Kim, S. *Tetrahedron Lett.* **1976**, 1063. (c) Just, G.; Lim, M.-I. *Can. J. Chem.* **1977**, *55*, 2993. (d) Kozikowski, A. P.; Floyd, W. C. *Tetrahedron Lett.* **1978**, 19. (e) Just, G.; Liak, T. J.; Lim, M.-I.; Potvin, P.; Trantrizons, Y. S. *Can. J. Chem.* **1980**, *58*, 2024. (f) Kozikowski, A. P.; Ames, A. *J. Am. Chem. Soc.* **1981**, *103*, 3923.

(4) For reviews on this topic, see: (a) Buchanan, J. B. *Prog. Chem. Org. Nat. Prod.* **1983**, *44*, 243. (b) Saito, T.; Noyori, R. *Yuki Gosei Kagaku Kyokaishi* **1980**, *38*, 947.

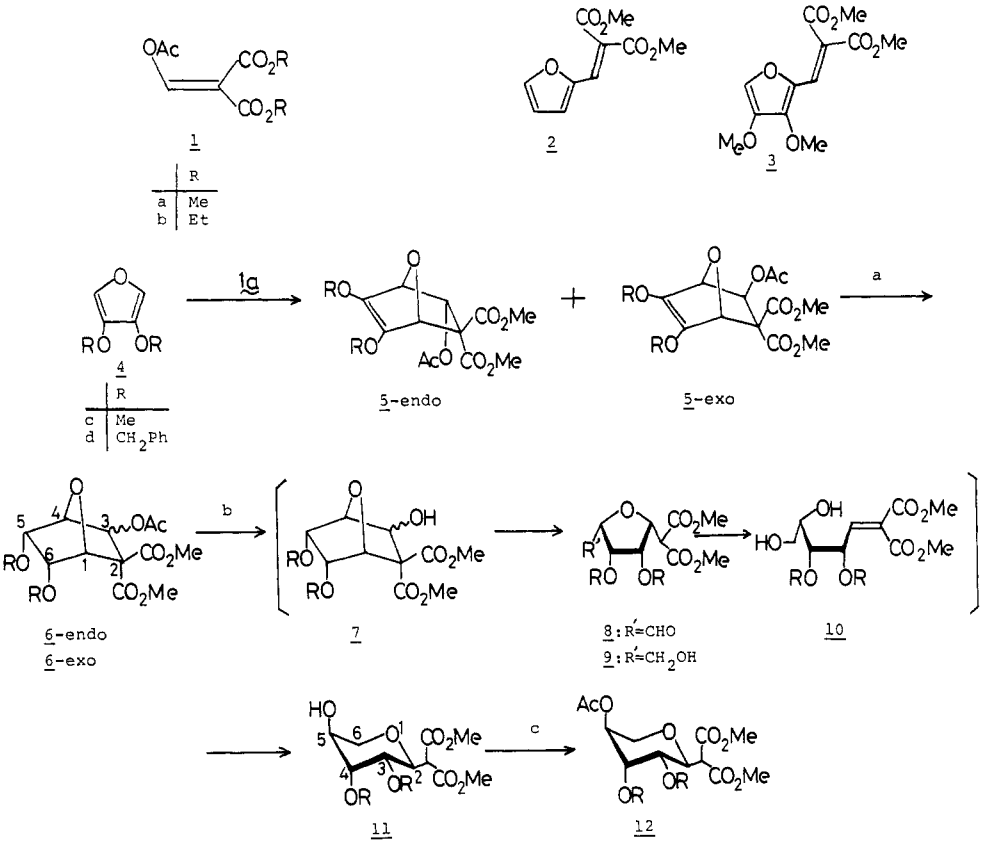
0022-3263/88/1953-5464$01.50/0

Scheme II[a]



[a] RRA, see Scheme I.

Scheme III[a]



[a] (a) H_2, Pd–C, MeOH; (b) K_2CO_3, $NaBH_4$, MeOH; (c) Ac_2O, pyridine.

an efficient enantioselective synthesis of carbocyclic β-D-ribofuranosylmalonate (chiral D).[5] An extension of this method to the synthesis of the corresponding C-nucleoside precursor D′ (Scheme II), however, would be expected to meet two serious problems: (1) How would one obtain the corresponding adduct B′ from the reaction of A with furan? (2) Since the RRA reaction should necessarily be carried out under basic conditions, an inversion of the malonyl group at the anomeric position of the final product D′ is expected due to retro Michael ring opening to the methylenemalonate E followed by recyclization.

In this paper, we report a solution to these two problems and describe an efficient and stereoselective synthesis of β-ribofuranosylmalonate from furan. Experimental details concerning the synthesis of dimethyl and diethyl (acetoxymethylene)malonates,[6] together with the stereoselective synthesis of lyxopyranosyl and ribofuranosyl C-glycosides from 3,4-bis(benzyloxy)furan, are also reported.[7]

Results and Discussion

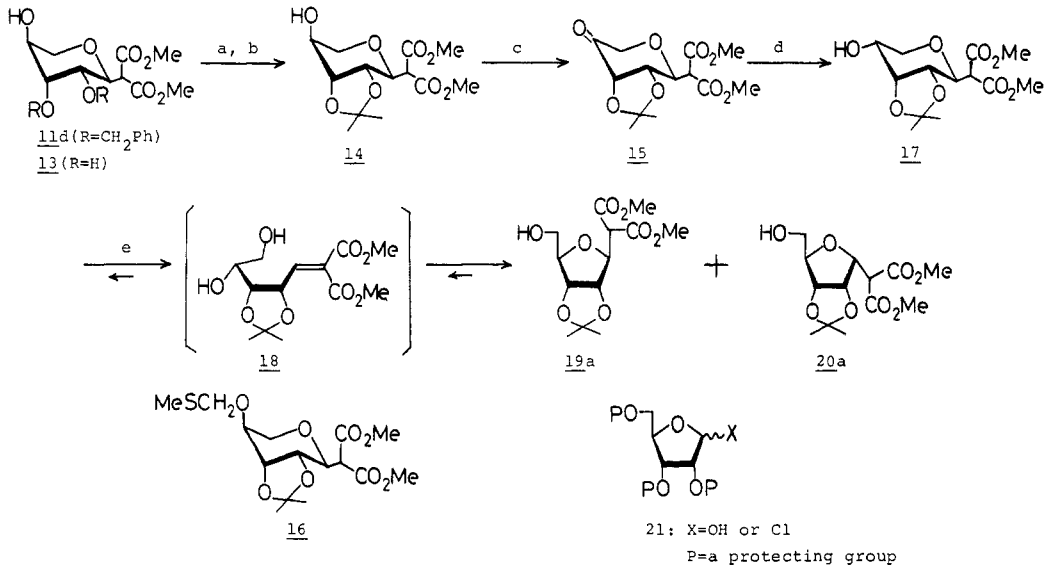
Though the Diels–Alder reaction of furan with a variety of dienophiles is a highly useful reaction as a basic strategy for the synthesis of C-nucleosides,[4] furan fails to undergo the cycloaddition due to its low reactivity and easy cycloreversion of the corresponding adduct. As expected, furan itself did not react with dimethyl (acetoxymethylene)malonate (**1a**) (Scheme III) at ambient temperature under ordinary conditions. A variety of catalysts were also examined in order to achieve the desired Diels–Alder reaction. Unfortunately, however, even use of titanium tetrachloride as the catalyst (which showed a marked acceleration effect in the Diels–Alder reaction of **1a** with cyclopentadiene[1,5]) resulted in the formation of dimethyl 2-furfurylidenemalonate (**2**) in low yield, and none of the desired Diels–Alder adduct was obtained. At this stage, we initiated two alternative lines of study in order to obtain the Diels–Alder adduct of dialkyl (acetoxymethylene)malonate (**1**) with furan and its oxygenated derivatives, which finally would lead to the desired β-ribofuranosylmalonate according to our strategy.

