ENANTIOSELECTIVE SYNTHESIS OF 6-SUBSTITUTED 5,6-DIHYDRO-α-PYRANONES, (+)-GONIOTHALAMIN AND (-)-ARGENTILACTONE

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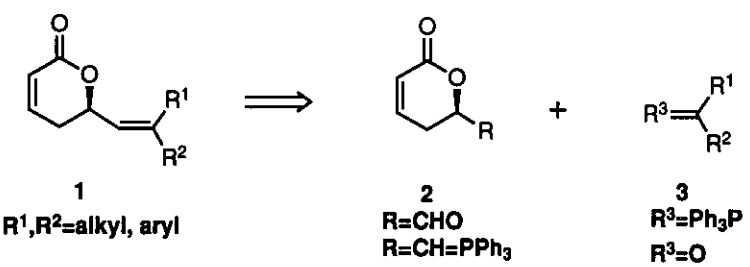
Abstract—An enantioselective synthesis of (+)-goniothalamin and (-)-argentilactone has been accomplished by employing the Wittig reactions of phosphoranes with the aldehyde (**12**) generated *in situ* by Swern oxidation of the alcohol (**13**) as a key step.

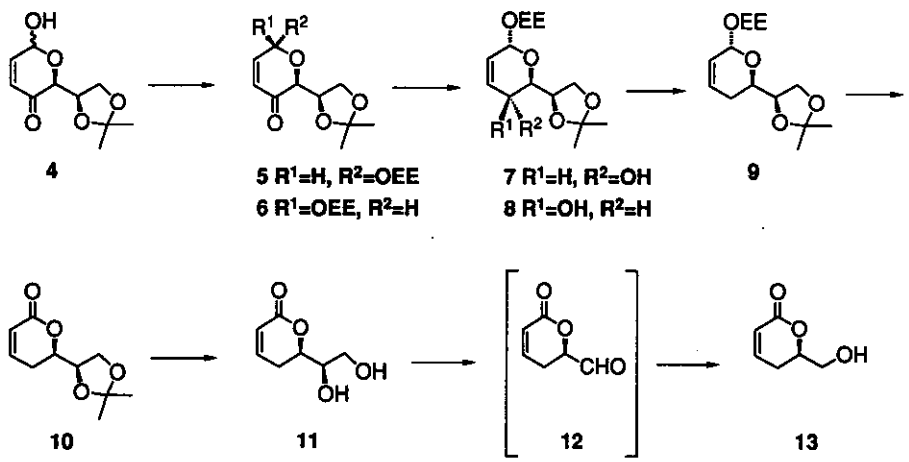
A number of compounds having 6-substituted 5,6-dihydro-α-pyrone (**1**) ring system such as goniothalamin,[1] argentilactone,[2] anamarine,[3] and CI-920,[4] have been isolated from plants and fungi.[5] These natural products have been the targets of several syntheses due to their interesting biological activities[1b,4] and their structural features.[5] Based on the retrosynthetic analysis of **1**, an olefinic α,β-unsaturated lactone could be obtained by a Wittig reaction between two fragments (**2**) and (**3**) (Scheme 1). Attempts to prepare the aldehyde (**2**, R: CHO)[1d] and the phosphorane (**2**, R: $CH=PPh_3$)[6] so far reported failed because of their instability, and the corresponding pyranosides have been used as their equivalents.[1d,6,7]



Scheme 1

We sought to reinvestigate this synthetic approach to develop a facile method for the synthesis of **1** as part of our continuing studies on the synthesis of lactonic antibiotics utilizing furans.[1f,8] Here we report the synthesis of (+)-goniothalamin (**15**) and (-)-argentilactone (**16**) employing the Wittig olefination of the aldehyde (**12**) with the corresponding phosphoranes as a key step.

