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The First Example of Di-π-Methane Rearrangement in Nature: Cephalotanols A and B, Two Novel Rearranged Norlignan Glycosides from *Cephalotaxus fortunei* Hook

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Abstract: A pair of unique diastereoisomers of norlignan glycosides named cephalotanols A (**1**) and B (**2**), together with two known compounds, have been isolated from the twigs and leaves of *Cephalotaxus fortunei* Hook. Their structures were elucidated by using a combination of spectroscopic techniques and comparison of experimental and calculated electronic circular dichroism (ECD) data. To our knowledge, cephalotanols A and B represent the first rearranged norlignan glycosides with diphenylvinylcyclopropane core found in natural sources, of which biosynthetic pathways originating from co-occurring precursors 3*S*-4′-*O*-*β*-D-glucopyranosylhinokiresinol (**3**) and 3*S*-4′′-*O*-*β*-D-glucopyranosylhinokiresinol (**4**) via di-π-methane rearrangement is proposed.

Keywords: *Cephalotaxus fortunei*; norlignan; diphenylvinylcyclopropane;structural elucidation; di-π -methane rearrangement. © 2022 ACG Publications. All rights reserved.

1. Introduction

Multiphenylvinylcyclopropane systems were photoproducts of multiphenylphentadiene on direct irradiation [1]. Multiphenylvinylcyclopropanes have always been used as reactants and/or intermediate products in metalloenzyme-catalyzed and photocatalytic reactions [2-6]. Hitherto, there is no relevant report about the isolation and biosynthetic pathway of this framework from natural sources.

The genus *Cephalotaxus*, comprising about 50 species around the world, belongs to the tribe Cephalotaxaceae, from which cephalotane-type and abietane diterpenoids, homoerythrina- and cephalotaxine-type alkaloids, flavonoids and lignans are the main metabolites [7-13]. *Cephalotaxus fortunei* Hook. is an endemic evergreen coniferous to China, which was protected as a vulnerable species due to over utilization [14]. As part of a program to search for bioactive molecules from *Cephalotaxus* plants, two novel rearranged norlignan glycosides cephalotanols A (**1**) and B (**2**), along

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with two norlignans (**3** and **4**) were obtained from the twigs and leaves of *C. fortunei* Hook. All compounds were tested for anti-inflammatory activity against LPS-induced NO production in RAW 264.7 macrophages, but all compounds were inactive. Herein, we presented the detailed experimental procedure, structural characterization, and biogenetic hypothesis of these compounds.

Figure 1. Structures of compounds **1**–**4** isolated from *C. fortunei* Hook

2. Materials and Methods

2.1. General Experimental Procedures

Optical rotations were measured on a Rudolph Research Analytical autopol VI automatic polarimeter (Rudolph Research Analytical, NJ, USA). UV data were recorded on a Shimadzu UV-2550 UV-visible spectrophotometer (Shimadzu, Kyoto, Japan). IR spectra were recorded on a Perkin-Elmer 577 spectrometer (Wellesley, MA, USA) with KBr disks. 1D and 2D NMR spectra were recorded on Bruker AM-500 with TMS as internal standard. ESIMS was obtained on a Bruker Daltonics esquire 3000 plus instrument (Bruker Daltonics, Bremen, Germany). HRESIMS was carried out on a LCT Premier XE (Waters) mass spectrometer (Milford, MA, USA). Semi-preparative HPLC was performed on a Waters 1525 pump and a YMC-Pack ODS-A column (250 × 10 mm, S-5 µm, 12 nm, Japan). Silica gel (300–400 mesh) was used for normal phase column chromatography. C_{18} reversed-phase silica gel (150–200 mesh, Merck), Sephadex LH-20 (Amersham Biosciences) were used for reversed-phase column chromatography. Precoated silica gel GF_{254} plates (Qingdao Marine Chemical Plant, Qingdao, China) were used for TLC experiment, and spots were detected by spraying with 10% H_2SO_4 in EtOH by heating. Standard sugar of D-glucose for optical analysis was purchased from J&K Scientific Ltd., China.

2.2. Plant Material

The twigs and leaves of *C. fortunei* Hook. were collected from Qingyuan, Zhejiang province of China. A voucher sample (No. JiaXu1906) was deposited in College of Pharmacy, Jiaxing University.

