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Asymmetric synthesis of triepoxyzerumbol

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Abstract—The achiral sesquiterpene zerumbone **1**, which is readily available from wild ginger, has a unique functionality and reactivity making it a convenient starting material for its conversion into useful compounds, such as paclitaxel. Optically active triepoxyzerumbol (−)-**3** and its acetate (+)-**4** were synthesized by lipase-catalyzed enantioselective transesterification of racemic **3**. Under optimized conditions, a lipase from *Alcaligenes* sp. (Meito QL) catalyzed the reaction of racemic **3** with isopropenyl acetate in THF at 35 °C to afford (1*S*)-**3** and (1*R*)-**4** with an *E*-value of 79. The absolute configuration of (1*R*)-**4** was determined by single crystal X-ray diffraction of its ester with a chlorine atom using the anomalous dispersion effect.
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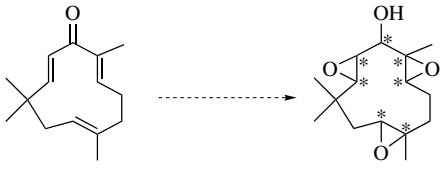
1. Introduction

Recently, natural materials-related diversity-oriented synthesis (NMRDOS) has been described by Kitayama[1] as a promising approach for the synthesis of diverse molecules, starting from natural sources; zerumbone **1**[2] with its structural features has the potential to become one of the most important compounds displaying NMRDOS character. Zerumbone **1**, which has a powerful latent reactivity and contains three double bonds, two conjugated and one isolated, and a doubly conjugated carbonyl group in an eleven-membered ring structure, is a monocyclic sesquiterpene found as the major component of the essential oil of wild ginger, *Zingiber zerumbet* Smith. It is anticipated to be a powerful tool in the implementation of green chemistry with respect to the provision of materials produced via the cultivation of ginger. The largest amount of zerumbone is obtained when the rhizome is harvested in summer.[3]

Zerumbone **1** exhibits a variety of interesting reactions, for example, transannular ring contraction and cyclization,[4–6] regio- and diastereoselective conjugate additions,[4] and various regiospecific ring cleavage reactions.[5,7] Much of its chemistry remains to be explored in order to fully exploit the availability and versatility of this substance as a starting material for the synthesis of other important compounds.

Novel optically active substances as a chiral building block derived from zerumbone[8–10] containing three double bonds can possibly be of use in various industrial fields such as medicine, perfumery, liquid crystal industry, and electronics industry. Moreover, oxidized species of zerumbone have the potential to not only be converted into non-natural sugar derivatives, but also to be incorporated into materials as a chiral auxiliary (Scheme 1).



zerumbone, 1

Scheme 1.

From the viewpoint of diversity, zerumbone **1** has great potential since a variety of stereochemically distinct

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compounds can be theoretically generated from the epoxidations of zerumbone **1** provided that each isomer can be synthesized and isolated as an optically active compound (Scheme 1). A versatile route for obtaining isomerically pure compounds resides in the utility of enzymes for the resolution of optically inactive epoxides of zerumbone **1**. For example, if a lipase selectively recognizes the different stereoisomers and if it catalyzes transesterifications with high efficiency, this technique can be applicable for the synthesis and isolation of the enantiomerically pure epoxides of zerumbone **1**. Herein we report our development of reliable procedures for the preparation of racemic oxidized species of zerumbol and their optical resolution into the optically pure compounds by lipase-catalyzed transesterifications in the presence of the lipase from *Alcaligenes* sp. (Meito QL).

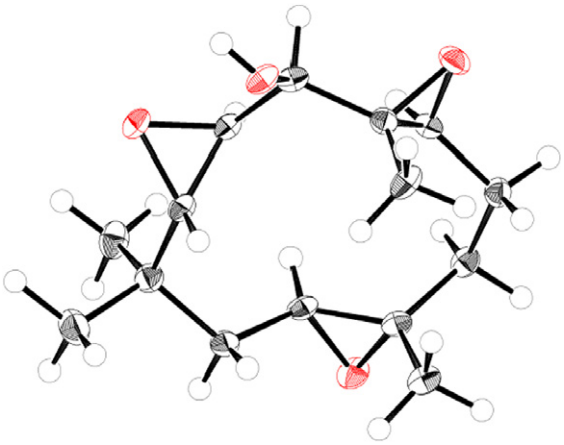


Figure 1. ORTEP drawing of the crystal structure of triepoxyzerumbol *rac*-**3**.

