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New Taxane Diterpenoids from the Roots of Taiwanese *Taxus mairei*

Ya-Ching SHEN,*[,a] Yao-To CHANG,[a] Yu-Chi LIN,[a] Chung-Ling LIN,[a] Yao-Haur KUO,[b] and Ching-Yeu CHEN[a]

[a] *Institute of Marine Resources, National Sun Yat-sen University; 70 Lien-Hai Rd., Kaohsiung, Taiwan, Republic of China: and* [b] *National Research Institute of Chinese Medicine; Taipei, Taiwan, Republic of China.*

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Five new taxane diterpenoids, taxumairols G (1), H (2), I (3), J (4), and L (5) were isolated from extracts of the roots of Taiwanese *Taxus mairei* (LEMEE & LEVL.) S. Y. Hu. Compounds 1—4 belong to the new 11(15→1)-*abeo*-taxene system, having a tetrahydrofuran ring along carbons C-2, C-3, C-4 and C-20. Compounds 3 and 4 contain an isopropenyl group at C-1 while compounds 1 and 2 are attached with a benzoxyl group at C-15. The structures of compounds 1—5 were determined on the basis of two-dimensional (2D)-NMR techniques including correlation spectroscopy (COSY), heteronuclear single quantum coherence (HSQC), heteronuclear multiple bond correlation (HMBC), and nuclear Overhauser effect spectroscopy (NOESY) experiments.

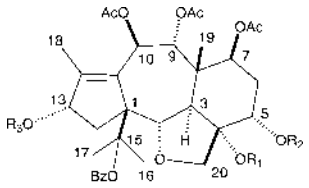
Key words *Taxus mairei*; Taxaceae; taxane diterpenoids; taxumairols

Nearly 400 taxane diterpenoids have been isolated and identified.[1—3] Taiwan yew *Taxus mairei* is an evergreen shrub growing at high altitudes (2600 m) in the northern and central parts of Taiwan. Recent studies on the taxane diterpenoids of *T. mairei* have resulted in the isolation of taxumairols N and O from the roots,[4] and taxumairol R from the root bark,[5] taxumains A and B from the twigs,[6] taxumairol M and taxumairone A from the seeds,[7,8] 13-deacetylcanadensene and 7-deacetylcanadensene from the needles,[9] and taxumairols U—W from the stem bark.[10] Owing to the special geographic and weather conditions, yew trees grown in Taiwan appear different from *Taxus chinensis* var. *mairei* in mainland China. Comparison of the chemical constituents of *T. chinensis* var. *mairei* and of *T. mairei* revealed distinct differences. Our investigation on taxoids present in this particular tree for chemotaxonomic and structure–activity relationship (SAR) purposes[11—13] have led to the isolation and structure elucidation of five new taxoids (**1**—**5**) from Taiwanese *T. mairei*.

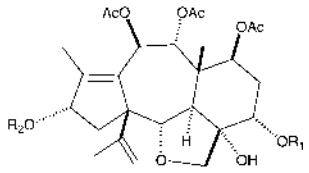
Results and Discussion

Column chromatography, preparative TLC (Si gel and RP-C_{18}), and reverse-phase HPLC of the ethanolic extract of roots of *T. mairei* yielded taxumairols G (**1**), H (**2**), I (**3**), J (**4**), and L (**5**).

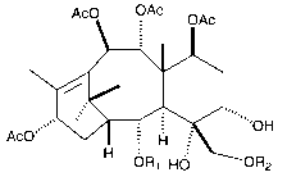
Taxumairol G (**1**), $[\alpha]$ +5.5° (CH_2Cl_2), had the molecular formula $C_{37}H_{46}O_{14}$ as derived from negative high resolution (HR)-FAB-MS. IR indicated the presence of benzoyl (1714, 1450, 1371 cm^{-1}), hydroxyl (3460 cm^{-1}), and acetyl (1745, 1739, 1732 cm^{-1}) groups. The ^{1}H-NMR data of **1** (Table 1) indicated a benzoyl group (δ 7.93, d, J=7.4 Hz; δ 7.40, t, J=7.4 Hz and δ 7.54, t, J=7.4 Hz), five acetyl singlets (δ 1.73, 2.05, 2.08×2, 2.11), four methyl singlets (δ 1.46, 1.72, 1.75, 1.80), two pairs of coupled doublets at δ 4.44, 3.77 (H-20, J=11.5 Hz), 4.86 (H-9, J=4.5 Hz), and 6.01 (H-10, J=4.5 Hz), and four oxygenated methine protons at δ 4.34 (H-5, dd, J=8, 11 Hz), δ 4.96 (H-7, dd, J=12.7, 3.1 Hz), δ 5.12 (H-2, d, J=7.5 Hz), and δ 5.74 (H-13, t, J=7.1 Hz). The connectivities of H-2/H-3, H-5/H-6/H-7, H-9/H-10, and H-13/H-14 were established by the correlation spectroscopy (COSY) spectrum of **1**. Analysis of the ^{13}C-NMR and heteronuclear single quantum coherence (HSQC) spectra (Table 1) revealed that **1** is a 11(1→15)-*abeo*-taxane with a novel 2,20-tetrahydrofuran ring.[2,3] The dimethyl carbinol group at C-1 was observed from the adjacent quaternary carbons at δ 65.2 (C-1) and δ 87.7 (C-15), and cross-peaks from Me-16 (δ 1.72) and Me-17 (δ 1.80) to C-1 and C-15 as well as correlations of geminal dimethyl (16/17) in the heteronuclear multiple bond correlation (HMBC) spectrum (Table 1). Moreover, long-range correlations were found among H-20/C-2, C-3, and C-4. Additional HMBC data such as H-



1 R_1 = Ac, R_2 = H, R_3 = Ac
2 R_1 = R_2 = R_3 = H
6 R_1 = R_2 = R_3 = Ac
7 R_1 = H, R_2 = R_3 = Ac



3 R_1 = H, R_2 = Ac
4 R_1 = R_2 = H
8 R_1 = R_2 = Ac



5 R_1 = R_2 = Ac
9 R_1 = R_2 = H

* To whom correspondence should be addressed. e-mail: ycshen@mail.nsysu.edu.tw

Table 1. ^{1}H- and ^{13}C-NMR ($CDCl_3$) Spectral Data of Taxumairol G (**1**)

