Phytochemical Studies on *Stemona aphylla*: Isolation of a New Stemofoline Alkaloid and Six New Stemofurans

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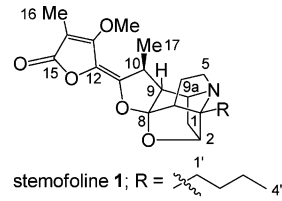
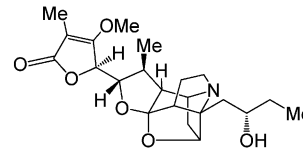
A new stemofoline alkaloid, (2′*S*)-hydroxy-(11*S*,12*R*)-dihydrostemofoline (**3**), new stemofurans M−R (**8**−**13**), and known compounds stemofoline (**1**), (2′*S*)-hydroxystemofoline (**2**), stemofuran E (**4**), stemofuran F (**5**), stemofuran J (**6**), and stilbostemin F (**7**) have been isolated from the root extracts of *Stemona aphylla*. The structures and relative configurations of these new compounds have been determined by spectroscopic data interpretation and from semisynthetic studies. These natural and semisynthetic alkaloids were tested for acetylcholinesterase inhibitory activities and were found to be 10−20 times less active than 1′,2′-didehydrostemofoline itself. Stemofurans **4**, **6**, **8**, **11**, and **13** were tested for their antibacterial and antifungal activities. Three of these showed antibacterial activities against MRSA with MIC values of 15.6 μg/mL.

The *Stemona* family of alkaloids has been structurally classified by Pilli into eight different groups.[1] The pyrrolo[1,2-*a*]azepine nucleus is common to all compounds in six of these groups, while a pyrido[1,2-*a*]azepine ring system is found in the stemocurtisine group of *Stemona* alkaloids.[1−10] A miscellaneous group comprising five *Stemona* alkaloids has also been identified.[1] Greger has classified the *Stemona* alkaloids into three skeletal types based on their proposed biosynthetic origins.[2] Recently, a new structural type of *Stemona* alkaloid was identified with the isolation of two alkaloids from *Stemona sessilifolia* (Miq.) (Stemonaceae) having an unusual pyrido[1,2-*a*]azonine nucleus.[11] The pure alkaloids derived from the extracts of the leaves and roots of *Stemona* species have insect toxicity, antifeedent and repellent activities,[1,4,5,12−14] and antitussive activities.[15] The antifungal properties of these extracts, however, are due to stilbenoid molecules that include substituted 2-phenylbenzofuran compounds (stemofurans A−K).[16] We report here the isolation and structure determination of the novel stemofoline alkaloid (2′*S*)-hydroxy-(11*S*,12*R*)-dihydrostemofoline (**3**), novel 2-phenylbenzofurans, stemofurans M−R (**8**−**13**), known alkaloids (**1** and **2**), and known stilbenoids (stemofurans E, F, and J and stilbostemin F) from root extracts of *Stemona aphylla*. Studies of the activity of alkaloids **1**−**3** and two analogues against AChE and the antibacterial and antifungal activities of five of the stemofurans are also reported.

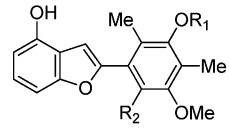


stemofoline **1**; R =

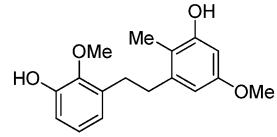
(2′*S*)-hydroxystemofoline **2**; R =



(2′*S*)-hydroxy-(11*S*,12*R*)-dihydrostemofoline **3**



stemofuran E **4**; R_1=H, R_2=H
stemofuran F **5**; R_1=H, R_2=Me
stemofuran J **6**; R_1=Me, R_2=H



stilbostemin F **7**

Results and Discussion

The roots of *S. aphylla* were collected in Lampang Province, Thailand, in April 2009 at a location different from that of our previous study on this plant species.[17] An ethanol extract (100.0 g) of the roots was partitioned between 50% aqueous MeOH and CH_2Cl_2 to yield 8.86 g of CH_2Cl_2 extract. Successive separations of 4.0 g of the crude material by column chromatography (CC), and in some cases preparative TLC or LC, gave the known alkaloids stemofoline (**1**) (395.0 mg) and (2′*S*)-hydroxystemofoline (**2**) (70.0 mg) and the new alkaloid (2′*S*)-hydroxy-(11*S*,12*R*)-dihydrostemofoline (**3**) (14.0 mg). Known phenylbenzofurans, stemofuran E (**4**) (13.2 mg), stemofuran F (**5**) (1.8 mg), and stemofuran J (**6**) (33.9 mg), the known dihydrostilbene stilbostemin F (**7**) (0.8 mg), and six new phenylbenzofurans, stemofuran M (**8**) (6.4 mg), stemofuran N (**9**) (0.9 mg), stemofuran O (**10**) (0.6 mg), stemofuran P (**11**) (5.8 mg), stemofuran Q (**12**) (2.0 mg), and stemofuran R (**13**) (12.8 mg), were also isolated (Figure 1). The two known alkaloids and the four known stilbenoids were identified by comparison of their spectroscopic/spectrometric data (NMR and MS) with those reported.[12,18,19]

The HRESIMS (*m*/*z* 406.2216 $[MH]^+$, calcd 406.2230) of **3** showed that it had the molecular formula $C_{22}H_{32}NO_6$, consistent with a dihydro derivative of **2**. The ^1H and ^{13}C NMR spectra of **3** indicated the presence of the polycyclic ring system of stemofoline (**1**)[11,16] and an OH group at C-2′ similar to that of (2′*S*)-

