Supporting Information

A Green Synthesis and Antibacterial Activity of Ferrocene-based Thiazole Derivatives in Choline chloride/Glycerol Eutectic Solvent

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1. General information

The chemicals used in this work were obtained from Energy Chemical and were used without purification. Melting points were determined by use of a WRS-1B melting-point apparatus and were uncorrected. The $^1$H (400 MHz) and $^{13}$C (100 MHz) NMR spectra were recorded on an Agilent 400-MR spectrometer using CDCl$_3$ or DMSO-d$_6$ as solvent. The reported chemical shifts (δ values) are given in parts per million downfield from tetramethylsilane (TMS) as the internal standard (NMR abbreviations: s = singlet, d = doublet, t = triplet, q = quartet, dd = doublet of doublets, m = multiplet, $J$ = coupling constant). The mass spectra were determined using a MSD VL ESI1 spectrometer. HRMS (ESI) data were acquired on an Bruker Customer microTOF-Q 125 high-resolution mass spectrometer. Elemental analyses were carried out on an EA 2400II elemental analyzer (PerkinElmer, Waltham, MA). The progress of reactions was monitored by TLC on silica gel GF254 using ethyl acetate/petroleum ether (1:2) as the eluent.

2. General procedure for the preparation of the substrates 2l-u

These compounds 2l-u were synthesized by Friedel–Crafts thioamidation reaction according to the literature method[1]: The respective 1-alkylindole or 9-alkylcarbazole (10.0 mmol) was added to methanesulfonic acid (15 mL) under ice-cooling bath. To the solution was then added potassium thiocyanate (1.12 g, 11.5 mmol) slowly with stirring. The resulting reaction mixture was stirred at room temperature for about 5 h. After the completion of the reaction (TLC eluent for reaction monitorization), the mixture was poured into cold water (30 mL). The resulting precipitate was collected by filtration and recrystallized from ethyl acetate to give the corresponding products of carbothioamides 2l-u with analytically pure.

3. Preparation of the DES ChCl/Gly

The procedure for the preparation of the DES ChCl/Gly based on the method of literature[2]: A mixture of choline chloride (14.0 g, 0.1 mol) and glycerol (18.4 g, 0.2 mol) was heated up to 100 °C in a flask with stirring for 2h until a clear solution was produced. After cooling to room temperature and vacuum drying for 5 h, the resulting DES ChCl/Gly was sealed for later use.

4. General procedure for the synthesis of the targeted products 3a-u

Bromoacetylferrocene 1 (0.5 mmol, 0.154 g) and respective thioureas (2a-k), 1-alkylindole-3- (2l-p) or 9-alkylcarbazole-3-carbothioamides (2q-u) (0.55 mmol) was mixed in 6 mL of the ChCl/Gly (1 : 2 mol/mol). The resulting reaction mixture was stirred at 85 °C for 6~8 hours (as monitored by TLC). After the reaction was completed, the mixture was diluted with an equal volume of water and extracted using dichloromethane (DCM) (3 x 5 mL). The deep eutectic solvent could be easily isolated after removing H$_2$O from the aqueous layer under vacuum, and could be further used for the next run reaction. The combined DCM layer was dried over Na$_2$SO$_4$ followed by evaporation of the solvent under reduced vacuum to afford a crude solid product, which was further purified by recrystallization from ethanol to give the corresponding pure compounds 3a-u.

5. Characterization data of products 3a-u

N-Phenyl-4-ferrocenylthiazol-2-amine (3a)
Orange solid, yield 82%, mp 161.1-162.0 °C; IR (KBr): v 3102, 3074, 1621, 1578, 1525, 1493, 1110 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 4.32 (s, 5H, Fe-H), 4.44 (s, 2H, Fe-H), 4.81 (s, 2H, Fe-H), 6.25 (s, 1H, ArH), 7.34 (t, J = 8.0 Hz, 1H, ArH), 7.40 (d, J = 8.0 Hz, 2H, ArH), 7.49 (t, J = 8.0 Hz, 2H, ArH), 11.68 (s, 1H, NH); ¹³C NMR (100 MHz, CDCl₃) δ: 67.12, 70.37, 70.58, 71.67, 94.48, 121.04, 127.40, 130.22, 136.51, 141.29, 167.33. MS (ESI, m/z): 361.2 [M + H]⁺. HRMS (ESI, m/z) calculated for C₁₀H₁₀FeN₂NaS [M + Na]⁺: 383.0276, found 383.0269. Anal. Calcld for C₁₀H₁₀FeN₂S: C, 63.35; H, 4.48; N, 7.78. Found: C, 63.52; H, 4.54; N, 7.61.

