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ORIGINAL ARTICLE

Phytochemical and biological studies of *Solanum schimperianum* Hochst

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Abstract Chemical reinvestigation of the aerial parts of *Solanum schimperianum* Hochst led to the isolation of ten compounds, lupeol (**1**), β-sitosterol (**2**), β-sitosterol glucoside (**3**), oleanolic acid (**4**), teferidin (**5**), teferin (**6**), ferutinin (**7**), 5-hydroxy-3,7,4′-trimethoxyflavone (**8**), retusin (**9**) and kaempferol-3-*O*-β-D-glucopyranoside (**10**). Compounds **5**–**7** were isolated for the first time from Solanaceae and compounds **1**–**4** and **8**–**9** for the first time from *Solanum schimperianum*. The structure elucidation of the isolated compounds was based on careful inspection of spectral data including 1D (^{1}H and ^{13}C NMR), 2D (^{1}H–H COSY, HMQC and HMBC, ROESY), UV, MS and IR, in addition to, comparison with literatures. The antimicrobial activity of the extracts as well as the isolated compounds was tested. Only hexane extract showed activity against *Bacillus subtilus* and *Staphylococcus aureus*.

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1. Introduction

The genus *Solanum* is the largest genera of the family Solanaceae consisting of more than 1700 species distributed all over the world. In Saudi Arabia, the genus is represented by about 16 species, mainly in West and Southwest side of the country (Chaudhary, 2001; Collenette, 1999). Several species of genus *Solanum* are used in the folk medicine of different countries, Brazil, India, Taiwan, Germany, South Africa and Kenya, as remedy for various ailments such as hypoglycemic (Kar et al., 2006), hepatoprotective (Son et al., 2003), hepatotonic (De Silva et al., 2003), laxative, appetizer, cardiotonic (Mans et al., 2004), antispasmodic, renal pain, epilepsy (Perez et al., 2006; Schwarz et al., 2005), gastric, liver disorder (Antonio et al., 2004; Mesia-Velal et al., 2002), treatment of bronchitis, itches, body aches, cancer (Koduru et al., 2006; Oboh et al., 2005). Genus *solanum* is a rich source for many classes of compounds such as alkaloids (Emmanuel et al., 2006; Ndebia et al., 2007), steroids (Ferro et al., 2005; Jairo et al., 1998; Yoshimitsu et al., 2003) and phenolic compounds)El-Sayed and Hassan, 2006; Hodek et al., 2002; Sarmento Silva and Bezerra Nascimento, 2004). *Solanum schimperianum* Hochst grows throughout Southern region of Saudi Arabia. It is also

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widely distributed in the tropical Africa. The plant is locally known as Millyan and Nakhab (Chaudhary, 2001). *Solanum schimperianum* plant has no known folkloric usage. The literature survey showed the isolation of one coumarin, esculetin and four flavonols; astragalin, isoquercitin, 3-kaempferol-diglucoside and rutin, four glycoalkaloids; α-solamargine and β-solamargine, β-solanopubamine, and γ-solamarine (Al-Rehaily et al., 2011; Angenot, 1969; Coune and Denoel, 1975). The methanol extract of *Solanum schimperianum* was reported to have significant antitrypanosomal activity (Abdel-Sattar et al., 2009). The present study deals with the isolation and characterization of ten compounds, as well as the antimicrobial study of the extracts and all the pure compounds.

2. Materials and methods

2.1. Plant materials

The aerial parts of *Solanum schimperianum* Hochst were collected from Abha region in March 2005. The plant was identified by Dr. M. Atiqur Rahman Prof. of Taxonomy, College of Pharmacy, King Saud University. A voucher specimen (# 14903) was deposited at the herbarium in the College of Pharmacy at King Saud University (KSU).

2.2. General experimental procedure

HPLC/ESI MS is carried out using a Finnigan LCQ-DECA mass spectrometer connected to UV detector; EI MS were measured on Finnigan 8430 mass spectrometer; Melting points were determined on a Mettler FP 80 Central Processor supplied with a Mettler FP 81 MBC Cell Apparatus, and were uncorrected; Specific rotations were measured as solutions in methanol or chloroform, unless otherwise specified, on a Perkin–Elmer 241 Mc polarimeter, using a one-decimeter tube; Infra Red spectra were recorded on Perkin–Elmer FTIR model 1600 spectrophotometer, USA; ^{1}H and ^{13}C NMR spectra were recorded in $CDCl_3$ and DMSO-d_6 on a Bruker Avance DRX – 500 instrument (Central Lab. at the College of Pharmacy, KSU) at 500 MHz for protons and 125 MHz for carbons using the residual solvent signal as an internal standard and/or NMR measurements done by Prof. Dr. Peter Procksh at the institute of Organic Chemistry and Macromolecular Chemistry of Heinrich-Heine University, Düsseldorf. ^{1}H and ^{13}C NMR spectra were recorded at 300 K on Bruker DPX 300, ARX 400, 500 or AVANCE DMX 600 NMR spectrometers. All 1D and 2D spectra were obtained using the standard Bruker software.

2.3. Extraction and Isolation

The dried and grounded aerial parts of *Solanum schimperianum* (2.4 kg) were consecutively extracted at room temperature with *n*-hexane (3 × 5 L) and ethyl acetate (3 × 5 L) to yield after evaporation *in vacuo* **A**, 5.24 g and **B**, 25.32 g.

n-Hexane extract (**A**, 5 g) was chromatographed on a silica gel column. The elution was started with petroleum ether and ethyl acetate and polarity was increased up to 3:1. The collected fractions (100 ml each) were pooled according to their TLC behavior into 5 fractions. Fraction 1 (900.23 mg) gave **1** (153.2 mg, 3.06%) by crystallization in a mixture of chloroform and methanol. Fraction 2 (350.50 mg) was crystallized to afford 72.8 mg of compound **2** 1.46%. Fraction 3 (879.76 mg) was rechromatographed over silica gel using petroleum ether and ethyl acetate (1:3) afforded **3 (**100.3 mg, 2.01%). Repeated crystallization of fraction 4 (935.45 mg) from methanol afforded **4 (**50.30 mg, 1.01%). Fraction 5 (1.52 g) was chromatographed over silica gel column and eluted using increased polarity of methanol in chloroform (0–10%) and resulted in four pooled subfractions (i–iv). Compounds **5** (17.23 mg, 0.34%) and **6** (12.31 mg, 0.34%) were isolated from subfractions (i) (200.53 mg) and (ii) (320.73 mg) were chromatographed over chromatotron (1 mm plate) using 5% and 10% ethyl acetate in hexane respectively. while subfraction (iii) (680.43 mg) was chromatographed over chromatotron (2 mm plate) using 20% ethyl acetate in hexane gave **7** (108.12 mg, 2.16%).