(5) Katagiri, N.; Haneda, T.; Hayasaka, E.; Watanabe, N.; Kaneko, C. *J. Org. Chem.* **1988**, *53*, 226.

(6) Diethyl (acetoxymethylene)malonate has been synthesized recently from the potassium salt of diethyl (hydroxymethylene)malonate and acetyl chloride; see: Wolff, I. A.; Olds, D. W.; Hilvert, G. E. *Synthesis* **1984**, 732. This method was modified by us for the preparation of the ester in large scale.

(7) Some of this study has been reported as communications; see: (a) Reference 1. (b) Katagiri, N.; Akatsuka, H.; Haneda, T.; Kaneko, C. *Chem. Lett.* **1987**, 2257.

Scheme IV[a]



[a] (a) H_2, Pd–C, HCl, MeOH; (b) *p*-TsOH, $Me_2C(OMe)_2$, acetone; (c) Ac_2O, DMSO; (d) $NaBH_4$, MeOH; (e) NaOMe, MeOH.

Previously, we communicated that some of these problems were solved by using 3,4-dialkoxyfuran as the diene.[7b] Heating of a solution of 3,4-dimethoxyfuran (**4c**)[8] and **1a** in benzene in a sealed tube at 90 °C for 3 days resulted in the formation of dimethyl (3,4-dimethoxyfurfurylidene)malonate (**3**) in 17% yield together with a trace of **5c**-*exo*. The desired adduct **5c** was obtained as a mixture of endo and exo isomers (ca. 1:1) in quantitative yield when **4c** was allowed to react with **1a** without solvent at room temperature for 9 days. Separation by column chromatography on silica gel gave only the exo isomer, **5c**-*exo*. None of the endo isomer was obtained because it reverted to the starting materials by retro Diels–Alder reaction during column chromatography. At a higher temperature (40 °C), the reaction of **1a** with **4c** for 5 days gave the exo isomer, **5c**-*exo*, as the sole product.

The above experiments indicate that **5c**-*endo* is especially prone to retro Diels–Alder reaction and reverts to the starting materials either at 40 °C or in the presence of silica at room temperature. It is also evident that at around 80 °C, even the exo isomer, **5c**-*exo*, reverts to the starting materials and, at 90 °C or above, the Michael-type adduct **3** is obtained in an irreversible manner. In accordance with these observations, similar reaction of 3,4-bis(benzyloxy)furan (**4d**)[8] with **1a** at 40 °C gave the single adduct **5d**-*exo* as the sole product.

To convert the Diels–Alder adducts **5** to ribofuranosylmalonate derivatives, the following reactions have been examined. Catalytic reduction of **5c** (a 1:1 mixture of endo and exo isomers) with 10% Pd–C in methanol gave the dihydro derivatives **6c**-*endo* and **6c**-*exo* in quantitative yield. The diastereomeric products were separable by chromatography. The reduction occurs selectively from the less hindered exo side of **5c**, and two methoxyl groups of compounds **6c** have the endo configuration. Similarly, catalytic reduction of **5d**-*exo* gave the dihydro derivative **6d**-*exo* in quantitative yield.

Dihydro compound **6c**-*exo* obtained was submitted to RRA reaction. Thus, **6c**-*exo* was treated with K_2CO_3–$NaBH_4$ in methanol at room temperature for 4 h to give the lyxopyranosyl C-glycoside **11c** in 85% yield. The signal at δ 4.21 (dd, 1 H, J = 5.5 and 10.0 Hz, 2-H) in the ^1H NMR spectrum of **11c** indicates that compound **11c** is a lyxopyranosyl derivative and the configuration of the malonyl residue is equatorial.[13] In the same manner, **6d** was transformed into the benzylated lyxopyranosyl C-glycoside **11d**. In order to clarify further their structures, we acetylated compounds **11c** and **11d** in the usual manner to give the corresponding monoacetylated products **12**, whose ^1H NMR spectra were consistent with the lyxopyranosyl structures as described in the Experimental Section.

Formation of lyxopyranosyl C-glycosides **11** from the bicyclo compound **6** can be explained by the route shown in Scheme III. Thus, the alcohol **7** initially formed by simple methanolysis undergoes the C–C bond fission through retrograde aldol reaction to give the aldehyde **8**. Reduction of the formyl group of **8** with $NaBH_4$ results in the formation of dimethyl lyxofuranosylmalonate (**9**), whose cleavage to **10** by retro Michael reaction followed by recyclization leads to the observed pyranosyl product **11**. It is clear that the transformation of **9** to **10** is facilitated by the steric hindrance because all of the substituents in **9** occupy the same side of tetrahydrofuran ring.

We have examined the conversion of **11d** to the desired β-ribofuranosylmalonate **19a** (Scheme IV). Thus, the triol **13**, which was obtained by catalytic hydrogenation of **11d** in acidic medium, was protected as acetonide **14**. Ketone **15** derived from **14** by Moffatt oxidation[9] was reduced with sodium borohydride to give the inverted alcohol, ribopyranosylmalonate **17**, in high yield. In the above oxidation reaction, compound **16** was also formed as a bypro-

(8) Iten, P. X.; Hofmann, A. A.; Eugster, C. H. *Helv. Chim. Acta* **1978**, *61*, 430.

(9) Cook, A. F.; Moffatt, J. G. *J. Am. Chem. Soc.* **1967**, *89*, 2697.

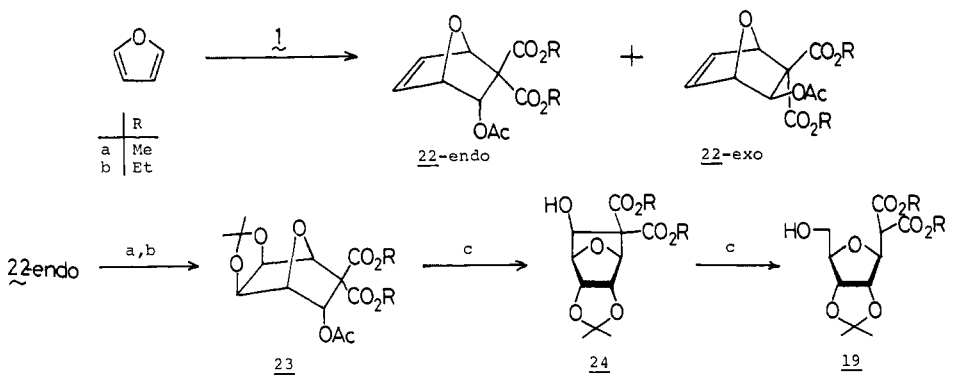
(10) (a) Ohrui, H.; Fox, J. J. *Tetrahedron Lett.* **1973**, 1951. (b) Ohrui, H.; Jones, G. H.; Moffatt, J. G.; Madox, M. L.; Christensen, A. T.; Byram, S. K. *J. Am. Chem. Soc.* **1975**, *97*, 4602.