2.3. Extraction and Isolation

The air-dried powders of the twigs and leaves of *C. fortunei* Hook. (1 kg) were extracted with 95% EtOH for three times at ambient temperature. The crude extract (60 g) was extracted with EtOAc/H_2O soluble system resulting in crude EtOAc extract (23 g). The crude EtOAc extract was subjected to silica gel column chromatography and eluted with petroleum ether/acetone (20:1–1:1) to yield four fractions (A–D). Fraction D (4 g) was separated using C_{18} reversed-phase silica

(MeOH/H_2O, 30–90%) to give three fractions, D1–D3. D1 (1.1 g) was further separated using silica gel column chromatography ($CHCl_3$/MeOH, 50:1–5:1) to give four fractions, D1a–D1d. D1c2 (0.55 g) was chromatographed over C_{18} reversed-phase silica and LH-20 to give D1a2a-1 (0.08 g). Mixture of **1** and **2** (8 mg), and mixture of **3** and **4** (9 mg) were obtained from fraction D2c2a by semipreparative HPLC using an eluent of 30% CH_3OH/H_2O. Compounds **1** (3 mg) and **2** (3 mg) were further purified by semipreparative HPLC using an eluent of 23% CH_3CN/H_2O.

*Cephalotanol A (**1**):* colorless oil; $[\alpha]^{20}_{D}$ −25 (*c* 0.10, MeOH); UV (MeOH) λ_{max} (log ε) 207 (4.05) and 228 (3.97) nm; ECD (*c* 0.1, MeOH) λ_{max} ($\Delta\varepsilon$) 205 (−14.5), 213 (+4.4), 229 (−5.5) nm; ^1H and ^{13}C NMR, see Table 1; HRESIMS (negative-ion mode) *m/z* 413.1599 $[M - H]^-$ (calcd. 413.1600).

*Cephalotanol B (**2**):* colorless oil; $[\alpha]^{21}_{D}$ −31 (*c* 0.10, MeOH); UV (MeOH) λ_{max} (log ε) 207 (4.05) and 228 (3.97) nm; ECD (*c* 0.1, MeOH) λ_{max} ($\Delta\varepsilon$) 209 (−13.0), 222 (−10.3) nm; ^1H and ^{13}C NMR, see Table 1; HRESIMS (negative-ion mode) *m/z* 413.1599 $[M - H]^-$ (calcd. 413.1600).

2.4. NO Production Inhibitory Assay

The RAW 264.7 macrophages were seeded in 96-well plates with 1×10^4 cells/well and allowed to adhere for 6 h at 37 °C in a humidified atmosphere containing 5% CO_2. After that the RAW 264.7 macrophages were pretreated with compounds for 2 h, followed by 1 mg/L LPS for 24 h. Aminoguanidine was used as a positive control. NO production in the cell culture medium was determined by using a commercially available kit (Beyotime, Haimen, China). Nitrite production was measured at OD 550. Percent inhibition was calculated using the following equation: % inhibition = $(A - B)/(A - C) \times 100$, where A = LPS (+), sample (−); B = LPS (+), sample (+); and C = LPS (−), sample (−).

2.5. Enzymatic Hydrolysis and Absolute Configuration Determination of the Monosaccharide

Compounds **1** and **2** (2.0 mg each) were dissolved in water (2.0 mL), and β-cellulase (5.0 mg) was added to the solution. The reaction temperature was kept at 37 °C for 48 h. After incubation, the reaction mixtures were extracted with EtOAc, and the aqueous layers were compared with an authentic sugar standard by TLC (CH_3OH : H_2O = 5 : 1, R_f value of 0.7 for glucose). The liberated sugar was identified as D-glucose by comparing its optical rotation value ($[\alpha]^{20}_{D}$ +44 for **1**; $[\alpha]^{20}_{D}$ +37 for **2**) with that of an authentic sample of D-glucose ($[\alpha]^{20}_{D}$ +56).

