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蛇足石杉内生真菌 *Neofusicoccum* sp. F483 的化学成份研究

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摘要: 植物内生真菌是重要的生物资源, 来自植物不同组织的内生菌还有一大部分未被人们所认识, 该研究通过查阅国内外相关文献, 发现内生菌产生的化合物大多具有生物学活性。在此基础上以蛇足石杉(*Huperzia serrata*)为材料, 从其茎部分离纯化得到 1 株内生真菌, 提取这株真菌的总 DNA, 用 PCR 扩增 ITS 片段, 将测序结果在 GenBank 数据库中进行比对, 最终鉴定为葡萄座腔菌属(*Neofusicoccum* sp.)。具体方法: (1) 对内生真菌 *Neofusicoccum* sp. F483 进行固体培养基发酵, 并用混合有机溶剂提取得代谢产物; (2) 采用硅胶、Sephadex LH-20 凝胶色谱柱层析、半制备 HPLC 等方法对代谢产物的化学成分进行分离; (3) 利用理化性质及¹H-NMR、¹³C-NMR、ESI-MS 等波谱数据鉴定化合物结构。结果表明: 共分离得到 8 个化合物, 经过波谱数据分析并结合文献对照鉴定结构为 fusaproliferin (1)、过氧麦角甾醇(2)、麦角甾醇(3)、1-(furan-2-yl)-2-hydroxyethanone (4)、脑苷脂 C (5)、腺嘌呤核苷(6)、versicolactone B (7)、versicolactone A (8)。该研究结果可为进一步从植物内生菌中挖掘有价值的天然活性产物奠定基础, 为新的药用植物内生菌资源的开发利用提供理论依据。

关键词: 蛇足石杉; 内生真菌; 固体发酵; 化学成分; 生物活性

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Chemical constituents of endophyte *Neofusicoccum* sp. F483 from *Huperzia serrata*

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Abstract: As we know, the plant endophytic fungi are some important biological resources, and up to now, a large part of the plant endophytes which came from a variety of plant organizations had not yet been recognized by the people, and on the basis of checking out relative technical literature reported in both at home and abroad, the great majority chemical constituents produced by the endophytes were found to possess certain biological activity. This thesis was the further search for new active natural products from pteridophyte *Huperzia serrate* endophytes. *H. serrate* (Thunb.) Trev. was collected from Xichou County, Wenshan Prefecture, Yunnan Province. A endophytic fungus was isolated and purified from the stem of *H. serrate*. After extracting total DNA of this strain, internal transcribed

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spacer (ITS) was amplified by polymerase chain reaction (PCR), then the amplified product was sequenced. Fragment sequencing results were compared to the GenBank sequence database, and eventually, this strain was identified as *Neofusicoccum* and was named as *Neofusicoccum* sp. F483. In this study, we adopted the following three methods: (1) The endophytic fungus *Neofusicoccum* sp. F483 was fermented with solid medium, and then, fungi with medium were extracted with mixed organic solvent, and the secondary metabolites were obtained; (2) The chemical composition of the fermented metabolites were isolated by column chromatography methods including normal-phase silica gel, Sephadex LH-20, and reversed-phase semi-preparative HPLC; (3) The isolated chemical components were identified by their physical and chemical properties, and a combination of spectroscopic techniques including electrospray ionization mass spectrum (ESI-MS) and one-dimensional nuclear magnetic resonance ($^1\text{H-NMR}$, $^{13}\text{C-NMR}$) spectroscopic analysis. The results were as follows: eight compounds were separated and identified from *Neofusicoccum* sp. F483, and their structures were elucidated by analyzing their spectral data and comparing with the relevant reported literature. They were identified as follows: fusaproliferin (**1**), $5\alpha,8\alpha$ -epidiory-(22E,24R) ergosta-6,22-dien-3 β -ol (**2**), ergosterol (**3**), 1-(furan-2-yl)-2-hydroxyethanone (**4**), cerebroside C (**5**), adenosine (**6**), versicolactone B (**7**) and versicolactone A (**8**). It will lay a foundation for further mining the valuable natural products from plant endophytes, and will provide a theoretical basis for the development and utilization of the new medicinal plant endophytes resources.

