Biological Activities of NHC–Pd(II) Complexes Based on Benzimidazolylidene N-heterocyclic Carbene (NHC) Ligands Bearing Aryl Substituents †

Ibrahim Al Nasr 1,2, Nedra Touj 3, Waleed Koko 2, Tariq Khan 4, Ismail Özdemir 5,6,*, Sedat Yaşar 5,6 and Naceur Hamdi 3,7,*

1 Department of Biology, College of Science and Arts, Qassim University, Unaizah 51911, Saudi Arabia; insar@qu.edu.sa
2 Department of Science Laboratories, College of Science and Arts, Qassim University, Ar Rass 52719, Saudi Arabia; Wa.Mohamed@qu.edu.sa
3 Research Laboratory of Environmental Sciences and Technologies (LR16ES09), Higher Institute of Environmental Sciences and Technology, University of Carthage, Hammam-Lif 2050, Tunisia; toujnedra@gmail.com
4 Department of Clinical Nutrition, College of Applied Health Sciences, Qassim University, Ar Rass 52719, Saudi Arabia; sirtariqayub@gmail.com
5 Department of Chemistry, Faculty of Science and Art, İnönü University, Malatya 44280, Turkey; ismail.ozdemir@inonu.edu.tr (I.O.); sedat.yasar@inonu.edu.tr (S.Y.)
6 Catalysis Research and Application Center, İnönü University, Malatya 44280, Turkey
7 Department of Chemistry, College of Science and Arts, Qassim University, Ar Rass 52719, Saudi Arabia
* Correspondence: naceur.hamdi@isste.rnu.tn; Tel.: +966-556394839
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Abstract: N-heterocyclic carbene (NHC) precursors (2a–i), their pyridine-enhanced precatalyst preparation stabilization and initiation (PEPPSI)-themed palladium N-heterocyclic carbene complexes (3a–i) and palladium N-heterocyclic triphenylphosphines complexes (4a–i) were synthesized and characterized by elemental analysis and 1H NMR, 13C NMR, IR, and LC–MS spectroscopic techniques. The (NHC)Pd(II) complexes 3–4 were tested against MCF7 and MDA-MB-231 cancer cells, Escherichia coli, methicillin-resistant Staphylococcus aureus (MRSA), Candida albicans microorganisms, Leishmania major promastigotes and amastigotes, Toxoplasma gondii parasites, and Vero cells in vitro. The biological assays indicated that all compounds are highly active against cancer cells, with an IC50 < 1.5 µg mL⁻¹. Eight compounds proved antibacterial and antileishmanial activities, while only three compounds had strong antifungal activities against C. albicans. In our conclusion, compounds 3 (b, f, g, and h) and 4b are the most suitable drug candidates for anticancer, antimicrobial, and antiparasitical.

Keywords: Pd(II)–N-heterocyclic carbene (NHC) complexes; benzimidazolium salts; biological activities; cytotoxicity

1. Introduction

Since the discovery of N-heterocyclic carbenes (NHCs) [1], NHCs have emerged as efficient ligands, and their transition metal complexes have been widely applied as organometallic catalysts [2–8]. In particular, NHC–Pd complexes have been utilized in coupling reactions [2–4]. In many cases, NHC–Pd complexes are formed in situ, which sometimes gives different results compared to those obtained with preformed compounds [9–12]. As a result, a series of well-defined NHC–Pd complexes were developed, and their catalytic activities were fully evaluated in organic transformations [13–26].
The Pd(II)–NHC complexes are the foremost agents and are applied as catalytic agents in many organic reactions [27–29]. They are also promising candidates with diverse bioassays properties [19,30].

Based on the structural correlations between palladium and platinum complexes, Pd(II)-based complexes have become a group of antitumor compounds of interest with the same activities as Pt(II)-based compounds for metallotherapeutical uses [31]. However, despite their potential activity as antitumor agents, only a few numbers of Pd(II)–NHC compounds have been mentioned previously, but their antitumor activities were found to be more efficient [32–34]. There is similarity in the mode of action for both Pd(II) and Pt(II)–NHC by affecting directly the organelles of cancer cells [35]. In our recent results, we found the structure of Ag(I)–NHC compounds and respective benzimidazolium salt to be of potent antitumor property [36,37].