4-Ferrocenyl-N-(o-tolyl)thiazol-2-amine (3b)

Yellow solid, yield 79%, mp 167.1-168.5 °C; IR (KBr): v 3200, 2879, 1619, 1585, 1549, 1404, 1300, 1057 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 2.44 (s, 3H, Me), 4.37 (s, 5H, Fe-H), 4.45 (s, 2H, Fe-H), 4.76 (s, 2H, Fe-H), 6.14 (s, 1H, ArH), 7.20-7.25 (m, 2H, ArH), 7.29 (d, J = 7.6 Hz, 1H, ArH), 7.35 (d, J = 7.6 Hz, 1H, ArH), 11.03 (s, 1H, NH); ¹³C NMR (100 MHz, CDCl₃) δ: 18.84, 67.48, 70.60, 70.65, 71.92, 95.00, 109.99, 122.60, 127.61, 128.60, 132.09, 133.37, 135.54, 141.44. MS (ESI, m/z): 375.1 [M + H]⁺. HRMS (ESI, m/z) calculated for C₁₀H₁₀FeN₂NaS [M + Na]⁺: 397.0432, found 397.0423. Anal. Calcld for C₁₀H₁₀FeN₂S: C, 64.18; H, 4.85; N, 7.48. Found: C, 64.31; H, 4.77; N, 7.23.

4-Ferrocenyl-N-(p-tolyl)thiazol-2-amine (3c)

Yellow solid, yield 87%, mp 159.3-160.1 °C; IR (KBr): v 3109, 2924, 1627, 1599, 1541, 1454, 1326, 1115 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 2.36 (s, 3H, Me), 4.30 (s, 5H, Fe-H), 4.40 (s, 2H, Fe-H), 4.79 (s, 2H, Fe-H), 6.23 (s, 1H, ArH), 7.24 (d, J = 7.6 Hz, 2H, ArH), 7.26 (d, J = 7.6 Hz, 2H, ArH), 7.62 (d, J = 7.6 Hz, 1H, ArH), 11.40 (s, 1H, NH); ¹³C NMR (100 MHz, CDCl₃) δ: 21.25, 67.60, 70.65, 71.82, 95.65, 121.67, 130.87, 133.94, 137.73, 141.13, 168.07. MS (ESI, m/z): 375.2 [M + H]⁺. HRMS (ESI, m/z) calculated for C₁₀H₁₀FeN₂NaS [M + Na]⁺: 397.0432, found 397.0437. Anal. Calcld for C₁₀H₁₀FeN₂S: C, 64.18; H, 4.85; N, 7.48. Found: C, 64.01; H, 4.88; N, 7.65.

N-(4-Methoxyphenyl)-4-Ferrocenylthiazol-2-amine (3d)

Yellow solid, yield 91%, mp 168.3-169.1 °C; IR (KBr): v 3071, 2735, 1616, 1575, 1526, 1509, 1474, 1328, 1128 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 3.82 (s, 3H, OMe), 4.29 (s, 5H, Fe-H), 4.40 (s, 2H, Fe-H), 4.76 (s, 2H, Fe-H), 6.17 (s, 1H, ArH), 6.95 (d, J = 7.6 Hz, 2H, ArH), 7.30 (d, J = 7.6 Hz, 2H, ArH), 11.19 (s, 1H, NH); ¹³C NMR (100 MHz, CDCl₃) δ: 55.73, 67.14, 70.41, 71.88, 94.58, 115.40, 124.29, 129.37, 141.16, 159.05, 169.02. MS (ESI, m/z): 391.1 [M + H]⁺. HRMS (ESI, m/z) calculated for C₁₀H₁₆FeN₂NaOS [M + Na]⁺: 413.0382, found 413.0374. Anal. Calcld for C₁₀H₁₆FeN₂OS: C, 61.55; H, 4.65; N, 7.18. Found: C, 61.68; H, 4.60; N, 7.29.

N-(4-Ethylphenyl)-4-fenrocenylthiazol-2-amine (3e)

