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New triterpene saponins from the aerial parts of *Androsace umbellata*†

Zhi-Qi Yin,^a Lei Wang,^{ab} Cheng-Hua Li,^a Dong-Mei Zhang,^b Wei Zhang,^{ab} Ying Wang,^b Ming Zhao,^c Chun-Tao Che^c and Wen-Cai Ye^b

Six new oleanane-type triterpene saponins, androsides A–F (1–6), along with two known compounds (7–8), were isolated from the aerial parts of *Androsace umbellata*. The structures were determined on the basis of spectroscopic data and acid hydrolysis. The aglycones in 1–5 are novel structures. Cytotoxicity assays using HepG2, HepG2/ADM, MCF-7, MCF-7/ADR and MDA-MB-231 cell lines indicated that 7 and 8, both bearing a 13 β ,28-epoxy group, were active. Compound 8 was shown to induce apoptosis in the HepG2/ADM cells.

Introduction

Plants of the genus *Androsace* (Primulaceae) include 120 species, of which about 73 species are distributed mainly in China.¹ Pharmacological studies have demonstrated that *Androsace* plants possess anti-tumor, anti-inflammatory and anti-virus properties,² and phytochemical investigations revealed triterpene saponins and flavonoids as major ingredients.³ *Androsace umbellata* is distributed in Asia, especially China, Japan and India. The whole plant of *A. umbellata* has been used in Chinese folk medicine for the treatment of laryngopharyngitis, tonsillitis and hydropsia.⁴ Recently, triterpene saponins isolated from *A. umbellata* were found to show cytotoxic activity against human tumor cell lines.⁵ Saxifragifolin D could inhibit breast cancer cell growth and induce interplay between apoptosis and autophagy.⁶

In the search for bioactive constituents from *A. umbellata*, we have reported several triterpene and phenolic glycosides from this plant.^{7,8} Continuing phytochemical studies now led to the isolation of six new triterpenesaponins, androsides A–F (1–6) (Fig. 1), along with two known saponins (7–8).

Results and discussion

Structural elucidation

An ethanol extract of the aerial parts of *A. umbellata* was subjected to repeated column chromatography over silica gel, ODS

silica gel and Sephadex LH-20 to afford six new triterpene saponins, androsides A–F (1–6), along with saxifragifolin B (7) and saxifragifolin A (8).⁹

Androside A (1) was obtained as an amorphous powder. Positive results from both Liebermann–Burchard and Molisch reactions indicated a triterpene glycoside structure. The molecular formula of 1 was determined to be C₃₆H₅₆O₁₁ by the quasi-molecular ion [M + Na]⁺ at *m/z* 687.3709 (calcd for C₃₆H₅₆O₁₁Na: 687.3714) in HR-ESI-MS. The IR spectrum showed characteristic absorptions for hydroxyl (3442 cm⁻¹), carboxyl (1726 cm⁻¹) and olefinic bonds (1646 cm⁻¹). Acid hydrolysis of 1 afforded D-glucose, which were detected by derivatization and HPLC analysis.

The ¹H NMR spectrum of 1 (Table 1) displayed six tertiary methyl signals at δ_{H} 0.85, 0.85, 0.86, 1.29, 1.38, and 1.80 (each 3H, s), an olefinic proton at δ_{H} 5.62 (1H, br s), as well as an anomeric protons at δ_{H} 6.46 (1H, d, *J* = 8.0 Hz). The ¹³C NMR and DEPT spectra (Table 1) exhibited 36 carbon signals, 30 of which could be attributed to the aglycone. The ¹³C NMR resonances at δ_{C} 122.5 and 144.7 further suggested the presence of a $\Delta^{12,13}$ double bond on an oleanane skeleton.¹⁰ When the ¹³C NMR spectrum of 1 was compared with that of ardisicrenoside

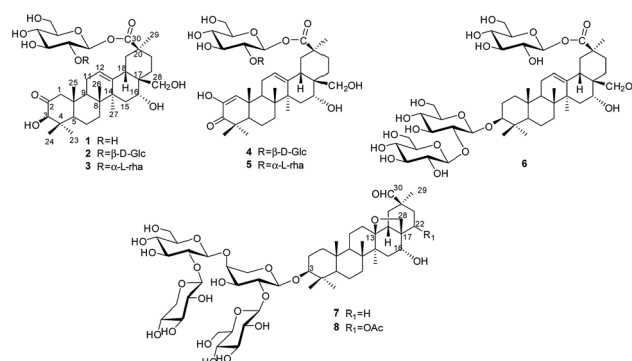


Fig. 1 Chemical structures of 1–8.

^aDepartment of Natural Medicinal Chemistry & State Key Laboratory of Natural Medicines, China Pharmaceutical University, Nanjing 210009, P.R. China. E-mail: cpu-yzq@cpu.edu.cn; Tel: +86-025-86185371

^bInstitute of Traditional Chinese Medicine and Natural Products, College of Pharmacy, Jinan University, Guangzhou 510632, P.R. China

^cDepartment of Medicinal Chemistry and Pharmacognosy, WHO Collaborating Center for Traditional Medicine, College of Pharmacy, University of Illinois at Chicago, Chicago, IL 60612, USA

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Table 1 ^1H NMR and ^{13}C NMR spectroscopic data of compounds **1**, **2** and **4** (δ in ppm, J in Hz, $\text{C}_5\text{D}_5\text{N}$)^{a,b}

