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Chemical studies on the parasitic plant *Thonningia sanguinea* Vahl†

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Thonningia sanguinea Vahl plays an important role in traditional medicine in many African cultures. A study of the *n*-hexane fraction of the whole plant of *T. sanguinea* led to the isolation of two glucocerebroside molecular species **TSC-1** and **TSC-2**, one β-sitosteryl-3β-D-glucopyranoside-6′-*O*-fatty acid ester molecular species, **TSS-1**, and seven known triterpenes (**1–7**). The ethyl acetate fraction also afforded five known lignans (**8–12**) and one known flavanone (**13**). Their structures were elucidated by means of chemical and spectroscopic methods (methanolysis, NMR and mass spectrometry). Spectral analyses of the glucocerebrosides revealed mainly sphingosine-type (**TSC-1**) and phytosphingosine-type (**TSC-2**) cerebrosides, with both possessing mainly 2-hydroxy fatty acid and β-D-glucopyranose moieties. **TSS-1** was found to be a β-sitosterol-type with fatty acid methyl esters and β-D-glucopyranoside moieties. The classes of compounds isolated from this plant are well known for their interesting biological activities including antimicrobial, antioxidant, anticancer, antiinflammatory and analgesic. They may therefore be responsible in part or in whole for these activities, hence validating the traditional uses of the plant. To the best of our knowledge, this is the first report on the isolation of all these compounds from *T. sanguinea*.

1. Introduction

Thonningia sanguinea Vahl is a flowering plant in the monotypic genus *Thonningia* of the family Balanophoraceae. Synonyms for the plant include *T. angolensis, T. coccinea* Mangenot, *T. dubia* Hemsl., *T. elegans* Hemsl., and *T. ugandensis* Hemsl. It is a fleshy subterranean herb growing from an underground tuber. It is a parasitic plant growing on the terminal roots of host plants such as *Hevea brasiliensis*, *Phoenix dactylifera* and *Theobroma cacao*.[1] The flowering stem produces a bright red or pink inflorescence containing male and female flowers. The plant grows in Tropical Africa, from Senegal to Ethiopia, south to Angola, Zambia and Tanzania. It is commonly found in rainforests, gallery forests and adjacent woodland.[1] Commonly known in English as "ground pineapple", it is also known as "kwaebedwaa" in the local Akan language of Ghana.

T. sanguinea is best known for its use in traditional medicine in many African countries. In Ghanaian traditional medicine for instance, this plant is used in treatment of bronchial asthma sometimes for prophylaxis,[2] sexually transmitted diseases and as an aphrodisiac. It is used to treat diarrhoea and worm infestation in Cote d'Ivoire and Congo. It is also mixed with *Capsicum* to produce a topical cream for treating haemorrhoids and torticollis. It is also used to treat dysentery, sore throat, skin infections, abscesses, dental caries, gingivitis, fever, malaria, heart disease, rickets, and rheumatism.[1,3,4]

Chemically, an aqueous and hydroalcoholic flower extract of *T. sanguinea* revealed the presence of alkaloids, catechin tannins, flavonoids, saponins, quinones and polyphenols on preliminary screening.[5] Brevifolin carboxylic acid (BCA),[6] gallic acid (GA)[6] and two ellagitannins: thonningianins A (Th A) and Th B[7] are the only four compounds reported to have been isolated from the plant. N'guessan *et al.* reported that both GA and BCA, isolated from *T. sanguinea* demonstrated moderate antibacterial activity against *Salmonella enteritidis*, *Salmonella typhimurium*, and *Salmonella abony* in the disc diffusion method, with significant antioxidant activity in the DPPH radical scavenging activity assay.[6] GA is well known as a potent antioxidant phenolic compound, with numerous biological activities including antitumor, antimicrobial and antimelanogenic.[6] BCA has been shown to inactivate HBsAg and inhibit hepatitis B virus replication and tumour growth.[8] The ellagitannins isolated from the plant also possessed hepatoprotective actions, potent antimicrobial effects[4,6,7,9] and significant free radical scavenging activity against DPPH by ESR analysis.[7] Th A effectively inhibited of the proliferation of HepG-2 human hepatocellular carcinoma cells by inducing apoptosis. This was observed as an increase in the sub-G1 cell population,

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DNA fragmentation, and increase in the content of reactive oxygen species.[10] Th A was also shown to be a potent *in vitro* inhibitor of rat liver crude glutathione S-transferases (GSTs) and hGSTP1-1 activity.[11]

Biological study on *T. sanguinea* plant extracts (*in vivo* and *in vitro* assays) indicated the prophylactic potential of the aqueous extract and its *n*-butanolic fraction in bronchial asthma. The active agents extracted into *n*-butanol and may be flavonoids and/or phenolic in nature.[12] The anticoccidial activity of the extract against *Eimeria* sp. sporazoites,[13] antibacterial effects against some multidrug resistant strains of *Salmonella enterica*[16] and their effects on extended spectrum-β-Lactamases (ESBL) producing *Escherichia coli* and *Klebsiella pneumoniae* strains[3] have been reported. The significant antimalarial effects of *T. sanguinea* root extracts against *Plasmodium falciparum* (*in vitro*),[14] *Plasmodium berghei* and *Plasmodium chabaudi* (*in vivo*)[1] have also been reported. The aqueous extract of *T. sanguinea* exhibited hepatoprotective activity towards a variety of different toxicants including galactosamine, carbon tetrachloride and aflatoxin B1.[2,15] It also suppressed CYP3A2 and CYP1A2 expression at the level of transcription,[16] protects against aflatoxin B1 acute hepatotoxicity in Fischer 344 rats[2] and also inhibits the liver drug metabolising enzymes of rats.[17]

The aqueous decoction of *T. sanguinea* has been used for more than thirty five years as a mono-herbal product produced by the Centre for Plant medicine Research, Akuapem-Mampong, Ghana (CPMR) under the registered names CAMPA-T® and NINGER®. Due to the reported clinical effectiveness of these herbal formulations at the CPMR clinic, they have been approved for use as standardised herbal medicines by the Food and Drug Authority. CAMPA-T® and NINGER® are now part of the Essential Herbal Medicines List recommended for use in pilot herbal clinics under the Integrated Herbal Medicine Services Programme in public hospitals. These *T. sanguinea*-based products are prescribed for the management of arthritic pain, sexual weakness, male and female infertility, dysmenorrhoea, amenorrhoea and uterine fibroids. Therefore, *T. sanguinea* is an important medicinal plant that is contributing immensely to public health care in Ghana.

Despite the interesting clinical usage in Ghana, as well as the reported pharmacological activities of the extracts of *T. sanguinea*, there is no detailed study on the chemical composition of the plant. In this report, we seek to provide a chemical profile for *T. sanguinea* to better understand these reported pharmacological activities and give credence to its use in traditional medicine.

