Journal of Wood Science

ORIGINAL ARTICLE

Extractives elucidation of *Taiwania cryptomerioides* sapwood

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Abstract

Taiwania (*Taiwania cryptomerioides* Hayata) has long been regarded as a living fossil from the Tertiary period of Mesozoic Era for its distinguished yellowish-red color with purplish-pink streaks presented in its heartwood. With this elegant appearance that matches the color "red" for good fortune in the Taiwanese culture, Taiwania is supposed to be a popular wood in Taiwan where it is a native species of. Extractives contribute to the properties of wood. It is a fascinating subject to investigate extractives biosynthesis in the process of heartwood formation. Up to date, there is no phytochemistry study of Taiwania sapwood. In this study, three new sesquiterpenoids, Taiwania A (**1**), Taiwania B (**2**), and Taiwania C (**3**), together with 75 known compounds in the Taiwania sapwood. The structures of extractives were determined by analysis of spectroscopic data and comparison with the literatures. This study supported secondary reaction lignans could be found in sapwood that confirmed our previous research on the Taiwania-type of heartwood formation.

Keywords: *Taiwania cryptomerioides*, Sesquiterpenoids, Sapwood, Essential oil, Heartwood formation

Introduction

Heartwood is the large part of the wood, and the extractives contained in it are closely related to the properties of the wood, such as strength, durability, color, and odor. The formation mechanism of heartwood has always been of interest and an important research topic for researchers. The heartwood formation could be classified into three types based on distribution patterns of extractives in stem wood of various trees species [1, 2]. Type I heartwood formation, i.e., Robinia-type heartwood formation, where the accumulation of phenolic extractives starts in the transition zone (TZ). In this case, no phenolic precursors were found in the aging sapwood. Type II (Juglans-type) heartwood formation, where the phenolic precursors gradual accumulated centripetally with progressive aging of the sapwood tissues. The extractives that characterize the Type II heartwood were formed in the TZ either by de novo biosynthesis or secondary reactions (oxidation or hydrolysis) of precursor substances. Type III (Taiwania-type) heartwood formation, which most of phenolic compounds are synthesized in sapwood [2].

Taiwania (*Taiwania cryptomerioides* Hayata) is a native tree species growth in Taiwan. Taiwania also is the highest conifer in East Asia, it can reach 80 m. From 1960s to date, Taiwania is the important plantation species in Taiwan. Due to its excellent durability and processing property, Taiwania is the popular wood material for building and furniture. With regard to phytochemical study of Taiwania, more than 300 compounds, including terpenoids, lignans, isoflavones, and other compounds have been isolated from Taiwania during the past 90 years [3–23]. The putative bioactivities compounds of Taiwania, and evaluated the potential usages of the phytochemicals isolated from Taiwania for pharmacological applications were carried on by our research group. We demonstrated that sesquiterpenoids isolated from the heartwood of Taiwania against bacteria, fungi, mite, and termite [24–28]. The diterpenoids also exhibited the antioxidant and anti-inflammatory activities [29,

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30]. In the meantime, the lignans of Taiwania presented the potent anti-inflammatory, antiviral, and anticancer activities [26, 31–37].

The mechanism of heartwood formation in Taiwania is very unique. We found that most of the skeletons of the compounds are already synthesized in the sapwood. Although there have been numerous research reports on the chemical composition of Taiwan cedar, so far, no discussion has been made on its sapwood composition. For understanding the heartwood formation in Taiwania, it is important to clarify the difference of composition between the heartwood and sapwood. This study accurately distinguished sapwood from heartwood in Taiwania, focusing the composition investigation of Taiwania sapwood. Totally, 78 compounds from sapwood of Taiwania, including 3 new skeleton sesquiterpenoids. The results obtained in this study provide a valuable reference for further heartwood formation and metabolites biosynthesis investments.

Materials and methods

General experimental procedures

^{1}H, ^{13}C, and 2D NMR spectra were recorded on a Bruker AVANCE III NMR spectrometer (Bruker, Billerica, Massachusetts, US), acquiring ^{1}H data at 400 MHz and ^{13}C data at 100 MHz, using standard experiments from Bruker pulse programs library. High-resolution mass spectrometry (HR-MS) was determined using an LTQ Orbitrap XL (Thermo Fisher Scientific, Waltham, Massachusetts, U.S.). The compositions of the essential oil were analyzed by an ITQ 900 mass spectrometer coupled to a TRACE GC Ultra gas chromatography (Thermo Fisher Scientific, Waltham, Massachusetts, U.S.). Methanol (MeOH) extracts were fractionated on silica gel 60 (230–400 mesh ASTM, Merck) and then purified with semi-preparative normal-phase column (luna silica (2), 250 × 10 mm, 5 μm, Phenomenex) on an Agilent 1100 HPLC (Agilent Technologies, Santa Clara, California, U.S.).

