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Note

Synthesis, spectral characterization and electrochemical properties of 1*H*-3-(*o*-, *m*- and *p*-ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehydes

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ABSTRACT

New ferrocene derivatives – 1*H*-1-phenylpyrazole-4-carboxaldehydes containing *o*-, *m*- and *p*-ferrocenylphenyl group at position 3 – were synthesized and characterized. The electrochemical investigation showed that the position of the ferrocenyl group does not affect the redox potential of these compounds. The X-ray crystal structure of the *ortho*-derivative is also presented. The screening for the *in vitro* antimicrobial activity against eleven bacterial and three fungal/yeast strains exhibited complete inactivity of these aldehydes, but *n*-butyl imines of *ortho* and *meta* derivatives showed moderate activity compared to those of the used standards.

1. Introduction

It is well known that substitution of an aromatic nucleus of certain organic compounds with a ferrocene unit can lead to products possessing unexpected properties which are absent or less manifest in the parent molecule. This fact was the main driving force in synthesis of most known ferrocene derivatives: many new molecules were designed to be derivatives of known compounds (that already possess desired properties) in which a certain group was replaced with the ferrocene unit (expecting an improved property). Thus, many ferrocenes are of widespread interest in material sciences [1], like macromolecules containing ferrocene units, which combine novel optical, electrical, magnetic and chemical characteristics with the possibilities of polymers [2,3]. Bioconjugates containing this metallocene represent a new class of biomaterials, where the organometallic unit serves as a molecular scaffold, a sensitive probe, a chromophore, a biological marker, a redox-active site, a catalytic site, etc. [4]. A multitude of ferrocene-containing ligands are of great interest in coordination chemistry [1,5], and complexes of transition metals with such ligands, particularly with the chiral ones, are widely used as catalysts in organic synthesis [1,6]. Nowadays, many ferrocene derivatives have been biologically evaluated against certain diseases [7–15]. Since many heterocyclic compounds exhibit biological activities, it is not surprising that plenty of ferrocene-containing heterocycles have been synthesized so far. Although the pyrazole motif makes up the core structure of numerous biologically active compounds [16], it did not prompt chemists to put intensive efforts into synthesis of ferrocene derivatives of pyrazole. Thus, only a limited number of publications have been devoted to this problem until present [17,18]. We recently reported the synthesis of 1*H*-3-ferrocenyl-1-phenylpyrazole-4-carboxaldehyde (Scheme 1; R^1 = phenyl, R^2 = ferrocenyl) [19] by the literature method [20] used in the synthesis of the corresponding non-ferrocene derivatives (Scheme 1, R^1, R^2 = alkyl or aryl). This concept, as shown in Scheme 1, involves condensation of methyl ketones with hydrazines followed by cyclization of the obtained hydrazones under Vilsmeier–Haack conditions. In the present paper, we wish to report on the synthesis, spectral characterization, and electrochemical properties of three new 1*H*-1,3-diphenylpyrazole-4-carboxaldehyde containing ferrocene.

2. Results and discussion

2.1. Synthesis

In the first step of this synthesis (Scheme 2), we prepared ferrocenylacetophenones **3a–c** by coupling of ferrocene with the

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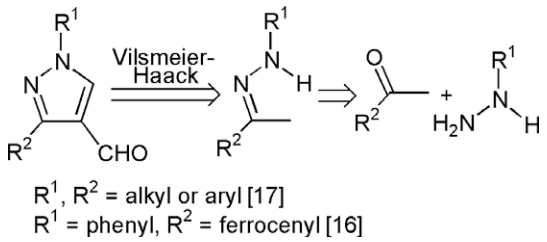


Scheme 1.

appropriate diazonium salts **2a–c**, obtained by diazotation of the corresponding aminoacetophenones **1a–c**, as described elsewhere [21–23]. Methylketones **3a–c** were treated with phenylhydrazine to give the corresponding hydrazones **4a–c**. When these hydrazones were treated with three equivalents of phosphoryl chloride in dimethylforamide (Vilsmeier–Haack reaction), the desired aldehydes 1*H*-3-(*o*-ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (**5a**), 1*H*-3-(*m*-ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (**5b**), and 1*H*-3-(*p*-ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (**5c**) were obtained in 21%, 60%, and 68%, respectively.