2. Experimental

2.1. General experimental information

NMR spectra were recorded in chloroform-*d*, methanol-d_4 and pyridine-d_5 (Nacalai Tesque, Inc., Kyoto, Japan) with Varian Unity Plus 400 spectrometer (Palo Alto, CA, USA) operating at 400 MHz for ^{1}H and 100 MHz for ^{13}C, and with a JEOL JNM-AL 300 spectrometer (JEOL Ltd, Tokyo, Japan) at 300 MHz for ^{1}H NMR. The UV spectra were recorded using a double beam Shimadzu UV-visible spectrophotometer (model UV-1601 PC, Kyoto City, Japan). IR spectra were recorded using a Jasco FT/IR-410 K spectrometer (Jasco Co. Ltd., Tokyo, Japan) with a range of 400–4000 cm^{-1}. FAB-MS spectra were recorded on a JMS 700N spectrometer (JEOL Ltd., Tokyo, Japan) in positive ion mode, with glycerol or *m*-nitrobenzyl alcohol, with or without NaCl, as the matrix. The optical rotation measurements were done using a Jasco P-1020 polarimeter (Jasco Co. Ltd., Tokyo, Japan). Extraction and isolation of compounds were done the following solvents: acetone, acetonitrile, *n*-butanol, chloroform, ethyl acetate, *n*-hexane and methanol (Nacalai Tesque, Inc., Kyoto, Japan). Column chromatography (CC) was performed using Sephadex LH-20 (25–100 mm, GE Healthcare UK Ltd., Buckinghamshire HP7 9NA, UK), silica gel Purasil 60 Å, 230–400 mesh (Whatman, Sanford, ME, USA) and Cosmosil 140C_{18}-PREP silica gel 90 Å, 40–63 mesh (Nacalai Tesque, Inc., Kyoto, Japan). TLC was performed on 0.25 mm thick, precoated silica gel 60 F_{254} and silica gel RP-18 F_{254} plates (Merck, Darmstadt, Germany). Prep. TLC was performed on 2 mm thick PLC silica gel 60 F_{254} glass plates (Merck, Darmstadt, Germany). Spots were developed with 5% H_2SO_4 : MeOH and detected by illumination under a short wavelength UV (254 nm). Analytical HPLC was performed on a Cosmosil 5C_{18}-AR-II 4.6 mm × 250 mm column (Nacalai Tesque, Inc., Kyoto, Japan) with methanol (Nacalai Tesque, Inc., Kyoto, Japan) at a flow rate of 0.8 mL min^{-1} and Cosmosil-sugar-D 4.6 ID × 250 mm, 1 mL min^{-1}, refractive index (RI) detector using 95% acetonitrile. Preparative HPLC was performed on a Develosil 5C_{18} 4.6 mm × 150 mm column (Nacalai Tesque, Inc., Kyoto, Japan) using 100% MeOH as solvent, at a flow rate of 0.5 mL min^{-1} on a Jasco DG-2080-53 Plus degasser, Jasco PU-2080 Plus pump, Jasco AS-2055 Plus auto sampler, Jasco CO-2065 Plus column oven (maintained at 35 °C) and Jasco MD-2018 Plus PDA detector (Jasco Co. Ltd., Tokyo, Japan).

2.2. Plant collection and identification

Thonningia sanguinea whole plant was collected by the staff of the Centre for Plant Medicine Research from the eastern region of Ghana in the month of January, 2015 and authenticated by the curator of their herbarium. A voucher specimen with the number CSRPM no. 140 was assigned to the sample.

2.3. Extraction and isolation

The whole plant of *T. sanguinea* was shade-dried for seven days and pulverised. The dried powdered plant material (3.5 kg) was extracted by cold maceration with MeOH (3 × 10 L for 3 days), followed by MeOH : $CHCl_3$ (1 : 1; 3 × 10 L for 3 days). The filtrates were pooled together and concentrated *in vacuo* using the rotary evaporator. The methanol/chloroform crude extract (423 g) was dissolved in distilled water and serially partitioned between *n*-hexane, ethyl acetate, *n*-butanol solvents to obtain the *n*-hexane (20 g), ethyl acetate (260 g), *n*-butanol (88 g) and aqueous (30 g) fractions. The *n*-hexane fraction (20 g) was subjected to silica gel CC (800 g) using *n*-hexane : EtOAc (9 : 1–1 : 9), $CHCl_3$: MeOH (8 : 2–6 : 4) and 80% acetone to give sixteen sub-fractions (H-1–H-16). Fraction H-4 (500 mg) was subjected to repeated silica gel CC using *n*-hexane : EtOAc

(8.5 : 1.5–1 : 1) to afford compound **6** (200 mg). Fraction H-5 (330 mg) was subjected to repeated silica gel CC using $CHCl_3$-: MeOH (1 : 0–1 : 1) to afford seven fractions. H-5-6 (138 mg) was further chromatographed on a C_{18} RP silica gel column (10 g) using MeOH : H_2O (8 : 2–1 : 0) and acetone : H_2O (1 : 1–1 : 0) to afford compound **7** (22 mg). Fraction H-10 (600 mg) was chromatographed on silica gel (20 g) using $CHCl_3$: MeOH (9.8 : 0.2–1 : 1) to afford eleven sub-fractions (H-10-1–H-10-11). H-10-4 (350 mg) was further chromatographed on a C_{18} RP silica gel column (10 g) using 100% MeOH to afford compound **1** (28 mg), **TSS-1** (94 mg) and a mixture purified by preparative HPLC using 100% MeOH to afford compound **2** (40 mg) and **4** (15 mg). Fraction H-13 (2.3 g) was chromatographed on silica gel (100 g) using $CHCl_3$: MeOH (9.8 : 0.2–2 : 8) to afford five sub-fractions H-13-1–H-13-5. H-13-4 (340 mg) was subjected to repeated silica gel CC using $CHCl_3$: MeOH (9.5 : 0.5–1 : 1) to afford **TSC-1** (30 mg), **TSC-2** (45 mg) and a mixture purified by preparative HPLC using 100% MeOH to afford compound **3** (13 mg) and **5** (8 mg). The ethyl acetate fraction (70 g) was subjected to silica gel CC (240 g) using $CHCl_3$: MeOH (9.8 : 0.2–3 : 7) and 80% acetone to afford twenty two sub-fractions (E-1–E-22). Fraction E-2 (1.08 g) was subjected to silica gel CC (10 g) using *n*-hexane : EtOAc (8 : 2–2 : 8) to give fourteen sub-fractions (E-2-1–E-2-14) which afforded compound **8** (100 mg) and **9** (200 mg). Fraction E−9 (500 mg) was subjected to silica gel CC (15 g) using $CHCl_3$: MeOH (9.9 : 0.1–9.6 : 0.4) to give sixteen sub-fractions (E-9-1–E-9-16). E-9-7 (175 mg) was sub-jected to repeated silica gel CC (10 g) using *n*-hexane : EtOAc (8 : 2–1 : 1) and $CHCl_3$: MeOH (9.7 : 0.3–1 : 1) to afford compound **10** (14 mg) and **11** (23 mg). E-9-8 (168 mg) was chromatographed on a C_{18} RP silica gel column (10 g) using MeOH : H_2O (3 : 7–4 : 6) to afford compound **12** (117 mg) and **13** (18 mg).

2.3.1 TSS-1. White amorphous powder. IR ν_{max}/cm^{-1}: 3350 (hydroxy), 1720 (carbonyl). Positive-ion FAB-MS: *m*/*z* 837, 851, 865, 879, 893, 806, 907, 921, 935, 949, 963 and 977 $[M + Na]^+$ series. ^1H NMR ($CDCl_3$) δ_H: 0.68–0.93 (3H, t), 1.25 (2H, s, nCH_2), 4.37 (1H, d, J = 8.0 Hz, glucose H-1′). ^{13}C NMR: see Spectral data.

2.3.2. TSC-1. White amorphous powder. IR ν_{max}/cm^{-1}: 3422 (hydroxy), 1640 and 1540 (amide). $[\alpha]_D^{20} = -31.3$ (*c* 0.1 in MeOH). Positive-ion FAB-MS: *m*/*z* 736, 764, 778, 792, 806, 820, 834, 848 and 862 $[M + Na]^+$ series. ^1H NMR (C_5D_5N) δ_H: 0.86 (6H, br. t), 4.89 (1H, d, J = 8.0 Hz, glucose H-1″). ^{13}C NMR: see Table 1.

2.3.3 TSC-2. White amorphous powder. IR ν_{max}/cm^{-1}: 3289 (hydroxy), 1640, 1540 (amide). $[\alpha]_D^{22} = +29$ (*c* 0.1 in MeOH). Positive-ion FAB-MS: *m*/*z* 810, 824, 838, 852, 866 and 880 $[M + Na]^+$ series. ^1H NMR (C_5D_5N) δ_H: 0.83 (6H, br. t), 4.93 (1H, d, J = 8.0 Hz, glucose H-1″). ^{13}C NMR: see Table 1.

2.3.4 Methanolysis of TSC-1. TSC-1 (5 mg) was heated with 5% HCl in MeOH (0.5 mL) at 70 °C for 8 h in a sealed small-volume vial. The reaction mixture was extracted with *n*-hexane and the extract was concentrated *in vacuo* to yield a mixture of fatty acid methyl ester (FAME) products. The methanolic layer was neutralized with Ag_2CO_3, filtered, and the filtrate was concentrated *in vacuo* to give a mixture of long chain base (LCB) and methyl glycoside products. The mixture was further evaporated and reacted with acetic anhydride/pyridine (1 : 1) (0.2 mL) at 70 °C for 8 h in a sealed small-volume vial followed by evaporation *in vacuo* to dryness. The mixture was separated using preparative TLC to afford the LCB, LCB acetates and LCB glucoacetates. ^1H, ^{13}C NMR and FAB-MS analyses were performed on the FAMEs and the LCB products.

