Supporting Information

Synthesis of Five-Membered Cyclic Nitrones Based on the Lewis Acid-Catalysed [3+2]-Annulation Reaction of Donor-Acceptor Cyclopropanes with 1,4,2-Dioxazoles

Zhe-Hao Wang, Huan-Huan Zhang*, Peng-Fei Xu and Yong-Chun Luo*

State Key Laboratory of Applied Organic Chemistry, College of Chemistry and Chemical Engineering, Lanzhou University, Lanzhou 730000, P. R. China

E-mail: zhanghh@lzu.edu.cn; luoych@lzu.edu.cn

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1. General information

Chemicals and solvents were either purchased from commercial suppliers or purified by standard techniques. Analytical thin-layer chromatography (TLC) was performed on silica gel plates with F-254 indicator and compounds were visualized by irradiation with UV light. Flash chromatography was carried out utilizing silica gel 200-300 mesh. The $^1$H NMR spectra was recorded on 400 MHz spectrometers, and the $^{13}$C NMR was recorded on 100 MHz spectrometer. The spectra were recorded in CDCl$_3$ at room temperature. $^1$H and $^{13}$C NMR chemical shifts are reported in ppm relative to either the residual solvent peak ($^{13}$C) ($\delta = 77.00$ ppm) or TMS ($^1$H) ($\delta = 0$ ppm as an internal standard. Data for $^1$H NMR are reported as follows: chemical shift ($\delta$ ppm), multiplicity (s = singlet, d = doublet, t = triplet, m = multiplet, br = broad), integration, coupling constant (Hz) and assignment. HRMS were performed on FT–ICRMS mass instrument (ESI). Enantiomeric excess values were determined by HPLC with a CHIRALPAK OD-3 column with i-PrOH and n-hexane.

2. Experimental procedures

Cyclopropanes used in this work were prepared according to the methods reported in literature.$^1$ Dioxazoles were synthesized according to the literature.$^{2,3}$ spectral data of 6h matched that reported in the literature.$^4$

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2.1 Procedure for the synthesis of dioxazole 2h

\[
\text{EtO}_2 \text{Et} + \begin{array}{c} \text{Ph} \text{NH} \text{OH} \end{array} \xrightarrow{\text{DCM, r.t., 86\%}} \begin{array}{c} \text{Ph} \text{N} \text{O} \text{Ph} \end{array}
\]

1,1-Diethoxycyclohexane (7.0 mmol, 1.20 g) and D-camphorsulfonic acid (2.3 mmol, 0.53 g) were added to the solution of N-hydroxybenzamide (2.7 mmol, 0.32 g) in DCM (50 mL). The reaction mixture was stirred at room temperature. When N-hydroxybenzamide was fully exhausted (monitored by TLC), the reaction was quenched with saturated NaHCO\(_3\) solution. Then the reaction mixture was extracted with dichloromethane, and the combined organic layers was dried over anhydrous Na\(_2\)SO\(_4\). After removing the solvent, the residue was purified by column chromatography on silica gel (petroleum ether/ethyl acetate, V:V = 15:1) to afford the dioxazole 2h as a colorless oil in 86% isolated yield.

2.2 General procedure for the synthesis of cyclic nitrone 3

\[
\begin{array}{c} \text{R}_1^1 \text{CO}_2 \text{R}_2^1 + \begin{array}{c} \text{O} \text{N} \end{array} \xrightarrow{\text{4 Å MS, Yb(OTf)}_3 (10 \text{ mol \%})} \begin{array}{c} \text{R}_2^2 \text{CO}_2 \text{R}_2^2 \end{array} \end{array} \xrightarrow{\text{DCE, Reflux}} \begin{array}{c} \text{R}_3 \text{O}_2 \text{C} \end{array}
\]

The 4 Å MS (200 mg), Yb(OTf)\(_3\) (12.4 mg, 0.02 mmol, 0.10 equiv), D-A cyclopropane 1 (0.24 mmol, 1.20 equiv), dioxazole 2 (0.20 mmol, 1.00 equiv) and 1,2-dichloroethane (1 mL) were sequentially added into a dry flask under argon atmosphere. Then, the reaction mixture was stirred and heated to reflux. Upon completion of the reaction (monitored by TLC), the solvent was removed under reduced pressure. Purification of the residue by column chromatography on silica gel (petroleum ether/ethyl acetate) offered the corresponding nitrone 3.

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2.3 Procedure for the [3+2]-annulation reaction of cyclic nitrone 3a with dimethyl acetylenedicarboxylate

\[
\begin{align*}
\text{Ph} & \quad \text{MeO}_2\text{C} \\
\text{MeO}_2\text{C} & + \quad \text{CO}_2\text{Me} \\
3a & \quad \text{DCE} \quad \text{Ph} & \quad \text{MeO}_2\text{C} \\
\text{MeO}_2\text{C} & + \quad \text{CO}_2\text{Me} \\
5 & \quad \text{Ph} & \quad \text{MeO}_2\text{C} \\
& \quad \text{MeO}_2\text{C} & \quad \text{CO}_2\text{Me} \\
& \quad \text{Ph} & \quad \text{MeO}_2\text{C} \\
7 & \quad \text{MeO}_2\text{C} & \quad \text{CO}_2\text{Me}
\end{align*}
\]

Nitrone 3a (0.6 mmol, 211.8 mg) was mixed with dimethyl acetylenedicarboxylate 5 (1.8 mmol, 255.8 mg) in 1,2-dichloroethane (1 mL). The reaction mixture was stirred at 60 °C until nitrone 3a was fully exhausted (monitored by TLC). After removal the solvent, the residue was purified by silica gel chromatography (petroleum ether/ethyl acetate, V:V = 3:1) to give the product 7 (24.8 mg) in 8% yield.

2.4 Procedure for the Lewis acid/D-A cyclopropane co-catalysed annulation reactions of dimethyl acetylenedicarboxylate with 1,2,4-dioxazole.

\[
\begin{align*}
\text{Ph} & \quad \text{MeO}_2\text{C} \\
\text{MeO}_2\text{C} & + \quad \text{CO}_2\text{Me} \\
2 & \quad \text{C}_2\text{Me} \\
\text{Ph} & \quad \text{MeO}_2\text{C} \\
\text{MeO}_2\text{C} & + \quad \text{CO}_2\text{Me} \\
1a (25 \text{ mol }\%) & \quad \text{Yb(OTf)}_3 (10 \text{ mol }\%) \\
& \quad \text{DCE, reflux, 48h} \\
& \quad \text{MeO}_2\text{C} \\
& \quad \text{Ph} \\
6 (78\%) & \quad \text{MeO}_2\text{C} \\
& \quad \text{Ph}
\end{align*}
\]