Position	^{13}C (ppm)[a]	^{1}H[b]	COSY	HMBC
1	65.2 s			Me16, Me17, H2 H3, H10, H14
2	79.8 d	5.12 (d, 7.5)	H3	H3, H14, H20
3	50.5 d	2.47 (dd, 7.1, 1.6)	H2, H20A	H5, δ 4.55, H2, H20, Me19
4	94.3 s			H3, H20
5	71.6 d	4.34 (dd, 8, 11)	H6	H3, H20
6	30.2 t	2.06 m, 1.89 m	H5, H7	
7	69.9 d	4.96 (dd, 12.7, 3.1)	H6	H6, Me19
8	43.0 s			H2, H3, H9, Me19
9	73.6 d	4.86 (d, 4.5)	H10	H10, Me19
10	69.3 d	6.01 (d, 4.5)	H9	H9
11	135.5 s			H9, H10, H13, H14, Me18
12	145.2 s			H10, H13, H14b, Me18
13	81.2 d	5.74 (t, 7.1)	H14	H14
14	35.6 t	2.77 (dd, 7.7, 14.6)	H13	H2
		2.15 (dd, 14.6, 7.5)		
15	87.7 s			H14, H2, Me16, Me17
16	24.0 q	1.72 s		Me17
17	25.3 q	1.80 s		Me16
18	13.0 q	1.75 s	H13	
19	15.2 q	1.46 s		H3, H9
20A	72.8 t	4.44 (d, 11.5)	H20	
20B		3.77 (d, 11.5)	H20	
4-OAc	169.2 s	2.08 s		
	21.0 q			
7-OAc	172.3 s	2.11 s[c]		H7
	20.9 q			
9-OAc	169.0 s	2.08 s[c]		H9
	21.0 q			
10-OAc	169.1 s	2.05 s[c]		H10
	20.8 q			
13-OAc	170.5 s	1.73 s[c]		H13
	21.1 q			
$OCOC_6H_5$	165.9 s			*o*-C_6H_5
i	132.7 s			
o	129.4 d	7.93 (d, 7.4)	*m*-C_6H_5	*p*-C_6H_5, *m*-C_6H_5
m	128.3 d	7.40 (t, 7.4)	*o*,*p*-C_6H_5	
p	132.6 d	7.54 (t, 7.4)	*m*-C_6H_5	*o*-C_6H_5
OH		4.55 (br s)		

a) S=C, D=CH, T=CH_2, Q=CH_3. Multiplicities and assignments made by HMQC and HMBC. *b*) Multiplicities and coupling constants in Hz in parentheses. *c*) Data interchangeable.

3/C-1, C-2, C-4, C-8, and C-19 and Me-18/C-11, C-12, Me-19/C-7, C-8, and C-9 and H-10/C-8, C-11 and C-12 fully supported the structure of **1** and had a rearranged 5/7/6-membered ring with a tetrahydrofuran ring. Four acetoxyl groups were arranged at C-7, C-9, C-10, and C-13 due to HMBC correlations of their methine protons with the corresponding carbonyl signals. The remaining groups, including an acetyl, a hydroxyl, and a benzoyl moiety were placed tentatively at C-4, C-5, and C-15. A literature survey indicated that taxuspine K, isolated from *Taxus cuspidata*, and taxuyunnanine E, isolated from *Taxus yunnanensis*, are two analogues of **1**.[3,14—16] Detailed comparison of the proton and carbon resonances of H-5, C-5 (δ 71.6), and C-4 (δ 94.3) of **1** with those of taxuspine K and taxuyunnanine E revealed that the remaining acetyl and hydroxyl groups should be located at C-4 and C-5, respectively. Although these compounds had similar ^{1}H- and ^{13}C-NMR data, the chemical shifts of C-15 (δ 87.7), C-16 (δ 24.0), and C-17 (δ 25.3) in **1** were markedly different from those of taxuyunnanine E. This led to the conclusion that the benzoyl moiety might be attached at C-15. Upon acetylation, taxumairol G (**1**) yielded compound **6**, which showed an additional acetyl singlet at δ 1.99. The H-5 signal was also shifted downfield from 4.34 ppm in **1** to δ 5.86 ppm in **6**. The assignments of proton and carbon chemical shifts of **6** were completed by extensive two-dimensional (2D)-NMR analysis (COSY, HSQC, and HMBC). The relative stereochemistry of **1** was determined from coupling constants and nuclear Overhauser effect spectroscopy (NOESY) data. The NOESY correlations of H-2/H-9, Me-16, Me-17, and H-9/Me-19 in **1** suggested that H-2, H-9, Me-19, and the dimethyl carbinol group were in β-orientation. Correlations between H-3/H-7 and H-10/Me-18 agreed with the α-configuration of H-3, H-7, and H-10. Correlations between the *ortho* protons of the benzoyl group and H-2 and Me-19 not only assigned the benzoyl to C-15 but also confirmed that the C-1 benzoyl dimethyl carbinol moiety is in the β-orientation. The small coupling constant between H-9 and H-10 (J=3.8 Hz), results from the anti-orientation of two acetoxyls at C-9 and at C-10 and the gauche-relationship of H-9 and H-10, which leads to a dihedral angle of 45° between H-9 and H-10.[17] Intense cross-peaks between H-9 and H-10 in the NOESY spectrum of **1** were also observed. A chair-like conformation of ring B and ring C consistent with the results from NOESY experiments is given in

Fig. 1. The large coupling constants of H-5 (J=8, 11 Hz) suggested that the C-5 hydroxyl group should be in the α-orientation. This might be explained by calculation of the dihedral angles of H-5/C-5/C-6/H-6B (30°) and H-5/C-5/C-6/H-6A (165°).