The ethyl acetate extract, (**B**, 10 g), was chromatographed over silica gel column using petroleum ether with increasing amount of ethyl acetate. Fractions eluted with 5% ethyl acetate in petroleum ether afforded **8** (12.11 mg, 0.12%). Fractions eluted with 10% ethyl acetate in petroleum ether afforded **9** (5.13 mg, 0.05%). The impure fractions were pooled together (5.21 g) and chromatographed over silica gel column using chloroform with increasing polarity with methanol. Fraction at 50% methanol in chloroform (1.53 g) was showing one major spot, which was further chromatographed over Sephadex column using 10% H_2O in methanol to afford 63 mg of compound **10**, 0.63%.

2.4. Acid hydrolysis

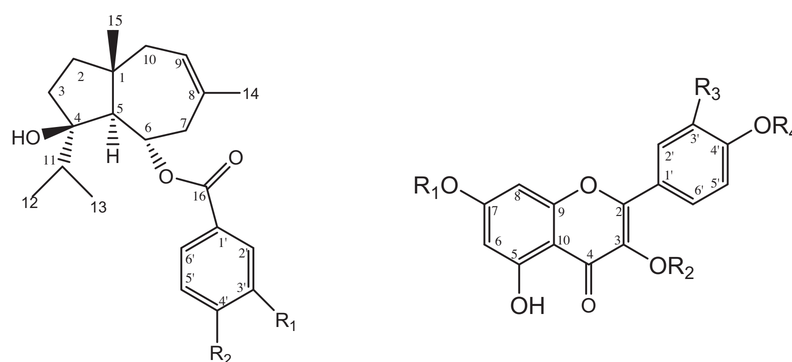
Acid hydrolysis of compound **10** afforded glucose as the sugar residue confirmed by co-TLC with authentic sample.

2.5. Antimicrobial assay

The extracts and all the pure compounds were tested for antimicrobial activity against *Bacillus subtilus* (ATCC 6633), *Staphylococcus aureus* (ATCC 292136), *Escherichia coli* (ATCC 25922), *Pseudomonas aeruginosa* (ATCC 15442), *Candida albicans* (ATCC 90023) and *Mycobacterium smegmatis* (ATCC 35797) microorganism using agar-cup diffusion method (Hugo and Russell, 1992). Briefly 20 ml of Nutrient Agar (Hi Media Pvt LTD) was poured into the Petri-dish and 8 mm well bored in the agar. 1 mg and 100 µg of each extract and pure compounds, respectively, were dissolved in 200 µL of dimethylsulfoxide and poured into the wells. The plates were incubated for 24 h at 37 °C and the zone of inhibition was measured in mm. DMSO was used as negative control, while Chloramphenicol was used as a positive control for Gram-positive.

3. Results

Ten compounds were isolated from the different extract of *Solanum schimperianum*. The structures of compounds **5–10** are presented in Fig. 1. The antimicrobial activities of hexane and ethyl acetate extracts as well as the isolated compounds were studied.



Compound	R_1	R_2
5	H	H
6	OCH_3	OH
7	H	OH

Compound	R_1	R_2	R_3	R_4
8	CH_3	CH_3	H	CH_3
9	CH_3	CH_3	OCH_3	CH_3
10	H	Glu	H	H

Figure 1 Structures of compounds 5–**10**.

*3.1. The physical and spectral data of compounds **1–10***

*3.1.1. Compound **1***

White powder; mp 210 °C; FTIR (KBr) 3235, 1640, 1382, 1185,1105 cm^{-1}; UV λ_{max} (MeOH) 200 nm; ^1H NMR (500 MHz, $CDCl_3$): δ 4.69, 4.56 (each 1H, m, H-29), 3.18 (1H, m, H-3), 1.69 (3H,s H-30), 1.04 (3H, s, H-26), 0.98 (3H, s, H-23), 0.97 (3H, s, H-27), 0.84, 0.79 and 0.77 (each 3H, s, H-25, 28, 24); ^{13}C NMR (125 MHz, $CDCl_3$): δ 150.8 (C-20), 109.3 (C-6), 78.9 (C-3), 55.2 (C-5), 50.3 (C-9), 48.2 (C-18), 47.8 (C-19), 42.9 (C-17), 42.5 (C-14) 40.8 (C-8) 39.9 (C-22), 38.8 (C-4), 38.5 (C-1), 38.0 (C-13), 37.1 (C-10), 35.4 (C-16), 34.2 (C-7), 29.8 (C-21), 27.9 (C-23), 27.4 (C-15), 27.1 (C-2), 25.0 (C-12), 20.9 (C-11), 19.2 (C-30), 18.2 (C-6), 17.8 (C-28), 16.1 (C-25), 15.9 (C-26), 15.3 (C-24), 14.5 (C-27); EI MS *m*/*z* 426 $[M]^+$.