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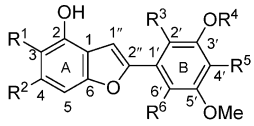
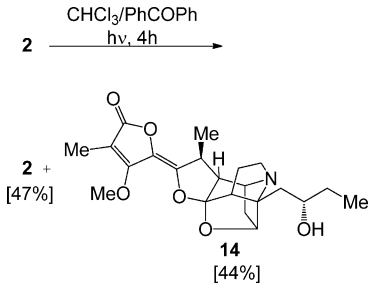


stemofuran M **8**; R^1=H, R^2=OMe, R^3=Me, R^4=H, R^5=H, R^6=H
stemofuran N **9**; R^1=H, R^2=OMe, R^3=H, R^4=Me, R^5=H, R^6=H
stemofuran O **10**; R^1=H, R^2=H, R^3=Me, R^4=Me, R^5=Me, R^6=Me
stemofuran P **11**; R^1=H, R^2=OMe, R^3=Me, R^4=Me, R^5=H, R^6=H
stemofuran Q **12**; R^1=Me, R^2=OMe, R^3=Me, R^4=H, R^5=H, R^6=H
stemofuran R **13**; R^1=H, R^2=OMe, R^3=Me, R^4=Me, R^5=Me, R^6=H

Figure 1. New stemofurans **8**−**13** (compound numbering is based on that proposed by Greger[16]).

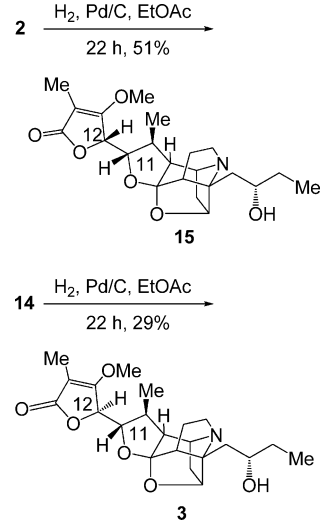
Scheme 1



hydroxystemofoline (**2**).[11] However, comparison of the ^{13}C/DEPT NMR spectra of **3** with that of **2** showed that C-11 and C-12 in **3** were methine carbons rather than quaternary carbons as seen in **2**. The ^{1}H NMR spectrum of **3** showed two mutually coupled methine proton signals at δ 3.78 (dd, $J_{10,11}$ = 9.0 Hz, $J_{11,12}$ = 2.5 Hz, H-11) and δ 4.58 (br s, $W_{1/2}$ = 2.5 Hz, H-12), which also indicated that compound **3** was an 11,12-dihydrostemofoline. NOESY experiments showed a significant cross-peak between the C-10 methyl protons (H-17) and H-11, indicating their *syn* stereochemical relationship. Thus, assuming that **3** had the same absolute configuration as stemofoline (**1**) in rings A−C, we assigned the 11*S* configuration to compound **3**. This configuration was later confirmed by semisynthesis of **3** from **2** in two steps. NMR experiments on **3**, however, did not permit assignment of the configuration at C-12. In 2004, Mungkornasawakul[14] reported the isolation of (11*S*,12*R*)-dihydrostemofoline from *Stemona burkillii* Prain and the semisynthesis of (11*S*,12*S*)-dihydrostemofoline by hydrogenation of stemofoline (**1**). The ^{1}H and ^{13}C NMR spectra of these compounds were similar but not identical. Indeed, there was a significant difference in the chemical shifts and coupling constants for the signals of H-11 and H-12 in the ^{1}H NMR spectra of these two compounds, especially $J_{11,12}$, which was 3 Hz in (11*S*,12*R*)-dihydrostemofoline and 7 Hz in (11*S*,12*S*)-dihydrostemofoline. On the basis of these differences we assigned the 12*R* configuration to **3**. The 2′*S* configuration of **3** was determined by its semisynthesis from **2**, as outlined in Scheme 1. The *Z* to *E* isomerization of compound **2** by exposure to irradiation from a 500 W sun lamp for 4 h in chloroform solution and acetophenone gave a 1:1 mixture of **2** and **14**, which were separated by CC in yields of 47% and 44%, respectively (Scheme 1). Hydrogenation of **2** over Pd/C in EtOAc provided the (11*S*,12*S*)-dihydrostemofoline derivative **15** (d, $J_{11,12}$ = 6.5 Hz), while that of **14** gave the natural product **3** (Scheme 2). On the basis of a comparison of the ^{1}H and ^{13}C NMR chemical shifts with those of the synthesized compounds, alkaloid **3** was assigned as (2′*S*)-hydroxy-(11*S*,12*R*)-dihydrostemofoline. The complete ^{1}H and ^{13}C NMR assignments for **3** and **15** based on extensive COSY, NOESY, HSQC, and HMBC experiments are shown in Table S2−S4 of the Supporting Information.

The benzofurans **8**−**13** were characterized by two independent aromatic systems separated by the furan ring of the benzofuran moiety. The connectivities of the directly coupled protons were determined using H/H-COSY experiments, and the positions of

Scheme 2



methyl and methoxy groups in ring A or methyl and methoxy groups in ring B were elucidated by NOESY experiments (summarized in Table S1, Supporting Information). HSQC and HMBC experiments confirmed the assignments of the structures and allowed assignment of the quaternary carbon atoms in the ^{13}C NMR spectra (see Supporting Information). The molecular formulas of compounds **8**−**13** were determined by HRESIMS.