Taxumairol H (**2**), [α] +2.6° (CH_2Cl_2), had the composition $C_{33}H_{42}O_{12}$ as derived from electron impact (EI)-MS and distortionless enhancement by polarization transfer (DEPT) spectral data. As in **1**, the presence of four methyl (δ 1.43, 1.70, 1.76, 1.80), three acetyl (δ 1.74, 1.98, 2.05), and a benzoyl (δ 7.39, 7.50, 7.93) groups, and two pairs of doublets (δ 3.81, 3.92, J=10.2 Hz, H-20; 5.97, 4.82, J=3.6 Hz, H-10, H-9) indicated that compound **2** was a close analogue of **1** (Table 2). Detailed comparison of the ^{1}H- and ^{13}C-NMR spectra of **2** with those of taxumairol G (**1**) revealed that the two compounds differ at C-4 and C-13. The proton signal of H-13 was observed at δ 4.69, suggesting that the acetyl group of C-13 in **1** was replaced by a hydroxyl in **2**. The additional hydroxyl group should be at C-4 because the chemical shifts of C-4, C-20, and C-5 in **2** appeared at δ 83.0, 76.3, and 74.1 relative to δ 94.3, 72.8, and 71.6 in **1**. This structural elucidation was in agreement with the results of COSY, HSQC, and HMBC experiments. The HMBC spectrum of **2** showed very similar correlations to those of **1**, confirming the location of the acetoxyl groups at C-7, C-9, and C-10, and the benzoyl dimethyl carbinol group at C-1 (Table 2). The stereochemistry of **2** was assigned by comparison of the chemical shifts and coupling constants with those of compound **1**, while a NOESY experiment confirmed the assignment. The coupling constant between H-2 and H-3 agreed with the α-configurations of both the C-2 oxygen and of H-3. The coupling patterns of H-7 and H-5 and of H-9 and H-10 (J=3.6 Hz) are similar to those of compound **1**. Acetylation of compound **2** yielded a diacetylated compound (**7**), in which the signals of H-13 and H-5 were shifted downfield to

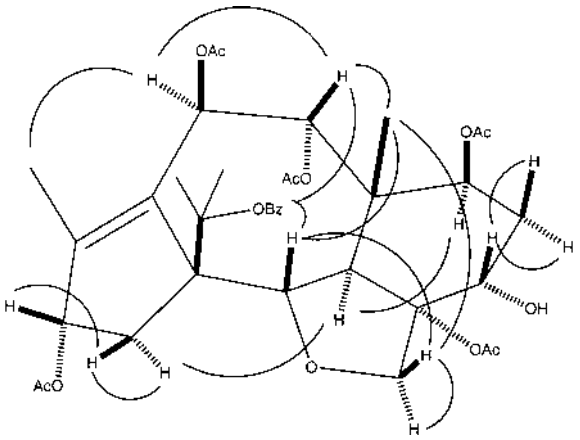


Fig. 1. NOESY Correlation of Taxumairol G (**1**)

Table 2. ^{1}H- and ^{13}C-NMR ($CDCl_3$) Spectral Data of Taxumairol H (**2**)

Position	^{13}C (ppm)[a]	^{1}H[b]	COSY	HMBC
1	65.0 s			Me16, Me17, H2, H10
2	80.5 d	5.10 (d, 7.0)	H3	
3	51.0 d	2.27 (d, 7.0)	H2, H20A	H9, Me19
4	83.0 s			H20
5	74.1 d	4.30 (dd, 7.2, 11.2)	H6	
6	31.4 t	1.95 m, 1.80 m	H5, H7	
7	70.8 d	4.85 (dd, 11.7, 2.7)	H6	Me19
8	43.7 s			H2, H7, H9, Me19
9	73.7 d	4.82 (d, 3.6)	H10	H10, Me19
10	69.8 d	5.97 (d, 3.6)	H9	H9
11	133.4 s			H9, H10, Me18
12	149.0 s			H10, Me18
13	78.5 d	4.69 (t, 7.2)	H14	
14	38.9 t	2.68 (dd, 7.8, 14.1)	H13	
		2.05 m		
15	87.9 s			H2, Me16, Me17
16	24.0 q	1.70s		Me17
17	25.3 q	1.80s		Me16
18	12.9 q	1.76s	H13	
19	15.0 q	1.43s		
20A	76.3 t	3.92 (d, 10.2)	H20	
20B		3.81 (d, 10.2)	H20	
7-OAc	171.2 s	1.98 s[c]		H7
	21.1 q			
9-OAc	169.3 s	2.05 s[c]		H9
	20.9 q			
10-OAc	169.0 s	1.74sc		H10
	20.7 q			
$OCOC_6H_5$	166.0 s			*o*-C_6H_5
i	132.8 s			
o	129.4 d	7.93 (d,7.4)	*m*-C_6H_5	*p*-C_6H_5, *m*-C_6H_5
m	128.3 d	7.39 (t,7.4)	*o*,*p*-C_6H_5	
p	132.6 d	7.50 (t,7.4)	*m*-C_6H_5	*o*-C_6H_5
OH		5.30 (br s)		

a) S=C, D=CH, T=CH_2, Q=CH_3. Multiplicities and assignments made by HMQC and HMBC. *b*) Multiplicities and coupling constants in Hz in parentheses. *c*) Data interchangeable.