The 4 Å MS (200 mg), Yb(OTf)_3 (25 mg, 0.04 mmol, 0.10 equiv), D-A cyclopropane 1 (24 mg, 0.1 mmol, 0.25 equiv), dioxazole 2 (71 mg, 0.4 mmol, 1.00 equiv) and 1,2-dichloroethane (2 mL) were sequentially added into a dry flask under argon atmosphere. Then, the reaction mixture was stirred and heated to reflux. Upon completion of the reaction (48 h), the solvent was removed under reduced pressure. Purification of the residue by column chromatography on silica gel (petroleum ether/ethyl acetate) offered the oxazole 6 (81 mg, 0.31 mmol) in 78% yield. cyclopropane 1a (21 mg, 0.09 mmol) was recycled in 90% yield.
2.5. Decarboxylation procedure for the nitrone 3a

![Chemical structure]  

Nitrone 3a (0.3 mmol, 106 mg) was dissolved in the mixture of methanol and concentrated hydrochloric acid (4 mL, V:V=1:1). The reaction mixture was stirred at room temperature vigorously. When nitrone 3a was exhausted completely (monitored by TLC), the solvent was removed by rotary evaporator. Then, the residue was dissolved by ethanol (1 mL) and basified by triethylamine (0.1 mL). The resulting mixture was stirred for additional 4 hours. Then, the solvent was removed and the residue was purified by silica gel column chromatography (petroleum ether/ethyl acetate, V:V = 3:1). Product 8 was obtained in 84 % yield.

2.6 Procedure for the 1,3-dipolar cycloaddition of nitrone 8 with methyl propiolate

![Chemical structure]  

Nitrone 8 (0.2 mmol, 47.4 mg) was mixed with methyl propiolate (1 mmol, 84.1 mg) in toluene (1 mL) and was heated for 2.5 h at 80 °C. After removal of solvent, the residue was purified by silica gel chromatography (petroleum ether/ethyl acetate, V:V = 12:1) to give the product 9 (38.5 mg) in 65% yield.
2.7 Procedure for the synthesis of oxaziridine 10

A solution of nitrone 3a (0.2 mmol, 70.6mg) in anhydrous and degassed benzene (2 mL) was placed in a quartz tube equipped with an ultraviolet lamp (365 nm). The solution was irradiated at room temperature with continuous stirring. Upon completion of the reaction (monitored by TLC), the solvent was removed to give the crude mixture of oxaziridine which was purified by column chromatography on silica gel (petroleum ether/ethyl acetate, V:V = 5:1) to afford the oxaziridine 10 in 75% yield.

2.8 Procedure for the reduction of nitrone 3a

To a solution of nitrone (0.3 mmol, 106 mg) in anhydrous THF (3 mL) at 0 °C was added LiAlH₄ (3.0 mmol, 114 mg) under argon atmosphere. After stirring at 0 °C for 15 mins, the reaction was allowed to warmed up to room temperature and continued to stir until 3a completely conversed (monitored by TLC), the reaction was cooled to 0 °C and quenched with H₂O (3 mL). The reaction mixture was extracted with dichloromethane, then the combined organic phase were dried over MgSO₄. After filtration and evaporation, the residue was purified by flash column chromatography on silica gel to afford the hydroxylamine 11 (68.2 mg) in 76% yield. (petroleum ether/ethyl acetate, V:V = 1:1 ).
3. Characterization data of Products

4,4-bis(methoxycarbonyl)-2,5-diphenyl-3,4-dihydro-2H-pyrrole 1-oxide (3a)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (63.5 mg, 0.18 mmol, 90 % yield); mp: 154–156 °C; $R_f = 0.26$ (EtOAc/ petroleum ether, v/v = 1/2);

$^1$H NMR (400 MHz, CDCl$_3$) δ 8.30–8.27 (m, 2H), 7.44–7.36 (m, 8H), 5.38 (t, $J = 8.0$ Hz, 1H), 3.81 (s, 3H), 3.71 (s, 3H), 3.37 (dd, $J = 13.2$ Hz, 8.0 Hz, 1H), 2.83 (dd, $J = 13.6$ Hz, 8.0 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) δ 169.4, 168.9, 138.8, 136.6, 130.2, 128.9, 128.2, 128.0, 127.9, 76.4, 63.3, 53.5, 53.4, 38.2; HRMS calcd for C$_{20}$H$_{20}$NO$_5$ [M+H]$^+$: 354.1336, found for: 354.1338. The enantiomeric excess of product (R)-3a was determined to be 91.2 % ee by HPLC with an OD-H column. (n-hexane:i-PrOH = 50:50), 1 mL/min; major enantiomer $t_R = 6.78$ min, minor enantiomer $t_R = 33.70$ min;

2-(4-fluorophenyl)-4,4-bis(methoxycarbonyl)-5-phenyl-3,4-dihydro-2H-pyrrole 1-oxide (3b)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (65.3 mg, 0.18 mmol, 88 % yield); mp: 138–140 °C; $R_f = 0.36$ (EtOAc/ petroleum ether, v/v = 1/2); $^1$H NMR (400 MHz, CDCl$_3$) δ 8.28–8.25 (m, 2H), 7.42–7.40 (m, 3H), 7.37–7.33 (m, 2H), 7.15–7.08 (m, 2H), 5.37 (t, $J = 8.4$ Hz, 1H), 3.81 (s, 3H), 3.73 (s, 3H), 3.37 (dd, $J = 13.6$ Hz, 8.0 Hz, 1H), 2.80 (dd, $J = 13.2$ Hz, 8.4 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) δ 169.4, 168.8, 163.0 (d, $J = 22.0$ Hz), 138.7, 132.4, 130.3, 129.7 (d, $J = 9.0$ Hz), 128.2, 128.1, 127.9, 115.9 (d, $J = 22.0$ Hz), 75.7, 63.2, 53.6, 53.5, 38.1; HRMS calcd for C$_{20}$H$_{19}$FNO$_5$ [M+H]$^+$: 372.1242, found for: 372.1241.

2-(4-chlorophenyl)-4,4-bis(methoxycarbonyl)-5-phenyl-3,4-dihydro-2H-pyrrole 1-oxide (3c)

N O
MeO$_2$C
MeO$_2$C
F
N O
MeO$_2$C
MeO$_2$C
Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:1) gave as white solid (69.7 mg, 0.18 mmol, 90 % yield); mp: 113–115 °C; \( R_f = 0.46 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.29–8.24 (m, 2H), 7.43–7.38 (m, 5H), 7.30 (dt, \( J = 8.4 \) Hz, 2.4 Hz, 2H), 5.37 (t, \( J = 8.4 \) Hz, 1H), 3.81 (s, 3H), 3.72 (s, 3H), 3.36 (dd, \( J = 13.6 \) Hz, 8.0 Hz, 1H), 2.78 (dd, \( J = 13.6 \) Hz, 8.4 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.3, 168.8, 138.9, 135.1, 135.0, 130.4, 129.2, 128.1, 127.9, 75.7, 63.3, 53.6, 53.5, 38.0; HRMS calcd for C\(_{20}\)H\(_{19}\)ClNO\(_5\) [M+H]\(^+\): 388.0946, found for: 388.0947.