Plant materials

A 30-year-old Taiwania used in this study was collected from the Huisun Experimental Forest Station of National Chung-Hsing University in August 2014; and was identified by Prof Yen- Hsueh Tseng, Department of Forestry, National Chung Hsing University. The voucher specimen was deposited in the herbarium of the same university. The sapwood chips (excluding the heartwood and knots) were prepared from a green cut tree and stored in room temperature with avoiding light irradition.

Extraction and isolation

Air-dried sapwood chips (*ca.* 10 kg) were extracted with MeOH (80 L) for 7 days at ambient temperature three times and concentrated under vacuum to yield the MeOH extract (46 g). The MeOH extract was partitioned between H_2O and ethyl acetate (EtOAc) (1:1 for volume) three times to provide EtOAc soluble fraction (18.7 g). The EtOAc soluble fraction was subjected to chromatography using a silica gel (90 g) column eluted with *n*-hexane–EtOAc which gradient elution by changing 100:0, 95:5, 90:10, 85:15, 80:20, 75:25, 70:30, 60:40, 50:50, 40:60, 30:70, 20:80, 10:90, and 0:100 for 1 L, respectively. The elution was collected by 500 mL to get 1 to 28 fractions. After thin layer chromatography tracing, 1 to 6 fractions were combined to fraction A (1.8 g), 7 to 8 fractions were combined to fraction B (0.5 g), 9 to 11 fractions were combined to fraction C (1.0 g), 12 to 14 fractions were combined to fraction D (0.6 g), 15 to 17 fractions were combined to fraction E (0.7 g), 18 to 20 fractions were combined to fraction F (0.7 g), 21 to 22 fractions were combined to fraction G (0.4 g), 23 to 25 fractions were combined to fraction H (0.6 g), 26 to 27 fractions were combined to fraction I (0.2 g), 28 fraction was fraction J (0.5 g). The fractions were further purified by repeating HPLC using the *n*-hexane–EtOAc mixture as solvent system through a semi-preparative normal-phase column to give 55 known compounds and 3 new compounds.

Essential oil analysis

The air-dried sapwood chips (350 g) were subjected to hydrodistillation for 8 h using a Clevenger type apparatus. The moisture-free oil which yield 0.01% was obtained by treating with anhydrous Na_2SO_4. The compositions of the essential oils were analyzed by an ITQ Series GC mass system, equipped with a DB-5MS capillary column (30 m length × 0.25 mm inside diameter × 0.25 μm film thickness, J & W Scientific) and helium as a carrier gas with a flow rate of 1 ml min^{-1}. The injector temperature was 240 ℃ and spilt ratio was 1:200. The oven temperature was start at 40 ℃, and increased by 5 ℃ min^{-1} to 130 ℃, then rose to 160 ℃ at a rate of 2 ℃ min^{-1}, finally increased to 280 ℃ by 10 ℃ min^{-1} and held for 10 min. The EI source was 70 eV and 250 ℃. Quantification was obtained from percentage peak areas from the gas chromatogram. A Wiley/ NBS Registry of Mass Spectral Data search and authentic reference compounds were used for substance identification. The Kovats retention index (KI), which is a parameter calculated in reference to *n*-alkanes that converts retention times into system-independent constants, was also confirmed [38]. Chromatography

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results expressed as area percentages were calculated with a response factor of 1.0.

Results and discussion

Volatile organic compounds analysis of sapwood

Table 1 presents the analysis result of essential composition of Taiwania sapwood. Totally, 25 compounds were identified in sapwood essential oil, including one monoterpenoid, α-terpineol (**4**); 23 sesquiterpenoids, namely α-copaene (**5**), α-cedrene (**6**), β-cedrene (**7**), β-copaene (**8**), γ-muurolene (**9**), α-muurolene (**10**), γ-cadinene (**11**), δ-cadinene (**12**), calamenene (**13**), α-cadinene (**14**), α-calacorene (**15**), elemol (**16**), globulol (**17**), cedrol (**18**), 1,10-di-*epi*-cubenol (**19**), *epi*-cubenol (**20**), γ-eudesmol (**21**), δ-cadinol (**22**), T-muurolol (**23**), α-eudesmol (**24**), α-cadinol (**25**), 8-cedren-13-ol (**26**), and cadalene (**27**); and one diterpenoid, ferruginol (**28**). Among them, α-cadinol (16.74%) was the most abundant compound.