2. Results and discussion

As shown in Scheme 2, zerumbone **1** was treated with MCPBA at room temperature to afford 6,7-epoxyzerumbone **2** in 90% yield.[7] Epoxide **2** was reacted with 6 equiv of 10% NaOCl in acetonitrile at room temperature for 10 h, until **2** was consumed completely and was then followed by treatment with $NaBH_4$ in ethanol at room temperature for 3 h to afford racemic triepoxyzerumbol *rac*-**3** in 45% yield as a single diastereomer.

Monoclinic single crystals of *rac*-**3** were obtained by recrystallization from EtOH and subjected to X-ray analysis. The X-ray structure is shown in Figure 1 and it clearly reveals compound **3** to be a racemic mixture with a stereochemistry of (1*RS*,2*SR*,3*SR*,6*SR*,7*SR*,10*SR*,11*SR*).

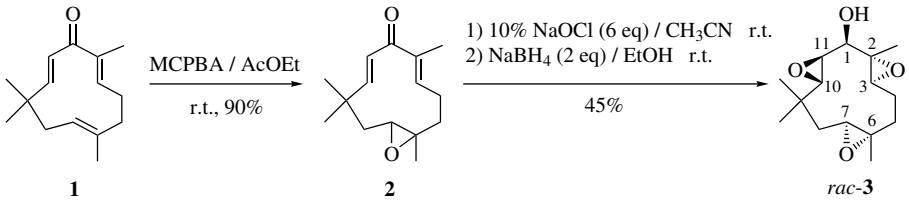
As shown in Scheme 3, the lipase-catalyzed kinetic transesterification of **3** was then investigated. Kitayama et al. reported a guide for the selection of the solvent to be used in the lipase-catalyzed high-enantioselective transesterifications.[11] As previously reported in many cases, *n*-propyl ether, diisopropyl ether, or THF are recommended,[11] since the reciprocals of the dielectric constants of these solvents were approximately 0.3. The reaction was monitored by GC using a capillary column (DB-5), Inj: 190 °C, Det: 190 °C, column: 170 °C, retention time [(−)-**3**: 22 min, (+)-**4**: 36 min]. The configuration was determined by GC using a capillary column CP-CD (CP-cyclodextrin-B-236-M-19), Inj: 180 °C, Det: 180 °C, column: 160 °C, retention time [(+)-**3**: 158 min, (−)-**3**: 154 min, (+)-**4**: 234 min, (−)-**4**: 235 min].

Table 1 shows the results from the attempted transesterifications of *rac*-**3** with isopropenyl acetate in THF in the presence of 19 lipases. Several lipases, especially for *Alcaligenes* sp., produced the corresponding acetate in good conversion. The combination of Meito QL and THF gave the highest *E*-value (enantiomeric ratio)[12] of 79. Amano AK, which was successfully utilized for the stereoselective transesterifications of zerumbol,[9] showed only poor selectivity for the transesterification of racemic epoxide derivative *rac*-**3**.

Plots of the rates of formation of acetate **4** employing the lipases of Meito QL in six solvents (DMF, DIPE, THF, EtOAc, toluene, and hexane) are shown in Figure 2. The reaction was slowest in the polar solvent (DMF), and faster with in the non-polar solvent (hexane). However, the enantioselectivity of both reactions were reduced in these transesterifications. Consequently, the *E*-value reached a maximum with the combination of the lipase Meito QL in a solvent of medium polarity such as THF.