2.2. Spectral characterization

The structures of aldehydes **5a–c** were characterized by IR, ^{1}H, and ^{13}C NMR spectral data. The strong bands at 1678–1682 cm^{-1} in the IR spectra of all the compounds may be assigned to the carbonyl group stretching vibrations. Also, for each spectrum, the most characteristic bands are those attributable to the aromatic and pyrazolyl groups ν(C=C)Ar and ν(C=N)Py between 1500 and 1598 cm^{-1}. The increase of ν(C=O) frequency in the order *ortho* < *para* < *meta* is not easy to explain due to numerous effects: conjugation, polarizability of the aromatic rings, the conformation of the molecule and intermolecular interaction in the solid state. These effects show influence on the position of other frequencies in the IR spectra as well as their shape and intensity [24]. The NMR spectra utterly confirm the structures of compounds **5a–c**. Thus, signals of unsubstituted cyclopentadiene ring protons of all three aldehydes have almost the same position in ^{1}H NMR spectra. The signals of aldehyde and pyrazole protons of compounds **5b** and **5c** appear at almost the same positions which, however, are noticeable different from those of compound **5a** (shifted to higher field). A very similar picture could be seen from the ^{13}C NMR spectra,

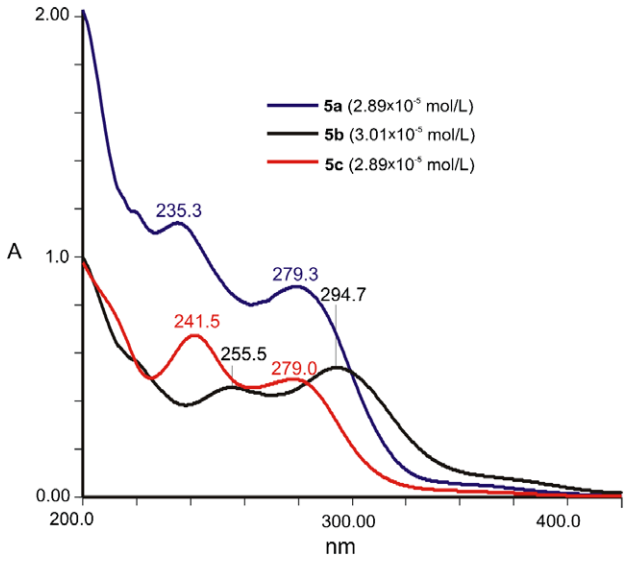
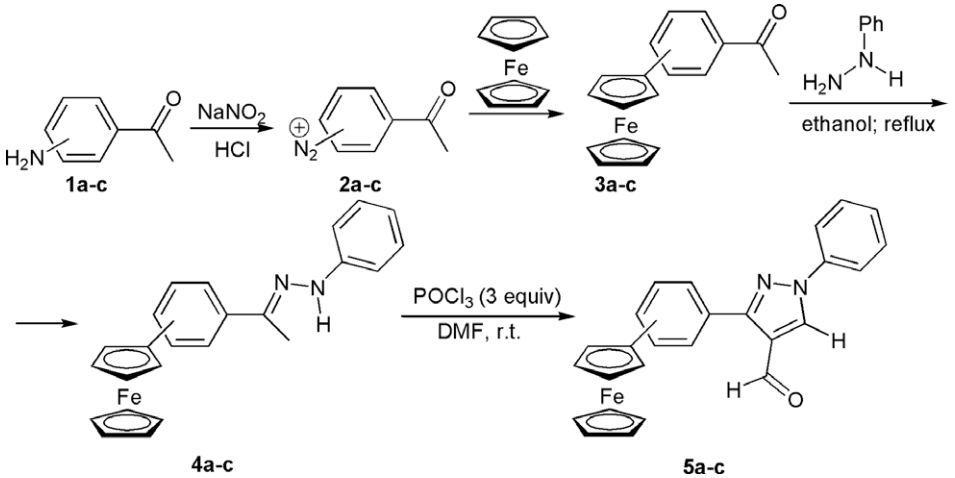


Fig. 1. UV spectra of compounds **5a–c** in acetonitrile.

apparently as a consequence of the vicinity of the ferrocene and pyrazole units in **5a.** However, in the UV spectra (showing two absorption maxima), compounds **5a** and **5b** exhibit more similarity whereas the absorption maxima of **5c** are shifted to higher wavelengths (Fig. 1).

