铁棍山药皮化学成分研究

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摘要: 采用硅胶柱色谱、中压液相色谱、葡聚糖凝胶Sephadex LH-20柱色谱以及高压制备液相色谱等技术, 从铁棍山药皮醇提取物的二氯甲烷部位分离得到19个化合物。通过理化性质和波谱数据分析, 鉴定出以下结构, 菲类(6个): 7′-hydroxybleformin E (**1**), 1,7-二羟基-5-甲氧基-9,10-二氢菲 (**2**), 6-methoxycoelonin (**3**), 6-羟基-2,4,7-三甲氧基菲 (**4**), 2,7-二羟基-4,6-二甲氧基菲 (**5**), 5,7-二甲氧基-2,3-菲二醇 (**6**); 联苄类 (3个): 二氢松脂素 (**7**), 2′,3-二羟基-5-甲氧基联苯 (**8**), 去甲基山药素IV (**9**); 二苯基庚烷类 (8个): 1,7-双(4-羟基苯基)-1,5-环氧-3-羟基庚烷 (**10**), engelheptanoxide C (**11**), diosniponol A (**12**), (+)-hannokinol (**13**), (3*S*,5*S*)-3,5-二羟基-1-(4-羟基苯基)-7-(4-羟基-3-甲氧基苯基)庚烷 (**14**), (3*S*,5*S*)-3,5-二羟基-1,7-双(4-羟基-3-甲氧基苯基)庚烷 (**15**), 六氢姜黄素 (**16**), (5*S*)-5-羟基-1-(4-羟基-3-甲氧基苯基)-7-(4-羟基苯基)-3-庚酮 (**17**); 其他类 (2个): 1个生物碱类, 阿魏酰酪胺 (**18**) 和1个脂肪酸类, 十八碳二烯酸-2,3-二羟丙基酯 (**19**)。化合物**1**为新化合物; 首次对**2**的^{1}H NMR、^{13}C NMR谱信号进行了全归属; 化合物**2**、**11**、**16**～**19**为首次从薯蓣科植物中分离得到; 化合物**3**、**6**和**12**为首次从山药中分离得到。*α*-葡萄糖苷酶抑制活性筛选显示其中13个化合物对*α*-葡萄糖苷酶具有不同程度的抑制活性。

关键词: 铁棍山药皮; 化学成分; 联苄; 二苯基庚烷; *α*-葡萄糖苷酶抑制活性

中图分类号: R284 **文献标识码**: A **文章编号**: 0513-4870(2025)12-3749-09

Chemical constituents from Chinese Yam (*Dioscorea opposita* Thunb.) peel

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Abstract: Nineteen compounds were isolated from the dichloromethane portion of the ethanol extract of Chinese Yam (*Dioscorea opposita* Thunb.) peel, using various chromatographic techniques including: silica gel column chromatography, medium-pressure liquid chromatography, Sephadex LH-20 gel column chromatography, and preparative high-performance liquid chromatography. Based on the physicochemical properties and spectral data, their structures were determined as follows: six phenanthrenes: 7′-hydroxybleformin E (**1**), 1,7-dihydroxy-5-methoxy-9,10-dihydrophenanthrene (**2**), 6-methoxycoelonin (**3**), 6-hydroxy-2,4,7-trimethoxyphenanthrene (**4**), 2,7-dihydroxy-4,6-dimethoxyphenanthrene (**5**), 5,7-dimethoxy-2,3-phenanthrenediol (**6**); three bibenzyls: dihydropino-

收稿日期: 2025-08-18; 修回日期: 2025-09-25.

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DOI: 10.16438/j.0513-4870.2025-0981

sylvin (**7**), 2′,3-dihydroxy-5-methoxybibenzyl (**8**), demethyl batatasin IV (**9**); eight diarylheptanoids: 1,7-bis(4-hydroxyphenyl)-1,5-epoxy-3-hydroxyheptane (**10**), engelheptanoxide C (**11**), diosniponol A (**12**), (+)-hannokinol (**13**), (3*S*,5*S*)-3,5-dihydroxy-1-(4-hydroxyphenyl)-7-(4-hydroxy-3-methoxyphenyl)heptane (**14**), (3*S*,5*S*)-3,5-dihydroxy-1,7-bis(4-hydroxy-3-methoxyphenyl)heptane (**15**), hexahydrocurcumin (**16**), (5*S*)-5-hydroxy-1-(4-hydroxy-3-methoxyphenyl)-7-(4-hydroxyphenyl)-3-heptanone (**17**); other compounds: one alkaloid, feruloyltyramine (**18**), and one fatty acid, octadecadienoic acid-2,3-dihydroxypropyl ester (**19**). Compound **1** is a new compound, whereas the ^{1}H NMR and ^{13}C NMR spectral signals of **2** were fully attributed. compounds **2**, **11**, **16**−**19** were isolated from the Dioscoreaceae family for the first time, while compounds **3**, **6**, and **12** were the first to be reported from *D. opposita*. Among these, thirteen compounds showed differential inhibitory activities against *α*-glucosidase.

Key words: Chinese Yam (*Dioscorea opposita* Thunb.) peel; chemical composition; bibenzyls; diphenylheptane; *α*-glucosidase inhibitory activity

山药为薯蓣科植物薯蓣 (*Dioscorea opposita* Thunb.) 的干燥根茎, 是主产于河南省焦作市温县、武陟等沿沁河一带 (古怀庆府) 的道地药材, 素有“四大怀药”之美誉[1]。《神农本草经》记载其有“主治伤中, 补虚羸, 除寒热邪气, 补中益气力, 久服耳目聪明, 轻身不饥延年”等功效, 是我国传统的药食同源之佳品[2]。在食用和加工过程中, 通常需要去除约占鲜品质量20%的山药皮, 这些副产物大多被直接废弃, 既造成资源浪费又带来环境负担[3]。随着中药现代化的发展, 加强解决怀山药非药用部位的综合开发利用, 提升其资源价值已成为亟待解决的重要课题。本研究以温县铁棍山药皮为研究对象, 从其95%乙醇提取物的二氯甲烷萃取部位中, 系统分离鉴定了19个化合物 (图1), 其中化合物**1**为新化合物, 化合物**2**、**11**、**16**～**19**为首次从薯蓣科植物中分离得到, 化合物**3**、**6**和**12**为首次从山药中分离得到。*α*-葡萄糖苷酶抑制活性筛选结果显示, 其中13个化合物表现出不同程度的抑制活性 (IC_{50}值为0.08～12.47 mg·mL^{-1}), 为解决怀山药皮的综合开发利用提供了参考。