| Position | 1 | | 2 | | 4 | | | |
|----------|---------------------------|---------------------|-----------------------|------------------------------|---------------------|-----------------------|---------------------------|-----------------------|
| | δ_{H} | δ_{C} | δ_{H} | δ_{C} | δ_{H} | δ_{C} | | |
| 1 | 2.23, br d (12.0) | 2.48, m | 53.8, CH ₂ | 2.21, d (12.5) | 2.47, m | 53.8, CH ₂ | 6.52, s | 129.5, CH |
| 2 | — | — | 211.1, C | — | — | 211.1, C | — | 146.3, C |
| 3 | 4.19, s | — | 83.3, CH | 4.17, s | — | 83.3, CH | — | 201.1, C |
| 4 | — | — | 45.7, C | — | — | 45.7, C | — | 44.6, C |
| 5 | 1.55, br d (10.8) | — | 54.8, CH | 1.56, br d (11.0) | — | 54.8, CH | 1.65, br d (9.2) | 54.1, CH |
| 6 | 1.36, 1.54, m | — | 18.9, CH ₂ | 1.36, 1.56, m | — | 18.9, CH ₂ | — | 19.1, CH ₂ |
| 7 | 1.35, 1.68, m | — | 32.8, CH ₂ | 1.34, 1.69, m | — | 32.8, CH ₂ | 1.34, 1.68, m | 33.0, CH ₂ |
| 8 | — | — | 40.3, C | — | — | 40.3, C | — | 40.6, C |
| 9 | 2.02, m | — | 46.7, CH | 2.02, m | — | 46.7, CH | 2.04, m | 42.8, CH |
| 10 | — | — | 43.2, C | — | — | 43.6, C | — | 38.4, C |
| 11 | 1.70, 2.01, m | — | 23.6, CH ₂ | 1.76, m | — | 23.7, CH ₂ | 1.90, 2.05, m | 23.8, CH ₂ |
| 12 | 5.62, s | — | 122.5, CH | 5.79, br s | — | 122.4, CH | 5.74, br s | 122.6, CH |
| 13 | — | — | 144.7, C | — | — | 144.8, C | — | 145.0, C |
| 14 | — | — | 41.9, C | — | — | 42.0, C | — | 42.2, C |
| 15 | 1.63, m 2.20, br d (13.4) | — | 34.9, CH ₂ | 1.63, m 2.19, dd (6.8, 10.8) | — | 34.8, CH ₂ | 1.60, m 2.21, br d (11.1) | 34.8, CH ₂ |
| 16 | 4.66, s | — | 74.0, CH | 4.72, br s | — | 74.0, CH | 4.72, br s | 74.1, CH |
| 17 | — | — | 40.4, C | — | — | 40.4, C | — | 40.6, C |
| 18 | 2.78, m | — | 43.4, CH | 2.65, m | — | 43.4, CH | 2.86, dd (10.8, 11.6) | 43.8, CH |
| 19 | 2.35, br d (12.7) | — | 44.7, CH ₂ | 2.41, m 2.88, t (13.0) | — | 44.2, CH ₂ | 2.42, 2.88, m | 44.1, CH ₂ |
| | 2.85, d (12.2) | — | — | — | — | — | — | — |
| 20 | — | — | 44.6, C | — | — | 44.6, C | — | 44.6, C |
| 21 | 2.48, m | — | 33.6, CH ₂ | 2.53, m | — | 33.4, CH ₂ | 2.50, m | 33.9, CH ₂ |
| 22 | 2.35, br d (12.7) | — | 31.8, CH ₂ | 2.46, m | — | 31.8, CH ₂ | 2.43, m | 31.8, CH ₂ |
| | 2.57, m | — | — | — | — | — | — | — |
| 23 | 1.29, s | — | 29.4, CH ₃ | 1.28, s | — | 29.4, CH ₃ | 1.19, s | 27.8, CH ₃ |
| 24 | 0.85, s | — | 17.3, CH ₃ | 0.84, s | — | 17.2, CH ₃ | 1.11, s | 20.2, CH ₃ |
| 25 | 0.85, s | — | 16.6, CH ₃ | 0.85, s | — | 16.6, CH ₃ | 1.10, s | 22.1, CH ₃ |
| 26 | 0.86, s | — | 16.5, CH ₃ | 0.85, s | — | 16.5, CH ₃ | 0.92, s | 17.4, CH ₃ |
| 27 | 1.80, s | — | 27.3, CH ₃ | 1.80, s | — | 27.2, CH ₃ | 1.76, s | 27.1, CH ₃ |
| 28 | 3.65, dd (8.2, 2.0) | — | 70.0, CH ₂ | 3.52, 3.68, dd (10.8) | — | 70.1, CH ₂ | 3.53, 3.70, dd (9.5) | 70.1, CH ₂ |
| 29 | 1.38, s | — | 28.6, CH ₃ | 1.48 s | — | 28.5, CH ₃ | 1.49, s | 28.4, CH ₃ |
| 30 | — | — | 177.1, C | — | — | 177.1, C | — | 177.2, C |
| Glc1' | 6.46, d (8.0) | — | 95.9, CH | 6.38, d (8.0) | — | 93.7, CH | 6.39, d (8.0) | 93.7, CH |
| 2' | 4.21, t (8.1) | — | 74.5, CH | 4.46, d (8.7) | — | 81.3, CH | 4.46, t (8.5) | 81.3, CH |
| 3' | 4.28, t (8.1) | — | 78.6, CH | 4.20, t (8.9) | — | 78.5, CH | 4.20, t (8.9) | 79.7, CH |
| 4' | 4.30, br d (9.1) | — | 71.3, CH | 4.29, m | — | 71.0, CH | 4.29, t (9.0) | 71.0, CH |
| 5' | 4.01, m | — | 79.3, CH | 3.94, m | — | 79.0, CH | 3.94, m | 79.0, CH |
| 6' | 4.34, dd (4.5, 11.6) | — | 62.4, CH ₂ | 4.30, dd (5.3, 9.5) | — | 62.3, CH ₂ | 4.30, br d (9.0) | 62.3, CH ₂ |
| | 4.42, d (9.8) | — | — | 4.41, dd (4.5, 11.6) | — | — | 4.41, br d (10.8) | — |
| Glc1'' | — | — | — | 5.53 d (8.0) | — | 105.6, CH | 5.55 d (8.0) | 105.6, CH |
| 2'' | — | — | — | 4.73, br s | — | 76.4, CH | 4.72, br s | 76.4, CH |
| 3'' | — | — | — | 4.33, t (8.7) | — | 78.2, CH | 4.33, t (9.0) | 78.2, CH |
| 4'' | — | — | — | 4.32, t (8.7) | — | 71.4, CH | 4.32, t (9.0) | 71.4, CH |
| 5'' | — | — | — | 3.89, m | — | 78.4, CH | 3.89, m | 78.4, CH |
| 6'' | — | — | — | 4.30, 4.41, m | — | 62.6, CH ₂ | 4.30, 4.41, m | 62.6, CH ₂ |

^a ^1H NMR Spectrum was measured at 500 MHz; ^{13}C NMR Spectrum was measured at 125 MHz. ^b Overlapping signals were reported without designating multiplicity.