The aim of this work was to study the activities against cancer cells, Escherichia coli, methicillin-resistant Staphylococcus aureus (MRSA), Candida albicans, Leishmania major, Toxoplasma gondii of novel benzimidazolium salts 2a–i, PEPPSI-type N-functionalized N-heterocyclic carbene complexes 3 and palladium N-heterocyclic triphenylphosphine complexes 4. In addition, their cytotoxicity was tested using Vero cells.

2. Results and Discussion

2.1. Synthesis and Characterization

N-heterocyclic carbene ligands have proven to be very useful for designing new metal complexes for catalysis. [38]. All of the benzimidazolium salts used as NHC precursors were prepared similarly by using the published procedures [39,40]. As shown in Scheme 1, benzimidazolone salts 2a–2i were synthesized in good yields by quaternization of compound 1 in DMF at 70 °C for 3 days with the corresponding arylchlorides or bromides. The benzimidazolium salts 2a–2i are stable in air and moisture, both in the solid-state and in solution. They were characterized by $^1$H-NMR, $^{13}$C(1H) NMR, IR, and elemental analysis techniques.

![Scheme 1. Protocol synthesis of benzimidazolium salts 2a–2i.](image)

The structures of the benzimidazole salts 2 can be easily confirmed by the spectroscopic data of $^1$HNMR. The characteristic carbonic protons (NCHN) are located at 10.56, 11.06, 11.40, 11.24, 10.01,
10.81, 11.05, 11.23, and 11.27 ppm, respectively. The corresponding methylene protons appear at 4.94, 5.76; 4.91, 5.83; 4.89, 5.73; 4.87, 5.83; 4.83, 5.59; 4.81, 5.74; 4.73, 5.59; 4.78, 5.72; 4.79, and 5.73 ppm, respectively, which are comparable to the literature reported values [41–44]. As expected, the absence of pro-carbene protons can be observed upon coordination of the benzimidazole salts with the palladium (II), confirming the formation of the NHC–Pd(II) complexes.

Complexes were obtained by substitution of the pyridine by the triphenylphosphine, with moderate yields (40%–49%) (Scheme 2). As expected, the absence of the signals for the carbene carbon atoms of salts 2a–2i appear at 142.98, 143.67, 142.62, 142.79, 141.38, 142.32, 141.81, 141.78, and 141.81 ppm, respectively, which are consistent with signals for other NHC–Pd(II) complexes [45]. The Pd(II)–N-heterocyclic carbene (NHC) complexes 3 were synthesized by treatment of the benzimidazolium salts with the precursor PdCl₂ in pyridine in the presence of an excess of potassium carbonate. These metal(II) complexes were obtained as colored solids in 75%–88% yield. Complexes 4 were obtained by substitution of the pyridine by the triphenylphosphine, with moderate yields (40%–49%) (Scheme 2).

Scheme 2. Protocol synthesis of Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4.

The elemental analysis data of the Pd(II)–N-heterocyclic carbene (NHC) complex 3c is in agreement with the theoretical values for the synthesized complexes. The benzylic -CH₂– proton signals H₁ and H₁′′ for complex 3c as representatives were observed at 5.03 and 5.99 ppm, respectively, and the aromatic protons appeared at δ between 6.86 and 7.48 ppm whilst the pyridine protons were detected as three signals at 7.28, 7.70 and 8.95 ppm.

The carbene carbon signals of Pd(II)–N-heterocyclic carbene (NHC) complex 3c were observed at δ 163.37 ppm in the 13C NMR spectrum, while the C₁ and C₁′′ carbon signals were at δ 48.76 and 53.31 ppm, respectively. The mass spectrum of the same complex gave the most prominent peak at m/z = 295.2.