(11) Cermain, F.; Chapleur, Y.; Castro, B. *Synthesis* **1983**, 119.

(12) (a) Banks, G. T.; Barrow, K.; Chain, E. B.; Fuller, A. T.; Mellows, G.; Woolford, M. *Nature (London)* **1971**, *234*, 416. (b) Chain, E. B.; Mollow, G. *J. Chem. Soc. Chem. Commun.* **1977**, 318. (c) Clayton, J. P.; O'Hanlon, P. J.; Rogers, N. H, *Tetrahedron Lett.* **1980**, *21*, 881. (d) O'Hanlon, P. J.; Rogers, N. H.; Tyler, J. W. *J. Chem. Soc., Perkin Trans. 1* **1983**, 2655.

(13) For a recent study on the chemical synthesis of pseudomonic acids, see: (a) Williams, D. R.; Moore, J. L.; Yamada, M. *J. Org. Chem.* **1986**, *51*, 3916. (b) Barrish, J. C.; Lee, H. L.; Baggiolini, E. G.; Uskokovic, M. R. *J. Org. Chem.* **1987**, *52*, 1375 and references cited therein.

Scheme V[a]



[a] (a) OsO_4, 4-methylmorpholine *N*-oxide, AcOEt–acetone; (b) *p*-TsOH, $Me_2C(OMe)_2$, acetone; (c) K_2CO_3, $NaBH_4$, MeOH.

duct. Ribofuranosylmalonate was obtained as a mixture of β- and α-anomers (**19a** and **20a**) from **17** by treatment of sodium methoxide in methanol (0 °C, 2 h). Although the anomers could not be separated by chromatography, the ratio of α- and β-anomers was determined by ^1H and ^{13}C NMR spectra to be ca. 3:2. In the ^{13}C NMR spectrum of **20a**, signals due to two methyl carbons of the isopropylidene group of the α-anomer are observed at δ 24.95 and 26.19, within the range strongly indicative of the α configuration (24.9 ± 0.3 and 26.3 ± 0.2), whereas those for the β-anomer are observed at δ 25.54 and 27.48, clearly in the β range (25.5 ± 0.2 and 27.5 ± 0.2).[10b]

It is evident from the above result that conversion of **17** to ribofuranosylmalonate, though possible, resulted in the formation of both anomers (**19a** and **20a**) with the undesired α-anomer **20a** always predominating. In the method for introduction of a malonyl group at the anomeric position of an appropriately protected D-ribose **21**,[10,11] which should also be carried out under strongly basic conditions, it was found that the major product was the thermodynamically more stable α-anomer (chiral **20**: hydroxyl groups are appropriately protected). Poor stereoselectivity at the anomeric center is, of course, due to equilibration via ring-opened intermediate **18**. Hence, we did not pursue this route further, though it affords a nice route either to lyxopyranosyl or ribopyranosyl C-glycoside (**13** and **17**), the former of which constitutes the skeleton of pseudomonic acids, being a unique family of potent and promising antibiotics.[12,13]

A second approach to the stereoselective synthesis of β-ribofuranosylmalonate **19** involved the use of high-pressure conditions for the Diels–Alder reaction.[14] As reported in the preceding paper,[15] the Diels–Alder reaction of dialkyl (acetoxymethylene)malonate (**1**: R = Me and Et) with furan at 10–11 kbar gave, as expected, the adduct **22** (Scheme V) in satisfactory yield. Since the endo adduct **22**-*endo* is the major adduct and hence readily available in a large quantity, we examined the synthesis of β-ribofuranosylmalonate **19** using this endo adduct as the starting material. Thus, the endo adduct **22a**-*endo* obtained in ca. 40% yield from the Diels–Alder reaction of **1a** with furan at 10 kbar was hydroxylated to give the *exo*-diol, which was converted to the acetonide **23a**-*endo*. The conversion from **22a**-*endo* to **23a**-*endo* proceeded in almost quantitative yield. When **23a**-*endo* was treated with methanol containing potassium carbonate and sodium borohydride (each 5 molar equiv to **23a**-*endo*) for 15 min at 0 °C, the expected ribofuranosylmalonate was obtained in quantitative yield. The structure of the product was determined unequivocally from the 500-MHz ^1H NMR spectrum. If the above RRA reaction was carried out under the same conditions except for a longer period, **20a**, as well as a trace amount of **17**, was formed. Thus, for example, when **23a**-*endo* was submitted to RRA reaction (0 °C for 30 min), **19a** and **20a** were obtained in ca. 10:1 ratio, together with a trace amount of **17**.

The same reaction (0 °C for 15 min) if applied to **23b**-*endo* gave the simple hydrolysis product **24b**-*endo* and **19b** in 40 and 42% yields, respectively. This result shows that the alkyl group of the diester function affects the rate of retrograde aldol reaction of **23**. Of course, **24b**-*endo* if submitted to the same RRA reaction (0 °C for 30 min) gave quantitatively the ribofuranosylmalonate as a mixture of **19b** and **20b** (ca. 9:1). As is evident from the above results, if the RRA reaction was carried out at a longer period than 15 min at 0 °C or at an elevated temperature, the ratio of **20**:**19** increased gradually. However, if the RRA reaction of **23** is carried out under carefully controlled conditions (0 °C, 15 min), one can obtain **19** stereoselectively. This fact shows that, under these conditions, reopening of **19** to **18** does not occur to a significant extent.

Thus, a very short and highly stereoselective synthesis of C-nucleoside precursor **19** from furan is accomplished by the use of a high-pressure Diels–Alder reaction as well as a carefully controlled RRA reaction.

Experimental Section

General. All melting points were determined on a Yanaco Model MP instrument and are uncorrected. IR spectra were measured on a JASCO A-102 spectrometer. ^1H NMR spectra at 60 MHz, 100 MHz, and 500 MHz were recorded with JEOL JNM-PMX 60 si, JEOL JNM-FX100, and JEOL JNM-FX500 spectrometers using tetramethylsilane (TMS) as an internal standard, respectively. The abbreviations of signal patterns are as follows: s, singlet; d, doublet; t, triplet; q, quartet; m, multiplet; dd, doublet of doublet; br, broad; br s, broad singlet. Low- and high-resolution mass spectra (MS) were obtained on a Hitachi M-52G and JEOL JMS-01SG-2 instrument, respectively. Wakogel (C-200) and Merck Kiesel-gel 60 F254 were employed for silica gel column and preparative thin-layer chromatography (TLC), respectively. The ratio of a mixture of solvents for chromatography was shown as volume:volume.