Key words: *Huperzia serrata*; endophyte fungus; solid fermentation; chemical constituents; biological activity

蛇足石杉 (*Huperzia serrata*) 属石杉科 (Huperiaceae) 石杉属 (*Huperzia* Benth.) 蕨类植物, 有救命王、金不换、千层塔等之称。它分布于全国各地, 也广布于亚洲、大洋洲、以及中美洲等其他地区 (余红英等, 2001)。其全草对于治疗跌打损伤、瘀血肿痛、精神分裂等疾病有一定的疗效 (张君诚等, 2008)。近年来, 传统药用植物以及特殊生境中植物的内生真菌研究是一个新兴的研究热点 (Tan *et al.*, 2001), 对蛇足石杉内生菌有了研究报道: 龚玉霞等 (2007) 采用内生菌常规分离法对健康的蛇足石杉植株内生真菌进行了分离和筛选得到 180 株内生菌, 分属于 *Alternaria*、*Cephalosporium*、*Guignardia* 等 13 个属; 俞超等 (2009) 从药用植物蛇足石杉中分离出内生真菌进行初步的研究; 汪涯等 (2011) 采用平板分离法分离蛇足石杉内生真菌共分离到 127 株内生真菌, 分属于 *Penicillium*、*Aspergillus*、*Podospora* 等 19 个属, 并对其中乙酰胆碱酯酶抑制活性成分进行了研究。

本文从蛇足石杉茎部分离得到 1 株内生真菌 *Neofusicoccum* sp. F483, 为了进一步寻找新型的活性化合物, 对其发酵产物进行了研究。从此株内生真菌的次级代谢产物中得到 8 个化合物, 通过波谱分析, 结构鉴定为 fusaproliferin (**1**)、过氧麦角甾醇 (**2**)、麦角甾醇 (**3**)、1-(furan-2-yl)-2-hydroxyethanone (**4**)、脑苷脂 C (**5**)、腺嘌呤核苷 (**6**)、versicolactone B (**7**)、versicolactone A (**8**)。

1 材料与仪器

1.1 菌种来源和发酵

蛇足石杉的植株于 2013 年 8 月采集于云南文山州西畴县。内生真菌分离自蛇足石杉的茎部, 菌种保存于中国科学院昆明植物研究所植物化学与西部植物资源持续利用国家重点实验室。

F483 的总 DNA 提取根据文献 (吴发红等, 2009) 采用改进的 CTAB 法。实验中 F483 的鉴定选用真菌 ITS 鉴定所使用的通用引物 ITS4 和 ITS5, 引物序列分别为 ITS4 (5' > TCCTCCGCT-TATTGATATGC < 3') 和 ITS5 (5' > GGAAGTAAAGTCGTAACAAG < 3')。按以下步骤进行 PCR 操作: 加 r-taq 酶预变性 15 min (95 °C); 变性 40 s (95 °C); 退火 40 s (55 °C); 延伸 90 s (72 °C), 30 个循环; 延伸 10 min (72 °C)。PCR 后回收到 500~700 bp 的核酸片段, 将测序结果在 GenBank 数据库中进行比对, 结果显示该序列与葡萄座腔菌属 (*Neofusicoccum*) 的同源性高达 99%, 故鉴定为葡萄座腔菌属真菌 (*Neofusicoccum*), 同时命名为 F483。

将 F483 活化 2 代后接种在 PDA 培养基 (配方为马铃薯净重 200 g, 煮沸 30 min 后过滤取汁; 葡萄糖 20 g; 琼脂 15 g; 自来水 1 L, pH 自然) 上, 固体平板发酵 30 L, 于 28 °C 温室中培养 16 d。