2.3.5 Methanolysis of TSC-2. In the same manner as described for **TSC-1**, **TSC-2** (5 mg) was methanolyzed and the reaction mixture was worked up to give the FAMEs, LCB, LCB acetates and LCB glucoacetates. The ^1H, ^{13}C NMR and FAB-MS analyses were performed on the FAMEs and the LCB products.

2.3.6 FAB-MS analysis of the FAME mixture from TSC-1. Positive molecular ion peaks at 287, 315, 329, 343, 357, 371, 385, 399 and 413 $[M + H]^+$ indicated the presence of C-16, C-18–C-25 fatty acid methyl esters in **TSC-1**. See Fig. 1.

2.3.7 FAB-MS analysis of the LCB products from TSC-1. Positive ion FAB-MS analysis showed molecular ion peaks at 395 [M+] (LCB) and 424 $[M + H]^+$ (LCB acetate) indicating the presence of a C-16 LCB, while 652 $[M + Na]^+$ (LCB glucoacetate) indicated the presence of a C-18 LCB in **TSC-1**. See Fig. 1.

2.3.8 FAB-MS analysis of the FAME mixture from TSC-2. Positive molecular ion peaks at 343, 357, 371, 385, 399 and 413 $[M + H]^+$ indicated the presence of C-20–C-25 fatty acid methyl esters in **TSC-2**. See Fig. 1.

2.3.9 FAB-MS analysis of the LCB products from TSC-2. Positive ion FAB-MS analysis showed molecular ion peaks at 455 [M+] (LCB acetate) and 484 $[M + H]^+$ (LCB acetate) indicating the presence of a C-16 and C-18 LCB respectively in **TSC-2**. See Fig. 1.

2.3.10 Identification of the sugar moiety in TSC-1. TSC-1 (5 mg) was heated with 5% HCl in MeOH (0.5 mL) at 70 °C for 8 h in a sealed small-volume vial. The reaction mixture was extracted with $CHCl_3$ to remove the release fatty acid. The methanolic was neutralized with Ag_2CO_3 to give the methylated sugar followed by HPLC analysis HPLC analysis (Cosmosil-sugar-D, 4.6 ID × 250 mm, 1 mL min^{-1}, RI detector, 95% acetonitrile) against standard glucose and galactose. **TSC-1** showed a retention time identical to glucose (glucose t_R = 14.11 min, galactose t_R = 13.27 min). In the same way, the sugar moiety was identified as glucose for **TSC-2** and **TSS-1**.

2.3.11 Determination of the absolute configuration of the glucose moiety in TSC-1 (Tanaka *et al.* Method).[18] The glycosidic bond in **TSC-1** (2 mg, 1.1 × 10^6 mol) was hydrolyzed by heating in 0.5 M HCl (0.1 mL) and neutralized with Amberlite IRA400. After drying *in vacuo*, the residue was dissolved in pyridine (0.1 mL) containing L-cysteine methyl ester hydrochloride (0.5 mg) and heated at 60 °C for 1 h. A 0.1 mL solution of *o*-tolyl isothiocyanate (0.5 mg) in pyridine was added to the mixture, which was heated at 60 °C for 1 h. The reaction mixture was directly analyzed by reversed-phase HPLC. The peaks at 18.68 min which were coincided with the aryl-isothiocyanate derivative of D-glucose (L-glucose t_R = 19.22 min). In the same way as described for TSC-1, the absolute configuration of the glucose moiety (D-form) of **TSC-2** (at t_R = 18.5 min) and **TSS-1** (at t_R = 18.7 min) were also determined. See Fig. 1 and 2; Spectral data.

Table 1 ^{1}H and ^{13}C NMR spectral data of **TSC-1** and **TSC-2** (measured in C_5D_5N)[a]

	TSC-1		TSC-2	
Position	^{1}H	^{13}C	^{1}H	^{13}C
NH	8.35 (1H, d, J = 8.8 Hz)		8.55 (1H, d, J = 8.8 Hz)	
1a	4.21 (dd, J = 10.0, 5.0 Hz, 1H)	70.8	4.29 (dd, J = 10.0, 5.0 Hz, 1H)	69.8
1b	4.77 (1H, m)		4.70 (d, J = 5.0 Hz, 1H)	
2	4.77 (1H, m)	54.0	4.70 (1H, m)	51.1
3	4.71 (1H, m)	71.8	4.59 (1H, m)	71.8
4	5.97 (1H, m)	131.4	4.49 (1H, m)	
5	5.97 (1H, m)	131.4		
x	5.48 (1H, m)	129.9	5.48 (1H, m)	129.5
y	5.49 (1H, m)	129.9	5.48 (1H, m)	130.0
1′		175.0		175.0
2′	4.59 (1H, m)	71.8	4.29 (1H, m)	71.8
$-CH_3$	0.86 (3H, t)	13.6	0.83 (3H, t)	13.6
1″	4.89 (1H, d, J = 8.0 Hz)	105.5	4.93 (1H, d, J = 8.0 Hz)	104.9
2″	4.03 (1H, m)	74.5	4.00 (1H, m)	75.2
3″	4.23 (1H, m)	78.0	4.18 (1H, m)	77.9
4″	4.21 (1H, m)	71.6	4.18 (1H, m)	70.8
5″	3.90 (1H, m)	78.0	3.85 (1H, m)	77.9
6a″	4.36 (1H, m)	62.0	4.29 (1H, m)	62.0
6b″	4.59 (1H, m)		4.56 (1H, m)	

[a] Spectra were acquired at 23 °C. Chemical shifts are given in δ (ppm) and are referenced to internal solvent signals for C_5D_5N at 7.19 (δ_H) and 123.5 (δ_C) ppm. *X* and *y* are olefinic signals (double bond location).

2.4. Spectral data

2.4.1 β-Sitosteryl-3β-D-glucopyranoside-6′-*O*-methyl esters (TSS-1). ^{1}H NMR (chloroform-*d*, 300 MHz, TMS) δ_H (ppm), 0.84 (3H, terminal Me), 0.68 (3H, s, H-18), 0.84 (3H, s, J = 7.8 Hz, H-29), 0.87 (3H, s, H-26), 0.88 (3H, s, H-27), 1.01 (3H, s, H-19), 1.25 (2H, s, $n$$CH_2$), 3.55 (1H, m, H-3a), 5.36 (1H, m, H-5) and 3.37–4.53 (6H, m, H-2′-H-6′-glucose), 4.37 (1H, d, J = 8.0 Hz, H-1′-glucose). ^{13}C NMR (chloroform-*d* 100 MHz, TMS) δ_C (ppm), 37.24 (C-1), 29.70 (C-2), 79.54 (C-3), 38.88 (C-4), 140.26 (C-5), 122.19 (C-6), 31.92 (C-7), 31.92 (C-8), 50.14 (C-9), 36.71 (C-10), 21.04 (C-11), 39.74 (C-12), 42.31 (C-13), 56.73 (C-14), 24.28 (C-15), 28.23 (C-16), 56.05 (C-17), 11.84 (C-18), 19.33 (C-19), 36.12 (C-20), 18.76 (C-21), 33.92 (C-22), 26.05 (C-23), 45.81 (C-24), 29.12 (C-25), 19.01 (C-26), 19.81 (C-27), 23.04 (C-28), 11.96 (C-29), 101.18 (C-1′), 73.58 (C-2′), 75.89 (C-3′), 69.99 (C-4′), 73.96 (C-5′), 63.10 (C-6′), 174.79 (C-1″), 34.21 (C-2″), 24.94 (C-3″), 29.30–29.76 ($n$$CH_2$) and 14.12 (terminal Me).[19]