Table 3. ^{1}H- and ^{13}C-NMR ($CDCl_3$) Spectral Data of Taxumairol I (**3**)

Position	^{13}C (ppm)[a]	^{1}H[b]	COSY	HMBC
1	59.2 s			H16, Me17, H10, H2, H14
2	82.1 d	4.69 (d, 7.2)	H3	H20
3	51.6 d	2.28 (d,7.2)	H2	H9, H20, Me19
4	82.9 s			H3, H20
5	73.4 d	4.35 (dd, 7.2, 11.8)	H6	H3
6	31.6 t	2.03 m, 1.87 m	H5, H7	H5
7	70.8 d	5.00 (dd, 12.2, 3.3)	H6	Me19
8	43.8 s			H9, H10, Me19, H2, H3
9	73.6 d	4.87 (d, 4.3)	H10	H10, Me19, H3
10	69.3 d	5.85 (d, 4.3)	H9	H9
11	135.8 s			H9, H10, Me18
12	141.3 s			H10, Me18, H14
13	81.1 d	5.70 (t, 7.0)	H14	H14, Me18
14	38.5 t	2.30 m, 1.88 m	H13	H2
15	148.9 s			H14, H2, H16, Me17
16	110.6 t	4.77 br s		Me17
17	20.9 q	1.77 s		H16
18	20.1 q	1.70 s	H13	
19	15.2 q	1.40 s		
20A	76.5 t	3.87 (d, 10.2)	H20	H3, H5
20B		3.81 (d, 10.2)	H20	
7-OAc	170.6 s	2.00 s		H7
	20.0 q			
9-OAc	169.8 s	2.08 s		H9
	20.8 q			
10-OAc	169.0 s	1.95 s		H10
	19.8 q			
13-OAc	171.2 s	2.10 s		H13
	20.4 q			

a) S=C, D=CH, T=CH_2, Q=CH_3. Multiplicities and assignments made by HMQC and HMBC. *b*) Multiplicities and coupling constants in Hz in parentheses.

5.79 and 5.30 ppm, respectively. Thus diacetyl taxumairol H was identical to taxumairol G.

Taxumairol I (**3**), $[\alpha]$ +73.5° (CH_2Cl_2), had the composition $C_{28}H_{38}O_{11}$ as determined by negative HR-FAB-MS. Analysis of the ^{1}H- and ^{13}C-NMR spectra of **3** revealed that it was an analogue of **1** and **2** but lacked a benzoyl moiety. Surprisingly, only three methyl groups (δ 1.40, 1.70, and 1.77) were observed and an unusual broad singlet (two protons) appeared at δ 4.77 (H-16). In addition to four acetyls (δ 1.95, 2.00, 2.08, and 2.10), characteristic peaks included two pairs of doublets (δ 3.81, 3.87, J=10.2 Hz, H-20; 5.85, 4.87, J=4.3 Hz, H-10, H-9), a doublet δ 4.69 (H-2), and a double doublet at δ 4.35 (H-5). Detailed comparison of ^{1}H-NMR data with those of **2** suggested that compound **3** contains an additional acetyl group at C-13, since the chemical shift of H-13 in **3** appeared at δ 5.70 (t, J=7.0 Hz) relative to δ 4.69 in **2**. These findings were supported by the ^{13}C-NMR spectrum of **3**, which showed resonances of C-13, C-12, and C-11 at δ 81.1, 141.3, and 135.8, while the corresponding signals in **2** were at δ 78.5, 149.0, and 133.4. The chemical shifts of C-1, C-15, C-16, and C-17 for **3** were at 59.2, 148.9, 110.6, and 20.9 ppm, respectively, while they occurred at 65.0, 87.9, 24.0, and 25.3 ppm in compound **2**. The structure of **3** was further confirmed by COSY, HMQC, and HMBC studies (Table 3). The HMBC of **3** showed connectivities of C-1, C-15/H-2, H-14, H-16, Me-17, and C-2 (δ 82.1), C-3, C-4 (δ 82.9)/H-20 as well as of C-20/H-5, confirming not only the 1-methyl-ethenyl at C-1, but also the tetrahydrofuran ring at C-2 and C-20. The relative stereochemistry of **3** was determined from chemical shifts, couping constants, and NOESY data. The NOESY correlations of H-13/H-14β and H-13/Me-17 in **3** suggested that H-13 and the propylene group were in the β-orientation. Correlation of H-10/Me-18 indicated that H-10 was in the α-disposition. Correlation of H-9/Me-19 and Me-19/H-2, and Me-19/H-20β agreed with a β-configuration of H-9 and H-2. A coupling constant of 4.3 Hz between H-9 and H-10 indicated that the conformation of the B ring was the same as those of **1** and **2**. NOESY correlations from H-5 to H-6β and H-6α to H-7 were consistent with the proposed relative stereochemistry at C-5. Acetylation of **3** provided a pentacetate (**8**), in which the signal of H-5 was shifted downfield to 5.31 ppm.

Taxumairol J (**4**), +9.8° (c=0.2, CH_2Cl_2), had the composition $C_{26}H_{36}O_{10}$ as derived from a *quasi*-molecular ion at *m*/*z* 509 in low-resolution FAB-MS. IR indicated the presence of hydroxyl (3450 cm^{-1}) and acetyl (1743 cm^{-1}) groups, as was found in **3**. Analysis of the ^{1}H- and ^{13}C-NMR spectra of **4** revealed that it was an analogue of **3** (Table 4). Three methyl singlets appeared at δ 1.40, 1.67, and 1.76. Characteristic peaks included two olefinic singlets at δ 4.81 and 4.75, as well as two pairs of doublets at δ 5.80 and 4.85 for H-10 and H-9 (J=4.2 Hz), and at δ 3.90 and 3.80 for H-20 (J=10.2 Hz). The ^{13}C-NMR spectrum of **4** exhibited signals for C-1, C-15, C-16, and C-17 at δ 59.2, 149.6, 110.1, and 20.9, respectively, similar to those in **3**. The assignment of each proton and each carbon was confirmed by COSY, HSQC, and further HMBC experiments (Table 4). Comparison of the ^{1}H-NMR data with those of **3** revealed that the only difference was the presence of three acetyl (δ 1.94, 1.99, and 2.06) and three hydroxyl groups in **4** instead of four acetyl and two hydroxyl groups in **3**. The signal of H-13 in **4** at δ 4.70 implies that a hydroxyl is attached to C-13. The stereochemistry of **4**

Table 4. ^{1}H- and ^{13}C-NMR ($CDCl_3$) Spectral Data of Taxumairol J (**4**)