*3.1.2. Compound **2***

White powder; mp 136 °C; FTIR (KBr) 4330 cm^{-1} (OH), 1050 cm^{-1} (C–O), 2900, cm^{-1}(for C–H), 1430 cm^{-1}(C≡C); ^1H NMR (500 MHz, $CDCl_3$): δ 5.38 (br s, H-6), 3.50 (1H, m, H-3), 0.99 (3H, s, H-19), 0.85 (3H, d, J = 7.5 Hz, H-26), 0.83 (3H, J = 7.5 Hz, H-27), 0.81 (3H, t, J = 7.5 Hz, H-29), 0.66 (3H, s, H-18); ^{13}C NMR (125 MHz, $CDCl_3$): δ 140.5 (C-5), 121.8 (C-6), 71.9 (C-3), 56.8 (C-14), 56.1 (C-17), 50.2 (C-9), 45.8 (C-24), 42.4 (C-13), 42.4 (C-4) 39.8 (C-12), 37.3 (C-1), 36.3 (C-10), 36.5 (C-20), 34.0 (C-22), 31.9 (C-7, 8), 31.7 (C-2), 29.2 (C-25), 28.3 (C-16), 26.1 (C-23), 24.4 (C-15), 23.1 (C-28), 21.2 (C-11), 19.9 (C-27), 19.4 (C-26), 19.1 (C-19), 18.8 (C-21), 12.0 (C-18), 11.9 (C-29); EI MS *m*/*z* 414 $[M]^+$ for $C_{29}H_{50}O$.

*3.1.3. Compound **3***

White crystals (MeOH); mp 289–290 °C; {Rf; 0.31 (4% methanol in chloroform}; FTIR (KBr) 3500–3200 cm^{-1} (OH), 1026 cm^{-1} (C–O), 2920, 2820 cm^{-1}(for C–H), 1460 cm^{-1} (C≡C); UV λ_{max} ($CHCl_3$) 243 nm; ^1H NMR (500 MHz, DMSO-d_6): δ 5.38 (br s, H-6), 4.26 (1H, d, J = 7 Hz, anomeric proton of glucose), 3.52 (1H, m, H-3), 1.05 (3H, s, H-19), 0.86 (6H, d, J = 7.5 Hz, H-26, H-27), 0.85 (3H, t, J = 7.5 Hz, H-29), 0.71 (3H, s, H-18); ^{13}C NMR (125 MHz, DMSO-d_6): δ 140.5 (C-5), 121.1 (C-6), 76.9 (C-3), 56.2 (C-14), 55.4 (C-17), 49.6 (C-9), 45.2 (C-24), 41.8 (C-13), 40.1 (C-4) 39.4 (C-12) 38.8 (C-1), 36.2 (C-10), 35.5 (C-20), 33.4 (C-22), 31.4 (C-7, 8), 29.3 (C-2), 28.8 (C-16, 25), 27.7 (C-23), 25.6 (C-15), 23.8 (C-28), 22.6 (C-11), 20.3 (C-27), 18.9 (C-26), 19.7 (C-19), 19.1 (C-21), 11.8 (C-18), 11.6 (C-29), 100.8 (C-1′), 76.8 (C-3′), 76.7 (C-5′), 73.5 (C-5′), 70.1 (C-4′), 61.1 (C-6′); EI MS *m*/*z* 576 $[M]^+$ for $C_{35}H_{60}O_6$, *m*/*z* 414 $[M^+$-glucose].

*3.1.4. Compound **4***

White powder; mp 196–198 °C ($CHCl_3$–MeOH); {R_f; 0.59 (5% methanol in chloroform}; UV λ_{max} ($CHCl_3$) 205, 277, 329 nm; FTIR (KBr), 3429 (OH), 1695 (C≡O); ^1H NMR (500 MHz, DMSO-d_6): δ 5.16 (1H, m, H-12), 3.40 (1H, dd, 4.0, 14 Hz, H-3), 1.09 (3H, s, H-27), 0.90 (3H, s, H-26), 0.88 (9H, s, H-23, H-25, H-30), 0.72 (3H, s, H-29), 0.68 (3H, s, H-24); ^{13}C NMR (125 MHz, DMSO-d_6): δ 178.5 (C-28), 143.8 (C-13), 121.5 (C-12), 76.8 (C-3), 54.8 (C-5), 47.1 (C-9), 45.7 (C-19), 45.4 (C-17), 41.3 (C-14), 40.8 (C-18), 38.9 (C-8), 38.2 (C-4), 38.1 (C-1), 36.6 (C-10), 38.9 (C-8), 33.3 (C-21), 32.8 (C-29), 32.4 (C-7), 32.1 (C-22), 30.3 (C-20), 28.2 (C-23), 27.2 (C-15), 26.9 (C-2), 25.6 (C-27), 23.3 (C-30), 22.9 (C-11), 22.6 (C-16), 18.0 (C-6), 16.8 (C-26), 16.0 (C-24), 15.1 (C-25); EI MS *m*/*z* 456 $[M^+]$ for $C_{30}H_{48}O_3$.

*3.1.5. Compound **5***

Yellow residue, $[\alpha]_D$ +37.5° (*c* = 1.0, chloroform); UV λ_{max} 258 nm; FTIR (KBr) 3285, 1698, 1609 cm^{-1}; The EI MS $[M]^+$ at *m*/*z* 342 for $C_{22}H_{30}O_3$; ^1H, ^{13}C NMR (500 and 125 MHz, $CDCl_3$) Table 1.

*3.1.6. Compound **6***

White powder; mp 78–80 °C; $[\alpha]_D$ +86.5° (*c* = 1.0, chloroform); UV λ_{max} (CH_3OH) 265 nm; FTIR (KBr) 3200–3600,

Table 1 ^{1}H and ^{13}C NMR data of compounds **5**–**7** in $CDCl_3$.