2.4.2 β-Sitosteryl-3β-D-glucopyranoside-6′-*O*-palmitate (1). ^{1}H NMR (chloroform-*d*, 300 MHz, TMS) δ_H (ppm), 0.84 (3H, terminal Me), 0.68 (3H, s, H-18), 0.84 (3H, s, J = 7.8 Hz, H-29), 0.87 (3H, s, H-26), 0.88 (3H, s, H-27), 1.01 (3H, s, H-19), 1.25 (2H, s, $n$$CH_2$), 3.55 (1H, m, H-3a), 5.36 (1H, m, H-5) and 3.37–4.37 (6H, m, H-2′-H-6′-glucose), 4.37 (1H, d, J = 8.0 Hz, H-1′-glucose). ^{13}C NMR (chloroform-*d*, 100 MHz, TMS) δ_C (ppm), 37.24 (C-1), 29.70 (C-2), 79.54 (C-3), 38.88 (C-4), 140.26 (C-5), 122.19 (C-6), 31.92 (C-7), 31.92 (C-8), 50.14 (C-9), 36.71 (C-10), 21.04 (C-11), 39.74 (C-12), 42.31 (C-13), 56.73 (C-14), 24.28 (C-15), 28.23 (C-16), 56.05 (C-17), 11.84 (C-18), 19.33 (C-19), 36.12 (C-20), 18.76 (C-21), 33.92 (C-22), 26.05 (C-23), 45.81 (C-24), 29.12 (C-25), 19.01 (C-26), 19.81 (C-27), 23.04 (C-28), 11.96 (C-29), 101.18 (C-1′), 73.58 (C-2′), 75.89 (C-3′), 69.99 (C-4′), 73.96 (C-5′), 63.10 (C-6′), 174.79 (C-1″), 34.21 (C-2″), 24.94 (C-3″), 29.30 (C-4″), 29.51 (C-5″), 29.71 (C-6″), 29.66 (C-7″–C-12″), 29.36 (C-13″), 31.84 (C-14″), 22.68 (C-15″) and 14.12 (C-16″).[19]

2.4.3 β-Sitosterol (2). ^{1}H NMR (chloroform-*d*, 300 MHz, TMS) δ_H (ppm), 0.71 (3H, s, H-19), 0.80 (3H, s, H-26), 0.82 (3H, s, H-27), 0.83 (3H, s, H-29), 0.91, (3H, s, H-21), 1.03 (3H, s, H-18), 3.51 (1H, m, H-3), 5.14 (1H, m, H-23) and 5.31 (1H, t, H-6). ^{13}C NMR (pyridine-d_5, 100 MHz, TMS) δ_C (ppm), 37.4 (C-1), 30.2 (C-2), 108.5 (C-3), 42.3 (C-4), 140.9 (C-5), 121.9 (C-6), 32.0 (C-7), 32.1 (C-8), 50.3 (C-9), 36.9 (C-10), 21.2 (C-11), 39.9 (C-12), 42.5 (C-13), 56.8 (C-14), 24.5 (C-15), 28.5 (C-16), 56.2 (C-17), 11.9 (C-18), 19.4 (C-19), 36.3 (C-20), 21.2 (C-21), 34.2 (C-22), 26.4 (C-23), 51.3 (C-24), 29.4 (C-25), 19.9 (C-26), 21.2 (C-27), 25.4 (C-28), and 12.1 (C-29).[20]

2.4.4 β-Sitosterol-3β-D-glucopyranoside (3). ^{1}H NMR (pyridine-d_5, 300 MHz, TMS) δ_H (ppm), 0.71 (3H, s, H-19), 0.80 (3H, s, H-26), 0.82 (3H, s, H-27), 0.83 (3H, s, H-29), 0.91, (3H, s, H-21), 1.03 (3H, s, H-18), 3.55 (1H, m, H-3), 5.31 (1H, t, H-6) and 3.38–4.37 (5H, m, H-2′-H-5′, glucose), 4.42 (1H, d, J = 8.0 Hz, H-1′-glucose). ^{13}C NMR (pyridine-d_5, 100 MHz, TMS) δ_C (ppm), 37.4 (C-1), 30.2 (C-2), 78.4 (C-3), 39.3 (C-4), 140.9 (C-5), 121.9 (C-6), 32.0 (C-7), 32.1 (C-8), 50.3 (C-9), 36.9 (C-10), 21.2 (C-11), 39.9 (C-12), 42.5 (C-13), 56.8 (C-14), 24.5 (C-15), 28.5 (C-16), 56.2 (C-17), 11.9 (C-18), 19.4 (C-19), 36.3 (C-20), 19.0 (C-21), 34.2 (C-22), 26.4 (C-23), 46.0 (C-24), 29.4 (C-25), 19.9 (C-26), 19.2 (C-27), 23.4 (C-28), 12.1 (C-29), 102.6 (C-1′), 75.3 (C-2′), 78.1 (C-3′), 71.7 (C-4′), 78.4 (C-5′) and 62.8 (C-6′).[20]

2.4.5 β-Stigmasterol (4). ^{1}H NMR (pyridine-d_5, 300 MHz, TMS), δ_H (ppm), 0.66 (3H, s, H-18), 0.86 (3H, d, J = 7.7 Hz, H-26), 0.84 (3H, d, J = 6.1 Hz, H-27), 0.88 (3H, t, J = 6.1 Hz, H-29), 1.01 (3H, s, H-19), 1.05 (3H, d, J = 6.5 Hz, H-21), 3.53 (1H, m, H-3a), 5.15 (dd, J = 8.4, 15.1 Hz, H-22), 5.02 (dd, J = 8.4, 15.1 Hz, H-23)

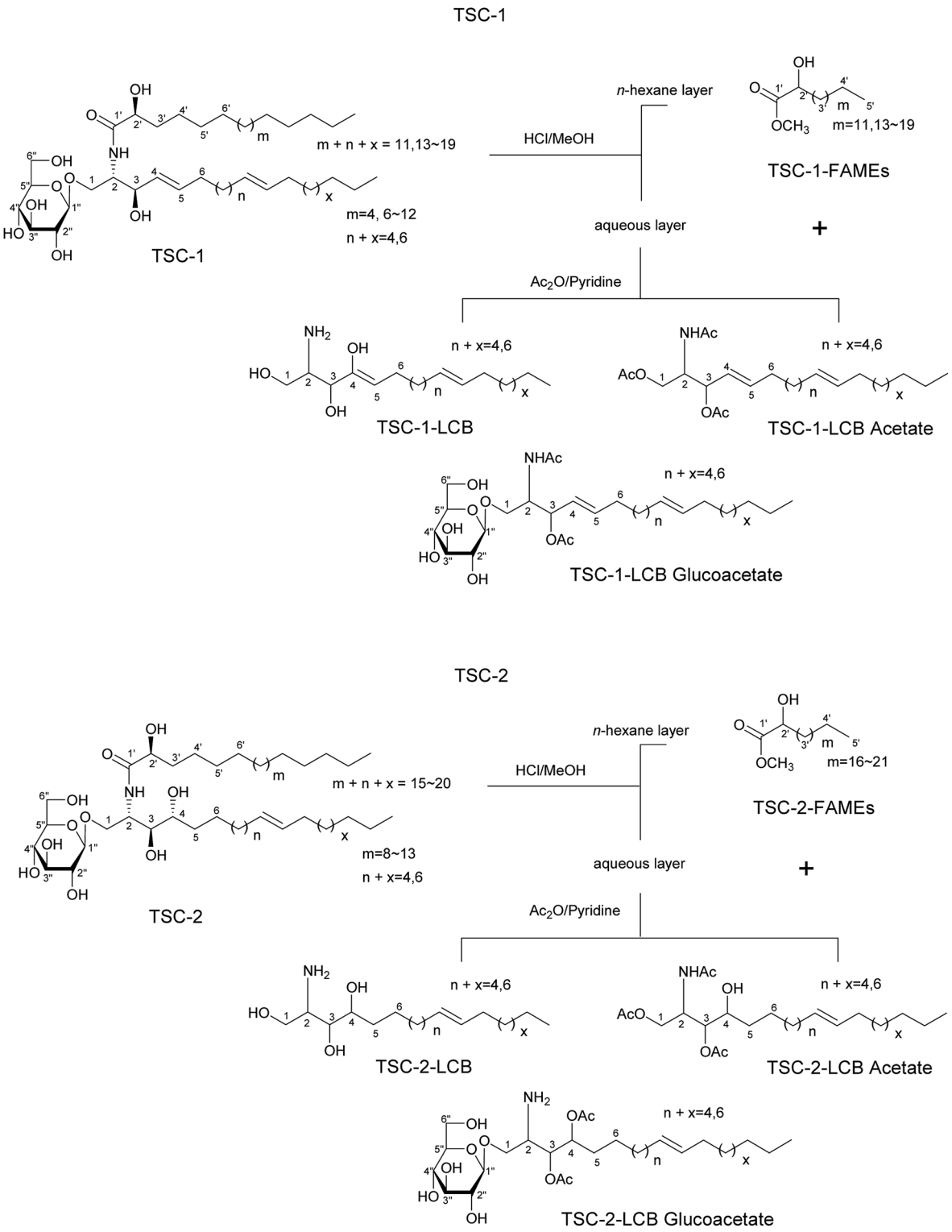

Fig. 1 Structures of TSC-1 and TSC-2.