Dimethyl (Acetoxymethylene)malonate (1a). A solution of dimethyl (methoxymethylene)malonate[16] (5.2 g, 0.03 mol) in 1.5% aqueous NaOH (100 mL) was stirred at 0 °C for 30 min. After the solution was made acidic with 10% aqueous HCl, the mixture was extracted with chloroform. The organic layer was

(14) Matsumoto, K.; Sera, A. *Synthesis* **1985**, 999.
(15) Sera, A.; Ohara, M.; Kubo, T.; Itoh, K.; Yamada, H.; Mikata, Y.; Kaneko, C.; Katagiri, N. *J. Org. Chem.*, preceding paper in this issue.
(16) Dimethyl (methoxymethylene)malonate was prepared from dimethyl malonate and trimethyl orthoformate, according to the procedure for the synthesis of diethyl (ethoxymethylene)malonate: Parham, W. E.; Reed, L. J. *Organic Syntheses*; Wiley: New York, 1955; Collect. Vol. III, p 395.

dried over anhydrous sodium sulfate and concentrated in vacuo. The residue was distilled in vacuo to give dimethyl (hydroxymethylene)malonate (4.3 g, 90%): bp 118–120 °C (5 mmHg); mp 43–45 °C; IR ($CHCl_3$) 1720, 1700 (sh), 1650 (sh), 1645 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.78, 3.92 (2 s, 6 H, ester Me), 8.35 (d, 1 H, J = 13.5 Hz, olefinic H), 13.36 (d, 1 H, J = 13.5 Hz, enolic OH). Pyridine (10 mL) was added dropwise to a solution of this compound (3 g, 0.019 mol) in acetic anhydride (10 mL) with stirring and ice cooling. After being allowed to stand at room temperature for 3 h, the reaction mixture was poured into water and extracted with benzene. The organic layer was washed with water and dried over anhydrous sodium sulfate. The solvent was evaporated, and the residue was distilled in vacuo to give **1a** (3 g, 78%): bp 92–95 °C (2 mmHg); IR ($CHCl_3$) 1785, 1720, 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.27 (s, 3 H, OAc), 3.81, 3.87 (2 s, 6 H, ester Me), 8.44 (s, 1 H, olefinic proton); high-resolution MS m/z, M^+ calcd for $C_8H_{10}O_6$ 202.0478, found 202.0457.

Diethyl (Acetoxymethylene)malonate (1b). A suspension of diethyl (ethoxymethylene)malonate (10.8 g, 0.05 mol) in 1% aqueous NaOH (200 mL) was stirred at room temperature for 1 h. The reaction mixture was acidified with dilute HCl and extracted with ether. The ethereal solution was washed with water, dried, and evaporated. Distillation of the residue in vacuo gave diethyl (hydroxymethylene)malonate (7.8 g, 83%) as a colorless oil: bp 70–72 °C (3 mmHg); ^1H NMR ($CDCl_3$) δ 1.30 (t, 3 H, J = 7 Hz), 1.36 (t, 3 H, J = 7 Hz), 4.27 (q, 2 H, J = 7 Hz), 4.36 (q, 2 H, J = 7 Hz), 8.30 (d, 1 H, J = 13 Hz), 13.40 (d, 1 H, J = 13 Hz). Acetic anhydride (15 mL) and pyridine (15 mL) were added successively to a solution of the ester (7.5 g, 0.326 mol) in benzene (50 mL). The mixture was allowed to stand overnight at room temperature and then poured into ice–water. The organic layer was washed with water, dried, and evaporated in vacuo. The residue was distilled in vacuo to give **1b** (6.6 g, 88%) as a colorless oil: bp 105–107 °C (0.09 mmHg); IR ($CHCl_3$) 1785, 1720, 1650 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.32 (t, 3 H, J = 7 Hz), 1.34 (t, 3 H, J = 7 Hz), 2.27 (s, 3 H), 4.27 (q, 2 H, J = 7 Hz), 4.36 (q, 2 H, J = 7 Hz), 8.39 (s, 1 H). Anal. Calcd for $C_{10}H_{14}O_6$: C, 52.17; H, 6.13. Found: C, 52.02; H, 6.15.

Lewis Acid Catalyzed Reaction of Dimethyl (Acetoxymethylene)malonate (1a) with Furan. $TiCl_4$ (three drops) was added to a solution of **1a** (0.404 g, 2 mmol) and furan (1 mL) in dry benzene (1.5 mL) with stirring and ice–salt cooling. The mixture was stirred for 1 h with ice–salt cooling and then diluted with benzene. The solution was washed with water, dried, and evaporated in vacuo. The residue (0.9 g) was chromatographed on a silica gel column. Elution with hexane–ethyl acetate (4:1) gave **2** (63 mg, 15%) as a colorless oil: IR ($CHCl_3$) 1725, 1630 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.76 (s, 3 H, OMe), 3.80 (s, 3 H, OMe), 6.40 (dd, 1 H, J = 3.5, 2 Hz), 6.70 (d, J = 3.5 Hz), 7.35 (s, 1 H), 7.41 (d, 1 H, J = 2 Hz). Anal. Calcd for $C_{10}H_{10}O_5$: C, 57.14; H, 4.80. Found: C, 57.01; H, 4.52.

Diels–Alder Reaction of Dimethyl (Acetoxymethylene)malonate (1a) with 3,4-Dimethoxyfuran (4c). (1) A solution of **1a** (200 mg, 1.0 mmol) and **4c** (140 mg, 1.1 mmol) was allowed to stand without solvent at room temperature for 9 days. The reaction mixture was solidified, and its ^1H NMR spectrum showed not only that the starting materials **1a** and **4c** were consumed completely but also that the solid was a mixture of **5c**-*endo* and **5c**-*exo* (1:1). The mixture was chromatographed on silica gel (15 g), and elution with hexane–ethyl acetate (3:1) gave the starting material **4c** (30 mg, 21%). Further elution with the same solvent gave dimethyl 6-*exo*-acetoxy-2,3-dimethoxy-7-oxabicyclo[2.2.1]-hept-2-ene-5,5-dicarboxylate (**5c**-*exo*) as colorless prisms: mp 115–116 °C (hexane–ether); IR ($CHCl_3$) 1755, 1738, 1691 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.07 (s, 3 H, OAc), 3.68 (s, 3 H, OMe), 3.74 (s, 6 H, OMe × 2), 3.79 (s, 3 H, OMe), 4.65 (d, 1 H, J = 2 Hz, 1-H), 5.16 (d, 1 H, J = 2 Hz, 4-H), 5.87 (s, 1 H, 6-H). Anal. Calcd for $C_{14}H_{18}O_9$: C, 50.91; H, 5.49. Found: C, 50.66; H, 5.29. **5c**-*endo*: ^1H NMR ($CDCl_3$) δ 2.00 (s, 3 H, OAc), 4.98 (dd, 1 H, J = 1, 4 Hz, 1-H), 5.11 (d, 1 H, J = 1 Hz, 4-H), 6.01 (d, 1 H, J = 4 Hz, 6-H).

(2) A solution of **1a** (7.9 g, 0.04 mol) and **4c** (5.0 g, 0.04 mol) was warmed at 40 °C for 5 days. The crystalline reaction mixture was washed with ether to give **5c**-*exo* (8.46 g, 72%).

(3) A solution of **1a** (650 mg, 3.2 mmol) and **4c** (370 mg, 2.9 mmol) in dry benzene (4 mL) was heated at 90 °C in a sealed tube for 80 h. After evaporation of the solvent in vacuo, the residue was chromatographed on silica gel (10 g). Elution with hexane–ethyl acetate (5:1) gave successively the starting material **4c** (175 mg, 47%) and dimethyl (3,4-dimethoxyfurfurylidene)malonate (**3**) as pale yellow leaves: mp 108–109 °C (ether); IR ($CHCl_3$) 1726, 1632 cm^{-1}; ^1H NMR ($CDCl_3$) δ 3.74 (s, 3 H, OMe), 3.80 (s, 3 H, OMe), 3.87 (s, 3 H, OMe), 3.98 (s, 3 H, OMe), 7.06 (s, 1 H, ring H), 7.48 (s, 1 H, olefinic H). Anal. Calcd for $C_{12}H_{14}O_7$: C, 53.33; H, 5.22. Found: C, 53.06; H, 5.17. Further elution with hexane–ethyl acetate (3:1) gave a trace of **5c**-*exo*.