Yellow solid, yield 85%, mp 139.5-141.2 °C; IR (KBr): v 3073, 2964, 2817, 1619, 1576, 1258, 1119 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 1.24 (t, J = 7.6 Hz, 3H, CH₃CH₂), 2.68 (q, J = 7.6 Hz, 2H, CH₂CH₃), 4.31 (s, 5H, Fe-H), 4.42 (s, 2H, Fe-H), 4.80 (s, 2H, Fe-H), 6.21 (s, 1H, ArH), 7.27 (d, J = 8.0 Hz, 2H, ArH), 7.37 (d, J = 8.0 Hz, 2H, ArH), 7.46 (d, J = 8.0 Hz, 2H, ArH), 7.50 (d, J = 8.0 Hz, 2H, ArH), 7.54 (d, J = 8.0 Hz, 2H, ArH), 7.59 (d, J = 8.0 Hz, 2H, ArH).
7.30 (d, J = 8.0 Hz, 2H, ArH), 11.44 (s, 1H, NH); 13C NMR (100 MHz, CDCl₃) δ : 15.42, 28.45, 67.48, 70.62, 70.69, 71.87, 94.93, 121.65, 129.63, 134.11, 141.20, 143.97, 167.89. MS (ESI, m/z): 389.2 [M + H]⁺. HRMS (ESI, m/z) caleld for C₁₉H₁₉FeN₂NaS [M + Na]⁺: 411.0589, found 411.0597. Anal. Caled for C₁₉H₁₉FeN₂S: C, 64.95; H, 5.19; N, 7.21. Found: C, 65.09; H, 5.39; N, 7.06.

N-(4-Fluorophenyl)-4-Ferrocenylthiazol-2-amine (3f)

Yellow solid, yield 76%, mp 145.3-145.7 °C; IR (KBr): v 3073, 2911, 1618, 1544, 1504, 1214, 1164 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ : 4.32 (s, 5H, Fe-H), 4.43 (s, 2H, Fe-H), 4.79 (s, 2H, Ar-H), 6.22 (s, 1H, Ar-H), 7.17 (d, J = 8.0 Hz, 2H, Ar-H), 7.39 (d, J = 8.0 Hz, 2H, Ar-H), 11.52 (s, 1H, NH); 13C NMR (100 MHz, CDCl₃) δ : 67.19, 68.93, 69.63, 102.50, 110.81, 116.45, 126.08, 140.45, 147.54, 161.40. MS (ESI, m/z): 379.2 [M + H]⁺. HRMS (ESI, m/z) caleld for C₁₇H₁₇FFeN₂NaS [M + Na]⁺: 401.0182, found 401.0185. Anal. Caled for C₁₇H₁₇FFeN₂S: C, 60.33; H, 4.00; N, 7.41. Found: C, 60.14; H, 4.15; N, 7.37.

N-(4-Chlorophenyl)-4-Ferrocenylthiazol-2-amine (3g)

Orange solid, yield 80%, mp 177.3-177.8 °C; IR (KBr): v 3330, 2850, 1596, 1559, 1520, 1307, 1263, 1213 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ : 4.16 (s, 5H, Fe-H), 4.41 (s, 2H, Fe-H), 4.90 (s, 2H, Fe-H), 7.09 (s, 1H, Ar-H), 8.02 (d, J = 8.0 Hz, 2H, Ar-H), 8.36 (d, J = 8.4 Hz, 2H, Ar-H), 11.10 (s, 1H, NH); 13C NMR (100 MHz, CDCl₃) δ : 67.19, 68.93, 69.63, 102.50, 110.81, 116.45, 126.08, 140.45, 147.54, 161.40. MS (ESI, m/z): 395.1, 397.0 [M + H]⁺. HRMS (ESI, m/z) caleld for C₁₇H₁₇ClFeN₂NaS [M + Na]⁺: 416.9887, found 416.9895. Anal. Caled for C₁₇H₁₇ClFeN₂S: C, 57.82; H, 3.83; N, 7.10. Found: C, 57.64; H, 3.75; N, 6.91.

N-(4-Bromophenyl)-4-Ferrocenylthiazol-2-amine (3h)

Yellow solid, yield 83%, mp 162.7- 164.2 °C; IR (KBr): v 3073, 2713, 1618, 1551, 1521, 1487, 1072 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ : 4.20 (s, 5H, Fe-H), 4.31 (s, 2H, Fe-H), 4.69 (s, 2H, Fe-H), 6.06 (s, 1H, Ar-H), 7.14 (d, J = 8.0 Hz, 2H, Ar-H), 7.42 (d, J = 8.0 Hz, 2H, Ar-H), 11.51 (s, 1H, NH); 13C NMR (100 MHz, CDCl₃) δ : 68.57, 71.31, 71.48, 95.61, 109.99, 120.68, 123.57, 133.57, 135.46, 141.76, 167.26. MS (ESI, m/z): 438.9, 441.1 [M + H]⁺. HRMS (ESI, m/z) caleld for C₁₇H₁₇BrFeN₂NaS [M + Na]⁺: 460.9381, found 460.9372. Anal. Caled for C₁₇H₁₇BrFeN₂S: C, 51.96; H, 3.44; N, 6.38. Found: C, 51.74; H, 3.56; N, 6.19.