结果与讨论

1 结构鉴定

化合物**1**为棕色粉末。根据其高分辨质谱 (HR-ESI-MS) 的准分子离子峰 (*m*/*z* 525.153 4, 计算值

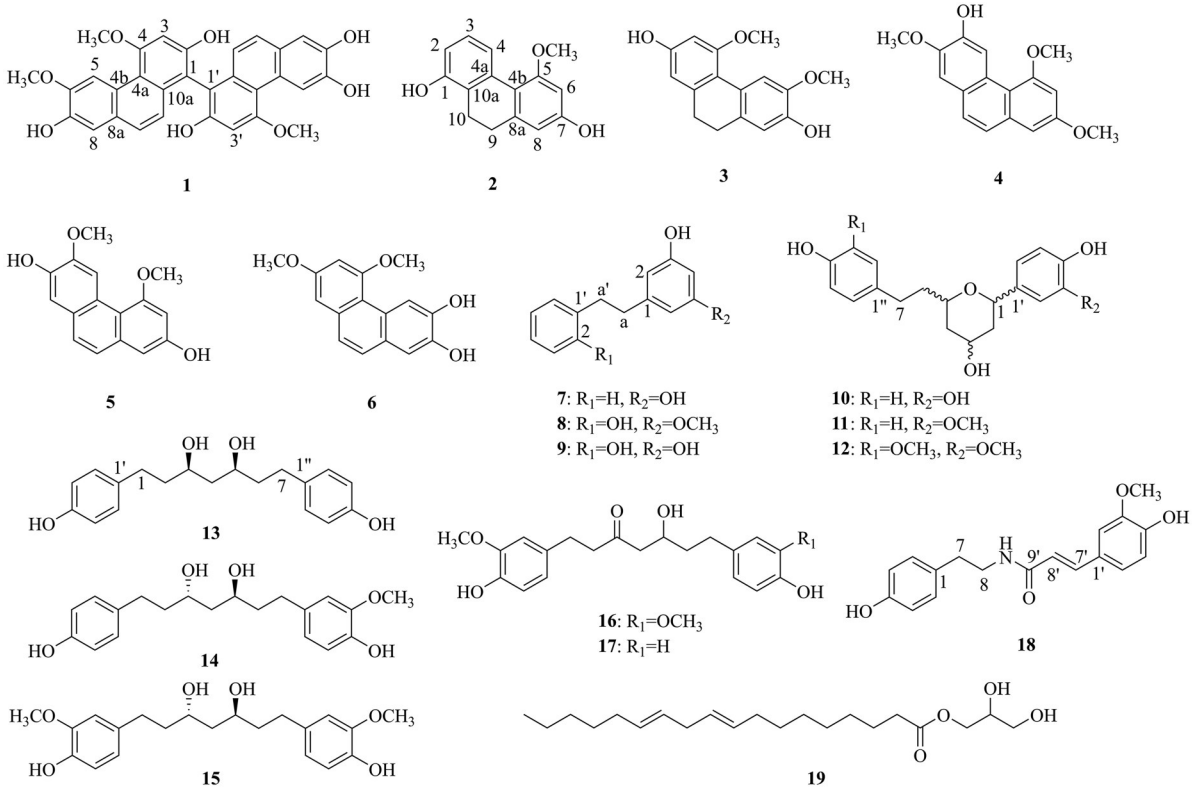


Figure 1 The structures of compounds **1**−**19**

525.154 4) 推断其分子式为$C_{31}H_{24}O_8$, 不饱和度为20。化合物**1**的核磁数据表明其为联菲类化合物[4], ^{1}H NMR (CD_3OD, 400 MHz) 谱 (表1) 显示10个芳香氢质子信号, 包括6个单峰信号δ_H 9.21 (1H, s, H-5), 9.12 (1H, s, H-5′), 7.10 (1H, s, H-8), 7.08 (1H, s, H-8′), 6.98 (1H, s, H-3) 和6.95 (1H, s, H-3′); 2对邻位耦合的双峰信号 (J = 9.2 Hz): δ_H 7.28 (H-9)/6.91 (H-10), 7.25 (H-9′)/6.85 (H-10′)。此外, 还可观察到3个甲氧基信号δ_H 4.18 (6H, s, 4,4′-OCH_3), 4.05 (3H, s, 6-OCH_3)。其^{13}C NMR (CD_3OD, 100 MHz) 谱 (表1) 共示有31个碳信号, 其中28个为芳烃碳, 包括8个连氧碳: δ_C 160.5/160.6 (C-4/4′), 154.5/154.4 (C-2/2′), 148.9/145.3 (C-6/6′), 146.0/146.5 (C-7/7′); 10个季碳: δ_C 135.8/135.8 (C-10a/10′a), 128.5/128.1 (C-8a/8′a), 126.2/126.5 (C-4b/4′b), 116.7/116.5 (C-4a/4′a), 111.5/111.1 (C-1/1′); 10个叔碳: δ_C 127.9/128.2 (C-9/9′), 123.8/123.0 (C-10/10′), 112.4/112.5 (C-8/8′), 110.2/113.9 (C-5/5′), 99.9/99.7 (C-3/3′), 以及3个甲氧基碳δ_C 56.3 (4-OCH_3), 56.1 (6-OCH_3), 56.0 (4′-OCH_3)。在化合物**1**的HMBC谱中, H-3与C-1/C-2/C-4/C-4a、H-5与C-4a/C-4b/C-6/C-7/C-8a、H-8与C-4b/C-6/C-7/C-9、H-9与C-4b/C-8/C-8a/C-10a、H-10与C-1/C-4a/C-8a/C-10a相关, 以及4-OCH_3和6-OCH_3分别与C-4和C-6的相关信号, 由此确定该菲类单元为2,7-二羟基-4,6-二甲氧基-菲。该单元结构通过^{1}H-^{1}H COSY谱 (H-9/H-10相关) 和NOESY谱 (4-OCH_3/H-3、6-OCH_3/H-5相关) 得到进一步确证 (图2)。同样, 基于HMBC、^{1}H-^{1}H COSY和NOESY谱图数据的综合分析, 鉴定出另一个菲类化合物单元为2′,6′,7′-三羟基-4′-甲氧基菲 (图2)。C-1和C-1′的化学位移值 (δ_C 111.5和δ_C 118.1) 及其季碳特征表明, 两个菲单元通过C-1与C-1′之间的C-C单键直接相连[5]。综上, 化合物**1**被鉴定为2,7,2′,6′,7′-五羟基-4,6,4′-三甲氧基-1,1′-联菲, 其与bleformin E[6]的区别仅在于7′位由羟基取代了甲氧基。故命名化合物**1**为7′-hydroxy-bleformin E。