3. Results and Discussion

3.1. Structure Elucidation

Cephalotanol A (**1**) had a molecular formula of $C_{23}H_{26}O_7$ with 11 degrees of unsaturation as determined by the negative mode HR-ESIMS (*m/z* 413.1599 $[M - H]^-$, calcd for $C_{23}H_{25}O_7$ 413.1600). The ^1H and ^{13}C NMR spectra (Table 1) of **1** exhibited signals due to two para-disubstituted aromatic rings [$\delta_{H-2,6}$ 6.79 (d, 2H, *J* = 8.5 Hz); $\delta_{H-3,5}$ 6.54 (d, 2H, *J* = 8.5 Hz); $\delta_{H-2',3',5',6'}$ 6.86 (s, 4H); δ_{C-1} 128.0, δ_{C-2} 129.7, δ_{C-3} 114.2, δ_{C-4} 155.1, δ_{C-5} 114.2, δ_{C-6} 129.7, $\delta_{C-1'}$ 131.6, $\delta_{C-2'}$ 129.3, $\delta_{C-3'}$ 115.5, $\delta_{C-4'}$ 155.9, $\delta_{C-5'}$ 115.5, and $\delta_{C-6'}$ 129.3], a vinyl group [δ_{H-8} 5.80 (ddd, *J* = 17.0, 10.3, 8.1 Hz); δ_{H-9a} 5.28 (dd, *J* = 17.0, 1.5 Hz); δ_{H-9b} 5.02 (dd, *J* = 10.3, 1.5 Hz); δ_{C-8} 140.5 and δ_{C-9} 111.7], a β-glucopyranosyl group, and three methines. The functionalities above accounted for 10 degrees of unsaturation, and the remaining one attributed to a cyclopropane. Based on the information above, compound **1** was deduced to be a glucoside of diphenylvinylcyclopropane.

Analysis of ^1H-^1H COSY spectrum for **1** established the key fragment **a** based on the correlations of H_2-9 (δ_H 5.28 and 5.02) via H-8 (δ_H 5.80) to H-8′ (δ_H 2.29), H-8′ via H-7 (δ_H 2.41) to H-7′ (δ_H 2.43) (Figure 2A). In the HMBC spectrum (Figure 2A), the two phenyls were located at C-7 and C-7′, respectively, which was determined by the HMBC correlations of H-2′(6′)/C-7′ and H-2(6)/C-7. The

glycosidic linkage is hard to determine by HMBC due to the very closely chemical shifts of C-4′ and C-4″ (δ_C 155.1 and 155.9). However, the correlations between the anomeric hydrogen of the glucopyranosyl and the H-3′, 5′ could be observed in the ROESY spectrum, which suggested that the glucopyranosyl should be fixed at C-4′. Its absolute configuration was determined as D-glycopyranosyl by comparing the optical rotation of enzymatic hydrolysate of **1** ($[\alpha]^{20}_D$ +44) with that of the authentic glucose sample ($[\alpha]^{20}_D$ +56). The spin-spin coupling constants of H-8′/H-7′ (*J* = 5.5 Hz), H-8′/H-7 (*J* = 5.5 Hz), and H-7/H-7′(*J* = 9.5 Hz) suggested **1** to be 7-*trans*-7′-*trans*-diphenylvinylcyclopropane [15], which was further confirmed by the ROESY correlations of H-7/H-8, H-7′/H-8, H-8′/H-2(6), and H-8′/H-2′(6′) (Figure 2B). Thus, the relative structure of **1** was determined as shown.

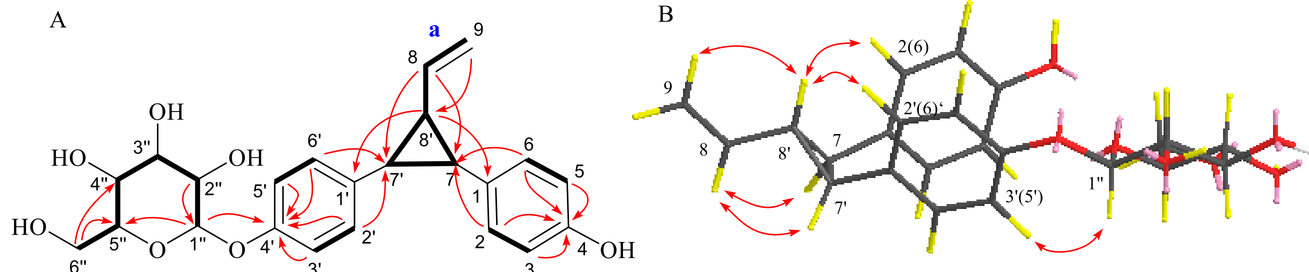

Figure 2. (A) Key ^{1}H • ^{1}H COSY (bold •), HMBC (H→C) of **1**. (B) Selected ROESY (H↔H) correlations of **1**.