Identification of sapwood non-volatile organic compounds

Three new compounds (**1–3**) (Fig. 1) and 55 known compounds were identified from sapwood of Taiwania. The known compounds were identified by spectra data and comparing with literature data. The identified known compounds were one fatty acid, *i.e.,* 4,6,6-trimethylheptanoic acid (**29**) [39]; 6 benzenoids, which were ficusol (**30**) [40], vanillin (**31**) [41], *trans-p*-hydroxycinnamaldehyde (**32**) [42], 4-(3-hydroxypropyl)-2-methoxyphenol (**33**) [43], β-hydroxypropiovanillone (**34**) [44], and 3-methoxy-4-hydroxybenzoic acid (**35**) [44]; 12 sesquiterpenoids, including (2β,3α)-α-corocalene-2,3-diol (**36**) [17], *epi*-cubenol (**20**) [45], cryptomeridiol (**37**) [46], cedrol (**18**) [47], T-cadinol (**38**) [47], T-muurolol (**23**) [47], α-cadinol (**25**) [48], β-eudesmol (**39**) [49], (4R)-4-hydroxy-1,10-*seco*-muurol-5-ene-1,10-dione (**40**) [50], dysodensiol D (**41**) [51], 1α-hydroxy-4α*H*-1,2,3,4-tetrahydrocadalen-15-oic acid (**42**) [52], and 1-hydroxy-1,2,3,4-tetrahydrocadalen-15-oic acid (**43**) [53]; 6 diterpenoids, i.e., 3β-hydroxysugiol (**44**) [54], ferruginol (**28**) [55], hinokiol (**45**) [56], hinokione

Table 1 Chemical composition of the essential oil of sapwood of Taiwania

RT (min)	Constituent	KI[a]	Contents (%)	Identification[b]
13.82	α-Terpineol	1196	0.38	MS, KI, ST
18.83	α-Copaene	1376	0.13	MS, KI, ST
20.04	α-Cedrene	1417	2.46	MS, KI, ST
20.28	β-Cedrene	1425	0.41	MS, KI, ST
20.60	β-Copaene	1436	0.16	MS, KI, ST
21.81	γ-Muurolene	1475	1.32	MS, KI, ST
22.54	α-Muurolene	1498	3.51	MS, KI
23.02	γ-Cadinene	1512	5.67	MS, KI
23.17	δ-Cadinene	1516	9.35	MS, KI, ST
23.27	Calamenene	1519	2.37	MS, KI, ST
23.76	α-Cadinene	1534	1.02	MS, KI, ST
23.91	α-Calacorene	1538	7.27	MS, KI
24.15	Elemol	1545	0.24	MS, KI, ST
25.57	Globulol	1583	0.21	MS, KI
26.43	Cedrol	1608	8.74	MS, KI, ST
26.68	1,10-di-*epi*-Cubenol	1616	1.43	MS, KI, ST
27.13	1-*epi*-Cubenol	1630	1.08	MS, KI, ST
27.29	γ-Eudesmol	1635	1.18	MS, KI, ST
27.66	δ-Cadinol	1647	7.07	MS, KI, ST
27.72	T-Muurolol	1648	8.36	MS, KI, ST
27.82	α-Eudesmol	1651	3.48	MS, KI, ST
28.14	α-Cadinol	1661	16.74	MS, KI, ST
28.44	8-Cedren-13-ol	1670	0.47	MS, KI
28.66	Cadalene	1677	3.17	MS, KI, ST
36.66	Ferruginol	2345	4.34	MS, KI, ST
Total identified (%)		90.56		

[a] Kovats index on a DB-5MS column in reference to n-alkanes

[b] MS, NIST and Wiley libraries spectra and the literature; KI, Kovats index; ST, authentic standard compounds