化合物**2**为棕色粉末。根据其高分辨质谱 (HR-ESI-MS) 的准分子离子峰 (m/z 243.102 3 $[M+H]^+$, 计算值243.101 6) 推断其分子式为$C_{15}H_{14}O_3$, 不饱和度为9。^{1}H NMR (400 MHz, CD_3OD) 谱给出一组1,2,3-三取代苯环信号: δ_H 7.72 (1H, dd, J = 8.0, 1.2 Hz), 7.00 (1H, dd, J = 8.0, 8.0 Hz), 6.66 (1H, dd, J = 8.0, 1.2 Hz), 显示典型的邻位和间位耦合特征组合的芳香族ABC自旋系统[7]。另外, 可见2个间位耦合的芳香氢δ_H 6.42 (1H, d, J = 2.2 Hz), 6.35 (1H, d, J = 2.2 Hz), 1个甲氧基δ_H 3.80 (1H, s) 和2个亚甲基δ_H 2.72 (2H, dd, J = 8.6, 5.0 Hz), 2.62 (2H, dd, J = 8.6, 5.0 Hz)。^{13}C NMR (100 MHz, CD_3OD) 显示了12个芳烃碳δ_C 159.8, 158.2, 154.0, 143.0, 135.5, 126.7, 125.1, 120.9, 116.8, 113.6, 108.3, 99.2; 1个甲氧基碳δ_C 55.8和2个亚甲基碳δ_C 31.4, 22.2, 综上表明化合物**2**为9,10-二氢菲类化合物。根据HMBC谱中的相关信号: H-2/C-1/C-4/C-10a, H-3/C-1/C-2/C-4/C-4a, H-4/C-2/C-4b/C-10a, H-6/C-5/C-7/C-8/C-4b, H-8/C-6/C-7/C-9/C-4b, H-9/C-8/C-8a/C-10/C-10a/C-4b, H-10/C-1/C-4a/C-8a/10a, 5-OCH_3/C-5 (图3)。鉴定化合物**2**的结构为1,7-二羟基-5-甲氧基-9,10-二氢菲 (1, 7-dihydroxy-5-methoxy-9, 10-dihydrophenanthrene)。经SciFinder数据库文献检索, 发现该化合物是从兰科植物新疆火烧兰 *Epipactis palustris* (L.) Crantz根茎中分离得到[8]。该研究通过质谱 ($[M]^+$, 242和[M-15])、^{1}H NMR谱中δ_H 2.60 (单峰, 四个质子) 和δ_H 3.74 (甲氧基信号), 及乙酸酐法证明2个羟基的存在, 并通过^{13}C NMR谱与已知化合物coelonin (2,7-二羟基-4-甲氧基-9,10-二氢菲) 的文献[9,10]数据比对, 鉴定该化合物为1,7-二羟基-5-甲氧基-9,10-二氢菲。这种有限的质谱和氢谱数据, 及结合文献比对而推断出的结构, 缺乏直接证据支持 (如芳香氢数据及碳谱数据缺失, 未经二维谱验证等), 导致该化合物的结构鉴定存在不确定性。为此, 本文通过综合分析^{1}H NMR、^{13}C NMR、HSQC及HMBC谱图数据, 准确鉴定了化合物**2**的结构, 并完成了所有碳氢信号的系统归属。

2 活性评价

山药皮中部分化合物对α-葡萄糖苷酶的抑制活性筛选结果见表2, 阳性药阿卡波糖的IC_{50}为0.002 8 mg·mL^{-1}, 化合物**2**、**6**、**7**和**9**具有中等抑制活性IC_{50}分别为0.15、0.37、0.08和0.69 mg·mL^{-1}, 其他化合物活性较弱。

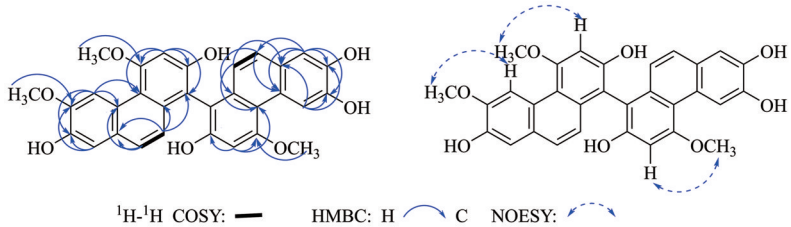


Figure 2 The key ^{1}H-^{1}H COSY, HMBC and NOESY correlations for **1**

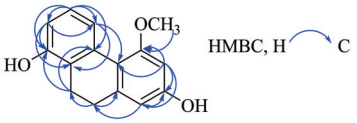


Figure 3 The key HMBC correlations of **2**

Table 1 ^{1}H NMR (400 MHz) and ^{13}C NMR (100 MHz) data of compounds **1** and **2** (δ in ppm; measured in CD_3OD)

Position	**1**		**2**	
	δ_C	δ_H (J in Hz)	δ_C	δ_H (J in Hz)
1	111.5		154.0	
2	154.5		113.6	6.66, dd (8.0, 1.2)
3	99.9	6.98, s	126.7	7.00, dd (8.0, 8.0)
4	160.5		120.9	7.72, dd (8.0, 1.2)
4a	116.7		135.5	
4b	126.2		116.8	
5	110.2	9.21, s	159.8	
6	148.9		99.2	6.42, d (2.2)
7	146.0		158.2	
8	112.4	7.10, s	108.3	6.35, d (2.2)
8a	128.5		143.0	
9	127.9	7.28, d (9.2)	31.4	2.72, dd (8.6, 5.0)
10	123.8	6.91, d (9.2)	22.0	2.62, dd (8.6, 5.0)
10a	135.8		125.1	
1′	111.1			
2′	154.4			
3′	99.7	6.95, s		
4′	160.6			
4′a	116.5			
4′b	126.5			
5′	113.9	9.12, s		
6′	145.3			
7′	146.5			
8′	112.5	7.08, s		
8′a	128.1			
9′	128.2	7.25, d (9.2)		
10′	123.0	6.85, d (9.2)		
10′a	135.8			
4-OCH_3	56.3	4.18, s		
5-OCH_3			55.8	3.80, s
6-OCH_3	56.1	4.05, s		
4′-OCH_3	56.0	4.18, s		

Table 2 IC_{50} of different compounds inhibiting α-glycosidase activity. $n = 3$, $\bar{x} \pm s$

Compound	IC_{50}/mg·mL^{-1}	Compound	IC_{50}/mg·mL^{-1}
2	0.15 ± 0.09	**12**	6.95 ± 0.80
6	0.37 ± 0.40	**13**	4.91 ± 0.12
7	0.08 ± 0.03	**14**	9.90 ± 1.67
8	7.61 ± 0.26	**15**	12.47 ± 1.48
9	0.69 ± 0.04	**16**	11.71 ± 2.01
10	8.71 ± 0.54	**17**	8.89 ± 1.32
11	1.43 ± 0.42	Acarbose	0.002 8 ± 0.000 5

