

真菌 NBERC_49006 的次级代谢产物及其除草活性研究

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摘要:为明确除草活性真菌 NBERC_49006 中的活性物质基础, 对其次级代谢产物进行研究。通过对菌株大量发酵, 采用乙酸乙酯提取, 凝胶柱色谱和制备高效液相色谱分离纯化得到 7 个化合物, 并通过理化性质、LC-MS 及 NMR 鉴定为 trichothecin (1)、8-deoxy-trichothecin (2)、englermycenolic acid a (3)、englermycenolic acid b (4)、rosololactone (5)、rosenonolactone (6)、2 α -hydroxy-cis-communic acid (7)。其中, 化合物 3、4 和 7 首次从该菌株中得到, 而且化合物 7 是首次从微生物中得到。除草活性测试表明化合物 1 和 2 对拟南芥具有较强的除草活性, LC₅₀ 值分别为 9.30 和 28.98 $\mu\text{g}/\text{mL}$ 。该研究可为真菌源除草先导化合物的发现提供良好的研究基础。

关键词: 粉红单端孢菌; 次级代谢产物; trichothecin; 8-deoxy-trichothecin; 除草活性

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Secondary metabolites from fungus NBERC_49006 with herbicidal activity

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Abstract: In order to clarify the active substance basis of herbicidal fungus NBERC_49006, its secondary metabolites were studied. Seven compounds were isolated by large-scale fermentation, extraction, preparative HPLC and gel column chromatography. The structures were elucidated on the basis of spectral characteristics and identified as: trichothecin (1), 8-deoxy-trichothecin (2), englermycenolic acid A (3), englermycenolic acid B (4), rosololactone (5), rosenonolactone (6), 2 α -hydroxy-cis-communic acid (7). Among them, compounds 2, 4 and 7 were isolated from the strain for the first time, and compound 7 was obtained from microorganism for the first time. The results of bioassay test showed that compounds 1 and 2 had obvious herbicidal activity against *Arabidopsis thaliana* with the LC₅₀ value of 9.30 and 28.98 $\mu\text{g}/\text{mL}$, respectively. The results of this study can provide a good basis for the discovery of lead compounds with herbicidal activities from fungal.

Key words: *Trichothecium roseum*; secondary metabolites; trichothecin; 8-deoxy-trichothecin; herbicidal activity

自农业起源以来, 杂草一直是造成农作物减产的主要生物因素, 能够导致 30% ~ 90% 的作物产量损失^[1]。天然产物具有结构多样、环境友好等特点, 被认为是最具有前景的农药活性先导的来源^[2]。真菌能产生丰富的次生代谢产物, 从中发现了许多具有除草活性的天然化合物^[3]。如由病原真菌 *Phoma macrostoma* 产生的 Macrocidin A, 是一种吡咯酸化合物, 已经申请专利作为除草剂使用^[4]。从内脐蠕孢属真菌 *Drechslera australiensis* 的发酵液中得到 Holadysenterine, 试验研究表明其对

多种杂草的除草活性与合成除草剂 2,4-D 相当^[5]。从植物病原菌 *Cochliobolus australiensis* 中分离得到 Chloromonilinic acids C 和 D 能明显抑制美洲蒺藜草的胚根生长^[6]。

本课题组在真菌源农药活性天然产物的筛选过程中, 得到一株具有除草活性的真菌 NBERC_49006, 经鉴定为粉红单端孢菌 (*Trichothecium roseum*), 其乙酸乙酯提取物对拟南芥 (*Arabidopsis thaliana*) 表现出较好的除草活性。对菌株进行大量发酵、提取分离、结构鉴定, 得到 2 个倍半萜类化合物: trichothecin (1) 和 8-deoxy-trichothecin (2), 5 个二萜类化合物: englermycenolic acid A (3)、englermycenolic acid B (4)、rosololactone (5)、rosenonolactone (6)、2 α -hydroxy-cis-communic acid (7)。对 7 个化合

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物进行了除草活性测试,旨在发现具有除草活性的真菌源天然产物。

1 仪器与器材

1.1 菌种

菌株分离于湖北咸宁土壤(2015年12月采样),通过形态鉴定和18S rDNA 比对分析鉴定为粉红单端孢菌(*Trichothecium roseum*),现菌种保存于湖北省生物农药工程研究中心(编号为NBERC_49006)。