The 1H NMR spectra of the Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4 showed less intense and downfield shifted signals of benzimidazoles compared to the free ligands. In the 13C NMR spectra of the complexes, a downfield shift in C=N resonance of the ligands upon complexation indicates
the binding of benzimidazoles to palladium through the NHC carbene atom. The aromatic carbons of
the benzene ring resonate between 112 and 152 ppm. The methyl peak in the Pd(II)–N-heterocyclic
carbene (NHC) complexes 3–4 is observed approximately between 16 and 34 ppm. These results are in
agreement with the data of other such complexes [46–49].

2.2. Biological Evaluation

2.2.1. Anticancer Evaluation

Table 1 indicates that all of the compounds were highly efficient and active against the two types
of cancer cells investigated in this study. Their IC\textsubscript{50} were in the range of 1.4 to 0.3 \(\mu\text{g mL}^{-1}\). Regarding
MCF7, 3g and 3f were the most active with IC\textsubscript{50} = 0.518 and 0.675 \(\mu\text{M}\), respectively.

Table 1. Anticancer activity of Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4.

| Pd(II)–NHC Complexes 3–4 | Anticancer Activity IC\textsubscript{50} in \(\mu\text{M}\) |
|--------------------------|---------------------------------|
|                          | MCF7   | MDA-MB-231 |
| 3a                       | 1.180  | 1.011      |
| 3b                       | 1.416  | 0.885      |
| 3c                       | 1.270  | 1.452      |
| 3d                       | 1.677  | 1.304      |
| 3e                       | 1.288  | 1.127      |
| 3f                       | 0.675  | 1.012      |
| 3g                       | 0.518  | 1.036      |
| 3h                       | 1.062  | 0.708      |
| 3i                       | 1.812  | 1.318      |
| 4a                       | 1.160  | 1.546      |
| 4b                       | 1.871  | 0.936      |
| 4c                       | 1.499  | 1.226      |
| 4d                       | 1.111  | 1.25       |
| 4e                       | 1.417  | 1.031      |
| 4f                       | 1.181  | 1.05       |
| 4g                       | 0.802  | 0.936      |
| 4h                       | 1.139  | 0.886      |
| 4i                       | 0.6 ± 0.04 | 0.4 ± 0.03 |

2.2.2. Antimicrobial Activities

Table 2 indicates that 8 compounds had antibacterial activity against \(E.\ coli\) better than the reference
drug, but 3g and 4f were the most potent with an inhibition zone (IZ) of 26.3 mm. The compounds
3f, 4f, and 4c were more active compounds than the reference drug against MRSA with IZ of 28.5,
28.0, and 27.0 mm, respectively. Compounds 3b, 3g, and 4e had the best antifungal activity against
\(C.\ albicans\) with IZ of 32.0, 29.5, and 29.0 mm, respectively. Table 2 NHC metals, particularly silver
synthesized compounds as well as copper derivatives, have been previously found to have potent
antibacterial activities [50,51]. Our findings support the previous results.
Table 2. Antimicrobial profile of synthesized derivative Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4.

