Two New Diterpenes from *Solidago canadensis*

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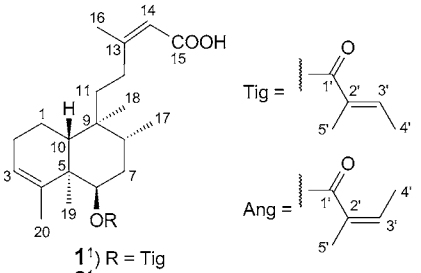
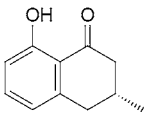
Two new clerodane-type diterpenes, solidagocanins A and B (**1** and **2**, resp.), as well as two known compounds, mellein (**3**) and physcion (**4**), were isolated from the aerial parts of *Solidago canadensis*. The structures of the new compounds were elucidated by spectroscopic analyses, including 2D-NMR techniques.

Introduction. – Diterpenes and polyacetylenes are common constituents in members of the tribe Astereae [1–5]. In recent years, a large number of reports have appeared dealing with the biological activities of these compounds. Diterepenes exhibit insect-antifeedant, antifungal, antibacterial, and antiviral activities [3][6]. In the course of searching for the new bioactive natural products from the Asteraceae plants, two new clerodane-type diterpenoids, solidagocanins A and B[2]) (**1** and **2**, resp.), as well as two known compounds, mellein (**3**) and physcion (**4**), were isolated from the aerial parts of *Solidago canadensis*. This article describes the isolation and structure elucidation of the new compounds.



1[1]) R = Tig
2[1]) R = Ang



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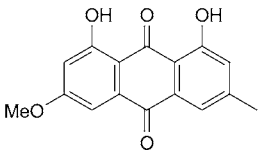

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Results and Discussion. – Repeated column chromatography of the AcOEt extract from the aerial parts of *S. canadensis* yielded compounds **1**–**4**.

[1]) These two authors have contributed equally to this work.

[2]) Trivial atom numbering; for systematic names, see *Exper. Part.*

Solidagocanin A[2]) (**1**) was obtained as a white powder and assigned to possess a molecular formula $C_{25}H_{38}O_4$ on the basis of the HR-ESI-MS (*m/z* 403.2835 ($[M+H]^+$)), which indicated seven degrees of unsaturation. The ^{1}H-NMR spectrum (*Table 1*) showed two secondary Me groups (δ(H) 0.85 (*d*, $J = 6.4$ Hz) and 1.78 (*d*, $J = 7.0$ Hz)) and five tertiary Me groups (δ(H) 1.05, 1.25, 1.54, 1.79, and 2.20 (5*s*)). As determined by a DEPT experiment, the down-field ^{13}C-NMR signals (*Table 2*) corresponded to two C=O groups (δ(C) 172.3 and 167.6), six olefinic C-atoms (δ(C) 115.0, 124.2, 129.1, 136.8, 138.2, and 164.3), and one O-bearing C-atom (δ(C) 74.4); the high-field region showed seven Me (δ(C) 12.2, 14.4, 15.4, 18.3, 19.5, 24.7, and 28.6), five CH_2 (δ(C) 21.8, 26.5, 31.5, 34.2, and 35.6), and two CH groups (δ(C) 31.9 and 44.4) as well as two quaternary C-atoms (δ(C) 38.5 and 42.9) (*Table 2*). The ^{1}H-NMR signals at δ(H) 6.79 (*m*, H–C(3′)), 1.78 (*d*, $J = 7.0$ Hz Me(4′)), and 1.79 (*s*, Me(5′)), along with the corresponding ^{13}C-NMR signals at δ(C) 167.6 (C(1′)), 129.1 (C(2′)), 136.8 (C(3′)), 14.4 (C(4′)), and 12.2 (C(5′)) indicated the presence of a tigloyl (Tig) group [4]. The ^{1}H-NMR, ^{13}C-NMR, and HMBC data (*Fig.*) of **1** suggested that **1** had the same constitution as (6β)-6-(tigloyloxy)kolavenic acid [4]. Comparison of the ^{13}C-NMR spectra of **1** and (6β)-6-(tigloyloxy)kolavenic acid (*Table 2*) showed that they only differed in the configuration of the C=C bond at C(13). The configuration of this C=C bond was determined by NOESY experiments. H–C(14) and the Me(16) were *trans*-oriented in (6β)-6-(tigloyloxy)kolavenic acid [4]. However, the NOESY correlation between Me(16) and H–C(14) of **1** indicated that H–C(14) and the Me(16) were *cis*-oriented (*Fig.*), similar to the situation in (7α,13*Z*)-7-(acetyloxy)kolavenic acid [4]. Thus, the structure of **1** was elucidated as shown in the *Figure*, and it was named solidagocanin A.

