RESEARCH ARTICLE

Pyrophen Produced by Endophytic Fungi Aspergillus sp Isolated from Piper crocatum Ruiz & Pav Exhibits Cytotoxic Activity and Induces S Phase Arrest in T47D Breast Cancer Cells

Puji Astuti¹*, Willy Erden², Wahyono¹, Subagus Wahyuono¹, Triana Hertiani¹

Abstract

Ethyl acetate extracts obtained from culture of endophytic fungi Aspergillus sp isolated from Piper crocatum Ruiz & Pav, have been shown to possess cytotoxic activity against T47D breast cancer cells. Investigations were here conducted to determine bioactive compounds responsible for the activity. Bioassay guided fractionation was employed to obtain active compounds. Structure elucidation was performed based on analysis of LC-MS, ¹H-NMR, ¹³C-NMR, COSY, DEPT, HMQC, HMBC data. Cytotoxicity assays were conducted in 96 well plates against T47D and Vero cell lines. Bioassay guided isolation and chemical investigation led to the isolation of pyrophen, a 4-methoxy-6-(1'-acetamido-2'-phenylethyl)-2H-pyran-2-one. Further analysis of its activity against T47D and Vero cells showed an ability to inhibit the growth of T47D cells with IC₅₀ values of 9.2 µg/mL but less cytotoxicity to Vero cells with an IC₅₀ of 109 µg/mL. This compound at a concentration of 400 ng/mL induced S-phase arrest in T47D cells.

Keywords: Aspergillus sp - cytotoxic - T47D - pyrophen - S - phase arrest

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Introduction

Breast cancer is the major cause of death from cancer in women with about 508000 women was estimated died from this disease in 2011 (IARC, 2012; WHO, 2013). The high incidence in developed countries is also occurring in developing countries and the number is increasing due to in part the increase in life expectancy and changes in lifestyles. In addition, the lack of early detection program and inadequate diagnosis and medical facilities result in low survival rates (IARC, 2008). Despite this huge global health problem, the available conventional chemotherapeutic agents possess side effects to normal cells. Therefore, there is an urgent need to discover and develop new compounds to treat breast cancer.

Exploration of endophytic fungi have gained increased interest among scientist as these microorganisms produce biologically-active compounds with therapeutic values (Zhao et al., 2009; Santiago et al., 2012; do Nascimento et al., 2015; Richardson et al., 2015). Many of the compounds have been reported to produce bioactive compounds against various types of cancer cell lines (Chui et al., 2011; Zheng et al., 2013; Zhu et al., 2013; Chen et al., 2015; Wang et al., 2015). Previous studies in our laboratory demonstrated that ethyl acetate extract obtained from the culture of Aspergillus sp isolated from the stem of

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50
4
6
2
Values and Selectivity Index of Fractions Generated from Ethyl Acetate Extract

Table 1. IC$_{50}$ Values and Selectivity Index of Fractions Generated from Ethyl Acetate Extract

<table>
<thead>
<tr>
<th>Fractions</th>
<th>F1</th>
<th>F2</th>
<th>F3</th>
<th>F4</th>
<th>F5</th>
</tr>
</thead>
<tbody>
<tr>
<td>IC$_{50}$ (µg/mL) against T47D cells</td>
<td>142.9</td>
<td>82.6</td>
<td>6.9</td>
<td>9.2</td>
<td>48.4</td>
</tr>
<tr>
<td>IC$_{50}$ (µg/mL) against Vero cells</td>
<td>439.5</td>
<td>308.4</td>
<td>53.8</td>
<td>109</td>
<td>338.8</td>
</tr>
<tr>
<td>Selectivity Index</td>
<td>3.1</td>
<td>3.7</td>
<td>7.8</td>
<td>11.8</td>
<td>7.0</td>
</tr>
</tbody>
</table>

Bioassay guided isolation of cytotoxic compound

Ethyl acetate extract was partitioned using preparative thin layer chromatography (stationary phase=silica gel 60 PF$_{254}$; mobile phase=ethyl acetate: methanol=9:1) to obtain five fractions to be tested for cytotoxic activities. The most cytotoxic fraction with the highest score of selectivity index was further purified using preparative thin layer chromatography (stationary phase: silica gel 60 PF$_{254}$; mobile phase: ethyl acetate: n-hexane=9:1) to obtain bioactive compounds.