Position	Compound **5**		Compound **6**		Compound **7**	
	δ_H (δ ppm, J = *Hz*)	δ_C	δ_H (δ ppm, J = *Hz*)	δ_C	δ_H (δ ppm, J = *Hz*)	δ_C
1	–	44.0 *s*	–	44.0 *s*	–	44.0 *s*
2	1.20 (1H, *m*), 1.49 (1H, *m*)	41.3 *t*	1.29 (1H, *m*), 1.57 (1H, *m*)	41.3 t	1.28(1H, *m*), 1.58 (1H, *m*)	41.3 *t*
3	1.56 (1H, *m*), 1.89 (1H, *m*)	31.8 *t*	1.60 (1H, *m*), 1.97 (1H, *m*)	31.7 *d*	1.66(1H, *m*), 1.97 (1H, *m*)	31.6 *t*
4	–	86.3 *s*	–	86.3 *s*	–	86.8 *s*
5	1.95 (1H, *d*, *J* = 10.5)	60.0 *d*	1.99 (1H, *m*)	60.1 *d*	1.98 (1H, *m*)	60.1 *d*
6	5.23 (1H, *d t*, *J* = 3.0, 10.5)	71.4 *d*	5.29 (1H, *dt*, *J* = 2.5, 10.5)	71.1 *d*	5.30 (1H, *t*, *J* = 10.5)	71.2 *d*
7	2.23 (1H, *dd*, *J* = 2.5, 13.0) 2.50 (1H, *t*, *J* = 13.0)	41.4 *t*	2.32 (1H, *dd*, *J* = 2.5, 13.0)2.55 (1H, *t*, *J* = 13.0)	41.4 *t*	2.31 (1H, *d*, *J* = 13.0) 2.58 (1H, *t*, *J* = 13.0)	41.4 *t*
8	–	133.5 *s*	–	133.6 *s*	–	133.5 *s*
9	5.49 (1H, br *t*)	125.2 *d*	5.58 (1H, br *t*)	125.2 *d*	5.58 (1H, br *s*)	125.2 *d*
10	1.92 (1H, *d*, *J* = 8.0) 2.02 (1H, *d*, *J* = 8.0)	41.1 *t*	1.98 (1H, *m*), 2.02 (1H, *m*)	41.0 *t*	1.98 (1H, *m*),2.02 (1H, *m*)	41.0 *t*
11	1.85 (1H, *s* ep, *J* = 6.5)	37.2 *d*	1.95 (1H, *m*)	37.3 *d*	1.88 (1H, *m*)	37.1 *d*
12	0.77 (3H, *d*, *J* = 7.0)	17.4 q	0.88 (3H, *d*, *J* = 6.5)	17.5 q	0.87 (3H, *d* *J* = 6.5)	17.5 q
13	0.89 (3H, *d*, *J* = 7.0)	18.5 q	0.99 (3H, *d*, *J* = 6.5)	18.5 q	0.96 (3H, d, *J* = 6.5)	18.5 *q*
14	1.76 (3H, *s*)	26.4 q	1.85 (3H, *s*)	26.4 q	1.84 (3H, *s*)	26.4 *q*
15	1.04 (3H, *s*)	20.2 q	1.13 (3H, *s*)	20.2 q	1.12 (3H, *s*)	20.2 *q*
16	–	166.5 *s*	–	166.3 *s*	–	166.9 *s*
1′	–	130.6 *s*	–	122.7 *s*	–	122.5 *s*
2′	7.96 (1H, *dd*, *J* = 8.0, 1.0)	129.6 *d*	7.58 (1H, *d*, *J* = 2)	111.9 *d*	7.95 (1H, *d*, *J* = 8.0)	132.0 *d*
3′	7.39 (1H, *t*, *J* = 8.0)	128.5 *d*	–	146.3 *s*	6.91 (1H, *d*, *J* = 8.0)	115.4 *d*
4′	7.51 (1H, *t d*, *J* = 8.0, 1.0)	133.0 *d*	–	150.2 *s*	–	160.6 *s*
5′	7.39 (1H, *t*, *J* = 8.0)	128.5 *d*	6.98 (1H, *d*, *J* = 8)	114.2 *d*	6.91 (1H, *d*, *J* = 8.0)	115.4 *d*
6′	7.96 (1H, *dd*, *J* = 8.0, 1.0)	129.6 *d*	7.63 (1H, *dd*, *J* = 2.0, 8.0)	124.2 *d*	7.95 (1H, *d*, *J* = 8.0)	132.0 *d*
OCH_3	–	–	3.97 (3H, *s*)	56.0 *q*	–	–
OH	–	–	6.08	–	–	–

Table 2 ^{1}H and ^{13}C NMR data of compounds **8–10** in DMSO-d_6.

Position	Compound **8***		Compound **9***		Compound **10**	
	δ_H (δ ppm, J = Hz)	δ_C	δ_H (δ ppm, J = Hz)	δ_C	δ_H (δ ppm, J = Hz)	δ_C
2	–	156.7 *s*	–	156.1 *s*	–	156.4
3	–	138.5 *s*	–	137.0 *s*	–	133.2
4	–	176.1 *s*	–	175.7 *s*	–	177.4
5	–	161.2 *s*	–	160.9 *s*	–	161.2
6	6.35 (1H, *d*, J = 1.9)	98.0 *d*	6.38 (1H, *s*)	98.1 *d*	6.21 (1H, *d*, J = 2.5)	98.7
7	–	166.0 *s*	–	163.0 *s*	–	164.1
8	6.72 (1H, *d*, J = 1.9)	92.2 *d*	6.79 (1H, *s*)	93.3 *d*	6.43 (1H, *d*, J = 2.5)	93.6
9	–	157.0 *s*	–	157.2 *s*	–	156.2
10	–	104.0 *s*	–	104.0 *s*	–	104.0
1′	–	122.6 *s*	–	121.9 *s*	–	120.9
2′	8.03 (1H, *d*, J = 9.2)	129.9 *d*	7.65 (1H, *s*)	115.1 *d*	8.04 (1H, *d*, J = 8.5)	130.8
3′	7.11 (1H, *d*, J = 9.2)	114.0 *d*	–	147.7 *s*	6.88 (1H, *d*, J = 8.5)	115.1
4′	–	161.9 *s*	–	149.6 *s*	–	159.9
5′	7.11 (1H, *d*, J = 9.2)	114.0 *d*	7.15 (1H, *d*, J = 8.5)	115.9 *d*	6.88 (1H, *d*, J = 8.5)	115.1
6′	8.03 (1H, *d*, J = 9.2)	129.9 *d*	7.72 (1H, *dd*, J = 8.5, 1.9)	119.9 *d*	8.04 (1H, *d*, J = 8.5)	130.8
1″	–	–	–	–	5.45 (1H, *d*, J = 7.0)	100.9
2″	–	–	–	–	3.22 (1H, m) *	74.2
3″	–	–	–	–	3.08 (1H, m) *	77.4
4″	–	–	–	–	3.18(1H, m) *	76.4
5″	–	–	–	–	3.10 (1H, m) *	69.9
6″	–	–	–	–	3.35 (1H, br *s*), 3.84 (1H, *t*, J = 3.0)	60.9
OH	12.50 (1H, *s*)	–	12.60 (1H, *s*)	–	12.61 (1H, *s*)	–
3-OCH_3	3.79 (3H, *s*)	59.5 *q*	3.81 (3H, *s*)	60.6	–	–
7-OCH_3	3.84 (3H, *s*)	55.9 *q*	3.85 (3H, *s*)	56.4	–	–
4′-OCH_3	3.84 (3H, *s*)	55.5 *q*	3.85 (3H, *s*)	56.5	–	–
3′-OCH_3	–	–	3.85 (3H, *s*)	56.2	–	–