2-(4-bromophenyl)-4,4-bis(methoxycarbonyl)-5-phenyl-3,4-dihydro-2H-pyrrole 1-oxide (3d)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (82.8 mg, 0.19 mmol, 96 % yield); mp: 112–114 °C; \( R_f = 0.38 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.28–8.25 (m, 2H), 7.57–7.53 (m, 2H), 7.43–7.39 (m, 3H), 7.26–7.23 (m, 2H), 5.35 (t, \( J = 8.4 \) Hz, 1H), 3.80 (s, 3H), 3.72 (s, 3H), 3.36 (dd, \( J = 13.6 \) Hz, 8.0 Hz, 1H), 2.76 (dd, \( J = 13.6 \) Hz, 8.4 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.3, 168.7, 139.0, 135.6, 132.1, 130.4, 129.5, 128.1, 127.9, 123.1, 75.8, 63.3, 53.6, 53.5, 37.9; HRMS calcd for C\(_{20}\)H\(_{19}\)BrNO\(_5\) [M+H]\(^+\): 432.0441, found for: 432.0445.

2-(2-bromophenyl)-4,4-bis(methoxycarbonyl)-5-phenyl-3,4-dihydro-2H-pyrrole 1-oxide (3e)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (38.4 mg, 0.09 mmol, 45 % yield); mp: 121–123 °C; \( R_f = 0.35 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.33–8.31 (m, 2H), 7.60 (dd, \( J = 8.0 \) Hz, 1.2 Hz, 1H), 7.45–7.42 (m, 3H), 7.36–7.32 (m, 1H), 7.27–7.19 (m, 2H), 5.82 (dd, \( J = 8.8 \) Hz, 6.0 Hz, 1H), 3.78 (s, 3H), 3.64 (s, 3H), 3.42 (dd, \( J = 13.6 \) Hz, 8.8 Hz, 1H), 2.79 (dd, \( J = 13.2 \) Hz, 6.0 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.0, 168.9, 140.3, 136.3, 133.1, 130.4, 129.9, 128.1, 127.9, 127.8, 123.3, 76.3, 63.5, 53.7, 53.3, 37.1; HRMS calcd for C\(_{20}\)H\(_{19}\)BrNO\(_5\) [M+H]\(^+\): 432.0441, found...
for: 432.0450.

4,4-bis(methoxycarbonyl)-5-phenyl-2-(o-tolyl)-3,4-dihydro-2H-pyrrole 1-oxide (3f)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (63.1 mg, 0.17 mmol, 86 % yield); mp: 118–120 °C; \( R_f = 0.35 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.33–8.29 (m, 2H), 7.44–7.40 (m, 3H), 7.25–7.18 (m, 4H), 5.64 (t, \( J = 8.0 \) Hz, 1H), 3.80 (s, 3H), 3.68 (s, 3H), 3.35 (dd, \( J = 13.2 \) Hz, 8.4 Hz, 1H), 2.75 (dd, \( J = 13.2 \) Hz, 7.6 Hz, 1H), 2.40 (s, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.3, 169.1, 139.2, 136.2, 135.1, 130.9, 130.2, 128.5, 128.4, 128.1, 127.9, 126.6, 126.2, 73.8, 63.5, 53.6, 53.3, 37.4, 19.2; HRMS calcd for C\(_{21}\)H\(_{22}\)NO\(_5\) [M+H]^+: 368.1492, found for: 368.1494.

4,4-bis(methoxycarbonyl)-5-phenyl-2-(m-tolyl)-3,4-dihydro-2H-pyrrole 1-oxide (3g)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 1:1) gave as white solid (61.7 mg, 0.17 mmol, 84 % yield); mp: 110–112 °C; \( R_f = 0.20 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.32–8.29 (m, 2H), 7.42–7.39 (m, 3H), 7.33–7.29 (m, 1H), 7.20–7.16 (m, 3H), 5.35 (t, \( J = 8.4 \) Hz, 1H), 3.81 (s, 3H), 3.74 (s, 3H), 3.35 (dd, \( J = 13.2 \) Hz, 8.0 Hz, 1H), 2.81 (dd, \( J = 13.2 \) Hz, 8.4 Hz, 1H), 2.38 (s, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.5, 168.9, 138.6, 136.6, 135.1, 130.1, 130.0, 129.7, 128.8, 128.4, 128.0, 127.9, 124.8, 76.4, 63.3, 53.5, 53.4, 38.2, 21.4; HRMS calcd for C\(_{21}\)H\(_{22}\)NO\(_5\) [M+H]^+: 368.1492, found for: 368.1493.

4,4-bis(methoxycarbonyl)-5-phenyl-2-(p-tolyl)-3,4-dihydro-2H-pyrrole 1-oxide (3h)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (63.8 mg, 0.17 mmol, 87 % yield); mp: 123–125 °C; \( R_f = 0.26 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.30–8.27 (m, 2H), 7.41–7.38 (m, 3H), 7.26–7.20 (m, 4H), 5.34 (t, \( J = 8.4 \) Hz, 1H), 3.80 (s, 3H),
3.71 (s, 3H), 3.34 (dd, $J = 13.2$ Hz, 8.0 Hz, 1H), 2.82 (dd, $J = 13.2$ Hz, 8.8 Hz, 1H), 2.36 (s, 3H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 169.4, 168.9, 138.9, 138.4, 133.6, 130.1, 129.6, 128.3, 128.0, 127.8, 127.7, 76.1, 63.2, 53.5, 53.3, 38.1, 21.1; HRMS calcd for C$_{21}$H$_{22}$NO$_5$ [M+H]$^+$: 368.1492, found for: 368.1491.

4,4-bis(methoxycarbonyl)-2-(4-methoxyphenyl)-5-phenyl-3,4-dihydro-$2H$-pyrrole 1-oxide (3i)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 1:1) gave as white solid (55.9 mg, 0.15 mmol, 73 % yield); mp: 125–127 °C; $R_f = 0.21$ (EtOAc/petroleum ether, v/v = 1/2); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.29–8.26 (m, 2H), 7.41–7.38 (m, 3H), 7.31–7.29 (m, 2H), 6.96–6.93 (m, 2H), 5.32 (t, $J = 8.4$ Hz, 1H), 3.82 (s, 3H), 3.81 (s, 3H), 3.74 (s, 3H), 3.34 (dd, $J = 13.6$ Hz, 8.0 Hz, 1H), 2.81 (dd, $J = 13.6$ Hz, 8.4 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 169.5, 168.9, 160.0, 138.2, 130.1, 129.2, 128.4, 128.3, 128.0, 127.8, 114.3, 75.8, 63.0, 55.2, 53.4, 38.0, 30.8, 14.1; HRMS calcd for C$_{21}$H$_{22}$NO$_6$ [M+H]$^+$: 384.1442, found for: 384.1443.