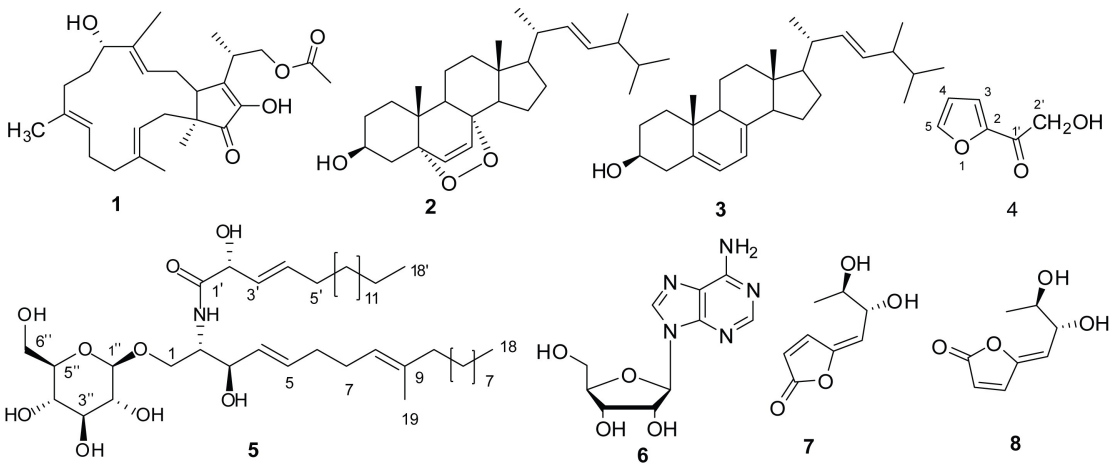


图 1 化合物 1~8 的结构
Fig. 1 Structures of compounds 1~8

1.2 仪器与试剂

TMS 作为内标, 化学位移值 δ 单位为 ppm, 耦合常数 J 单位为 Hz; 核磁共振波谱仪 (Bruker AM-400 型, Avance III 600 型); Sephadex LH-20 葡聚糖凝胶 (Amersham Pharmacia 公司); 质谱仪 (Finnigan LCQ-Advantage 型); 柱色谱层析用硅胶 G, 200~300 目, GF-254, 薄层层析用 GF-254 硅胶板 (青岛海洋化工厂), 柱色谱层析硅胶 H (Merck 公司); LC3000 型-高效液相色谱仪: RP-C₁₈ 7 μm 10 \times 250 mm (北京创新通恒科技有限公司); TLC 显色剂: 5% 浓硫酸乙醇溶液; HPLC 分析用色谱纯 (甲醇) 溶剂。

2 提取与分离

用配比溶剂 (乙酸乙酯-甲醇-冰醋酸 80 : 15 : 5, v/v/v) 将 F483 固体发酵物浸泡提取 3 次, 依次间隔 3、2、1 d, 得到发酵粗提物, 用乙酸乙酯萃取, 减压浓缩得到总浸膏 27 g。浸膏采取柱层析 (200~300 目) 分离后, 依次以石油醚-乙酸乙酯 (100 : 4~6 : 4) 及氯仿-甲醇 (9 : 1~0 : 100) 梯度洗脱得到 12 个组分 (Fr. 1~Fr. 12)。Fr. 3 (4 g) 经 Sephadex LH-20 (氯仿/甲醇 1 : 1) 洗脱, 再经硅胶柱色谱 (氯仿/甲醇 100 : 3) 洗脱得到化合物 2 (4.1 mg) 和化合物 3 (3.7 mg); Fr. 4 (600 mg) 经 Sephadex LH-20 (氯仿/甲醇 1 : 1) 洗脱, 再经硅胶柱色谱 (石油醚/丙酮 100 : 5) 洗脱得到化合物 4 (3.5 mg); Fr. 5 (705 mg) 经 Sephadex LH-20 (氯