实验部分

1D 和 2D NMR 用 Bruker AVANCE-III (400 MHz) 型核磁共振波谱仪测定 (四甲基硅烷为内标, 化学位移 δ 用 ppm 表示, 德国 Bruker 公司)。中压液相色谱仪 (MPLC, Grace, 美国); 多维制备色谱仪 (Puri Master-7000, 上海科哲生化科技有限公司); 岛津高效液相色谱仪 (岛津, 日本); 制备色谱柱 (Shiseido Capcellpak C18, 250 mm × 20 mm); Sephadex LH-20 (25～100 μm, 通用电器医疗集团, 美国); YMC gel ODS-AQ (50 μm, YMC 有限公司, 日本); MCI gel CHP20P (75～150 μm, 三菱化学有限公司, 日本); 柱层析硅胶 (100～200 目, 200～300 目, 青岛海洋化工厂分厂); 薄层层析及制备型薄层层析 HSGF254 硅胶板 (烟台江友硅胶开发有限公司); 高效液相色谱用乙腈、甲醇 (Dikma, 色谱级, 美国); 薄层层析用乙酸乙酯、三氯甲烷、甲醇 (分析纯, 国药集团); 柱层析用乙酸乙酯、二氯甲烷、甲醇 (工业级, 上海润捷化学试剂有限公司)。温县铁棍山药皮由河南省温县怀药办提供, 并由温县怀药办刘永康老师鉴定为薯蓣科薯蓣 *Dioscorea opposita* Thunb. 的干燥根茎皮, 凭证标本 (No.SYP 2021040201) 保存于上海中医药大学中药研究所。

1 提取与分离

干燥温县铁棍山药皮 8.20 kg, 粉碎, 用 95% 乙醇室温冷浸提取三次 (3×70 L), 浓缩后得到浸膏 1.0 kg。再用二氯甲烷将浸膏溶解后与 2 倍量的 100～200 目硅胶∶硅藻土 (1∶1) 拌样, 依次用石油醚、二氯甲烷、乙酸乙酯和甲醇萃取。

二氯甲烷部位 33.8 g 与 1 倍量的 100～200 目硅胶拌样后, 经硅胶 (200～300 目) 柱色谱, 石油醚−乙酸乙酯 (5∶1～0∶1) 不同比例依次进行洗脱, TLC 检测, 合并相同组分, 得到 4 个组分 (Fr. 1～Fr. 4)。

Fr. 1 共计 2.31 g, 经混合溶剂石油醚−二氯甲烷−甲醇 (5∶5∶1) 溶解后上样甲醇凝胶柱洗脱。共获得 4 个组分 (Fr. 1-1～Fr. 1-4)。Fr. 1-3 共计 1.1 g, 经制备液相色谱 (35% 乙腈−水等度洗脱), 得到化合物 **7** (50 mg, t_R = 45.0 min) 和 **8** (632 mg, t_R = 50.0 min)。Fr. 1-4 共计 370.0 mg, 经甲醇重结晶得到化合物 **4** (200 mg)。

Fr. 2 共计 15.14 g 与 2 倍量的 ODS 拌样后, 上样于中压制备柱, 经甲醇−水 (3∶7～1∶0) 梯度洗脱, 共获得 10 个组分 (Fr. 2-1～Fr. 2-10)。Fr. 2-3 共计 1.6 g, 与 1 倍量的硅胶拌样后, 上样于 20 倍装柱量的硅胶柱, 经石油醚−乙酸乙酯 (2∶1) 等度洗脱后, 再经制备液相色谱 (35%～60% 乙腈−水梯度洗脱 30 min), 得到化合物 **5** (10 mg, t_R = 12.2 min)、**11** (10 mg, t_R = 7.1 min)、**13** (23 mg, t_R = 6.1 min)、**14** (20 mg, t_R = 6.4 min) 和 **18** (30 mg, t_R = 12.5 min)。按同样的方法从 Fr. 2-4 (500.0 mg) 和 Fr. 2-8 (390.0 mg) 组分中获得化合物 **1** (30 mg, t_R = 14.5 min)、**12** (35 mg, t_R = 7.6 min)、**15** (45 mg, t_R = 6.6 min)、**16** (110 mg, t_R = 8.8 min) 和 **17** (45 mg, t_R = 8.5 min)。

Fr. 3共计6.3 g与1倍量的ODS拌样后, 上样于中压制备柱, 经甲醇−水 (3∶7～1∶0) 梯度洗脱, 共获得4个组分 (Fr. 3-1～Fr. 3-4)。Fr. 3-2共计100 mg, 经制备液相色谱 (35% 乙腈−水等度洗脱) 得到化合物**3** (10 mg, t_R = 18.0 min) 和**2** (30 mg, t_R = 20.0 min)。Fr. 3-4共计700.0 mg, 经甲醇重结晶得到化合物**6** (400 mg)。Fr. 3-5共计100 mg, 经制备液相色谱梯度洗脱, 乙腈−水 (35∶65～95∶5), 得到化合物**19** (10 mg, t_R = 32.0 min)。

Fr. 4共计1.84 g经混合溶剂石油醚−二氯甲烷−甲醇 (5∶5∶1) 溶解后上样甲醇凝胶柱洗脱。共获得4个组分 (Fr. 4-1～Fr. 4-4)。Fr. 4-3共计200 mg, 经制备液相色谱 (35%～60% 乙腈−水梯度洗脱30 min), 得到化合物**9** (45 mg, t_R = 8.8 min) 和**10** (50 mg, t_R = 6.8 min)。

2 结构鉴定

7′-Hydroxybleformin E (**1**) 为棕色粉末。HR-ESI-MS *m/z*: 525.153 4 $[M+H]^+$ (计算值$C_{31}H_{25}O_8^+$, 525.154 4); IR (KBr): 3 297、2 936、2 848、1 731、1 585、1 463、1 445、1 201、1 135 cm^{-1}; ^1H NMR和^{13}C NMR数据见表1。

1,7-Dihydroxy-5-methoxy-9,10-dihydrophenanthrene (**2**) 为棕色粉末。HR-ESI-MS *m/z* 243.102 3 $[M+H]^+$, (计算值$C_{15}H_{15}O_3^+$, 243.101 6); IR (KBr): 3 261、2 980、2 839、2 434、1 593、1 452、1 325、1 310、1 157、1 064、796 cm^{-1}; ^1H NMR 和^{13}C NMR数据见表1。