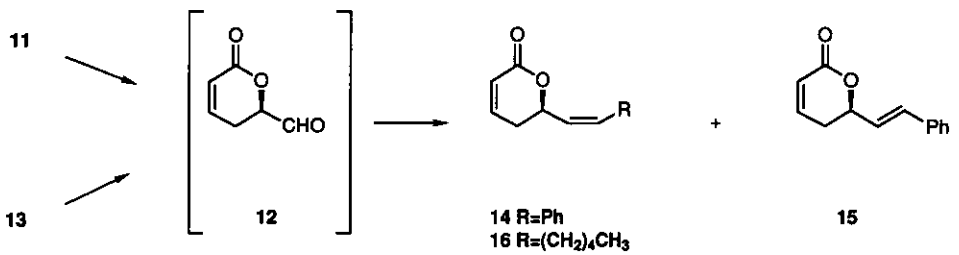
The requisite aldehyde (**12**) was prepared as follows (Scheme 2). Treatment of the lactol (**4**),[8c] derived from (2*S*,3*R*)-1,2-*O*-isopropylidene-3-(2-furyl)glycerol, with ethyl vinyl ether and a catalytic amount of pyridinium *p*-toluenesulfonate afforded the ethoxyethyl ethers (**5**) and (**6**) in 97.5 % yield in a ratio of 8 : 1, respectively. Reduction of the major isomer (**5**) with sodium borohydride in aqueous tetrahydrofuran (THF) gave the alcohols (**7**) and (**8**), 87.3 % yield, in a ratio of 5.2 : 1, respectively. Alcohol (**7**) was deoxygenated by successive methanesulfonylation and lithium aluminum hydride reduction of the mesylate to furnish the dihydropyran (**9**) in 64 % overall yield.[9] Deprotection of the ethoxyethyl group in **9** afforded the lactol, which on exposure to pyridinium dichromate (PDC) in *N*, *N*-dimethylformamide (DMF) provided the α,β-unsaturated lactone (**10**) in 62 % overall yield. Removal of the acetonide group in **10** on acid treatment gave the diol (**11**) quantitatively. Oxidative cleavage of the glycol (**11**) with sodium periodate in dicholoromethane and water proceeded smoothly to produce the aldehyde (**12**) *in situ* which, however, could not be isolated due to decomposition of **12** during the workup. Successive reduction of the reaction mixture with sodium borohydride in the same pot afforded the alcohol (**13**) in 62.2 % yield and this result proved the desired aldehyde (**12**) to be formed in the oxidation reaction.



Scheme 2

We, therefore, explored sequential reactions which involved *in situ* generation of **12** followed by a Wittig olefination (Scheme 3). Glycol cleavage of **11** with lead tetraacetate in dichloromethane gave the aldehyde (**12**), whose solution was further treated with 3 equiv. of benzylidenetriphenylphosphorane to furnish a mixture of *Z*- and *E*-olefins (**14**) and (**15**), 15.5 % yield, in a ratio of 3.9 : 1, respectively. We next examined successive Swern oxidation and Wittig olefination reaction[10] of the alcohol (**13**). Swern oxidation[11] of **13** gave **12** cleanly, which, without isolation, was treated with 10 equiv. of the phosphorane to afford the Wittig condensation products (**14**) and (**15**), 75 % yield, in a ratio of 3.1 : 1, respectively. *Z*-Olefin (**14**) was easily isomerized by employing photoreaction[12] in the presence of diphenyl disulfide in benzene to give the desired *E*-olefin (**15**), (+)-goniothalamin, mp 82-82.5 °C (lit.,[1e] mp 81-82 °C), $[\alpha]_D^{23}$ +177.5 ° (c 0.35, $CHCl_3$)

{lit.,[1e] $[\alpha]_D$ +178.5 ° (c 2, $CHCl_3$)}, in 64.5 % yield, together with **14** in 32.5 %yield. The spectroscopic data of the synthetic goniothalamin are identical with those reported.[1a]



Scheme 3

(-)-Argentilactone was also synthesized in the same manner. Addition of hexylidenetriphenylphosphorane to **12** provided (-)-argentilactone (**16**), $[\alpha]_D^{22}$ -22.4 ° (c 0.23, EtOH) {(lit.,[2a] $[\alpha]_D$ -21.1° (c 2.25, EtOH)}, in 65.3 % yield. Its spectroscopic data are identical with those reported.[2a]

Thus, we have succeeded in the enantioselective synthesis of (+)-goniothalamin and (-)-argentilactone employing the Wittig reaction of phosphoranes with the aldehyde (**12**) generated *in situ* as a key step and this synthetic approach would be applicable to the syntheses of other types of 6-substituted 5,6-dihydro-α-pyrones.