Cytotoxic activity

T47D (Human ductal breast epithelial tumor cell line) and Vero (cell line) were cultured in RPMI 1640 supplemented with 10% heat inactivated fetal bovine serum (FBS), 1% penicillin/streptomycin and 1 µg/mL fungizone. The cultures were incubated in a humidified incubator at 37°C with 5% CO$_2$. A hundred µl of media containing 5x10$^4$ cells was added to 96-well plate and incubated for 48 hours until 70% - 80% confluent. Extracts or isolates were added to the wells at various concentrations for 4 hours at 37°C and the reaction was stopped by adding 100 µl of 10% SDS. The plates were read in microplate reader (Bio-Rad) at 595 nm. Data generated were used to plot a dose-response curve of which the concentration of fractions/isolates required to kill 50% of cell population (IC$_{50}$) was determined. Selectivity index was calculated by dividing IC$_{50}$ values of fractions/isolates against T47D cells towards IC$_{50}$ values of fractions/compounds against normal Vero cells.

Cell cycle analysis

Three mL of media containing 5x10$^4$ T47D cells were inoculated in six well plates and incubated for 24 hours prior to treatment with bioactive compound. The cells were treated with various concentrations of bioactive compound and further incubated for 16 hours. The cells were harvested and re-suspended in PBS containing 50 µg/mL propidium iodide and ready for cell cycle distribution analysis using flow cytometer BD FACSCaliburTM (BD Biosciences).

Structure elucidation of cytotoxic compound

Structure elucidation was conducted based on analysis of LC-MS, 1H-NMR, 13C-NMR, COSY, DEPT, HMBC, HMBC data. Phyrophen: white crystalline powder; ESI-MS m/z 288.2834 [M+H]+ (calcd for C$_{16}$H$_{17}$NO$_4$, 288.2834); 1 H and 13C NMR in DMSO-d6, see Table 2.

Results

Bioassay guided isolation and bioactivity testing

Ethyl acetate extract was partitioned by preparative thin layer chromatography to obtain five fractions. These fractions were tested for cytotoxicity against T47D and Vero cells. Among five fractions tested fraction 4 was found to have the highest selectivity index (Table 1). This fraction contains a bioactive compound having 95.97% purity as determined by Liquid Chromatography (Figure 1). This compound exhibited IC$_{50}$ of 9.2 µg/mL against T47D and IC$_{50}$ of 109.0 µg/mL against normal Vero cells. Further cell cycle analysis demonstrated that this compound induced S-phase arrest when it was administered at 400 ng/mL (Figure 2).

Structure elucidation of the cytotoxic compound

LC-MS peak of isolate appeared at T$_{R}$ 3.24 min having a 95.97% of purity. Molecular weight of 287 amu was revealed by analysing a pseudomolecular ion peak at m/z 288.2834 having a 100% abundance referred to [M+H]+, which is confirmed by the presences of peaks of [M+Na]+ at m/z 310.2870; [2M+H]+ at m/z 575.6121 and [2M+Na]+ at 597.6084.

1H-NMR data showed that the isolate contains at least 17 protons distributed from the most upfield region at δ 1.78 (3H, s) referred to a -CH$_3$ having an electron-withdrawing neighbour, up to the most down field proton, at δ 8.49 (1H, d, J=8.4 Hz). Evaluation of splitting pattern and coupling constants suggests two isolated substructures which is confirmed by the 1H-1H COSY measurement, i.e.: -CH$_2$-CH-NH- and a monosubstituted benzene.