C^{11} signals for carbons of rings B–E were almost identical (Table 1). On the other hand, a ketone carbon signal resonating at δ_{C} 211.1 was observed, which was assigned to C-2 by the HMBC correlations between δ_{C} 211.1 and δ_{H} 2.23 and 2.48 (H-1), as well as between δ_{C} 211.1 and δ_{H} 4.19 (H-3) (Fig. 2). Thus, the aglycone of **1** was determined to be 2-oxo-3 β ,16 α , 28-trihydroxy-olean-12-en-30-oic acid, which was further confirmed by comparison of the NMR data for ring A of **1** with those of dilenic acid B.¹⁰

For the glycone part, the anomeric carbon signal at δ_{C} 95.9 showed correlation with proton at δ_{H} 6.46 ($d, J = 8.0$ Hz) in the HSQC spectrum. Detailed analysis of the HSQC, HMBC and ROESY data of **1** led to the assignment of a glucopyranosyl unit (Table 1). The β -configuration of the anomeric proton was confirmed by the large $^3J_{\text{H}1-\text{H}2}$ coupling constant. The linkage position of the sugar unit was determined with the aid of HMBC data (Fig. 2), in which correlation between H-1 of glucose (δ_{H} 6.46) and C-30 of the aglycone (δ_{C} 177.1) was clearly observed. In



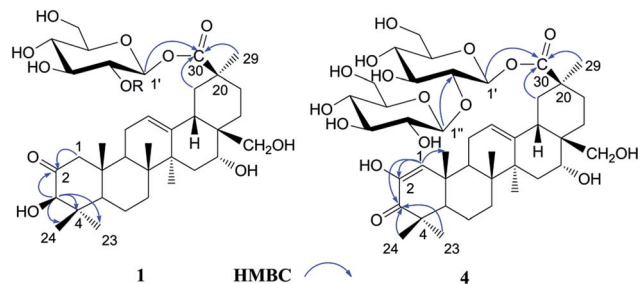


Fig. 2 Selected key HMBC correlations of **1** and **4**.

conclusion, all available evidence suggested the structure of 2-oxo-3 β , 16 α , 28-trihydroxy-olean-12-en-30-oic acid 30-O- β -D-glucopyranosyl ester for **1**. It is noteworthy that the aglycone of **1** is reported for the first time.

Androside B (**2**) was isolated as an amorphous powder. The high resolution ESI-MS spectrum showed a quasi-molecular ion at m/z 849.4259 [$M + H$]⁺ (calcd for C₄₂H₆₇O₁₆: 849.4243), consistent with the molecular formula C₄₂H₆₆O₁₆. The ¹H NMR spectrum of **2** (Table 1) displayed six tertiary methyl signals at δ_H 0.84, 0.85, 0.85, 1.28, 1.48, and 1.80 (each s), an olefinic proton at δ_H 5.79 (br s), as well as two anomeric protons at 6.38 (d, $J = 8.0$ Hz) and 5.53 (d, $J = 8.0$ Hz). The ¹³C NMR data (Table 1) were similar to those of **1** except for the appearance of an additional glucopyranosyl unit (δ_C 105.6, 76.4, 78.2, 71.4, 78.4, 62.6). Acid hydrolysis of **2** afforded D-glucose only, which was identified by derivatization and HPLC analysis. Comparison of the NMR data of **2** with those of **1** revealed the downfield shift (+6.8 ppm) for C-2' of glucose, suggesting an additional glucopyranosyl residue at C-2'. This conclusion was supported by the HMBC correlation between H-1'' (δ_H 5.53) of the terminal glucose and C-2' (δ_C 81.3) of the inner glucose. Based on the above evidence, **2** was determined to be 2-oxo-3 β , 16 α , 28-trihydroxy-olean-12-en-30-oic acid 30-O- β -D-glucopyranosyl(1 \rightarrow 2)-glucopyranosyl ester.

The molecular formula of androside C (**3**) was determined to be C₄₂H₆₆O₁₅ by HR-ESI-MS (833.4288 [$M + Na$]⁺; calcd for C₄₂H₆₆O₁₅Na: 833.4293). The ¹H and ¹³C NMR spectral features of the aglycone (Table 2) were similar to those of **2**, suggesting the same aglycone structure. For the glycone part of **3**, the presence of two sugar units was implied by the observation of two anomeric proton signals at δ_H 6.32 (d, $J = 8.0$ Hz) and 6.56 (br s), as well as two anomeric carbon signals at δ_C 101.5 and 94.5. Indeed, acid hydrolysis of **3** yielded L-rhamnose and D-glucose. The anomeric configurations of D-glucose and L-rhamnose were determined to be β and α , respectively, based on the coupling constants of the anomeric protons and ¹³C NMR data.¹²

The sequence and linkage of the sugars were then determined by 2D NMR analysis. Thus, HMBC cross peaks between H-1'' (δ_H 6.56) of rhamnose and C-2' (δ_C 76.1) of glucose, and between H-1' of glucose (δ_H 6.32) and C-30 of the aglycone (δ_C 177.3), were clearly observed. The above findings led to the assignment of **3** as 2-oxo-3 β , 16 α , 28-trihydroxy-olean-12-en-30-oic acid 30-O- α -L-rhamnopyranosyl(1 \rightarrow 2)- β -D-glucopyranosyl ester.

Androside D (**4**) was shown to possess a molecular formula C₄₂H₆₄O₁₆ from its HR-ESI-MS data, m/z 847.4088 [$M + Na$]⁺