| Pd(II)–NHC Complexes 3–4 | Antimicrobial Activity (50 µg/disc) |
|--------------------------|-----------------------------------|
|                          | E.coli    | MRSA      | C.albicans |
| 3a                       | 20.3 ± 1.1 | 17.4 ± 0.3 | 18.0 ± 0.2 |
| 3b                       | 18.3 ± 1.6 | 17.5 ± 0.4 | 32.0 ± 0.3 |
| 3c                       | 19.3 ± 0.6 | 19.0 ± 0.1 | 12.0 ± 0.3 |
| 3d                       | 18.3 ± 0.6 | 15.0 ± 1.0 | 19.0 ± 0.6 |
| 3e                       | 12.0 ± 0.6 | 18.0 ± 0.8 | 20.0 ± 0.7 |
| 3f                       | 25.0 ± 0.4 | 28.5 ± 2.5 | 26.0 ± 0.0 |
| 3g                       | 26.3 ± 1.8 | 26.5 ± 1.4 | 29.5 ± 1.4 |
| 3h                       | 22.4 ± 0.6 | 23.0 ± 0.1 | 28.0 ± 0.0 |
| 3i                       | 19.0 ± 1.2 | 18.5 ± 0.6 | 20.0 ± 0.8 |
| 4a                       | 25.0 ± 0.5 | 22.0 ± 0.4 | 26.0 ± 0.9 |
| 4b                       | 23.0 ± 0.5 | 26.0 ± 0.5 | 27.0 ± 0.5 |
| 4c                       | 25.0 ± 0.6 | 27.0 ± 0.5 | 28.0 ± 0.3 |
| 4d                       | 18.5 ± 2.2 | 19.5 ± 0.6 | 19.0 ± 0.4 |
| 4e                       | 19.3 ± 1.5 | 18.5 ± 0.6 | 29.0 ± 0.7 |
| 4f                       | 26.3 ± 0.6 | 28.0 ± 0.0 | 15.0 ± 0.9 |
| 4g                       | 18.3 ± 0.6 | 15.0 ± 1.5 | 22.0 ± 0.8 |
| 4h                       | 24.0 ± 0.6 | 20.0 ± 0.3 | 23.0 ± 0.9 |
| 4i                       | 22.0 ± 1.0 | 24.5 ± 2.5 | 26.0 ± 0.0 |
| Tetracycline             | 22.3 ± 1.5 | 26.5 ± 1.5 | -           |
| Fluconazole              | -         | -         | 28.0 ± 0.8 |

Values are mean, value ± standard deviation of three different replicates. * The concentration was 50 µg.

2.2.3. Antileishmanial Activities

Table 3 shows that all of the compounds except 3e, 4g, and 4h possess antileishmanial activity against both L. major amastigotes and promastigotes in vitro with an IC₅₀ less than 7 µg mL⁻¹. Eight compounds had an IC₅₀ less than 1.0 µg mL⁻¹ against the two stages. Nine compounds had an IC₅₀ less than 1.0 µg mL⁻¹ against L. major amastigotes, namely, 3 (a–d, f, and h) and 4 (a, b, and i). In addition, 11 compounds showed an IC₅₀ less than 1.0 µg mL⁻¹ against L. major promastigotes, namely, 3 (a–d, f) and 4 (a–d, f, and i). The SI values of all active compounds were in the range of 6–46.6, which indicates the safety threshold of these compounds. Compound 4b was the most active and strongest among all of them with an IC₅₀ less than 0.2 and 0.4 µg mL⁻¹ against L. major amastigotes and promastigotes, respectively, with SI values greater than 24 and 12, respectively, better than the results of the amphotericin B (Amb) reference drug. In recent conducted investigations, NHC gold complexes showed promising antileishmanial activities against L. infantum promastigotes and amastigotes in vitro [52]. These results support our finding here for Pd(II)–NHC complexes 3–4 against L. major promastigotes and amastigotes in vitro.

2.2.4. Antitoxoplasmal Activities

Table 4 indicates that only 7 compounds possess good antitoxoplasmal activity against T. gondii in vitro with an IC₅₀ less than 5 µg mL⁻¹. These compounds are 3a, 3b, 3c, 3h, 4a, 4b, and 4c with IC₅₀ of 4.2, 3.9, 4.6, 1.2, 4.8, 3.6, and 3.9 µg mL⁻¹, respectively. However, their SI values were found to be less than 2. Although NHC carbene metal complexes with silver and gold derivatives were found in previous studies to show good antiparasitical activities against apicomplexan protozoa such as Plasmodium spp. [53], these findings are not in agreement with our results for (NHC) palladium metallic complexes against T. gondii.
Table 3. Antileishmanial activity of Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4 against *L. major* promastigotes and amastigotes.