4,4-bis(methoxycarbonyl)-5-phenyl-2-(3,4,5-trimethoxyphenyl)-3,4-dihydro-$2H$-pyrrole 1-oxide (3j)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 1:2) gave as white solid (65.6 mg, 0.15 mmol, 74 % yield); mp: 136–138 °C; $R_f = 0.15$ (EtOAc/petroleum ether, v/v = 1/1); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.29–8.26 (m, 2H), 7.42–7.40 (m, 3H), 6.59 (s, 2H), 5.30 (t, $J = 8.0$ Hz, 1H), 3.86 (s, 6H), 3.84 (s, 3H), 3.79 (s, 3H), 3.76 (s, 3H), 3.36 (dd, $J = 13.6$ Hz, 8.4 Hz, 1H), 2.82 (dd, $J = 13.6$ Hz, 8.0 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 169.6, 168.9, 153.6, 138.6, 138.2, 130.3, 128.1, 128.0, 127.9, 104.7, 63.2, 60.7, 56.1, 53.6, 53.5, 53.4, 37.8; HRMS calcd for C$_{23}$H$_{26}$NO$_8$ [M+H]$^+$: 444.1653, found for: 444.1654.

2-ethyl-4,4-bis(methoxycarbonyl)-5-phenyl-3,4-dihydro-$2H$-pyrrole 1-oxide (3k)

s10
Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (18.3 mg, 0.06 mmol, 30 % yield); mp: 93–95 °C; \( R_f = 0.45 \) (EtOAc/ petroleum ether, v/v = 1/1); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.19–8.15 (m, 2H), 7.42–7.36 (m, 3H), 4.20 (ddd, \( J = 16.8 \) Hz, 8.4 Hz, 3.6 Hz, 1H), 3.77 (s, 3H), 3.72 (s, 3H), 3.03 (dd, \( J = 12.0 \) Hz, 4.0 Hz, 1H), 2.47 (dd, \( J = 12.8 \) Hz, 8.0 Hz, 1H), 2.35–2.25 (m, 1H), 1.83–1.72 (m, 1H), 1.02 (t, \( J = 7.6 \) Hz, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.8, 169.3, 138.1, 130.1, 128.5, 128.1, 128.0, 73.1, 63.2, 53.6, 53.5, 34.5, 25.2, 9.1; HRMS calcd for \( C_{16}H_{20}NO_5 \) [M+H]+: 306.1336, found for: 306.1335.

4,4-bis(methoxycarbonyl)-5-phenyl-2-vinyl-3,4-dihydro-2\( H \)-pyrrole 1-oxide (3l)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:2) gave as white solid (33.3 mg, 0.11 mmol, 55 % yield); mp: 82–84 °C; \( R_f = 0.38 \) (EtOAc/ petroleum ether, v/v = 1/1); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.22–8.20 (m, 2H), 7.41–7.37 (m, 3H), 6.05 (ddd, \( J = 17.2 \) Hz, 10.0 Hz, 7.2 Hz, 1H), 5.49–5.45 (m, 2H), 4.83–4.77 (dd, \( J = 15.2 \) Hz, 7.6 Hz, 1H), 3.77 (s, 3H), 3.73 (s, 3H), 3.13 (dd, \( J = 12.0 \) Hz, 8.0 Hz, 1H), 2.64 (dd, \( J = 12.0 \) Hz, 8.0 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.2, 169.3, 138.1, 130.1, 128.5, 128.1, 128.0, 73.1, 63.3, 53.4; HRMS calcd for \( C_{16}H_{18}NO_5 \) [M+H]+: 304.1179, found for: 304.1181.

4,4-bis(methoxycarbonyl)-2,2-dimethyl-5-phenyl-3,4-dihydro-2\( H \)-pyrrole 1-oxide (3m)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as colorless oil (16.7 mg, 0.05 mmol, 30 % yield); \( R_f = 0.38 \) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.18–8.16 (m, 2H), 7.39–7.36 (m, 3H), 3.74 (s, 6H), 2.83 (s, 2H), 1.51 (s, 6H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 169.9, 135.9, 129.8, 128.8, 128.0, 127.9, 73.8, 62.3, 53.4, 53.3, 42.7, 26.3, 25.0; HRMS calcd for \( C_{16}H_{20}NO_5 \) [M+H]+: 306.1336, found for: 306.1336.

4,4-bis((allyloxy)carbonyl)-2,5-diphenyl-3,4-dihydro-2\( H \)-pyrrole 1-oxide (3n)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave
as colorless oil (62.2 mg, 0.15 mmol, 77 % yield); $R_f = 0.38$ (EtOAc/ petroleum ether, v/v = 1/2); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.31–8.29 (m, 2H), 7.44–7.34 (m, 8H), 5.85–5.66 (m, 2H), 5.40 (t, $J = 8.0$ Hz, 1H), 5.28–5.17 (m, 4H), 4.70 (dd, $J = 2.4$ Hz, 1.2 Hz, 1H), 4.68 (dd, $J = 2.4$ Hz, 1.2 Hz, 1H), 4.61–4.59 (m, 2H), 3.39 (dd, $J = 13.2$ Hz, 8.0 Hz, 1H), 2.85 (dd, $J = 13.6$ Hz, 8.4 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.5, 168.1, 138.8, 136.7, 128.9, 128.8, 128.1, 128.0, 127.7, 119.7, 119.6, 76.4, 67.3, 67.0, 63.6, 38.1; HRMS calcd for C$_{24}$H$_{24}$NO$_5$ [M+H$^+$]: 406.1656, found for: 406.1649.

4,4-bis((benzyloxy)carbonyl)-5-phenyl-2-vinyl-3,4-dihydro-2H-pyrrole 1-oxide (3o)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as colorless oil (54.6 mg, 0.12 mmol, 60 % yield); $R_f = 0.26$ (EtOAc/ petroleum ether, v/v = 2/1); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.11–8.08 (m, 2H), 7.33–7.21 (m, 9H), 7.14–7.09 (m, 4H), 5.97 (ddd, $J = 17.6$ Hz, 10.4 Hz, 7.6 Hz, 1H), 5.42–5.37 (m, 2H), 5.16 (s, 1H), 5.15 (s, 1H), 5.13 (s, 2H), 4.73 (dd, $J = 12.8$ Hz, 4.0 Hz, 1H), 3.10 (dd, $J = 12.8$ Hz, 8.0 Hz, 1H), 2.63 (dd, $J = 12.0$ Hz, 8.0 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.6, 168.2, 137.8, 134.3, 134.2, 133.3, 129.9, 128.6, 128.5, 128.4, 128.3, 128.1, 127.9, 121.3, 74.9, 68.5, 68.3, 63.8, 35.3; HRMS calcd for C$_{28}$H$_{26}$NO$_5$ [M+H$^+$]: 456.1805, found for: 456.1804.