(calcd for C₄₂H₆₄O₁₆Na: 847.4092). The IR spectrum displayed characteristic absorptions of hydroxyl (3424 cm⁻¹), carboxyl (1728 cm⁻¹) and olefinic bonds (1642 cm⁻¹). In the UV spectrum, an absorption maximum at 270 nm indicated the presence of an α , β -unsaturated ketone. The ¹H NMR spectrum of **4** (Table 1) displayed signals for six tertiary methyl groups [δ_H 0.92, 1.10, 1.11, 1.19, 1.49 and 1.76 (each s)], two olefinic protons [δ_H 6.52 (s) and 5.74 (br s)], and two anomeric protons [δ_H 6.39 (d, $J = 8.0$ Hz) and 5.55 (d, $J = 8.0$ Hz)]. In the ¹³C NMR and DEPT spectra (Table 1), 42 carbon signals (Table 1) were observed, of which 30 signals could be assigned to the aglycone. Comparison of the NMR data of **4** with those of **2** revealed the signals were almost identical, except for differences in ring A. The HMBC correlations between C-3 (δ_C 201.1) and H-1 (δ_H 6.52)/H-23 (δ_H 1.19)/H-24 (δ_H 1.11) led to the assignment of a carbonyl at the C-3 position (Fig. 2). Furthermore, HMBC cross peaks between H-1 (δ_H 6.52) and C-2 (δ_C 146.3)/C-5 (δ_C 54.1)/C-9 (δ_C 42.8)/C-25 (δ_C 22.1) revealed a double bond between C-1 and C-2, as well as a hydroxyl group at C-2 (Fig. 2). These conclusions could be further confirmed by the ROESY correlations between H-1 (δ_H 6.52) and H-9 (δ_H 2.04), and between H-1 and H-25 (δ_H 1.10). Therefore, the aglycone of **4** was identified to be 3-oxo-2, 16 α , 28-trihydroxy-olean-1, 12-dien-30-oic acid.

For the glycone part, D-glucose was identified by acid hydrolysis and HPLC analysis. The NMR data for the sugar chain of **4** were identical to those of **2**, indicating the presence of 30-O- β -D-glucopyranosyl(1 \rightarrow 2)-glucopyranosyl ester, which could be further verified by an HMBC experiment (Fig. 2). Thus, HMBC correlations between H-1 (δ_H 6.52) of the outer glucose and C-2 (δ_C 81.3) of the inner glucose, as well as between H-1 (δ_H 6.39) of the inner glucose and C-30 (δ_C 177.2) of aglycone, were observed. Based on the above evidence, the structure of **4** was established to be 3-oxo-2, 16 α , 28-trihydroxy-olean-1, 12-dien-30-oic acid 30-O- β -D-glucopyranosyl(1 \rightarrow 2)-glucopyranosyl ester.

The molecular formula of androside E (**5**) was assigned as C₄₂H₆₄O₁₅ on the basis of its HR-ESI-MS data (m/z 831.4143 [$M + Na$]⁺; calcd for C₄₂H₆₄O₁₅Na: 831.4137). The ¹H and ¹³C NMR spectra (Table 2) indicated that **5** was also a triterpene saponin bearing two sugar units. The NMR data of **5** were similar to those of **4**, except the signals of glucopyranosyl in **4** (δ_C 105.6, 76.4, 78.2, 71.4, 78.4 and 62.5) were now replaced by those of a rhamnopyranosyl unit (101.5, 72.5, 72.5, 73.9, 69.8 and 18.8). Acid hydrolysis of **5** yielded D-glucose and L-rhamnose. The chemical shifts and J values of the anomeric protons indicated the β -configuration of glucopyranosyl and α -configuration of rhamnopyranosyl units. In the HMBC spectrum, cross-peaks were observed between H-1 (δ_H 6.58) of rhamnose and C-2 (δ_C 76.2) of glucose, as well as between H-1 (δ_H 6.34) of glucose and C-30 (δ_C 177.2) of aglycone. Thus, the structure of **5** was determined to be 3-oxo-2, 16 α , 28-trihydroxy-olean-1, 12-dien-30-oic acid 30-O- α -L-rhamnopyranosyl(1 \rightarrow 2)- β -D-glucopyranosyl ester. It is noteworthy that the new aglycone structure in **4** and **5** is reported for the first time.

The molecular formula of androside F (**6**) was determined to be C₄₈H₇₈O₂₀ by its HR-ESI-MS spectrum (m/z 1009.4775 [$M + Cl$]⁻; calcd for C₄₈H₇₈O₂₀Cl, 1009.4775). The ¹H and ¹³C NMR spectroscopic data of the aglycone (Table 2) were in good



Table 2 ^1H NMR and ^{13}C NMR spectroscopic data of compounds **3**, **5** and **6** (δ in ppm, J in Hz, $\text{C}_5\text{D}_5\text{N}$)^{a,b}