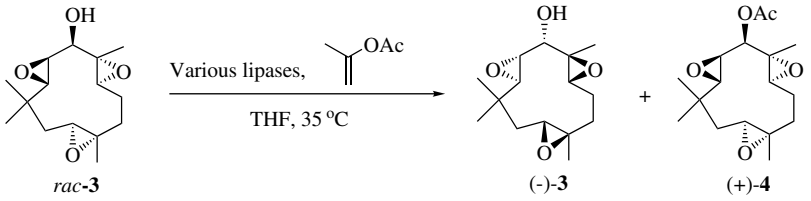
Table 2 shows the results from the transesterification of *rac*-**3** using Meito QL with isopropenyl acetate in THF under various temperature conditions (10, 20–23, 35, 45, and 55 °C). Below 23 °C, although the conversions were very low despite being very low for 10 days, the stereoselectivities were very high ($E > 2000$). A decrease in the molecular vibrations of the lipase might play a major role improving the affinity with one of the isomers of *rac*-**3**. On the other hand, at temperatures over 45 °C, the conversions significantly improved although the stereoselectivities were poor.

The dynamic nature of the lipase might hamper the stereoselectivity since the active site of the lipase impacted by



1 **2** *rac*-**3**

Scheme 2.



Scheme 3.

Table 1. Transesterification of *rac*-**3** using various lipases in THF

Lipase	Source	Time (h)	Conversion (%)	*E*-value
Meito AL	*Achromobacter* sp.	120	N.R	—
Meito PL	*Alcaligenes* sp.	120	4	5
Meito 266	*Alcaligenes* sp.	114	51	21
Meito QL	*Alcaligenes* sp.	472	34	79
Meito QLM	*Alcaligenes* sp.	120	50	9
Amano A	*Aspergillus niger*	312	2.7	18
Amano PS	*Burkholderia cepacia*	314	1.5	1
Meito SL	*Burkholderia cepacia*	120	4	6
Meito MY	*Candida cylindracea*	312	3.2	10
Meito OF 360	*Candida cylindracea*	312	N.R	—
Amano AY	*Candida rugosa*	314	0.01	—
Amano M	*Mucor javanicus*	312	N.R	—
Amano AK	*Pseudomonas stutzeri*	314	4.7	4
Amano GC	*Penicillium roqueforti*	314	0.07	—
Amano R	*Penicillium roqueforti*	120	N.R	—
Meito TL	*Pseudomonas stutzeri*	120	18	4
Meito UL	*Rhizopus* sp.	120	N.R	—
Pancreatin F	*Porcine liver*	120	N.R	—
PLE-A	*Porcine liver*	120	0.3	—

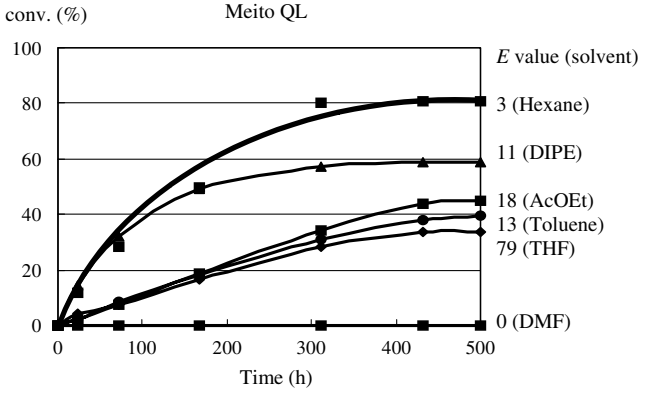


Figure 2. Reaction rate of transesterification of *rac*-**3**.

Table 2. Transesterification of *rac*-**3** under various temperatures

Temperature (°C)	Time (h)	Conversion (%)	*E*-value
10	240	5	2100
20–23	240	4	2100
35	470	34	79
45	240	27	8
55	240	36	1

the vibrations might be advantageous for improving the reaction rate of the transesterification.

3. Absolute configuration

As shown in Scheme 4, the absolute configuration of (+)-**4** was determined by anomalous dispersion of heavy atom derivatives. For this purpose, acetate (+)-**4** was converted into its 4-chlorobenzoate **5** with a purity of 96% ee.

A monoclinic crystal of **5** was obtained by recrystallization from EtOH and subjected to X-ray analysis. The X-ray structure is shown in Figure 3 and the absolute configuration of (1*R*,2*R*,3*S*,6*S*,7*S*,10*S*,11*R*) was elucidated for compound (+)-**4**.