Table 1. NMR Spectroscopic Data (^{1}H 500 MHz, ^{13}C 125 MHz, CD_3OD) for **1** and **2**

position	**1**		**2**	
	• H, mult	**• C, mult**	**• H, mult**	**• C, mult**
1		128.0, C		128.1, C
2	6.79, d (8.5)	129.7, CH	6.78, d (8.5)	129.6, CH
3	6.54, d (8.5)	114.2, CH	6.54, d (8.5)	114.2, CH
4		155.1, C		155.1, C
5	6.54, d (8.5)	114.2, CH	6.54, d (8.5)	114.2, CH
6	6.79, d (8.5)	129.7, CH	6.78, d (8.5)	129.6, CH
7	2.41, dd (9.5, 5.5)	31.8, CH	2.41, dd (9.5, 5.5)	31.7, CH
8	5.80, ddd (17.0, 10.3, 8.1)	140.5, CH	5.79, ddd (17.0, 10.3, 8.1)	140.5, CH
9	a 5.28, dd (17.0, 1.5) b 5.02, dd (10.3, 1.5)	111.7, CH_2	a 5.28, dd (17.0, 1.5) b 5.02, dd (10.3, 1.5)	111.7, CH_2
1 •		131.6, C		131.6, C
2 •	6.86, s	129.3, CH	6.87, s	129.4, CH
3 •	6.86, s	115.5, CH	6.87, s	115.6, CH
4 •		155.9, C		155.9, C
5 •	6.86, s	115.5, CH	6.87, s	115.6, CH
6 •	6.86, s	129.3, CH	6.87, s	129.4, CH
7 •	2.43, dd (9.5, 5.5)	31.5, CH	2.43, dd (9.5, 5.5)	31.5, CH
8 •	2.29, ddd (8.1, 5.5, 5.5)	28.8, CH	2.28, ddd (8.1, 5.5, 5.5)	28.9, CH
1 • •	4.81, d (7.3)	100.9, CH	4.81, d (7.3)	101.0, CH
2 • •	3.43, m	73.5, CH	3.43, m	73.5, CH
3 • •	3.44, m	76.5, CH	3.44, m	76.5, CH
4 • •	3.39, m	69.9, CH	3.39, m	69.9, CH
5 • •	3.40, m	76.6, CH	3.40, m	76.6, CH
6 • •	a 3.88, dd (12.0, 1.9) b 3.69, dd (12.0, 5.1)	61.1, CH_2	a 3.88, dd (12.0, 1.9) b 3.69, dd (12.0, 5.1)	61.1, CH_2

The first example of di-π-methane rearrangement in nature.

Compound **2** gave a same molecular formula $C_{23}H_{26}O_7$ by its HR-ESIMS (*m/z* 413.1599 [M – H]$^-$, calcd for $C_{23}H_{25}O_7$ 413.1600). When comparing the ^{1}H and ^{13}C NMR spectra of **2** and **1**, they give highly coincident NMR data, which indicates that compound **2** was the isomers of **1**. Their subtle differences were observed in the aromatic region of ^{1}H NMR and ^{13}C NMR spectra by compared with those of mixture (Figure 3 and 4) prior to separation. The ROESY correlations between the anomeric hydrogen of the glucopyranosyl and the H-3′, 5′ also indicated the location of glucopyranosyl at C-4′. In addition, the almost consistent ROESY spectra of **2** and **1** further provided that these two compounds were a pair of diastereoisomers.