仿/甲醇 1 : 1) 洗脱, 再经反向半制备柱 RP-C₁₈ 以甲醇-水 (80 : 20~100 : 0) 梯度洗脱 30 min 得化合物 1 (4.5 mg); Fr. 10 (1 g) 经 Sephadex LH-20 (甲醇) 洗脱, 再经硅胶柱色谱 (氯仿/甲醇 100 : 5) 洗脱得化合物 5 (5.3 mg); Fr. 11 (1.1 g) 通过 Sephadex LH-20 (氯仿/甲醇 1 : 1) 洗脱, 再经 Sephadex LH-20 (甲醇) 洗脱, 得到化合物 6 (3.3 mg); Fr. 9 (1.5 g) 通过 Sephadex LH-20 (氯仿/甲醇 1 : 1) 洗脱, 再经反向半制备柱 RP-C₁₈ 以甲醇-水 (5 : 95~70 : 30) 梯度洗脱 30 min 得化合物 7 (3.8 mg) 和化合物 8 (3.5 mg)。

3 结构鉴定

化合物 1 C₂₇H₄₀O₅, 无定型固体, ESI-MS m/z : 445 [M + H]⁺; ¹H-NMR (CDCl₃, 600MHz) δ_{H} : 2.68 (1H, d, J = 10.3 Hz, H-23), 5.25 (1H, m, H-3), 5.12 (1H, brs, H-7), 4.06 (1H, d, J = 7.9 Hz, H-11), 5.38 (1H, brs, H-13), 2.81 (1H, m, H-15), 2.80 (1H, dd, J = 7.0, 14.3 Hz), 0.99 (3H, s, H-19), 1.64 (6H, s, H-20/H-21), 1.56 (3H, s, H-22), 4.30 (2H, m, H-24), 1.31 (3H, d, J = 7.2 Hz, H-25), 2.02 (1H, s, -OCCH₃); ¹³C-NMR (CDCl₃, 150 MHz) δ_{C} : 207.9 (s, C-18), 170.9 (s, -OCCH₃), 147.3 (s, C-17), 146.7 (s, C-16), 138.1 (C-4), 136.5 (s, C-12), 132.8 (s, C-8), 128.9 (d, C-13), 124.3 (d, C-7), 121.3 (d, C-3), 76.5 (d, C-11), 66.4

(t, C-24), 49.5 (d, C-15), 49.0 (s, C-1), 40.3 (t, C-5), 39.1 (t, C-2), 34.9 (t, C-9), 33.7 (d, C-23), 29.6 (t, C-10), 28.7 (t, C-14), 23.8 (t, C-10), 20.9 (q, -OCCH₃), 16.2 (q, C-19), 15.5 (q, C-20), 15.3 (q, C-21), 14.5 (q, C-25), 10.4 (q, C-22)。上述数据与 Nihashi *et al.* (2002) 报道一致, 故鉴定该化合物为 fusaproliferin。

化合物 2 C₂₈H₄₄O₃, 无色针晶; ESI-MS m/z : 429 [M + H]⁺; ¹H-NMR (CDCl₃, 400 MHz) δ_{H} : 6.50 (1H, d, $J = 10.5$ Hz, H-7), 6.24 (1H, d, $J = 10.5$ Hz, H-6), 5.23 (1H, dd, $J = 19.0, 9.3$ Hz, H-22), 5.15 (1H, dd, $J = 19, 10.1$ Hz, H-23), 3.99 (1H, m, H-3), 0.98 (3H, m, H-21), 0.90 (3H, d, $J = 8.6$ Hz, H-28), 0.86 (3H, s, H-19), 0.82 (3H, m, H-27), 0.80 (3H, m, H-26); ¹³C-NMR (CDCl₃, 100 MHz) δ_{C} : 135.4 (d, C-6), 135.2 (d, C-22), 132.2 (d, C-23), 130.7 (d, C-7), 82.1 (s, C-5), 79.4 (s, C-8), 66.4 (d, C-3), 56.1 (d, C-17), 51.6 (d, C-14), 51.0 (d, C-9), 44.5 (s, C-13), 42.7 (d, C-24), 39.7 (d, C-20), 39.3 (t, C-12), 37.0 (t, C-4), 36.9 (s, C-10), 34.6 (t, C-1), 33.0 (d, C-25), 30.1 (t, C-2), 28.6 (t, C-15), 23.3 (t, C-11), 20.8 (q, C-21), 20.6 (t, C-16), 19.9 (q, C-27), 19.6 (q, C-26), 18.1 (q, C-19), 17.5 (q, C-28), 12.8 (q, C-18)。上述数据与陆云德等(2013) 报道一致, 故鉴定该化合物为过氧麦角甾醇。