In order to rule out that the single crystal utilized for the X-ray analysis consists of (−)-**4**, which is the 2% impurity in the product of (+)-**4**, the following controlled experiment was performed. The single crystal, whose size was 0.60 mm × 0.15 mm × 0.10 mm, was dissolved in MeOH and hydrolyzed with NaOH at room temperature. The solvent was carefully removed in vacuo and the residue analyzed by GC using an optically active capillary column. The traces of the GC analysis are shown in Figure 4 and clearly indicate that the single crystal consisted of the product (+)-**4** and not the impurity (−)-**4**.

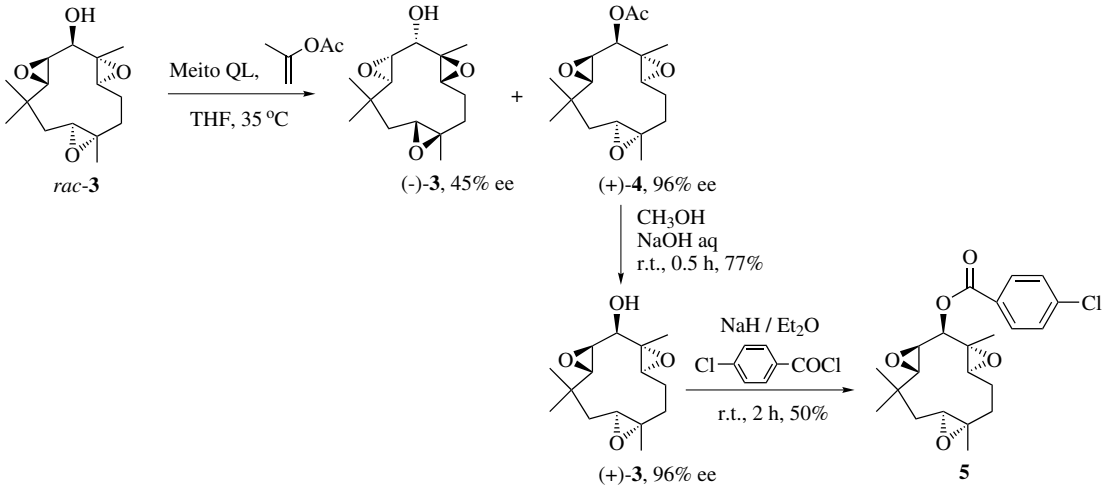
4. Conclusion

Racemic triepoxyzerumbol **3** was easily prepared diastereoselectively from zerumbone **1**. Optically active triepoxyzerumbol (−)-**3** and its acetate (+)-**4** were synthesized by lipase-catalyzed enantioselective transesterification of racemic **3**. Under the optimized reaction conditions, a lipase from *Alcaligenes* sp. (Meito QL) and isopropenyl acetate in THF at 30 °C afforded (1*S*)-**3** and (1*R*)-**4** with an *E*-value of 79. The absolute configuration of (1*R*)-**4** was determined by single crystal X-ray diffraction of its ester. Since we found that the lipase selectively recognizes the different stereoisomers and since the enantioselective transesterification proceeded with high selectivity, we believe that this procedure can be generally applied for the preparation of epoxyzerumbones with other stereochemistry.

5. Experimental

5.1. General methods

NMR spectra were obtained at 270 MHz for protons, and 68 MHz for ^{13}C in $CDCl_3$ with tetramethylsilane (TMS) as the internal standard, unless otherwise noted. Chemical



Scheme 4.

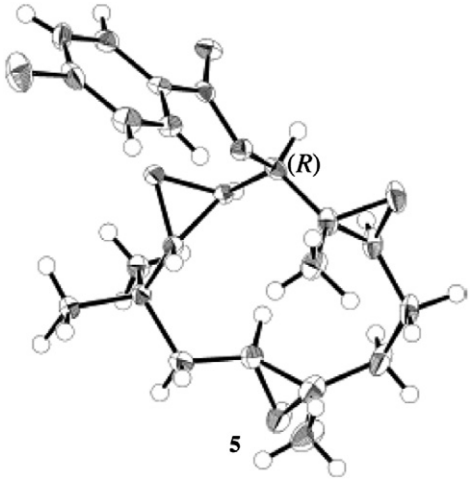


Figure 3. ORTEP drawing of the crystal structure of tripoxyesters **5**.