EXPERIMENTAL SECTION

Melting points were mesasured with a Yanagimoto MP apparatus and are uncorrected. Ir spectra were recorded on a Hitachi 260-10 spectrophotometer. ^{1}H-Nmr spectra were obtained for solution in $CDCl_3$ on a JEOL GSX-270 insturument, and chemical shifts are reported on the δ-scale from internal TMS. Mass spectra were measured with a JEOL JMS D-300 spectrometer. Optical rotations were taken with a JASCO DIP-360 polarimeter.

(2*S*, 6*S*)- and (2*S*, 6*R*)-6-(1-Ethoxyethoxy)-2-[(4*R*)-2, 2-dimethyl-1, 3-dioxolan- 4-yl]-6*H*-pyran-3(2*H*)-ones (5) and (6) : To a stirred solution of the lactol (**4**) (45 mg, 0.21 mmol) in CH_2Cl_2 (5 ml) were added ethyl vinyl ether (0.2 ml, 2.10 mmol) and pyridinium *p*-toluenesulfonate (0.6 mg, 0.02 mmol) at 0°C, and stirring was continued for 5 h at room temperature under argon atmosphere. After addition of saturated aqueous $NaHCO_3$ solution, the mixture was extracted with CH_2Cl_2. The combined organic layer was washed with brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave a residue, which was purified by column chromatography on silica gel using hexane-EtOAc (15:2, v/v) as eluent. The first fraction gave the α-anomer (**5**) (52 mg, 86.5%) as a colorless oil. Ir ($CHCl_3$) υ_{max} : 1698 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 1.23 and 1.24 (each 1.5H, each t, *J*=7.3 Hz, OCH_2*Me*), 1.38 and 1.41 (each 3H, each s, CMe_2), 1.42 and 1.44 (each 1.5H, each d, *J*=5.5 Hz, CH*Me*) 3.50-3.88 (2H, m, CH_2Me), 3.92-3.98 (1H, m, 5'-H), 4.20-4.28 (1H, m, 5'-H), 4.40-4.53 (2H, m, 2-H and 4'-H), 5.01 and 5.07 (each 0.5H, each q, *J*=5.5 Hz, OC*H*Me), 5.62 and 5.64 (each

0.5H, each d, *J*=3.7 Hz, 6-H), 6.13 and 6.14 (each 0.5H, each d, *J*=9.8 Hz, 4-H), and 6.84 and 6.91 (each 0.5H, each dd, *J*=3.7 and 9.8 Hz, 5-H). Ms (m/z) : Calcd for $C_{13}H_{19}O_6$ (M^+-15) : 271.1182. Found : 271.1177. *Anal.* Calcd for $C_{14}H_{22}O_6$: C, 58.73 ; H, 7.75. Found : C, 58.46 ; H, 7.93. The second fraction gave the β-anomer (**6**) (6.5 mg, 11.0%) as a colorless oil. Ir ($CHCl_3$) υ_{max} : 1692 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 1.22 and 1.23 (each 1.5H, each t, *J*=7.3 Hz, OCH_2*Me*), 1.36 and 1.42 (each 3H, each s, CMe_2), 1.46 (3H, d, *J*=5.5 Hz, CH*Me*) 3.55 and 3.82 (each 1H, each dq, *J*=7.3 and 9.8 Hz, C*H*$_2$Me), 3.94 and 4.12 (each 1H, each dd, *J*=6.1 and 8.5 Hz, 2×5'-H), 4.07 (1H, d, *J*=6.1 Hz, 2-H), 4.59 (1H, q, *J*=6.1 Hz, 4'-H), 5.03 (1H, q, *J*=5.5 Hz, OC*H*Me), 5.63 (1H, each br s, 6-H), 6.17 (1H, dd, *J*=1.8 and 10.4 Hz, 4-H) and 6.90 (1H, dd, *J*=1.8 and 10.4 Hz, 5-H). Ms (m/z) : Calcd for $C_{13}H_{19}O_6$ (M^+-15) : 271.1181. Found : 271.1176.