Based on the analysis above, **1** and **2** possessed the same axisymmetric structural core of 7-*trans*-7′-*trans*-diphenylvinylcyclopropane with two stereocenters at C-7 and C-7′. The subtle NMR difference between **1** and **2** mainly resulted from the glycosidic linkage position, which arise only two possibilities of (7*R*,7′*S*,8′*R*) and (7*S*,7′*R*,8′*S*) for their structures. The structures of **1** and **2** were determined by comparing the experimental ECD spectra with the quantum chemical ECD calculations in Gaussian 09 software. The theoretically calculated ECD curve of (7*R*,7′*S*,8′*R*)-4′-*O*-*β*-D-glucopyranosyl-diphenylvinylcyclopropane and (7*S*,7′*R*,8′*S*)-4′-*O*-*β*-D-glucopyranosyl-diphenylvinyl-cyclopropane were in good agreement with the experimental ECD spectra of **1** and **2** (Figure 5), respectively. Due to the influence of glucopyranosyl moiety, experimental and theoretical ECD curves of **1** and **2** did not show in an opposite manner. Consequently, the structures of **1** and **2** were identified as depicted and named cephalotanols A and B, respectively.

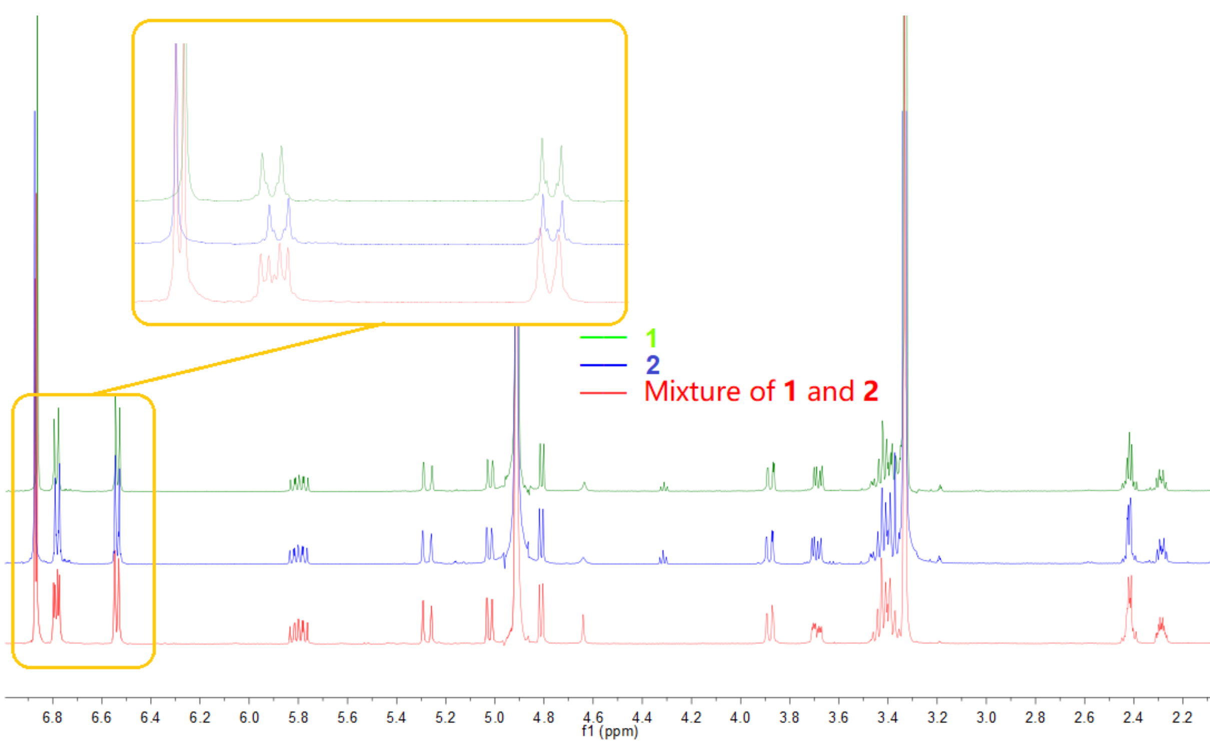

Figure 3. ^{1}H NMR spectra of **1**, **2**, and mixture of **1** and **2**

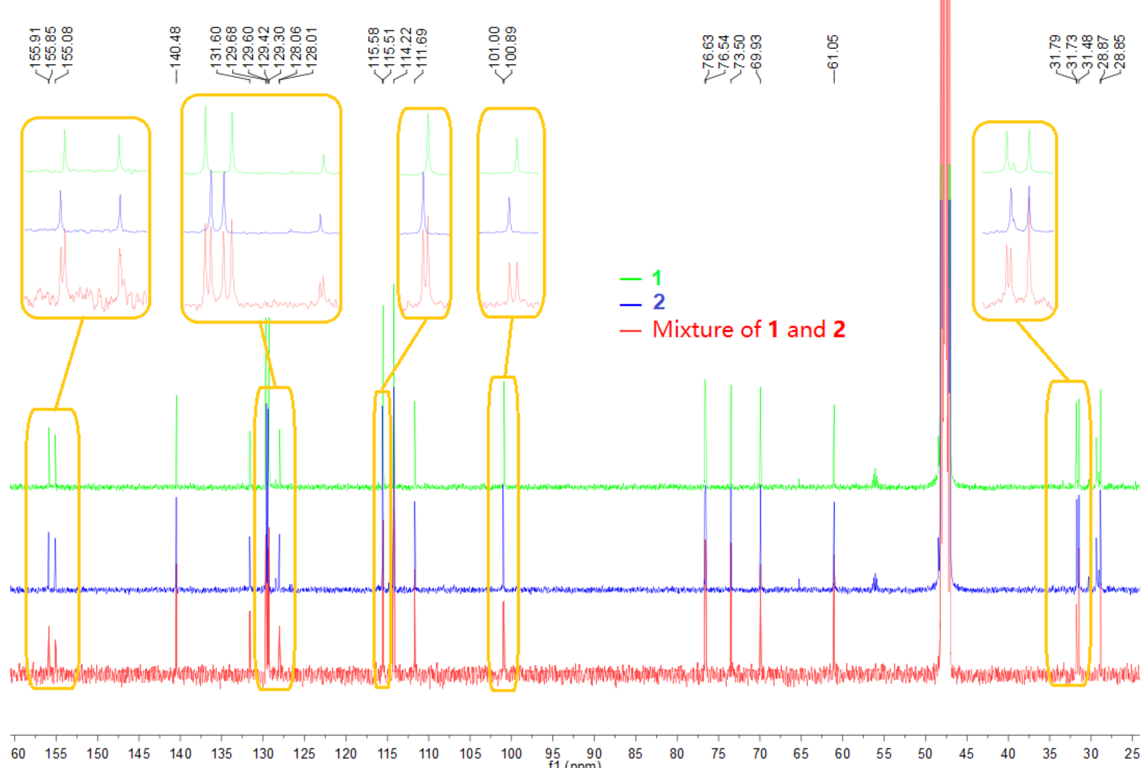

Figure 4. ^{13}C NMR spectra of **1**, **2**, and mixture of **1** and **2**

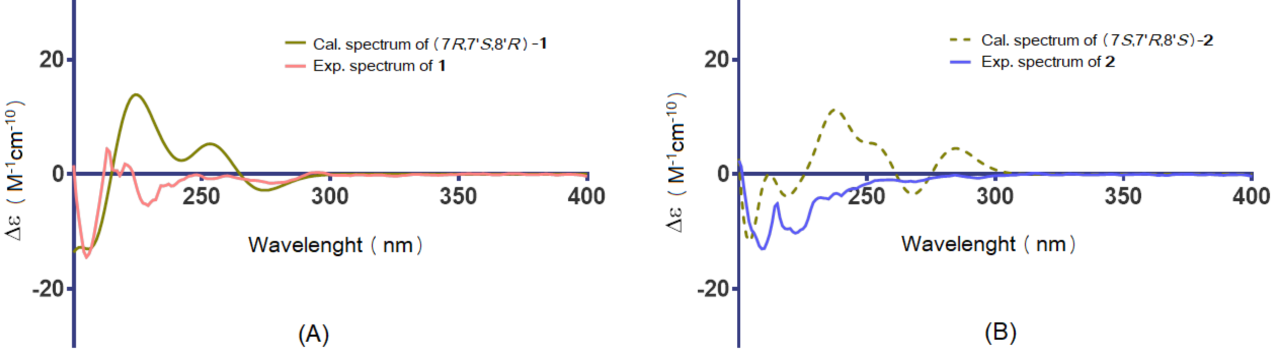

Figure 5. Experimental ECD spectra of **1** (A) and **2** (B) in MeOH and the calculated ECD spectra of the model molecules at the b3lyp/6–31 + g(d, p) level in MeOH.