Table 1. *^{1}H-NMR Data* (at 27°, $CDCl_3$, 400 MHz) *of* **1** *and* **2**[2]). δ in ppm, *J* in Hz.

H-Atom	**1**	**2**
CH_2(1)	1.33–1.42, 1.94–2.03 (2*m*)	1.31–1.41, 1.90–2.00 (2*m*)
CH_2(2)	1.89–2.08 (*m*)	1.83–2.02 (*m*)
H–C(3)	5.49 (br. *s*)	5.47 (br. *s*)
H–C(6)	4.98 (br. *s*)	5.01 (br. *s*)
CH_2(7)	1.55–1.63, 1.75–1.84 (2*m*)	1.50–1.60, 1.75–1.85 (2*m*)
H–C(8)	1.88–1.96 (*m*)	1.83–1.91 (*m*)
H–C(10)	1.51–1.58 (*m*)	1.46–1.54 (*m*)
CH_2(11)	1.63–1.70, 1.82–1.90 (2*m*)	1.58–1.66, 1.77–1.86 (2*m*)
CH_2(12)	2.02–2.12, 2.22–2.32 (2*m*)	2.00–2.10, 2.20–2.30 (2*m*)
H–C(14)	5.71 (*s*)	5.69 (*s*)
Me(16)	2.20 (*s*)	2.18 (*s*)
Me(17)	0.85 (*d*, $J = 6.4$, 3 H)	0.83 (*d*, $J = 6.4$)
Me(18)	1.05 (*s*)	1.02 (*s*)
Me(19)	1.25 (*s*)	1.24 (*s*)
Me(20)	1.54 (*s*)	1.54 (*s*)
H–C(3′)	6.79 (*m*)	5.97 (*m*)
Me(4′)	1.78 (*d*, $J = 7.0$)	1.96 (*d*, $J = 7.0$)
Me(5′)	1.79 (*s*)	1.81 (*s*)

Table 2. *^{13}C-NMR Data of* **1**, **2**, *and (13Z)-*__1__ [4][a])[2]). Recorded at 27°, $CDCl_3$, 100 MHz; δ in ppm.