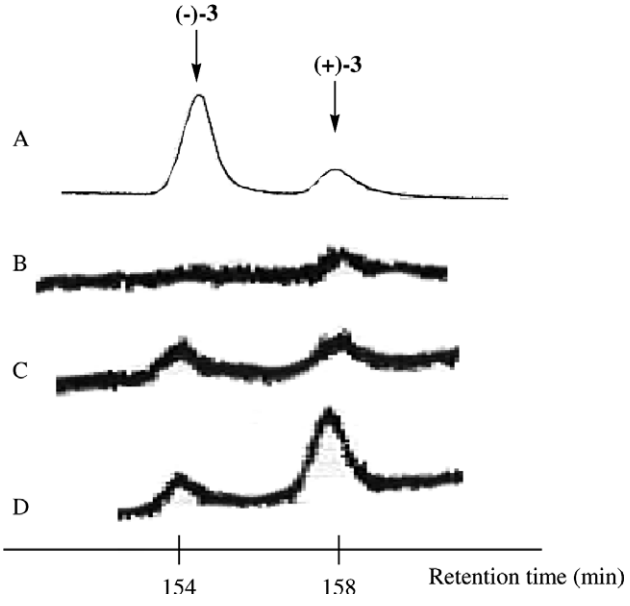


Figure 4. GC charts of various samples of compound **3**. Samples have been analyzed by an optically active capillary column. Trace A: 45% ee of (−)-**3** obtained from Meito QL-catalyzed reaction; trace B: **3** obtained from hydrolysis of optically active single crystal **4** used by X-ray measurement; trace C: racemic **3**; trace D: coinjection of sample B and C.

shifts δ were reported in ppm from TMS. Mass spectra were recorded at 70 eV, and high-resolution mass spectra (HRMS) were obtained by direct injection. The X-ray diffraction and CCDC numbers appear in the section on compound data. Chemicals were of commercially available reagent grade, and used without further purification.

5.2. (1*RS*,2*SR*,3*SR*,6*SR*,7*SR*,10*SR*,11*SR*)-2,3-6,7-10,11-Triepoxy-2,6,9,9-tetramethylcycloundecan-1-ol, *rac*-3

A solution of 10% NaOCl (31.6 mL, 6.0 equiv) was added into a solution of **2** (2.0 g, 8.54 mmol) in acetonitrile (27 mL) at room temperature and stirred at the same temperature for 24 h. The progress of the reaction was monitored by TLC (hexane/AcOEt = 2:1). The solvent was removed on a rotary evaporator to afford a white solid (1.53 g). $NaBH_4$ (165.7 mg, 4.36 mmol) was added into a solution of the white solid (1.53 g) in EtOH (200 mL) at room temperature and stirred at the same temperature for 3 h. The progress of the reaction was monitored by TLC (hexane/AcOEt = 1:2). H_2O (50 mL) was carefully added to the mixture at 0 °C and the aqueous solution was extracted with AcOEt (3 × 30 mL). The combined organic extracts were washed with brine (3 × 30 mL), dried over Na_2SO_4, and concentrated on a rotary evaporator. The residue was subjected to silica gel column chromatography using hexane and AcOEt (4:1) as an eluent to afford the single diastereomer of (1*RS*,2*SR*,3*SR*,6*SR*,7*SR*,10*SR*,11*SR*)-2,3-6,7-10,11-triepoxy-2,6,9,9-tetramethylcycloundecan-1-ol, *rac*-**3** in 45% (1.03 g) yield.

Mp 159–161 °C. IR (KBr) 3436, 2970, 1461 cm^{-1}. ^1H NMR ($CDCl_3$): δ 0.92 (s, 3H, CH_3 at C2), 1.18 (s, 3H, CH_3 at C6), 1.15–1.23 (m, 1H, CH at C4), 1.27 (s, 3H, CH_3 at C9), 1.32 (s, 3H, CH_3 at C9), 1.51 (ddd, 1H, J = 11.2, 6.3, and 2.6 Hz, CH at C5), 1.66 (dd, 1 H, J = 5.6 and 2.6 Hz, CH at C8), 1.66 (dd, 1H, J = 3.6 and