(2*S*, 3*R*, 6*S*)- and (2*S*, 3*S*, 6*S*)-6-(1-Ethoxyethoxy)-2-[(4*R*)-2, 2-dimethyl-1, 3-dioxolan-4-yl]-3, 6-dihydro-2*H*-pyran-3-ols (7) and (8) : To a stirred solution of the enone (**5**) (560 mg, 1.96 mmol) in THF (1 ml) was added dropwise a solution of sodium borohydride (112 mg, 2.94 mmol) in water (5 ml) at 0°C, and stirring was continued for 30 min at the same temperature. After addition of saturated aqueous NH_4Cl solution, the organic layer was evaporated. The mixture was extracted with EtOAc, and the combined organic layer was washed with brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave a residue, which was purified by column chromatography on silica gel using hexane-EtOAc (9:2, v/v) as eluent. The first fraction gave the α-alcohol (**7**) (413 mg, 73.3%) as a colorless oil. Ir ($CHCl_3$) υ_{max} : 3505 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 1.21 and 1.22 (each 1.5H, each t, *J*=7.3 Hz, OCH_2*Me*), 1.36-1.46 (9H, m, CMe_2 and OCH*Me*), 2.34 and 2.41 (each 0.5H, each d, *J*=5.5 Hz, OH), 3.43-4.12 (5H, m, 4'-H, 2×5'-H, and OC*H*$_2$Me), 4.20-4.32 (1H, m , 3-H), 4.38-4.46 (1H, m, 2-H), 4.89 and 4.97 (each 0.5H, each q, *J*=4.9 Hz, OC*H*Me), 5.21 and 5.27 (each 0.5H, each br s, 6-H), 5.70 and 5.78 (each 0.5H, each dt, *J*=2.4 and 10.4 Hz, 5-H), and 5.94 and 5.98 (each 0.5H, each br s, 4-H). Ms (m/z) : Calcd for $C_{13}H_{21}O_6$(M^+-15) : 273.1337. Found : 273.1337. *Anal.* Calcd for $C_{14}H_{24}O_6$: C, 58.31; H, 8.39. Found : C, 58.77 ; H, 8.55. The second fraction gave the β-alcohol (**8**) (79.2 mg, 14.0%) as colorless needles after recrystallization from hexane-Et_2O, mp 72-73°C. Ir ($CHCl_3$) υ_{max} : 3480 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 1.22 and 1.23 (each 1.5H, each t, *J*=7.3 Hz, OCH_2*Me*), 1.38-1.44 (9H, m, CMe_2 and OCH*Me*), 2.03 and 2.07 (each 0.5H, each d, *J*=7.3 Hz, OH), 3.43-3.93 (4H, m, 2×5'-H and OC*H*$_2$Me), 3.98 and 4.07 (each 0.5H, each dd, *J*=2.4 and 7.3 Hz, 3-H), 4.15-4.21 (1H, m, 4'-H), 4.43 (1H, q, *J*=7.3 Hz, 2-H), 4.97 and 5.05 (each 0.5H, each q, *J*=4.9 Hz, OC*H*Me), 5.26 and 5.36 (each 0.5H, each d, *J*=3.1 Hz, 6-H), 5.88 and 5.96 (each 0.5H, each dd, J=3.1 and 9.8 Hz, 5-H), and 6.11-6.19 (1H, m, 4-H). Ms (m/z) : Calcd for $C_{13}H_{21}O_6$ (M^+-15) : 273.1338. Found : 273.1339. *Anal.* Calcd for $C_{14}H_{24}O_6$: C, 58.31; H, 8.39. Found : C, 58.16 ; H, 8.58.