2.3. X-ray analysis of compound *5a*

Single-crystal X-ray diffraction structure analysis of **5a** reveals the conformations of the flexible parts of this molecule. Thus, the aldehyde moiety lies in the pyrazole ring plane, the *N*-phenyl ring is rotated out of the pyrazole plane by 31°, and the *C*-phenyl by 67°. In turn, the Cp ring and the phenyl ring are twisted by 44°. The Cp rings are almost eclipsed (Fig. 2). The distances between the Cp ring centroids and the Fe atom are both 1.65 Å. The aldehyde oxygen accepts a weak hydrogen bond from C(13)–H of the *C*-phenyl ring at the symmetry position (2−*x*,−1/2 + *y*,1/2−*z*) with H···O 2.66 Å, C···O 3.504 Å, and a C–H···O angle of 150°, whereas N(1) accepts another hydrogen bond from C(7)–H of the substituted Cp ring at (3/2−*x*,1/2 + *y*, *z*) with H···N 2.74 Å, C···N 3.457 Å, and a C–H···N angle of 133°.



Scheme 2.

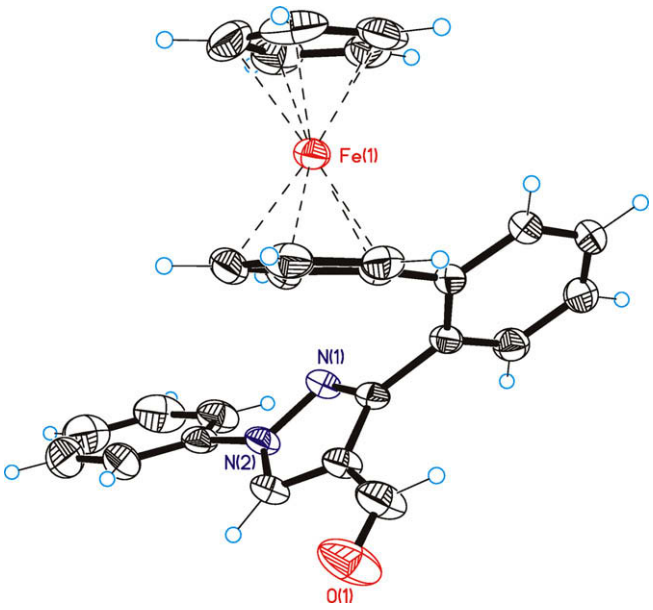


Fig. 2. Crystal structure of 1*H*-3-(*o*-ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (50% thermal ellipsoids).

2.4. Electrochemistry

The electrochemical properties of compounds **5a–c** were investigated by cyclic voltammetry in acetonitrile containing 0.1 mol/L lithium perchlorate as a supporting electrolyte. All three aldehydes exhibit a reversible one-electron redox couple at almost the same potential (396, 394 and 396 mV, respectively; Fig. 3, red[1], blue, and green solid curves). The difference between anodic and cathodic peak potentials is close to the theoretical value and independent of the scan rate *v*. Both anodic and cathodic peak currents are proportional to the square root of the scan rate (Fig. 4), and their ratio is independent of the scan rate, indicating a diffusion-controlled process.

The position of the ferrocene unit in these isomers apparently does not affect significantly the redox potential which is more than 100 mV higher than that of unsubstituted ferrocene (Fig. 3, dashed curve), as expected.

2.5. Biology

The synthesized aldehydes were screened for their *in vitro* antimicrobial activity against eleven bacterial and three fungal/yeast strains. Using a disk diffusion assay [25,26], the compounds were tested at the dose of 250 μg per disk (applied in a DMSO solution), measuring the diameters of the growth inhibition zones to the nearest mm. The susceptibility zones measured were clear zones around the disc inhibiting the microbial growth. Surprisingly, all the three compounds were completely inactive towards all the tested strains (see Table 1). Despite it, the known reactivity of aldehydes, as well as the potential biological activity of compounds possessing the pyrazole ring [16], makes the synthesized compounds promising starting materials in synthesis of numerous derivatives. Thus, the reaction of these aldehydes with *n*-butylamine could serve as a good example. The products of this reaction – the corresponding imines **6a**–**c** (Fig. 5) – were isolated and characterized by spectral data (see the Experimental section) and tested for their *in vitro* antimicrobial activity under conditions

[1] For interpretation of color in Fig. 3, the reader is referred to the web version of this article.