1.2 仪器与试剂

Bruker AVANCE(500 MHz;600MHz)核磁共振仪(TMS为内标, δ 为ppm, J 为Hz)(德国Bruker BioSpin公司);Waters 2695液质联用仪(美国Waters公司);Waters 2767高效液相制备仪(Waters 2525泵,带2767自动收集系统,2996二极管阵列检测器,色谱工作站Masslynx V4.0);色谱柱:Sunfire C₁₈ OBD制备柱(5 μ m,19 \times 250 mm/10 \times 250 mm,爱尔兰)、Welch Ultimate XB-Phenyl制备柱(3 μ m,10 \times 250 mm,中国)、Innoval ODS-2制备柱(5 μ m,10 \times 250 mm,中国);柱色谱Sephadex LH-20凝胶(GE Healthcare Bio-Sciences AB,瑞士)。提取分离用试剂乙酸乙酯和乙腈均为国药集团生产。

1.3 培养基

马铃薯葡萄糖琼脂培养基(PDA);发酵培养基:麦芽糖6.25 g/L,麦芽提取物6.25 g/L,酵母提取物1 g/L,蛋白胨0.625 g/L,磷酸二氢钾1.25 g/L,硫酸镁0.625 g/L。

2 实验方法

2.1 真菌发酵

将粉红单端孢菌斜面菌种接种于平皿中(PDA培养基)培养7天,再接入100瓶发酵培养基(200 mL/500 mL锥形瓶),在28 $^{\circ}$ C、120 rpm 振荡培养7天得发酵液。

2.2 发酵产物的提取与分离

大量发酵20 L的发酵液中加入等体积的乙酸乙酯搅拌提取3次,提取液过滤后真空浓缩得到提取物3.5 g。

将提取物用少量甲醇溶解,经Sephadex LH-20柱层析,用甲醇洗脱,洗脱组分通过HPLC检测合并为4段(A~D)。B(0.6 g)经制备色谱柱(Sunfire C₁₈ OBD制备柱,5 μ m,19 \times 250 mm,24 mL/min)进行分离,洗脱梯度为5~100%乙腈,洗脱40 min,得到10个组分(A1~A10),A3经重结晶得到化合物

1(32.6 mg),A4经制备HPLC(Innoval ODS-2制备柱,5 μ m,10 \times 250 mm,7.5 mL/min)进一步纯化得到化合物3(5.9 mg)和7(2.9 mg),A6经重结晶得到化合物6(3.2 mg),A7和A8经制备HPLC(Welch Ultimate XB-Phenyl制备柱,3 μ m,10 \times 250 mm,7.5 mL/min)进一步纯化分别得到化合物2(2.9 mg)和4(4.5 mg),A9经制备HPLC(Sunfire C₁₈ OBD制备柱,5 μ m,10 \times 250 mm,7.5 mL/min)得到化合物5(23.0 mg)。

2.3 分离成分除草活性测定

选取拟南芥和狗牙根(*Cynodon dactylon*)为杂草,拟南芥种子由本课题组微生物资源研究室提供,狗牙根种子为市售,已脱壳。拟南芥、脱壳狗牙根种子经除菌处理后以无菌水反复振荡、浸洗5次以上,移除积水,种子摊开置于无菌操作台中吹干,备用。把经过高压灭菌后的水琼脂加入96孔组织培养板(深孔),冷却后备用。把拟南芥、狗牙根种子分别转接到琼脂表面,接入种子量以单层种子全部覆盖水琼脂表面为准。样品以含0.1% Tween-80的无菌水溶解,测试拟南芥时样品浓度为10 μ g/mL,测试狗牙根时样品浓度为32 μ g/mL,空白对照为0.1% Tween-80的无菌水,重复2次^[7,8]。培养条件为:温度20 $^{\circ}$ C,相对湿度70%~80%,每天光照9 h,光照强度8000 lx。从第5天开始检查并记录活性,根据除草活性反应的不同,使用分级指标数(0、3、5、7、9)标记除草活性,0表示没有除草活性,株高与空白对照一致,3、5、7表示株高分别为空白对照的70%、50%以及30%,除草活性依次增强,9表示除草活性最强,种子没有发芽。