(2*R*, 6*S*)-6-(1-Ethoxyethoxy)-2-[(4*R*)-2, 2-dimethyl-1, 3-dioxolan-4-yl]-3, 6-dihydro-2*H*-pyran (9) : To a stirred solution of the alcohol (**7**) (300 mg, 1.04 mmol) in CH_2Cl_2 (4 ml) were added triethylamine (0.44 ml, 3.13 mmol), *N*, *N*-dimethylaminopyridine (25 mg, 0.21 mmol) and methanesulfonyl chloride (0.16 ml, 2.08 mmol) at 0°C under argon atmosphere, and stirring was continued for 15 min at the same temperature. After addition of brine, the mixture was extracted with CH_2Cl_2, and the organic layer was dried over Na_2SO_4 and evaporated to give the crude mesylate, whitch was relatively unstable. A small amount of the sample was

purified for analytical data by column chromatography on silica gel using hexane-EtOAc (5:1, v/v) as eluent to afford the mesylate as a colorless oil. ^{1}H-Nmr ($CDCl_3$) δ : 1.22 (3H, t, *J*=7.3 Hz, OCH_2*Me*), 1.36 and 1.38 (each 1.5H, each d, *J*=5.5 Hz, OCH*Me*), 1.37 and 1.42 (each 3H, each s, CMe_2), 3.10 and 3.11 (each 1.5H, each s, OSO_2Me), 3.40-4.10 (5H, m, 4'-H, 2×5'-H, and OCH_2CH_3), 5.22 and 5.25 (each 0.5H, each br s, 3-H), 5.34 and 5.38 (each 0.5H, each br s, 6-H), 5.81 and 5.88 (each 0.5H, each ddd, *J*=1.8, 3.1, and 10.4 Hz, 5-H), 6.11 and 6.15 (each 0.5H, each br d, *J*=1.8 Hz, 4-H). The mesylate was used for the next reaction without purification. To a stirred suspension of lithium aluminum hydride (198 mg, 5.21 mmol) in THF (5 ml) was added a solution of the mesylate in THF (5 ml) at 0°C and the reaction mixture was stirred for 6 h at 50°C under argon atmosphere. After addition of 20% aqueous sodium hydroxide solution, the mixture was stirred for 30 min and white precipitate was filtered off. The filtrate was washed with brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave a residue, which was purified by column chromatography on silica gel using hexane-EtOAc (10:1,v/v) as eluent to afford the titled compound (**9**) (182 mg, 64.3%) as a colorless oil. ^{1}H-Nmr ($CDCl_3$) δ : 1.22 (3H, t, *J*=7.3 Hz, OCH_2*Me*), 1.37 and 1.40 (each 1.5H, each d, *J*=5.5 Hz, OCH*Me*), 1.38 and 1.42 (each 3H, each s, CMe_2), 1.80-2.17 (2H, m, 2×3-H), 3.40-4.20 (6H, m, 2-H, 4'-H, 2×5'-H, and OCH_2CH_3), 4.94 and 5.02 (each 0.5H, each q, *J*=5.5 Hz, $OCHCH_3$), 5.19 and 5.30 (each 0.5H, each br s, 6-H), 5.65-5.74 (0.5H, m, 5-H), 5.75-5.82 (0.5H, m, 5-H), and 5.97-6.08 (1H, m, 4-H). Ms (m/z) : Calcd for $C_{13}H_{21}O_5$ (M^+-15) : 257.1387. Found : 257.1382.

