Synthesis, Characterization and Catalytic Activity of a Novel 2-(3’-amino-phenyl)benzimidazoyl Palladium(II) Complex

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Abstract: The synthesis and characterization of a novel aminophenyl benzimidazole Pd (II) complex is reported. The complex proved as an efficient catalyst for the Sonogashira cross-coupling reaction of ten different aryl bromides with trimethylsilylethylene to yield a wide range of aryl trimethylsilylethynes. The reaction involves use of the novel complex and triethylamine.

Keywords: Benzimidazole, binuclear complex, cross-coupling reaction, coordination induced shift, trimethylsilylethynes.

1. INTRODUCTION

Palladium complexes with substituted benzimidazoles as N-donor ligands are important catalysts with applications in hydrogenation. Heck, Sonogashira and Suzuki cross-coupling reactions [1-4]. The Sonogashira coupling is a fundamental and important reaction for the synthesis of aryl acetylene derivatives [5-8], which in turn can be applied for preparing natural products [9], bioactive compounds [10] and in material sciences [11].

Several examples of Pd-catalyzed Sonogashira reactions in aqueous media have been reported. Many of these reactions are carried out in an aqueous-organic solvent mixture and in some cases, special phosphine ligands and copper salts are required in order to reach high reaction efficiency [12, 13].

Our laboratory is involved in the synthesis and reactions of some novel organosilyl based reagents. A diverse variety of organosilicon based reagents were prepared and their reactions studied [14-18]. In continuation of our investigations on organosilyl based reagents [19, 20], the synthesis, characterization and catalytic activity of complexes containing transition metals with substituted N-heterocycles were undertaken. Benzimidazole complexes earlier prepared were screened for catalytic activities [1, 21-24] and were found to be efficient catalysts for oxidations and hydrogenations [25-29].

We now report the synthesis and characterization of the novel di-µ-bromodi(2-(3’-aminophenyl) benzimidazole)[di bromodipalladium(II) complex and its application in the Sonogashira cross-coupling reaction of aryl bromides with trimethylsilylethylene under solvent and copper free conditions.

2. MATERIALS AND METHOD

All the reagents used were of analytical grade. The solvents used were purified according to standard literature procedures. Microanalyses were carried out on a Finnegan Eager 300 elemental analyzer. IR (nujol mull) spectra were recorded on Agilent Technologies Cary 630 FTIR and Far-IR spectra were recorded on Thermo Nicolet model 6700. Electronic spectra were recorded on Shimadzu UV 3101PC spectrometer. FAB mass spectra were recorded on a JEOL SX102 mass spectrometer using argon/xenon as the FAB gas and m-nitrobenzyl alcohol as the matrix. TGA were
recorded on Perkin Elmer Diamond TG/DTA with a heating rate of 15 °C min⁻¹ in nitrogen atmosphere. Molar conductivity measurements were made on a Systronic conductivity meter 304-cell type CD-10. ¹H and ¹³C NMR spectra of the complex were recorded on Bruker DRX500 NMR spectrometer with tetramethylsilane (TMS) as the internal standard and DMSO-d₆ as the solvent. ¹H NMR and ¹³C NMR of novel cross coupled products were recorded on a Bruker AMX 400 spectrometer using CDCl₃ with TMS as internal standard. Chemical shifts are reported in δ (ppm downfield from TMS). ESI-MS were recorded on Bruker HCT ultra ETD II.

EXPERIMENTAL

Synthesis of Complex [Pd₂Br₄(m-APB)₂].2H₂O and its Spectral Data

PdBr₄ (1 mmol) in methanol (10 mL) was treated 1 drop of HBr followed by 2 mmol of the ligand 2-(3-aminophenyl)benzimidazolic (m-APB) in methanol (10 mL). The mixture was refluxed for 6 h during which a yellow colored solid separated. The solid was filtered, washed with methanol and dried in vacuo to obtain 0.630 g of complex [Pd₂Br₄(m-APB)₂].2H₂O 65% Yield. mp 225 °C. Molar conductivity Λ (10⁻³ M solution in DMF) = 27 Ω⁻¹cm²mol⁻¹; IR: 3621, 3418, 3192, 1604, 1587, 1471, 1237, 1175, 869, 785, 739, 689 cm⁻¹; ¹H NMR (CDCl₃) δ: 5.65 (b, 2H, NH₂), 6.90 (d, 1H, J = 8.0 Hz), 7.38 (t, 1H, J = 7.6 Hz) 7.45 (b, 1H, J = 7.2 Hz), 7.55 (t, 1H, J = 7.6 Hz), 7.59 (m, 2H), 8.51(d, 1H, J = 8.0 Hz), 8.62 (d, 1H, J = 7.6 Hz) 13.50 (s, 1H, NH) ppm ; ¹³C NMR (CDCl₃) δ: 112.02, 113.85, 116.90, 119.47, 122.88, 129.15, 129.31, 132.91, 140.90, 148.81, 153.00, 123.78; Anal Found: C, 31.46; H, 3.10; N, 8.58. Calcd: C, 31.64; H, 2.66; N, 8.51. Mass of [Pd₂Br₄(m-APB)₂] Calcd: 951.6, Found: 951.0;

General Procedure for the Sonogashira Reaction and Spectral Data

A mixture of aryl bromide 1a-j (1 mmol), trimethylsilyl ethynyl (1.5 mmol), triethylamine (2.0 mmol) and the catalyst [Pd₂Br₄(m-APB)₂].2H₂O (1.4 mol%) were heated in a sealed tube placed in an oil bath at 100°C for 7 hr. The reaction was monitored using thin layer chromatography. After the completion of reaction, the reaction mixture was cooled to ambient temperature, diluted with diethyl ether (20 mL), filtered through celite to remove left over solids, and concentrated in vacuo. The crude product was then subjected to column chromatography using silica gel (100-200 mesh) and 1:10 ethyl acetate/hexane (60-80 °C fraction) to isolate the aryl substituted trimethylsilyl ethynyls 2a-j in greater than 80% yield.