将样品及阳性对照硝磺草酮配制成浓度为1.00 mg/mL的母液,以含0.1% TW-80的无菌水对半稀释成12个不同浓度梯度,每个浓度设2个重复,重复试验3次,按上述同样方法进行培养,7天后检查并记录结果,计算LC₅₀。

3 实验结果

3.1 化合物结构鉴定

化合物1 白色粉末(CH₃OH);ESI-MS: m/z 333[M+H]⁺; ¹H NMR(CD₃OD,500 MHz) δ :6.55(1H, J =5.8,1.5 Hz,H-10),6.42(1H,dd, J =11.5,7.3 Hz,H-19),5.80(1H,dd, J =11.5,1.9 Hz,H-18),5.64(1H,dd, J =7.9,3.7,H-4),4.08(1H,d, J =5.8 Hz,H-11),3.87(1H,d, J =5.2 Hz,H-2),3.11(1H,d, J =4.0 Hz,H-13a),2.91(1H,

d , $J = 4.2$ Hz, H-13b), 2.87 (1H, d , $J = 1.5$ Hz, H-7a), 2.64 (1H, dd , $J = 15.6, 7.9$ Hz, H-3a), 2.27 (1H, dd , $J = 15.4, 1.5$ Hz, H-7b), 2.13 (3H, dd , $J = 7.3, 1.8$ Hz, CH₃-20), 2.04 (1H, ddd , $J = 15.6, 5.3, 3.7$ Hz, H-3b), 1.78 (3H, s , CH₃-16), 1.06 (1H, d , $J = 1.0$ Hz, CH₃-15), 0.71 (3H, s , CH₃-14); ¹³C NMR (CD₃OD, 125 MHz) δ : 200.8 (s , C-8), 167.5 (s , C-17), 147.2 (d , C-19), 139.5 (d , C-10), 138.7 (s , C-9), 121.2 (d , C-18), 80.9 (d , C-2), 75.0 (d , C-4), 71.3 (d , C-11), 66.7 (s , C-12), 49.5 (s , C-5), 48.2 (t , C-13), 44.8 (s , C-6), 43.1 (t , C-7), 37.7 (t , C-3), 18.7 (q , C-15), 15.3 (q , C-16), 15.7 (q , C-20), 6.1 (q , C-14)。以上数据与文献^[9]报道基本一致,故确定该化合物为 trichothecin。

化合物 2 白色粉末 (CH₃OH); ESI-MS: m/z 319 [M + H]⁺; ¹H NMR (CD₃OD, 500 MHz) δ : 6.40 (1H, dd , $J = 11.5, 7.3$ Hz, H-19), 5.81 (1H, dd , $J = 11.5, 1.8$ Hz, H-18), 5.63 (1H, dd , $J = 7.9, 3.6$ Hz, H-4), 5.40 (1H, dd , $J = 5.8, 1.5$ Hz, H-10), 3.86 (1H, d , $J = 5.2$ Hz, H-2), 3.64 (1H, d , $J = 5.8$ Hz, H-11), 3.12 (1H, d , $J = 4.0$ Hz, H-13a), 2.84 (1H, d , $J = 4.2$ Hz, H-13b), 2.58 (1H, dd , $J = 15.6, 7.8$ Hz, H-3a), 2.17 (3H, dd , $J = 7.3, 1.8$ Hz, CH₃-20), 1.89 ~ 2.05 (4H, m , H-3b, H-7a, H-8a, H-8b), 1.73 (3H, s , CH₃-16), 1.42 (1H, m , H-7b), 0.98 (3H, s , CH₃-15), 0.72 (3H, s , CH₃-14); ¹³C NMR (CD₃OD, 125 MHz) δ : 167.4 (s , C-17), 146.9 (d , C-19), 141.3 (s , C-9), 121.3 (d , C-18), 119.4 (d , C-10), 80.7 (d , C-2), 75.2 (d , C-4), 74.8 (d , C-11), 66.7 (s , C-12), 49.8 (s , C-5), 48.2 (t , C-13), 41.6 (s , C-6), 37.7 (t , C-3), 28.8 (t , C-8), 24.9 (t , C-7), 18.7 (q , C-15), 23.6 (q , C-16), 16.2 (q , C-20), 6.1 (q , C-14)。以上数据与文献^[10]报道基本一致,故确定该化合物为 8-deoxy-trichotecin。