Dimethyl 6-*exo*-Acetoxy-2,3-bis(benzyloxy)-7-oxabicyclo[2.2.1]hept-2-ene-5,5-dicarboxylate (5d-*exo*). A solution of **1a** (2.33 g, 11.5 mmol) and **4d** (3.22 g, 11.5 mmol) in dry benzene (2 mL) was warmed at 40 °C for 4 days. After evaporation of the solvent in vacuo, the residue was chromatographed on silica gel (120 g). Elution with hexane–ethyl acetate (4:1) gave the starting material **4d** (1.12 g, 35%). Further elution with the same solvent gave the product **5d**-*exo* (3.18 g, 57%) as colorless columns: mp 96–98 °C (ether); IR ($CHCl_3$) 1742, 1692 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.06 (s, 3 H, OAc), 3.58 (s, 3 H, OMe), 3.78 (s, 3 H, OMe), 4.67 (d, 1 H, J = 2 Hz, 1-H), 4.75 (d, 1 H, J = 11 Hz, C*H*HPh), 4.96 (s, 2 H, CH_2Ph), 4.98 (d, 1 H, J = 11 Hz, CH*H*Ph), 5.20 (d, 1 H, J = 2 Hz, 4-H), 5.94 (s, 1 H, 6-H), 7.20–7.42 (m, 10 H, Ph × 2). Anal. Calcd for $C_{26}H_{26}O_9$: C, 64.72; H, 5.43. Found: C, 64.88; H, 5.41.

Dimethyl 3-*endo*-Acetoxy-5,6-*endo*-dimethoxy-7-oxabicyclo[2.2.1]heptane-2,2-dicarboxylate (6c-*endo*) and Dimethyl 3-*exo*-Acetoxy-5,6-*endo*-dimethoxy-7-oxabicyclo[2.2.1]heptane-2,2-dicarboxylate (6c-*exo*). A mixture of **5c** (1.0 g, 3 mmol) (a mixture of endo and exo isomers, 1:1) and 10% Pd–C (100 mg) in MeOH (20 mL) was shaken under a hydrogen atmosphere (1 atm) at room temperature for 1 h. The catalyst was filtered, the filtrate was evaporated in vacuo, and the residue was chromatographed on a silica gel (60 g) column. Elution with hexane–ethyl acetate (2:1) gave **6c**-*exo* (0.50 g, 50%) and **6c**-*endo* (0.46 g, 46%), successively. **6c**-*exo*: colorless prisms; mp 111–113 °C (ether); IR ($CHCl_3$) 1744 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.04 (s, 3 H, OAc), 3.37 (s, 3 H, OMe), 3.52 (s, 3 H, OMe), 3.73 (s, 3 H, CO_2Me), 3.77 (s, 3 H, CO_2Me), 3.83 (dd, 1 H, J = 5.5, 9.0 Hz, 5-H), 4.63 (d, 1 H, J = 4.7 Hz, 1-H), 6.17 (s, 1 H, 3-H). Anal. Calcd for $C_{14}H_{20}O_9$: C, 50.60; H, 6.07. Found: C, 50.32; H, 6.14. **6c**-*endo*: colorless leaves; mp 85–86 °C (hexane–ether); IR ($CHCl_3$) 1743 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.16 (s, 3 H, OAc), 3.39 (s, 3 H, OMe), 3.42 (s, 3 H, OMe), 3.70 (s, 3 H, CO_2Me), 3.80 (s, 3 H, CO_2Me), 3.95 (dd, 1 H, J = 5.0, 8.3 Hz, 5-H), 4.73 (t, 1 H, J = 5.0 Hz, 4-H), 5.32 (d, 1 H, J = 5.0 Hz, 1-H), 5.60 (d, 1 H, J = 5.0 Hz, 3-H). Anal. Calcd for $C_{14}H_{20}O_9$: C, 50.60; H, 6.07. Found: C, 50.31; H, 6.06.

Dimethyl 3-*exo*-Acetoxy-5,6-*endo*-bis(benzyloxy)-7-oxabicyclo[2.2.1]heptane-2,2-dicarboxylate (6d-*exo*). A mixture of **5d**-*exo* (507 mg, 1.05 mmol) and 10% Pd–C (65 mg) in MeOH (20 mL) was shaken in a hydrogen atmosphere (1 atm) at room temperature for 1 h. The catalyst was filtered, and the filtrate was concentrated in vacuo to give **6d**-*exo* (479 mg, 94%) as colorless needles: mp 132–133 °C (ether); IR ($CDCl_3$) 1744 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.05 (s, 3, OAc), 3.34 (s, 3 H, OMe), 3.76 (s, 3 H, OMe), 3.90–4.06 (m, 2 H, 5, 6-H), 4.37 (d, 1 H, J = 11 Hz, C*H*HPh), 4.58 (m, 1 H, 4-H), 4.64 (d, 1 H, J = 12 Hz, C*H*HPh), 4.67 (d, 1 H, J = 11 Hz, CH*H*Ph), 4.87 (d, 1 H, J = 12 Hz, CH*H*Ph), 5.15 (m, 1 H, 1-H), 6.39 (s, 1 H, 3-H), 7.15–7.52 (m, 10 H, Ph × 2). Anal. Calcd for $C_{26}H_{28}O_9$: C, 64.45; H, 5.83. Found: C, 64.40; H, 5.62.

General Procedure for the Reductive Retrograde Aldol Reaction of Bicyclo Compound 6: Formation of (±) Lyxopyranosyl C-Glycosides 11. K_2CO_3 (5 mmol) was added to a solution of **6** (1 mmol) in absolute MeOH (10 mL) with stirring and ice cooling. After the mixture was stirred at 0 °C for 30 min, $NaBH_4$ (5 mmol) was added to it. The reaction mixture was stirred for an additional 4 h at room temperature and then neutralized with AcOH. After evaporation of the solvent in vacuo, water and $CHCl_3$ were added to the residue. The $CHCl_3$ layer was washed with water, dried, and condensed in vacuo. The residue was chromatographed on silica. Elution with the appropriate solvent gave the lyxopyranosyl C-glycosides **11**.

Dimethyl (5β-hydroxy-3α,4α-dimethoxytetrahydro-2*H*-pyran-2β-yl)malonate (**11c**): colorless oil (85%); eluent, hexane–ethyl acetate (1:2); IR ($CHCl_3$) 3480, 1754, 1733 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ selected peaks 1.95 (br s, 1 H, OH), 3.38 (s, 3 H, OMe),

3.50 (s, 3 H, OMe), 3.72 (s, 3 H, CO_2Me), 3.73 (s, 3 H, CO_2Me), 4.21 (dd, 1 H, J = 5.5, 10.0 Hz, 2-H); high-resolution MS m/z, M^+ calcd for $C_{12}H_{20}O_8$ 292.1158, found 292.1170.