| Pd(II)–NHC Complexes 3–4 | C<sub>50</sub> of Vero Cells at µg mL<sup>−1</sup> | Amastigote IC<sub>50</sub> at µg mL<sup>−1</sup> | Promastigote IC<sub>50</sub> at µg mL<sup>−1</sup> | Amastigote SI | Promastigote SI |
|--------------------------|-----------------------------|-----------------------------|-----------------------------|--------------|----------------|
| 3a                       | 6.1 ± 1.8                   | 0.5 ± 0.07                  | 0.5 ± 0.09                  | 12.2         | 12.2           |
| 3b                       | 3.6 ± 1.2                   | 0.3 ± 0.04                  | 0.6 ± 0.07                  | 12.0         | 6.0            |
| 3c                       | 6.6 ± 1.7                   | 0.4 ± 0.05                  | 0.6 ± 0.11                  | 16.4         | 11.0           |
| 3d                       | 28.0 ± 3.6                  | 0.6 ± 0.09                  | 0.7 ± 0.13                  | 46.6         | 39.9           |
| 3e                       | 22.8 ± 3.3                  | 17.4 ± 3.8                  | 7.6 ± 1.9                   | 1.3          | 3.0            |
| 3f                       | 16.4 ± 2.8                  | 0.7 ± 0.12                  | 0.6 ± 0.09                  | 23.4         | 27.3           |
| 3g                       | 29.8 ± 6.4                  | 2.7 ± 0.6                   | 3.2 ± 0.7                   | 11.1         | 9.3            |
| 3h                       | 1.8 ± 0.7                   | 0.7 ± 0.09                  | 1.6 ± 0.3                   | 2.6          | 1.1            |
| 3i                       | 15.9 ± 3.0                  | 2.9 ± 0.8                   | 6.3 ± 2.0                   | 5.5          | 2.5            |
| 3j                       | 8.9 ± 2.9                   | 0.3 ± 0.07                  | 0.4 ± 0.07                  | 29.0         | 22.4           |
| 3k                       | 4.8 ± 1.5                   | <0.2                       | 0.4 ± 0.08                  | >24          | 12.0           |
| 3l                       | 4.9 ± 1.1                   | 1.1 ± 0.6                   | 0.8 ± 0.06                  | 4.5          | 6.2            |
| 3m                       | 6.1 ± 1.6                   | 1.6 ± 0.7                   | 0.4 ± 0.03                  | 3.8          | 15.2           |
| 3n                       | 13.1 ± 2.7                  | 2.4 ± 0.9                   | 1.6 ± 0.5                   | 5.5          | 8.2            |
| 3o                       | 19.9 ± 3.2                  | 1.7 ± 0.7                   | 0.5 ± 0.07                  | 11.7         | 39.8           |
| 3p                       | 34.4 ± 6.6                  | 2.9 ± 0.9                   | 15.4 ± 2.8                  | 11.9         | 2.2            |
| 3q                       | 35.4 ± 5.9                  | 14.3 ± 2.6                  | 32.8 ± 6.1                  | 2.5          | 1.1            |
| 3r                       | 9.9 ± 2.8                   | 0.5 ± 0.03                  | 0.9 ± 0.1                   | 19.8         | 11.0           |
| AmB                      | 7.4 ± 2.64                  | 0.46 ± 0.07                 | 0.78 ± 0.09                 | 16.09        | 9.49           |

Table 4. Antitoxoplasmal activity of Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4 against *T. gondii*.