and 5.33 (1H, m, H-6). ^{13}C NMR (pyridine-d_5, 100 MHz, TMS) δ_C (ppm), 37.4 (C-1), 30.2 (C-2), 109.5 (C-3), 42.3 (C-4), 140.9 (C-5), 121.9 (C-6), 32.1 (C-7), 32.0 (C-8), 50.3 (C-9), 36.9 (C-10), 21.2 (C-11), 39.8 (C-12), 42.3 (C-13), 56.9 (C-14), 24.5 (C-15), 28.3 (C-16), 56.9 (C-17), 12.1 (C-18), 19.4 (C-19), 40.7 (C-20), 21.4 (C-21), 138.8 (C-22), 129.4 (C-23), 51.4 (C-24), 32.1 (C-25), 21.2 (C-26), 19.1 (C-27), 25.7 (C-28) and 12.1 (C-29).[19]

2.4.6 β-Stigmasterol-3β-D-glucopyranoside (5). ^{1}H NMR (pyridine-d_5, 300 MHz, TMS) δ_H (ppm), 0.68 (3H, s, H-18), 0.88 (3H, d, J = 6.4 Hz, H-27), 0.89 (3H, t, J = 7.5 Hz, H-29), 0.92 (3H,

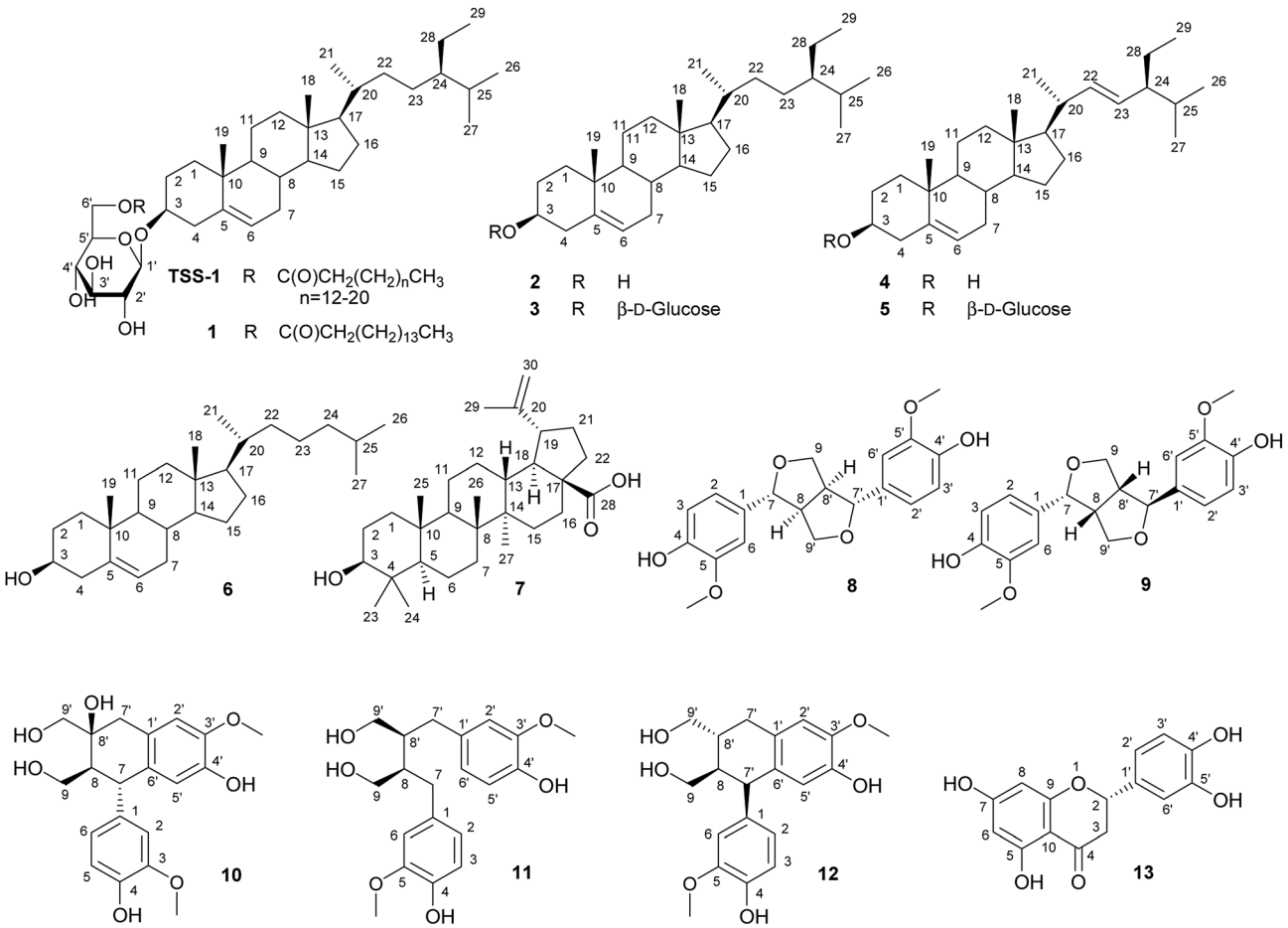

Fig. 2 Structure of TSS-1 and comp. 1–13.

d, J = 6.5 Hz, H-26), 0.95 (3H, s, H-19), 1.09 (3H, d, J = 6.4 Hz, H-21), 4.317 (1H, m, H-3a), 5.07 (dd, 1H, J = 8.9, 15.1 Hz, H-23), 5.23 (dd, 1H, J = 8.7, 15.1 Hz, H-22), 5.33 (H-6) and 3.38–4.37 (5H, m, H-2′-H-5′-glucose), 4.42 (1H, d, J = 8.0 Hz, H-1′-glucose). ^{13}C NMR (pyridine-d_5, 100 MHz, TMS) δ_C (ppm), 37.4 (C-1), 30.2 (C-2), 78.6 (C-3), 39.3 (C-4), 140.9 (C-5), 121.9 (C-6), 32.1 (C-7), 32.0 (C-8), 50.3 (C-9), 36.9 (C-10), 21.2 (C-11), 39.8 (C-12), 42.3 (C-13), 56.9 (C-14), 24.5 (C-15), 28.3 (C-16), 56.9 (C-17), 12.1 (C-18), 19.4 (C-19), 40.7 (C-20), 21.4 (C-21), 138.8 (C-22), 129.4 (C-23), 51.4 (C-24), 32.1 (C-25), 21.2 (C-26), 19.1 (C-27), 25.7 (C-28), 12.5 (C-29), 102.5 (C-1′), 75.3 (C-2′), 78.1 (C-3′), 71.7 (C-4′), 78.4 (C-5′) and 62.8 (C-6′).[20]

2.4.7 Cholesterol (6). ^{1}H NMR (chloroform-d, 400 MHz, TMS) δ_H (ppm), 0.69, 1.02 (6H, s, C-18, C-19), 0.83 (6H, t, C-26, C-27), 0.93 (3H, d, J = 6.5 Hz, C-21), 3.55 (1H, m, H-3) and 5.38 (1H, s, H-6). ^{13}C NMR (chloroform-d, 100 MHz, TMS) δ_C (ppm), 37.4 (C-1), 31.7 (C-2), 71.8 (C-3), 43.3 (C-4), 140.9 (C-5), 121.7 (C-6), 32.0 (C-7), 31.7 (C-8), 50.3 (C-9), 36.9 (C-10), 21.2 (C-11), 39.9 (C-12), 36.2 (C-13), 56.8 (C-14), 24.5 (C-15), 28.5 (C-16), 56.2 (C-17), 11.9 (C-18), 19.4 (C-19), 35.8 (C-20), 23.9 (C-21), 36.2 (C-22), 23.9 (C-23), 39.6 (C-24), 22.6 (C-25) and 22.6 (C-26).[21]