2.6 Hz, CH at C8), 2.14 (ddd, 1H, $J = 6.6$, 5.3, and 3.6 Hz, CH at C5), 2.27 (dddd, 1H, $J = 11.2$, 5.3, 3.0, and 2.6 Hz, CH at C4), 2.68 (dd, 1H, $J = 5.6$ and 2.6 Hz, CH at C3), 2.73 (dd, 1H, $J = 6.3$ and 3.6 Hz, CH at C7), 2.79 (d, 1H, $J = 6.6$ Hz, CH at C10), 3.02 (dd, 1H, $J = 6.6$ and 3.6 Hz, CH at C11), 3.77 (d, 1H, $J = 3.9$ Hz, CH at C1), ^{13}C NMR δ 13.3 (CH_3 at C9), 17.0 (CH_3 at C9), 17.9 (CH_3 at C1), 23.9 (C4), 30.2 (CH_3 at C6), 33.4 (CH_3 at C9), 36.5 (C8), 38.4 (C5), 53.5 (C11), 58.7 (C7), 59.4 (C10), 60.5 (C3), 60.6 (C2) 62.1 (C6), 71.3 (C1). HRMS m/z: calcd mass for $C_{15}H_{24}O_4$, 268.1675; found, 268.1668.

5.3. Crystallographic study of *rac*-3

A colorless prism, $0.10 \times 0.20 \times 0.30$ mm, primitive, space group $P2_1/n$ (no. 14), $a = 10.386(3)$, $b = 16.615(4)$, $c = 16.753(4)$ A, $\beta = 93.967(3)°$, $V = 2884.1(12)$ Å^3, $Z = 8$, $D_c = 1.236$ g/cm^3, μ(Mo-Kα) = 0.88 cm^{-1} was used for data collection. The intensity data were measured on a Rigaku Mercury CCD detector using Mo-Kα radiation at a temperature of -180 ± 1 °C. The structure was solved by direct methods (SIR97)[13] and expanded using Fourier techniques (DIRDIF99).[14] All the calculations were performed using the CRYSTALSTRUCTURE crystallographic software package. The final cycle of full-matrix least-squares refinement was based on 5377 observed reflections ($I > 2.00\sigma(I)$) and 529 variable parameters and gave $R_1 = 0.061$ and $wR_2 = 0.054$. The value of the goodness of fit indicator was 1.002 (summary of data CCDC 640384).

5.4. General procedure of lipase-catalyzed transesterification of *rac*-3

A mixture of *rac*-**3** (20 mg, 0.075 mmol), isopropenyl acetate (2.0 mL, 20.1 mol), and the lipase (dry Meito QL, 50 mg) in THF (6 mL: water content <1.0% v/v) was stirred for 472 h at 35 °C. The conversion was 32%. The reaction was followed by gas chromatography using a column of DB-5 (detector and injection temperature, 190 °C; column temperature, 170 °C; carrier gas, He; FID detector). Under these conditions, the retention time of *rac*-**3** and its corresponding acetate were 22 min and 36 min, respectively. The reaction mixture was filtered and the filtrate was concentrated. Chromatography on silica gel, eluting with a 4:1 mixture of hexane and EtOAc, afforded (−)-**3** and (+)-acetate **4** in 45% and 96% ee, respectively, as determined by gas chromatography using a column of CPCD (detector and injection temperature, 180 °C; column temperature, 160 °C; carrier gas He; FID detector). Under these conditions, the retention times were (−)-**3**, 154 min; (+)-**3**, 158 min; (+)-**4**, 234 min; (−)-**4**, 235 min.

5.5. (1*S*,2*R*,3*R*,6*R*,7*R*,10*R*,11*R*)-2,3-6,7-10,11-Triepoxy-2,6,9,9-tetramethylcycloundecan-1-ol, (−)-3

$[\alpha]_D^{23.5} = -58.8$ (c 0.100, $CHCl_3$) 45% ee.

