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Synthesis and properties study of novel ferrocenyl isoxazole derivatives

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A synthetic procedure based on the 1,3-dipolar cycloaddition reactions of nitrile oxides and ethynylferrocene derived from ferrocene has been developed to synthesize new ferrocenyl-isoxazole derivatives. The stable solids were thoroughly characterized by ^{1}H NMR, FT-IR, and mass spectroscopy. The structure of (η^5-C_5H_5) Fe (η^5-C_5H_4) $C_3HNOC_6H_4CH_3$ was determined by single-crystal X-ray diffraction. The electrochemical behaviors of the synthesized ferrocenyl-isoxazole derivatives were also studied. Copyright © 2006 John Wiley & Sons, Ltd.

KEYWORDS: ferrocene; isoxazole; 1,3-dipolar cycloaddition, electrochemistry, crystal structure

INTRODUCTION

The 1,3-dipolar cycloaddition reaction[1–3] (1,3-DC) is an important tool for the synthesis of a variety of five-numbered heterocyclic compounds that are difficult to access through other routes. The starting materials for this carbon–carbon coupling method are olefins, aldehydes and aliphatic primary nitro compounds. These compounds are often relatively inexpensive and easily available chemicals, which make the method more attractive.[4–7]

Isoxazole and its derivatives play an important role in the synthesis of potential medicines including anti-infective, antitumour, cardiovascular and nervous system agents.[8–10] Isoxazole derivatives have also served as a versatile building block in organic synthesis. The main method that has been employed generally to prepare isoxazole derivatives is 1,3-dipolar cycloaddition of alkenes or alkynes with nitrile oxides from the dehydrohalogenation of hydroximoyl chlorides in the presence of triethylamine.[11–13]

During the last three decades, much attention has been devoted to the chemistry of ferrocenyl complexes because ferrocene combines chemical versatility with high thermal stability.[14] These properties, together with the exceptional electrochemical properties of ferrocene, make ferrocene-based complexes good candidates for the preparation of new materials with applications in organic synthesis,[15–17] asymmetric catalysis,[18,19] nonlinear optics[20] and electrochemistry[21] due to the quasi-reversible oxidation of iron(II). A large number of studies have reported the study of the electroanalytical behaviour of ferrocenyl-substituted azaheterocycles, which is motivated by the analytical applications of these heterocyclic compounds and also by their biological properties (bacteriostatics, plant growth inhibitors).[21–28] However, to the best of our knowledge, the synthesis of ferrocenyl-substituted isoxazoles has not been widely investigated except for a few examples,[29] so we have initiated a program dealing with ferrocenylisoxazole derivatives. In our previous research, ferrocene derivatives containing 1,3,4-thiadiazole rings have been synthesized and their voltammetric behaviour was also studied.[30] In continuation of our studies on the synthesis of ferrocenyl-substituted azaheterocycles[31–33] and 1,3-dipolar cycloaddition,[34] herein we present the synthesis of ferrocenyl-substituted isoxazoles using the 1,3-dipolar cycloaddition reaction, and their electroanalytical behavior was studied by cyclic voltammetry (CV).

The required ethynylferrocene precursor was firstly synthesized from ferrocene in 62% yield according to previous literature.[34] The mono-substituted ferrocenyl-isoxazole derivatives were prepared from corresponding aldoxime in a one-pot operation (Scheme 1): after aldoxime and *N*-chlorosuccinimide (NCS) had been stirred at 30 °C for 40 min, ethynylferrocene and triethylamine were added,