6-Methoxycoelonin (**3**) 为棕色粉末。HR-ESI-MS *m/z*: 273.111 4 $[M+H]^+$ (计算值$C_{16}H_{17}O_4^+$, 273.112 1); ^1H NMR (400 MHz, CD_3OD) δ_H: 7.84 (1H, s, H-4), 6.63 (1H, s, H-1), 6.41 (1H, d, *J* = 2.3 Hz, H-6), 6.31 (1H, d, *J* = 2.3 Hz, H-8), 3.85 (6H, s, 4,6-OCH_3), 2.65 (4H, m, H-9, 10); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 159.0 (C-5), 157.6 (C-7), 146.6 (C-3), 145.2 (C-2), 141.9 (C-8a), 132.2 (C-10a), 126.1 (C-4a), 116.8 (C-4b), 115.3 (C-1), 113.6 (C-4), 108.5 (C-8), 99.4 (C-6), 56.6 (3-OCH_3), 56.0 (5-OCH_3), 32.0 (C-9), 30.2 (C-10)。波谱数据与文献报道的6-methoxycoelonin[11]一致, 故该化合物确定为6-methoxycoelonin。

6-Hydroxy-2,4,7-trimethoxyphenanthrene (**4**) 为棕色粉末。HR-ESI-MS *m/z*: 285.113 3 $[M+H]^+$ (计算值$C_{17}H_{17}O_4^+$, 285.112 1); ^1H NMR (400 MHz, $CDCl_3$) δ_H: 9.12 (1H, s, H-5), 7.60 (1H, d, *J* = 8.7 Hz, H-9), 7.50 (1H, d, *J* = 8.8 Hz, H-10), 7.18 (1H, s, H-8), 6.86 (1H, d, *J* = 2.5 Hz, H-1), 6.73 (1H, d, *J* = 2.5 Hz, H-3), 4.07 (3H, s, 7-OCH_3), 4.00 (3H, s, 4-OCH_3), 3.94 (3H, s, 2-OCH_3); ^{13}C NMR (100 MHz, $CDCl_3$) δ_C: 159.6 (C-2), 157.6 (C-4), 145.5 (C-7), 145.1 (C-6), 134.8 (C-10a), 127.6 (C-4b), 126.9 (C-8a), 125.7 (C-9), 124.9 (C-10), 115.5 (C-4a), 112.2 (C-5), 107.6 (C-1), 101.1 (C-8), 98.9 (C-3), 55.8 (7-OCH_3), 55.6 (4-OCH_3), 55.4 (2-OCH_3)。波谱数据与文献报道的6-hydroxy-2,4,7-trimethoxyphenanthrene[12]一致, 故该化合物确定为6-hydroxy-2,4,7-trimethoxyphenanthrene。

2,7-Dihydroxy-4,6-dimethoxyphenanthrene (**5**) 为深棕色粉末。HR-ESI-MS *m/z*: 271.096 6 $[M+H]^+$ (计算值$C_{16}H_{15}O_4^+$, 271.096 5); ^1H NMR (400 MHz, CD_3OD) δ_H: 8.97 (1H, s, H-5), 7.53 (1H, d, *J* = 8.7 Hz, H-9), 7.35 (1H, d, *J* = 8.8 Hz, H-10), 7.24 (1H, d, *J* = 5.6 Hz, H-8), 6.79 (1H, d, *J* = 2.4 Hz, H-1), 6.71 (1H, d, *J* = 2.3 Hz, H-3), 4.06 (3H, s, 4-OCH_3), 3.96 (3H, s, 6-OCH_3); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 160.9 (C-4), 157.4 (C-2), 147.8 (C-6), 146.9 (C-7), 136.5 (C-10a), 128.5 (C-8a), 127.9 (C-9), 126.9 (C-4b), 125.1 (C-10), 115.5 (C-4a), 113.7 (C-8), 109.4 (C-5), 105.4 (C-1), 99.8 (C-3), 56.1 (6-OCH_3), 55.9 (4-OCH_3)。波谱数据与文献报道的2,7-dihydroxy-4,6-dimethoxyphenanthrene[13]一致, 故该化合物确定为2,7-dihydroxy-4,6-dimethoxyphenanthrene。

5,7-Dimethoxy-2,3-phenanthrenediol (**6**) 为深棕色粉末。HR-ESI-MS *m/z*: 271.096 7 $[M+H]^+$ (计算值$C_{16}H_{15}O_4^+$, 271.096 5); ^1H NMR (400 MHz, CD_3OD) δ_H: 8.99 (1H, s, H-4), 7.47 (1H, d, *J* = 8.7 Hz, H-9), 7.39 (1H, d, *J* = 8.8 Hz, H-10), 7.16 (1H, s, H-1), 6.85 (1H, d, *J* = 2.5 Hz, H-8), 6.71 (1H, d, *J* = 2.5 Hz, H-6), 4.04 (3H, s, 4-OCH_3), 3.87 (3H, s, 6-OCH_3); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 160.6 (C-5), 158.7 (C-7), 146.6 (C-2), 145.5 (C-3), 136.0 (C-8a), 128.4 (C-10a), 128.3 (C-10), 126.1 (C-9), 125.3 (C-4a), 116.6 (C-4), 113.7 (C-1), 112.7 (C-4b), 102.3 (C-8), 99.6 (C-6), 55.9 (7-OCH_3), 55.7 (5-OCH_3)。波谱数据与文献报道的5,7-dimethoxy-2,3-phenanthrenediol[14]一致, 故该化合物确定为5,7-dimethoxy-2,3-phenanthrenediol。

Dihydropinosylvin (**7**) 为棕色粉末。HR-ESI-MS *m/z*: 215.106 5 $[M+H]^+$ (计算值$C_{14}H_{15}O_2^+$, 215.106 7); ^1H NMR (400 MHz, CD_3OD) δ_H: 7.24 (2H, m, H-3′,5′), 7.14 (3H, m, H-2′,4′,6′), 6.14 (2H, s, H-2,6), 6.09 (1H, s, H-4) 2.85 (2H, m, H-a), 2.72 (2H, m, H-a′); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 159.4 (C-3,5), 145.4 (C-1), 143.2 (C-1′), 129.5 (C-2′,6′), 129.3 (C-3′,5′), 126.8 (C-4′), 108.0 (C-2, 6), 101.2 (C-4), 39.3 (C-a), 38.9 (C-a′)。波谱数据与文献报道的dihydropinosylvin[15]一致, 故该化合物确定为dihydropinosylvin。