化合物 3 C₂₈H₄₄O, 无色针状结晶; ESI-MS m/z : 397 [M + H]⁺; ¹H-NMR (CDCl₃, 400 MHz) δ_{H} : 5.58 (1H, dd, $J = 5.5, 2.4$ Hz, H-6), 5.39 (1H, m, H-7), 5.21 (2H, m, H-22, 23), 3.67 (1H, m, H-3), 1.04 (3H, d, $J = 6.7$ Hz, H-21), 0.94 (3H, s, H-19), 0.92 (3H, d, $J = 7.0, 7.0$ Hz, H-28), 0.84 (3H, d, $J = 6.4$ Hz, H-26 或 H-27), 0.83 (3H, d, $J = 6.4$ Hz, H-26 或 27), 0.63 (3H, s, H-18); ¹³C-NMR (CDCl₃, 100 MHz) δ_{C} : 141.3 (s, C-8), 139.7 (s, C-5), 135.5 (d, C-22), 131.9 (d, C-23), 119.5 (d, C-6), 116.2 (d, C-7), 70.4 (d, C-3), 55.6 (d, C-17), 54.5 (d, C-14), 46.2 (d, C-9), 42.8 (d, C-24), 40.7 (t, C-4), 40.4 (d, C-20), 39.0 (t, C-12), 38.3 (t, C-1), 37 (s, C-10), 33.0 (d, C-25), 31.9 (t, C-2), 28.3 (t, C-16), 22.9 (t, C-15), 21.1 (t,

C-11), 19.9 (q, C-27), 19.6 (q, C-26), 17.6 (q, C-28), 16.2 (q, C-19), 12.0 (q, C-18)。上述数据与樊晓飞等(2013) 报道一致, 故鉴定该化合物为麦角甾醇。

化合物 4 C₆H₆O₃, 无色针状结晶; ESI-MS m/z : 127 [M + H]⁺; ¹H-NMR (CDCl₃, 600MHz) δ_{H} : 7.63 (d, $J = 1.0$ Hz, H-5), 7.31 (d, $J = 3.4$ Hz, H-3), 6.61 (dd, $J = 1.7, 3.6$ Hz, H-4), 4.74 (2H, brs, H₂-2'), 3.26 (s, OH-2'); ¹³C-NMR (CDCl₃, 150 MHz) δ_{C} : 187.7 (s, C-1'), 147.1 (d, C-5), 117.9 (d, C-3), 112.6 (d, C-4), 65.1 (t, C-2')。上述数据与 Fujimoto *et al.* (1996) 报道一致, 故鉴定该化合物为 1-(furan-2-yl)-2-hydroxyethanone。