Position	^{13}C (ppm)[a]	^{1}H[b]	COSY	HMBC
1	59.2 s			H16, Me17
2	82.2 d	4.75 (overlap)	H3	
3	51.6 d	2.30 (d, 7.1)	H2	H9, Me19
4	83.0 s			
5	73.6 d	4.30 (br t)	H6	
6	31.6 t	1.95 m, 1.83 m	H5, H7	
7	71.0 d	4.92 (d, 9.6)	H6	Me19
8	43.9 s			H9, Me19
9	73.9 d	4.85 (d, 4.2)	H10	H10, Me19
10	69.7 d	5.80 (d, 4.2)	H9	H9
11	134.3 s			H9, H10
12	144.4 s			H10, Me18
13	79.3 d	4.70 (t, overlap)	H14	Me18
14	41.4 t	2.18 m, 1.95 m	H13	
15	149.6 s			H14, H2, H16, Me17
16	110.1 t	4.81 s, 4.75 s		Me17
17	20.9 q	1.67 s		
18	12.2 q	1.76 s	H13	
19	15.3 q	1.40 s		
20A	76.3 t	3.90 (d, 10.2)	H20	
20B		3.80 (d, 10.2)	H20	
7-OAc	170.9 s	1.99 s		H7
	21.0 q[c]			
9-OAc	169.8 s	2.06 s		H9
	21.2 q[c]			
10-OAc	169.0 s	1.94 s		H10
	21.3 q[c]			

a) S=C, D=CH, T=CH_2, Q=CH_3. Multiplicities and assignments made by HMQC and HMBC. *b*) Multiplicities and coupling constants in Hz in parentheses. *c*) Data interchangeable.

was established on the basis of NOESY observations of the sequence Me-18/H-10/H-9/Me-19/H-2/Me-17 and chemical correlation with compound **3**. Finally, taxumairol J (**4**) was experimentally assigned to be 13-deacetyltaxumairol I. Thus upon acetylation, **4** yielded a diacetylated compound identical to compound **8**.

Taxumairol L (**5**), $[\alpha]$ +12.8° (MeOH), had the composition $C_{32}H_{46}O_{14}$ as deduced from EI, FAB-MS, and negative HR-FAB-MS at *m/z* 653 ($C_{32}H_{45}O_{14}$, $[M-H]^-$). IR indicated the presence of hydroxyl (3430, 3405 cm^{-1}) and acetoxyl (1741 cm^{-1}) groups. The characteristic resonances in the ^{1}H- and ^{13}C-NMR spectra (Table 5), such as signals for four methyl and six acetyl groups, as well as for an oxymethylene moiety (δ 66.5) indicated that **5** is a 6/8/6 taxane with an opened oxetane ring skeleton.[18] This was corroborated by detailed analysis of the ^{1}H–^{1}H COSY and HMBC spectra of **5** (Table 5). Cross-peaks deduced from the COSY spectrum were H1 (δ 1.80)/H2 (δ 5.51), H2/H3 (δ 3.25); H5 (δ 3.93)/H6 (δ 1.90, 1.70) and H6/H7 (δ 5.66); H9 (δ 5.78)/H10 (δ 6.20); H13 (δ 5.64)/H14 (δ 2.60, 2.00), H13/Me18 (δ 2.24), and H20A (δ 4.13)/H20B (δ 4.51). These results suggest that taxumairol L (**5**) has only two hydroxyl groups at C-4 and C-5. Detailed comparison of the ^{1}H- and ^{13}C-NMR spectral data of **5** with those of taxumairol N (**9**)[4] suggested that the hydroxyl groups at C-2 and C-20 in **9** were replaced by acetoxyl groups in **5**. Further evidence was provided by analysis of the HMBC data (Table 5), which fully supported the structure of **5**. In the HMBC spectrum, long-range correlations of H-10, Me-16, Me-17, and Me-18 to C-11 (δ 134.0), H-14β to C-2 (δ 72.3), and H-3, Me-16, and Me-17 to C-1 (δ 47.5) and C-15 (δ 37.0) indicated that **5** contains a cyclohexene with geminal dimethylgroups as ring A. The correlation peaks between H-3, H-5, H-20, and C-4 (δ 77.8) and between H-3, H-20, and C-5 (δ 69.3) revealed that **5** has an opened oxetane ring with C-4 being hydroxylated. The presence of an eight-membered ring (ring B) and a cyclohexane ring (ring C) was also established from HMBC correlations (H-2/H-3/H-7/H-9/C-8; H-10/Me-19/C-9; H-10/C-9/C-11; H-3/C-2). The configurations of substituents at C-2, C-5, C-7, C-9, C-10, and C-13 were determined to be α, α, β, α, β, and α, respectively, by comparison of the observed coupling constants and carbon shift data with those of taxumairol N (**9**). The broad singlet of H-5 agrees with an α-configuration of the hydroxyl group at C-5 in the ^{1}H-NMR spectrum of **5**. The coupling constant between H-9 and H-10 (J=10.9 Hz) in **5** is similar to that of taxumairol N (**9**), indicating that both compounds have the same stereogenic centers.

Compounds **1**—**4** are novel *abeo*-taxane diterpenoids with a 2,20- tetrahydrofuran ring system. The occurrence of compounds **1**—**5** in Taiwanese *T. mairei* may be of chemotaxonomic significance. Thus taxumairol L was concluded to be diacetyl taxumairol N.

Experimental

Optical rotations were measured with a JASCO DIP-1000 polarimeter. IR and UV spectra were recorded with a HORIBA FT-720 and a HITACHI U-3210 spectrophotometer, respectively. EI-MS, FAB-MS and HR-FAB-MS were measured with VG Quettro 5022 and JEOL JMS-SX 102 mass spectrometers. ^{1}H-, ^{13}C-NMR, COSY, HSQC, HMBC, and NOESY spectra were recorded using Bruker FT-300 (Avance) or Varian FT-500 (Inova) NMR instruments.