2-((4-Ferrocenylthiazol-2-yl)amino)phenol (3i)

Yellow solid, yield 74%, mp 188.6-189.6 °C; IR (KBr): v 3074, 2968, 1612, 1523, 1392, 1143 cm⁻¹; ¹H NMR (400 MHz, DMSO-d₆) δ : 4.20 (s, 5H, Fe-H), 4.42 (s, 2H, Fc-H), 4.86 (s, 2H, Fc-H), 5.69 (s, 1H, OH), 6.92 (s, 1H, Ar-H), 6.94-6.98 (m, 1H, Ar-H), 7.07 (d, J = 7.6 Hz, 1H, Ar-H), 7.18 (t, J = 7.6 Hz, 1H, Ar-H), 7.59 (d, J = 7.6 Hz, 1H, Ar-H), 10.53 (s, 1H, NH); 13C NMR (100 MHz, DMSO-d₆) δ : 67.16, 69.98, 70.02, 75.27, 100.19, 117.07, 120.12, 123.64, 126.05, 127.88, 141.55, 150.34, 168.15. MS (ESI, m/z): 376.8 [M + H]⁺. HRMS (ESI, m/z) caleld for C₁₉H₁₈FeNO₃NaS [M + Na]⁺: 399.0225, found 399.0217. Anal. Caled for C₁₉H₁₈FeNO₃S: C, 60.65; H, 4.29; N, 7.45. Found: C, 60.89; H, 4.25; N, 7.57.

S4
N-Methyl-4-ferrocenylthiazol-2-amine (3j)

Red solid, yield 76%, mp 144.0-144.7 °C; IR (KBr): v 3200, 2879, 1585, 1549, 1404, 1300, 1157 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 2.91 (s, 3H, Me), 4.02 (s, 5H, Fe-H), 4.17 (s, 2H, Fe-H), 4.57 (s, 2H, Fe-H), 5.65 (s, 1H, NH), 6.28 (s, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 32.39, 66.71, 68.46, 69.45, 80.67, 98.14, 109.99, 150.85. MS (ESI, m/z): 299.1 [M + H]⁺. HRMS (ESI, m/z) calcd for C₁₄H₁₄FeN₂S [M + Na]⁺: 321.0120, found 321.0113. Anal. Calcd for C₁₄H₁₄FeN₂S: C, 56.39; H, 4.73; N, 9.39. Found: C, 56.51; H, 4.66; N, 9.57.

N-(Benzo[d][1,3]dioxol-5-yl)-4-ferrocenylthiazol-2-amine (3k)

Yellow solid, yield 81%, mp 175.2-175.8 °C; IR (KBr): v 3083, 1995, 1612, 1523, 1392, 1143 cm⁻¹; ¹H NMR (400 MHz, CDCl₃) δ: 4.26 (s, 5H, Fe-H), 4.39 (s, 2H, Fe-H), 4.75 (s, 2H, Fe-H), 6.03 (s, 2H, OCH₂O), 6.20 (s, 1H, ArH) 6.81-6.84 (m, 3H, ArH), 11.25 (s, 1H, NH); ¹³C NMR (100 MHz, CDCl₃) δ: 66.99, 70.29, 70.48, 71.77, 94.56, 102.19, 104.09, 109.01, 116.08, 130.45, 141.20, 147.29, 148.90, 168.78. MS (ESI, m/z): 405.2 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₀H₁₄FeN₂O₂NaS [M + Na]⁺: 427.0175, found 427.0167. Anal. Calcd for C₂₀H₁₄FeN₂O₂S: C, 59.42; H, 3.99; N, 6.93. Found: C, 59.67; H, 4.13; N, 7.12.

2-(1-Methyl-1H-indol-3-yl)-4-ferrocenylthiazole (3l)

Yellow solid, yield 74%, mp 122.0-122.8 °C; IR (KBr): v 3107, 2934, 1618, 1545, 1467, 1373, 1358, 1179; ¹H NMR (400 MHz, CDCl₃) δ: 3.76 (s, 3H, CH₃), 4.04 (s, 5H, Fe-H), 4.24 (s, 2H, Fe-H), 4.80 (s, 2H, Fe-H), 6.86 (s, 1H, ArH), 7.24-7.30 (m, 3H, ArH), 7.75 (s, 1H, ArH), 8.29 (d, J = 8.4 Hz, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 33.21, 67.29, 68.75, 69.57, 106.84, 109.70, 109.98, 121.14, 122.73, 125.41, 125.47, 129.12, 137.29, 154.48, 161.94. MS (ESI, m/z): 399.1 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₂H₁₈FeN₂S [M + Na]⁺: 421.0438, found 421.0422. Anal. Calcd for C₂₂H₁₈FeN₂S: C, 66.34; H, 4.56; N, 7.03. Found: C, 66.56; H, 4.37; N, 7.21.