4,4-bis(methoxycarbonyl)-2-phenyl-5-(p-tolyl)-3,4-dihydro-2H-pyrrole 1-oxide (3p)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (60.9 mg, 0.17 mmol, 83 % yield); mp: 142–144 $^\circ$C; $R_f = 0.33$ (EtOAc/ petroleum ether, v/v = 1/2); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.22–8.21 (m, 2H), 7.43–7.33 (m, 5H), 7.22–7.20 (m, 2H), 5.37 (t, $J = 8.0$ Hz, 1H), 3.79 (s, 3H), 3.71 (s, 3H), 3.35 (dd, $J = 13.2$ Hz, 8.0 Hz, 1H), 2.79 (dd, $J = 13.2$ Hz, 8.0 Hz, 1H), 2.37 (s, 3H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 169.5, 168.9, 140.6, 138.8, 136.8, 128.9, 128.8, 128.7, 127.8, 127.6, 125.5, 76.2, 63.2, 53.5, 53.3, 38.2, 21.4; HRMS calcd for C$_{21}$H$_{22}$NO$_3$ [M+H$^+$]: 368.1492, found for: 368.1492.
5-(4-chlorophenyl)-4,4-bis(methoxycarbonyl)-2-phenyl-3,4-dihydro-2H-pyrrole 1-oxide (3q)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as white solid (69.7 mg, 0.18 mmol, 90% yield); mp: 140–142 °C; R_f = 0.34 (EtOAc/ petroleum ether, v/v = 1/2); ¹H NMR (400 MHz, CDCl₃) δ 8.30–8.27 (m, 2H), 7.45–7.32 (m, 7H), 5.37 (t, J = 8.0 Hz, 1H), 3.81 (s, 3H), 3.73 (s, 3H), 3.37 (dd, J = 13.2 Hz, 8.0 Hz, 1H), 2.81 (dd, J = 13.6 Hz, 8.4 Hz, 1H) ppm; ¹³C NMR (100 MHz, CDCl₃) δ 169.3, 168.7, 137.8, 136.4, 135.8, 129.4, 129.1, 128.8, 128.5, 128.1, 127.9, 127.5, 126.8, 76.5, 63.2, 53.6, 53.5, 38.2; HRMS calcd for C₂₀H₁₉ClNO₅ [M+H]⁺: 388.0946, found for: 388.0945.

4,4-bis(methoxycarbonyl)-2-phenyl-5-(thiophen-2-yl)-3,4-dihydro-2H-pyrrole 1-oxide (3r)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:1) gave as white solid (67.5 mg, 0.19 mmol, 94% yield); mp: 151–153 °C; R_f = 0.40 (EtOAc/ petroleum ether, v/v = 1/2); ¹H NMR (400 MHz, CDCl₃) δ 7.55 (d, J = 4.0 Hz, 1H), 7.50 (d, J = 5.6 Hz, 1H), 7.43–7.36 (m, 3H), 7.33–7.30 (m, 2H), 7.16 (t, J = 8.4 Hz, 1H), 5.39 (t, J = 8.0 Hz, 1H), 3.81 (s, 3H), 3.80 (s, 3H), 3.50 (dd, J = 13.2 Hz, 8.0 Hz, 1H), 2.81 (dd, J = 13.6 Hz, 8.4 Hz, 1H) ppm; ¹³C NMR (100 MHz, CDCl₃) δ 169.1, 168.2, 136.3, 136.0, 129.4, 129.1, 129.0, 128.7, 127.7, 126.4, 74.4, 62.6, 53.6, 53.5, 38.2; HRMS calcd for C₁₈H₁₄NO₅S [M+H]⁺: 360.0900, found for: 360.0901.

2-(4-chlorophenyl)-4,4-bis(methoxycarbonyl)-5-(thiophen-2-yl)-3,4-dihydro-2H-pyrrole 1-oxide (3s)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:1) gave as white solid (72.3 mg, 0.18 mmol, 92% yield); mp: 122–124 °C; R_f = 0.43 (EtOAc/ petroleum ether, v/v = 1/2); ¹H NMR (400 MHz, CDCl₃) δ 7.55 (d, J = 4.0 Hz, 1H), 7.52 (d, J = 4.8 Hz, 1H), 7.
39–7.37 (m, 2H), 7.28–7.25 (m, 2H), 7.17 (t, \(J = 4.8\) Hz, 1H), 5.37 (t, \(J = 8.0\) Hz, 1H), 3.82 (s, 3H), 3.80 (s, 3H), 3.50 (dd, \(J = 13.6\) Hz, 8.4 Hz, 1H), 2.77 (dd, \(J = 13.2\) Hz, 8.0 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 169.0, 168.0, 135.1, 134.8, 129.3, 129.2, 129.1, 128.9, 126.5, 73.6, 62.5, 53.7, 53.6, 38.0; HRMS calcd for C\(_{18}\)H\(_{17}\)ClNO\(_5\)S [M+H]\(^+\): 394.0510, found for: 394.0513.

4,4-bis(methoxycarbonyl)-5-(thiophen-2-yl)-2-(p-tolyl)-3,4-dihydro-2\(H\)-pyrrole 1-oxide (3t)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:1) gave as white solid (64.2 mg, 0.17 mmol, 86 % yield); mp: 120–122 °C; \(R_f = 0.47\) (EtOAc/ petroleum ether, v/v = 1/2); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.54 (ddd, \(J = 4.0\) Hz, 1.2 Hz, 0.4 Hz, 1H), 7.21 (s, 4H), 7.15 (dd, \(J = 5.2\) Hz, 4.0 Hz, 1H), 5.35 (t, \(J = 8.0\) Hz, 1H), 3.82 (s, 3H), 3.79 (s, 3H), 3.48 (dd, \(J = 13.2\) Hz, 8.0 Hz, 1H), 2.80 (dd, \(J = 13.6\) Hz, 8.4 Hz, 1H), 2.35 (s, 3H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 169.2, 168.2, 139.0, 135.7, 133.2, 129.7, 129.5, 129.0, 128.6, 127.7, 126.3, 74.1, 62.5, 53.5, 38.1, 21.2; HRMS calcd for C\(_{19}\)H\(_{20}\)NO\(_5\)S [M+H]\(^+\): 374.1057, found for: 374.1058.

4,4-bis(methoxycarbonyl)-5-phenethyl-2-phenyl-3,4-dihydro-2\(H\)-pyrrole 1-oxide (3u)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 1:1) gave as colorless oil (65.5 mg, 0.17 mmol, 86 % yield); \(R_f = 0.36\) (EtOAc/ petroleum ether, v/v = 1/1); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \(\delta\) 7.43–7.34 (m, 3H), 7.32–7.24 (m, 6H), 7.22–7.18 (m, 1H), 5.19 (t, \(J = 8.0\) Hz, 1H), 3.79 (s, 3H), 3.78 (s, 3H), 3.27 (dd, \(J = 14.0\) Hz, 8.4 Hz, 1H), 3.07–3.00 (m, 2H), 2.98–2.83 (m, 2H), 2.67 (dd, \(J = 14.0\) Hz, 8.0 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \(\delta\) 168.7, 168.2, 142.3, 141.3, 136.8, 129.0, 128.9, 128.5, 128.4, 127.6, 126.1, 74.9, 63.2, 53.5, 35.7, 29.6; HRMS calcd for C\(_{22}\)H\(_{24}\)NO\(_5\) [M+H]\(^+\): 382.1649, found for: 382.1647.