| Position | 3 | | 5 | | 6 | |
|----------|--|-----------------------|---------------------------------------|-----------------------|--|-----------------------------------|
| | δ_{H} | δ_{C} | δ_{H} | δ_{C} | δ_{H} | δ_{C} |
| 1 | 2.17, 2.46, m | 53.8, CH ₂ | 6.54, s | 129.5 d | 0.88, 1.41, m | 38.9, CH ₂ |
| 2 | — | 211.1, C | — | 146.3, C | 2.18, 1.78, m | 26.6, CH ₂ |
| 3 | 4.18, s | 83.3, CH | — | 201.1, C | 3.27, dd (8.0, 2.0) | 88.9, CH |
| 4 | — | 45.7, C | — | 44.6, C | — | 39.5, C |
| 5 | 1.56, m | 54.8, CH | 1.65, m | 54.1, CH | 0.71, d (11.7) | 55.8, CH |
| 6 | — | 18.9, CH ₂ | — | 19.1, CH ₂ | 1.42, 1.29, m | 18.4, CH ₂ |
| 7 | 1.34, 1.68, m | 32.8, CH ₂ | 1.34, 1.68, m | 33.0, CH ₂ | 1.56, 1.27, m | 33.2, CH ₂ |
| 8 | — | 40.3, C | — | 40.6, C | — | 40.0, C |
| 9 | 2.02, t (9.8) | 46.8, CH | 2.04, m | 42.8, CH | 1.66, t (8.9) | 47.0, CH |
| 10 | — | 43.4, C | — | 38.4, C | — | 36.8, C |
| 11 | 1.76, m | 23.7, CH ₂ | 1.9, 2.05, m | 23.8, CH ₂ | 1.78, m | 23.7, CH ₂ |
| 12 | 5.79, br s | 122.4, CH | 5.84, br s | 122.6, CH | 5.64, br s | 123.1, CH |
| 13 | — | 144.8, C | — | 145.0, C | — | 144.7, C |
| 14 | — | 41.9, C | — | 42.2, C | — | 41.7, C |
| 15 | 1.63, br d (14.2) 2.18, br d (12.2) 4.62, br s | 34.9, CH ₂ | 1.60, 2.18, m | 34.8, CH ₂ | 1.61, 2.19, 4.66, br s | 34.9, CH ₂ 74.2, CH |
| 16 | — | 74.0, CH | 4.62, br s | 74.1, CH | — | 40.4, C |
| 17 | — | 40.5, C | — | 40.6, C | — | 43.2, CH |
| 18 | 2.88, m | 42.8, CH | 2.88, m | 43.0, CH | 2.74, m | 44.7, CH ₂ |
| 19 | 2.49, 2.91, m | 44.1, CH ₂ | 2.45, 2.91, m | 44.0 t | 2.34, 2.78, m | 44.7, C |
| 20 | — | 44.7, C | — | 44.6, C | — | 44.7, C |
| 21 | 2.50, m | 33.9, CH ₂ | 2.50, m | 33.9, CH ₂ | 2.49, 1.58, m | 33.6, CH ₂ |
| 22 | 2.35, 2.43, m | 31.8, CH ₂ | 2.35, 2.43, m | 31.8, CH ₂ | 2.58, 2.34, m | 31.8, CH ₂ |
| 23 | 1.29, s | 29.4, CH ₃ | 1.20, s | 27.8, CH ₃ | 1.25, s | 28.1, CH ₃ |
| 24 | 0.84, s | 17.3, CH ₃ | 1.10, s | 20.2, CH ₃ | 1.09, s | 16.9, CH ₃ |
| 25 | 0.85, s | 16.6, CH ₃ | 1.12, s | 22.1, CH ₃ | 0.82, s | 15.7, CH ₃ |
| 26 | 0.86, s | 16.5, CH ₃ | 0.93, s | 17.4, CH ₃ | 0.87, s | 16.8, CH ₃ |
| 27 | 1.81, s | 27.3, CH ₃ | 1.77, s | 27.1, CH ₃ | 1.81, s | 27.4, CH ₃ |
| 28 | 3.62, dd (8.2, 2.0) | 69.8, CH ₂ | 3.62, dd (8.2, 2.0) | 70.1, CH ₂ | 3.65, dd (8.2, 2.0) | 70.0, CH ₂ |
| 29 | 1.54, s | 28.4, CH ₃ | 1.54, s | 28.4, CH ₃ | 1.37, s | 28.6, CH ₃ |
| 30 | — | 177.3, C | — | 177.2, C | — | 177.1, C |
| Glc1' | 6.32, d (8.0) | 94.5, CH | 6.34, d (8.0) | 94.5, CH | 4.88, d (7.5) | 105.0, CH |
| 2' | 4.51, t (8.8) | 76.1, CH | 4.53, m | 76.2, CH | 4.21, dd (2.8.8.8) | 83.4, CH |
| 3' | 4.32, t (9.0) | 78.6, CH | 4.33, m | 79.7, CH | 4.25, dd (4.0.9.0) | 77.9, CH |
| 4' | 4.23, m | 71.7, CH | 4.24, m | 71.8, CH | 4.11, t (9.3) | 71.7, CH |
| 5' | 3.96, m | 79.7, CH | 3.97, m | 78.6, CH | 3.88, m | 78.3, CH |
| 6' | 4.26, m 4.36, dd (2.5.11.8) | 62.4, CH ₂ | 4.26, br d (9.4) 4.36, br d (11.4) | 62.6, CH ₂ | 4.42, br d (10.0) 4.51, dd (2.3.11.7) | 62.7, CH ₂ |
| Glc1'' | — | — | — | — | 5.34, d (7.5) | 106.0, CH |
| 2'' | — | — | — | — | 4.09, t (9.0) | 77.1, CH |
| 3'' | — | — | — | — | 4.21, dd (2.8.8.8) | 78.2, CH |
| 4'' | — | — | — | — | 4.11, t (9.3) | 71.6, CH |
| 5'' | — | — | — | — | 3.88, m | 77.9, CH |
| 6'' | — | — | — | — | 4.42, br d (10.0) 4.45, dd (3.2.11.5) | 62.8, CH ₂ |
| Rha 1'' | 6.56, s | 101.5, CH | 6.56, br s | 101.5, CH | — | — |
| 2'' | 4.73, m | 72.5, CH | 4.74, m | 72.5, CH | — | — |
| 3'' | 4.52, t (8.8) | 72.5, CH | 4.53, m | 72.5, CH | — | — |
| 4'' | 4.28, m | 74.1, CH | 4.28, br d (7.9) | 73.9, CH | — | — |
| 5'' | 4.66, dd (6.2, 9.4) | 70.1, CH | 4.66, dd (6.2, 9.9) | 69.8, CH | — | — |
| 6'' | 1.73, d (6.1) | 18.8, CH ₃ | 1.73, d (6.1) | 18.8, CH ₃ | — | — |
| Glc 1''' | — | — | — | — | 6.45, d (8.0) | 95.9, CH |
| 2''' | — | — | — | — | 4.21, dd (2.8.8.8) | 74.4, CH |
| 3''' | — | — | — | — | 4.29, t (7.5) | 78.6, CH |
| 4''' | — | — | — | — | 4.30, t (6.9) | 71.2, CH |
| 5''' | — | — | — | — | 3.99, m | 79.3, CH |
| 6''' | — | — | — | — | 4.33, dd (4.8.11.8) 4.42, br d (10.0) | 62.4, CH ₂ |

^a ^1H NMR Spectrum was measured at 500 MHz; ^{13}C NMR Spectrum was measured at 125 MHz. ^b Overlapping signals were reported without designating multiplicity.



agreement with those of ardisicrenoside C¹¹. The β -configuration of 3-OH and α -configuration of 16-OH were deduced by the coupling constants of H-3 (dd, $J = 8.0, 2.0$ Hz) and H-16 (br s), respectively. Thus, the aglycone of **6** was determined to be jacquinic acid (3 β , 16 α , 28-trihydroxy-olean-12-en-30-oic acid). The NMR data for the sugar moiety and GC analysis of the derivatives of its acid hydrolysed to the assignment of three β -D-glucopyranose units. Connectivity of the sugars was determined on the basis of HMBC data. Thus, correlations between H-1 of the inner glucose [δ_{H} 4.88 (1H, d, $J = 7.5$ Hz)] and C-3 of the aglycone (δ_{C} 88.9), between H-1 of the outer glucose [δ_{H} 5.34 (1H, d, $J = 7.5$ Hz)] and C-2 of the inner glucose (δ_{C} 83.4), as well as between H-1 of the third glucose [δ_{H} 6.45 (1H, d, $J = 8.0$ Hz)] and C-30 (δ_{C} 177.1) of the aglycone, were observed. These data revealed the structure of sugar chain as shown in Fig. 1, which was further confirmed by comparison of the NMR data with those of asteryunnanoside I.¹³ Consequently, the structure of **6** was elucidated to be 3-O- β -D-glucopyranosyl(1 \rightarrow 2)- β -D-glucopyranosyl 3 β ,16 α ,28-trihydroxy-olean-12-en-30-oic acid 30-O- β -D-glucopyranosyl ester.