* Carbons assignments based on HMBC spectrum and comparison with literature.

1695, 1620, 1595 and 1520 cm^{-1}; The EI MS $[M]^+$ at m/z 388 for $C_{23}H_{32}O_5$; ^{1}H, ^{13}C NMR (500 and 125 MHz, $CDCl_3$) Table 1.

3.1.7. Compound 7

White powder, mp 121–122 °C; $[\alpha]_D$ +66.1^o (c = 1.36, ethanol); UV λ_{max} (CH_3OH) 265 and 300 nm; FTIR (KBr) 3200–3600, 1690, 1530, 1610 cm^{-1}; The EI MS $[M]^+$ at m/z 358 for $C_{22}H_{30}O_4$; ^{1}H, ^{13}C NMR (500 and 125 MHz, $CDCl_3$) Table 1.

3.1.8. Compound 8

Yellow needles (methanol, chloroform); mp 144–146 °C; {R_f; 0.85, (20% ethyl acetate: n-hexane)}; UV λ_{max} MeOH (254, 349), MeOH/NaOMe (268, 376), MeOH/$AlCl_3$ (275, 290 sh., 355, 399), MeOH/$AlCl_3$/HCl (264 sh., 276, 347, 497) MeOH/NaOAc (255, 351), MeOH/NaOAc/H_3BO_3 (254, 349); ESI MS $[M+H]^+$ at m/z 329 for $C_{18}H_{16}O_6$; ^{1}H, ^{13}C NMR (500 and 125 MHz, DMSO-d_6) Table 2.

3.1.9. Compound 9

Yellow needles (methanol, chloroform); mp 152–154 °C; {R_f 0.71, (20% ethyl acetate: n-hexane)}; UV λ_{max} MeOH (254, 345), MeOH/NaOMe (250, 327 sh., 382), MeOH/$AlCl_3$ (266, 280 sh., 300 sh., 377), MeOH/$AlCl_3$/HCl (264, 284, 366, 400 sh.) MeOH/NaOAc (253, 341), MeOH/NaOAc/H_3BO_3 (254, 341); FTIR (KBr) 3421, 1631, and 1603 cm^{-1}; ESI MS at m/z 359 $[M+1]^+$ for $C_{19}H_{18}O_7$; ^{1}H, ^{13}C NMR (500 and 125 MHz, DMSO-d_6) Table 2.

3.1.10. Compound 10

Yellow needles (methanol, chloroform); mp 228 °C; R_f value; 0.8 [Butanol: acetic acid: Water, 24:10;10]; UV λ_{max}; MeOH (266, 351), MeOH/NaOMe (275, 327 sh., 399), MeOH/$AlCl_3$ (274, 304 sh., 352, 397), MeOH/$AlCl_3$/HCl (273, 303 sh., 342, 393 sh.) MeOH/NaOAc (274, 315 sh., 390), MeOH/NaOAc/H_3BO_3 (266, 351);The ESI MS $[M^+ + H]$ at m/z 449 for $C_{21}H_{20}O_{11}$, 287 [M^+ - glu + H], m/z 153 $[C_7H_5O_4]$ and 121 $[C_7H_5O_2]$; ^{1}H, ^{13}C NMR (500 and 125 MHz, DMSO-d_6) Table 2.

4. Discussion

4.1. Identification of the isolated compounds

Compounds **1–4** were isolated from *n*-hexane extract and gave positive Liebermann's and Salkowiski's tests indicating its; steroidal and triterpenoidal nature respectively. The compounds showed exact TLC and co-TLC R_f values with that of reference compounds obtained from pharmacognosy department, College of pharmacy, KSU. Compounds **1–4** were identified as lupeol, β-sitosterol, β-sitosterol glucoside and oleanolic acid, respectively by direct comparison of its physical and spectroscopic data, namely, mp; mmp and ^{1}H NMR, with authentic samples.

Compound **5:** The UV spectrum of **5** showed an absorption band at 258 nm indicated the presence of an aromatic ring. The FTIR spectrum displayed absorption bands at 3285 cm^{-1} for hydroxyl group, 1698 cm^{-1} for ester carbonyl

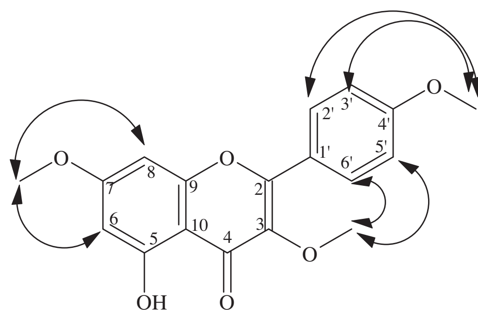


Figure 2 Important ROESY correlations of compound **8**.