(E)-4,4-bis(methoxycarbonyl)-2-phenyl-5-styryl-3,4-dihydro-2\(H\)-pyrrole 1-oxide (3v)
Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as colorless oil (26.3 mg, 0.07 mmol, 35 % yield); $R_f = 0.34$ (EtOAc/ petroleum ether, v/v = 2/1); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 8.32 (d, $J = 16.4$ Hz, 1H), 7.54–7.52 (m, 2H), 7.44–7.31 (m, 8H), 7.03 (d, $J = 16.4$ Hz, 1H), 5.29 (t, $J = 8.4$ Hz, 1H), 3.85 (s, 3H), 3.84 (s, 3H), 3.38 (dd, $J = 13.6$ Hz, 8.0 Hz, 1H), 2.68 (dd, $J = 13.6$ Hz, 8.4 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 169.1, 168.4, 138.4, 137.3, 137.2, 136.7, 129.0, 127.6, 127.5, 115.0, 114.8, 75.3, 62.1, 53.6, 53.5, 36.5; HRMS calcd for C$_{22}$H$_{22}$NO$_5$ [M+H]$^+$: 380.1492, found for: 380.1493.

**4,4-bis(methoxycarbonyl)-5-pentyl-2-phenyl-3,4-dihydro-2$H$-pyrrole 1-oxide (3w)**

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 1:1) gave as colorless oil (53.4 mg, 0.15 mmol, 77 % yield); $R_f = 0.18$ (EtOAc/ petroleum ether, v/v = 1/2); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.41–7.31 (m, 3H), 7.27–7.25 (m, 2H), 5.15 (t, $J = 8.0$ Hz, 1H), 3.83 (s, 3H), 3.81 (s, 3H), 3.24 (dd, $J = 14.0$ Hz, 8.8 Hz, 1H), 2.69–2.55 (m, 3H), 1.65–1.58 (m, 2H), 1.38–1.30 (m, 4H), 0.92–0.87 (m, 3H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.9, 168.4, 138.4, 137.3, 137.2, 136.7, 129.0, 127.6, 127.5, 115.0, 114.8, 75.3, 62.1, 53.6, 53.5, 36.5; HRMS calcd for C$_{19}$H$_{26}$NO$_5$ [M+H]$^+$: 348.1805, found for: 348.1804.

**2-(4-bromophenyl)-4,4-bis(methoxycarbonyl)-5-phenethyl-3,4-dihydro-2$H$-pyrrole 1-oxide (3x)**

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 2:1) gave as colorless oil (86.9 mg, 0.19 mmol, 90 % yield); $R_f = 0.32$ (EtOAc/ petroleum ether, v/v = 1/2); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.55–7.52 (m, 2H), 7.32–7.16 (m, 7H), 5.16 (t, $J = 8.4$ Hz, 1H), 3.79 (s, 3H), 3.78 (s, 3H), 3.25 (dd, $J = 14.0$ Hz, 8.8 Hz, 1H), 3.05–2.84 (m, 4H), 2.63 (dd, $J = 14.0$ Hz, 8.0 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 168.5, 168.0, 142.7, 141.0, 135.6, 132.1, 129.3, 128.4, 126.1, 123.1, 74.2, 63.1, 53.6, 35.3, 35.4, 29.4; HRMS calcd for C$_{22}$H$_{23}$BrNO$_5$ [M+H]$^+$: 460.0754, found for: 460.0760.
Tetramethyl 3a,6-diphenyl-5,6-dihydropyrrolo[1,2-b]isoxazole-2,3,4,4(3aH)-tetracarboxylate (7)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:1) gave as colorless oil (24.8 mg, 0.05 mmol, 8 % yield); \( R_f = 0.48 \) (EtOAc/petroleum ether, v/v = 2/1); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 7.59–7.54 (m, 4H), 7.42–7.38 (m, 2H), 7.36–7.29 (m, 4H), 4.84 (dd, \( J = 12.8 \) Hz, 5.6 Hz, 1H), 3.85 (s, 3H), 3.83 (s, 3H), 3.76 (s, 3H), 3.12 (s, 3H), 3.05 (dd, \( J = 14.0 \) Hz, 12.8 Hz, 1H), 2.43 (dd, \( J = 14.0 \) Hz, 5.6 Hz, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 170.7, 168.9, 164.0, 159.5, 153.7, 142.6, 138.1, 128.7, 128.2, 128.0, 127.8, 127.2, 109.4, 83.9, 76.7, 69.4, 65.4, 53.2, 52.2, 52.0, 41.1; HRMS calcd for C\(_{26}\)H\(_{26}\)NO\(_9\) [M+H]^+: 496.1602, found for: 496.1615. HRMS calcd for C\(_{26}\)H\(_{26}\)NO\(_9\) [M+H]^+: 496.1602, found for: 496.1615.

2,5-diphenyl-3,4-dihydro-2H-pyrrole 1-oxide (8)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 3:1) gave as white solid (59.7 mg, 0.25 mmol, 84 % yield); mp: 98–100 °C; \( R_f = 0.24 \) (EtOAc/petroleum ether, v/v = 3/1); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 8.44–8.41 (m, 2H), 7.47–7.40 (m, 3H), 7.39–7.30 (m, 5H), 5.29–5.26 (m, 1H), 3.32–3.15 (m, 2H), 2.72–2.62 (m, 1H), 2.27–2.19 (m, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 140.0, 138.6, 130.2, 129.2, 128.8, 128.3, 128.2, 127.3, 127.0, 79.1, 29.2, 26.1; HRMS calcd for C\(_{16}\)H\(_{16}\)NO [M+H]^+: 238.1226, found for: 238.1224.