Cytotoxicity

The cytotoxicity of **1–8** was tested in human hepatoma carcinoma cell lines (HepG2 and HepG2/ADM) and human breast cancer cell lines (MCF-7, MCF-7/ADR and MDA-MB-231) by MTT assay. As shown in Table 3, among the tested compounds, only **7** and **8** bearing a 13 β ,28-epoxy group exhibited inhibitory activity in these cancer cell lines, with IC₅₀ values in the range of 36.19–51.86 μM and 9.29–17.71 μM , respectively. It was observed that the drug resistant cancer cell line HepG2/ADM was more sensitive to compound **8** than its parental cell line HepG2, while the sensitivities of MCF-7, MCF-7/ADR and MDA-MB-231 towards compound **8** were almost equivalent. Compound **7** exhibited similar cytotoxic activities in all tested cell lines.

In the presence of compound **8**, an increase in sub-G₁ DNA content was observed in HepG2/ADM cells after 72 h treatment in a dose-dependent manner (Fig. 3A). Apoptosis was analyzed by Annexin V-FITC/PI double staining assay and the population

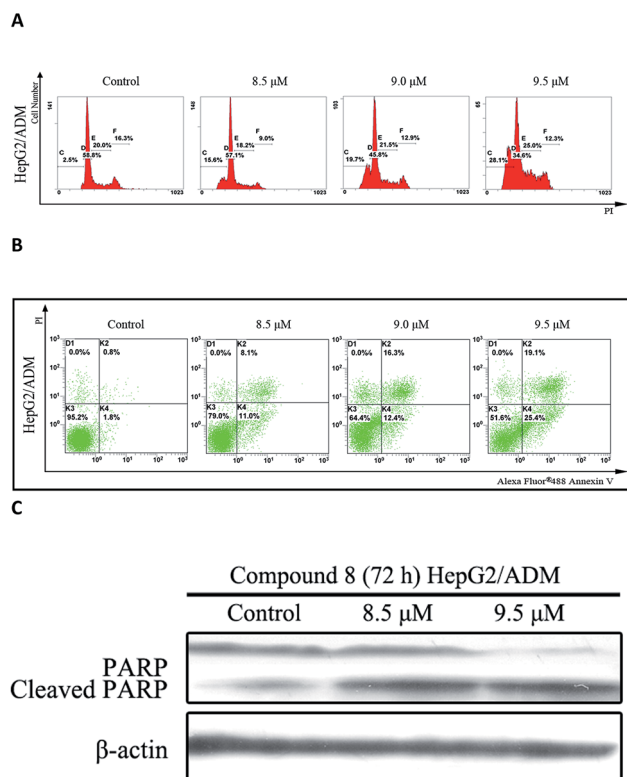


Fig. 3 Apoptosis induced by **8** in HepG2/ADM cells. (A) Flow cytometric analysis of DNA content of HepG2/ADM cells treated with **8** (8.5 μM , 9.0 μM and 9.5 μM) for 72 h. (B) Flow cytometry analysis of apoptotic rate of HepG2/ADM cells induced by **8** (8.5 μM , 9.0 μM and 9.5 μM) for 72 h. (C) Western blot analysis of cleaved PARP in HepG2/ADM cells after treatment with **8** (8.5 μM and 9.5 μM) for 72 h. β -actin served as a loading control.

of apoptotic cells was quantified. As shown in Fig. 3B, the population of early and late apoptotic cells was increased from 19.1% to 44.5% in a dose-dependent manner. Compound **8** also induced PARP cleavage (Fig. 3C), a marker of apoptosis.¹⁴ Taken together, the findings suggested that compound **8** induced apoptosis in HepG2/ADM cells.

Table 3 The cytotoxic activities of compounds **1–8** in HepG2, HepG2/ADM, MCF-7, MCF-7/ADM and MDA-MB-231 cancer cells^a

| Compounds | IC ₅₀ ($\bar{x} \pm \text{SD}$) μM^b | | | | |
|------------------|--|-------------------|------------------|------------------|------------------|
| | HepG2 | HepG2/ADM | MCF-7 | MCF-7/ADR | MDA-MB-231 |
| DOX ^c | 0.18 \pm 0.03 | 143.62 \pm 5.12 | 0.85 \pm 0.24 | 37.86 \pm 5.56 | 21.13 \pm 0.15 |
| 1 | >200 | >200 | >200 | >200 | >200 |
| 2 | >200 | >200 | >200 | >200 | >200 |
| 3 | >200 | >200 | >200 | >200 | >200 |
| 4 | >200 | >200 | >200 | >200 | >200 |
| 5 | >200 | >200 | >200 | >200 | >200 |
| 6 | >200 | >200 | >200 | >200 | >200 |
| 7 | 40.34 \pm 2.51 | 36.19 \pm 2.57 | 42.57 \pm 3.75 | 43.86 \pm 2.50 | 51.86 \pm 5.86 |
| 8 | 17.71 \pm 0.62 | 9.97 \pm 0.46 | 10.32 \pm 0.13 | 10.52 \pm 1.13 | 9.29 \pm 0.32 |

^a Cytotoxic activities of compounds **1–8** were tested by using MTT assay. All data are presented as means \pm standard deviation of at least three independent experiments. ^b IC₅₀: concentration of the tested compound inhibiting 50% cell growth. ^c DOX: doxorubicin was used as positive control.