| Pd(II)–NHC Complexes 3–4 | C<sub>50</sub> of Vero Cells at µg mL<sup>−1</sup> | Antitoxoplasma IC<sub>50</sub> at µg mL<sup>−1</sup> | SI |
|--------------------------|-----------------------------|-----------------------------|----|
| 3a                       | 6.1 ± 1.8                   | 4.2 ± 0.9                   | 1.5          |
| 3b                       | 3.6 ± 1.2                   | 3.9 ± 0.9                   | 0.9          |
| 3c                       | 6.6 ± 1.7                   | 4.6 ± 1.1                   | 1.4          |
| 3d                       | 28.0 ± 3.6                  | 18 ± 3.6                    | 1.6          |
| 3e                       | 22.8 ± 3.3                  | 8.1 ± 1.9                   | 2.8          |
| 3f                       | 16.4 ± 2.8                  | 13.8 ± 2.7                  | 1.2          |
| 3g                       | 29.8 ± 6.4                  | 18.1 ± 2.8                  | 1.6          |
| 3h                       | 1.8 ± 0.7                   | 1.2 ± 0.2                   | 1.5          |
| 3i                       | 15.9 ± 3.0                  | 8.5 ± 1.7                   | 1.9          |
| 3j                       | 8.9 ± 2.9                   | 4.8 ± 1.1                   | 1.9          |
| 3k                       | 4.8 ± 1.5                   | 3.6 ± 0.9                   | 1.3          |
| 3l                       | 4.9 ± 1.1                   | 3.9 ± 0.8                   | 1.3          |
| 3m                       | 6.1 ± 1.6                   | 11.9 ± 2.0                  | 0.5          |
| 3n                       | 13.1 ± 2.7                  | 6.3 ± 1.8                   | 2.1          |
| 3o                       | 19.9 ± 3.2                  | 38.4 ± 6.5                  | 0.5          |
| 3p                       | 34.4 ± 6.6                  | 25.3 ± 4.1                  | 1.4          |
| 3q                       | 35.4 ± 5.9                  | 21.7 ± 4.3                  | 1.6          |
| 3r                       | 9.9 ± 2.8                   | 7.8 ± 1.7                   | 1.3          |
| ATO                      | 9.3 ± 2.08                  | 0.09 ± 0.02                 | 103.33       |

3. Experimental Section

**General Methods**

All manipulations were carried out under argon using standard Schlenk line techniques. Chemicals and solvents were purchased from Sigma-Aldrich Co. (Poole, Dorset, UK). The solvents used were purified by distillation and were transferred under argon. DMAc analytical grade (99%) was not distilled before use. KOAc (99%) was employed. Benzimidazoles salts 1–2, palladium PEPPSI complexes 3, palladium triphenylphosphine 4, and biological assays were done according to our
previous work [40,52] and they are given in supplementary materials. Elemental analyses were performed by ElementalVario EL III Carlo Erba 1108 (Malatya, Turkey). The melting points of the complexes and NHC precursors were determined using Stuart automatic melting point apparatus (SMP-40) (Malatya, Turkey). IR spectra were recorded on ATR unit in the range of 400–4000 cm⁻¹ with Perkin Elmer Spectrum 100 Gladi ATR FT/IR Spectrophotometer (Malatya, Turkey). ¹H NMR and ¹³C NMR spectra were recorded using a Bruker Avance III HD spectrometer operating at 400 MHz (¹H NMR) and at 100 MHz (¹³C NMR) in CDCl₃ or DMSO-d₆ (Malatya, Turkey). NMR multiplicities are abbreviated as follows: s = singlet, d = doublet, t = triplet, hept = heptet, and m = multiplet signal. The NMR studies were carried out in high-quality 5-mm NMR tubes. The chemical shifts (δ values) are reported in ppm relative to tetramethylsilane for ¹H, ¹³C NMR spectra as standard. Coupling constants (J values) are given in hertz. The HRMS (ESI) electrospray ionization mass spectra were recorded on a Shimadzu LCMS-IT-Tof spectrometer in CH₃CN/CHCl₃. (Malatya, Turkey) Column chromatography was performed using silica gel 60 (70–230 mesh).

4. Conclusions

In this work, Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4 have been already synthesized and characterized starting from benzimidazolium salts (2a-i). The molecular structures of the benzimidazolium salts (2a-i) and the Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4 have been characterized by elemental analysis and ¹H- and ¹³C-NMR spectra. The present results indicate that all of the synthesized Pd(II)–N-heterocyclic carbene (NHC) complexes 3–4 had potent anticancer activity, particularly 3g, 3f, 3h, and 4i. The compounds 3f, 3g, and 4c are the most active antibacterial drugs, while 3b, 3g, and 4e proved to be very strong antifungals. In this investigation, 8 compounds were found to be most active against both L. major promastigotes and amastigotes with high SI values. Compound 4b had the most potent activity against L. major. These candidates need more investigations of their mode of action and drug standardization.