Dimethyl [3α,4α-bis(benzyloxy)-5β-hydroxytetrahydro-2*H*-pyran-2β-yl]malonate (**11d**): colorless oil (90%); eluent, hexane–ethyl acetate (2:1); IR ($CHCl_3$) 3472, 1737 cm^{-1}; ^1H NMR ($CDCl_3$) δ selected peaks 2.20 (br s, 1 H, OH), 3.63 (s, 6 H, OMe × 2), 4.50, 4.78 (d, 1 H each, J = 12 Hz, CH_2Ph), 7.10–7.48 (m, 10 H, Ph × 2); high-resolution MS m/z, $M^+ - CH_2Ph$ calcd for $C_{17}H_{21}O_8$ 353.1236, found 353.1221.

Dimethyl (5β-Acetoxy-3α,4α-dimethoxytetrahydro-2*H*-pyran-2β-yl)malonate (12c). A solution of **11c** (20 mg, 0.068 mmol) in acetic anhydride (2 mL) and pyridine (0.5 mL) was allowed to stand at room temperature for 10 h. The reaction mixture was condensed in vacuo, and the residue was chromatographed on a silica gel (2 g) column. Elution with hexane–ethyl acetate (1:1) gave **12c** (22 mg, 97%) as a viscous oil: IR ($CHCl_3$) 1742, 1743 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 2.12 (s, 3 H, OAc), 3.36 (s, 3 H, OMe), 3.53 (s, 3 H, OMe), 3.57 (dd, 1 H, J = 3.0, 10.0 Hz, 3-H), 3.72 (d, 1 H, J = 6.0 Hz, malonyl H), 3.75 (dd, 1 H, 4-H), 3.80 (d, 1 H, J = 13.5 Hz, 6-H axial), 3.88 (dd, 1 H, J = 2, 13.5 Hz, 6-H equatorial), 4.29 (dd, 1 H, J = 6.0, 10.0 Hz, 2-H), 4.97 (dd, 1 H, 5-H). Anal. Calcd for $C_{14}H_{22}O_9$: C, 50.29; H, 6.63. Found: C, 50.01; H, 6.45.

Dimethyl [5β-Acetoxy-3α,4α-bis(benzyloxy)tetrahydro-2*H*-pyran-2β-yl]malonate (12d). Employing the same procedure given for the synthesis of **12c**, we obtained **12d** from **11d** in quantitative yield.

12d: IR ($CHCl_3$) 1737 cm^{-1}; ^1H NMR ($CDCl_3$) δ 2.07 (s, 3 H, OAc), 3.62, 3.69 (s, 3 H each, OMe), 3.70–3.90 (m, 4 H), 3.96, 4.38 (m, 2 H each), 4.47, 4.68 (m, 2 H each, CH_2Ph), 4.91 (m, 1 H, 6-H), 7.18–7.43 (m, 10 H, Ph × 2); high-resolution MS m/z, $M^+ - CH_2Ph$ calcd for $C_{19}H_{23}O_9$ 395.1352, found 395.1375.

Dimethyl (3α,4α,5β-Trihydroxytetrahydro-2*H*-pyran-2β-yl)malonate Acetonide (14). A mixture of **11d** (1.80 g, 4.05 mmol) and 5% Pd–C (200 mg) in MeOH (0.3%, 180 mL) containing concentrated HCl was shaken in a hydrogen atmosphere (1 atm) at room temperature for 30 min. The catalyst was filtered off, and the filtrate was condensed in vacuo. *p*-Toluenesulfonic acid (55 mg, 0.29 mmol) was added to a solution of the residue (**13**, 1.21 g) and 2,2-dimethoxypropane (15 mL) in acetone (50 mL) with ice cooling and stirring. After the mixture was stirred at room temperature for 2 h, sodium bicarbonate (50 mg, 0.60 mmol) was added to it with ice cooling and stirring, and the whole was stirred for 5 min. The reaction mixture was filtered, and the filtrate was condensed in vacuo. The residue was chromatographed on a silica gel (70 g) column. Elution with hexane–ethyl acetate (1:1) gave **14** (860 mg, 70%) as colorless needles (hexane–ether): mp 83–84 °C; IR ($CHCl_3$) 3420, 1748 (sh), 1738 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.35, 1.48 (s, 3 H each, isopropylidene Me), 3.68 (d, 1 H, J = 7 Hz, H-2), 3.75 (s, 6 H, OMe × 2); high-resolution MS m/z, M^+ – Me calcd for $C_{12}H_{17}O_8$ 289.0923, found 289.0903.

Dimethyl (3α,4α-Dihydroxy-5-oxotetrahydro-2*H*-pyran-2β-yl)malonate Acetonide (15). Acetic anhydride (2 mL) was added to a solution of **14** (247 mg, 0.81 mmol) in dimethyl sulfoxide (4.5 mL). The mixture was allowed to stand at room temperature for 14 h and condensed in vacuo. The residue was extracted with $CHCl_3$. The organic layer was washed with water, dried, and evaporated. The residue was chromatographed on a silica gel (8 g) column. Elution with hexane–ethyl acetate (3:1) gave **16** (45 mg, 15%) as a pale yellow oil. Further elution with hexane–ethyl acetate (2:1) gave **15** (159 mg, 65%) as a colorless oil.

15: IR ($CHCl_3$) 1752 (sh), 1742 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.38, 1.46 (s, 3 H each, isopropylidene Me), 3.76, 3.79 (s, 3 H each, OMe × 2); high-resolution MS m/z, M^+ calcd for $C_{13}H_{18}O_8$ 302.1002, found 302.0999.

16: IR ($CHCl_3$) 1758 (sh), 1738 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.34, 1.47 (s, 3 H each, isopropylidene Me), 2.15 (s, 3 H, SMe), 3.71 (s, 6 H, OMe × 2); high-resolution MS m/z, M^+ – Me calcd for $C_{14}H_{21}O_8S$ 349.0957, found 349.0943.

Dimethyl (3α,4α,5α-Trihydroxytetrahydro-2*H*-pyran-2β-yl)malonate Acetonide (17): Protected Ribopyranosyl C-Glycoside. $NaBH_4$ (98 mg, 2.6 mmol) was added to a solution of **15** (156 mg, 0.52 mmol) in absolute MeOH (12 mL) with ice cooling and stirring. After the mixture was stirred for 50 min at 0 °C, in order to decompose excess $NaBH_4$ we added acetic acid to the mixture. The solvent was evaporated off, and the residue was chromatographed on a silica gel (10 g) column. Elution with hexane–ethyl acetate (1:1) gave **17** (155 mg, 99%) as a colorless oil: IR ($CHCl_3$) 3450, 1755 (sh), 1736 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.37, 1.51 (s, 3 H each, isopropylidene Me), 2.15 (br d, 1 H, J = 9.5 Hz, OH), 3.45 (t, 1 H, J = 10.6 Hz, 6-H axial), 3.56 (d, 1 H, J = 7.5 Hz, malonyl H), 3.74, 3.76 (s, 3 H each, OMe), 3.89 (dd, 1 H, J = 9.0, 7.5 Hz, 2-H), 3.90 (dd, 1 H, J = 10.6, 6.0 Hz, 6-H equatorial), 3.99 (br m, 1 H, 5-H), 4.23 (dd, 1 H, J = 9.0, 4.6 Hz, 3-H), 4.48 (t, 1 H, J = 4.6 Hz, 4-H).