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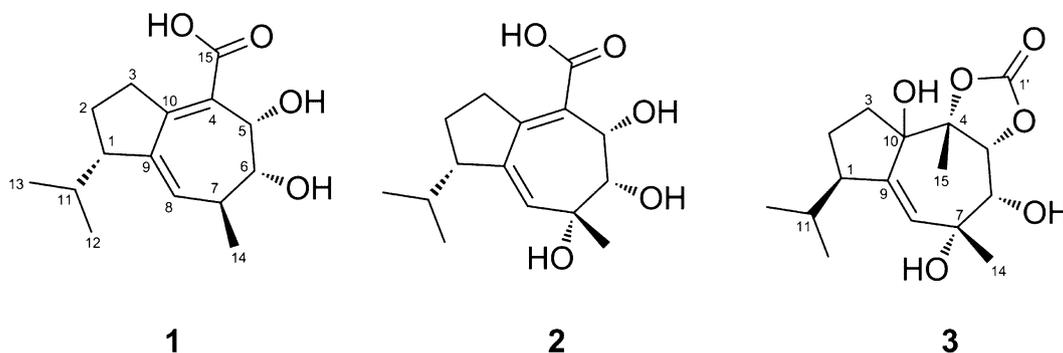
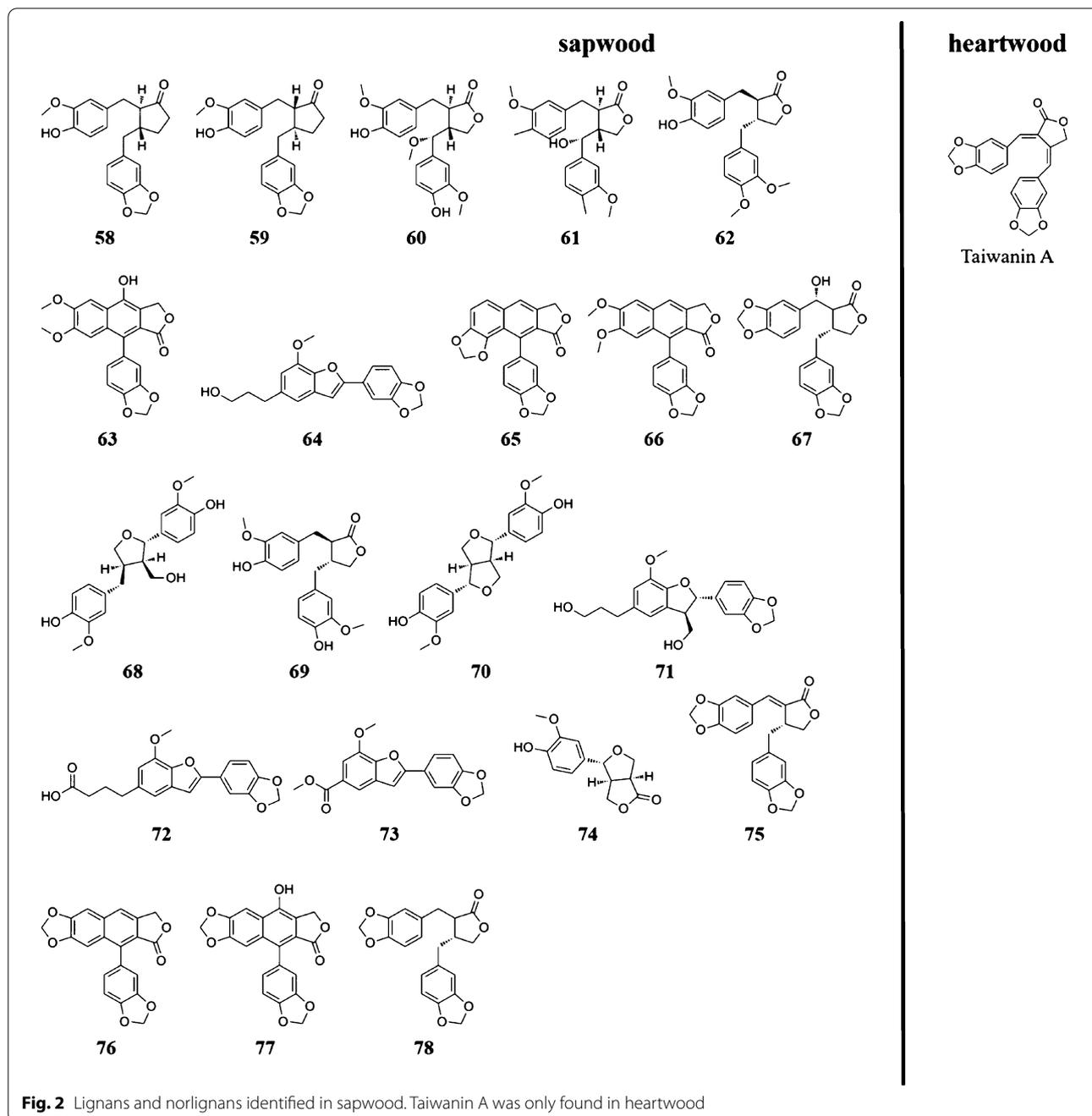**Fig. 1** The chemical structures of Taiwania A (**1**), Taiwania B (**2**), and Taiwania C (**3**)