化合物 3 白色粉末 (CH₃OH); ESI-MS: m/z 319 [M + H]⁺; ¹H NMR (CD₃OD, 500 MHz) δ : 5.65 (1H, dt , $J = 17.2, 9.8$ Hz, H-15), 5.12 (1H, dd , $J = 9.8, 2.2$ Hz, H-16a), 4.95 (1H, dd , $J = 17.2, 2.2$ Hz, H-16b), 4.63 (1H, brs , H-17a), 4.52 (1H, $br. s$, H-17b), 4.09 (1H, tt , $J = 11.5, 4.3$, H-2), 2.41 (1H, overlapped, H-12a), 2.37 (1H, overlapped, H-3a), 2.24 (1H, t , $J = 9.8$ Hz, H-14), 2.09 (1H, ddd , $J = 12.0, 4.3, 1.9$ Hz, H-1a), 2.02 (1H, overlapped,

H-12b), 1.98 (1H, overlapped, H-7a), 1.89 (1H, overlapped, H-11a), 1.87 (1H, overlapped, H-6a), 1.69 (1H, dq , $J = 13.4, 3.6$ Hz, H-6b), 1.24 (3H, s , CH₃-19), 1.13 (1H, overlapped, H-8), 1.11 (1H, overlapped, H-5), 1.09 (1H, overlapped, H-11b), 1.00 (1H, overlapped, H-9), 0.97 (1H, overlapped, H-3b), 0.89 (1H, overlapped, H-1b), 0.86 (1H, overlapped, H-7b), 0.76 (3H, s , CH₃-20); ¹³C NMR (CD₃OD, 125 MHz) δ : 181.2 (s , C-18), 152.5 (s , C-13), 141.3 (d , C-15), 116.9 (t , C-16), 106.8 (t , C-17), 65.4 (d , C-2), 56.7 (d , C-5), 56.1 (d , C-14), 55.9 (d , C-9), 49.4 (t , C-1), 47.7 (t , C-3), 46.0 (t , C-4), 42.9 (d , C-8), 40.1 (s , C-10), 37.1 (t , C-12), 35.4 (t , C-7), 29.5 (q , C-19), 28.2 (t , C-11), 24.3 (t , C-6), 14.4 (q , C-20)。以上数据与文献^[11]报道基本一致,故确定该化合物为 engleromycenolic acid A。

化合物 4 白色粉末 (CH₃OH); ESI-MS: m/z 317 [M - H]⁻; ¹H NMR (CD₃OD, 600 MHz) δ : 5.83 (1H, dd , $J = 15.0, 9.3$ Hz, H-15), 4.93 (1H, dd , $J = 15.0, 0.8$ Hz, H-16a), 4.84 (1H, dd , $J = 9.3, 0.8$ Hz, H-16b), 3.91 (1H, m , H-2), 2.38 (1H, dd , $J = 13.8, 3.2$ Hz, H-1a), 2.19 (1H, overlapped, H-3a), 2.18 (1H, overlapped, H-6a), 1.93 (1H, dd , $J = 14.6, 4.9$ Hz, H-6b), 1.82 (1H, m , H-1b), 1.65 (1H, m , H-11a), 1.60 (1H, m , H-8), 1.59 (1H, overlapped, H-12a), 1.47 (1H, overlapped, H-7a), 1.45 (1H, overlapped, H-14a), 1.39 (1H, overlapped, H-3b), 1.36 (1H, overlapped, H-11b), 1.31 (1H, overlapped, H-7b), 1.30 (1H, overlapped, H-12b), 1.27 (3H, s , CH₃-19), 1.10 (1H, dt , $J = 11.5, 2.1$ Hz, H-14b), 1.04 (3H, s , CH₃-17), 0.94 (3H, s , CH₃-20); ¹³C NMR (CD₃OD, 150 MHz) δ : 181.0 (s , C-18), 152.4 (d , C-15), 138.8 (s , C-10), 129.7 (s , C-5), 109.4 (t , C-16), 66.4 (d , C-2), 50.0 (s , C-4), 46.0 (t , C-3), 40.6 (t , C-14), 39.1 (d , C-8), 38.9 (s , C-9), 37.3 (s , C-13), 35.6 (t , C-1), 33.7 (t , C-12), 32.8 (t , C-11), 28.3 (t , C-6), 26.7 (t , C-7), 25.5 (q , C-19), 23.7 (q , C-17), 16.9 (q , C-20)。以上数据与文献^[11]报道基本一致,故确定该化合物为 engleromycenolic acid B。