2.4.8 Betulinic acid (7). ^{1}H NMR (chloroform-d, 400 MHz, TMS) δ_H (ppm), 4.93 (1H, brs, H-29b), 4.76 (1H, brs, H-29a), 3.52 (1H, m, H-18), 3.46 (1H, m, H-3), 1.78 (3H, s, H-30), 1.27, (3H, s, H-23), 1.21 (3H, s, H-24), 0.84 (3H, s, H-25), 1.04 (3H, s, H-26), 1.05 (3H, s, H-27). ^{13}C NMR (pyridine-d_5, 100 MHz, TMS) δ_C (ppm), 39.22 (C-1), 28.24 (C-2), 78.07 (C-3), 39.48 (C-4), 55.85 (C-5), 18.73 (C-6), 34.76 (C-7), 41.05 (C-8), 50.89 (C-9), 37.55 (C-10), 21.14 (C-11), 26.05 (C-12), 38.55 (C-13), 42.79 (C-14), 30.23 (C-15), 32.83 (C-16), 56.58 (C-17), 47.73 (C-18), 49.69 (C-19), 151.29 (C-20), 29.96 (C-21), 37.46 (C-22), 28.62 (C-23), 16.32 (C-24), 16.32 (C-25), 19.42 (C-26), 14.85 (C-27), 178.86 (C-28), 109.93 (C-29) and 19.42 (C-30).[22]

2.4.9 (+)-Epipinoresinol (8). ^{1}H NMR (chloroform-d, 400 MHz, TMS) δ_H (ppm), 6.97–6.76 (6H, m, H-6′, 6″, 3′, 3″, 2′, 2″), 3.95 (3H, s, H-5′, OMe), 3.85 (3H, s, H-5″, OMe), 3.83–3.75 (2H, m, H-9, 9′), and 3.37–3.28 (2H, m, H-8, 8′). ^{13}C NMR (chloroform-d 100 MHz, TMS) δ_C (ppm), 146.69, 146.39 (C-3, 3′), 145.29, 144.56 (C-4, 4′), 133.00, 130.30 (C-1, 1′), 119.17, 116.37 (C-6, 6′), 114.19 (C-5, 5′), 108.47, 108.30 (C-2, 2′), 87.71, 82.07 (C-7, 7′), 70.95, 69.67 (C-9, 9′), 55.97, 55.91 (3, 3′ –OMe) and 54.46, 50.1 (C-8, 8′).[23]

2.4.10 (+)-Pinoresinol (9). ^{1}H NMR (chloroform-d, 400 MHz, TMS) δ_H (ppm), 6.9 (2H, d, J = 1.5 Hz, H-6′, 6″), 6.78 (2H, d, J = 8.0 Hz, H-3′, 3″), 6.71 (2H, dd, J = 1.5, 8.0 Hz, H-2′, 2″), 4.73 (2H, d, J = 5.0 Hz, H-7, 7′), 4.24 (2H, dd, J = 7.0, 9.5 Hz, H-9), 3.88 (2H, dd, J = 4.0, 9.5 Hz, H-9′), 3.80 (6H, s, H-5′, 5″, OMe) and 3.09 (2H, m, H-8, 8′). ^{13}C NMR (chloroform-d 100 MHz,

TMS) δ_C (ppm), 146.67 (C-3, 3′), 145.19 (C-4, 4′), 132.85 (C-1, 1′), 118.93 (C-6, 6′), 114.23 (C-5, 5′), 108.55 (C-2, 2′), 85.84 (C-7, 7′), 71.63 (C-9, 9′), 55.92 (3, 3′ –OMe) and 54.12 (C-8, 8′).[23]

2.4.11 (+)-Cycloolivil (10). ^{1}H NMR (methanol-d_4, 400 MHz, TMS) δ_H (ppm), 6.75 (1H, d, J = 8.0 Hz, H-5), 6.73 (1H, d, J = 8.0 Hz, H-2), 6.67 (1H, dd, J = 8.0, 2.0 Hz, H-6), 6.61 (1H, s, H-2′), 6.12 (1H, s, H-5′), 4.62 (1H, m, H-7), 3.82 (1H, m, H-9b), 3.80 (3H, s, OMe), 3.79 (1H, d, J = 11.2 Hz, H-9′b), 3.75 (3H, s, OMe), 3.59 (2H, m, H-9′a), H-9b, 3.37 (1H, m, H-7′b), 2.61 (1H, m, 7′) and 2.05 (1H, m, H-8). ^{13}C NMR (methanol-d_4, 100 MHz, TMS) δ_C (ppm), 149.23, 147.39 (C-3, 3′) 146.20, 145.39 (C-4, 4′), 138.02 (C-1′), 133.75 (C-1), 126.60 (C-6′), 123.12 (C-6), 117.38, 116.01, 113.22, 112.35 (C-5, 5, 2, 2′), 74.90 (C-8′), 69.50 (C-9), 61.00 (C-9′), 56.35, 56.33 (OMe), 47.90 (C-8), 45.0 (C-7) and 40.10 (C-7′).[24]

2.4.12 (+)-Secolariciresinol (11). ^{1}H NMR (methanol-d_4, 400 MHz, TMS) δ_H (ppm), 6.66 (2H, d, J = 8.0 Hz, H5, H-5′), 6.64 (2H, d, J = 2.0 Hz, H-2, 2′), 6.53 (2H, dd, J = 8.0, 2.0 Hz, H-6, 6′), 3.73 (6H, s, H-3, 3′, –OCH_3), 3.57 (4H, m, H-9, 9′), 2.68 (2H, m, H-7′a, 7a) and 1.90 (2H, br m, H-8, 8′). ^{13}C NMR (methanol-d_4, 100 MHz, TMS) δ_C (ppm), 79.9 (C-2), 43.5 (C-3), 197.2 (C-4), 165.2 (C-5), 96.7 (C-6), 167.3 (C-7), 95.8 (C-8), 164.3 (C-9), 103.2 (C-10), 131.5 (C-1′), 114.7 (C-2′), 146.1 (C-3′), 147.1 (C-4′), 116.0 (C-5′) and 119.2 (C-6′).[25]

2.4.13 (+)-Isolariciresinol (12). ^{1}H NMR (methanol-d_4, 400 MHz, TMS) δ_H (ppm), 6.75 (2H, d, J = 8.0 Hz, H-5, 5′), 6.67 (2H, d, J = 2.0 Hz, H-2, 2′), 6.43 (2H, m, H-6, 6′), 6.2 (2H, s, H-6, 6′), 3.80, 3.82 (6H, s, H-3, 3′ –OMe), 3.74–3.34 (4H, m, H-9, 9′), 2.77 (2H, m, H-7′, 7) and 1.99 (2H, m, H-8, 8′). ^{13}C NMR (methanol-d_4, 100 MHz, TMS) δ_C (ppm), 138.6 (C-1), 113.8 (C-2), 149.0 (C-3), 145.9 (C-4), 117.4 (C-5), 129.0 (C-6), 39.9 (C-7), 48.0 (C-8), 65.9 (C-9), 134.2 (C-1′), 112.4 (C-2′), 147.2 (C-3′), 145.3 (C-4′), 116.0 (C-5′), 129.0 (C-6′), 39.9 (C-7′), 48.0 (C-8′), 62.2 (C-9′) and 56.4 (OMe).[23]

2.4.14 (+)-Eriodictyol (13). ^{1}H NMR (methanol-d_4, 400 MHz, TMS) δ_H (ppm), 6.91 (1H, s, H-2′), 6.78 (1H, s, H-5′), 5.90 (1H, d, J = 2.2, H-8), 5.88 (1H, d, J = 2.2, H-6), 5.28 (1H, dd, J = 12.8; 3.0 Hz, H-2), 3.06 (1H, dd, J = 17.2, 12.8 Hz, H-3a) and 2.66 (1H, dd, J = 17.2, 3.0 Hz, H-3b). ^{13}C NMR (methanol-d_4, 100 MHz, TMS) δ_C (ppm), 80.53 (C-2), 44.13 (C-3), 197.80 (C-4), 165.5 (C-5), 97.07 (C-6), 168.50 (C-7), 96.20 (C-8), 164.87 (C-9), 103.35 (C-10), 131.80 (C-1′), 114.73 (C-2′), 146.54 (C-3′), 146.92 (C-4′), 116.28 (C-5′) and 119.29 (C-6′).[26]

3. Results and discussion

Chromatographic separation of the *n*-hexane fraction, from the chloroform/methanol crude extract of *T. sanguinea* whole plant lead to the isolation of two glucocerebroside molecular species **TSC-1** and **TSC-2**, and one β-sitosteryl-3β-D-glucopyranoside-6′-*O*-fatty acid ester molecular species **TSS-1**, together with seven known triterpenes: β-sitosteryl-3β-D-glucopyranoside-6′-*O*-palmitate **1**, β-sitosterol **2**, β-sitosterol-3β-D-glucopyranoside **3**, β-stigmasterol **4**, β-stigmasterol-3β-D-glucopyranoside **5**, cholesterol **6** and betulinic acid **7**. Five known lignans: (+)-epipinoresinol **8**, (+)-pinoresinol **9**, (+)-cycloolivil, **10**, (+)-secoisolariciresinol **11** and (+)-isolariciresinol **12** and one known flavanone (+)-eriodictyol **13**, were also isolated from the ethyl acetate fraction of *T. sanguinea* whole plant. The known compounds were identified by comparison with authentic samples or reported spectral and physical data. See Fig. 1 and 2; Spectral data.