Compound **8** had the molecular formula $C_{17}H_{16}O_5$. The ^{1}H NMR spectrum showed resonances for three benzofuran protons at δ 7.01 (s, 1H, H-1″), 6.69 (br s, 1H, H-5), and 6.35 (d, J = 1.5 Hz, 1H, H-3), an OH at δ 8.73 (br s, 1H, 2-OH), and a methoxy group at δ 3.82 (s, 3H, 4-O-CH_3). The *meta*-like coupling between the aromatic protons H-3 and H-5 and the NOESY correlations between both of these aromatic proton resonances and the C-4 methoxy group confirmed the benzofuran moiety. The substituted phenyl group of **8** showed two aromatic proton signals [δ 6.88 (d, J = 2.5 Hz, 1H, H-6′) and 6.53 (d, J = 2.5 Hz, 1H, H-4′)], an aromatic methyl resonance at δ 2.35 (s, 3H, 2′-CH_3), an OH resonance at δ 8.73 (br s, 1H, 3′-OH), and an OCH_3 signal at δ 3.79 (s, 3H, 5′-OCH_3). The *meta*-like coupling between the aromatic protons H-4′ and H-6′ and the NOESY correlations between both of these aromatic resonances and the C-5′ OCH_3 group and between H-1″ and the C-2′ methyl substituent confirmed the structural assignment of the substituted phenyl moiety.

Compound **9** had the molecular formula $C_{17}H_{16}O_5$. The ^{1}H NMR spectrum showed resonances for three benzofuran protons, an OH, and an OCH_3. This NMR pattern indicated compounds **8** and **9** had the same benzofuran ring structures. The substituted phenyl group of **9** showed three singlet aromatic proton signals [δ 7.01 (s, 2H, 2′-H and 6′-H) and 6.67 (s, 1H, 4′-H)] and a signal for two OCH_3 groups at δ 3.87 (3′ and 5′). The NOESY correlations between H-1″ and both H-2′ and H-6′ indicated that the latter two protons occupied *ortho* positions relative to the benzofuran substituent on the phenyl ring.

The NMR spectra of compound **10** ($C_{19}H_{20}O_4$) indicated that compounds **6** and **10** had the same benzofuran ring structures. The fully substituted symmetrical phenyl group of **10** showed aromatic methyl group signals at δ 2.27 (s, 3H, 4′-CH_3) and 2.10 (s, 6H, 2′-CH_3 and 6′-CH_3) and resonances for two identical OCH_3 groups at δ 3.72 (3′ and 5′). The NOESY correlation between H-1″ and the two identical methyl groups at δ 2.10 indicated that they were at C-2′ and C-6′. The OCH_3 groups were at C-3′ and C-5′, evident from NOESY correlations to the C-2′, C-4′, and C-6′ methyl groups.

The HRESIMS of compound **11** indicated a molecular formula of $C_{18}H_{18}O_5$. The ^{1}H NMR spectrum showed resonances for three benzofuran protons, an OH at δ 8.98 (br s, 1H, 2-OH), and an OCH_3 at δ 3.82 (s, 3H, 4-O-CH_3). This NMR pattern indicated

Table 1. Minimum Amount of Sample Found to Inhibit AChE As Indicated by a White Zone of Inhibition

	minimum inhibitory requirement	
compound	ng	nmol
galanthamine	1	0.003
1′,2′-didehydrostemofoline	5	0.012
1	10	0.026
2	10	0.025
3	50	0.123
14	10	0.025
15	100	0.247

that compounds **8**, **9**, and **11** had the same benzofuran ring structures. The substituted phenyl group of **11** showed aromatic proton signals at δ 6.92 (d, J = 2.0 Hz, 1H, H-6′) and 6.49 (d, J = 2.0 Hz, 1H, H-4′), an aromatic methyl resonance at δ 2.31 (s, 3H, 2′-CH_3), and two OCH_3 signals at δ 3.87 (3′) and 3.84 (5′). NOESY correlations between 2′-CH_3 and both H-1″ and the 3′-OCH_3 indicated that compound **11** was the C-2′ methyl analogue of compound **9**.

Compound **12** had the molecular formula $C_{18}H_{18}O_5$. The ^{1}H NMR spectrum showed benzofuran protons at δ 7.13 (s, 1H, H-1″) and 6.76 (s, 1H, H-5), an OH resonance at δ 8.47 (br s, 1H, 2-OH), a methyl resonance at δ 2.15 (s, 3H, 3-CH_3), and a methoxy signal at δ 3.89 (s, 3H, 4-OCH_3). The NOESY correlations for the benzofuran ring between the 3-CH_3 and both the 2-OH and 4-O-CH_3 indicated that compound **12** was the C-3 methyl analogue of compound **8**. The substituted phenyl group of **12** showed aromatic proton signals at δ 6.89 (d, J = 2.5 Hz, 1H, H-6′) and 6.52 (d, J = 2.5 Hz, 1H, H-4′), an aromatic methyl resonance at δ 2.34 (s, 3H, 2′-CH_3), a hydroxyl resonance at δ 8.47 (br s, 1H, 3′-OH), and a methoxy signal at δ 3.79 (s, 3H, 5′-OCH_3). This NMR pattern indicated that compounds **8** and **12** had the same phenyl ring structures.