Dimethyl [3α,4α-Dihydroxy-5β-(hydroxymethyl)tetrahydrofur-2β- and -2α-yl]malonate Acetonides (19a and 20a): Protected Ribofuranosyl C-Glycoside. A NaOMe–MeOH solution, prepared from absolute MeOH (2 mL) and NaH (9 mg, 0.375 mmol), was added to a solution of **17** (34 mg, 0.11 mmol) in absolute MeOH (2 mL) with ice cooling and stirring. After being stirred at 0 °C for 2 h, the mixture was neutralized with acetic acid. After evaporation of the solvent, the residue was chromatographed on a silica gel (5 g) column. Elution with hexane–ethyl acetate (2:3) gave the ribofuranosyl C-glycoside (20 mg, 59%) as a mixture of **19a** and **20a** (**19a**:**20a** = 2:3): IR ($CHCl_3$) 3420, 1750, 1735 cm^{-1}; high-resolution MS m/z, M^+ – Me calcd for $C_{12}H_{17}O_8$ 289.0923, found 289.0925. The structures of **19a** and **20a** were determined by comparison of their ^1H and ^{13}C NMR spectra with those of protected methyl ribofuranosylacetate, which was previously synthesized by Moffatt et al.[10b] Detailed spectral data of pure **19a** will be shown separately (vide infra).

20a: ^1H NMR ($CDCl_3$, 500 Hz) δ 1.32, 1.49 (s, 3 H each, isopropylidene Me), 3.62 (dd, 1 H, J = 11.5, 6.0 Hz, CH*H*OH), 3.65 (dd, 1 H, J = 11.5, 4.2 Hz, C*H*HOH), 3.76, 3.80 (s, 3 H each, OMe), 3.86 (d, 1 H, J = 10.4 Hz, malonyl H), 4.16 (ddd, 1 H, J = 6.0, 4.2, 1.3 Hz, 5-H), 4.60 (dd, 1 H, J = 10.4, 4.4 Hz, 2-H), 4.71 (dd, 1 H, J = 6.3, 13 Hz, 4-H), 4.93 (dd, 1 H, J = 6.3, 4.4 Hz, 3-H); ^{13}C NMR ($CDCl_3$) δ 24.95 (q, isopropylidene Me), 26.19 (q, isopropylidene Me), 52.72 (q, OMe), 53.02 (d, malonyl 2-C), 62.23 (t, CH_2OH), 79.32 (d), 81.14 (d), 82.34 (d), 84.31 (d), 113.08 [s, isopropylidene $C(Me)_2$], 167.03 (s, C=O), 168.32 (s, C=O).

Dimethyl 3-*endo*-Acetoxy-5,6-*exo*-dihydroxy-7-oxabicyclo[2.2.1]heptane-2,2-dicarboxylate Acetonide (23a). An OsO_4–BuOH solution (7 mL) [prepared from OsO_4 (2 g), *t*-BuOH (200 mL), and a small amount of H_2O_2] and 4-methylmorpholine *N*-oxide (60% aqueous solution, 17 mL) were added to a solution of **22a**-*endo*[15] (940 mg, 3.5 mmol) in ethyl acetate–acetone (2:1, 15 mL) with stirring. The mixture was stirred at room temperature for 2 h and extracted with ethyl acetate. The organic layer was washed with brine, dried, and evaporated. The residue was chromatographed on a silica gel (20 g) column. Elution with hexane–ethyl acetate (1:2) gave the diol (1.13 g), which was dissolved in acetone (20 mL). 2,2-Dimeth›xypropane (5 mL) and *p*-toluenesulfonic acid (20 mg) were added successively to the solution with ice cooling and stirring. After being allowed to stand at room temperature for 1 h, the reaction mixture was neutralized with $NaHCO_3$ and filtered. The filtrate was condensed in vacuo, and the residue was chromatographed on a silica gel (35 g) column. Elution with hexane–ethyl acetate (4:1) gave **23a** (990 mg, 83%) as colorless needles (hexane–ether): mp 125–126 °C; IR ($CHCl_3$) 1765 (sh), 1745 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.33, 1.47 (s, 3 H each, isopropylidene Me), 2.07 (s, 3 H, OAc), 3.72, 3.81 (s, 3 H each, OMe), 4.60 (d, 1 H, J = 5.8 Hz, 5- or 6-H), 4.68 (dd, 1 H, J = 5.8, 1.0 Hz, 4-H), 4.80 (d, 1 H, J = 1.0 Hz, 1-H), 5.26 (d, 1 H, J = 5.8 Hz, 5- or 6-H), 5.96 (d, 1 H, J = 5.8 Hz, 3-H). Anal. Calcd for $C_{15}H_{20}O_9$: C, 52.32; H, 5.86. Found: C, 52.19; H, 5.87.

Diethyl 3-*endo*-Acetoxy-5,6-*exo*-dihydroxy-7-oxabicyclo-[2.2.1]heptane-2,2-dicarboxylate Acetonide (23b). Employing the same procedure given for the synthesis of **23a**, we obtained **23b** (418 mg, 77%) from **22b**-*endo*[15] (435 mg, 1.46 mmol).

23b: colorless leaves (hexane); mp 107–108 °C; IR ($CHCl_3$) 1765, 1740 cm^{-1}; ^1H NMR ($CDCl_3$) δ 1.23 (t, 3 H, J = 7.3 Hz, $CO_2CH_2CH_3$), 1.27 (t, 3 H, J = 7.3 Hz, $CO_2CH_2CH_3$), 1.32 (s, 3 H, isopropylidene Me), 1.46 (s, 3 H, isopropylidene Me), 4.12–4.30 (m, 4 H, $CO_2CH_2CH_3$ × 2), 4.59 (d, 1 H, J = 5.6 Hz, 6-H), 4.69 (dd, 1 H, J = 1.0, 5.6 Hz, 4-H), 4.79 (d, 1 H, J = 1.0 Hz, 1-H), 5.30 (d, 1 H, J = 5.6 Hz, 5-H), 5.95 (d, 1 H, J = 5.6 Hz, 3-H). Anal. Calcd for $C_{17}H_{24}O_9$: C, 54.83; H, 6.50. Found: C, 54.87; H, 6.50.

Dimethyl [3α,4α-Dihydroxy-5β-(hydroxymethyl)tetrahydrofur-2β-yl]malonate Acetonide (19a): Protected Di-

methyl β-Ribofuranosylmalonate. $NaBH_4$ (29 mg, 0.77 mmol) and K_2CO_3 (104 mg, 0.75 mmol) were added to a solution of **23a** (51 mg, 0.15 mmol) in absolute MeOH (10 mL) with ice cooling and stirring. The mixture was stirred at 0 °C for 10 min and neutralized with acetic acid–MeOH (1:1). After evaporation of the solvent, the residue was chromatographed on a silica gel (8 g) column. Elution with hexane–ethyl acetate (2:1) gave **19a** (45 mg, 100%) as a colorless oil: IR ($CHCl_3$) 3420, 1750, 1735 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 1.35, 1.54 (s, 3 H each, isopropylidene Me), 2.75 (br s, 1 H, OH), 3.66 (br dd, 1 H, J = 9.1, 3.1 Hz, C*H*HOH), 3.78 (d, 1 H, J = 6.9 Hz, H-2), 3.78, 3.79 (s, 3 H each, OMe), 3.81 (dd, 1 H, J = 9.1, 3.1 Hz, CH*H*OH), 4.13 (dt, 1 H, J = 3.6, 3 Hz, 5-H), 4.51 (dd, 1 H, J = 6.9, 4.1 Hz, 2-H), 4.72 (dd, 1 H, J = 6.8, 4.1 Hz, 3-H), 4.77 (dd, 1 H, J = 6.8, 3.6 Hz, 4-H); ^{13}C NMR ($CDCl_3$) δ 25.54 (q, isopropylidene Me), 27.48 (q, isopropylidene Me), 52.96 (q, OMe), 54.37 (d, malonyl 2-C), 62.76 (t, CH_2OH), 81.49 (d), 82.60 (d), 83.31 (d), 85.48 (d), 114.13 [s, isopropylidene $C(Me)_2$], 167.32 (s, C=O), 167.68 (s, C=O); high-resolution MS m/z, M^+ – Me calcd for $C_{12}H_{17}O_8$ 289.0924, found 289.0911.