Experimental section

General experimental procedures

Melting points were measured on an X-4 micro melting point apparatus (without correction). Optical rotations were obtained by a Jasco P-1020 digital polarimeter in a 0.1 dm length cell. IR spectra were determined on a Nicolet Impact 410 plus infrared spectrometer with KBr disc. 1D and 2D NMR experiments were performed on a Bruker AV-500 spectrometer using pyridine-*d*₅ as solvent with tetramethylsilane (TMS) as internal reference. ESI-MS data were carried out on a HP-1100 LC/EST mass spectrometer. HR-ESI-MS data were measured on an Agilent 6210 ESI/TOF mass spectrometer. TLC was performed on precoated silica gel GF254 (Yantai Chemical Industry Research Institute, P. R. China) and precoated RP-18 F254 S plates (Merck). Silica gel (200–300 mesh; Qingdao Marine Chemical Factory, P. R. China), octadecylsilanized silica gel (ODS, YMC Co. Ltd.) and Sephadex LH-20 (Pharmacia Biotec AB) were used for column chromatographies. *D*-Glucose, *L*-glucose, *D*-rhamnose, and *L*-rhamnose were obtained from Sigma-Aldrich (USA).

Plant material

The fresh aerial parts of *Androsace umbellata* (Lour.) Merr. were collected in Nanjing city, Jiangsu Province of P. R. China, in March of 2004, and were authenticated by Prof. Min-Jian Qin (China Pharmaceutical University). A voucher specimen (no. 20040316) was deposited in the herbarium of China Pharmaceutical University, Nanjing, P. R. China.

Extraction and isolation

The fresh aerial parts of *A. umbellata* (2.5 kg) were pulverized and extracted with 70% EtOH three times (each 2 h) under reflux. The extract was concentrated under vacuum and suspended in H₂O, then successively extracted with petroleum ether, EtOAc and *n*-BuOH. The *n*-BuOH extract (100 g) was separated by silica gel column chromatography eluted with gradient CHCl₃–CH₃OH (85 : 15 → 1 : 1, v/v) to give six fractions (A–E). Fraction A (10 g) was chromatographed on silica gel eluting with CHCl₃–CH₃OH (95 : 5 → 85 : 15, v/v) and purified by ODS column chromatography [CH₃OH–H₂O (40 : 60 → 75 : 25, v/v)] to afford **1** (22 mg), **2** (12 mg) and **4** (13 mg). Fraction B (5 g) was subjected to silica gel eluting with CHCl₃–CH₃OH (95 : 5 → 80 : 20, v/v), then separated by ODS column chromatography [CH₃OH–H₂O (45 : 55 → 80 : 20, v/v)] to obtain **3** (16 mg) and **5** (10 mg). Fraction C (3.5 g) was subjected to ODS column chromatography [CH₃OH–H₂O (45 : 55 → 80 : 20, v/v)], and purified by Sephadex LH-20 (CH₃OH) to yield **6** (21 mg). Fraction D (15 g) was separated by silica gel and eluted with CHCl₃–CH₃OH (90 : 10 → 1 : 1, v/v) to give five subfractions (D1–D5). Compounds **7** (23 mg) and **8** (48 mg) were obtained from subfraction D3 by ODS column chromatography [CH₃OH–H₂O (35 : 65 → 77 : 25, v/v)].

Characterization of new compounds

Androside A (1). Amorphous powder; $[\alpha]_{\text{D}}^{23} = +138.00$ (*c* 0.092, MeOH); IR (KBr) ν_{max} : 3442, 2928, 1726, 1646, 1458, 1376,

1319, 1205, 1070, 825, 562 cm⁻¹; for ¹H NMR and ¹³C NMR spectroscopic data, see Table 1; HR-ESI-MS *m/z*: 687.3709 [M + Na]⁺ (calculated for C₃₆H₅₆O₁₁Na, 687.3714).

Androside B (2). Amorphous powder; $[\alpha]_{\text{D}}^{23} = +47.08$ (*c* 0.130, MeOH); IR (KBr) ν_{max} : 3442, 2925, 1712, 1632, 1463, 1378, 1258, 1203, 1067 cm⁻¹; for ¹H NMR and ¹³C NMR spectroscopic data, see Table 1; HR-ESI-MS *m/z*: 849.4259 [M + Na]⁺ (calculated for C₄₂H₆₇O₁₆Na, 849.4243).

Androside C (3). Amorphous powder; $[\alpha]_{\text{D}}^{23} = +35.61$ (*c* 0.132, MeOH); IR (KBr) ν_{max} : 3425, 2972, 2929, 1760, 1723, 1636, 1461, 1393, 1374, 1316, 1258, 1059, 626, 560 cm⁻¹; for ¹H NMR and ¹³C NMR spectroscopic data, see Table 2; HR-ESI-MS *m/z*: 833.4288 [M + Na]⁺ (calculated for C₄₂H₆₆O₁₅Na, 833.4293).

Androside D (4). Amorphous powder; $[\alpha]_{\text{D}}^{23} = +80.28$ (*c* 0.085, MeOH); IR (KBr) ν_{max} : 3424, 2923, 1630, 1451, 1382, 1163, 1074, 1044, 995, 607 cm⁻¹; for ¹H NMR and ¹³C NMR spectroscopic data, see Table 1; HR-ESI-MS *m/z*: 847.4088 [M + Na]⁺ (calculated for C₄₂H₆₄O₁₆Na, 847.4092).

Androside E (5). Amorphous powder; $[\alpha]_{\text{D}}^{23} = +92.00$ (*c* 0.030, MeOH); IR (KBr) ν_{max} : 3424, 2928, 1728, 1642, 1459, 1403, 1383, 1320, 1236, 1077, 893, 628, 565 cm⁻¹; for ¹H NMR and ¹³C NMR spectroscopic data, see Table 2; HR-ESI-MS *m/z*: 831.4143 [M + Na]⁺ (calculated for C₄₂H₆₄O₁₅Na, 831.4137).

Androside F (6). Amorphous powder; $[\alpha]_{\text{D}}^{23} = +40.38$ (*c* 0.052, MeOH); IR (KBr) ν_{max} : 3424, 2926, 1730, 1642, 1460, 1384, 1203, 1077, 629 cm⁻¹; for ¹H NMR and ¹³C NMR spectroscopic data, see Table 2; HR-ESI-MS *m/z*: 1009.4775 [M + Cl]⁻ (calculated for C₄₈H₇₈O₂₀Cl, 1009.4775).