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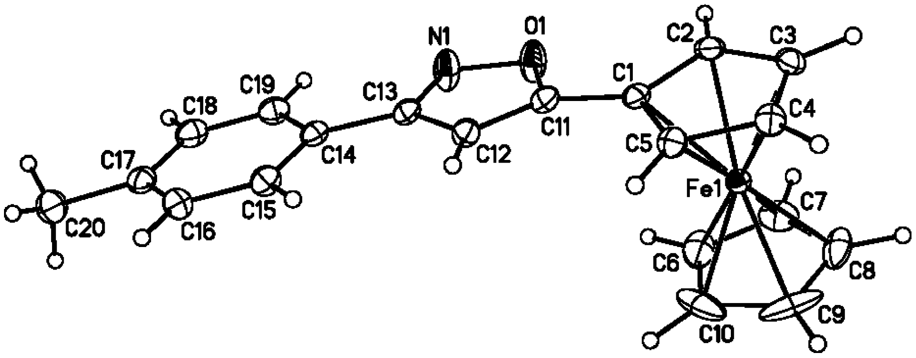

Figure 1. The structure of 5-ferrocenyl-3-(4-methylphenyl)-isoxazole (**5a**).

and the reaction mixture was stirred at room temperature for 20–22 h. The corresponding products were obtained in moderate to good yields. These mono-substituted ferrocenyl-isoxazole derivatives were purified by column chromatography and characterized by ^{1}H NMR spectroscopy and mass spectrometry, and compound **4a** was further elucidated by X-ray crystallographic analysis. Figure 1 shows the X-ray crystal structure of compound **5a**. All the results were in full agreement with the proposed structures.

To demonstrate the scope and potential for this kind of 1,3-dipolar cycloaddition reaction, a series of different substituted aldoximes **3** were reacted with ethynylferrocene at room temperature in the presence of triethylamine as the base. The results are summarized in Table 1. As shown, almost all reactions proceeded to completion in reasonable reaction times and the corresponding products were obtained on moderate to excellent yields, while the product yield was dependent on the electronic features of aryl substituents of the corresponding aldoxime derivatives. The 1,3-dipolar cyclization was formed in excellent to good yields in the reaction of ethylnylferrocene with aldoxime with an electron-donating substituent group on the benzene ring (Table 1, entries 1a–f), whereas an electron-withdrawing substituent lowered the yield (Table 1, entries 1g–j). To our surprise, the 1,3-dipolar cycloaddition reaction of 4-nitrobenzaldoxime with ethynylferrocene under the same reaction condition gave the corresponding product in very low yield. It should be emphasized here that the ferrocenyl-isoxazole derivative **5k** containing a furan ring was obtained in an overall yield of 65% from furanaldoxime under similar reaction conditions (Table 1, entry 1k). The above results indicated that electron-donating substituents would favor this version of the 1,3-dipolar cycloaddition.

In view of the interest in assessing the existence of electronic interactions of these ferrocenyl-isoxazole derivatives, we examined the ferrocene ligands **5a–k** on a glassy carbon electrode in $CH_3CN–CH_2Cl_2$ (3 : 2)–0.1 mol/l $TBAPF_6$. The magnitude of the electrochemical shift on ligands provides important thermodynamic information. The shift in redox potential on ligand is related to the ratio of ligands constant for the oxidized and reduced forms. The electrochemical values of ferrocenyl-isoxazole derivatives are presented in Table 2.

Figure 2 shows the cyclic voltammograms of **5f** [Fig. 2(a)], **5j** [Fig. 2(c)] and **5c** [Fig. 2(b)]. It can be seen that **5c** can be oxidized more easily than **5f**. In contrast, **5j** can be reduced more easily than **5f**. Those results could be explained by the electrochemical behaviors of the groups contained by **5j** and **5c**. The methoxy group could increase the density of electron cloud of benzene ring, and the nitryl could decrease the density of electron cloud of benzene ring. Therefore, the substituents on the aromatic ring would affect the redox of ferrocenyl-isoxazole derivatives.[36]

In conclusion, a variety of monoferrocenyl-isoxazoles were synthesized by trapping *in situ* ethynylferrocene with the nitrile oxides generated from the appropriate aldoximes in a practical one-pot operation in moderate to excellent yields. The X-ray crystal structure of 5-ferrocenyl-3-(4-methylphenyl)-isoxazole was determined. From the cyclic voltammograms of ferrocenyl-isoxazoles, we found that they all showed reversible redox behaviors and could be used as catalysts in electrochemical reactions.