Compound **13** had the molecular formula $C_{19}H_{20}O_5$. The ^{1}H NMR spectrum showed resonances for three benzofuran protons [δ 7.02 (s, H-1″), 6.70 (br s, H-5), and 6.36 (br s, H-3)], an OH at δ 8.95 (br s, 2-OH), and a methoxy group at δ 3.82 (s, 3H, 4-O-CH_3). This NMR pattern indicated that compounds **8**, **9**, **11**, and **13** had the same benzofuran ring structures. The substituted phenyl group of **13** showed a singlet aromatic proton signal at δ 7.16 (H-6′), two aromatic methyl resonances at δ 2.41 (s, 2′-CH_3) and 2.16 (s, 4′-CH_3), and methoxy signals at δ 3.90 (s, 5′-OCH_3) and 3.72 (s, 3′-OCH_3). This NMR pattern indicated that compounds **6** and **13** had the same phenyl ring structures.

Insecticidal activity shown by root extracts of *Stemona* plants has been closely associated with the acetylcholinesterase (AChE) inhibitory activities of their alkaloid components.[2,3,14,20] Compounds **1**−**3**, **14**, and **15** were therefore screened by TLC bioautography for their AChE inhibitory activities using the method of Hostettmann et al.[21] and galanthamine and 1′,2′-didehydrostemofoline as positive controls. The results are shown in Table 1.

In our earlier studies on the AChE inhibitory activities of several pyrrolo[1,2-*a*]azepine *Stemona* alkaloids and their analogues we found that 1′,2′-didehydrostemofoline and (1′*R*)-hydroxystemofoline were the most active compounds, with minimum inhibitory concentrations of 5 ng.[22] These compounds, however, were not as active as the positive control galanthamine (minimum inhibitory concentration of 1 ng). Compounds **1**, **2**, and **14** were the most active among the five compounds tested, with a MIC of 10 ng, while compounds **3** and **15** were significantly less active, with a MIC of 50 and 100 ng, respectively, perhaps due to the lack of rigidity of the C-11−C-12 double bond.

Antimicrobial activities of compounds **4**, **6**, **8**, **11**, and **13** against the Gram-negative bacteria *Escherichia coli* and *Klebsiella pneumoniae* and the Gram-positive bacteria *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus* (MRSA), and *Streptococcus pyogenes* and the antifungal activities against *Candida albicans* and *Cryptococcus neoformans* were determined.[23] Two antibiotic agents, gentamycin and amphotericin B, were used as the positive controls for the antibacterial activity and antifungal activity, respectively. The antimicrobial activities are shown in Table 2. Antibacterial activities of the tested compounds were generally weak to poor against the Gram-negative bacteria. Compounds **8**, **11**, and **13** showed modest activities against *S. aureaus.* All compounds were less active than the positive control gentamycin, except for compounds **4**, **6**, and **13** against MRSA, which all had MICs of 15.6 μg/mL, which was significantly less than that of the control (MIC 45.0 μg/mL). Structurally these three compounds all have a 2′,3′,4′,5′-tetrasubstituted B ring, which is the same as that in compounds **6** and **13**. Compound **4** has a 3′-hydroxy group rather than a 3′-methoxy group as found in compounds **6** and **13**. While the testing of a larger number of benzofuran compounds of a greater structural diversity would be required for sound structure−activity conclusions to be drawn, nevertheless, it appears that the substitution pattern on the B ring is important for antibacterial activity against MRSA. The antifungal activities of benzofurans **11** and **13** against *C. albicans* were the same as the positive control amphotericin B, while compounds **4**, **6**, and **8** had slightly weaker activities (Table 2). All benzofuran compounds were less active than the positive control against *C. neoformans*. Compounds **4**, **6**, and **11** showed good activities with MIC values of 7.8 μg/mL, while compounds **8** and **13** were less active. The antifungal activities of **4** and **6** were consistent with that of a previous study, showing that **4** had strong activity against *C. herbarum* and **6** had strong activity against *P. grisea*.[16]

Experimental Section

General Experimental Procedures. ^{1}H (500 MHz), ^{13}C (125 MHz), and 2D NMR spectra were recorded on a Varian Unity 500 spectrometer. High-resolution ESIMS were obtained with a Micromass QTOF 2 mass spectrometer using a cone voltage of 30 V and polyethyleneglycol as an internal reference. TLC analysis were performed on aluminum-backed Merck 60 GF_{254} silica gel, and bands were detected by UV light (λ 254 nm) or stained with Dragendorff's reagent. Column chromatography (CC) was performed using Merck GF_{254} flash silica gel (40−63 μm). Preparative TLC was performed using Merck TLC silica gel 60 F_{254} (20 × 20 cm). Preparative-LC analysis was performed using a Waters PrepLC system (Waters Corporation, Milford, MA, USA) equipped with a Waters Prep degasser and a Waters 2489 UV/visible detector. Separation was performed on a Phenomenex Gemini C18 column (110 Å, 21.2 × 150 mm, 5 μm) with a sample injection volume of 10 mL. Solvent A (H_2O containing 0.1% formic acid) and solvent B (acetonitrile containing 0.1% formic acid) were used as mobile phases. Isocratic elution was performed using 40% B at a flow rate of 24.0 mL/min.

Plant Material. Roots of *S. aphylla* were collected in Lampang Province, Thailand, in April 2009. A voucher specimen (number 09-111) was deposited at the herbarium of the Department of Biology, Chiang Mai University. Plant material was identified by Mr. James F. Maxwell from the Department of Biology, Chiang Mai University.

Extraction and Isolation. The ground root, dried in an oven at 50 °C, of *Stemona aphylla* (15.14 kg) was extracted with 95% EtOH (4 × 10 L) for 16 days (4 days for each extraction) at rt. The extract was evaporated to give a dark residue (1.45 kg). A portion of the residue (100.0 g) was partitioned between 200 mL of 50% aqueous MeOH and 200 mL of CH_2Cl_2 (3 times) to yield 8.86 g of crude CH_2Cl_2 extract.