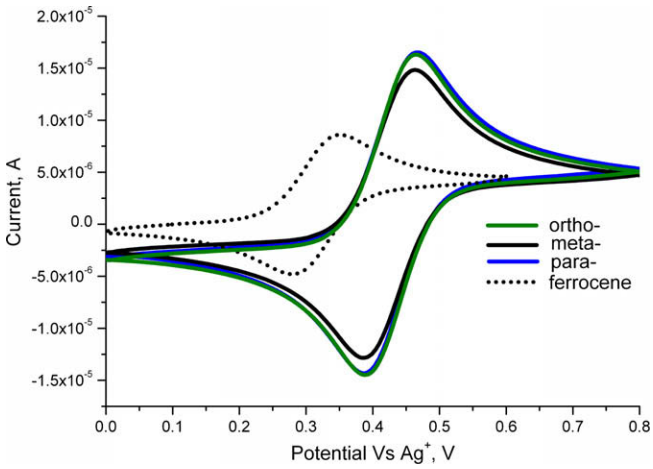


Fig. 3. Cyclovoltamograms of compounds **5a–c** and ferrocene at Pt disc in 0.1 M $LiClO_4$ in acetonitrile at $v = 0.1$ V/s.

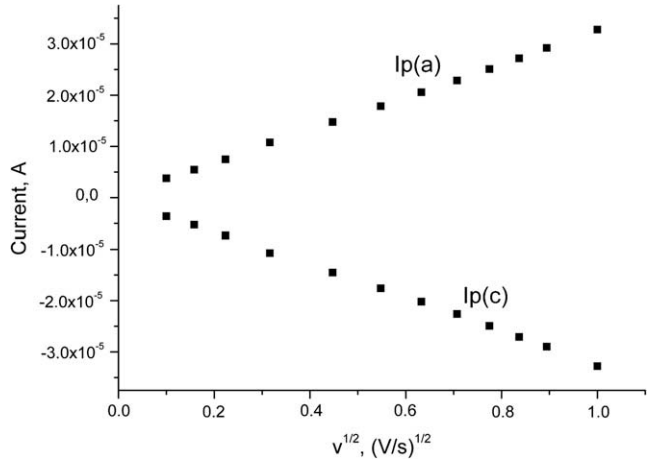


Fig. 4. Anodic and cathodic peak current of **5a** obtained at different scan rates in acetonitrile.

described above for aldehydes **5a**–**c**. As it can be seen from data listed in Table 1, obtained results are noteworthy. Thus, all the tested bacteria exhibited certain susceptibility to *ortho* derivative **6a**, most of them were susceptible to *meta* compound **6b**, but all were completely resistant to *para* imine **6c**. Two used fungal organisms (*Aspergillus niger* and *Candida albicans)* were resistant to compounds **6b** and **6c**, whereas all the tested compounds were completely inactive against the yeast strain *Saccharomyces cerevisiae*. However, imine **6a** showed the growth reduction of the two fungal strains being comparable to that exhibited by the standard used as a positive control (nistatine).

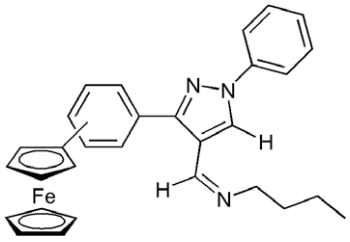
2.6. Conclusion

In conclusion, we synthesized and characterized by spectral and electrochemical data three new aldehydes containing both a pyrazole ring and a ferrocene unit. Although they do not exhibit antimicrobial activity themselves, these compounds are good starting materials for synthesis of numerous other derivatives that could behave quite differently. This idea we illustrated by synthesis and screening for antimicrobial activity of *n*-butyl imines of these aldehydes, founding that two of them exhibit moderate antimicrobial activity against some strains. It points out that further investigations in this direction are justified.