(**46**) [57], sugiol (**47**) [58], and sandaracopimarinol (**48**) [59]; 9 steroids, 3-*epi*-6-deoxocathasterone (**49**) [60], 7α-hydroxysitosterol (**50**) [61], 7β-hydroxysitosterol (**51**) [62], 7-ketositosterol (**52**) [63], 6β-hydroxystigmast-4-en-3-one (**53**) [63], ergone (**54**) [64], stigmast-4-en-3-one (**55**) [65], stigmastan-3-one (**56**) [66], and β-sitosterol (**57**) [67]; 21 lignans and norlignans (Fig. 2), which were (-)-pluviatolide (**58**) [68], (+)-pluviatolide (**59**) [68], (+)-7-methoxymatairesinol (**60**) [69], 7′-hydroxymatairesinol (**61**) [70], arctigenin (**62**) [71], diphyllin (**63**) [72], egonol (**64**) [73], helioxanthin (**65**) [74], justicidin B (**66**) [75], (2S,3R)-2-[(1S)-1-hydroxy-1-(3,4-methylenedioxyphen)methyl]-3-(3,4-methylenedioxybenzyl)-4-butanolide (**67**) [76], lariciresinol (**68**) [77], matairesinol (**69**) [78], pinoresinol (**70**) [79], 9,9′-dihydroxy-3,4-methylenedioxy-3′-methoxy(7-*O*-4′,8–5′)neolignan (**71**) [6], 4-[2-(1,3-benzodioxol-5-yl)-7-methoxy-1-benzofuran-5-yl]butanoic acid (**72**) [80], methyl 2-(1,3-benzodioxol-5-yl)-7-methoxy-1-benzofuran-5-carboxylate (**73**) [81], salicifoliol (**74**) [82], savinin (**75**) [83], Taiwanin C (**76**) [75], Taiwanin E (**77**) [84], and hinokinin (**78**) [85].

It is worthy to note, Taiwanin A was not found in sapwood of Taiwania (Fig. 2). According to the record, Taiwanin A is the unique lignan found in the heartwood of Taiwania; it only has been identified in Taiwania, not in other plants. Kampe and Magel classified the heartwood formation into two types based on distribution patterns of extractives in stem wood of various trees species [1]. (1) Type I (Robinia-type) heartwood formation, where the accumulation of phenolic extractives starts in the transition zoon, while no phenolic precursors were found in the aging sapwood. (2) Type II (Juglans-type) heartwood formation, where the phenolic precursors gradual accumulated centripetally with progressive aging of the sapwood tissues. Our previously study proposed the type III, Taiwania-type of heartwood formation, which was found the secondary reaction for lignans in sapwood [2]. This study further confirms that secondary reaction

lignans occurred in sapwood of Taiwania. The biosynthesis of lignans, e.g., matairesinol, hinokinin, savinin, helioxanthin, and Taiwanin E has been synthesized in the sapwood.