Plant Material The roots of *T. mairei* (Lemee & Levl.) S. Y. Hu were purchased in Kaohsiung, Taiwan, in October 1995. A voucher specimen is

Table 5. ^{1}H- and ^{13}C-NMR ($CDCl_3$) Spectral Data of Taxumairol L (**5**)

Position	^{13}C (ppm)[a]	^{1}H[b]	COSY	HMBC
1	47.5 d	1.80 m	H2, H14	Me16, Me17, H3
2	72.3 d	5.51 m	H1, H3	H3
3	43.5 d	3.25 (d, 4.5)	H2	H5
4	77.8 s			H3, H5, H20
5	69.3 d	3.93 (br s)	H6	H3, H20
6	31.4 t	1.90 m, 1.70 m	H5, H7	H7
7	68.1 d	5.66 m	H6	H5, H9, Me19
8	45.5 s			H2, H3, H7, H9
9	75.6 d	5.78 (d, 10.9)	H10	H10, Me19
10	71.8 d	6.20 (d, 10.9)	H9	H9
11	134.0 s			H10, Me16, Me17, Me18
12	138.8 s			H10, H14β, Me18
13	69.4 d	5.64 (overlap)	H14	H14
14	27.0 t	2.60 m(β), 2.00 m	H13	H2
15	37.0 s			H10, Me16, Me17
16	25.5 q	1.70 s		Me17
17	31.8 q	1.00 s		Me16
18	15.8 q	2.24 s	H13	
19	14.8 q	0.97s		H3, H7, H9
20A	65.0 t	4.13 (d, 12)	H20	H3
20B		4.51 (d, 12)	H20	
2-OAc	169.2 s	2.20 s		H2
	20.6 q			
7-OAc	169.5 s	2.05 s[c]		H7
	20.5 q			
9-OAc	171.3 s	2.10 s[c]		H9
	20.3 q			
10-OAc	169.0 s	1.97 s[c]		H10
	20.2 q			
13-OAc	170.3 s	2.03 s[c]		H13
	21.4 q			
20-OAC	170.0 s	2.12 s		H-20
	20.4 q			
OH		3.34 s, 3.00 s		

a) S=C, D=CH, T=CH_2, Q=CH_3. Multiplicities and assignments made by HMQC and HMBC. *b*) Multiplicities and coupling constants in Hz in parentheses. *c*) Data interchangeable.

kept in the Institute of Marine Resources, National Sun Yat-sen University.

Extraction and Isolation Dried roots (90 kg) were ground and repeatedly extracted with EtOH (300 l) at room temperature. The combined extracts were concentrated to a brown tar (9.5 kg), which was extracted with a solvent mixture of *n*-hexane/EtOAc in the following ratios and volumes 2 : 1, 45 l; 1 : 1, 48 l; 1 : 2, 45 l; EtOAc, 12 l, to give four portions A (900 g), B (1080 g), C (1500 g), and D (2500 g). Part of portion A (500 g) was applied on a Si gel column (5 kg) and eluted with a solvent mixture of CH_2Cl_2–Me_2CO of increasing polarity to provide a fraction (150 g). Rechromatography of this residue on a Si gel column (1.6 kg) and elution with *n*-hexane–EtOAC in the following ratios and volumes 5 : 1, 4 l; 10 : 3, 5 : 2, 2 : 1 and 1 : 1, each 10 l, yielded a residue (97 g), which was crystallized to afford 1β-dehydroxybaccatin VI (47 g). The mother liquid (50 g) was further chromatographed on a Si gel column (600 g) and eluted with *n*-hexane–CH_2Cl_2–MeOH (70 : 70 : 1, 60 : 60 : 1, 50 : 50 : 1, 40 : 40 : 1, 4 l each) to afford six fractions A (30 g), B (8 g), C (5.6 g), D (2 g), E (1 g), and F (1.2 g). Part of fraction A (1.3 g) was separated by HPLC (RP-C18) using MeOH/H_2O/CH_3CN (6 : 1 : 3; 75 : 10 : 15) to afford taxumairols G (**1**, 20 mg), I (**3**, 2 mg), J (**4**, 2 mg), and a residue (132 mg). This residue was applied to preparative TLC plates, and development with *n*-hexane–CH_2Cl_2–MeOH (7 : 7 : 1) gave taxumairol H (**2**, 34 mg). Fraction D (2 g) was applied on a Sephadex LH-20 column and eluted with CH_2Cl_2–MeOH (1 : 1) to give a residue (1.2 g). Part of the residue (50 mg) was purified by HPLC (RP-C18) using MeOH/H_2O/CH_3CN (6 : 3 : 1) to afford taxumairol L (**5**, 5 mg).

Taxumairol G (**1**): Isolated as an amorphous solid: $[\alpha]_D^{25}$ +5.5° (*c*=0.2, CH_2Cl_2); UV λ_{max} (log ε) (MeOH) nm: 224 (4.07); IR (neat) ν_{max} 3460, 1745, 1739, 1731, 1714, 1450, 1371, 1277, 1024, 715 cm^{-1}; ^{1}H- and ^{13}C-NMR ($CDCl_3$): Table 1; EI-MS *m*/*z* (rel. int.) 612 ([M−AcOH−Ac]$^+$, 0.1), 596 ([M−2AcO]$^+$, 0.2), 548 ([M−C_6H_5CO−AcO]$^+$, 0.2), 533 ([M−3AcOH−H]$^+$, 1), 491 ([M−3AcOH−Ac−H]$^+$, 2), 473 ([M−4AcOH−H]$^+$, 2), 431 ([M−4AcOH−Ac−H]$^+$, 4), 413 ([M−5AcOH−H]$^+$, 2), 373 (6), 372 (32), 357 (8), 329 (13), 313 (18), 297 (3), 269 (4), 252 (7), 149 (12), 133 (12), 121 (10), 105 (100), 77 (21), 43 (79); negative HR-FAB-MS *m*/*z* 713.2803 ([M−H]$^-$, Calcd for $C_{37}H_{45}O_{14}$, 713.2812).