Table 1
The antimicrobial activity (diameters of growth inhibition zones[a]) of the synthetesized ferrocene aldehydes and teir *n*-butyliines in a disk diffusion assay at a dose of 250 μg per disk.

Microorganism/sample	5a	5b	5c	6a	6b	6c	Tetracycline	Nistatine
B. subtilis	n.a.	n.a.	n.a.	15	14	n.a.	26	n.t.
Cl. pyogenes	n.a.	n.a.	n.a.	13	n.a.	n.a.	27	n.t.
Enterococcus sp.	n.a.	n.a.	n.a.	13	13	n.a.	27	n.t.
M. flavus	n.a.	n.a.	n.a.	15	14	n.a.	30	n.t.
S. lutea	n.a.	n.a.	n.a.	15	n.a.	n.a.	25	n.t.
S. aureus	n.a.	n.a.	n.a.	15	14	n.a.	26	n.t.
E. coli	n.a.	n.a.	n.a.	15	13	n.a.	27	n.t.
K. pneumoniae	n.a.	n.a.	n.a.	17	n.a.	n.a.	23	n.t.
S. enteritidis	n.a.	n.a.	n.a.	13	14	n.a.	24	n.t.
P. vulgaris	n.a.	n.a.	n.a.	13	13	n.a.	25	n.t.
P. aeruginosa	n.a.	n.a.	n.a.	15	14	n.a.	27	n.t.
A. niger	n.a.	n.a.	n.a.	16	n.a.	n.a.	n.t.	17
C. albicans	n.a.	n.a.	n.a.	16	n.a.	n.a.	n.t.	18
S. cerevisiae	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.	n.t.	15

n.a. – Not active; n.t. – not tested.
[a] Mean values (in mm) of five experiments, including the diameter of the disc (6 mm).



6a-c

Fig. 5. n-Butylimines of aldehydes **5a–c**.

3. Experimental

3.1. General

All chemicals were commercially available and used as received, except that the solvents were purified by distillation. Chromatographic separations were carried out using silica gel 60 (Merck, 230–400 mesh ASTM), whereas silica gel 60 on Al plates, layer thickness 0.2 mm (Merck) was used for TLC. Electrochemical measurements were performed by using a CH Instruments (Austin, TX) potentiostat CHI760b Electrochemical Workstation. A standard three-electrode cell (5 mL) equipped with a platinum wire and a silver wire immersed in 0.1 M $LiClO_4$ solution in CH_3CN as the counter and reference electrode, respectively. A platinum disk (d = 2 mm) was used as the working electrode. IR measurements were carried out with a Perkin–Elmer FTIR 31725-X spectrophotometer. NMR spectra were recorded on a Varian Gemini (200 MHz) spectrometer, using $CDCl_3$ as the solvent and TMS as the internal standard. Chemical shifts are expressed in δ (ppm).The assignment of all reported signals in ^{1}H NMR spectra was carried out by means of 1D and 2D homo- and heteronuclear correlated NMR spectroscopy. UV measurements were performed on a Perkin–Elmer Lambda 35 double-beam UV–VIS spectrophotometer.

3.2. Crystal structure determination

Crystal data and refinement details for 1-phenyl-3-(*o*-ferrocenylphenyl)pyrazole-4-carboxaldehyde (**5a**): M = 432.29, orthorhombic, space group *Pbca* , a = 19.9175(3) Å, b = 9.9238(2) Å, c = 20.6948(4) Å, V = 4090.48(13) Å^3, Z = 8, D_c = 1.404 g cm^{-3}, μ = 0.758 mm^{-1}, $F(000)$ = 1792, T = 233(2) K. A total of 24371 reflections was collected, and 4013 reflections were unique (R_{int} = 0.0321). The final R_1 and wR_2 were 0.0350 and 0.0794 for 271 parameters and 3492 reflections [$I > 2\sigma(I)$]. The X-ray crystallographic data were collected on a Nonius KappaCCD diffractometer with graphite-monochromated Mo Kα (λ = 0.71073 Å) radiation. The structure was solved by direct methods and refined using full-matrix least squares on F^2. All calculations were performed using the SHELXL-97 program package.