Two known norlignans, 3*S*-4′-*O*-*β*-D-glucopyranosylhinokiresinol (**3**) and 3*S*-4′′-*O*-*β*-D-glucopyranosylhinokiresinol (**4**) [16] were also isolated, which were determined by comparison of their ESIMS and NMR data with literature data. All compounds were evaluated for anti-inflammatory activity against LPS-induced NO production in RAW 264.7 macrophages, but all compounds were inactive.

3.2. Biosynthetic pathway of Cephalotanols A (1) and B (2)

According to the unique structural architecture of diphenylvinylcyclopropane in **1** and **2**, the plausible biosynthetic pathway is proposed in Scheme 1. The biosynthetic precursors are traced to two co-exsiting known norlignans, 3*S*-4′-*O*-*β*-D-glucopyranosylhinokiresinol (**3**) and 3*S*-4′′-*O*-*β*-D-

glucopyranosylhinokiresinol (**4**). Di-π-methane rearrangement of diphenylpentadienes **3** and **4** under irradiation might afford diphenylvinylcyclopropane products **1** and **2** [1,17–20]. Compounds **3** and **4** undergo a $2_{\pi} + 2_{\pi}$ cycloaddition of the vinyl group with the *ipso*-C-8′ bond of the styryl to yield the cyclopropyldicarbinyl diradical intermediate **i**. There are two possible bond cleavage for the intermediate **i**. The opening ring of intermediate **i** proceeds preferentially by pathway **a** to produce the double benzylic radical, intermediate **ii**, which is more stable than benzylic radical and primary radical, intermediate **iii**. Intermediate **ii** subsequently gave **1** and **2** by cycloaddition.

	R_1	R_2
1 and **3**	Glc	H
2 and **4**	H	Glc

Scheme 1. Plausible biosynthetic pathways for compounds **1** and **2**

4. Conclusion

Multiphenylvinylcyclopropanes as photoproducts are used in metalloenzyme-catalyzed and photocatalytic reactions. The discovery of diphenylvinylcyclopropane derivatives and their precursors provide irrefutable evidence for the natural existence of such skeleton and their origin from lignan by photochemical reaction. In this study, a pair of diastereoisomers of norlignan glycoside named cephalotanols A (**1**) and B (**2**), together with their precursors 3*S*-4′-*O*-*β*-D-glucopyranosylhinokiresinol (**3**) and 3*S*-4″-*O*-*β*-D-glucopyranosylhinokiresinol (**4**) were isolated from *C. fortunei* Hook. Their structures and absolute configurations were elucidated by spectroscopic data and calculated ECD analyses. This work not only enriched the chemical constituents of the *Cephalotaxus* plants, but also provided a clue for clarifying the plant classification basis on homologous structures.

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Supporting Information

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References

[1] H.E. Zimmerman and M.J. Zuraw (1989). Photochemistry in a box. Photochemical reactions of molecules entrapped in crystal lattices: Mechanistic and exploratory organic photochemistry, *J. Am. Chem. Soc.* **111**, 7974・7989.

[2] A. Kapat, T. Sperger, S. Guven and F. Schoenebeck (2019). *E*-Olefins through intramolecular radical relocation, *Science* **363**, 391–396.

[3] S.O. Scholz, E.P. Farney, S. Kim, D.M. Bates and T.P. Yoon (2016). Spin-selective generation of triplet nitrenes: Olefin aziridination through visible-light photosensitization of azidoformates, *Angew. Chem. Int. Ed*. **55**, 2239・2242.

[4] Z.J. He, C.S. Yi and W.A. Donaldson (2004). Ruthenium-catalyzed hydrovinylation of dienoates:model studies directed toward the C10-C18 segment of ambruticin, *Synlett* **7**, 1312–1314.

[5] P. Müller, Baud, C. Baud and Y. Jacquier (1998). The rhodium(II)-catalyzed aziridination of olefins with {[(4-nitrophenyl)sulfonyl]imino}phenyl-lambda(3)-iodane, *Can. J. Chem*. **76**, 738・750.