2-(1-Ethyl-1H-indol-3-yl)-4-ferrocenylthiazole (3m)

Yellow solid, yield 71%, mp 116.4-118.2 °C; IR (KBr): v 3104, 2969, 1611, 1541, 1468, 1395, 1335, 1195; ¹H NMR (400 MHz, CDCl₃) δ: 1.54 (t, J = 7.2 Hz, 3H, CH₂CH₃), 4.11 (s, 5H, Fe-H), 4.25 (q, J = 6.8 Hz, 2H, CH₂CH₃), 4.31 (s, 2H, Fe-H), 4.87 (s, 2H, Fe-H), 6.96 (s, 1H, ArH), 7.29-7.33 (m, 2H, ArH), 7.39 (t, J = 7.6 Hz, 1H, ArH), 7.82 (s, 1H, ArH), 8.39 (d, J = 8.4 Hz, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 15.39, 41.39, 67.26, 68.69, 69.54, 106.82, 109.74, 109.96, 121.06, 121.25, 122.58, 125.58, 127.37, 136.34, 154.48, 161.98. MS (ESI, m/z): 413.0 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₃H₂₀FeN₂S [M + Na]⁺: 435.0594, found 435.0609. Anal. Calcd for C₂₃H₂₀FeN₂S: C, 67.00; H, 4.89; N, 6.79. Found: C, 66.84; H, 5.04; N, 6.65.

2-(1-Butyl-1H-indol-3-yl)-4-ferrocenylthiazole (3n)

Yellow solid, yield 68%, mp 94.6-96.2 °C; IR (KBr): v 3117, 2974, 1615, 1543, 1469, 1395, 1356, 1175; ¹H NMR (400 MHz, CDCl₃) δ: 0.89 (t, J = 7.2 Hz, 3H, CH₃), 1.32 (sext, J = 7.2 Hz, 2H, CH₂), 1.82 (quint, J = 7.2 Hz, 2H, CH₂), 4.06 (s, 5H, Fe-H), 4.10 (t, J = 7.2 Hz,
2H, CH₂), 4.26 (s, 2H, Fe-H), 4.82 (s, 2H, Fe-H), 6.85 (s, 1H, ArH), 7.22-7.25 (m, 2H, ArH), 7.31 (d, J = 7.6 Hz, 1H, ArH), 7.69 (s, 1H, ArH), 8.32 (d, J = 8.0 Hz, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 11.70, 18.16, 30.18, 44.49, 65.29, 66.74, 67.62, 104.86, 107.83, 107.96, 118.97, 119.24, 120.52, 123.48, 125.99, 134.61, 152.49, 159.94. MS (ESI, m/z): 441.3 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₅H₂₆Fe₇N₈S₂ [M + Na⁺]: 463.0907, found 463.0893. Anal. Calcd for C₂₅H₂₆Fe₇N₈S₂: C, 68.18; H, 5.49; N, 6.36. Found: C, 68.29; H, 5.64; N, 6.11.

2-(1-Benzyl-1H-indol-3-yl)-4-ferrocenylthiazole (3o)

Yellow solid, yield 76%, mp 167.5-168.4 °C; IR (KBr): ν 3115, 2970, 1618, 1543, 1470, 1396, 1352, 1172; ¹H NMR (400 MHz, DMSO-d₆) δ: 4.08 (s, 5H, Fe-H), 4.35 (s, 2H, Fe-H), 4.90 (s, 2H, Fe-H), 5.54 (s, 2H, ArCH₃), 7.23-7.32 (m, 5H, ArH), 7.35 (d, J = 8.0 Hz, 2H, ArH), 7.44 (s, 1H, ArH), 7.58 (d, J = 8.0 Hz, 1H, ArH), 8.33 (s, 1H, ArH), 8.36 (d, J = 8.4 Hz, 1H, ArH); ¹³C NMR (100 MHz, DMSO-d₆) δ: 49.79, 67.38, 68.96, 69.65, 80.86, 108.22, 110.78, 111.45, 121.26, 121.56, 123.07, 125.43, 127.61, 127.99, 129.07, 130.08, 136.77, 138.02, 154.32, 161.78. MS (ESI, m/z): 475.1 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₅H₂₆Fe₇N₈S₂ [M + Na⁺]: 497.0751, found 497.0768. Anal. Calcd for C₂₅H₂₆Fe₇N₈S₂: C, 70.89; H, 4.67; N, 5.91. Found: C, 71.10; H, 4.53; N, 6.15.