3.3. Biological assay

The *in vitro* antimicrobial activities of compounds **5a–c** and **6a–c** were tested against a panel of laboratory control strains belonging (except one, see below) to the American Type Culture Collection Maryland, USA. Antibacterial activity was evaluated against six Gram-positive and five Gram-negative bacteria. The Gram-positive bacteria used were: *Bacillus subtilis* (ATCC 6633), *Clostridium pyogenes* (ATCC 19404), *Enterococcus* sp. (ATCC 25212), *Micrococcus flavus* (ATCC 10240), *Sarcina lutea* (ATCC 9341) and *Staphylococcus aureus* (ATCC 6538). The Gram-negative bacteria utilized in the assays were: *Klebsiella pneumoniae* (ATCC 10031), *Proteus vulgaris* (ATCC 8427), *Pseudomonas aeruginosa* (ATCC 27857) and *Salmonella enteritidis* (ATCC 13076). The Gram-negative bacterium *Escherichia coli* 95 was obtained from the Institute of Immunology and Virology "Torlak", Belgrade, Serbia. The antifungal activity was tested against three organisms *A. niger* (ATCC 16404), *C. albicans* (ATCC 10231) and *S. cerevisiae* (ATCC 9763). Employing a disk diffusion method, according to NCCLS (1997), the following nutritive media were used: Antibiotic Medium 1 (Difco Laboratories, Detroit Michigan USA) for growing Gram-positive and Gram-negative bacteria, Tripton soy agar (TSA – Torlak, Belgrade) for *C. albicans* and *A. niger*, and Sabouraud dextrose agar (Torlak, Belgrade) for *S. cerevisiae*. Nutritive media were prepared according to the instructions of the manufacturer. All agar plates were prepared in 90 mm Petri dishes with 22 ml of agar, giving a final depth of 4 mm. One-hundred microliters of a suspension of the tested microorganisms (10^8 cells per ml) were spread on the solid media plates. Sterile filter paper disks ("Antibiotica Test Blattchen", Schleicher and Schuell, Dassel, Germany, 6 mm in diameter) were impregnated with 50 μl of the samples solutions (5 mg/ml) in DMSO (all solutions were filter-sterilized using a 0.45 μm membrane filter), i.e. 250 μg per disk, and placed on inoculated plates. These plates, after standing at 4 °C for 2 h, were incubated at 37 °C for 24 h for bacteria and at 30 °C for 48 h for the fungi. Standard disks of Tetracycline and Nystatine (origin – Institute of Immunology and Virology "Torlak", 30 μg of the active component, diameter 6 mm) were used individually as positive controls, while the disks imbued with 50 μl of pure DMSO were used as a negative control. The diameters of the inhibition zones were measured in millimeters (to the nearest mm) using a "Fisher-Lilly Antibiotic Zone Reader" (Fisher Scientific Co., USA). Each test was performed in quintuplicate. In order to evaluate statistically any significant differences among mean values, a one-way ANOVA test was used. In all tests the significance level at which we evaluated critical values differences was 5%.

3.4. General procedure for the Vilsmeier–Haack reaction

To a solution of the corresponding ferrocenylacetophenone (3.040 g, 10.00 mmol) and phenylhydrazine (1.150 g, 10.65 mmol) in EtOH (10 mL) two drops of glacial AcOH were added. The mixture was refluxed for 1.5 h and then cooled to r.t. The precipitate obtained was isolated by filtration *in vacuo*, washed with cold EtOH (5 mL), dried for 1 h in *vacuo* over $CaCl_2$, and dissolved in DMF (15 mL). Argon was bubbled through the solution for 20 min and then the solution was cooled in an ice bath. To the cold solution

$POCl_3$ (2.25 mL, 27.22 mmol) was added drop-wise under argon. After 30 min the bath was removed and the reaction mixture was stirred for 18 h at r.t. The mixture was poured into a beaker containing ice (30 g) and H_2O (30 mL), the resulting solution was hydrolyzed with Na_2CO_3 (40 g) in H_2O (100 mL) and stirred for 3 h at r.t. Crude aldehyde was extracted with toluene (3×100 mL), washed with water and brine. After drying (anhydrous Na_2SO_4), the solvent was evaporated and the residue purified on silica (toluene), yielding deep orange solids.