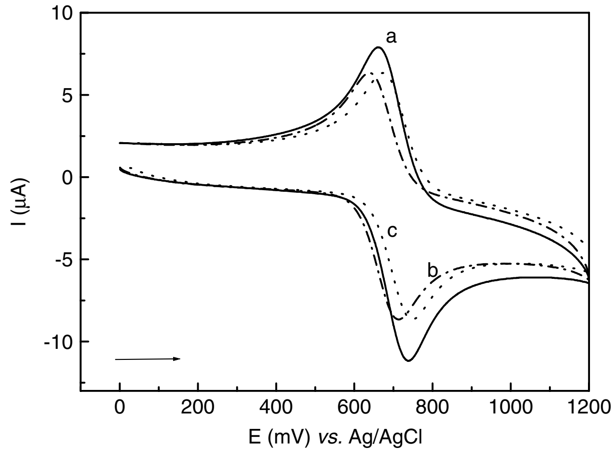

Figure 2. Cyclic voltammogram of (a) **5f**; (b) **5c**; and (c) **5j** in $CH_3CN–CH_2Cl_2$ (3 : 2) containing 0.1 mol l^{-1} $(n\text{-}C_4H_9)_4NPF_6$ at a scan rate of 0.100 V s^{-1}.

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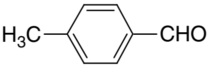
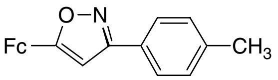
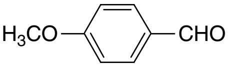
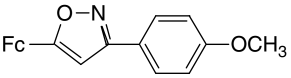
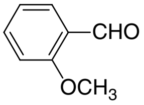
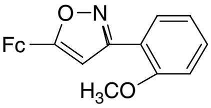
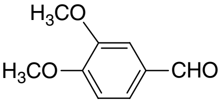
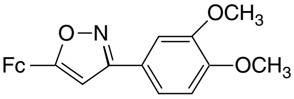
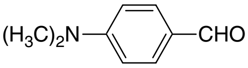
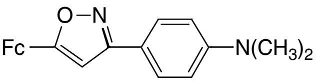
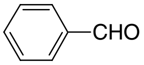
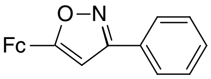
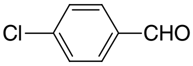
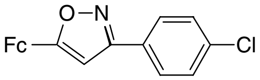
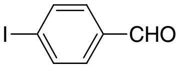
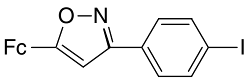
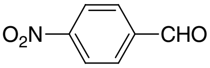
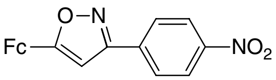
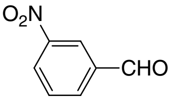
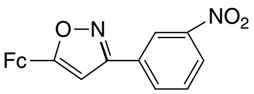
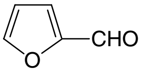
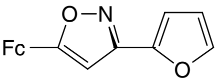
Table 1. Synthesis of 5-ferrocenyl isoxazoles

Entry (aldehyde)		Isoxazole		Time	Yield[a]
	**1a**		**5a**	20	89
	**1b**		**5b**	20	88
	**1c**		**5c**	20	85
	**1d**		**5d**	20	75
	**1e**		**5e**	20	53
	**1f**		**5f**	20	91
	**1g**		**5g**	20	85
	**1h**		**5h**	20	75
	**1i**		**5i**	22	38
	**1j**		**5j**	22	77
	**1k**		**5k**	20	65

[a] Isolated yields.

EXPERIMENTAL

All chemicals were obtained from commercial suppliers and used without further purification. Solvents such as DCM and DMF were freshly distilled. Column chromatography was performed with 100–200-mesh alumina. IR spectra were recorded on a Nicolet Nexus 470 FT-IR spectrometer. ^{1}H NMR spectra were recorded on a Bruker Avance DMX 300 instrument. All melting points were determined on an XT4A melting point apparatus.