化合物 5 C₄₃H₇₉NO₉, 无色针状结晶; ESI-MS m/z : 754 [M + H]⁺; ¹³H-NMR (CD₃OD, 600 MHz) δ_{H} : 5.85 (1H, dt d, $J = 15.4, 6.7, 1.1$ Hz, H-4'), 5.73 (1H, brdt, $J = 15.2, 6.4$ Hz, H-5), 5.50 (1H, ddt, $J = 15.4, 6.2, 1.3$ Hz, H-3'), 5.46 (1H, dd, $J = 13.5, 5.6$ Hz, H-4), 5.15 (1H, brt, $J = 5.7$ Hz, H-8), 4.43 (1H, d, $J = 6.1$ Hz, H-2'), 4.27 (1H, d, $J = 7.9$ Hz, H-1''), 4.15 (1H, m, H_a-1), 4.12 (1H, m, H-3), 4.00-3.95 (1H, m, H-2), 3.87 (1H, m, H_a-6''), 3.71 (1H, dd, $J = 10.4, 3.5$ Hz, H_b-1), 3.67 (1H, m, H_b-6''), 3.36 (1H, t, $J = 8.9$ Hz, H_b-3''), 3.30~3.27 (2H, m, H-4'', H-5''), 3.20 (1H, dd, $J = 9.1, 7.8$ Hz, H-2''), 2.07~2.01 (6H, m, H-6, H-7, H₂-5'), 1.98 (2H, t, $J = 7.2$ Hz, H-10), 1.59 (3H, brs, H-19), 1.41~1.27 (38H, m, H-11~17, H-6'~17'), 0.91 (6H, t, $J = 6.8$ Hz, H-18, H-18'); ¹³C-NMR (CD₃OD, 150 MHz) δ_{C} : 175.4 (s, C-1'), 136.7 (s, C-9), 134.7 (d, C-4'), 134.5 (d, C-5), 131.0 (d, C-4), 129.0 (d, C-3'), 124.9 (d, C-8), 104.7 (d, C-1''), 78.0 (d, C-5''), 77.9 (d, C-3''), 75.0 (d, C-2''), 74.1 (d, C-2'), 72.9 (d, C-3), 71.5 (d, C-4''), 69.7 (t, C-1), 62.6 (t, C-6''), 54.6 (d, C-2), 40.8 (t, C-10), 33.8 (t, C-6), 33.5 (t, C-5'), 33.1 (t, C-16, C-16'), 30.9~30.3 (14C, C-12~15, C-6'~15'), 29.2 (s, C-11), 28.8 (s, C-7), 23.8 (t, 2C, C-17, C-17'), 16.1 (q, C-19), 14.5 (q, 2C, C-18, C-18')。上述数据与崔香等(2013) 报道一致, 故鉴定该化合物为

脑苷脂 C。

化合物 **6** $C_{10}H_{13}N_5O_4$ ，白色粉末；ESI-MS m/z : 268 $[M + H]^+$ ； 1H -NMR (CD_3OD , 600 MHz) δ_H : 8.31 (1H, s, H-8), 8.18 (1H, s, H-2), 5.96 (1H, d, $J = 6.3$ Hz, H-1'), 4.74 (1H, d, $J = 5.6$ Hz, H-2'), 4.32 (1H, dd, $J = 2.4$, 4.8 Hz, H-3'), 4.16 (1H, d, $J = 2.2$ Hz, H-3'), 3.89 (1H, dd, $J = 12.7$, 2.4 Hz, H-5a'), 3.75 (1H, dd, $J = 12.5$, 2.4 Hz, H-5b')； ^{13}C -NMR (CD_3OD , 150 MHz) δ_C : 157.6 (s, C-6), 153.5 (d, C-2), 150.1 (s, C-4), 142.1 (d, C-8), 121.2 (s, C-5), 91.3 (d, C-1'), 88.2 (d, C-4'), 75.5 (d, C-2'), 72.7 (d, C-3'), 63.5 (t, C-5')。上述数据与吴笛等(2008)报道一致,故鉴定该化合物为腺嘌呤核苷。

化合物 **7** $C_8H_{10}O_4$ ，白色蜡状物；ESI-MS m/z : 171 $[M + H]^+$ ； 1H -NMR (CD_3OD , 600 MHz) δ_H : 8.03 (1H, d, $J = 5.6$ Hz, H-3), 6.32 (1H, dd, $J = 1.7$, 5.7 Hz, H-2), 5.82 (1H, dd, $J = 1.2$, 8.7 Hz, H-5), 4.29 (1H, dd, $J = 1.7$, 5.7 Hz, H-6), 3.77 (1H, dq, $J = 6.3$, 18.2 Hz, H-7), 1.18 (1H, d, $J = 6.3$ Hz, H-8)； ^{13}C -NMR (CD_3OD , 150 MHz) δ_C : 171.6 (s, C-1), 151.9 (s, C-4), 142.9 (d, C-3), 121.6 (d, C-2), 116.3 (d, C-5), 72.8 (d, C-6), 71.5 (d, C-7), 19.2 (q, C-8)。上述数据与 Zhuang *et al.*(2011)报道一致,故鉴定该化合物为 versicolactone B。