2′,3-Dihydroxy-5-methoxybibenzyl (**8**) 为棕色粉末。

HR-ESI-MS *m*/*z*: 245.118 0 $[M+H]^+$ (计算值 $C_{15}H_{17}O_3^+$, 245.117 2); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 6.99 (2H, m, H-4′,6′), 6.75 (1H, dd, *J* = 8.4, 0.9 Hz, H-3′), 6.70 (1H, td, *J* = 7.4, 1.1 Hz, H-5′), 6.28 (1H, s, H-2), 6.25 (1H, s, H-6), 6.18 (1H, t, *J* = 2.2 Hz, H-4), 3.69 (3H, s, 5-OCH_3), 2.83 (2H, m, H-a), 2.75 (2H, m, H-a′); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 162.1 (C-5), 159.2 (C-3), 156.3 (C-2′), 146.2 (C-1), 131.2 (C-6′), 129.4 (C-1′), 128.0 (C-4′), 120.4 (C-3′), 115.8 (C-5′), 109.1 (C-6), 106.5 (C-2), 99.8 (C-4), 55.5 (5-OCH_3), 37.4 (C-a), 33.6 (C-a′)。波谱数据与文献报道的2′,3-dihydroxy-5-methoxybibenzyl[16]一致, 故该化合物确定为2′,3-dihydroxy-5-methoxybibenzyl。

Demethyl batatasin IV (**9**) 为深棕色粉末。HR-ESI-MS *m*/*z*: 231.101 7 $[M+H]^+$ (计算值 $C_{14}H_{15}O_3^+$, 231.101 6); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 6.98 (2H, m, H-4′,6′), 6.75 (1H, d, *J* = 7.7 Hz, H-3′), 6.71 (1H, td, *J* = 7.4, 1.1 Hz, H-5′), 6.20 (2H, d, *J* = 1.9 Hz, H-2,6), 6.10 (1H, d, *J* = 1.7 Hz, H-4), 2.82 (2H, m, H-a), 2.70 (2H, m, H-a′); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 159.2 (C-3,5), 156.2 (C-2′), 146.2 (C-1), 131.1 (C-6′), 129.5 (C-1′), 127.9 (C-4′), 120.5 (C-3′), 115.8 (C-5′), 108.1 (C-2,6), 101.0 (C-4), 37.4 (C-a), 33.6 (C-a′)。波谱数据与文献报道的demethyl batatasin Ⅳ一致[17], 故该化合物确定为demethyl batatasin Ⅳ。

1,7-bis(4-hydroxyphenyl)-1,5-epoxy-3-hydroxyheptane (**10**) 为棕色粉末。HR-ESI-MS *m*/*z*: 315.159 3 $[M+H]^+$ (计算值 $C_{19}H_{23}O_4^+$, 315.159 1); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 7.20 (2H, d, *J* = 8.5 Hz, H-2′,6′), 6.99 (2H, d, *J* = 8.4 Hz, H-3′,5′), 6.77 (1H, d, *J* = 8.2 Hz, H-2″,6″), 6.68 (1H, dd, *J* = 8.4, 1.0 Hz, H-3″,5″), 4.25 (1H, d, *J* = 11.4 Hz, H-1), 3.83 (1H, m, H-3), 3.44 (1H, s, H-5), 2.64 (2H, m, H-7), 2.07 (1H, m, H-2*β*), 1.95 (1H, m, H-4*β*), 1.85 (1H, td, *J* = 13.9, 8.2 Hz, H-6), 1.72 (1H, td, *J* = 12.6, 7.9 Hz, H-6), 1.43 (1H, dd, *J* = 23.5, 11.5 Hz, H-2*α*), 1.24 (1H, dd, *J* = 23.3, 11.3 Hz, H-4*α*); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 157.9 (C-4′), 156.3 (C-4″), 134.6 (C-1′), 134.2 (C-1″), 130.4 (C-2″,6″), 128.6 (C-2′,6′), 116.1 (C-3″,5″), 116.0 (C-3′,5′), 78.7 (C-1), 76.3 (C-5), 69.0 (C-3), 43.6 (C-2), 41.8 (C-4), 39.3 (C-6), 31.9 (C-7)。波谱数据与文献报道的1,7-bis(4-hydroxyphenyl)-1,5-epoxy-3-hydroxyheptane[18,19]一致, 故该化合物确定为1,7-bis(4-hydroxyphenyl)-1,5-epoxy-3-hydroxyheptane。

Engelheptanoxide C (**11**) 为棕色粉末。HR-ESI-MS *m*/*z*: 345.169 8 $[M+H]^+$ (计算值 $C_{20}H_{25}O_5^+$, 345.169 7); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 7.00 (2H, d, *J* = 8.4 Hz, H-2″,6″), 6.97 (1H, d, *J* = 1.5 Hz, H-2′), 6.77 (1H, dd, *J* = 8.1, 1.8 Hz, H-6′), 6.77 (1H, d, *J* = 8.1 Hz, H-5′), 6.68 (2H, d, *J* = 8.4 Hz, H-3″,5″), 4.26 (1H, d, *J* = 11.3 Hz, H-1), 3.86 (3H, s, OCH_3-3′), 3.82 (1H, m, H-3), 3.44 (1H, m, H-5), 2.65 (2H, m, H-7), 2.09 (1H, m, H-2*β*), 1.96 (1H, m, H-4*β*), 1.86 (1H, dt, *J* = 13.8, 6.8 Hz, H-6), 1.74 (1H, ddd, *J* = 16.7, 8.8, 4.3 Hz, H-6), 1.43 (1H, m, H-2*α*), 1.24 (1H, m, H-4*α*); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 156.4 (C-4″), 148.2 (C-3′), 147.0 (C-4′), 135.3 (C-1″), 134.2 (C-1′), 130.4 (C-2″,6″), 120.0 (C-6′), 116.1 (C-3″,5″), 115.9 (C-5′), 111.1 (C-2′), 78.9 (C-1), 76.4 (C-5), 69.0 (C-3), 56.4 (OCH_3-3′), 43.7 (C-2), 41.8 (C-4), 39.2 (C-6), 31.8 (C-7)。波谱数据与文献报道的engelheptanoxide C[20]一致, 故该化合物确定为engelheptanoxide C。

Diosniponol A (**12**) 为深棕色粉末。HR-ESI-MS *m*/*z*: 375.179 9 $[M+H]^+$ (计算值 $C_{21}H_{27}O_6^+$, 375.180 2); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 6.96 (1H, d, *J* = 1.3 Hz, H-2′), 6.82 (1H, dd, *J* = 8.2, 1.5 Hz, H-6′), 6.77 (1H, d, *J* = 8.1 Hz, H-5′), 6.74 (1H, d, *J* = 1.5 Hz, H-2″), 6.70 (1H, d, *J* = 8.0 Hz, H-5″), 6.61 (1H, dd, *J* = 8.0, 1.6 Hz, H-6″), 4.24 (1H, d, *J* = 10.3 Hz, H-1), 3.85 (3H, s, OCH_3-3′), 3.82 (1H, m, H-3), 3.77 (3H, s, OCH_3-3″), 3.43 (1H, m, H-5), 2.65 (2H, m, H-7), 2.09 (1H, m, H-2*β*), 1.96 (1H, m, H-4*β*), 1.86 (1H, dt, *J* = 13.8, 6.8 Hz, H-6), 1.75 (1H, m, H-6), 1.43 (1H, dd, *J* = 23.4, 11.5 Hz, H-2*α*), 1.24 (1H, dd, *J* = 23.2, 11.4 Hz, H-4*α*); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 148.8 (C-3″), 148.8 (C-3′), 147.0 (C-4′), 145.4 (C-4″), 135.4 (C-1′), 135.0 (C-1″), 121.8 (C-6″), 120.0 (C-6′), 116.1 (C-5″), 115.9 (C-5′), 113.2 (C-2″), 111.1 (C-2′), 78.9 (C-1), 76.3 (C-5), 69.0 (C-3), 56.4 (OCH_3-3′), 56.3 (OCH_3-3″), 43.7 (C-2), 41.8 (C-4), 39.1 (C-6), 32.3 (C-7)。波谱数据与文献报道的diosniponol A[21]一致, 故该化合物确定为diosniponol A。