The cyclic voltammetric measurements were performed on a CHI660B electrochemical analysis system controlled by a personal computer and driven by dedicated software. Cyclic voltammetry (CV) was carried out with a conventional three-electrode configuration consisting of glassy carbon working electrode and platinum wire auxiliary electrode and an Ag–AgCl reference electrode. The voltammetric experiments were performed in a 10^{-3} mol l^{-1} solution of sample in HPLC-grade CH_2Cl_2–CH_3CN (2 : 3) containing 0.1 mol l^{-1} tetra-*n*-butylammonium hexafluorophosphate [$(n\text{-}C_4H_9)_4NPF_6$] as supporting electrolyte. All the potential values reported are relative to an Ag–AgCl electrode at room temperature. Pure nitrogen was employed for deoxygenation of the solutions and the glassy carbon electrode was cleaned thoroughly after each run. The cyclic voltammograms were recorded with a scan rate of 0.100 V s^{-1}.

Crystals of 5-ferrocenyl-3-(4-methylphenyl)-isoxazole **5a** were obtained by slow evaporation from a solution in hexane–DCM. This yielded a piece-like crystal that was dark red. The results of the structural analysis are summarized and illustrated in Table 3 and Fig. 2. X-ray crystallographic data were determined on a Rigaku Mercury CCD X-ray diffractmeter (3 kV, sealed tube) at 193 K using graphite monochromated Mo $K\alpha$ ($k = 0.71070$ AX).

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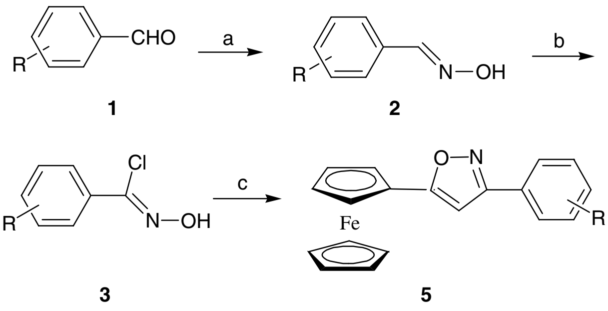
Table 2. Electrochemical date for compounds **5a–k**[35]

Compounds	$E^{0'}$ (ΔE_p)^a	$\Delta E^{0'}$ (mV)	K_{ox}/K_{red}(BEF)^b
Ferrocene	0.409(70)		
5a	0.682(75)	273	2.45×10^{-5}
5b	0.690(71)	281	1.79×10^{-5}
5c	0.675(76)	266	3.21×10^{-5}
5d	0.676(71)	267	3.1×10^{-5}
5e	0.700(65)	291	1.21×10^{-5}
5f	0.700(75)	291	1.21×10^{-5}
5g	0.704(69)	295	1.04×10^{-5}
5h	0.702(73)	293	1.12×10^{-5}
5i	0.777(73)	368	6.07×10^{-7}
5j	0.714(69)	305	7.05×10^{-6}
5k	0.683(72)	273	2.45×10^{-5}

[a] Potential formal is in V vs Ag–AgCl; ΔE_P is in mV. Data from cyclic voltammetry in $CH_3CN–CH_2Cl_2$ (3 : 2) containing 0.1 mol l^{-1} $(n\text{-}C_4H_9)_4NPF_6$ at a scan rate of 0.100 V s^{-1}.

[b] The equilibrium constants K_{ox} and K_{red} correspond to the ferrocenyl-isoxazole derivatives by the oxidized and reduced form. The ratio K_{ox}/K_{red} was calculated using the equation $\Delta E^{0'}nF/RT = \ln(K_{ox}/K_{red})$.



Scheme 1. Reagents and conditions: (a) $NH_2OH.HCl$, Na_2CO_3; (b) NCS, CH_2Cl_2; (c) ethynylferrocene, **4**, Et_3N.