2-(1-(4-Chlorobenzyl)-1H-indol-3-yl)-4-ferrocenylthiazole (3p)

Yellow solid, yield 73%, mp 177.7-179.5 °C; IR (KBr): ν 3114, 2968, 1617, 1541, 1474, 1393, 1337, 1174; ¹H NMR (400 MHz, CDCl₃) δ: 4.05 (s, 5H, Fe-H), 4.25 (s, 2H, Fe-H), 4.81 (s, 2H, Fe-H), 5.28 (s, 2H, ArCH₃), 6.91 (d, J = 8.4 Hz, 1H, ArH), 7.03 (d, J = 8.4 Hz, 2H, ArH), 7.19 (d, J = 8.4 Hz, 2H, ArH), 7.22-7.27 (m, 3H, ArH), 7.78 (s, 1H, ArH), 8.35 (d, J = 7.6 Hz, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 49.88, 67.30, 68.79, 69.56, 107.04, 109.99, 110.12, 121.39, 121.52, 123.12, 125.71, 128.12, 128.18, 129.09, 133.79, 135.01, 136.73, 154.49, 158.27. MS (ESI, m/z): 509.1, 511.0 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₆H₂₆ClFe₇N₈S₂ [M + Na⁺]: 531.0361, found 531.0383. Anal. Calcd for C₂₆H₂₆ClFe₇N₈S₂: C, 66.09; H, 4.16; N, 5.51. Found: C, 66.19; H, 4.34; N, 5.28.

2-(9-Methyl-9H-carbazol-2-yl)-4-ferrocenylthiazole (3q)

Yellow solid, yield 72%, mp 163.2-164.1 °C; IR (KBr): ν 3052, 2961, 1611, 1596, 1541, 1452, 1382, 1234, 1153; ¹H NMR (400 MHz, CDCl₃) δ: 8.60 (s, 1H, ArH), 8.12 (d, J = 7.6 Hz, 1H, ArH), 8.03 (d, J = 7.6 Hz, 1H, ArH), 7.44 (t, J = 7.6 Hz, 1H, ArH), 7.34 (d, J = 7.6 Hz, 2H, ArH), 7.23 (t, J = 8.4 Hz, 1H, ArH), 6.81 (s, 1H, ArH), 5.02 (s, 2H, Fe-H), 4.49 (s, 2H, Fe-H), 4.24 (s, 5H, Fe-H), 3.80 (s, 3H, CH₃); ¹³C NMR (100 MHz, CDCl₃) δ: 29.37, 68.39, 70.42, 71.42, 108.63, 108.77, 110.22, 118.82, 119.46, 120.72, 122.82, 123.00, 124.76, 125.25, 126.22, 141.51, 141.91, 155.53, 168.41. MS (ESI, m/z): 449.2 [M + H]⁺. HRMS (ESI, m/z) calcd for C₂₆H₂₆Fe₇N₈S₂ [M + Na⁺]: 471.0594, found 471.0611. Anal. Calcd for C₂₆H₂₆Fe₇N₈S₂: C, 69.65; H, 4.50; N, 6.25. Found: C, 69.49; H, 4.37; N, 6.42.

2-(9-Ethyl-9H-carbazol-2-yl)-4-ferrocenylthiazole (3r)

Yellow solid, yield 68%, mp 149.2-150.3 °C; IR (KBr): ν 3103, 2966, 1619, 1598, 1545, 1455, 1376, 1233, 1157; ¹H NMR (400 MHz, CDCl₃) δ: 1.49 (t, J = 6.8 Hz, 3H, CH₃CH₂), 4.40 (s, 5H, Fe-H), 4.43 (q, J = 6.8
Hz, 2H, CH₂CH₃), 4.45 (d, J=2.0 Hz, 2H,Fc-H), 4.98 (d, J=2.0 Hz, 2H,Fc-H), 7.02 (s, 1H, ArH), 7.31 (t, J = 7.6 Hz, 1H,ArH), 7.44-7.48 (m, 2H,ArH), 7.53 (t, J = 7.6 Hz, 1H,ArH), 8.15 (d, J = 7.6 Hz, 1H, ArH), 8.23 (d, J = 7.2 Hz, 1H, ArH), 8.74 (s, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 14.13, 38.01, 68.17, 68.56, 69.97, 70.91, 108.84, 109.00, 109.97, 119.16, 121.07, 123.25, 123.44, 124.94, 125.52, 126.38, 140.72, 141.13, 155.79, 168.60. MS (ESI, m/z): 463.0 [M + H⁺]. HRMS (ESI, m/z) calcd for C₇H₇FeN₂NaS [M + Na⁺]: 485.0751, found 485.0739. Anal. Caled for C₇H₇FeN₂S: C, 70.13; H, 4.80; N, 6.06. Found: C, 69.94; H, 4.71; N, 6.17.