(+)-Hannokinol (**13**) 为棕色粉末。HR-ESI-MS *m*/*z*: 317.174 6 $[M+H]^+$ (计算值 $C_{19}H_{25}O_4^+$, 317.174 7); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 7.00 (4H, d, *J* = 8.5 Hz, H-2′,6′,2″,6″), 6.69 (4H, dd, *J* = 8.2, 1.7 Hz, H-3′,5′,3″,5″), 3.82 (2H, dd, *J* = 11.7, 5.8 Hz, H-3, 5), 2.66 (2H, m, H-1), 2.54 (2H, m, H-7), 1.68 (4H, m, H-2, 6), 1.54 (2H, t, *J* = 6.1 Hz, H-4); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 156.3 (C-4′,4″), 134.5 (C-1′,1″), 130.3 (C-2′,2″), 116.1 (C-5′,5″), 68.7 (C-1), 45.6 (C-5), 41.4 (C-3), 32.1 (C-7)。波谱数据与文献报道的(+)-hannokinol[22]一致, 故该化合物确定为 (+)-hannokinol。

(3*S*,5*S*)-3,5-Dihydroxy-1-(4-hydroxyphenyl)-7-(4-hydroxy-3-methoxyphenyl)heptane (**14**) 为棕黑色粉末。HR-ESI-MS *m/z*: 347.185 6 $[M+H]^+$ (计算值 $C_{20}H_{27}O_5^+$, 347.185 3); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 7.00 (2H, d, *J* = 8.4 Hz, H-2′,6′), 6.76 (1H, brs, H-2″), 6.69 (3H, m, H-3′,5′,5″), 6.62 (1H, dd, *J* = 8.0, 1.8 Hz, H-6″), 3.82 (2H, m, H-3,5), 3.81 (3H, s, OCH_3-3″), 2.67 (2H, m, H-1), 2.55 (2H, m, H-7), 1.69 (4H, m, H-2,6), 1.54 (2H, t, *J* = 6.0 Hz, H-4); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 156.3 (C-4′), 148.8 (C-3″), 145.4 (C-4″), 135.3 (C-1″), 134.5 (C-1′), 130.3 (C-2′,6′), 121.8 (C-6″), 116.1 (C-3′,5′,5″), 113.2 (C-2″), 68.7 (C-3,5), 56.3 (OCH_3-3″), 45.6 (C-4), 41.4 (C-6), 41.3 (C-2), 32.6 (C-1), 32.1 (C-7)。波谱数据与文献报道的 (3*S*,5*S*)-3,5-dihydroxy-1-(4-hydroxyphenyl)-7-(4-hydroxy-3-methoxyphenyl)heptane[23]一致, 故该化合物确定为 (3*S*,5*S*)-3,5-dihydroxy-1-(4-hydroxyphenyl)-7-(4-hydroxy-3-methoxyphenyl)heptane。

(3*S*,5*S*)-3,5-Hihydroxy-1,7-bis(4-hydroxy-3-methoxyphenyl)heptane (**15**) 为棕色粉末。HR-ESI-MS *m/z*: 377.196 1 $[M+H]^+$ (计算值 $C_{21}H_{29}O_6^+$, 377.195 9); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 6.76 (2H, d, *J* = 1.5 Hz, H-2′,2″), 6.69 (2H, d, *J* = 8.0 Hz, H-5′,5″), 6.62 (2H, dd, *J* = 8.0, 1.5 Hz, H-6′,6″), 3.82 (8H, m, H-3,5, OCH_3-3′,3″), 2.67 (2H, m, H-1*β*, H-7*β*), 2.56 (2H, m, H-1*α*, H-7*α*), 1.70 (4H, m, H-2,6), 1.56 (2H, t, *J* = 6.0 Hz, H-4); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 148.8 (C-3′,3″), 145.4 (C-4′,4″), 135.2 (C-1′,1″), 121.8 (C-6′,6″), 116.1 (C-5′,5″), 113.2 (C-2′,2″), 68.7 (C-3,5), 56.3 (OCH_3-3′,3″), 45.7 (C-4), 41.4 (C-2,6), 32.6 (C-1,7)。波谱数据与文献报道的 (3*S*,5*S*)-3,5-dihydroxy-1,7-bis(4-hydroxy-3-methoxyphenyl)heptane[24]一致, 故该化合物确定为(3*S*,5*S*)-3,5-dihydroxy-1,7-bis(4-hydroxy-3-methoxyphenyl)heptane。

Hexahydrocurcumin (**16**) 为棕色粉末。HR-ESI-MS *m/z*: 375.180 1 $[M+H]^+$ (计算值 $C_{21}H_{27}O_6^+$, 375.180 2); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 6.74 (2H, d, *J* = 2.3 Hz, H-2′,2″), 6.70 (2H, d, *J* = 8.0 Hz, H-5′), 6.68 (2H, dd, *J* = 8.0, 1.5 Hz, H-5″), 6.60 (2H, dd, *J* = 7.9, 2.1 Hz, H-6′,6″), 4.01 (1H, m, H-5), 3.81 (3H, s, OCH_3-3′), 3.79 (3H, s, OCH_3-3″), 2.79～2.46 (8H, m, H-1,2,4,7), 1.68 (2H, m, H-6); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 211.9 (C-3), 148.8 (C-3′), 148.8 (C-3″), 145.7 (C-4′), 145.5 (C-4″), 134.8 (C-1″), 134.0 (C-1′), 121.8 (C-6″), 121.7 (C-6′), 116.1 (C-5″), 116.1 (C-5′), 113.1 (C-2′), 113.0 (C-2″), 68.2 (C-5), 56.3 (OCH_3-3′,3″), 51.2 (C-4), 46.3 (C-2), 40.4 (C-6), 32.4 (C-7), 30.2 (C-1)。波谱数据与文献报道的 hexahydrocurcumin[25]一致, 故该化合物确定为 hexahydrocurcumin。