化合物 5 白色粉末 (CH₃OH); ESI-MS: m/z 319 [M + H]⁺; ¹H NMR (CD₃OD, 600 MHz) δ : 5.82

(1H, dd, $J = 15, 9.3$ Hz, H-15), 4.93 (1H, dd, $J = 15$ Hz, H-16a), 4.85 (1H, dd, $J = 9.3$ Hz, H-16b), 4.09 (1H, dd, $J = 7.3, 3.2$ Hz, H-6), 2.10 (1H, dd, $J = 11.7, 5.1$ Hz, H-7a), 1.88 (1H, d, $J = 3.2$ Hz, H-5), 1.86 (1H, dd, $J = 11.7, 4.8$ Hz, H-7b), 1.26 (3H, s, CH₃-20), 1.23 (3H, s, CH₃-17), 1.02 (3H, s, CH₃-18); ¹³C NMR (CD₃OD, 150 MHz) δ : 184.6 (s, C-19), 152.5 (d, C-15), 109.6 (t, C-16), 90.4 (s, C-10), 63.8 (d, C-6), 56.6 (d, C-5), 47.3 (s, C-4), 41.5 (t, C-14), 39.2 (s, C-9), 37.4 (s, C-13), 37.3 (t, C-3), 33.7 (t, C-12), 33.2 (d, C-8), 33.2 (t, C-1), 32.0 (t, C-11), 23.0 (q, CH₃-17), 21.3 (t, C-2), 17.2 (q, CH₃-18), 14.2 (q, CH₃-20)。以上数据与文献^[12]报道基本一致,故确定该化合物为 rosolactone。

化合物 6 白色粉末 (CH₃OH); ESI-MS: m/z 317 [M + H]⁺; ¹H NMR ((CD₃)₂CO, 600 MHz) δ : 5.88 (1H, dd, $J = 15, 9.2$ Hz, H-15), 4.99 (1H, dd, $J = 15, 1.0$ Hz, H-16a), 4.89 (1H, dd, $J = 9.2, 1.0$ Hz, H-16b), 2.68 (1H, dd, $J = 10.3, 3.7$ Hz, H-8), 2.59 (1H, dd, $J = 12.1, 4.4$ Hz, H-5), 2.36 (1H, dd, $J = 16.0, 4.4$ Hz, H-6a), 2.12 (1H, dd, $J = 16.0, 12.1$ Hz, H-6b), 1.07 (3H, s, CH₃-18), 1.01 (3H, s, CH₃-17), 0.90 (3H, s, CH₃-20); ¹³C NMR ((CD₃)₂CO, 150 MHz) δ : 210.6 (s, C-7), 179.9 (s, C-19), 151.7 (d, C-15), 110.4 (t, C-16), 88.0 (s, C-10), 51.4 (d, C-5), 48.3 (s, C-8), 48.0 (s, C-4), 40.0 (s, C-9), 36.8 (t, C-6), 36.6 (t, C-3),

36.4 (s, C-13), 33.4 (t, C-14), 32.8 (t, C-12), 32.0 (t, C-11), 31.2 (t, C-1), 22.5 (q, CH₃-17), 21.3 (t, C-2), 17.8 (q, CH₃-18), 17.6 (q, CH₃-20)。以上数据与文献^[13]报道基本一致,故确定该化合物为 rosenonolactone。