Methyl 3a,6-diphenyl-3a,4,5,6-tetrahydropyrrolo[1,2-b]isoxazole-3-carboxylate (9)

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 12:1) gave as colorless oil (41.7 mg, 0.12 mmol, 65 % yield); \( R_f = 0.40 \) (EtOAc/petroleum ether, v/v = 8/1); \(^1\)H NMR (400 MHz, CDCl\(_3\)) \( \delta \) 7.74–7.72 (m, 2H), 7.47 (d, \( J = 7.2 \) Hz, 2H), 7.37–7.33 (m, 7H), 4.37 (dd, \( J = 11.2 \) Hz, 6.0 Hz, 1H), 3.17 (s, 3H), 2.82 (ddd, \( J = 19.2 \) Hz, 11.6 Hz, 8.0 Hz, 1H), 2.67 (ddd, \( J = 13.2 \) Hz, 7.2 Hz, 2.0 Hz, 1H), 2.19 (ddd, \( J = 15.6 \) Hz, 8.0 Hz, 2.4 Hz, 1H), 1.91–1.81 (m, 1H) ppm; \(^{13}\)C NMR (100 MHz, CDCl\(_3\)) \( \delta \) 164.2, 152.2, 145.3, 140.4, 128.5, 128.2, 127.5, 127.0, 126.9, 126.1, 113.6,
77.5, 73.4, 51.2, 36.5, 31.6; HRMS caleld for C$_{20}$H$_{20}$NO$_3$ [M+H]$^+$: 322.1438, found for: 322.1449.

**Dimethyl 2,5-diphenyl-6-oxa-1-azabicyclo[3.1.0]hexane-4,4-dicarboxylate (10)**

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 5:1) gave as colorless oil (53.0 mg, 0.15 mmol, 75 % yield); $R_f$ = 0.35 (EtOAc/ petroleum ether, v/v = 5/1); $^1$H NMR (400 MHz, CDCl$_3$) $\delta$ 7.54–7.51 (m, 2H), 7.45–7.37 (m, 2H), 7.34–7.18 (m, 6H), 4.87 (dd, $J$ = 12.0 Hz, 4.0 Hz, 1H), 3.77 (s, 3H), 3.20 (s, 3H), 3.06 (dd, $J$ = 20.0 Hz, 12.0 Hz, 1H), 2.85 (dd, $J$ = 16.0 Hz, 4.0 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CDCl$_3$) $\delta$ 169.1, 168.5, 139.2, 133.1, 129.3, 128.3, 128.1, 127.8, 127.3, 126.6, 92.0, 67.4, 64.9, 53.1, 52.5, 39.9; HRMS caleld for C$_{20}$H$_{20}$NO$_5$ [M+H]$^+$: 354.1331, found for: 354.1336.

**trans - (1-hydroxy-2,5-diphenylpyrrolidine-3,3-diyl)dimethanol (11)**

Purification by flash chromatography on silica gel petroleum ether/EtOAc (V/V = 1:1) gave as white solid (68.2 mg, 0.23 mmol, 76 % yield); mp: 196–198 °C; $R_f$ = 0.28 (EtOAc/ petroleum ether, v/v = 1/1); $^1$H NMR (400 MHz, CD$_3$OH) $\delta$ 7.56–7.54 (m, 4H), 7.37–7.32 (m, 4H), 7.27–7.23 (m, 2H), 4.17 (s, 1H), 4.00 (dd, $J$ = 10.8 Hz, 8.0 Hz, 1H), 3.73 (d, $J$ = 11.2 Hz, 1H), 3.65 (d, $J$ = 10.8 Hz, 1H), 3.28 (d, $J$ = 10.8 Hz, 1H), 2.85 (dd, $J$ = 14.4 Hz, 8.8 Hz, 1H), 2.24 (dd, $J$ = 14.4 Hz, 8.8 Hz, 1H), 1.82 (dd, $J$ = 13.2 Hz, 10.8 Hz, 1H) ppm; $^{13}$C NMR (100 MHz, CD$_3$OH) $\delta$ 144.2, 140.1, 129.5, 129.4, 129.1, 128.7, 128.1, 128.0, 76.1, 71.8, 67.4, 66.3, 47.5, 39.0; HRMS caleld for C$_{18}$H$_{22}$NO$_3$ [M+H]$^+$: 300.1594, found for: 300.1592.
4. $^1$H-NMR and $^{13}$C-NMR spectra of the compounds

$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3a

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3a
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3b

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3b
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3c

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3c
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3d

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3d
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3e

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3e
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound $3f$

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound $3f$
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound $3g$

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound $3g$
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3h

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3h
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3i

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3i
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3j

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3j
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3k

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3k
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3l

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3l
\(^1\)H-NMR (400 MHz, CDCl\(_3\)) spectra of compound 3m

\(^{13}\)C-NMR (100 MHz, CDCl\(_3\)) spectra of compound 3m
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3n

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3n
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3o

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3o
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3p

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3p
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3q

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3q
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3r

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3r
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3s

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3s
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3t

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3t
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound $3u$

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound $3u$
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3v

![H-NMR spectrum of compound 3v](image)

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3v

![C-NMR spectrum of compound 3v](image)
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound $3w$

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound $3w$
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 3x

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 3x
\(^1\)H-NMR (400 MHz, CDCl\(_3\)) spectra of compound 4h

All \(^1\)H-NMR spectral data of 4h matched that reported in the literature. \(^4\)
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 7

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 7
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 8

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 8
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 9

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 9
$^1$H-NMR (400 MHz, CDCl$_3$) spectra of compound 10

$^{13}$C-NMR (100 MHz, CDCl$_3$) spectra of compound 10
$^{1}$H-NMR (400 MHz, CD$_3$OH) spectra of compound 11

$^{13}$C-NMR (100 MHz, CD$_3$OH) spectra of compound 11
5. X-ray crystallographic data

X-ray Crystallographic Data of Compound rac-3a

<table>
<thead>
<tr>
<th>Bond precision:</th>
<th>C-C = 0.0058 Å</th>
<th>Wavelength=0.71073</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell:</td>
<td>a=9.683(2)</td>
<td>b=9.746(3)</td>
</tr>
<tr>
<td>alpha=68.90(2)</td>
<td>beta=72.87(2)</td>
<td>gamma=64.67(3)</td>
</tr>
<tr>
<td>Temperature:</td>
<td>289 K</td>
<td></td>
</tr>
<tr>
<td>Volume</td>
<td>Calculated</td>
<td>Reported</td>
</tr>
<tr>
<td>Space group</td>
<td>P -1</td>
<td>P -1</td>
</tr>
<tr>
<td>Hall group</td>
<td>-P 1</td>
<td>-P 1</td>
</tr>
<tr>
<td>Moiety formula</td>
<td>C_{20}H_{19}NO_5</td>
<td>C_{20}H_{19}NO_5</td>
</tr>
<tr>
<td>Sum formula</td>
<td>C_{20}H_{19}NO_5</td>
<td>C_{20}H_{19}NO_5</td>
</tr>
<tr>
<td>Mr</td>
<td>353.36</td>
<td>353.36</td>
</tr>
<tr>
<td>D_x,g cm^3</td>
<td>1.339</td>
<td>1.339</td>
</tr>
<tr>
<td>Z</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mu (mm^{-1})</td>
<td>0.097</td>
<td>0.097</td>
</tr>
<tr>
<td>F000</td>
<td>372.0</td>
<td>372.0</td>
</tr>
<tr>
<td>F000’</td>
<td>372.20</td>
<td></td>
</tr>
<tr>
<td>h, k, lmax</td>
<td>11, 12, 13</td>
<td>11, 12, 13</td>
</tr>
<tr>
<td>Nref</td>
<td>3443</td>
<td>3432</td>
</tr>
<tr>
<td>Tmin,Tmax</td>
<td>0.980, 0.986</td>
<td>0.778, 1.000</td>
</tr>
<tr>
<td>Tmin’</td>
<td>0.979</td>
<td></td>
</tr>
<tr>
<td>Correction method</td>
<td># Reported T Limits: Tmin= 0.778 Tmax= 1.000</td>
<td></td>
</tr>
<tr>
<td>AbsCorr</td>
<td>MULTI-SCAN</td>
<td></td>
</tr>
<tr>
<td>Data completeness</td>
<td>0.997</td>
<td></td>
</tr>
<tr>
<td>Theta(max)=</td>
<td>26.016</td>
<td></td>
</tr>
<tr>
<td>R(reflections)=</td>
<td>0.0696( 1875)</td>
<td></td>
</tr>
<tr>
<td>wR2(reflections)=</td>
<td>0.2149( 3432)</td>
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</tr>
<tr>
<td>S</td>
<td>1.041</td>
<td></td>
</tr>
<tr>
<td>Npar</td>
<td>237</td>
<td></td>
</tr>
<tr>
<td>Displacement ellipsoids are drawn at 30% probability level</td>
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</table>
X-ray Crystallographic Data of Compound (R)-3a