2-(9-Butyl-9H-carbazol-2-yl)-4-ferrocenythiazole (3s)

Orange solid, yield 65%, mp 107.8-108.7 °C; IR (KBr): ν 3118, 2959, 1610, 1594, 1541, 1458, 1366, 1237, 1161; ¹H NMR (400 MHz, CDCl₃) δ: 0.88 (t, J = 7.2 Hz, 3H, CH₃), 1.30-1.38 (sext, J = 7.2 Hz, 2H,CH₂), 1.81 (quint, J = 7.2 Hz, 2H,CH₂), 4.16 (s, 5H, FC-H), 4.26 (t, J = 7.2 Hz, 2H, CH₂), 4.39 (s, 2H, FC-H), 4.94 (s, 2H, FC-H), 6.88 (s, 1H, ArH), 7.22 (t, J = 8.0 Hz, 1H,ArH), 7.34-7.37 (m, 2H, ArH), 7.42 (t, J = 8.0 Hz, 1H, ArH), 8.03 (d, J = 8.0 Hz, 1H, ArH), 8.12 (d, J = 7.6 Hz, 1H, ArH), 8.62 (s, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 13.92, 20.57, 31.13, 43.06, 67.94, 69.72, 70.64, 82.19, 108.92, 109.03, 109.78, 118.91, 119.35, 120.79, 122.90, 123.06, 124.71, 125.14, 126.12, 140.96, 141.44, 155.52, 168.42. MS (ESI, m/z): 491.1 [M + H⁺]. HRMS (ESI, m/z) calcd for C₃₂H₃₂FeN₂NaS [M + Na⁺]: 513.1064 , found 513.1078. Anal. Caled for C₃₂H₃₂FeN₂S: C, 71.02; H, 5.34; N, 5.71. Found: C, 71.19; H, 5.28; N, 5.53.

2-(9-Benzyl-9H-carbazol-2-yl)-4-ferrocenythiazole (3t)

Yellow solid, yield 70%, mp 161.4-161.9 °C; IR (KBr): ν 3109, 2924, 2924, 1599, 1541, 1454, 1385, 1238, 1161; ¹H NMR (400 MHz, CDCl₃) δ: 4.09 (s, 5H, FC-H), 4.32 (s, 2H, FC-H), 4.88 (s, 2H, FC-H), 5.49 (s, 2H, CH₂), 6.96 (s, 1H, ArH), 7.08 (d, J = 8.4 Hz, 1H, ArH), 7.18-2.66 (m, 3H, ArH), 7.34 (t, J = 7.6 Hz, 2H, ArH), 7.40 (t, J = 7.6 Hz, 1H, ArH), 8.04 (d, J = 8.0 Hz, 1H, ArH), 8.71 (s, 1H, ArH); ¹³C NMR (100 MHz, CDCl₃) δ: 42.54, 66.63, 66.69, 68.28, 68.88, 107.55, 107.59, 109.70, 117.76, 118.01, 119.72, 122.15, 122.21, 123.51, 124.60, 124.81, 125.69, 127.92, 129.00, 132.70, 138.91, 139.37, 156.14, 166.77. MS (ESI, m/z): 525.2 [M + H⁺]. HRMS (ESI, m/z) calcd for C₃₂H₃₂FeN₂NaS [M + Na⁺]: 547.0907, found 547.0896. Anal. Caled for C₃₂H₃₂FeN₂S: C, 73.28; H, 4.61; N, 5.34. Found: C, 73.51; H, 4.70; N, 5.13.

2-(9-(4-Chlorobenzyl)-9H-carbazol-2-yl)-4-ferrocenythiazole (3u)