functionality and 1609 cm^{-1} for benzene ring, respectively. The EI MS spectrum of compound **5** showed a molecular ion peak $[M]^+$ at *m/z* 342, which is in agreement with the molecular formula $C_{22}H_{30}O_3$. The ^1H NMR and ^{13}C NMR spectral data (Table 1) were close to that type of compound reported (Miski et al., 1983) suggesting that **5** had the same sesquiterpene moiety as that for jaeschkeanadiol. The ^{13}C NMR spectra of compound **5** demonstrated 22 signals, 15 of which were very similar to those reported for the jaeschkeanadiol moiety of ferutinin (Chen et al., 2000). The remaining signals were attributed to an acyl moiety. A diagnostic feature in the ^1H NMR spectrum of **5** was the presence of one proton septet at δ_H 1.85 (H-11) and two methyl doublets at δ_H 0.77 (3H-12) and δ_H 0.89 (3H-13) for an isopropyl group. In addition, the spectrum showed one olefinic proton at δ_H 5.49 (IH, *br t*) was connected to carbon appeared at δ_C 125.2 (C-9) and showed COSY relation with both CH_2-10 (H_α at δ_H 1.92, *d*, J = 8.0 Hz) and (H_β at δ_H 2.02, *d*, J = 8.0 Hz). One deshielded methine proton resonating at δ_H 5.23 (δ_C 71.4) suggesting acylation at this position. Furthermore, three signals were clearly observed in the aromatic region of the ^1H NMR spectrum at δ_H 7.96 (2H, *dd*, J = 1.0, 8.0 Hz), 7.51 (1H, *td*, J = 1.0, 8.0 Hz) and 7.39 (2H, *t*, J = 8.0 Hz) indicated the presence of monosubstitueted benzene ring in the compound. The identification and connectivity of compound **5** was deduced *via* HMBC (Fig. 3). The aromatic protons at δ_H 7.96, which integrated for two protons (H-2′/H-6′) showed three bond correlations with ester carbonyl carbon at δ_C 166.5 (C-16), C-4′ (δ_C 133.0) and C-2′/C-6′ (δ_C 129.6), while the aromatic proton at δ_H 7.51 (H-4′) exhibited three bond correlations with C-2′/6′ (δ_C 129.6). In addition, the aromatic protons at δ_H 7.39 (H-3′/H-5′) displayed three bond correlations with C-1′ (δ_C 130.6) and C-3′/C-5′ (δ_C 128.5). These finding proved the presence of monosubstituted aromatic ring. Furthermore, the oxygenated proton at δ_H 5.23 (H-6) dis-

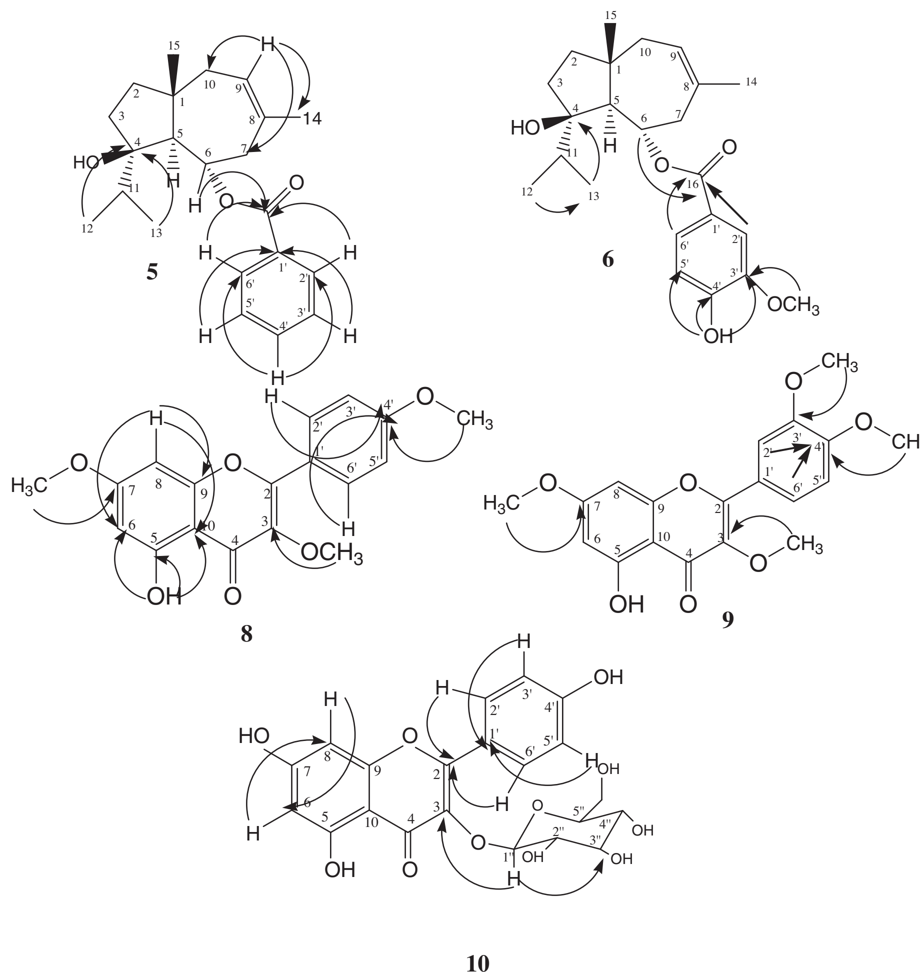


Figure 3 Key HMBC correlations of compounds **5**, **6**, **8**, **9** and **10**.

played three bond correlation with ester carbonyl carbon at δ_C 166.5 (C-16) verified the acylation at C-6 (δ_C 71.4). Based on the analysis of the spectral data, compound **5** was identified as daucane sesquiterpene, jaeschkeanadiol benzoate (teferidin) [Saidkhodzhaev and Nikonov 1976; Miski et al., 1983; Chen et al., 2000]. This is first time to isolate teferidin from the family *Solanaceae*.