(6*R*)-6-[(4*R*)-2, 2-Dimethyl-1, 3-dioxolan-4-yl]-5, 6-dihydro-2*H*-pyran-2-one (10) : To a stirred solution of compound (**9**) (115 mg, 0.42 mmol) in THF (0.7 ml) was added a solution of 75% aqueous acetic acid (2.8 ml) at 0°C, and stirring was continued for 1 h. Evaporation of the solvent gave the crude lactol. A small amount of the sample was purified for analytical data by column chromatography on silica gel using hexane-EtOAc (2:1,v/v) as eluent to afford the lactol as a colorless oil. Ir ($CHCl_3$) υ_{max} : 3400 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 1.39 and 1.45 (each 3H, each s, CMe_2), 1.80-1.95 (1H, m, 5-H), 2.00-2.15 (1H, m, 5-H), 3.20-3.35 (1H, br s, OH), 3.78 (1H, dd, *J*=6.7 and 7.9 Hz, 5'-H), 4.00-4.20 (3H, m , 4'-H, 5'-H and 6-H), 5.44 (1H, br s, 2-H), 5.70-5.87 (1H, m, 3-H) and 5.93-6.15 (1H, m, 4-H). Ms (m/z) : Calcd for $C_9H_{13}O_4$(M^+-15) : 185.0812. Found : 185.0805. The lactol was used for next reaction without purification. To a stirred solution of PDC (477 mg, 1.27 mmol) in DMF (0.9 ml) was added dropwise a solution of the crude lactol in DMF (0.9 ml) at 0°C, and stirring was continued for 4 h at room temperature under argon atmosphere. After addition of brine, the mixture was extracted with Et_2O. The combined organic layer was washed with brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave a residure, which was purified by column chromatography on silica gel using hexane-EtOAc (2:1, v/v) to afford the enone (**11**) (64.9 mg, 62%) as a colorless oil. Ir ($CHCl_3$) υ_{max} : 1735 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 1.38 and 1.45 (each 3H, each s, CMe_2), 2.27-2.63 (2H, m, 2×5-H), 4.05 and 4.09 (each 1H, each dd, *J*=6.1 and 8.5 Hz, 5'-H), 4.33 (1H, dt, *J*=4.3 and 6.1Hz, 4'-H), 4.54 (1H, dt, *J*=4.3 and 12.2 Hz, 6-H), 6.04 (1H, dd, *J*=2.4 and 9.8 Hz, 3-H), and 6.93 (1H, ddd, *J*=2.4, 6.1, and 9.8 Hz, 4-H). Ms (m/z) : Calcd for $C_{10}H_{14}O_4$ (M^+) : 198.0891. Found : 198.0876. *Anal.* Calcd for $C_{10}H_{14}O_4$: C, 60.59 ; H, 7.12. Found : C, 60.53 ; H, 7.33. $[\alpha]_D^{22}$ +134.3° (c 1.54, $CHCl_3$).

(6*R*)-6-[(1*R*)-1, 2-Dihydroxyethyl]-5, 6-dihydro-2*H*-pyran-2-one (11) : A solution of the enone (**10**) (1.3 g, 6.60 mmol) in 75% aqueous acetic acid (12 ml) was stirred at 40°C for 2 h. Evaporation of the solvent gave a residue, which was purified by column chromatography on silica gel using EtOAc as eluent to afford the diol **11** (1.03 g, 99.0%) as colorless leaflets after recrystallization from hexane-CH_2Cl_2, mp 84-84.5°C. Ir ($CHCl_3$) υ_{max} : 1735 and 3450 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 2.36 (1H, ddd, *J*=4.3, 6.1, and 18.9 Hz, 5-H), 2.67 (1H, ddt, *J*=2.4, 12.8, and 18.9 Hz, 5-H), 3.70-3.85 (3H, m, 1'-H and 2×2'-H), 3.90-4.50 (2H, br s, 2×OH), 4.56 (1H, dt, *J*=4.3 and 12.8 Hz, 6-H), 5.98 (1H, dd, *J*=2.4 and 9.8 Hz, 3-H), and 6.93 (1H, ddd, *J*=2.4, 6.1, and 9.8 Hz, 4-H). Ms (m/z) : Calcd for $C_7H_{11}O_4$ (M^++1) : 159.0657. Found : 159.0662. *Anal.* Calcd for $C_7H_{10}O_4$: C, 53.16; H, 6.37. Found : C, 52.98 ; H, 6.51. $[\alpha]_D^{28}$ +101.3° (c 1.53, MeOH).