(5*S*)-5-Hydroxy-1-(4-hydroxy-3-methoxyphenyl)-7-(4-hydroxyphenyl)-3-heptanone (**17**) 为棕色粉末。HR-ESI-MS *m/z*: 345.170 0 $[M+H]^+$ (计算值 $C_{20}H_{25}O_5^+$, 345.169 7); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 6.98 (2H, d, *J* = 8.3 Hz, H-2″,6″), 6.75 (1H, d, *J* = 2.3 Hz, H-5′), 6.69 (3H, m, H-2′,3″,5″), 6.60 (2H, m, H-6′), 4.02 (1H, m, H-5), 3.81 (3H, s, OCH_3-3′), 2.44～2.81 (8H, m, H-1, 2,4,7), 1.67 (2H, m, H-6); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 211.9 (C-3), 156.6 (C-4″), 148.8 (C-3′), 145.7 (C-4′), 134.9 (C-1″), 134.1 (C-1′), 130.3 (C-2″,6″), 121.8 (C-6′), 116.1 (C-5′), 116.1 (C-3″,5″), 113.1 (C-2′), 68.2 (C-5), 56.3 (OCH_3-3′), 51.2 (C-4), 46.3 (C-2), 40.4 (C-6), 32.4 (C-7), 30.2 (C-1)。波谱数据与文献报道的 (5*S*)-5-hydroxy-1-(4-hydroxy-3-methoxyphenyl)-7-(4-hydroxyphenyl)-3-heptanone[26]一致, 故该化合物确定为(5*S*)-5-hydroxy-1-(4-hydroxy-3-methoxyphenyl)-7-(4-hydroxyphenyl)-3-heptanone。

Feruloyltyramine (**18**) 为深棕色粉末。HR-ESI-MS *m/z*: 314.139 8 $[M+H]^+$ (计算值 $C_{18}H_{20}NO_4^+$, 314.138 7); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 7.44 (2H, d, *J* = 15.7 Hz, H-7′), 7.09 (1H, s, H-2′), 7.04 (1H, d, *J* = 8.3 Hz, H-2,6), 7.00 (1H, m, H-6′), 6.79 (1H, d, *J* = 8.1 Hz, H-5′), 6.72 (1H, d, *J* = 8.4 Hz, H-3,5), 6.41 (1H, d, *J* = 15.7 Hz, H-8′), 3.85 (3H, s, OCH_3-3′), 3.46 (2H, t, *J* = 7.3 Hz, H-8), 2.74 (2H, t, *J* = 7.3 Hz, H-7); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 169.2 (C-9′), 156.8 (C-4), 149.7 (C-4′), 149.2 (C-3′), 142.0 (C-7′), 131.3 (C-1), 130.7 (C-2, 6), 128.2 (C-1′), 123.2 (C-6′), 118.7 (C-8′), 116.5 (C-5′), 116.3 (C-3, 5), 111.5 (C-2′), 56.4 (OCH_3-3′), 42.9 (C-8), 35.7 (C-7)。波谱数据与文献报道的 feruloyltyramine[27]一致, 故该化合物确定为 feruloyltyramine。

Octadecadienoic acid-2,3-dihydroxypropyl ester (**19**) 为棕色粉末。HR-ESI-MS *m/z*: 355.282 1 $[M+H]^+$ (计算值 $C_{21}H_{39}O_4^+$, 355.284 3); ^{1}H NMR (400 MHz, CD_3OD) δ_H: 5.43～5.26 (4H, m, H-9′,10′,12′,13′), 4.15 (1H, dd, *J* = 11.4, 4.4 Hz, H-1*β*), 4.06 (1H, dd, *J* = 11.4, 6.2 Hz, H-1*α*), 3.85～3.78 (1H, m, H-3*α*), 3.55 (1H, dd, *J* = 5.6, 1.6 Hz, H-3*β*), 2.78 (2H, t, *J* = 6.2 Hz, H-11′), 2.35 (2H, t, *J* = 7.4 Hz, H-2′), 2.07 (4H, q, *J* = 6.6 Hz, H-8′,14′), 1.62 (2H, m, H-3′), 1.42～1.24 (14H, m, H-4′～7′,15′～17′), 0.91 (3H, t, *J* = 6.9 Hz, 18′-CH_3); ^{13}C NMR (100 MHz, CD_3OD) δ_C: 175.4 (C-1′), 130.9 (C-9′), 130.9 (C-13′), 129.1 (C-10′), 129.0 (C-12′), 71.1 (C-2), 66.5 (C-3), 64.1

(C-1), 34.9 (C-2′), 32.7 (C-7′), 30.7 (C-15′), 30.5 (C-6′), 30.3 (C-5′), 30.2 (C-4′), 30.2 (C-3′), 28.2 (C-8′,14′), 26.5 (C-11′), 26.0 (C-16′), 23.6 (C-17′), 14.5 (C-18′)。以上数据与文献[28]对照基本一致, 故该化合物确定为octadecadienoic acid-2,3-dihydroxypropyl ester。

3 活性测试

参考文献[29-31]方法采用PNPG法测定从铁棍山药皮中分离出来的单体化合物的α-葡萄糖苷酶抑制活性。配制0.1 mol·L^{-1} PBS、0.5 U·mL^{-1} α-葡萄糖苷酶溶液、2.5 mmol·L^{-1} PNPG溶液、0.2 mol·L^{-1} Na_2CO_3终止液以及10% DMSO溶液。

依次在96孔板中加入PBS、10% DMSO溶液、不同浓度的样品或阳性药物和α-葡萄糖苷酶后摇匀, 在37 ℃的恒温培养箱中孵育15 min。然后, 在每个孔中加入20 μL PNPG (2.5 mmol·L^{-1}), 摇匀, 再次放入37 ℃的恒温培养箱中培养15 min。最后, 在每个孔中加入0.2 mol·L^{-1}碳酸钠溶液80 μL停止反应, 使用酶标仪在405 nm处测定吸光度 (A) 值。通过GraphPad Prism 9.0软件计算各组数据并进行统计学分析。按下列公式计算各样品对α-葡萄糖苷酶的抑制率: 抑制率% = $[1-(A_{样品}-A_{背景}) / (A_{阴性}-A_{空白})] \times 100\%$

作者贡献: 杨俊杰是本文第一作者, 负责化合物分离和文章初稿撰写; 刘永康收集样品及提取; 吴其国负责活性筛选; 朱亮对分离和结构鉴定提供了一定帮助; 俞桂新和许红涛为本文通讯作者, 负责结构鉴定、数据核实及论文修改。

利益冲突: 所有作者均声明无任何利益冲突。

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