Compound **6** was obtained as white powder; mp 78–80 °C; $[\alpha]_D$ +86.5° (*c* 1.0, chloroform). The UV spectrum (CH_3OH) exhibited absorption maxima at 265 nm for the presence of the aromatic ring in the molecule. The IR spectrum of **6** has absorption bands at 3200–3600 cm^{-1} for hydroxyl groups, 1695 cm^{-1} for carbonyl ester, and bands at 1620, 1595 and 1520 cm^{-1} for aromatic nucleus. The EIMS spectrum of compound **6** exhibited a molecular ion peak $[M]^+$ at *m/z* 388, which is in agreement with the molecular formula $C_{23}H_{32}O_5$. The ^1H and ^{13}C NMR spectral data are presented in Table 1. The ^{13}C NMR spectra displayed 23 signals, which accounted for five methyls, four methylenes, seven methines and seven quaternary carbons. These NMR data are very close to those of teferidin and suggesting that **6** had exactly the same sesquiterpene moiety as of **5** and differ only in the acyl moiety. Identification the nature of acyl moiety was easily determined as vanillic acid through analysis of COSY and HMBC spectra. In COSY spectrum, the aromatic proton at δ_H 7.63 (*dd*, J = 2.0, 8.0 Hz, H-6′) showed an *ortho* coupling with the proton at δ_H 6.98 (*d*, J = 8.0 Hz, H-5′) and *meta* coupling with the proton at δ_H 7.58 (*d*, J = 2.0 Hz, H-2′), which proved the presence of tri-substituted aromatic ring. In HMBC correlations (Fig. 3), the methyl protons of the methoxy group at δ_H 3.97 showed three bond correlation with the carbon at δ_C 146.3 (C-3′) while the hydroxyl proton exhibited three bond correlations with the carbons at δ_C 146.3 (C-3′), δ_C 114.2 (C-5′) and two bond correlation with the carbon at δ_C 150.2 (C-4′) confirmed the position of the methoxy group at C-3′ and the hydroxyl function at C-4′. Thus, compound **6** was identified as teferin [Kh. Khasanov et al., 1974; Ahmed, 1998]. This is first time to isolate teferin from the family *Solanaceae*.

Compound **7**: The UV spectra of **7** showed absorption maxima at 265 and 300 nm. Its FTIR spectra exhibited absorption bands at 3200–3600 cm^{-1} for hydroxyl groups, 1690 cm^{-1} for carbonyl ester and 1530, 1610 cm^{-1} for aromatic nucleus. The EIMS spectrum showed a molecular ion peak $[M]^+$ at *m/z* 358 corresponding to the molecular formula $C_{22}H_{30}O_4$. The ^1H NMR and ^{13}C NMR spectral data of **7** (Table 1) suggested that **7** had the same sesquiterpene moiety as teferidin and teferin and differ only in the acyl moiety. The aceyl moiety was easily identified as *p*-hydroxybenzoic acid by observing two doublets in the ^1H NMR spectrum at δ_H 7.95 (2H, J = 8.0 Hz) and 6.91 (2H, J = 8.0 Hz), which displayed the *para* orientation of the hydroxyl group. Compound **7** was identified as ferutinin (jaeschkeanadiol *p*-hydroxybenzoate) in agreement to its physical and spectral data and by comparison with published data (Chen et al., 2000). This is first time to isolate ferutinin from the family *Solanaceae*.

Compound **8:** The UV spectral data with different shifting reagents indicated that this compound is a flavonoid with free hydroxyl group at C-5 (Mabry et al., 1970; Markham, 1982). The molecular formula of the compound **8** $C_{18}H_{16}O_6$, was obtained from the ESI-MS $[M+H]^+$ which showed a molecular ion peak at *m/z* 329. The ^1H NMR data (Table 2) are in agreement with the above data through the presence of three signals of methoxy group at δ_H 3.79 (3-OCH_3), 3.84 (7-OCH_3) and 3.84 (4′-OCH_3). In addition, the ^1H NMR showed AA′ BB′ spin system for *p*-disubstituted ring B arise from two doublets at δ_H 7.11 (H-3′ and H-5′) and δ_H 8.03 (H-2′ and H-6′) with (J = 9.2 Hz) and two *meta* coupled aromatic proton resonances for ring A recognized as doublets (J = 1.9 Hz) at δ_H 6.35 and 6.72, assignable to H-6 and H-8, respectively. The position of the various substituents at the flavone skeleton were further determined *via* HMBC (Fig. 3), in which the methoxy group at δ_H 3.79 (3-OCH_3) showed three bond correlation with C-3 at δ_C 138.5 and the methoxy group at δ_H 3.84 (7-OCH_3) exhibited three bond correlation with C-7 at δ_C 166.0, while the methoxy group at δ_H 3.84 (4′-OCH_3) displayed three bond correlations with C-4′ (δ_C 161.9). The aromatic proton at δ_H 6.72 (H-8) showed three bond correlations with C-6 (δ_C 98.0) and C-10 (δ_C 104.0) and two bond correlations with C-9 (δ_C 157.0) and C-7 (δ_C 166.0) confirming the position of one methoxy group at C-7. In addition, The aromatic protons at δ_H 8.03 (H-2′/H-6′) exhibited three bond correlations with C-4′ (δ_C 161.9) and C-2′/C-6′ (δ_C 129.9) and two bond correlation with C-3′/C-5′ (δ_C 114.0) while the aromatic protons at δ_H 7.11 (H-3′/H-5′) displayed three bond correlation with C-1′ (δ_C 122.6) and two bond correlation with C-4′ (δ_C 161.9) confirming the position of second methoxy group at C-4′. Analyzing the ROESY correlations (Fig. 2) further supporting these finding through the appearance of correlations between the methoxy group at δ_H 3.84 (7-OCH_3) and H-8 (δ_H 6.72), H-6 (δ_H 6.35) and correlations between the methoxy group at δ_H 3.84 (4′-OCH_3) and H-2′/H-3′. In addition the interaction between the methoxy group at δ_H 3.79 (3-OCH_3) and H-5′/H-6′. Careful review of the literature on flavone chemistry confirmed that the physical and spectral data of compound **8** were in full agreement with those reported for the 5-hydroxy-3,7,4′-trimethoxyflavone (Sunder et al., 1974; Voirin, 1983).