General procedure for preparation of 3-aryl-5-ferrocenyl isoxazoles 5a–k

Ethynylferrocene was prepared according to reference 15. Hydroxylamine hydrochloride (1.2 eq.) and sodium bicarbonate (1.5 eq.) were added to aldehyde in ethanol. The mixture was stirred at room temperature overnight. The precipitate was removed by filtration and washed with water. After drying, the aldoxime was obtained.

Aldoxime(1 mmol) and chlorosuccinimide (NCS, 1 mmol) were stirred in flask containing dry chloroform (3 ml).The reaction mixture was refluxed at 30 °C for 40 min. The ethynylferrocene(1 mmol) was added. Triethylamine (1.4 ml in 3 ml of CH_2Cl_2) was added drop by drop over about 30 min. Then, the reaction mixture was stirred at room temperature for 20–22 h.The solution was concentrated in vacuum. The residue was purified by flash column chromatography (n-hexane–EtOAc = 3 : 1) on alumina gel to afford red crystals.

Table 3. Crystal data and structure refinement for compound **5a**

Compound	**5a**
Empirical formula	$C_{20}H_{17}FeNO$
Formula weight	343.20
Temperature (K)	193(2)
Wavelength (Å)	0.71070
Crystal system	Monoclinic
Space group	p 21/c
Unit cell dimensions	
a (Å)	19.057(3)
b (Å)	7.5907(11)
c (Å)	10.8039(15)
α (deg)	90
β (deg)	99.133(4)
γ (deg)	90
Volume ($Å^3$)	1543.0(4)
Z	4
Calculated density (mg/m^3)	1.477
Absorption coefficient (mm^{-1})	0.981
F(000)	712
Crystal size (mm)	0.38 × 0.35 × 0.07
θ_{max} (deg)	25.34
Maximum indices *hkl*	22, 9, 12
Reflections collected/unique	14739/2821
R_{int}	0.0290
Absorption correction	Semi-empirical from equivalents
Maximum and minimum transmission	0.9345 and 0.7070
Data/restraints/parameters	2821/0/210
Goodness-of-fit on F^2	1.139
Final R indices [$I > 2\sigma(I)$]	$R_1 = 0.0387$, $wR_2 = 0.0866$
R indices (all data)	$R_1 = 0.0444$, $wR_2 = 0.0894$
Largest difference peak and hole (e A^{-3})	0.304 and −0.281

*5-Ferrocenyl-3-(4-methylphenyl)-isoxazole (**5a**)*

Red crystal; m.p. = 179–181 °C. IR (KBr): 1614, 1600, 1556, 1476, 1385, 1106, 1012, 818 cm^{-1}. ^1H NMR($CDCl_3$, 300 MHz): $\delta = 2.42$ (s, 3H, $-\mathbf{CH_3}$), 4.17 (s, 5H, $C_5\mathbf{H}_5$), 4.43 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.79 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.45 (s, 1H,CH of $-C_3\mathbf{H}ON-$), 7.30(d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 7.76 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 30.0, 67.0, 69.8, 70.0, 95.8, 130.1, 131.0, 162.2, 171.7$. EIMS: $m/z = 343.1$ (M^+).

*5-Ferrocenyl-3-(4-methoxyphenyl)-isoxazole (**5b**)*

Red crystal; m.p. = 108–111 °C. IR (KBr): 1612, 1581, 1513, 1467, 1400, 1280, 1096, 1024, 810 cm^{-1}. ^1H NMR($CDCl_3$, 300 MHz): $\delta = 3.91$ (s, 3H, $-O\mathbf{CH_3}$), 4.12 (s, 5H, $C_5\mathbf{H}_5$), 4.42 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.79 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.41(s, 1H,CH

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of $-C_3\mathbf{H}ON-$), 7.01 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 7.84 (dd, $J = 9$, 9 Hz, 2H, 2CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 55.3$, 67.0, 69.8, 70.0, 95.8, 128.1, 129.0, 162.2, 171.7. EIMS: $m/z = 359.1$ (M^+).