Acetylation of Taxumairol G (1) Taxumairol G (**1**, 10 mg) was acetylated with acetic anhydride (0.5 ml) and pyridine (0.5 ml) and the usual work-up furnished taxumairol G monoacetate (**6**, 8 mg). ^{1}H-NMR (300 MHz, $CDCl_3$): δ: 5.09 (1H, d, *J*=7.5 Hz, H-2), 2.87 (1H, d, *J*=7.5 Hz, H-3), 5.86 (1H, dd, *J*=10.6, 8.6 Hz, H-5), 1.80, 2.18 (2H, m, H-6), 5.45 (1H, dd, *J*=12.4, 3.5 Hz, H-7), 4.87 (1H, d, *J*=4 Hz, H-9), 6.01 (1H, d, *J*=4 Hz, H-10), 5.80 (1H, t, *J*=9.1 Hz, H-13), 1.80, 2.80 (2H, m, H-14), 1.47, 1.73, 1.76, 1.78 (12H, s, H-16, 17, 18, 19), 4.15 (1H, d, *J*=10.9 Hz, H-20a), 3.82 (1H, d, *J*=10.9 Hz, H-20b), 2.09, 2.08, 2.07, 2.06, 2.05×2, 1.99 (s, $OCOCH_3$), 7.96 (2H, d, *J*=7.2 Hz, *o*-C_6H_5), 7.42 (2H, t, *J*=7.2 Hz, *m*-C_6H_5), 7.54 (1H, t, *J*=7.2 Hz, *p*-C_6H_5); ^{13}C-NMR (75 MHz, $CDCl_3$) δ: 65.5 (s, C-1), 80.6 (d, C-2), 49.2 (d, C-3), 89.2 (s, C-4), 71.0 (d, C-5), 29.5 (t, C-6), 69.0 (d, C-7), 43.4 (s, C-8), 73.5 (d, C-9), 69.5 (d, C-10), 135.2 (s, C-11), 146.0 (s, C-12), 80.7 (d, C-13), 36.1 (t, C-14), 87.9 (s, C-15), 25.2 (q, C-16), 24.0 (q, C-17), 13.0 (q, C-18), 14.9 (q, C-19), 74.6 (t, C-20), 169.0, 169.4, 169.5, 169.9, 170.0, 170.6 (s, O$\underline{C}$O$\underline{C}$H$_3$), 20.7, 20.8, 21.0×2, 21.1, 22.0, (q, OCO$\underline{C}$H$_3$), 166.0 (s, O$\underline{C}$O$\underline{C}_6$H$_5$), 132.8 (s, C_6H_5, *i*), 129.6 (d, C_6H_5, *o*), 128.3 (d, C_6H_5, *m*), 132.7 (d, C_6H_5, *p*); HMBC (300 MHz, $CDCl_3$): [C-1, H-2, H-3, H-10], [C-3, H-2], [C-4, H-3, H-9, H-20], [C-5, H-9, H-20], [C-6, H-7], [C-8, H-2, H-3, H-6, H-9, H-19], [C-9, H-7, H-10], [C-10, H-9], [C-11, H-10, H-14, H-18], [C-12, H-10, H-14, H-18], [C-13, H-18], [C-14, H-2], [C-15, H-2, H-14, H-16, H-17], [C-16, H-17], [C-17, H-16], [C-19, H-3, H-7, H-9], [OAc-5, H-5], [OAc-7, H-7], [OAc-9, H-9], [OAc-10, H-10], [OAc-13, H-13], [OCO$\underline{C}_6$H$_5$, *o*-C_6H_5], [*i*, *p*-C_6H_5]; EI-MS *m*/*z* (rel. int.) 634 (0.1), 574 (0.4), 514 (2), 472 (2), 454 (2), 414 (5), 399 (2), 368 (3), 355 (3), 339 (2), 310 (3), 292 (5), 274 (5), 251 (11), 221 (7), 191 (14), 161 (17), 149 (32), 133 (52), 122 (25), 105 (91), 77 (52), 69 (21), 43 (100).

Taxumairol H (**2**): Isolated as an amorphous solid: $[\alpha]_D^{25}$ +2.6° (*c*=0.2,

CH_2Cl_2); UV λ_{max} (log ε) (MeOH) nm: 225 (4.15); IR (neat) ν_{max} 1745, 1712, 1450, 1369, 1250, 1157, 1138, 1113, 1068, 1028, 737, 715 cm^{-1}; ^{1}H- and ^{13}C-NMR ($CDCl_3$) in Table 2; EI-MS *m/z* (rel. int.) 552 ([M−AcOH−H_2O]$^+$, 0.3), 490 (0.3), 473 ([M−2AcOH−2H_2O]$^+$, 0.5), 448 (2), 430 ([M−3AcOH−H_2O−2H]$^+$, 2), 412 ([M−3AcOH−2H_2O−2H]$^+$, 1.5), 389 (6), 370 (44), 355 (3), 329 (9), 315 (12), 209 (12), 179 (11), 167 (17), 161 (24), 149 (31), 133 (24), 122 (36), 105 (100), 77 (30).

Acetylation of Taxumairol H (2) Taxumairol H (10 mg) was acetylated with acetic anhydride (0.5 ml) and pyridine (0.5 ml), and the usual work-up furnished taxumairol H diacetate (**7**, 7 mg). ^{1}H-NMR (300 MHz, $CDCl_3$): δ: 5.05 (1H, d, *J*=7.8 Hz, H-2), 2.39 (1H, d, *J*=7.8 Hz, H-3), 5.30 (1H, dd, *J*=11, 8.1 Hz, H-5), 5.08 (1H, overlapped, H-7), 4.86 (1H, d, *J*=3.9 Hz, H-9), 6.02 (1H, d, *J*=3.9 Hz, H-10), 5.79 (1H, t, *J*=7.2 Hz, H-13), 2.80 (1H, m, H-14), 1.44, 1.74, 1.78, 1.81 (12H, s, H-16, 17, 18, 19), 3.72 (1H, d, *J*=10.1 Hz, H-20a), 3.67 (1H, d, *J*=10.1 Hz, H-20b), 2.10, 2.08, 1.99, 1.78, 1.77 (s, $OCOCH_3$), 7.95 (2H, d, *J*=7.5 Hz, *o*-C_6H_5), 7.40 (2H, t, *J*=7.5 Hz, *m*-C_6H_5, 7.52 (1H, t, *J*=7.5 Hz, *p*-C_6H_5); EI-MS *m/z* (rel. int.) 596 ([M−2AcO]$^+$, 0.1), 533 ([M−3AcOH−H]$^+$, 0.5), 473 ([M−4AcOH−H]$^+$, 0.5), 414 ([M−5AcOH]$^+$, 7), 372 (4), 357 (26), 251 (10), 149 (10), 133 (18), 105 (100), 77 (25), 43 (93).