Yellow solid, yield 66%, mp 178.0-178.7 °C; IR (KBr): ν 3120, 2955, 1617, 1597, 1549, 1450, 1378, 1235, 1163; ¹H NMR (400 MHz, DMSO-d₆) δ: 4.08 (s, 5H, FC-H), 4.36 (s, 2H, FC-H), 4.93 (s, 2H, FC-H), 5.74 (s, 2H, CH₂), 7.21 (d, J = 8.4 Hz, 2H, ArH), 7.31 (d, J = 8.4 Hz, 1H, ArH), 7.36 (d, J = 7.6 Hz, 2H, ArH), 7.50 (t, J = 7.6 Hz, 1H, ArH), 7.60 (s, 1H, ArH), 7.69 (d, J = 8.0 Hz, 1H, ArH), 7.79 (d, J = 8.4 Hz, 1H, ArH), 8.11 (d, J = 8.0 Hz, 1H, ArH), 8.38 (d, J = 8.4 Hz, 1H, ArH), 8.82 (s, 1H, ArH); ¹³C NMR (100 MHz, DMSO-d₆) δ: 45.48, 67.43, 69.02, 69.70, 80.61, 110.37, 110.55, 111.03, 118.92, 120.25, 121.45, 122.70, 123.11, 124.94, 125.48, 127.03, 129.04, 132.36, 136.97, 141.09, 141.47, 155.38, 167.64. MS (ESI, m/z): 559.0, 561.1 [M + H⁺]. HRMS (ESI, m/z) calcd for C₃₂H₃₂ClFeN₂NaS [M + Na⁺]: 581.0518, found 581.0531. Anal. Caled for
C₃₂H₂₃ClFeN₂S:  C,  68.77;  H,  4.15;  N,  5.01.  Found:  C,  68.92;  H,  4.24;  N,  4.89.
6. $^1$H NMR and $^{13}$C NMR spectra of products 3a-u

Fig. S1 $^1$H NMR spectrum of 3a

Fig. S2 $^{13}$C NMR spectrum of 3a
Fig. S3 $^1$H NMR spectrum of 3b

Fig. S4 $^1$H NMR spectrum of 3b
Fig. S5 $^1$H NMR spectrum of 3c

Fig. S6 $^{13}$C NMR spectrum of 3c
Fig. S7 $^1$H NMR spectrum of 3d

Fig. S8 $^{13}$C NMR spectrum of 3d
Fig. S9 ¹H NMR spectrum of 3e

Fig. S10 ¹³C NMR spectrum of 3e
Fig. S11 $^1$H NMR spectrum of 3f

Fig. S12 $^{13}$C NMR spectrum of 3f
Fig. S13 $^1$H NMR spectrum of 3g

Fig. S14 $^{13}$C NMR spectrum of 3g
Fig. S15 $^1$H NMR spectrum of 3h

Fig. S16 $^{13}$C NMR spectrum of 3h
Fig. S17 $^1$H NMR spectrum of 3i

Fig. S18 $^{13}$C NMR spectrum of 3i
Fig. S19 $^1$H NMR spectrum of 3j

Fig. S20 $^{13}$C NMR spectrum of 3j
Fig. S21 $^1$H NMR spectrum of 3k

Fig. S22 $^{13}$C NMR spectrum of 3k
Fig. S23 $^1$H NMR spectrum of 3I

Fig. S24 $^{13}$C NMR spectrum of 3I
Fig. S25 $^1$H NMR spectrum of 3m

Fig. S26 $^{13}$C NMR spectrum of 3m
Fig. S27 ¹H NMR spectrum of 3n

Fig. S28 ¹³C NMR spectrum of 3n
Fig. S29 $^1$H NMR spectrum of 3o

Fig. S30 $^{13}$C NMR spectrum of 3o
Fig. S31 $^1$H NMR spectrum of 3p

Fig. S32 $^{13}$C NMR spectrum of 3p
Fig. S33 $^1$H NMR spectrum of 3q

Fig. S34 $^{13}$C NMR spectrum of 3q
Fig. S35 $^1$H NMR spectrum of $3r$

Fig. S36 $^{13}$C NMR spectrum of $3r$
Fig. S37 $^{13}$C NMR spectrum of 3s

Fig. S38 $^1$H NMR spectrum of 3s
Fig. S39 $^1$H NMR spectrum of 3t

Fig. S40 $^{13}$C NMR spectrum of 3t
Fig. S41 $^1$H NMR spectrum of 3u

Fig. S42 $^{13}$C NMR spectrum of 3u
7. Antibacterial activity assay

All these newly-synthesized compounds 3a-u herein were screened for their potential in vitro antibacterial activities against *Bacillus subtilis (B. subtilis)* [CMCC (B) 63501], *Staphylococcus aureus* (S. aureus) [CMCC (B) 26003], *Escherichia coli* (E. coli) [CMCC (B) 44102] and *Pseudomonas aeruginosa* (P. aeruginosa) [CMCC (B) 10104] by the broth microdilution assay. Each of the test compounds was dissolved in DMSO and then was serially diluted in different concentrations at 2-fold dilutions (250, 125, 62.5, 31.25, 15.625, 7.8125 μg/mL) to determine the MICs. Ciprofloxacin was used as the reference standard.

8. References