3.1. Chemistry

3.1.1 β-sitosteryl-3β-D-glucopyranoside-6′-*O*-fatty acid methyl ester molecular species (TSS-1). TSS-1 (94 mg) was obtained as a white amorphous solid, and showed as a single spot on silica gel TLC plate. It exhibited a strong absorption at 3350 cm^{-1} indicating the presence of a hydroxyl group and a band at 1720 cm^{-1} (carbonyl) indicating a stretching of a normal aliphatic ester. The ^{1}H and ^{13}C NMR spectra reveal characteristic signals for a β-sitosterol glucoside and long fatty acid methyl esters. A series of molecular ion peaks in the positive FAB-MS spectra confirmed the possible structure of **TSS-1**. See Fig. 2 and Spectral data.

The NMR spectral data of **TSS-1** in $CDCl_3$ showed resonances of a carboxylic acid group (δ_C 174.8), a long methylene chain centered at δ_H 1.25, (δ_C 29.1–29.9) and overlapped methyls at δ_H 0.68–0.85 (δ_C 14.1), indicating normal type terminal methyls of the fatty acids. The characteristic signals of a sitosterol skeleton were determined as follows: a methine proton at δ_H 3.55 (1H, m, H-3, δ_C 79.5) and an olefinic proton signal at δ_H 5.38 (1H, m, H-5, δ_C 140.3) were assigned as C-3 and C-5 respectively. Two angular methyl protons at δ_H 0.68 (3H, s) and 1.01 (3H, s), corresponding to δ_C 11.8 and 19.3 were assigned as C-18 and C-19 respectively. The proton signals at δ_H 0.87 (3H, s, δ_C 19.0; C-26) and 0.88 (3H, s, δ_C 19.8; C-27) indicated the presence of an isopropenyl group in the molecular structure. The proton signal at δ_H 0.84 (3H, t, J = 7.8 Hz; δ_C 11.9) was assigned as C-29. All other NMR assignments were in agreement with known β-sitosteryl-3β-D-glucopyranoside-6′-*O*-fatty acid methyl esters.[19] Characteristic signals indicative of a presence of a monosaccharide moiety at δ_H 3.38–4.53, 6H with an anomeric proton signal at δ_H 4.37 (1H, d, J = 7.8 Hz; δ_C 101.2) were observed. See Fig. 1 and Spectral data.

To identify the sugar moiety in **TSS-1**, the methylated sugar moiety in the aqueous layer after methanolysis was analysed by HPLC against standard sugars (glucose and galactose) and identified as glucose (glucose t_R = 14.11 min, galactose t_R = 13.27 min). The coupling constant of the anomeric proton at δ_H 4.38 (1H, d, J = 8.0 Hz) and the chemical shift of the anomeric carbon δ_C (101.2) confirmed the β-configuration of the glucopyranoside moiety (α-glucopyranoside: J = 3.7 Hz; δ_C 98.5).[18] The absolute configuration of the sugar moiety was determined by the Tanaka *et al.* method.[18] Direct HPLC analysis of the reaction mixture of the sugar moiety exhibited a peak at t_R = 18.7 min, which were coincided with the aryl-isothiocyanate derivative of D-glucose, confirming the absolute configuration of the sugar moiety (L-glucose t_R = 19.22 min).[18]

The positive FAB-MS spectral data showed a series of molecular ion peaks at *m*/*z*: 851, 865, 879, 893, 907, 921, 935, 949, 963 and 977 $[M + Na]^+$. Therefore, **TSS-1** is presumed to be a molecular species consisting of β-sitosteryl-3β-D-glucopyranoside-6′-*O*-fatty acid methyl ester possessing mainly a hydroxy fatty acid moiety (normal type terminal methyl groups at δ_C 14.2) and a β-D-glucopyranose moiety. The core structure of the

β-sitosterol-3β-D-glucopyranose skeleton of **TSS-1** was characterized by comparison of its ^{13}C NMR spectral data with that of known β-sitosterol-3β-D-glucopyranose-6-*O*-fatty acid esters.[19] See Fig. 2 and Spectral data.

3.1.2 Cerebrosides from TSC-1. TSC-1 (30 mg) was obtained as a white amorphous solid, and showed as a single spot on silica gel TLC plate. Strong hydroxy (3422 cm^{-1}) and amide absorptions (1650, 1540 cm^{-1}) were observed in the IR spectrum.

The NMR spectral data of **TSC-1** in C_5D_5N showed resonances of a secondary amide proton doublet at δ_H 8.35 (1H, d, J = 8.8 Hz), a long methylene chain, centered at δ_H 1.26, (δ_C 29.1–29.3) and overlapped methyls at δ_H 0.86 (δ_C 13.6), indicating the presence of a sphingolipid skeleton. Characteristic signals indicative of a monosaccharide moiety at δ_H 3.90–4.89 (6H), with the anomeric proton signal at δ_H 4.89 (1H, d, J = 8.0 Hz; δ_C 105.5) were observed. The characteristic resonances for the 2-amino-1,3,2′-triol region of the hydrocarbon chain were observed at δ_H 4.77 (1H, m, H-2), 4.59 (1H, m, H-2′), 4.77 (1H, m, H-1b), 4.21 (1H, m, H-1a), 4.71 (1H, m, H-3) corresponding to the following ^{13}C NMR data: δ_C 54.0 (C-2), 71.8 (C-2′), 70.8 (C-1), 71.8 (C-3), and an amide carbonyl signal at δ_C 175.0 (C-1′). See Fig. 1 and Table 1.

The presence of two disubstituted double bonds at δ_C 131.4 (2CH, C-4, C-5) and 129.9 (2CH) were observed. The *E* geometry for the double bonds was supported from the characteristic chemical shift of the allylic carbons at δ_C 32.2, 32.3 and 34. (*Z* geometry = δ_C 27.0).

The positive FAB-MS spectral data showed a series of molecular ion peaks due to $[M + Na]^+$ at *m*/*z*: 736, 764, 778, 792, 806, 820, 834 and 848. **TSC-1** is hence presumed to be a molecular species consisting of a sphingosine-type cerebroside possessing mainly a 2-hydroxy fatty acid moiety (normal type terminal methyls at δ_C 13.6) and a β-D-glucopyranose moiety.

The sphingosine skeleton was characterized by comparison of its ^{1}H and ^{13}C NMR spectral data (Fig. 1 and Table 1) with that of known cerebrosides.[27] The relative stereochemistry of the ceramide moiety is presumed to be (2*S*,3*R*,4*E*,2′*R*) since the characteristic ^{13}C NMR signals (C-1, 2, 3, 4, 1′ and 2′) in addition to the optical rotation value of ($[\alpha]_D^{20} = -31.3$) are in good agreement with those of the sphingosine-type glucocerebroside molecular species possessing a 2*S*,3*R*,4*E*,2′*R* configuration.[27] The analysis of the methylated sugar against standard sugars (glucose and galactose) using HPLC indicated that the sugar moiety in **TSC-1** was glucose (glucose t_R = 14.11 min, galactose t_R = 13.27 min). The coupling constant of the anomeric proton at δ_H 4.89 (1H, d, J = 8.0 Hz) and the chemical shift of the anomeric carbon δ_C (105.5) confirmed the β-configuration of the glucopyranoside moiety (α-glucopyranoside: J = 3.7 Hz; δ_C 98.5).[18] The absolute configuration of the sugar moiety was determined using the Tanaka *et al.* method.[18] HPLC analysis of the reaction mixture exhibited a peak at t_R = 18.68 min, which were coincided with the aryl-isothiocyanate derivative of D-glucose, confirming the absolute configuration of the sugar moiety (L-glucose t_R = 19.22 min).