A portion of the CH_2Cl_2 extract (4.00 g) was separated by CC on flash silica gel (400 g) using gradient elution from 100% CH_2Cl_2 to 20% MeOH/CH_2Cl_2 to give 13 fractions. Fraction 10 (1.799 g) was purified by CC using MeOH/CH_2Cl_2 (0:100 to 20:80, v/v) to yield seven fractions (fractions 10.1−10.7). Further separations of fraction 10.4 (998.0 mg) by CC, and in some cases preparative LC using isocratic elution with 40% MeCN/water containing 0.1% formic acid, gave stemofuran E (**4**) (13.2 mg), stemofuran F (**5**) (1.8 mg), stemofuran J (**6**) (15.5 mg), stilbostemin F (**7**) (0.8 mg), stemofuran M (**8**) (6.4 mg), stemofuran N (**9**) (0.9 mg), stemofuran O (**10**) (0.6 mg), stemofuran P (**11**) (5.8 mg), stemofuran Q (**12**) (2.0 mg), and stemofuran R (**13**) (12.8 mg). Compounds **10** and **12** could not be isolated in pure form,

Table 2. Antibacterial and Antifungal Activities (MIC in μg/mL)

	Gram-negative bacteria		Gram-positive bacteria			fungi	
compound	*E. coli*	*K. pneumoniae*	*S. aureus*	MRSA	*S. pyogenes*	*C. albicans*	*C. neoformans*
4	62.5	62.5	62.5	15.6		31.3	7.8
6	62.5	62.5	62.5	15.6	62.5	31.3	7.8
8	125.0	62.5	31.3	31.3	62.5	31.3	31.3
11	62.5	125.0	31.3	62.5		15.6	7.8
13	62.5	62.5	31.3	15.6		15.6	15.6
gentamycin	11.3	11.3	22.5	45.0	5.6		
amphotericin B						15.6	3.9

even after HPLC. Fraction 10.6 (917.0 mg) was purified by CC with gradient elution using MeOH/CH_2Cl_2 (0:100 to 20:80, v/v) to afforded stemofoline (**1**) (395.0 mg), (2′*S*)-hydroxystemofoline (**2**) (70.0 mg), and (2′*S*)-hydroxy-(11*S*,12*R*)-dihydrostemofoline (**3**) (14.0 mg). Tables of the NMR data of all compounds are in the Supporting Information.

(2′*S*)-Hydroxy-(11*S*,12*R*)-dihydrostemofoline (3): pale yellow gum; $[\alpha]_D^{25}$ +49 (*c* 0.2, $CHCl_3$); ^{1}H NMR δ 4.52 (br s, 1H, H-12), 4.24 (br s, 1H, H-2), 4.05 (s, 3H, O-CH_3), 3.72 (dd, J = 9.0, 2.5 Hz, 1H, H-11), 3.52 (dt, J = 10.5, 6.0 Hz, 1H, H-2′), 3.35 (br s, 1H, H-9a), 3.12 (ddd, J = 14.0, 10.5, 5.5 Hz, 1H, H-5a), 2.89 (ddd, J = 13.5, 8.5, 4.5 Hz, 1H, H-5b), 2.60−2.52 (m, 1H, H-10), 2.33 (d, J = 6.0 Hz, 1H, H-7), 2.01 (d, J = 12.5 Hz, 1H, H-1a), 1.94 (s, 3H, H-16), 1.86−1.79 (m, 1H, H-6a), 1.69−1.62 (m, 1H, H-6b), 1.63 (d, J = 12.5 Hz, 1H, H-1b), 1.59 (d, J = 14.0 Hz, 1H, H-1′a), 1.55 (dd, J = 11.0, 3.5 Hz, 1H, H-9), 1.49 (dd, J = 14.5, 10.5 Hz, 1H, H-1′b), 1.43 (quin, J = 7.0 Hz, 1H, H-3′a), 1.32 (quin, J = 7.0 Hz, 1H, H-3′b), 1.02 (d, J = 6.5 Hz, 3H, H-17), 0.85 (t, J = 7.5 Hz, 3H, H-4′); ^{13}C NMR δ 174.7 (C-15), 170.4 (C-13), 111.6 (C-8), 98.7 (C-14), 86.1 (C-11), 82.3 (C-3), 78.7 (C-2), 76.3 (C-12), 71.3 (C-2′), 61.0 (C-9a), 59.1 (OCH_3), 52.4 (C-7), 47.6 (C-9), 47.1 (C-5), 36.2 (C-1′), 34.1 (C-1), 33.2 (C-10), 30.7 (C-3′), 27.0 (C-6), 14.9 (C-17), 9.9 (C-4′), 8.8 (C-16); HRESIMS *m*/*z* 406.2216 $[MH]^+$, calcd for $C_{22}H_{32}NO_6$ 406.2230.

Stemofuran M (8): brown, amorphous solid; ^{1}H NMR δ 8.73 (br s, 1H, 2-OH), 8.73 (br s, 1H, 3′−OH), 7.01 (s, 1H, H-1″), 6.88 (d, J = 2.5 Hz, 1H, H-6′), 6.69 (br s, 1H, H-5), 6.53 (d, J = 2.5 Hz, 1H, H-4′), 6.35 (d, J = 1.5 Hz, 1H, H-3), 3.82 (s, 3H, 4-OCH_3), 3.79 (s, 3H, 5′-OCH_3), 2.35 (s, 3H, 2′-CH_3); ^{13}C NMR δ 160.4 (C-4), 159.0 (C-6), 157.4 (C-3′), 157.4 (C-5′), 153.9 (C-2″), 152.0 (C-2), 132.7 (C-1′), 115.2 (C-2′), 113.2 (C-1), 104.8 (C-6′), 103.6 (C-1″), 102.3 (C-4′), 98.2 (C-3), 88.3 (C-5), 55.9 (4-OCH_3), 55.5 (5′-OCH_3), 13.1 (2′-CH_3); HRESIMS *m*/*z* 301.1059 $[MH]^+$, calcd for $C_{17}H_{17}O_5$ 301.1076.