HPLC analysis for sugar residues

Each compound (2 mg) was dissolved in 4 mol L⁻¹ HCl (10 mL) and heated at 90 °C in water bath for 6 h. After reaction product was dissolved in H₂O. The mixture was extracted with EtOAc for three times. The aqueous layer containing sugars was concentrated to dryness, mixed with *L*-cysteine methyl ester hydrochloride, and heated at 60 °C in an oven in the presence of anhydrous pyridine (1 mL) for 1 h. Isothiocyanate (2 mg) was then added to the mixture and heated at 60 °C for another hour. Each reaction mixture was analyzed by HPLC under the following conditions: an Agilent 1200 chromatograph equipped with a Cosmosil 5C₁₈-MS-II column (4.6 × 250 mm i.d., Nacalai Tesque Inc.); mobile phase: isocratic elution of 25% CH₃CN–H₂O in 50 mmol L⁻¹ HCl; flow rate: 0.8 mL min⁻¹; injection volume: 10 μL; column temperature: 35 °C; UV detection wavelength: 250 nm. The standard *L*-rhamnose, *D*-rhamnose, *D*-glucose, *L*-glucose, *D*-xylose, *L*-xylose, *L*-arabinose and *D*-arabinose were run under the same conditions. Comparison of the retention time of the monosaccharide derivatives led to the determination of *D*-glucose (19.2 min) and *L*-rhamnose (32.6 min).

Cell cytotoxicity assay

Reagents. Doxorubicin (Dox), [3-(4,5)-dimethylthiazol-2-yl-2,5-diphenyl tetrazolium bromide] (MTT), propidium iodide (PI) and Ribonuclease A (RNase A) were obtained from Sigma-Aldrich (St. Louis, MO, USA). Annexin V-FITC/PI double staining assay kit was purchased from Biouniquer Tech (Jiangsu,



China). Antibodies against PARP were supplied by Santa Cruz Biotechnology (Santa Cruz, CA, USA). Antibodies against β -actin as well as Goat anti-Rabbit IgG H&L second antibody were obtained from Cell Signaling Technology (Beverly, MA, USA). BCA protein assay kit was purchased from Thermo Fisher Scientific (Rockford, IL, USA). Other chemicals were supplied by Sigma-Aldrich (St. Louis, MO, USA).

Cell culture. Human hepatocellular carcinoma cell line HepG2 was obtained from the American Type Culture Collection (Manassas, VA, USA). The Dox-resistant cancer cell lines, HepG2/ADM, was kindly provided by Professor Kwok-Pui Fung (School of Biomedical Sciences, The Chinese University of Hong Kong). Human breast cancer cell line MCF-7 (estrogen-positive) and Dox-resistant cancer cell lines MCF-7/ADR were kindly supplied by Professor Li-Wu Fu (Cancer Center, Sun Yat-Sen University). The human breast cancer cell lines MDA-MB-231 (estrogen-negative) was purchased from Cell Bank, Shanghai Institutes for Biological Sciences (Chinese Academy of Sciences, Shanghai, China). All cells were cultured in RPMI-1640 medium supplemented with 10% fetal bovine serum and 1% (v/v) penicillin–streptomycin in a humidified atmosphere with 5% CO₂ at 37 °C. Dox (1.2 μ M or 1.0 μ M) was added to the medium to keep the multidrug-resistant property of HepG2/ADM or MCF7/ADR cells, respectively.

Cytotoxicity assay. The cytotoxicities of compounds 1–8 were determined by MTT assay as previously described.⁶ Briefly, cells (5×10^3 per well) were treated with different concentrations of compounds for 72 h. Then, 5 mg mL⁻¹ MTT solution was added to each well after removing the medium and further incubated at 37 °C for 4 h. After that, the formazan crystals were dissolved in 100 μ L DMSO, and absorbance was measured at 570 nm by a microplate reader (Thermo Multiskan MK3, Waltham, MA, USA). Cells treated with medium (0.2% DMSO) was used as negative control. The concentration required to inhibit 50% cell growth (IC₅₀) was calculated from survival curves.

Cell cycle analysis. Cell cycle analysis was performed using a fluorescent probe PI as previously described.¹⁵ HepG2/ADM cells (3×10^5 per well) were cultured in the presence of compound 8 (8.5 μ M, 9.0 μ M or 9.5 μ M) for 72 h, followed by staining with 10 μ L PI (0.2 mg mL⁻¹) and 50 μ L RNase A (1 mg mL⁻¹) in 500 μ L PBS in the dark at 37 °C for 30 min, and examined by Epics XL flow cytometry (Beckman Coulter, Brea, CA, USA). DNA content in different phases of cell cycle was analyzed quantitatively using the Win MDI 2.8 software (The Scripps Institute, La Jolla, CA, USA).

Apoptosis analysis. Apoptosis analysis was measured using an Annexin V-FITC/PI double staining assay kit according to the manufacturer's protocol. HepG2/ADM cells (3×10^5 per well) were treated with compound 8 (8.5 μ M, 9.0 μ M and 9.5 μ M) for 72 h. After that, cells were incubated with Annexin V-FITC and PI solution (1 : 1) and tested by Epics XL flow cytometry (Beckman Coulter, Brea, CA, USA). Data were analyzed quantitatively with an EXPO32 ADC software (Beckman Coulter, Brea, CA, USA).

Western blot. Cleavage of PARP was evaluated by Western blot. HepG2/ADM cells (2×10^6 per dish) were cultured in the presence of compound 8 (8.5 μ M and 9.5 μ M) for 72 h. Cells were collected and then incubated with RIPA buffer

(20 \times phosphatase inhibitor, 0.5 M DTT and 0.1 M PMSF) on ice for 10 min. After centrifugation at 13 200 \times g at 4 °C for 15 min, the supernatant was gathered as total protein lysates and stored at –80 °C until use. Protein concentration was tested by the BCA protein assay kit. Electrophoresis and immunoblotting analysis was carried out as previously described.⁶

Conclusions

In this work, six new oleanane-type triterpene saponins and two known compounds were isolated from the aerial parts of *Androsace umbellata*. The structures were determined on the basis of spectroscopic data and acid hydrolysis. All new compounds showed no obvious cytotoxicity against the test cells. However, cytotoxicity assays indicated that 7 and 8, both bearing a 13 β ,28-epoxy group, were active. Compound 8 was shown to induce apoptosis in the HepG2/ADM cells. These results provide a basis for evaluating the structure–activity relationships of other oleanane-type triterpene saponins, as well as for developing the compound 8 as potential anti-hepatoma drug.

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