Supplementary Materials: The following are available online at http://www.mdpi.com/2073-4344/10/10/1190/s1. Figure S1. ¹H NMR spectrum of complex 3a in CDCl₃, Figure S2. ¹³C NMR spectrum of complex 3a in CDCl₃, Figure S3. HRMS spectra of complex 3a, Figure S4. ¹H NMR spectrum of complex 3b in CDCl₃, Figure S5. ¹³C NMR spectrum of complex 3b in CDCl₃, Figure S6. HRMS spectra of complex 3b, Figure S7. ¹H NMR spectrum of complex 3c in CDCl₃, Figure S8. ¹³C NMR spectrum of complex 3c in CDCl₃, Figure S9. HRMS spectrum of complex 3c, Figure S10. ¹H NMR spectrum of complex 3d in CDCl₃, Figure S11. ¹³C NMR spectrum of complex 3d in CDCl₃, Figure S12. HRMS spectra of complex 3d, Figure S13. ¹H NMR spectrum of complex 3e in CDCl₃, Figure S14. ¹³C NMR spectrum of complex 3e in CDCl₃, Figure S15. ¹H NMR spectrum of complex 3f in CDCl₃, Figure S16. ¹³C NMR spectrum of complex 3f in CDCl₃, Figure S17. HRMS spectra of complex 3f, Figure S18. ¹H NMR spectrum of complex 3g in CDCl₃, Figure S19. ¹³C NMR spectrum of complex 3g in CDCl₃, Figure S20. HRMS spectra of complex 3g, Figure S21. ¹H NMR spectrum of complex 3h in CDCl₃, Figure S22. ¹³C NMR spectrum of complex 3h in CDCl₃, Figure S23. HRMS spectra of complex 3h, Figure S24. ¹H NMR spectrum of complex 3i in CDCl₃, Figure S25. ¹³C NMR spectrum of complex 3i in CDCl₃, Figure S26. HRMS spectra of complex 3i, Figure S27. ¹H NMR spectrum of complex 4a in CDCl₃, Figure S28. ¹³C NMR spectrum of complex 4a in CDCl₃, Figure S29. ¹³P NMR spectrum of complex 4a in CDCl₃, Figure S30. HRMS spectra of complex 4a, Figure S31. ¹H NMR spectrum of complex 4b in CDCl₃, Figure S32. ¹³C NMR spectrum of complex 4b in CDCl₃, Figure S33. ¹³P NMR spectrum of complex 4b in CDCl₃, Figure S34. HRMS spectra of complex 4b, Figure S35. ¹H NMR spectrum of complex 4c in CDCl₃, Figure S36. ¹³C NMR spectrum of complex 4c in CDCl₃, Figure S37. ¹³P NMR spectrum of complex 4c in CDCl₃, Figure S38. HRMS spectra of complex 4c, Figure S39. ¹H NMR spectrum of complex 4d in CDCl₃, Figure S40. ¹³C NMR spectrum of complex 4d in CDCl₃, Figure S41. ¹³P NMR spectrum of complex 4d in CDCl₃, Figure S42. ¹H NMR spectrum of complex 4e in CDCl₃, Figure S43. ¹³C NMR spectrum of complex 4e in CDCl₃, Figure S44. ¹³P NMR spectrum of complex 4e in CDCl₃, Figure S45. HRMS spectra of complex 4b, Figure S46. ¹H NMR spectrum of complex 4f in CDCl₃, Figure S47. ¹³C NMR spectrum of complex 4f in CDCl₃, Figure S48. ¹³P NMR spectrum of complex 4f in CDCl₃, Figure S49. ¹H NMR spectrum of complex 4g in CDCl₃, Figure S50. ¹³C NMR spectrum of complex 4g in CDCl₃, Figure S51. ¹³P NMR spectrum of complex 4g in CDCl₃, Figure S52. ¹H NMR spectrum of complex 4h in CDCl₃, Figure S53. ¹³C NMR spectrum of complex 4h in CDCl₃, Figure S54. ¹³P NMR spectrum of complex 4h in CDCl₃, Figure S55. HRMS spectra of complex 4h.
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