In a similar manner, **23a** (51 mg, 0.15 mmol) was submitted to reductive retrograde aldol reaction at 0 °C for 30 min to give the ribofuranosyl C-glycoside (45 mg, 100%) as a mixture of **19a** and **20a** (**19a**:**20a** = 10:1).

Diethyl [3α,4α-Dihydroxy-5β-(hydroxymethyl)tetrahydrofur-2β-yl]malonate Acetonide (19b): Protected Diethyl β-Ribofuranosylmalonate. (1) $NaBH_4$ (20 mg, 0.56 mmol) and K_2CO_3 (76 mg, 0.55 mmol) were added successively to a solution of **23b** (40 mg, 0.11 mmol) in absolute MeOH (5 mL) with ice cooling and stirring. The mixture was stirred at 0 °C for 15 min and neutralized with acetic acid–MeOH (1:1). After evaporation of the solvent in vacuo, the residue was chromatographed on a silica gel (8 g) column. Elution with hexane–ethyl acetate (4:1) gave the starting material **23b** (9 mg, 23%). Further elution with hexane–ethyl acetate (3:1) gave a crystalline substance, which was recrystallized from hexane–ether to give diethyl 3-*endo*-hydroxy-5,6-*exo*-dihydroxy-7-oxabicyclo[2.2.1]heptane-2,2-dicarboxylate acetonide (**24b**) (14 mg, 40%). The mother liquor was condensed in vacuo to give **19b** (15 mg, 42%).

24b: colorless needles; mp 134–136 °C; ^1H NMR ($CDCl_3$) δ 1.23–1.28 (m, 6 H, $CO_2CH_2CH_3$ × 2), 1.24 (s, 3 H, isopropylidene Me), 1.45 (s, 3 H, isopropylidene Me), 2.35 (br d, 1 H, J = 8.0 Hz, OH), 3.80 (d, 1 H, J = 5.7 Hz), 4.11–4.30 (m, 4 H, $CO_2CH_2CH_3$ × 2), 4.31 (d, 1 H, J = 5.7 Hz), 4.63 (d, 1 H, J = 8.0 Hz), 4.99 (d, 1 H, J = 1.0 Hz); high-resolution MS m/z, M^+ – Me calcd for $C_{14}H_{19}O_8$ 315.1080, found 315.1077.

19b: colorless oil; IR ($CHCl_3$) 3460, 1735, 1730 cm^{-1}; ^1H NMR ($CDCl_3$, 500 MHz) δ 1.28 (t, 3 H, J = 7.0 Hz, $CO_2CH_2CH_3$), 1.29 (t, 3 H, J = 7.0 Hz, $CO_2CH_2CH_3$), 1.35 (s, 3 H, isopropylidene Me), 1.54 (s, 3 H, isopropylidene Me), 3.64 (dd, 1 H, J = 2.8, 12.5 Hz, C*H*HOH), 3.72 (d, 1 H, J = 7.0 Hz, malonyl H), 3.80 (dd, 1 H, J = 2.8, 12.5 Hz, CH*H*OH), 4.12 (dt, 1 H, J = 2.8, 3.7 Hz, 5-H), 4.19–4.28 (m, 4 H, $CO_2CH_2CH_3$ × 2), 4.51 (dd, 1 H, J = 3.7, 7.0 Hz, 2-H), 4.74 (dd, 1 H, J = 3.7, 5.5 Hz, 3- or 4-H), 4.77 (dd, 1 H, J = 3.7, 5.5 Hz, 3- or 4-H); ^{13}C NMR ($CDCl_3$) δ 14.03 (q, $CO_2CH_2CH_3$), 25.48 (q, isopropylidene Me), 27.42 (q, isopropylidene Me), 54.60 (d, malonyl 2-C), 61.82 (t, $CO_2CH_2CH_3$), 61.94 (t, $CO_2CH_2CH_3$), 62.70 (t, CH_2OH), 81.37 (d), 82.49 (d), 83.31 (d), 85.42 (d), 114.02 (s, isopropylidene CMe_2), 166.91 (s, CO_2Et), 167.21 (s, CO_2Et); high-resolution MS m/z, M^+ calcd for $C_{15}H_{24}O_8$ 332.1471, found 332.1431.

(2) In a similar manner, **24b** (14 mg, 0.042 mg) was treated with $NaBH_4$–K_2CO_3 in MeOH at 0 °C for 30 min to give the ribofuranosyl C-glycoside (14 mg, 100%) as a mixture of **19b** and diethyl [3α,4α-dihydroxy-5β-(hydroxymethyl)tetrahydrofur-2α-yl]malonate acetonide (**20b**) (**19b**:**20b** = 9:1).

20b: ^1H NMR ($CDCl_3$, 500 MHz) δ 1.27 (t, 3 H, J = 7.0 Hz, $CO_2CH_2CH_3$), 1.29 (t, 3 H, J = 7.0 Hz, $CO_2CH_2CH_3$), 1.32 (s, 3 H, isopropylidene Me), 1.48 (s, 3 H, isopropylidene Me), 3.61 (dd, 1 H, J = 6.0, 12.0 Hz, C*H*HOH), 3.64 (1 H, dd, J = 4.0, 12.0 Hz, CH*H*OH), 3.82 (d, 1 H, J = 10.0 Hz, malonyl H), 4.17 (ddd, 1 H, J = 1.5, 4.0, 6.0 Hz, 5-H), 4.17–4.30 (m, 4 H, $CO_2CH_2CH_3$ × 2), 4.59 (dd, 1 H, J = 4.0, 10.0 Hz, 2-H), 4.68 (dd, 1 H, J = 1.5, 6.0 Hz, 4-H), 4.93 (dd, 1 H, J = 4.0, 6.0 Hz, 3-H); ^{13}C NMR ($CDCl_3$) δ 14.15 (q, $CO_2CH_2CH_3$), 14.27 (q, $CO_2CH_2CH_3$), 25.01 (q, isopropylidene Me), 26.30 (q, isopropylidene Me), 53.19 (d, malonyl 2-C), 61.70 (t, $CO_2CH_2CH_3$), 61.94 (t, $CO_2CH_2CH_3$), 62.06 (t, CH_2OH), 79.20 (d), 81.26 (d), 82.31 (d), 84.25 (d), 113.13 (s, isopropylidene CMe_2), 166.74 (s, CO_2Et), 167.85 (s, CO_2Et); high-resolution MS m/z, M^+ – Me calcd for $C_{14}H_{21}O_8$ 317.1236, found 317.1215.

(3) Similarly, **23b** (50 mg, 0.13 mmol) was submitted to retrograde aldol reaction at room temperature for 2 h to give **19b** (38 mg, 74%) and **20b** (10 mg, 22%).

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