*5-Ferrocenyl-3-(2-methoxyphenyl)-isoxazole (**5c**)*

Red crystal; m.p. = 130–132 °C. IR (KBr): 1614, 1578, 1484, 1447, 1438, 1384, 1257, 1087, 1032, 720 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.95$ (s, 3H, $-OC\mathbf{H}_3$), 4.17 (s, 5H, $C_5\mathbf{H}_5$), 4.41 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.79 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.68 (s, 1H,CH of $-C_3\mathbf{H}ON-$), 7.01–7.09 (m, 2H, 2CH of $C_6\mathbf{H}_4$), 7.69 (t, $J = 9$ Hz, 1H, 1CH of $C_6\mathbf{H}_4$), 7.97 (dd, $J = 7.64$, 1.5 Hz, 1H, 1CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 55.3$, 67.1, 69.9, 70.1, 95.8, 123.1, 124.6, 128.1, 129.0, 162.2, 171.7. EIMS: $m/z = 359.1$ (M^+).

*5-Ferrocenyl-3-(3, 4-dimethoxyphenyl)-isoxazole (**5d**)*

Red crystal; m.p. = 108–111 °C. IR (KBr): 1616, 1575, 1518, 1490, 1095, 1030, 810 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.91$ (s, 1H, $-OC\mathbf{H}_3$), 3.99 (s, 1H, $-OC\mathbf{H}_3$) 4.17 (s, 5H, $C_5\mathbf{H}_5$), 4.43 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.79 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.43 (s, 1H, CH of $-C_3\mathbf{H}ON-$), 6.94 (d, $J = 9$ Hz, 1H, CH of $C_6\mathbf{H}_4$), 7.36 (d, $J = 9$ Hz, 1H, CH of $C_6\mathbf{H}_4$), 7.47 (s, 1H, CH of $C_6\mathbf{H}_4$).^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 55.4$, 67.0, 69.8, 70.2, 95.9, 126.1, 127.6, 129.0, 162.2, 171.8. EIMS: $m/z = 389.1$ (M^+).

*5-Ferrocenyl-3-(4-N, N-dimethylphenyl)-isoxazole (**5e**)*

Red crystal; m.p. = 189–192 °C. IR(KBr):1617, 1548, 1527, 1481, 1443, 1411, 1332, 1103, 1033, 810 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 3.09$ [s, 6H, $-N(C\mathbf{H}_3)_2$], 4.16 (s, 5H, $C_5\mathbf{H}_5$), 4.40 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.77 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.40 (s, 1H,CH of $-C_3\mathbf{H}ON-$), 6.76 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 7.73 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 44.7$, 67.1, 69.9, 70.1, 95.8, 128.1, 129.1, 162.2, 171.7. EIMS: $m/z = 372.1$ (M^+).

*5-Ferrocenyl-3-phenyl-isoxazole (**5f**)*

Red crystal; m.p. = 168–170 °C. IR (KBr): 1614, 1600, 1549, 1452, 1090, 1055, 770, 706 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 4.17$ (s, 5H, $C_5\mathbf{H}_5$), 4.43 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.80 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.48 (s, 1H, CH of $-C_3\mathbf{H}ON-$), 7.49 (d, $J = 6$ Hz, 3H, 3CH of $C_6\mathbf{H}_4$), 7.84–7.87 (dd, $J = 2$, 2Hz, 2H, 2CH of $C_6\mathbf{H}_4$).^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 67.0$, 69.8, 70.0, 95.8, 125.5, 127.4, 128.8, 162.2, 171.7. EIMS: $m/z = 329.0$ (M^+).

*5-Ferrocenyl-3-(4-chlorophenyl)-isoxazole (**5g**)*

Red crystal; m.p. = 199–201 °C. IR (KBr): 1613, 1576, 1518, 1491, 1092, 1024, 820 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 4.17$ (s, 5H, $C_5\mathbf{H}_5$), 4.44 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.79 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.44 (s, 1H, CH of $-C_3\mathbf{H}ON-$), 7.47 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 7.80 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$).^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 67.1$, 69.9, 70.1, 95.8, 128.0, 129.1, 162.2, 171.7. EIMS: $m/z = 363.0$ (M^+).