Stemofuran N (9): dark brown gum; ^{1}H NMR δ 8.96 (br s, 1H, 2-OH), 7.25 (s, 1H, H-1″), 7.01 (s, 1H, H-2′), 7.01 (s, 1H, H-6′), 6.69 (br s, 1H, H-5), 6.67 (s, 1H, H-4′), 6.35 (d, J = 1.5 Hz, 1H, H-3), 3.87 (s, 3H, 3′-OCH_3), 3.87 (s, 3H, 5′-OCH_3), 3.82 (s, 3H, 4-OCH_3); ^{13}C NMR δ 162.3 (C-3′), 162.3 (C-5′), 160.6 (C-4), 158.0 (C-6), 153.9 (C-2″), 152.1 (C-2), 133.4 (C-1′), 113.3 (C-1), 102.9 (C-6′), 102.9 (C-2′), 101.0 (C-4′), 100.5 (C-1″), 98.4 (C-3), 88.5 (C-5), 56.0 (4-O-CH_3), 55.8 (3′-OCH_3), 55.8 (5′-OCH_3); HRESIMS *m*/*z* 301.1056 $[MH]^+$, calcd for $C_{17}H_{17}O_5$ 301.1076.

Stemofuran O (10): brown gum; ^{1}H NMR δ 8.83 (br s, 1H, 2-OH), 7.13 (dd, J = 8.0, 8.0 Hz, 1H, H-4), 7.03 (d, J = 8.0 Hz, 1H, H-5), 6.83 (d, J = 1.0 Hz, 1H, H-1″), 6.72 (d, J = 8.0 Hz, 1H, H-3), 3.72 (s, 3H, 3′-O-CH_3), 3.72 (s, 3H, 5′-OCH_3), 2.27 (s, 3H, 4′-CH_3), 2.10 (s, 3H, 2′-CH_3), 2.10 (s, 3H, 6′-CH_3); ^{13}C NMR δ 157.3 (C-2″), 156.6 (C-3′), 156.6 (C-5′), 153.4 (C-6), 152.0 (C-2), 131.1 (C-1′), 127.8 (C-4′), 126.4 (C-2′), 126.4 (C-6′), 125.7 (C-4), 119.3 (C-1), 108.7 (C-3), 104.4 (C-1″), 103.6 (C-5), 60.2 (3′-OCH_3), 60.2 (5′-OCH_3), 13.8 (2′-CH_3), 13.8 (6′-CH_3), 10.0 (4′-CH_3); HRESIMS *m*/*z* 313.1422 $[MH]^+$, calcd for $C_{19}H_{21}O_4$ 313.1440.

Stemofuran P (11): brown gum; ^{1}H NMR δ 8.98 (br s, 1H, 2-OH), 7.01 (s, 1H, H-1″), 6.92 (d, J = 2.0 Hz, 1H, H-6′), 6.69 (br s, 1H, H-5), 6.58 (d, J = 2.0 Hz, 1H, H-4′), 6.35 (d, J = 1.5 Hz, 1H, H-3), 3.87 (s, 3H, 3′-OCH_3), 3.84 (s, 3H, 5′-O-CH_3), 3.82 (s, 3H, 4-O-CH_3), 2.31 (s, 3H, 2′-CH_3); ^{13}C NMR δ 160.5 (C-4), 159.9 (C-3′), 159.6 (C-5′), 157.5 (C-6), 153.7 (C-2″), 152.1 (C-2), 132.4 (C-1′), 116.9 (C-2′), 113.2 (C-1), 104.7 (C-6′), 104.0 (C-1″), 99.2 (C-4′), 98.3 (C-3), 88.3 (C-5), 56.2 (3′-OCH_3), 56.0 (4-OCH_3), 55.7 (5′-OCH_3), 13.1 (2′-CH_3); HRESIMS *m*/*z* 315.1217 $[MH]^+$, calcd for $C_{18}H_{19}O_5$ 315.1232.

Stemofuran Q (12): black, amorphous solid; ^{1}H NMR δ 8.47 (br s, 1H, 2-OH), 8.47 (br s, 1H, 3′−OH), 7.13 (s, 1H, H-1″), 6.89 (d, J = 2.5 Hz, 1H, H-6′), 6.76 (s, 1H, H-5), 6.52 (d, J = 2.5 Hz, 1H, H-4′), 3.89 (s, 3H, 4-O-CH_3), 3.79 (s, 3H, 5′-O-CH_3), 2.34 (s, 3H, 2′-CH_3), 2.15 (s, 3H, 3-CH_3); ^{13}C NMR δ 159.2 (C-5′), 158.5 (C-4), 157.4 (C-3′), 154.9 (C-2″), 153.4 (C-6), 148.8 (C-2), 132.9 (C-1′), 115.0 (C-2′), 112.9 (C-1), 107.4 (C-3), 104.7 (C-6′), 103.7 (C-1″), 102.2 (C-4′), 87.1 (C-5), 56.2 (4-O-CH_3), 55.4 (5′-OCH_3), 13.2 (2′-CH_3), 8.7 (3-CH_3); HRESIMS *m*/*z* 315.1237 $[MH]^+$, calcd for $C_{18}H_{19}O_5$ 315.1232.