<table>
<thead>
<tr>
<th>Bond precision:</th>
<th>C-C = 0.0026 Å</th>
<th>Wavelength=1.54184</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell:</td>
<td>a=8.2648(2)</td>
<td>b=10.1169(2)</td>
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<tr>
<td></td>
<td>c=10.9096(3)</td>
<td>alpha=90</td>
</tr>
<tr>
<td></td>
<td>beta=106.079(3)</td>
<td>gamma=90</td>
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<tr>
<td>Temperature:</td>
<td>173 K</td>
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<tr>
<td>Volume</td>
<td>876.51(4)</td>
<td>876.51(4)</td>
</tr>
<tr>
<td>Space group</td>
<td>P 21</td>
<td>P 1 2 1</td>
</tr>
<tr>
<td>Hall group</td>
<td>P 2yb</td>
<td>P 2yb</td>
</tr>
<tr>
<td>Moiety formula</td>
<td>C_{20}H_{19}NO_5</td>
<td>C_{20}H_{19}NO_5</td>
</tr>
<tr>
<td>Sum formula</td>
<td>C_{20}H_{19}NO_5</td>
<td>C_{20}H_{19}NO_5</td>
</tr>
<tr>
<td>Mr</td>
<td>353.36</td>
<td>353.36</td>
</tr>
<tr>
<td>Dx, g cm(^{-3})</td>
<td>1.339</td>
<td>1.339</td>
</tr>
<tr>
<td>Z</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Mu (mm(^{-1}))</td>
<td>0.799</td>
<td>0.799</td>
</tr>
<tr>
<td>F000</td>
<td>372.0</td>
<td>372.0</td>
</tr>
<tr>
<td>F000'</td>
<td>373.23</td>
<td></td>
</tr>
<tr>
<td>h, k, lmax</td>
<td>9, 12, 12</td>
<td>9, 12, 12</td>
</tr>
<tr>
<td>Nref</td>
<td>3098 [1644]</td>
<td>2269</td>
</tr>
<tr>
<td>Tmin, Tmax</td>
<td>0.886, 0.894</td>
<td>0.767, 1.000</td>
</tr>
<tr>
<td>Tmin'</td>
<td>0.859</td>
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<tr>
<td>Correction method= # Reported T Limits: Tmin= 0.767 Tmax= 1.000</td>
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</tr>
<tr>
<td>AbsCorr</td>
<td>MULTI-SCAN</td>
<td></td>
</tr>
<tr>
<td>Data completeness= 1.38/0.73</td>
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</tr>
<tr>
<td>R(reflections)= 0.0283(2242)</td>
<td>wR2(reflections)= 0.0747(2269)</td>
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<tr>
<td>S = 1.067</td>
<td>Npar= 237</td>
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</tr>
<tr>
<td>Displacement ellipsoids are drawn at 30% probability level</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
6. Chiral HPLC chromatograms

Chiral HPLC chromatogram of (S)-1a

<table>
<thead>
<tr>
<th>Peak</th>
<th>Processed Channel</th>
<th>Retention Time (min)</th>
<th>Peak Area (mAU*s)</th>
<th>Peak Area (%)</th>
<th>Peak Height (mAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DAD 230, 16 nm</td>
<td>18.042</td>
<td>3.68736e4</td>
<td>48.58</td>
<td>660.24542</td>
</tr>
<tr>
<td>2</td>
<td>DAD 230, 16 nm</td>
<td>21.343</td>
<td>3.90217e4</td>
<td>51.42</td>
<td>601.15894</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Peak</th>
<th>Processed Channel</th>
<th>Retention Time (min)</th>
<th>Peak Area (mAU*s)</th>
<th>Peak Area (%)</th>
<th>Peak Height (mAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DAD 230, 16 nm</td>
<td>18.416</td>
<td>7.73700e4</td>
<td>99.7096</td>
<td>928.00629</td>
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<tr>
<td>2</td>
<td>DAD 230, 16 nm</td>
<td>21.577</td>
<td>225.32170</td>
<td>0.2904</td>
<td>5.49626</td>
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</tbody>
</table>
Chiral HPLC chromatogram of the \((R)-3a\)

![Chiral HPLC chromatogram of the \((R)-3a\)](image)

<table>
<thead>
<tr>
<th>Peak</th>
<th>Processed Channel</th>
<th>Retention Time (min)</th>
<th>Peak Area (mAU*s)</th>
<th>Peak Area (%)</th>
<th>Peak Height (mAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DAD 254, 16 nm</td>
<td>6.781</td>
<td>7565.38525</td>
<td>52.84</td>
<td>225.82510</td>
</tr>
<tr>
<td>2</td>
<td>DAD 254, 16 nm</td>
<td>33.136</td>
<td>6751.08154</td>
<td>47.16</td>
<td>31.54109</td>
</tr>
</tbody>
</table>

![Chiral HPLC chromatogram of the \((R)-3a\)](image)

<table>
<thead>
<tr>
<th>Peak</th>
<th>Processed Channel</th>
<th>Retention Time (min)</th>
<th>Peak Area (mAU*s)</th>
<th>Peak Area (%)</th>
<th>Peak Height (mAU)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>DAD 254, 16 nm</td>
<td>6.778</td>
<td>6679.58350</td>
<td>95.59</td>
<td>197.24977</td>
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<tr>
<td>2</td>
<td>DAD 254, 16 nm</td>
<td>33.704</td>
<td>308.15250</td>
<td>4.41</td>
<td>2.50177</td>
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</tbody>
</table>