C-Atom	**1**	(13*Z*)-**1**	**2**
C(1)	34.2 (*t*)	34.6 (*t*)	34.2 (*t*)
C(2)	26.5 (*t*)	26.5 (*t*)	26.5 (*t*)
C(3)	124.2 (*d*)	124.2 (*d*)	124.5 (*d*)
C(4)	138.2 (*s*)	138.2 (*s*)	138.0 (*s*)
C(5)	42.9 (*s*)	42.9 (*s*)	42.9 (*s*)
C(6)	74.4 (*d*)	74.4 (*d*)	74.0 (*d*)
C(7)	31.5 (*t*)	31.5 (*t*)	31.6 (*t*)
C(8)	31.9 (*d*)	31.9 (*d*)	31.9 (*d*)
C(9)	38.5 (*s*)	38.5 (*s*)	38.4 (*s*)
C(10)	44.4 (*d*)	44.4 (*d*)	44.3 (*d*)
C(11)	21.8 (*t*)	21.8 (*t*)	21.6 (*t*)
C(12)	35.6 (*t*)	35.5 (*t*)	35.6 (*t*)
C(13)	164.3 (*s*)	162.9 (*s*)	164.2 (*s*)
C(14)	115.0 (*d*)	116.2 (*d*)	115.0 (*d*)
C(15)	172.3 (*s*)	172.2 (*s*)	172.0 (*s*)
C(16)	19.5 (*q*)	19.4 (*q*)	19.5 (*q*)
C(17)	15.4 (*q*)	15.3 (*q*)	15.4 (*q*)
C(18)	28.6 (*q*)	28.5 (*q*)	28.6 (*q*)
C(19)	24.7 (*q*)	24.7 (*q*)	24.7 (*q*)
C(20)	18.3 (*q*)	18.2 (*q*)	18.3 (*q*)
C(1′)	167.6 (*s*)	167.5 (*s*)	167.1 (*s*)
C(2′)	129.1 (*s*)	129.1 (*s*)	128.3 (*s*)
C(3′)	136.8 (*d*)	136.7 (*d*)	137.7 (*d*)
C(4′)	14.4 (*q*)	14.3 (*q*)	15.5 (*q*)
C(5′)	12.2 (*q*)	12.1 (*q*)	20.7 (*q*)

[a]) The known compound (13*Z*)-**1** was named (6β)-6-(tigloyloxy)kolavenic acid (=(2*E*)-3-methyl-5-{(1*S*,2*R*,4*R*,4a*R*,8a*R*)-1,2,3,4,4a,7,8,8a-octahydro-1,2,4a,5-tetramethyl-4-{[(2*E*)-2-methyl-1-oxobut-2-en-1-yl]oxy}naphthalen-1-yl}pent-2-enoic acid).

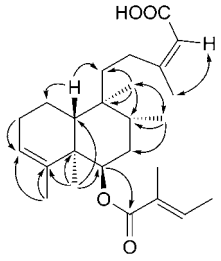

Figure. *Key HMBC* (H → C) *and NOESY* (H ↔ H) *correlations in* **1**

Solidagocanin B[2]) (**2**), obtained as a white powder, had a molecular formula $C_{25}H_{38}O_4$ according to the HR-ESI-MS (*m*/*z* 403.2832 ([*M* + H]$^+$)). The NMR, IR, and UV of **2** were quite similar to those of **1**, except for the characteristic signals due to an angeloyl (=(2*Z*)-2-methyl-1-oxobut-2-en-1-yl; Ang) group instead of the tigloyl (=(2*E*)-2-methyl-1-oxobut-2-en-1-yl; Tig) group in **1**. The ^{1}H-NMR signals of **2** at δ(H) 5.97 (*m*, H–C(3′)), 1.96 (*d*, *J* = 7.0 Hz, Me(4′)), and 1.81 (*s*, Me(5′)), along with

the corresponding ^{13}C-NMR signals at δ(C) 167.1 (C(1′)), 128.3 (C(2′)), 137.7 (C(3′)), 15.5 (C(4′)) and 20.7 (C(5′)) indicated the presence of an Ang group [4][7]. The HMBC between H–C(6) at δ(H) 5.01 and C(1′) at δ(C) 167.1 suggested that the Ang group was located at C(6). The NOESY correlation between Me(16) and H–C(14) of **2** indicated that H–C(14) and Me(16) were *cis*-oriented as in **1**, but different from the configuration of (6β)-6-(angeloyloxy)kolavenic acid [4].

The known compounds were identified as mellein (**3**) [8] and physcion (**4**) [9] by comparing their IR, UV, and NMR data with those reported in the literature.