5.6. (1*R*,2*R*,3*S*,6*S*,7*S*,10*S*,11*R*)-1-Acetoxy-2,3-6,7-10,11-triepoxy-2,6,9,9-tetramethylcycloundecane, (+)-4

Mp 185–187 °C. $[\alpha]_D^{23.5} = +50.6$ (c 0.100, $CHCl_3$) 96% ee. IR (KBr) 2976, 1753, 1460 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 0.88 (s, 3H, CH_3 at C2), 1.16 (s, 3H, CH_3 at C6), 1.26 (ddd, 1H, $J = 9.6$, 7.9, and 2.3 Hz, CH at C5), 1.29 (s, 3H, CH_3 at C9), 1.36 (s, 3H, CH_3 at C9), 1.51 (dddd, 1H, $J = 10.2$, 7.9, 8.6, and 2.3 Hz, CH at C4), 1.67 (dd, 1H, $J = 6.3$ and 2.3 Hz, CH at C8), 1.67 (dd, 1H, $J = 4.0$ and 2.3 Hz, CH at C8), 2.15 (dddd, 1H, $J = 9.6$, 7.9, 7.6, and 2.3 Hz, CH at C4), 2.11 (s, 3H, CH_3CO), 2.30 (ddd, 1H, $J = 8.6$, 7.6, and 2.3 Hz, CH at C5), 2.66 (dd, 1H, $J = 6.3$ and 4.0 Hz, CH at C7), 2.67 (d, 1H, $J = 12.5$ Hz, CH at C10), 2.87 (dd, 1H, $J = 10.3$ and 7.9 Hz, CH at C3), 3.02 (dd, 1 H, $J = 12.5$ and 4.0 Hz, CH at C11), 4.86 (d, 1H, $J = 4.0$ Hz, CH at C1), ^{13}C NMR δ 13.7 (CH_3 at C9), 16.8 (CH_3 at C9), 17.8 (CH_3 at C2), 20.6 (CH_3CO), 23.5 (C4), 29.9 (CH_3 at C6), 33.1 (C9), 36.1 (C5), 38.3 (C8), 51.1 (C11), 58.9 (C10), 59.3 (C3), 59.3 (C3), 60.0 (C2 and C6), 60.1 (C7), 73.1 (C1). 169.4 (CO). HRMS m/z: calcd mass for $C_{17}H_{26}O_5$, 310.1780; found, 310.1796.

5.7. (1*R*,2*R*,3*S*,6*S*,7*S*,10*S*,11*R*)-2,3-6,7-10,11-Triepoxy-2,6,9,9-tetramethylcycloundecanoyl 4-chlorobenzoate 5

A solution of aqueous NaOH (2.0 mL, 6.0 equiv) was added into a solution of (+)-**4** (30 mg, 0.097 mmol) in MeOH (0.5 mL) at room temperature and stirred at the same temperature for 0.5 h. The progress of the reaction was monitored by TLC (hexane/AcOEt = 4:1). H_2O (20 mL) was added to the mixture at room temperature and the aqueous solution was extracted with AcOEt (3×30 mL). The combined organic extracts were washed with brine (3×30 mL), dried over Na_2SO_4, and concentrated on a rotary evaporator. The residue was subjected to silica gel column chromatography using hexane and AcOEt (4:1) as an eluent to afford (1*R*,2*S*,3*S*,6*S*,7*S*,10*S*,11*S*)-2,3-6,7-10,11-triepoxy-2,6,9,9-tetramethylcycloundecan-1-ol, (+)-**3** in 78% (20.3 mg, 96% ee) yield.

Under an atmosphere of N_2, 96% ee of (+)-**3** in absolute Et_2O (2 mL) was added dropwise to a stirred suspension of sodium hydride (12 mg, 0.5 mmol) in absolute Et_2O (5 mL) for 10 min at room temperature. *p*-Chlorobenzoyl chloride (84 mg, 0.48 mmol) was added dropwise and the mixture was stirred for 13 h. Water (10 mL) was added and the mixture was extracted with Et_2O (3×30 mL). The combined ether solutions were washed with brine (3×30 mL), dried over Na_2SO_4, and concentrated on a rotary evaporator to afford a colorless solid residue. Chromatography on silica gel, eluting with a 8:1 mixture of hexane and EtOAc afforded (1*R*,2*R*,3*S*,6*S*,7*S*,10*S*,11*R*)-2,3-6,7-10,11-triepoxy-2,6,9,9-tetramethylcycloundecanoyl 4-chlorobenzoate **5** in 50% (15.4 mg) yield.