New sesquiterpenoids identification

Three new sesquiterpenoids were identified in this study, the structure's elucidation was reported in the following. Compound **1** was obtained as a colorless oil. The ^{1}H NMR spectrum of **1** (Table 2) displayed resonances for one doublet methyl [δ_{H} 1.18 (3H, d, *J* = 6.0 Hz)], and two oxymethines [δ_{H} 3.80 (1H, dd, *J* = 6.0, 10.3 Hz) and 4.95 (1H, dt, *J* = 2.2, 10.3 Hz)], an olefinic proton [δ_{H} 5.82 (1H, d, *J* = 6.0 Hz)], an isopropyl group [δ_{H} 0.86 (3H, d, *J* = 6.6 Hz), 0.97 (3H, d, *J* = 6.6 Hz), and 1.61 (1H, m)]. The ^{13}C NMR and distortionless enhancement by polarization transfer (DEPT) experiments revealed 15 carbon signals, consisting of three methyl, two aliphatic methylene, three aliphatic methine, two oxygenated methine, one olefinic methine, three quaternary olefinic, and one carboxyl carbons. Its high-resolution atmospheric pressure chemical ionization mass spectrometry (HR-APCI-MS) gave a [M + H]$^{+}$ ion at *m/z* 267.2663, establishing the molecular formula of **1** as $C_{15}H_{22}O_{4}$ with five degrees of unsaturation. Ascribing to cnjuged double bond, H-5 exhibited very low field at δ_{H} 4.95, and the carbon signals at δ_{C} 122.6 (CH), δ_{C} 132.8 (C), δ_{C} 134.0 (C), δ_{C} 157.8 (C), and δ_{C} 173.2 (C) indicated the existence of a C=CH, a C=C, and a O=C–OH systems. The remaining two degrees of unsaturation identified **1** as a bicyclic compound. The HMBC (Fig. 3) data showed correlations H-12/C-1, C-11, C-13; H-13/C-1, C-11, C-12, and the COSY (Fig. 4) signals showed coupling between the H-1/H-11; H-11/H-12; H-11/H-13. That confirmed the isopropyl group attached to C-1. From the COSY spectrum showed coupling between the H-1/H2; H-2/H-3; H-5/H-6; H-6/H-7; H-7/H-8; H-7/H-14, and the HMBC signal showed correlations H-5/C-10; H-6/C-14; H-7/C-9; H-8/C-1, C-6, C10;

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Fig. 2 Lignans and norlignans identified in sapwood. Taiwanin A was only found in heartwood

H-14/C-8. Taking the above evidences together, **1** identified as a 5–7 ring compound and pinpointed the location of 4-carboxyl group, OH-5, OH-6, and methyl group (Me)-7. The NOESY (Fig. 5) signals showed correlations of H-5/H-14; H-6/H-14; H-7/H-11 as well as the coupling constant confirmed that H-5, H-6, and Me-7 were β and isopropyl-1 and H-7 were α configuration. Based on these data confirmed the proposed structure of **1** and

named Taiwania A, and it is a new skeleton sesquiterpene to the best of our understanding.

Compound **2**, a colorless oil, was assigned a molecular formula of $C_{15}H_{22}O_5$ on the basis of HR-APCI-MS and ^{13}C NMR. The ^1H NMR and ^{13}C NMR data of **2** (Table 2) were similar to those of **1**, indicated that compound **2** was also the same type sesquiterpenoid derivative. Analysis of NMR data revealed that OH-7 of **2** replaced H-7 of **1**. This supported by the COSY (Fig. 4)

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Table 2 ¹H NMR data for compound 1, 2, and 3 (CDCl$_3$, δ in ppm)

No.	1		2		3	
	δ$_C$	δ$_H$	δ$_C$	δ$_H$	δ$_C$	δ$_H$
1	44.8	2.06 m	44.6	2.06 br s	43.8	2.02 m
2	26.3	1.61 m, 2.06 m	26.0	1.66 br s, 2.06 br s	23.6	1.79 m, 1.21 dd (4.0, 13.4)
3	16.8	2.27 m	16.9	2.29 br s	35.0	1.98 m, 1.65 dt (4.0, 7.2)
4	122.6	–	124.1	–	73.6	–
5	79.9	4.95 dt (2.2, 10.3)	80.8	4.80 br d (10.4)	79.1	4.66 d (9.1)
6	74.2	3.80 dd (6.0, 10.3)	80.4	3.70 d (10.4)	76.4	3.76 d (9.1)
7	37.0	2.78 sext (6.0)	74.9	-	71.3	-
8	134.0	5.82 d (6.0)[a]	135.6	5.75 s	132.8	5.75 d (1.6)
9	132.8	–	132.5	–	134.1	–
10	157.8	–	157.1	–	85.7	–
11	27.9	1.61 m	27.9	1.66 m	27.2	1.93 m
12	20.3	0.97 d (6.6)	20.3	0.97 d (6.6)	18.7	0.92 d (6.6)
13	21.5	0.86 d (6.6)	21.5	0.86 d (6.6)	21.9	0.97 (6.6)
14	13.6	1.18 d (6.0)	22.9	1.41 s	22.2	1.31 s
15	173.2	–	172.6	–	22.6	1.27 s
1′	–	–	–	–	153.5	–