[6] I. Nageli, C. Baud, G. Bernardinelli, Y. Jacquier and M. Moraon, P. Mullet(1997). Rhodium(II)-catalyzed CH insertions with {[(4-nitrophenyl)sulfonyl]imino}phenyl-lambda(3)-iodane, *Helv. Chim. Acta*. **80**, 1087・1105.

[7] Y.X. Cai, X.Y. Xie, Q.Q. Zhou, X. Huang and J.B Xu (2022). Two novel cephalotaxine-type alkaloids from *Cephalotaxus sinensis*, *Chin. J. Chin. Mater. Med*. **47**, 302・307.

[8] C.Y. Jiang, J.J. Xue, Y.Z Yuan, Y.Z. Li, C.X. Zhao, Q.X. Jing, X. Zhang, M.Y. Yang, T. Han, J. Bai, Z.L. Li, D.H. Li and H.M. Hua (2021). Progress in structure, synthesis and biological activity of natural cephalotane diterpenoids, *Phytochemistry* **192**, 112939.

[9] D.C. Hao, X.D. Hou, X.J Gu, P.G. Xiao, G.B. Ge (2021). Ethnopharmacology, chemodiversity, and bioactivity of *Cephalotaxus* medicinal plants, *Chin. J. Nat. Med*. **19**, 321・338.

[10] Z.P. Ge, Y.Y. Fan, W.D. Deng, C.Y. Zheng, T. Li and J.M. Yue (2021). Cephalodiones A-D: compound characterization and semisynthesis by [6+6] cycloaddition, *Angew. Chem. Int. Ed.* **60**, 9374–9378.

[11] L. Zhu, D.R. Zhu, W.X. Zhou, J.M. Zhu, L.J. Gong, Y. Li, L.Y. Kong and J.G. Luo (2021). Fortuneicyclidins A and B, pyrrolizidine alkaloids with a 7-azatetracyclo[5.4.3.0.0(2,8)] tridecane core, from *Cephalotaxus fortunei*, *Org. Lett*. **23**, 2807−2810.

[12] L. Zhu, L.J. Gong, D.R. Zhu, J.M. Zhu, Y. Li, L.Y. Kong and J.G. Luo (2021). Cephalotaxine-type alkaloids from the seeds of *Cephalotaxus fortunei* and their cytotoxic activities, *Phytochemistry* **191**, 112903.

[13] H. Abdelkafi, B. Nay (2012). Natural products from *Cephalotaxus* sp: chemical diversity and synthetic aspects, *Nat. Prod. Rep*. **29**, 845–869.

[14] D.J. Yu, Z.Y. Wu and H.B. Cui (1978). In Flora Republicae Popularis Sinicae (*Zhongguo Zhiwu Zhi*). **17**, 426–427.

[15] M. Balci (2005). Spin-spin splitting in 1H-NMR spectra. Basic ^{1}H- and ^{13}C-NMR spectroscopy, *Elsevier Science* Chapter **4**, 118.

[16] F.C. Meng, H. Liu, X.J. Huang, Y. Chang, D. Ren, L.G. Lin, Q.Q. Zeng and Q.W. Zhang (2017). Four new norlignan glycoside isomers from the twigs of *Cephalotaxus oliveri* Mast. *Tetrahedron Asymm*. **28**, 1686–1689.

[17] S.S. Hixson, P.S. Mariano and H.E. Zimmerman (1973). The di-・-methane and oxa-di-・-methane rearrangements, *Chem. Rev.* **73**, 531–551.

[18] H.E. Zimmerman and D. Armesto (1996). Synthetic aspects of the di-・-methane rearrangement, *Chem. Rev.* **96**, 3065・3112.

[19] R.Altundas and M.Balci (1997). The di-p-methane photorearrangement of 2,3-disubstituted benzobarrelenes: the effect of substituents of opposite polarity on the regioselectivity, *Aust. J. Chem*. **50**, 787.

[20] R. Altundas, A. Dastan, N.S. Ünaldi, K. Güven, O. Uzun and M. Balci (2002). The di-・-methane photorearrangement of 2,3-disubstituted benzobarrelenes and benzonorbornadiene ・ substituent effects in regioselectivity, *Eur. J. Org. Chem.* **2002**, 526・533.

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