Experimental Part

General. Column chromatography (CC): silica gel (SiO_2, 200–300 or 300–400 mesh; *Qingdao Marine Chemical Factory*). Anal. TLC: silica-gel plates (SiO_2; *Yantai Institute of Chemical Technology*); eluent petroleum ether/acetone 3:1; visualization under UV light, and by spraying with 10% aq. H_2SO_4 soln., followed by heating. Optical rotations (ORD): *Jasco-P-1020* spectropolarimeter. UV Spectra: *Shimadzu-UV-260* spectrophotometer; in anh. MeOH; λ_{max} (log ε) in nm. IR Spectra: *Avatar-360-ESP* spectrophotometer (*Thermo Nicolet*); KBr pellets; $\tilde{\nu}$in cm^{-1}. ^{1}H- and ^{13}C-NMR Spectra: *DRX-400* spectrometer; in $CDCl_3$; δ in ppm rel. to Me_4Si as internal standard, *J* in Hz. HR-ESI-MS: *Bruker-Apex-7.0-Tesla* FT-MS apparatus; in *m*/*z*.

Plant Material. The aerial parts of *Solidago canadensis* L. were collected in Shanghai, P. R. China, in August 2006. A voucher specimen (Qin-Zeng200601) is deposited with the Herbarium of Materia Medica, School of Pharmacy, the Second Military Medical University, Shanghai, P. R. China.

Extraction and Isolation. The air-dried, aerial parts (20 kg) of *S. canadensis* were extracted exhaustively with 80% aq. EtOH at r.t. The EtOH extract was concentrated to yield a semi-solid (1424 g), which was suspended in H_2O (1000 ml), and extracted with AcOEt (3 × 600 ml). The combined AcOEt phase was concentrated to yield a residue (105 g), part of which (100 g) was subjected to CC (2 kg of SiO_2, petroleum ether/AcOEt gradient): *Fractions 1–7. Fr. 5* (eluted with petroleum ether/AcOEt 3:1) was subjected to repeated CC (SiO_2; petroleum ether/AcOEt 4:1), and then to prep. TLC (petroleum ether/AcOEt 7:2): **1** (15 mg) and **2** (8 mg). *Fr. 4* (eluted with petroleum ether/AcOEt 5:1), was subjected to repeated CC (SiO_2, petroleum ether/AcOEt 8:1): **3** (6 mg). *Fr. 2* (eluted with petroleum ether/AcOEt 10:1) was subjected to repeated CC (SiO_2, petroleum ether/AcOEt 12:1), and then to prep. TLC (petroleum ether/acetone 20:1): **4** (4 mg).

Solidagocanin A (=*(2*Z*)-3-Methyl-5-{(1*S*,2*R*,4*R*,4a*R*,8a*R*)-1,2,3,4,4a,7,8,8a-octahydro-1,2,4a,5-tetramethyl-4-{[(2*E*)-2-methyl-1-oxobut-2-en-1-yl]oxy}naphthalen-1-yl}pent-2-enoic Acid*; **1**): White powder. $[\alpha]_D^{25} = +32$ (*c* = 0.05, MeOH). UV (MeOH): 219 (3.52). IR (KBr): 3441, 2967, 1700, 1694, 1636, 1437, 1256, 1156, 1072. ^{1}H- and ^{13}C-NMR: *Tables 1* and *2*. HR-ESI-MS: 403.2835 ($[M+H]^+$, $C_{25}H_{39}O_4^+$; calc. 403.2849).

Solidagocanin B (=*(2*Z*)-3-Methyl-5-{(1*S*,2*R*,4*R*,4a*R*,8a*R*)-1,2,3,4,4a,7,8,8a-octahydro-1,2,4a,5-tetramethyl-4-{[(2*Z*)-2-methyl-1-oxo-but-2-en-1-yl]oxy}naphthalen-1-yl}pent-2-enoic Acid*; **2**): White powder. $[\alpha]_D^{25} = +36$ (*c* = 0.05, MeOH). UV (MeOH): 218 (3.86). IR (KBr): 3429, 2967, 1710, 1690, 1639, 1438, 1385, 1232, 1158. ^{1}H- and ^{13}C-NMR: *Tables 1* and *2*. HR-ESI-MS: 403.2832 ($[M+H]^+$, $C_{25}H_{39}O_4^+$; calc. 403.2849).

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