Stemofuran R (13): dark brown, amorphous solid; ^{1}H NMR δ 8.95 (br s, 1H, 2-OH), 7.16 (s, 1H, H-6′), 7.02 (s, 1H, H-1″), 6.70 (br s, 1H, H-5), 6.36 (br s, 1H, H-3), 3.90 (s, 3H, 5′-OCH_3), 3.82 (s, 3H, 4-O−CH_3), 3.72 (s, 3H, 3′-O−CH_3), 2.41 (s, 3H, 2′-CH_3), 2.16 (s, 3H, 4′-CH_3); ^{13}C NMR δ 160.4 (C-4), 158.9 (C-3′), 157.5 (C-5′), 157.4 (C-6), 153.8 (C-2″), 152.0 (C-2), 129.8 (C-1′), 121.4 (C-4′), 120.3 (C-2′), 113.3 (C-1), 106.1 (C-6′), 103.4 (C-1″), 98.2 (C-3), 88.3 (C-5), 60.4 (3′-O-CH_3), 56.0 (4-O-CH_3), 13.9 (2′-CH_3), 9.5 (4′-CH_3); HRESIMS *m*/*z* 329.1354 $[MH]^+$, calcd for $C_{19}H_{21}O_5$ 329.1389.

Photoisomerization of (2′*S*)-Hydroxystemofoline (2). To a solution of **2** (21.2 mg, 0.053 mmol) in $CHCl_3$ (2 mL) was added acetophenone (20 μL). The mixture was prepared in a NMR tube and exposed to irradiation from a 500 W sun lamp for 4 h. The solvent was removed under vacuum to give a mixture (1:1) of **2** and **14** (19.2 mg, 90.6% yield) as a pale yellow gum. The crude product was purified by preparative TLC using EtOAc/MeOH (10:90) to give **2** (9.9 mg, 46.7% yield) as a pale yellow gum and **14** (9.3 mg, 43.9% yield) as a pale yellow gum.

(11*E*)-(2′*S*)-Hydroxystemofoline (14): pale yellow gum; $[\alpha]_D^{25}$ +105 (*c* 0.3, $CHCl_3$); ^{1}H NMR δ 4.37 (br s, 1H, H-2), 4.11 (s, 3H, OCH_3), 3.62 (dt, J = 9.0, 6.5 Hz, 1H, H-2′), 3.55 (br s, 1H, H-9a), 3.25 (ddd, J = 14.5, 9.5, 5.0 Hz, 1H, H-5a), 3.03 (ddd, J = 13.5, 9.0, 4.5 Hz, 1H, H-5b), 3.24−3.18 (m, 1H, H-10), 2.64 (d, J = 6.0 Hz, 1H, H-7), 2.07 (d, J = 13.0 Hz, 1H, H-1a), 2.04 (s, 3H, H-16), 2.02−1.96 (m, 1H, H-6a), 1.90−1.84 (m, 1H, H-6b), 1.83 (d, J = 12.5 Hz, 1H, H-1b), 1.74 (dd, J = 11.5, 3.0 Hz, 1H, H-9), 1.71 (d, J = 15.0 Hz, 1H, H-1′a), 1.66 (dd, J = 14.5, 10.0 Hz, 1H, H-1′b), 1.52 (quin, J = 7.0 Hz, 1H, H-3′a), 1.42 (quin, J = 7.0 Hz, 1H, H-3′b), 1.46 (d, J = 6.5 Hz, 3H, H-17), 0.95 (t, J = 7.5 Hz, 3H, H-4′); ^{13}C NMR δ 170.5 (C-15), 163.3 (C-13), 149.4 (C-11), 129.0 (C-12), 113.0 (C-8), 98.6 (C-14), 82.8 (C-3), 79.0 (C-2), 71.1 (C-2′), 60.8 (C-9a), 59.5 (O-CH_3), 51.9 (C-7), 46.0 (C-9), 47.1 (C-5), 36.2 (C-10), 36.2 (C-1′), 33.5 (C-1), 30.5 (C-3′), 26.7 (C-6), 16.2 (C-17), 9.8 (C-4′), 8.8 (C-16); HRESIMS *m*/*z* 404.2086 $[MH]^+$, calcd for $C_{22}H_{30}NO_6$ 404.2073.

Hydrogenation of 2. To a solution of **2** (8.4 mg, 0.021 mmol) in EtOAc (1 mL) was added Pd/C (ca. 5 mg). The mixture was left to stir under a hydrogen atmosphere (balloon) overnight at rt, when complete reaction was shown by TLC analysis. The mixture was filtered through Celite and evaporated under reduced pressure, and the crude product was purified by preparative TLC using MeOH/CH_2Cl_2 (5:95) to give **15** (4.3 mg, 51.2% yield) as a pale yellow gum.