[a] Coupling constants are presented in Hz
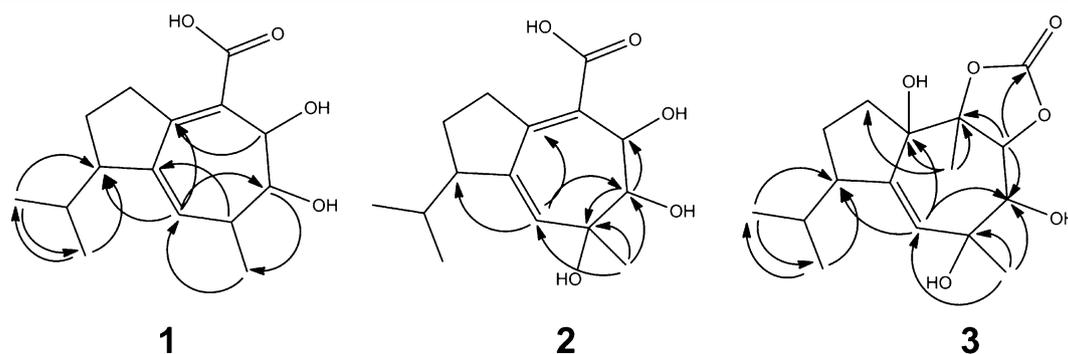
Fig. 3 Key HMBC correlations of Taiwania A (**1**), Taiwania B (**2**), and Taiwania C (**3**)
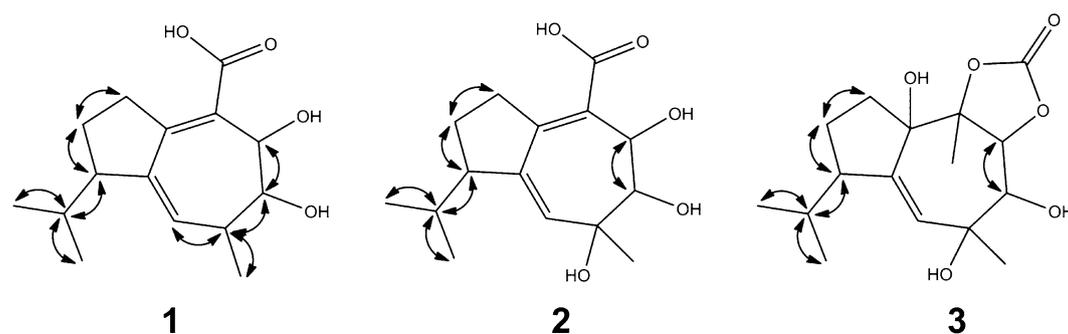
Fig. 4 The COSY correlations of Taiwania A (**1**), Taiwania B (**2**), and Taiwania C (**3**)

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Fig. 5 Key NOESY correlations of Taiwania A (**1**), Taiwania B (**2**), and Taiwania C (**3**)
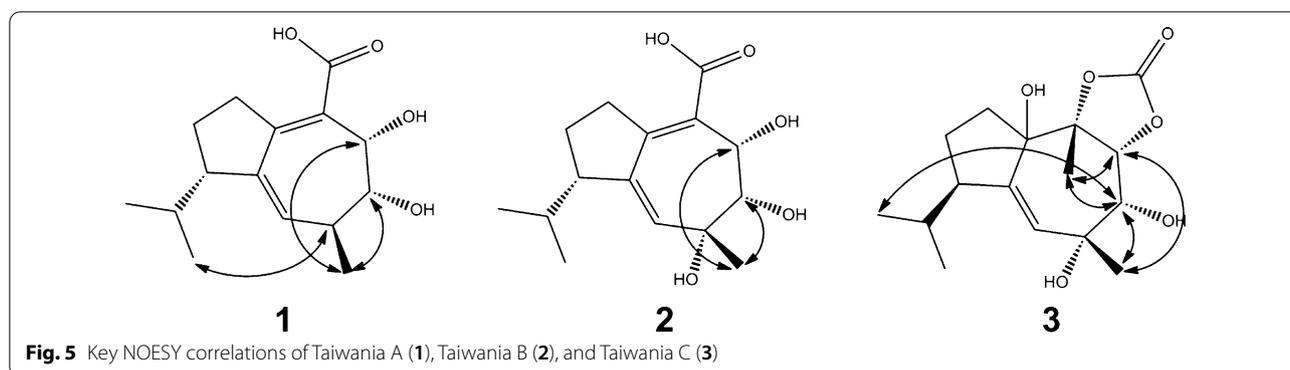
correlations showed H-1/H2; H-2/H-3; H-1/H-11; H-5/H-6; H-11/H-12, H-13, and HMBC (Fig. 3) correlation signals H-8/C-1, C-6, C-10; H-6/C-5, C-7; H-14/C-6, C-7, C-8. The NOESY (Fig. 5) correlations observed H-5/H-14; H-6/H-14. Hence, the structure of **2** is confirmed and named Taiwania B.