*5-Ferrocenyl-3-(4-iodophenyl)-isoxazole (**5h**)*

Red crystal; m.p. = 198–200 °C. IR (KBr): 1614, 1574, 1517, 1494, 1090, 1028, 811 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 4.17$ (s, 5H, $C_5\mathbf{H}_5$), 4.44 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.79(s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.43 (s, 1H, CH of $-C_3\mathbf{H}ON-$), 7.59 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 7.83 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$,75 MHz): $\delta = 67.0$, 69.8, 70.1, 95.9, 128.0, 129.0, 162.2, 171.7. EIMS: $m/z = 455.0$ (M^+).

*5-Ferrocenyl-3-(3-nitrophenyl)-isoxazole (**5i**)*

Red crystal; m.p. = 151–153 °C. IR (KBr) : 1617, 1576, 1519, 1496, 1093, 1031, 814 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 4.19$ (s, 5H, $C_5\mathbf{H}_5$), 4.48 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.83 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.56 (s, 1H, CH of $-C_3\mathbf{H}ON-$), 7.69 (t, $J = 9$ Hz, 1H, CH of $C_6\mathbf{H}_4$), 8.27 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 8.34 (m, 2H, 2CH of $C_6\mathbf{H}_4$), 8.66 (s, 1H, CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$,75 MHz): $\delta = 67.1$, 69.9, 70.3, 95.9, 124.1, 126.6, 127.5, 162.2, 171.7. EIMS: $m/z = 374.1$ (M^+).

*5-Ferrocenyl-3-(4-nitrophenyl)-isoxazole (**5j**)*

Red crystal; m.p. = 238–241 °C. IR (KBr): 1618, 1568, 1483, 1445, 1441, 1381, 1301, 1077, 1030, 710 cm^{-1}. ^{1}H NMR ($CDCl_3$, 300 MHz): $\delta = 4.19$ (s, 5H, $C_5\mathbf{H}_5$), 4.32 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.48 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.54 (s, 1H,CH of $-C_3\mathbf{H}ON-$), 8.06 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$), 8.41 (d, $J = 9$ Hz, 2H, 2CH of $C_6\mathbf{H}_4$). ^{13}C NMR ($CDCl_3$,75 MHz): $\delta = 67.1$, 69.9, 70.3, 95.9, 124.1, 127.5, 162.2, 171.7. EIMS: $m/z = 374.0$ (M^+).

*5-Ferrocenyl-3-furyl-isoxazole (**5k**)*

Red crystal; m.p. = 183–184 °C. IR(KBr): 1624, 1580, 1538, 1420, 1160, 1076 cm^{-1}. ^{1}H NMR ($CDCl_3$ 300 MHz): $\delta = 4.19$ (s, 5H, $C_5\mathbf{H}_5$), 4.47 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 4.81 (s, 2H, 2CH of $C_5\mathbf{H}_4$), 6.36 (d, $J = 3$ Hz, 1H, CH of $-C_3\mathbf{H}ON-$), 6.44 (s, 1H, 1CH of $-C_4\mathbf{H}_3O-$), 6.69 (d, $J = 3$ Hz, 2H, 2CH of $-C_4\mathbf{H}_3O-$). ^{13}C NMR ($CDCl_3$, 75 MHz): $\delta = 67.1$, 69.9, 70.1, 95.8, 107.8, 112.4, 145.6, 162.2, 171.7. EIMS: $m/z = 319.0$ (M^+).

Supplementary data

Crystallographic data have been deposited with the Cambridge Crystallographic Data Centre (CCDC 279756) for compound **5a**. Copies of the data can be obtained free of charge via www.ccdc.cam.ac.uk/conts/retrieving.html or CCDC, 12 Union Road, Cambridge CB21EZ, UK [Fax: (+44) 1223 336 033; email: deposit@ccdc.cam.ac.uk].

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