*3.4.1. 1H-3-(o-Ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (**5a**)*

Yield: 21%; m.p. 189 °C; IR (KBr, cm^{-1}): 3122, 2842, 2819, 1678, 1598, 1533, 1500, 1205, 761, 692; ^1H NMR (200 MHz, $CDCl_3$): $\delta = 4.04$ (s, 5H, Fc), 4.14 (t, 2H, $J = 1.9$ Hz, Fc), 4.19 (t, 2H $J = 1.9$ Hz, Fc), 7.32–7.52 (m, 6H, Ar), 7.75–7.79 (m, 2H, Ar), 7.91 (dd, 1H, $J = 7.3$ Hz and 2.0 Hz, Ar), 8.38 (s, 1H, Pz), 9.18 (s, 1H, CHO); ^{13}C NMR (200 MHz, $CDCl_3$): $\delta = 68.47$, 69.61, 69.99, 85.45, 119.41, 119.63, 122.66, 126.19, 127.62, 128.39, 128.87, 129.55, 130.63, 130.75, 138.92, 138.99, 155.56, 185.11.

*3.4.2. 1H-3-(m-Ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (**5b**)*

Yield: 60%; m.p. 124 °C; IR (KBr, cm^{-1}): 3119, 2922, 2856, 1682, 1597, 1524, 1500, 1204, 765; ^1H NMR (200 MHz, $CDCl_3$): $\delta = 4.07$ (s, 5H, Fc), 4.34 (t, 2H, $J = 1.8$ Hz, Fc), 4.71 (t, 2H $J = 1.8$ Hz, Fc), 7.37–7.66 (m, 6H, Ar), 7.80 (dd, 2H, $J = 7.3$ Hz and 1.5 Hz, Ar), 7.93 (t, 1H, $J = 1.6$ Hz, Ar), 8.55 (s, 1H, Pz), 10.09 (s, 1H, CHO); ^{13}C NMR (200 MHz, $CDCl_3$): $\delta = 66.69$, 69.12, 69.66, 84.79, 119.72, 122.65, 126.43, 126.59, 127.02, 127.92, 128.70, 129.64, 131.06, 131.35, 139.02, 140.07, 154.77, 185.04.

*3.4.3. 1H-3-(p-Ferrocenylphenyl)-1-phenylpyrazole-4-carboxaldehyde (**5c**)*

Yield: 68%; m.p. 181 °C; IR (KBr, cm^{-1}): 3137, 2855, 2831, 1680, 1596, 1517, 1208, 762; ^1H NMR (200 MHz, $CDCl_3$): $\delta = 4.06$ (s, 5H, Fc), 4.35 (t, 2H, $J = 1.8$ Hz, Fc), 4.70 (t, 2H $J = 1.8$ Hz, Fc), 7.37–7.61 (m, 5H, Ar), 7.75–7.81 (m, 4H, Ar), 8.52 (s, 1H, Pz), 10.08 (s, 1H, CHO); ^{13}C NMR (200 MHz, $CDCl_3$): $\delta = 66.58$, 69.25, 69.66, 84.31, 119.64, 122.49, 126.20, 127.81, 128.69, 128.82, 129.58, 131.14, 138.99, 140.78, 154.50, 184.98.

3.5. General procedure for the preparation of imines

Aldehyde (100 mg, 0.23 mmol) was suspended in 8 ml of methanol. To a suspension was added 18 mg (0.24 mmol, 5% excess) of *n*-butyl amine and one drop of glacial acetic acid, and the mixture was refluxed overnight. After reflux solvent was removed by vacuum distillation. Residue was dissolved in 10 ml of ether and solution was washed twice with 8 ml of water. Organic layer was separated, dried with anhydrous $CaCl_2$ and ether was evaporated yielding a pure dark orange oily imine.