(6*R*)-6-Hydroxymethyl-5, 6-dihydro-2*H*-pyran-2-one (13) : To a stirred solution of the diol (**11**) (50 mg, 0.32 mmol) in CH_2Cl_2-H_2O (1ml ; 4:1,v/v) was added portionwise $NaIO_4$ (136 mg, 0.64 mmol) at 0°C. After stirring for 30 min at the same temperature, ethylene glycol (26 µl, 0.47 mmol) was added to the mixture and stirring was continued further 10 min. $NaBH_4$ (15.6 mg, 0.41 mmol) was added to the solution portionwise, and the mixture was stirred for 30 min at 0°C. After addition of saturated aqueous NH_4Cl solution, the mixture was extracted with $CHCl_3$. The combined organic layer was washed with brine and dried over Na_2SO_4. Evaporation of the solvent gave a residue, which was purified by column chromatography on silica gel using EtOAc-benzene (3:1, v/v) as eluent to afford the alcohol (**13**) (25.2 mg, 62.2%) as a colorless oil. Ir ($CHCl_3$) υ_{max} : 1730 and 3350 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 2.27-2.40 (1H, m, 5-H), 2.55-2.69 (2H, m, 5-H and OH), 3.70-3.95 (2H, m, C*H*$_2$OH), 4.50-4.62 (1H, m, 6-H), 6.04 (1H, dd, *J*=3.7 and 9.8 Hz, 3-H) and 6.95 (1H, ddd, *J*=1.8, 6.1, and 9.8 Hz, 4-H). Ms (m/z) : Calcd for $C_6H_8O_3$ (M^+) : 128.0472. Found : 128.0472. $[\alpha]_D^{26}$ +174.95° (c 0.92, $CHCl_3$).

Wittig Reaction of Benzylidenetriphenylphosphorane with the Aldehyde (12) generated *in situ*
a) Oxidation of the Diol (11) : To a stirred solution of the diol (**12**) (100 mg, 0.63 mmol) in CH_2Cl_2 (2 ml) were added potassium hydrogen carbonate (127 mg, 1.27 mmol) and lead tetraacetate (309 mg, 0.70 mmol) at 0°C. After stirring for 30 min at the same temperature under argon atmosphere, benzylidenetriphenyl-phosphorane [prepared from benzyltriphenylphosphonium chloride (763 mg, 1.96 mmol) and *n*-butyllithium (1.60 M hexane solution ; 1.15 ml, 1.84 mmol) in THF (7 ml)] was added dropwise at 0°C and stirring was continued further 30 min. After addition of saturated aqueous NH_4Cl solution, the white precipitate was filtered off. Evaporation of the filtrate gave a residue, which was extracted with EtOAc. The combined organic layer was washed with brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave a resiudure, which was purified by column chromatography on silica gel using hexane-EtOAc (6:1, v/v) as eluent. The first fraction gave (6*R*)-6-[(*Z*)-styryl]-5, 6-dihydro-2*H*-pyran-2-one (**14**) (15.6 mg, 12.3%) as a colorless oil. Ir ($CHCl_3$) υ_{max} : 1725 cm^{-1}. ^{1}H-Nmr ($CDCl_3$) δ : 2.40-2.60 (2H, m, 2×5-H), 5.30 (1H, ddd, *J*=5.5, 8.6 and 9.8 Hz, 6-H), 5.83 (1H, dd, *J*=9.8 and 11.6 Hz, C*H*=CHPh), 6.05 (1H, ddd, *J*=1.2, 2.5, and 9.8 Hz, 3-H), 6.77 (1H, d, *J*=11.6 Hz, CH=C*H*Ph), 6.87 (1H, ddd, J=2.5, 4.9, and 9.8 Hz, 4-H), and 7.26-7.40 (5H, m, Ph). Ms (m/z) : Calcd for $C_{13}H_{12}O_2$ (M^+) : 200.0836. Found : 200.0830. *Anal.* Calcd for $C_{13}H_{12}O_2$: C, 77.98 ; H, 6.04. Found : C, 77.49 ; H, 6.03. $[\alpha]_D^{23}$ -310.2° (c 0.44, $CHCl_3$). The second fraction gave