Compound **9:** The UV spectral data with different shifting reagents indicated that this compound is a flavonoid with free hydroxyl group at C-5 (Mabry et al., 1970; Markham, 1982). The IR spectrum of **9** displayed bands at 3421, 1631, and 1603 cm^{-1} for OH, C≡O and C≡C functionalities, respectively. The molecular formula of **9** was assigned as $C_{19}H_{18}O_7$ by molecular ion peak at *m/z* 359 $[M+1]^+$ in ESI MS suggesting that compound **9** is very close to compound **8** with an additional methoxy group. This was supported by ^1H NMR data

Table 3 Results of antimicrobial screening of successive extracts (1 mg/ml) of *S. schimperianum*.

Micro-organism	Inhibition zone	
	Hexane extract	Ethyl acetate extract
Bacillus subtilis	+	–
Staphylococcus aureus	+	–
Escherichia coli	–	–
Pseudomonas aeruginosa	–	–
Mycobacterium smegmatis	–	–
Candida albicans	–	–

Chloramphenicol was used as positive control at a concentration of 4 μg/ml.
DMSO was used as negative control.
+ (The size of inhibition is > 10 mm in diameter).
– (The size of inhibition is < 10 mm in diameter).

of compound **9** (Table 2), which showed typical signals for H-6 and H-8 of ring A at δ_H 6.38 and 6.79, respectively. In addition, two singlet signals attributed to one methoxy group at δ_H 3.81 (3-OCH_3) and three methoxy groups at δ_H 3.85 (9H, s) for 3′-OCH_3, 4′-OCH_3 and 7-OCH_3. Besides that, the B-ring aromatic protons appeared as an ABX splitting system at δ_H 7.65 (*br s*, H-2′), 7.15 (*d*, J = 8.5 Hz, H-5′) and 7.72 (*dd*, J = 8.5, 1.9 Hz, H-6′). This analysis suggested that ring B was 3′,4′ disubstituted with two methoxy group. The positions of these methoxy groups were determined *via* HMBC experiment. The methoxy group at δ_H 3.81 should be located at C-3, based on its long range coupling with C-3 (δ_C 137.0). On the other hand, the HMBC correlations (Fig. 3) showed that the other three methoxy groups centered at δ_H 3.85 should be located at C-3′ (δ_C 147.7), C-4′ (δ_C 149.6) and/or C-7 (δ_C 163.0). The aromatic proton at δ_H 6.38 (H-6) showed three bond correlations with C-8 (δ_C 93.3), C-10 (δ_C 104.0) and two bond correlations with C-5 (δ_C 160.9) and C-7 (δ_C 163.0). Likewise, the aromatic proton at δ_H 6.79 (H-8) exhibited three bond correlations with C-10 (δ_C 104.0) and two bond correlations with C-7 (δ_C 166.0) and C-9 (δ_C 157.2), which confirmed the location of one methoxy resonating at δ_H 3.85 to C-7. In addition, the aromatic proton at δ_H 7.65 (H-2′) exhibited three bond correlations with C-2 (δ_C 156.1), C-4′ (δ_C 149.6) and two bond correlations with C-1′ (δ_C 121.9) and C-3′ (δ_C 147.7). While the aromatic proton at δ_H 7.15 (H-5′) displayed two bond correlation with C-4′ (δ_C 149.6) and the aromatic proton at δ_H 7.72 (H-6′) showed three bond correlation with C-4′ (δ_C 149.6) confirming the presence of other two methoxy groups at C-3′ and C-4′. Thus, compound **9** was identified as retusin (5-hydroxy-3,7,3′,4′-tetramethoxyflavone) by comparing its physical and spectral data with those reported (Silva, 2009). This is the first time to isolate 5-hydroxy-3,7,3′,4′-tetramethoxyflavone (retusin) from *Solanum shimperianum*.

Compound **10** The UV spectrum (MeOH) showed absorption bands at λ_{max} 266 and 351 nm, suggesting the flavonol nature of the compound (Mabry et al., 1970; Markham, 1982). Addition of sodium methoxide shifting reagent resulted in bathochromic shift of band I, which indicated the presence of free OH at C-4′. While, the bathochromic shift of +46 nm with aluminum chloride confirmed the existence of free hydroxyl group at C-5 and/or C-3. On the other hand, the presence of bathochromic shift in band II by 14 nm with sodium acetate indicated the presence of free hydroxyl group at C-7. The ESI-MS spectrum of compound **10** disclosed a molecular ion $[M^+ + H]$ at m/z 449, which is in agreement with the molecular formula $C_{21}H_{20}O_{11}$. The mass spectrum also showed a fragment ion peak at m/z 286 indicated loss of glucose moiety. The ^{1}H and ^{13}C NMR spectral data are presented in Table 2. The ^{13}C NMR data showed 19 signals, which were accounted for one methylene, eleven methines and nine quaternary carbon atoms. The ^{1}H NMR data and COSY spectrum showed two *meta*-coupled protons at δ_H 6.21 and 6.43 (J = 2.5 Hz) suggested the 5,7-disubstituted A ring of flavonoid and assigned to H-6 and H-8, respectively. In addition, there were AA′ BB′ spin system for *p*-disubstituted ring B arise from two doublets at δ_H 8.04 (H-2′ and H-6′) and δ_H 6.88 (H-3′ and H-5′) with (J = 8.5 Hz). Exchangeable proton appeared as sharp singlet at δ_H 12.61 was assigned to 5-OH. Furthermore, the ^{1}H and ^{13}C NMR spectra exhibited five methines and one methylene attributed to the glucose moiety. The linkage of the glucose moiety was found to be at C-3 from HMBC correlations (Fig. 3), as the anomeric proton at δ_H 5.45 (H-1″) showed three bond correlations with C-3 (δ_C 133.2). Based on the above data and reported records, compound **10** was identified as Kaempferol-3-*O*-glucopyranoside (Astrgalin) (Subramanian and Nair, 1970).

4.2. Biological activity

4.2.1. Antimicrobial activity

The antimicrobial activity of *Solanum schimperianum* extracts (1 mg/ml) are presented in Table 3. The hexane extract has only antimicrobial activity against *Bacillus subtilis* and *Staphylococcus aureus* while ethyl acetate extract has no antimicrobial activity, as well as the isolated compounds (100 μg/ml) were also devoid of any activity.

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