The molecular formula of compound **3** was $C_{16}H_{24}O_6$ by electrospray ionization mass spectrometry (ESI-MS) and NMR data, indicated five degree of unsaturation. Sixteen carbon signals were observed in the ^{13}C NMR spectrum of **3** and were assigned by the DEPT experiments displayed four aliphatic methyl, two aliphatic methylene, two aliphatic methine, two oxygenated methine, three oxygenated quaternary, one olefinic methine, one olefinic quaternary, and one carbonyl carbons. The carbon signals at δ_C 132.8 (CH), δ_C 134.1 (C), and δ_C 153.5 (C) indicated the existence of a C=CH and a C=O systems. The carbonyl carbon (C-1′) exhibited very high field at δ_C 153.5 supported that was carbonate group [–O–C(=O)–O–] [86]. The remaining three degrees of unsaturation identified **3** as a tricyclic compound. Its ^1H NMR spectrum of **3** (Table 2) showed the presence of four methyl protons [δ_H 0.92 (3H, d, $J = 6.6$ Hz), 0.97 (3H, d, $J = 6.6$ Hz), 1.27 (3H, s), 1.31 (3H, s)], two oxymethines protons [δ_H 3.76 (1H, d, $J = 9.1$ Hz) and 4.66 (1H, d, $J = 9.1$ Hz)], and an olefinic proton [δ_H 5.75 (1H, d, $J = 1.6$ Hz)]. The HMBC (Fig. 3) correlations showed H-12/C-1, C-11, C-13; H-13/C-1, C-11, C-12, and the COSY (Fig. 4) correlations showed H-1/H-11; H-11/H-12 and H-13 confirmed that the isopropyl group attached to C-1. The carbonyl carbon (C-1′) was attached on C-4 and C-5 by the HMBC correlations showed H-5/C-4, C-6, C-2′; H-15/C-3, C-4, C-10. The double bond was assigned to located C-8 and C-9, basing on the HMBC correlation showed H-8/C-1, C-6, C-10. The three hydroxyl groups were located at C-6, C-7, and C-10, respectively, which were assured by the HMBC correlations showed H-6/C-5, C-7, C-14; H-14/C-6, C-7, C-8; H-15/C-3, C-4, C-10. The NOESY

(Fig. 5) signals showed the correlations of H-5/H-14, H-15; H-6/H-11, H-12, H-13, H-14, H-15 indicated that isopropyl-1, Me-4, H-5, H-6, and Me-7 were in β orientation. On the basis of these data, compound **3** is assigned the proposed structure and named Taiwania C, and it is as a new natural product.

Conclusion

The biosynthesis and accumulation of the extractives is an important process for the formation of heartwood, and the content and types of the extractives in the heartwood also influence the special properties of wood. Previously, we proposed a new type of Taiwania-type heartwood formation mechanism, i.e., phenolic compounds have completed the secondary reaction in the sapwood, forming a complete structure (Tsao et al. [2]). Although the current research on the phytochemistry of Taiwania is quite complete, there is no research on the sapwood extractives. This study isolated and identified 78 compounds from sapwood of Taiwania, including 1 fatty acid, 6 monoaromatics, 1 monoterpenoid, 34 sesquiterpenoids, 6 diterpenoids, 9 steroids, and 21 lignans and norlignans. Among these, 3 new skeleton sesquiterpenoids, which were Taiwania A, Taiwana B, and Taiwania C were first time identified. During the past decades, a number of studies have reported the metabolites of Taiwania's wood. However, to our best of knowledge, this is the only study focusing on the elucidation of sapwood compounds. Interestingly, besides 3 new skeleton compounds, all of the 75 known compounds had been reported previously. This study confirmed again that the secondary reaction of lignans occurred in the sapwood of Taiwania. It provided the evidence for type III, Taiwania-type of heartwood formation (Tsao et al. [2]). However, the unique and dominant lignan, Taiwanin A, was not found in the sapwood. The result once again confirmed that all lignans of Taiwania are synthesized in sapwood, except Taiwanin A.

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