(+)-goniothalamin (**15**) (4 mg, 3.2%) as colorless needles after recrystallization from hexane-Et_2O, mp 82-82.5°C (lit.,[1e] mp 81-82°C). Ms (m/z) : Calcd for $C_{13}H_{12}O_2$ (M^+) : 200.0837. Found : 200.0832. $[\alpha]_D^{23}$ +177.5° (c 0.35, $CHCl_3$) {lit.,[1e] $[\alpha]_D$ +178.5° (c 2, $CHCl_3$)}. Its spectroscopic data were identical with those reported.[1a]

b) Oxidation of the Alcohol (13) : To a stirred solution of oxalyl chloride (50 µl, 0.59 mmol) in CH_2Cl_2 (0.5 ml) was added a solution of dimethyl sulfoxide (60 µl, 0.78 mmol) in CH_2Cl_2 (0.5 ml) at -65°C under argon atmosphere. After stirring for 15 min, the alcohol (**13**) (50 mg, 0.39 mmol) in CH_2Cl_2 (1 ml) was added and stirring was continued for 30 min at the same temperature. Triethylamine (0.27 ml, 1.95 mmol) was added, and the mixture was stirred for further 15 min at the same temperature. Benzylidenetriphenylphosphorane [prepared from benzyltriphenylphosphonium chloride (1.52 g, 3.90 mmol) and *n*-butyllithium (1.58 M hexane solution ; 2.42 ml, 3.70 mmol) in THF (15 ml)] was added dropwise at 0°C, and the mixture was stirred for 30 min at the same temperature. After addition of brine, the organic layer was evaporated. The mixture was extracted with CH_2Cl_2. The combined organic layer was washed with brine and dried over anhydrous Na_2SO_4. Evaporation of the solvent gave a residure, which was purified by column chromatography on silica gel using hexane-EtOAc (6:1, v/v) as eluent. The first fraction gave the (*Z*)-olefin (**14**) (44.2 mg, 57.0%) . The second fraction gave (+)-goniothalamin (**15**) (14.1 mg, 18.0%).

Photoisomerization of the (*Z*)-Olefin (14) : A solution of the (*Z*)-olefin (**14**) (60 mg, 0.30 mmol) and diphenyl disulfide (0.6 mg, 2.70 µmol) in benzene (50 ml) was irradiated with a 400 W high pressure mercury lamp through pyrex filter for 5 h at room temperature under argon atmosphere. Evaporation of the solvent gave a residure, which was purified by column chromatography on silica gel using hexane-EtOAc (6:1, v/v) as eluent. The first fraction gave the starting material (**14**) (19.5 mg, 32.5%). The second fraction gave (+)-goniothalamin (**15**) (38.7 mg, 64.5%).

(-)-Argentilactone (16) : To a stirred solution of oxalyl chloride (50 µl, 0.59 mmol) in CH_2Cl_2 (0.5 ml) was added a solution of dimethyl sulfoxide (60 µl, 0.78 mmol) in CH_2Cl_2 (0.5 ml) at -65°C under argon atmosphere. After stirring for 15 min, the alcohol (**13**) (50 mg, 0.39 mmol) in CH_2Cl_2 (1 ml) was added and stirring was continued for 30 min at the same temperature. Triethylamine (0.27 ml, 1.95 mmol) was added, and the mixture was stirred for further 15 min at the same temperature. Hexylidenetriphenylphosphorane [prepared from *n*-hexyltriphenylphosphonium bromide (1.67 g, 3.90 mmol) and *n*-butyllithium (1.59 M hexane solution ; 2.33 ml, 3.70 mmol) in THF (15 ml)] was added dropwise at 0°C, and the mixture was stirred for 30 min at the same temperature. After addition of brine, the organic layer was evaporated. The mixture was extracted with CH_2Cl_2. The combined organic layer was washed with brine and dried over Na_2SO_4. Evaporation of the solvent gave a residure, which was purified by column chromatography on silica gel using hexane-EtOAc (9:1, v/v) as eluent to afford (-)-argentilactone (**16**) (49.5 mg, 65.0%) as a colorless oil. Ms (m/z) : Calcd for $C_{12}H_{18}O_2$ (M^+) : 194.1305. Found : 194.1302. $[\alpha]_D^{22}$ -22.4° (c 0.23, EtOH) {lit.,[2a] $[\alpha]_D$ -21.1° (c 2.25, EtOH)}. Its spectroscopic data were identical with those reported.[2a]

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