化合物 7 白色粉末 (CH₃OH); ESI-MS: m/z 317 [M-H]⁻; ¹H NMR (CD₃OD, 500 MHz) δ : 6.83 (1H, dd, $J = 17.3, 10.9$ Hz, H-14), 5.32 (1H, t, $J = 6.6$ Hz, H-12), 5.19 (1H, d, $J = 10.9$ Hz, H-15a), 5.09 (1H, d, $J = 10.9$ Hz, H-15b), 4.89 (1H, s, H-17a), 4.51 (1H, s, H-17b), 4.14 (1H, m, H-2), 2.48 (1H, dd, $J = 15.6, 6.2$ Hz, H-11a), 2.41 (1H, overlapped, H-1a), 2.38 (1H, overlapped, H-7a), 2.24 (1H, m, H-11b), 2.16 (1H, m, H-3a), 1.99 (1H, overlapped, H-6a), 1.97 (1H, overlapped, H-7b), 1.84 (1H, m, H-6b), 1.80 (1H, m, H-9), 1.76 (3H, s, CH₃-16), 1.35 (1H, dd, $J = 12.2, 2.8$ Hz, H-5), 1.27 (3H, s, CH₃-18), 1.07 (1H, m, H-3b), 1.03 (1H, m, H-1b), 0.70 (3H, s, CH₃-20); ¹³C NMR (CD₃OD, 125 MHz) δ : 181.1 (s, C-19), 149.0 (s, C-8), 135.0 (d, C-14), 133.0 (s, C-13), 132.3 (d, C-12), 113.7 (t, C-15), 108.7 (t, C-17), 65.6 (d, C-2), 58.2 (d, C-9), 56.8 (d, C-5), 49.2 (t, C-3), 47.7 (t, C-1), 46.2 (s, C-4), 42.4 (s, C-10), 39.5 (t, C-7), 29.6 (q, CH₃-18), 26.9 (t, C-6), 23.5 (t, C-11), 20.0 (q, CH₃-16), 14.3 (q, CH₃-20)。以上数据与文献^[14]报道基本一致,故确定该化合物为 2 α -hydroxy-cis-communic acid。

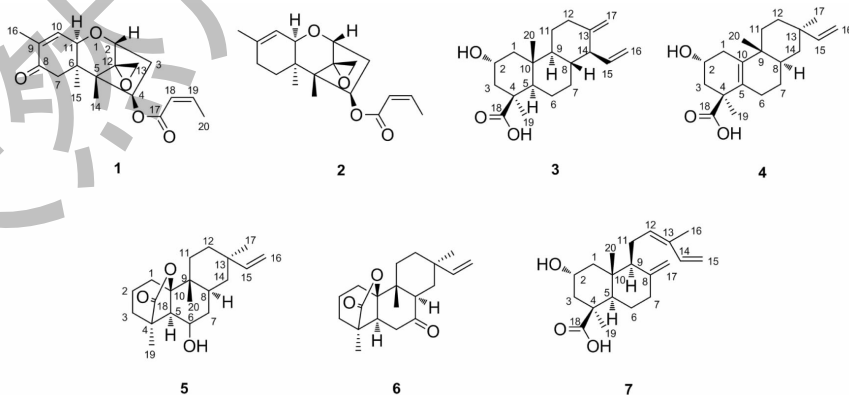


图 1 化合物 1~7 的化学结构

Fig. 1 The chemical structures of compounds 1-7

3.2 除草活性

除草活性测试结果表明化合物 1 对拟南芥具有

较强的除草活性,化合物 2 对拟南芥具有中等除草活性(表 1),LC₅₀值分别为 9.30 和 28.98 $\mu\text{g/mL}$ (表 2)。

表 1 化合物 1~7 的除草活性测试结果

Table 1 Herbicidal activities of compounds 1-7

化合物 Compound	拟南芥 <i>Arabidopsis thaliana</i>	狗牙根 <i>Cynodon dactylon</i>
1	9	0
2	5	0
3	0	0
4	0	0
5	0	0
6	0	0
7	0	0

注:化合物对拟南芥和狗牙根的测试浓度分别为 10 $\mu\text{g}/\text{mL}$ 和 32 $\mu\text{g}/\text{mL}$ 。

Note: For herbicidal tests, *Arabidopsis thaliana* at 10 $\mu\text{g}/\text{mL}$ and *Cynodon dactylon* at 32 $\mu\text{g}/\text{mL}$.

表 2 化合物 1 和 2 对拟南芥的除草活性

Table 2 Herbicidal activities of compounds 1 and 2 against *Arabidopsis thaliana*

化合物 Compound	LC ₅₀ ($\mu\text{g}/\text{mL}$)
1	9.30 \pm 2.03
2	28.98 \pm 4.86
硝磺草酮 Mesotrione	0.30 \pm 0.07

注:硝磺草酮为阳性对照。

Note: Mesotrione as positive control.