To determine the length of the FAMEs and LCB in the glucocerebrosides, the methanolysis products of **TSC-1** were subjected to ^{1}H, ^{13}C NMR, and FAB-MS analyses. Molecular ion peaks at 286, 314, 327, 343, 357, 371, 385, 399 and 413 $[M + H]^+$ indicated the presence of C-16, C-18–C-25 fatty acid methyl esters, possessing normal terminal methyl groups (δ_C 13.6). The LCB mixture showed molecular ion peaks at 395 [M+] (LCB) and 424 $[M + H]^+$ (LCB acetate) indicating the presence of a C-16 LCB, while 652 $[M + Na]^+$ (LCB glucoacetate) indicated the presence of a C-18 LCB in TSC-1. See Fig. 1.

3.1.3 Cerebrosides from TSC-2. TSC-2 (45 mg) was obtained as a white amorphous solid, seen as a single spot on normal-phase (silica gel) TLC plate. It exhibited strong hydroxy (3289 cm^{-1}) and amide absorptions (1650, 1540 cm^{-1}) in the IR spectrum.

The NMR spectra of **TSC-2** in C_5D_5N showed resonances for a secondary amide proton doublet at δ_H 8.55 (1H, d, J = 8.0 Hz), protons of a long methylene chain, centered at δ_H 1.25, (δ_C 29.1–29.8) and overlapped methyls at δ_H 0.83 (δ_C 13.6), indicating the presence of a sphingolipid skeleton. The proton signals at δ_H 3.85–4.93 (6H) and the anomeric proton signal at δ_H 4.93 (1H, d, J = 8.0 Hz; δ_C 104.9) confirmed the presence of a monosaccharide moiety.

TSC-2 showed characteristic resonances for the 2-amino-1,3,4,2′-tiol region of hydrocarbon chain with proton signals at δ_H 4.70 (1H, m, H-2), 4.29 (1H, m, H-2′), 4.70 (1H, m, H-1b), 4.29 (1H, m, H-1a), 4.59 (1H, m, H-3), and 4.49 (1H, m, H-4), corresponding to the following ^{13}C NMR data: δ_C 51.1 (C-2), 71.8 (C-2′), 69.8 (C-1), 71.8 (C-3) and an amide carbonyl signal at δ_C 175.0 (C-1′), see Table 1. A disubstituted double bond in the side chain of the base was observed at δ_C 129.5 and 130. The *E* geometry for the double bond was supported from the chemical shift of the allylic carbons at δ_C 32.3 and 34.9 (*Z* geometry = δ_C 27.0).

HPLC analysis of the methylated sugar moiety indicated the sugar moiety to be glucose (glucose t_R = 14.11 min, galactose t_R = 13.27 min). The coupling constant of the anomeric proton at δ_H 4.93 (1H, d, J = 8.0 Hz) and the chemical shift of the anomeric carbon δ_C (104.9) confirmed the β-configuration of the glucopyranoside moiety (α-glucopyranoside: J = 3.7 Hz; δ_C 98.5).[18] The absolute configuration of the sugar moiety was determined using the Tanaka *et al.* method.[18] HPLC analysis of the reaction mixture exhibited a peak at t_R = 18.5 min, which were coincided with the aryl-isothiocyanate derivative of D-glucose, confirmed the absolute configuration of the sugar moiety (L-glucose t_R = 19.22 min).

In the positive FAB-MS spectral of **TSC-2**, a series of molecular ion peaks due to 810, 824, 838, 852, 866 and 880 $[M + Na]^+$ were observed. Therefore, **TSC-2** is presumed to be a molecular species consisting of a phytosphingosine-type cerebroside possessing mainly a 2-hydroxy fatty acid moiety (normal methyls at δ_C 13.6) and a β-D-glucopyranose moiety.

The core structure of the phytosphingosine skeleton in **TSC-2** was characterized by comparison of its ^{1}H and ^{13}C NMR spectral data (Fig. 1 and Table 1) with that of known cerebrosides.[28] The relative stereochemistry of the ceramide moiety is presumed to be (2*S*,3*R*,4*R*,2′*R*) since the characteristic ^{13}C NMR signals (C-1, 2, 3, 4, 1′ and 2′) and the optical rotation value ($[\alpha]_D^{22} = +29.4$) are in good agreement with those of the

phytosphingosines-type glucocerebroside molecular species possessing a 2*S*,3*R*,4*R*,2′*R* configuration.[28]

In the FAB-MS analyses of the methanolysis products of **TSC-2**, the FAME mixture showed molecular ion peaks at 343, 357, 371, 383 and 413 $[M + H]^+$, indicating the presence of C-20–C-25 fatty acid methyl esters, possessing normal terminal methyl groups (δ_C 13.6). The LCB also indicated the presence of a C-16 and C-18 long chain base identified from the corresponding molecular ion peaks at of the LCB acetates at *m*/*z* 455 $[M + H]^+$ and 484 $[M + H]^+$ respectively. See Fig. 1 and Table 1.

3.2. Discussion

A sphingosine-type (**TSC-1**) and phytosphingosine-type (**TSC-2**) cerebrosides, with both containing mainly a 2-hydroxy fatty acids and β-D-glucopyranose moieties were isolated from the *n*-hexane fraction of *T. sanguinea* in this study. Cerebrosides and ceramides have received a lot of interest in their isolation and characterization due to their significant biological activities such as immunomodulatory antioxidant, antitumour, antiinflammatory and antiviral.[29,30]

Seven triterpenes were isolated from the *n*-hexane fraction of plant: β-sitosteryl-3β-D-glucopyranoside-*O*-fatty acid methyl esters molecular species **TSS-1**, β-sitosterol-3β-D-glucopyranoside-6′-*O*-palmitate **1**, β-sitosterol **2**, β-sitosterol-3β-D-glucopyranoside **3**, β-stigmasterol **4**, β-stigmasterol-3β-D-glucopyranoside **5**, cholesterol **6** and betulinic acid **7**. Biological functions of plant sterols include antihelmintic, antidiabetic, antiinflammatory, antiapoptotic, antinociceptive, antioxidant, immunomodulatory and neuroprotective in neurodegenerative disorders like Alzheimer's disease.[31,32]

Betulinic acid exhibits a variety of biological and medicinal properties such as inhibition of HIV, antibacterial, antimalarial, antiinflammatory, antihelmintic, antinociceptive, anti-HSV-1 and anticancer activities.[33]

The five lignans isolated from the ethyl acetate fraction of *T. sanguinea*: (+)-epipinoresinol **8**, (+)-pinoresinol **9**, (+)-cycloolivil **10**, (+)-secoisolariciresinol **11** and (+)-isolariciresinol **12** are reported to also have antiviral, antifungal, antimicrobial antifeedant and insecticidal properties and are probably related to plant defense against various pathogens and pests. They also have significant biological activities including antitumour, antiinflammatory, immunosuppression, cardiovascular, antioxidant and antiviral.[34] Pinoresinol and secoisolariciresinol are mammalian lignan precursors which are converted into enterodiol (END) and enterolactone (ENL) by the intestinal microflora.[22,35] These enterolignans afford protection against osteoporosis, cardiovascular diseases, liver diseases, hyperlipidemia, breast cancer, colon cancer, prostate cancer and menopausal syndrome.[25,36,37] The flavanone (+)-eriodictyol **13**, also isolated from the ethyl acetate fraction is reported to have significant antiinflammatory, anticancer, neurotrophic, and antioxidant effects.[38]

4. Conclusions

In summary, this paper describes the isolation of two glucocerebrosides, **TSC-1** and **TSC-2**, one molecular species **TSS-1**, seven triterpenes **1–7**, five lignans **8–12**, and one flavanone **13**, from the *n*-hexane and ethyl acetate fractions of whole plant of *T. sanguinea.* To the best of our knowledge, all the isolated compounds from *T. sanguinea* in this study are being reported for the first time. These compounds have a wide range of biological activities and may act individually or in synergy to produce these biological effects. They may therefore be partly, or wholly responsible for these biological actions, giving credence to the use of *T. sanguinea* in traditional medicine. Further work to increase the amount of isolated cerebrosides molecular species to determine the double bond location in the long chain bases as well as purify and characterize the individual pure cerebrosides is underway.

Conflicts of interest

There are no conflicts to declare.

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