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Antibacterial activity of cyclo(L-Pro-L-Tyr) and cyclo(D-Pro-L-Tyr) from Streptomyces sp. strain 22-4 against phytopathogenic bacteria

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Antibacterial activity of cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) from Streptomyces sp. strain 22-4 against phytopathogenic bacteria

Two bioactive cyclic dipeptides, cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr), were isolated from the culture broth of Streptomyces sp. strain 22-4 and tested against three economically important plant pathogens, Xanthomonas axonopodis pv. citri, Ralstonia solanacearum and Clavibacter michiganensis. Both cyclic dipeptides were active against X. axonopodis pv. citri and R. Solanacearum with MIC of 31.25 µg/mL. No activity could be observed against C. michiganensis.

Keywords: cyclo(l-Pro-l-Tyr); cyclo(d-Pro-l-Tyr); Streptomyces; phytopathogenic bacteria

1. Introduction

Screening for bioactive compounds from natural resources to use for medical and agricultural purposes is one of the major goals in medicinal chemistry. One of the major sources of these compounds is Streptomyces, a large genus bacteria that produce a vast diversity of secondary metabolites (Lucas et al. 2013) including cyclic dipeptides (Zhou et al. 2014). This class of metabolites contains a diketopiperazine core built with D and L amino acids, that displays a broad spectrum of biological activities including antimicrobial activity (Martins and Carvalho 2007).

Two promising cyclic dipeptides exhibiting potent antimicrobial activity are based on the cyclo(l-Pro-l-Tyr) (A) and cyclo(d-Pro-l-Tyr) (B) scaffolds (Figure 1). To date only the cyclo(l-Pro-l-Tyr) has been isolated from Streptomyces and here we report the isolation and molecular characterisation of both diastereomers produced by Streptomyces sp. strain 22-4. Furthermore, we also report the first antibacterial studies of both cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) against three economically important phytopathogenic bacteria.

2. Results and discussion

2.1 Isolation and structure determination of cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr)

From the culture broth of S. sp. strain 22-4, a mixture containing cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) was isolated. Separation of cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) proved to be difficult by HPLC as both diastereoisomers eluted at 25% MeOH/H2O. However, their structures were elucidated by HR-MS (Figure S1) and NMR (Figure S2-S7) in combination with Marfey’s method (Figure S8). The structures were further confirmed by
comparison with the $^1$H spectra of synthetic standards (Figure S2). To our knowledge this is the first time that both compounds have been isolated from $S$. sp strain 22-4. As several cyclic dipeptides have been previously reported from production broths (Prasad 1995), medium alone was extracted and carefully investigated by HPLC to confirm that neither cyclo(l-Pro-l-Tyr) or cyclo(d-Pro-l-Tyr) were present.

2.2 Antibacterial activity against plant pathogenic bacteria

Previously, both cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) has been isolated from several micro-organisms including Haloterrigena hispanica and Bacillus sp. N strain 22-4. As several cyclic dipeptides have been previously reported from production broths (Prasad 1995), medium alone was extracted and carefully investigated by HPLC to confirm that neither cyclo(l-Pro-l-Tyr) or cyclo(d-Pro-l-Tyr) were present.

To our knowledge, this is the first time that both compounds have been isolated from $S$. sp strain 22-4. As several cyclic dipeptides have been previously reported from production broths (Prasad 1995), medium alone was extracted and carefully investigated by HPLC to confirm that neither cyclo(l-Pro-l-Tyr) or cyclo(d-Pro-l-Tyr) were present.

To the best of our knowledge, this is the first time that both compounds have been isolated from Streptomyces. Due to the antimicrobial activity of both cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr), this led us to assess the biological activity on untested phytopathogenic bacteria. Bacterial wilt and canker in particular are important diseases in commercial crop plants, causing significant economic losses worldwide. In this work, both cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) were tested against X. axonopodis pv. citri, R. solanacearum and C. michiganensis. X. axonopodis pv. citri is an extremely persistent causative agent of bacterial canker in citrus (Brunings and Gabriel 2003) whilst R. solanacearum and C. michiganensis cause bacterial wilt in plants of the Solanaceae family (Gleason et al. 1993, Hayward 1991).

Both compounds exhibited activity against X. axonopodis pv. citri and R. solanacearum, albeit weak (MIC 31.25 µg/mL) when compared to standard antibacterial agents (Table 1). No antibacterial activity was observed against C. michiganensis even at relatively high concentrations (up to 500 µg/mL).

Although there is currently a small trade-off with potency, the broad spectrum of antimicrobial activity of cyclo(l-Pro-l-Tyr) and cyclo(d-Pro-l-Tyr) however means these compounds may have potential for use as agricultural biocontrol agents. This can be seen from a chitinase producing Streptomyces glauciniger WICC-A03 (Awad et al. 2014) or a related compound, cyclo(4-hydroxy-l-Pro-l-Trp) which has already been deployed as a non-toxic biopreservative agent to inhibit the growth of A. flavus and A. niger on peanut kernels (Kumar et al. 2014). With further toxicity testing and structure modification to improve the biological activity of cyclo(Pro-Tyr), this cyclic dipeptide may be a promising biocontrol agent for use in the agricultural industry.

3. Experimental
Experimental information is provided in Supplementary material.

4. Conclusion

This is the first time that both cyclo(L-Pro-L-Tyr) and cyclo(D-Pro-L-Tyr) were isolated from Streptomyces sp. strain 22-4 and we are the first to show their antibacterial activity against economically phytopathogenic bacteria X. axonopodis pv. citri and R. Solanacearum. With the use of toxic chemicals in agricultural industry to prevent the crop damage, the use of cyclic dipeptides as biological control agents may provide a sustainable approach to improve the crop quality without damaging the environment or human health.

Acknowledgement

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References


Table 1. Antibacterial activity of cyclo(l-Pro- l-Tyr) and cyclo(d-Pro- l-Tyr)

<table>
<thead>
<tr>
<th>Compound</th>
<th>Test bacteria with MIC (µg/mL)</th>
<th>X. axonopodis pv. citri</th>
<th>R. solanacearum</th>
</tr>
</thead>
<tbody>
<tr>
<td>cyclo(l-Pro- l-Tyr)</td>
<td></td>
<td>31.25</td>
<td>31.25</td>
</tr>
<tr>
<td>cyclo(d-Pro- l-Tyr)</td>
<td></td>
<td>31.25</td>
<td>31.25</td>
</tr>
<tr>
<td>chlortetracycline</td>
<td></td>
<td>0.12</td>
<td>-</td>
</tr>
<tr>
<td>streptomycin sulfate</td>
<td></td>
<td>-</td>
<td>3.91</td>
</tr>
</tbody>
</table>

Figure 1. Structures of (A) cyclo(l-Pro- l-Tyr) and (B) cyclo(d-Pro- l-Tyr)