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</tr>
</tbody>
</table>

Figure 1. Liquid Chromatography Profiles of Fraction 4 Containing Bioactive Compound. Volume of injection 20 µl, Flow 1 mL/min, Eluent MeOH + water = 95 + 6
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**Table 2. NMR data of Isolate measured by ¹H-NMR and ¹³C-NMR in DMSO-δ₆ (500 MHz)**

<table>
<thead>
<tr>
<th>Atom No.</th>
<th>δ C (ppm), DEPT</th>
<th>δ H (ppm), splitting pattern and J value (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>22.41, CH₃</td>
<td>1.78, 3H, s</td>
</tr>
<tr>
<td>1</td>
<td>169.03, C=O</td>
<td>-</td>
</tr>
<tr>
<td>NH</td>
<td>-</td>
<td>8.49, 1H, d, 8.4</td>
</tr>
<tr>
<td>α</td>
<td>52.98, CH</td>
<td>4.76, 1H, δδδ, 5.8, 9.1, 8.4</td>
</tr>
<tr>
<td>δ α</td>
<td>37.85, CH₂</td>
<td>2.89, 1H, δδδ, 13.7, 9.1</td>
</tr>
<tr>
<td>δ δ</td>
<td>-</td>
<td>3.01, 1H, δδδ, 13.7, 5.8</td>
</tr>
<tr>
<td>2'</td>
<td>163.78, C=O</td>
<td>-</td>
</tr>
<tr>
<td>5'</td>
<td>88.01, CH</td>
<td>5.57, 1H, d, 2.6</td>
</tr>
<tr>
<td>4'</td>
<td>170.77, C=O</td>
<td>-</td>
</tr>
<tr>
<td>3'</td>
<td>99.40, CH</td>
<td>6.05, 1H, d, 1.9</td>
</tr>
<tr>
<td>2''</td>
<td>163.21, O-C=C-</td>
<td>-</td>
</tr>
<tr>
<td>OCH₃</td>
<td>56.48, CH₃</td>
<td>3.78, 3H, s</td>
</tr>
<tr>
<td>2'', 6''</td>
<td>128.29, -CH=</td>
<td>7.22, 2H, d, 7.1</td>
</tr>
<tr>
<td>3'', 5''</td>
<td>129.05, -CH=</td>
<td>7.27, t, 7.1</td>
</tr>
<tr>
<td>4''</td>
<td>126.57, -CH=</td>
<td>7.18, d, 7.1</td>
</tr>
<tr>
<td>1''</td>
<td>137.27, C</td>
<td>-</td>
</tr>
</tbody>
</table>

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**Figure 2. Cell Cycle Distribution of T47D Cells without (A) and Treated with 400 ng/mL of Bioactive Compound (B).** T47D cells were inoculated in 6 well plate followed by 16h incubation with and without bioactive compound in humidified incubator at 37°C, 5% CO₂. The cells were analysis for cell cycle distribution by flow cytometry.

1³C-NMR resolved 14 carbon resonance peaks of which DEPT analyses revealed the presence of 1 secondary carbon at δ 37.85; 5 quartenary carbons at δ 170.77; 169.08; 163.78; and 163.21. ¹H-¹³C HMQC analyses distinguished 2 CH₃s at δ 22.41 and 56.48, while the rest 6 peaks reffered to CHs. Each peak at δ 129.06 and 128.30 represents the presence of 2 CHs having identical environment. These peaks together with a CH peak at δ 126.58 and δ 137.27 suggested the carbon resonances of a monosubstituted benzene. The presence of -CH₂-CH-NH- was confirmed by the ¹H-¹³C HMBC analyses, which at the same time proposed the substructure as shown in Figure 3.