Taxumairol I (**3**): Isolated as an amorphous powder: $[\alpha]_D^{25}$ +73.5° (*c*=0.2, CH_2Cl_2); IR (neat) ν_{max} 2954, 2925, 2854, 1739, 1446, 1371, 1242, 1174, 1068, 1030, 930, 737 cm^{-1}; ^{1}H- and ^{13}C-NMR ($CDCl_3$) in Table 3; FAB-MS *m/z*: 551 [M+H]$^+$; EI-MS *m/z* (rel. int.) 550 ([M]$^+$, 0.1), 490 ([M−AcOH]$^+$, 0.8), 472 ([M−AcOH−H_2O]$^+$, 1.3), 430 ([M−2AcOH]$^+$, 2), 412 ([M−2AcOH−H_2O]$^+$, 1.3), 370 ([M−3AcOH]$^+$, 3), 355 (2.3), 329 (2), 310 (3), 221 (5), 209 (9), 179 (7), 167 (14), 161 (19), 149 (30), 145 (23), 133 (28), 121 (20), 105 (24), 95 (25), 91 (17), 85 (25), 69 (20), 55 (18); negative HR-FAB-MS *m/z* 549.2344 ([M−H]$^-$, Calcd for $C_{28}H_{37}O_{11}$, 549.2330).

Acetylation of Taxumairol I (3) Taxumairol I (**3**, 1 mg) was acetylated with acetic anhydride (0.2 ml) and pyridine (0.2 ml) and the usual work-up furnished taxumairol I monoacetate (**8**, 0.7 mg). ^{1}H-NMR (300 MHz, $CDCl_3$): δ: 4.68 (1H, d, *J*=7.4 Hz, H-2), 2.38 (1H, d, *J*=7.6 Hz, H-3), 5.31 (1H, dd, *J*=12, 7 Hz, H-5), 5.10 (1H, m, H-7), 4.88 (1H, d, *J*=4.2 Hz, H-9), 5.85 (1H, d, *J*=4.2 Hz, H-10), 5.72 (1H, t, *J*=7.0 Hz, H-13), 4.80 (1H, br s, H-16), 4.76 (1H, br s, H-16), 1.43, 1.69, 1.74 (12H, s, H-17, 18, 19), 3.72 (1H, d, *J*=10.3 Hz, H-20a), 3.68 (1H, d, *J*=10.3 Hz, H-20b), 2.13, 2.09, 2.08, 1.99, 1.95 (s, $OCOCH_3$); EI-MS *m/z* (rel. int.) 574 (0.6, [M−H_2O]$^+$), 532 ([M−AcOH]$^+$, 4), 514 ([M−AcOH−H_2O]$^+$, 4), 474 (2), 472 ([M−AcOH−Ac−H_2O]$^+$, 5), 454 ([M−2AcOH−H_2O]$^+$, 8), 412 ([M−3AcOH]$^+$, 10), 397 (3), 370 (12), 357 (20), 352 ([M−4AcOH]$^+$, 309 (4), 292 ([M−5AcOH]$^+$, 14), 274 (([M−5AcOH−H_2O]$^+$, 9), 263 (9), 251 (19), 221 (17), 191 (35), 161 (56), 149 (98), 133 (100), 121 (42), 105 (93).

Taxumairol J (**4**): Isolated as an amorphous powder: $[\alpha]_D^{25}$ +9.8° (*c*=0.2, CH_2Cl_2); IR (neat) ν_{max} 3450, 1743, 1371, 1248, 1070, 1036 cm^{-1}; ^{1}H- and ^{13}C-NMR ($CDCl_3$) in Table 4; FAB-MS *m/z*: 509 [M+H]$^+$; EI-MS *m/z* (rel. int.) 444 (1.5), 394 (1), 272 (4), 255 (2), 236 (3), 209 (3), 179 (5), 167 (6), 149 (12), 121 (13), 97 (18), 95 (20), 91 (31), 83 (28), 69 (38), 57 (38), 55 (43).

Acetylation of Taxumairol J (4) Taxumairol J (1 mg) was acetylated with acetic anhydride (0.2 ml) and pyridine (0.2 ml) and the usual work-up furnished taxumairol J diacetate (1 mg) (spectral data [^{1}H-NMR and EI-MS] identical to those of compound **8**).

Taxumairol L (**5**): Isolated as an amorphous powder: $[\alpha]_D^{25}$ +12.8° (*c*=0.2, MeOH); IR (neat) ν_{max} 3430, 3405, 2918, 2850, 1741, 1373, 1238, 1030 cm^{-1}; ^{1}H- and ^{13}C-NMR ($CDCl_3$) in Table 5; FAB-MS *m/z*: 677 [M+Na]$^+$; EI-MS *m/z* (rel. int.) 595 ([M−AcO]$^+$, 0.3), 534 ([M−2AcOH]$^+$, 1.3), 492 (1), 474 ([M−3AcOH]$^+$, 1), 432 (1), 414 ([M−4AcOH]$^+$, 0.6), 372 (2), 354 ([M−5AcOH]$^+$, 1), 312 (2), 294 ([M−6AcOH]$^+$, 3), 263 (5), 221 (6), 181 (4), 161 (9), 161 (19), 149 (9), 133 (16), 121 (14), 119 (9), 105 (14); negative HR-FAB-MS *m/z* 653.2806 ([M−H]$^-$, Calcd for $C_{32}H_{45}O_{14}$, 653.2809).

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