化合物 **8** $C_8H_{10}O_4$ ，白色蜡状物；ESI-MS m/z : 171 $[M + H]^+$ ； 1H -NMR (CD_3OD , 600 MHz) δ_H : 7.67 (1H, d, $J = 5.5$ Hz, H-3), 6.30 (1H, d, $J = 5.20$ Hz, H-2), 5.46 (1H, d, $J = 9.2$ Hz, H-5), 4.53 (1H, dd, $J = 4.7$, 9.2 Hz, H-6), 3.82 (1H, m, H-7), 1.15 (3H, d, $J = 6.4$, H-8)； ^{13}C -NMR (CD_3OD , 150 MHz) δ_C : 171.5 (s, C-1), 151.9 (s, C-4), 145.9 (d, C-3), 121.1 (d, C-2), 116.3 (d, C-5), 71.6 (d, C-6), 71.4 (d, C-7), 18.8 (q, C-8)。上述数据与 Zhuang *et al.*(2011)报道一致,故鉴定该化合物为 versicolactone A。

4 讨论

传统药用植物以及特殊生境中植物的内生真菌

可能是重要生物资源 (Tan *et al.*, 2001)。目前来自植物不同组织的多数内生菌还未被人们认识,但相关文献报道过的内生菌产生的化合物多数具有生物学活性。本文从蛇足石杉内生真菌 *Neofusicoccum* sp. F483 的次级代谢产物中分离鉴定了 8 个化合物,分别是 fusaproliferin (**1**)、过氧麦角甾醇 (**2**)、麦角甾醇 (**3**)、1-(furan-2-yl)-2-hydroxyethanone (**4**)、脑苷脂 C (**5**)、腺嘌呤核苷 (**6**)、versicolactone B (**7**)、versicolactone A (**8**)。据文献报道,这些化合物具有一定的活性。苏日古格等(2012)通过研究发现麦角甾醇和麦角甾醇过氧化物对肝癌细胞 (HepG2) 的早期凋亡率分别是 41.2% 和 42.33%。冯建(2014)研究发现麦角甾醇和过氧麦角甾醇具有较好的抗氧化活性,麦角甾醇 EC_{50} 值为 $1.4 \text{ mg} \cdot \text{mL}^{-1}$,过氧麦角甾醇 EC_{50} 值为 $0.92 \text{ mg} \cdot \text{mL}^{-1}$,同时麦角甾醇对 BGC 胃癌细胞增殖的抑制率 (%) IC_{50} 值在 $100 \sim 142 \mu\text{g} \cdot \text{mL}^{-1}$ 范围内。魏丹丹等(2009)用 MTT 法检测过氧麦角甾醇的抗结核活性,发现当浓度超过 $20 \mu\text{g} \cdot \text{mL}^{-1}$ 时有抗结核活性。高虹等(2006)选用了小鼠体内 S180 肉瘤的抑制作为筛选抗肿瘤活性的模型,发现麦角甾醇据有较强的抑瘤活性。此外,据文献报道,麦角甾醇过氧化物具有抗癌活性、免疫抑制活性 (Fujimoto *et al.*, 1994)、抗炎 (Yasukawa *et al.*, 1994) 和促进血小板凝聚 (Lu *et al.*, 1994) 等作用。Koga *et al.* (1998) 发现脑苷脂 C 在水稻中对稻瘟病菌的识别和抵御稻瘟病菌的侵染发挥着关键的作用。Dong *et al.* (2005) 研究发现脑苷脂 C 对松材线虫的 LC_{50} 是 $110 \mu\text{g} \cdot \text{mL}^{-1}$ 。Cheung *et al.* (2000) 证实腺嘌呤核苷有很强的抑制血小板聚集的作用和镇静、抗缺氧及促进心肌组织摄取 86 Rb 的作用。

蛇足石杉内的活性成分主要为石松生物碱,本研究中尚未分离到与蛇足石杉化学成分相关的化合物。到目前为止研究蛇足石杉内生菌次级代谢产物的研究报道不多,本研究将为进一步发掘蛇足石杉内生菌中有益成分奠定基础。

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