4 结论

粉红单端孢菌是一种内生真菌,其主要次生代谢产物包括单端孢霉烯类(trichotecenes)和强心环肽类(cyclodepsipeptides)化合物。其中单端孢霉烯是一类含有三元环氧结构的三环倍半萜,主要生物活性是抗肿瘤、抗菌^[12,15,16];而强心环肽是一类环缩肽类化合物,具有免疫抑制作用^[17,18]。

本课题组发现粉红单端孢菌的乙酸乙酯提取物具有除草活性,并从提取物中分离纯化得到 7 个化合物,除了单端孢霉烯类化合物 1 和 2 以外,还有 5 个二萜类化合物 3~7,其中化合物 3 为闭木花烷(cleistanthane)型二萜,化合物 4~6 为玫瑰烷(rosane)型二萜,且 3 和 4 首次从粉红单端孢菌中得到,化合物 7 则为半日花烷(labdane)型二萜,首次从微生物中得到。除草活性测试表明化合物 1 和 2 对拟南芥有较好的除草活性,说明粉红单端孢菌中的除草活性物质为单端孢霉烯类化合物,而该类化合物除草作用未见文献报道,因此,可对其进行除草方面的进一步研究,为真菌源除草先导的发现提供良好的研究基础。

参考文献

- Quareshy M, Prusinska J, Li J, et al. A cheminformatics review of auxins as herbicides[J]. J Exp Bot, 2018, 69:265-275.
- Cao LL, Yan W, Gu CG, et al. New alkylitaconic acid derivatives from *Nodulisporium sp.* A21 and their auxin herbicidal activities on weed seeds[J]. J Agric Food Chem, 2019, 67:2811-2817.
- Cimmino A, Masi M, Evidente M, et al. Fungal phytotoxins with potential herbicidal activity: chemical and biological characterization[J]. Nat Prod Rep, 2015, 32:1629-1653.
- Graupner PR, Carr A, Clancy E, et al. The macrocidins: novel cyclic tetramic acids with herbicidal activity produced by *Phoma macrostoma*[J]. J Nat Prod, 2003, 66:1558-1561.
- Akbar M, Javaid A, Ahmed E, et al. Holadysenterine, a natural herbicidal constituent from *Drechslera australiensis* for management of *Rumex dentatus* [J]. J Agric Food Chem, 2014, 62:368-372.
- Masi M, Meyer S, Clement S, et al. Chloromonilinic acids C and D, phytotoxic tetrasubstituted 3-chromanonacrylic acids isolated from *Cochliobolus australiensis* with potential herbicidal activity against buffelgrass (*Cenchrus ciliaris*) [J]. J Nat Prod, 2017, 80:2771-2777.
- Zhao HP, Liu YX, Cui ZP, et al. Design, synthesis, and biological activities of arylmethylamine substituted chlorotriazine and methylthiotriazine compounds[J]. J Agric Food Chem, 2011, 59:11711-11717.
- Kang M, Guo DL, Hu J, et al. Chemical constituents in the broth of *Myrothecium verrucaria* with agrochemical activities [J]. Nat Prod Res Dev (天然产物研究与开发), 2015, 27:1892-1899.
- Ravindra T, Prasad A, Deepak P, et al. Trichothecin from endophytic fungus *Trichothecium sp.* and its anticancer effect on murine melanoma and breast cancer cell lines[J]. Curr Biochem Eng, 2015, 2:73-80.
- Chinworrungsee M, Wiyakrutta S, Sriubolmas N, et al. Cytotoxic activities of trichothecenes isolated from an endophytic fungus belonging to order hypocreales [J]. Arch Pharmacol Res, 2008, 31:611-616.
- Wang Y, Zhang L, Wang F, et al. New diterpenes from cultures of the fungus *Engleromyces goetzii* and their CETP inhibitory activity[J]. Nat Prod Bioprospect, 2015, 5:69-75.
- Zhou L, Qin J, Ma L, et al. Rosoloactone: a natural diterpenoid inducing apoptosis in human cervical cancer cells through endoplasmic reticulum stress and mitochondrial damage[J]. Biomed Pharmacother, 2017, 95:355-362.