Different effect of the protons environment of the CH₂ resulted two adjacent peaks at δ 2.89 (1H, dd, J=13.7, 9.1 Hz) and 3.01 (1H, dd, J=5.8, 13.7 Hz). A coupling constant value of 13.7 Hz corresponds to a geminal coupling of the CH₂, while a value of 5.8 Hz corresponds to a 3J trans coupling and 9.1 to a 3J cis coupling with the adjacent neighbour at δ 4.76 (1H, ddd, J=5.8, 9.1, 8.4 Hz) confirmed the proposed relative stereochemistry (Figure 3). The COSY correlate to the next proton at δ 8.49 of which both shares a coupling constant value of 8.4 Hz. This finding is in accordance to a presence of an amide moiety adjacent to a tertiary carbon as is also supported by the C13-NMR data and HMBC correlation. Further analyses of the COSY data reveals a present of two isolated neighboring proton having δ 5.57 (1H, d, J=2.6 Hz) and δ 6.05 (1H, d, J=1.9 Hz). A small coupling constant with the neighboring proton (J=1.9 Hz) suggesting that both protons are not directly attached to each other. The HMBC data correlate the protons with a quartenary carbon at δ 170.77 which is also seen by an isolated proton at δ 3.78 (3H, s). This isolated proton is in accordance to a resonance of a methoxy group by having a deshielded singlet peak having integration of 63. A full structure proposed to the compounds confirmed a molecular formula of C16H17NO4 which is fit to a 4-methoxy-6-(1’-acetamido-2’-phenylethyl)-2H-pyran-2-one, known as

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**Figure 3. Important HMBC and COSY data confirming the chemical structure of the isolate. ¹H-¹³C HMBC → ¹H-¹H COSY**

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**Figure 4. Important HMBC and COSY data confirming the chemical structure of the isolate. ¹H-¹³C HMBC → ¹H-¹H COSY**
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pyrophen (Figure 4).

Discussion

Pyrophen is an amino acid-pyrene derivative firstly isolated from Aspergillus niger on maize with the crystal configuration was reported in 1990 (Barnes et al., 1990). The spectroscopic data of this compound was published in 2000 (Varoglu and Crews, 2000), which is in accordance to the spectroscopic data of the bioactive compound isolated from this study. However a comparison of the spectral data reveal a huge shift of the signal of the NH-amide to the downfielded region. As already accepted for an exchangeable proton such as NH, unpredictable chemical shift could occurs, especially in the case of different solvent used. Pyrophen was also reported from a saltwater culture of A. niger isolated from a sponge Hyrtios proteus (Varoglu and Crews, 2000), the culture extract of A. niger EN-13 isolated from the inner tissue of the marine brown alga Colpomenia sinuosa, (Zhang et al., 2010) as well as the culture of Alternaria alternata strain D2006, isolated from the marine soft coral Dendronephthya hemprichi (Shaaban et al., 2012). It was interesting to note that Zhang and collaborators can separate pyrophen from its stereoisomer, isopyrophen, which was obtained from A. niger cultured on yellow maize. The compounds are different at the configuration of Cα as the chiral centre. Nevertheless, unlike pyrophen, Zhang et al (2010) described that the isopyrophen has planar structure, which was not the case for our compound.

In terms of bioactivities, pyrophen was reported to have no antimicrobial activities against Escherichia coli, Staphlococcus aureus, Candida albicans, and A. niger (Zhang et al., 2010) and no activities against several cancer cell lines (Varoglu and Crews, 2000). However, this compound was found to be active against C. albicans (Shaaban et al., 2012). This discrepancy might be resulted from the difference on the concentration used during their studies. In this study we found that pyrophen exhibited cytotoxicity against T47D cells. Cycle cycle analysis of T47D cells exposed with this compound at 400 ng/mL resulted in increased S phase cell population. Indeed, S phase arrest is one of mechanisms delaying progression of cell cycle in response to homeostatic regulators or DNA damage and this involves the decrease rate in DNA replication (Kaufmann and Kaufman, 1993). Further examination of its potential as anticancer agent is still under investigation.

In conclusion, these data suggest the potential activity of a phenethyl-α-pyrene derivative, pyrophen as anticancer agent. Further investigation on the mechanism on how this compound kills the cancer cells need to be explored.

Acknowledgements

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References