5.8. (1*R*,2*S*,3*S*,6*S*,7*S*,10*S*,11*S*)-2,3-6,7-10,11-Triepoxy-2,6,9,9-tetramethylcycloundecan-1-ol, (+)-3

$[\alpha]_D^{23.5} = +111.1$ (c 0.100 $CHCl_3$) 96% ee.

5.9. (1*R*,2*R*,3*S*,6*S*,7*S*,10*S*,11*R*)-2,3-6,7-10,11-Triepoxy-2,6,9,9-tetramethylcycloundecanoyl 4-chlorobenzoate 5

Mp 149–151 °C. IR (KBr) 3444, 2970,1732,1595 cm^{-1}. ^{1}H NMR ($CDCl_3$): δ 0.89 (s, 3H, CH_3 at C2), 1.12 (s, 3H, CH_3 at C6), 1.30 (ddd, 1H, $J = 9.6$, 7.6, and 1.7 Hz, CH

at C5), 1.32 (s, 3H, CH_3 at C9), 1.55 (dddd, 1H, $J = 10.2$, 7.9, 7.6, and 3.3 Hz, CH at C4), 1.49 (s, 3H, CH_3 at C9), 1.69 (dd, 1H, $J = 6.3$ and 2.0 Hz, CH at C8), 1.69 (dd, 1H, $J = 2.6$ and 2.0 Hz, CH at C8), 2.21 (dddd, 1H, $J = 9.9$, 9.6, 7.6, and 3.3 Hz, CH at C4), 2.32 (ddd, 1H, $J = 10.2$, 7.6, and 1.7 Hz, CH at C5), 2.71 (dd, 2H, $J = 6.3$ and 2.6 Hz, CH at C7), 2.74 (d, 1H, $J = 2.3$ Hz, CH at C10), 2.96 (dd, 1H, $J = 9.9$ and 7.9 Hz, CH at C3), 3.14 (dd, 1H, $J = 4.3$ and 2.6 Hz, CH at C11), 5.09 (d, 1H, $J = 4.3$ Hz, CH at C1), 7.43 (d, 2H, $J = 6.9$ Hz, CH at C2′), 7.96 (d, 1H, $J = 6.4$ Hz, CH at C3′), ^{13}C NMR δ 13.9 (CH_3 at C9), 16.8 (CH_3 at C9), 17.7 (CH_3 at C2), 23.5 (C4), 29.8 (C9), 33.2 (CH_3 at C6), 36.0 (C8), 38.2 (C5), 51.1 (C11), 59.1 (C10), 59.2 (C7), 60.1 (C3), 60.3 (C2,C6), 73.9 (C1), 127.9 (C1), 127.9 (C4′), 128.8 (C2′), 131.1 (C3′), 139.7 (C1′), 164.0 (CO). HRMS m/z: (M+H) calcd mass for $C_{22}H_{28}ClO_5$, 407.1614; found, 407.1625.

5.10. Crystallographic study of 5

A colorless prism crystal, crystal size $0.60 \times 0.15 \times 0.10\ mm^3$, monoclinic, space group $P2_1$ (no. 4), $a = 9.363(3)$, $b = 36.281(6)$, $c = 12.705(3)$ Å, $\beta = 104.649(10)°$, $V = 4175.7(16)$ Å^3, $Z = 8$, $D_{calcd} = 1.294$ g/cm^3, μ(Mo-Kα) = 2.124 cm^{-1}, was used for data collection. The intensity data were measured on a Rigaku R-AXIS RAPID using Mo-Kα radiation at a temperature of -180 ± 1 °C. The structure was solved by direct methods (SIR97)[13] and expanded using Fourier techniques (DIRDIF99).[14] All calculations were performed using the CRYSTAL STRUCTURE crystallographic software package. The final cycle of full-matrix least-squares refinement on F^2 was based on 15,358 reflections (all data) and 1441 variable parameters and gave $R_1 = 0.042$ ($I > 2.0\sigma(I)$) and $wR_2 = 0.075$ (all data). The value of the goodness of fit indicator was 1.036. Flack parameter was $-0.02(3)$.[15] (Summary of Data CCDC 640385).

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