(2′*S*)-Hydroxy-(11*S*,12*S*)-dihydrostemofoline (15): colorless gum; $[\alpha]_D^{25}$ +49 (*c* 0.3, $CHCl_3$); ^{1}H NMR δ 4.67 (br s, 1H, H-12), 4.25 (br s, 1H, H-2), 4.03 (s, 3H, O-CH_3), 3.65 (t, J = 7.0 Hz, 1H, H-11), 3.54 (dt, J = 9.0, 6.5 Hz, 1H, H-2′), 3.38 (br s, 1H, H-9a), 3.13 (ddd, J = 14.5, 9.5, 5.0 Hz, 1H, H-5a), 2.91 (ddd, J = 13.0, 8.5, 4.5 Hz, 1H, H-5b), 2.49−2.41 (m, 1H, H-10), 2.36 (d, J = 6.0 Hz, 1H, H-7), 1.98 (d, J = 12.0 Hz, 1H, H-1a), 1.89 (s, 3H, H-16), 1.88−1.81 (m, 1H, H-6a), 1.73−1.66 (m, 1H, H-6b), 1.67 (d, J = 12.0 Hz, 1H, H-1b), 1.60 (d, J = 14.5 Hz, 1H, H-1′a), 1.55 (d, J = 11.5 Hz, 1H, H-9), 1.52 (d, J = 10.5 Hz, 1H, H-1′b), 1.44 (quin, J = 7.0 Hz, 1H, H-3′a), 1.34 (quin, J = 6.5 Hz, 1H, H-3′b), 1.05 (d, J = 6.5 Hz, 3H, H-17), 0.86 (t, J = 7.5 Hz, 3H, H-4′); ^{13}C NMR δ 174.3 (C-15), 172.9 (C-13), 112.3 (C-8), 98.9 (C-14), 87.8 (C-11), 82.3 (C-3), 78.9 (C-2), 78.6 (C-12), 71.2 (C-2′), 61.0 (C-9a), 59.3 (OCH_3), 52.4 (C-7), 47.3 (C-9), 47.1 (C-5), 36.2 (C-1′), 34.9 (C-10), 34.0 (C-1), 30.6 (C-3′), 26.8 (C-6), 16.5 (C-17), 9.8 (C-4′), 8.4 (C-16); HRESIMS *m*/*z* 406.2237 $[MH]^+$, calcd for $C_{22}H_{32}NO_6$ 406.2230.

Hydrogenation of 14. To a solution of **14** (9.3 mg, 0.021 mmol) in EtOAc (1 mL) was added Pd/C (ca. 5 mg). The mixture was left to stir under a hydrogen atmosphere (balloon) overnight at rt when complete reaction was shown by TLC analysis. The mixture was filtered through Celite and evaporated under reduced pressure, and the crude product was purified by preparative TLC using MeOH/CH_2Cl_2 (5:95) to give **3** (2.7 mg, 29.0% yield) as a pale yellow gum.

(2′*S*)-Hydroxy-(11*S*,12*R*)-dihydrostemofoline (3): pale yellow gum; $[\alpha]_D^{25}$ +51 (*c* 0.2, $CHCl_3$); ^{1}H NMR δ 4.52 (br s, 1H, H-12), 4.24 (br s, 1H, H-2), 4.05 (s, 3H, O-CH_3), 3.72 (dd, J = 9.0, 2.5 Hz, 1H, H-11), 3.52 (dt, J = 10.0, 6.0 Hz, 1H, H-2′), 3.36 (br s, 1H, H-9a), 3.12 (ddd, J = 14.5, 10.5, 5.0 Hz, 1H, H-5a), 2.89 (ddd, J = 13.5, 8.5, 5.0 Hz, 1H, H-5b), 2.60−2.52 (m, 1H, H-10), 2.33 (d, J = 6.5 Hz, 1H, H-7), 2.01 (d, J = 12.0 Hz, 1H, H-1a), 1.94 (s, 3H, H-16), 1.86−1.79 (m, 1H, H-6a), 1.69−1.62 (m, 1H, H-6b), 1.63 (d, J = 11.5 Hz, 1H, H-1b), 1.59 (d, J = 14.5 Hz, 1H, H-1′a), 1.55 (dd, J = 11.0, 3.0 Hz, 1H, H-9), 1.49 (dd, J = 14.5, 10.5 Hz, 1H, H-1′b), 1.43 (quin, J = 7.0 Hz, 1H, H-3′a), 1.32 (quin, J = 7.0 Hz, 1H, H-3′b), 1.03 (d, J = 6.5 Hz, 3H, H-17), 0.85 (t, J = 7.5 Hz, 3H, H-4′); ^{13}C NMR δ 174.7 (C-15), 170.4 (C-13), 111.5 (C-8), 98.7 (C-14), 86.1 (C-11), 82.2 (C-3), 78.6 (C-2), 76.3 (C-12), 71.3 (C-2′), 60.9 (C-9a), 59.1 (O−CH_3), 52.4 (C-7), 47.5 (C-9), 47.1 (C-5), 36.1 (C-1′), 34.1 (C-1), 33.1 (C-10), 30.6 (C-3′), 26.9 (C-6), 14.9 (C-17), 9.8 (C-4′), 8.8 (C-16); HRESIMS *m/z* 406.2216 $[MH]^+$, calcd for $C_{22}H_{32}NO_6$ 406.2230.

Bioautography Procedure. TLC bioautography was performed using the method described by Hostettmann et al.[21] and according to our previous publication.[22]

Antimicrobial Activity Procedure. Studies of antimicrobial activities of compounds **4**, **6**, **8**, **11**, and **13** against *Escherichia coli*, *Klebsiella pneumoniae*, *Staphylococcus aureus*, methicillin-resistant *Staphylococcus aureus* (MRSA), *Streptococcus pyogenes*, *Candida albicans*, and *Cryptococcus neoformans* were carried out by the broth dilution method.[23] Antibiotics gentamicin and amphotericin B were used as positive controls.

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Supporting Information Available: Tables of the ^{1}H, ^{13}C, HMBC, and NOESY NMR data for compounds **3** and **8**−**15**. Copies of the ^{1}H NMR spectra of compounds **3** and **8**−**15**. This material is available free of charge via the Internet at http://pubs.acs.org.

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