*3.5.1. 1H-4-(Butyliminomethyl)-3-(o-ferrocenyl)-1-phenylpyrazol (**6a**)*

Dark orange oil; yield: 0.104 g (92%); m.p.: ^1H NMR (200 MHz, $CDCl_3$): 0.86 (t, 3H, $J = 7.20$ Hz, CH_3); 1.21 (m, 2H, CH_2); 1.44 (m, 2H, CH_2); 3.20 (t, 2H, $J = 6.80$ Hz, CH_2); 4.03 (s, 5H, Fc); 4.12 (t, 2H, $J = 1.80$ Hz, Fc); 4.21 (t, 2H, $J = 1.80$ Hz, Fc); 7.25–7.37 (m, 2H, Ar–H); 7.40–7.50 (m, 4H, Ar–H); 7.44 (s, 1H, CH=N); 7.79 (d, 2H, J = 7.80 Hz, Ar–H); 7.88 (d, 1H, $J = 7.40$ Hz, Ar-H); 8.38 (s, 1H, Pz); ^{13}C NMR (200 MHz, $CDCl_3$): 13.84, 20.36, 32.86, 61.25, 68.31, 69.55, 69.84, 85.57, 118.91, 119.44, 120.37, 125.37, 126.10, 126.68, 128.38, 129.43, 130.53, 130.91, 138.79, 139.63, 153.34, 153.94. IR (KBr, cm^{-1}): 3044, 2962, 2874, 1639, 1568, 1503, 1413, 1105, 956, 756.

*3.5.2. 1H-4-(Butyliminomethyl)-3-(m-ferrocenyl)-1-phenylpyrazol (**6b**)*

Dark orange oil; yield: 0.106 g (94%); m.p.: 190–191 °C (Dec.); ^1H NMR (200 MHz, $CDCl_3$): 0.96 (t, 3H, $J = 7.20$ Hz, CH_3); 1.40 (m, 2H, CH_2); 1.68 (m, 2H, CH_2); 3.59 (t, 2H, $J = 6.80$ Hz, CH_2); 4.07 (s, 5H, Fc); 4.33 (t, 2H, $J = 1.80$ Hz, Fc); 4.69 (t, 2H, $J = 1.80$ Hz, Fc); 7.28–7.57 (m, 6H, Ar); 7.78–7.84 (m, 3H, Ar); 8.38 (s, 1H, CH = N); 8.53 (s, 1H, Pz); ^{13}C NMR (200 MHz, $CDCl_3$): 13.87, 20.45, 33.05, 61.81, 66.60, 69.00, 69.59, 84.94, 119.22, 119.80, 126.19, 126.32, 126.43, 126.90, 126.97, 128.65, 129.49, 132.46, 139.61, 139.81, 153.17, 153.48. IR (KBr, cm^{-1}): 3052, 2963, 2874, 1637, 1566, 1503, 1412, 1013, 755.

*3.5.3. 1H-4-(Butyliminomethyl)-3-(p-ferrocenyl)-1-phenylpyrazol (**6c**)*

Dark orange oil; yield: 0.107 g (95%); m.p.: 190–191 °C (Dec.); ^1H-NMR (200 MHz, $CDCl_3$): 0.94 (t, 3H, $J = 7.20$ Hz, CH_3); 1.41 (m, 2H, CH_2); 1.68 (m, 2H, CH_2); 3.59 (t, 2H, $J = 6.80$ Hz, CH_2); 4.06 (s, 5H, Fc); 4.34 (t, 2H, $J = 1.80$ Hz, Fc); 4.69 (t, 2H, $J = 1.80$ Hz, Fc); 7.29–7.65 (m, 7H, Ar–H); 7.80 (d, 2H, $J = 7.80$ Hz, Ar–H); 8.38 (s, 1H, CH=N); 8.50 (s, 1H, Pz); ^{13}C NMR (200 MHz, $CDCl_3$): 13.84, 20.39, 33.05, 61.74, 66.47, 69.11, 69.61, 84.52, 119.15, 119.64, 126.19, 126.88, 126.94, 128.59, 129.43, 129.89, 139.57, 139.79, 152.91, 153.48. IR (KBr, cm^{-1}): 3064, 2963, 2875, 1632, 1565, 1503, 1465, 1411, 1084, 1014, 956, 746, 655.

4. Supplementary material

CCDC 690780 contains the supplementary data for this paper. These data can be obtained free of charge from the Cambridge Crystallographic Centre via http://www.ccdc.cam.ac.uk/data_request/cif.

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