4-(2'-Trimethylsilyl ethynyl)-2,3-dihydroinden-1-one (2a)

Solid, mp = 38 °C IR: 3030, 2955, 2899, 2149, 1716, 1575, 1473, 1247, 1045, cm⁻¹; ¹H NMR (CDCl₃) δ: 0.29 (s, 9H), 2.70-2.72 (m, 2H), 3.17-3.19 (2H, t, J = 5.6 Hz), 7.32-7.35 (t, 2H, J = 7.6 Hz), 7.65-7.67 (m, 2H); ¹³C NMR (CDCl₃) δ: 0.08, 25.47, 36.03, 100.37, 101.01, 122.09, 123.60, 127.38, 127.59, 137.10, 157.57, 193.57; ES-MS found: 229.0 Calcd:228.09

5-(2'-trimethylsilyl ethynyl)thiophen-2-yl Ethane (2b)

Solid, mp = 59 °C; IR: 3071, 2957, 2899, 2148, 1651, 1434, 1356, 1326, 1268, 1244, 1166, 1036 cm⁻¹; ¹H NMR (CDCl₃) δ: 0.02 (s, 9H), 2.54 (s, 3H), 7.18-7.19 (d, 1H, J = 4 Hz), 7.53-7.54 (d, 1H, J = 4 Hz); ¹³C NMR (CDCl₃) δ: 0.36, 26.78, 96.65, 103.11, 131.11, 131.89, 133.08, 144.53, 190.04; ES-MS found: 222.9 Calcd:222.0

3. RESULTS AND DISCUSSIONS

The ligand aminophenylbenzimidazolic (m-APB) was synthesized according to literature methods [30]. The palladium complex was synthesized by treating the 2-(3'-aminophenyl) benzimidazolic with an alcoholic solution of PdBr₂. The complex formed was insoluble in common organic solvents but soluble in DMF and DMSO solvents respectively. The complex was characterized by m.p., elemental analysis, IR, electronic, ¹H, ¹³C and 2D NMR spectral studies. A comparative account of ligand and complex are given in Table I. The thermogravimetric analysis was carried out for the synthesized palladium complex at a heating
Table 1. Coordination induced shift of the [Pd_{2}Br_{4}(m-APB)_{2}]2H_{2}O complex.

<table>
<thead>
<tr>
<th>C/N-H</th>
<th>'H NMR</th>
<th>C.i.s</th>
<th>C-atoms</th>
<th>$^{13}$C NMR</th>
<th>c.i.s</th>
</tr>
</thead>
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<tr>
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<td>13.50s</td>
<td>0.86</td>
<td>2</td>
<td>153.00</td>
<td>0.88</td>
</tr>
<tr>
<td>NH$_{2}$</td>
<td>5.65b</td>
<td>0.36</td>
<td>4</td>
<td>123.78</td>
<td>2.0</td>
</tr>
<tr>
<td>4</td>
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<td>1.07</td>
<td>5</td>
<td>129.15</td>
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</tr>
<tr>
<td>5</td>
<td>7.45t</td>
<td>0.29</td>
<td>6</td>
<td>129.31</td>
<td>-0.07</td>
</tr>
<tr>
<td>6</td>
<td>7.38t</td>
<td>0.22</td>
<td>7</td>
<td>122.88</td>
<td>1.1</td>
</tr>
<tr>
<td>7</td>
<td>8.51d</td>
<td>0.96</td>
<td>8</td>
<td>140.90</td>
<td>8.21</td>
</tr>
<tr>
<td>7'</td>
<td>7.59m</td>
<td>0.16</td>
<td>9</td>
<td>137.91</td>
<td>7.21</td>
</tr>
<tr>
<td>4'</td>
<td>6.90d</td>
<td>0.22</td>
<td>1'</td>
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<td>5'</td>
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<td>6'</td>
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<td>0.31</td>
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<td>113.85</td>
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<td>6'</td>
<td></td>
<td>116.90</td>
<td>1.32</td>
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</tbody>
</table>

The IR spectrum of the ligand displayed a broad peak $v_{\text{N-H}}$ of NH$_{2}$ at 3350 cm$^{-1}$ and $v_{\text{N-H}}$ of benzimidazole at 3209 cm$^{-1}$. $v_{\text{C-N}}$ and $v_{\text{C-C}}$ (ring) vibrations appeared at 1612 cm$^{-1}$ and these peaks shifted on complexation indicating co-ordination of the ligand through imine nitrogen (C=N) of benzimidazole ring [31].

The far-IR spectrum of the complex showed peaks corresponding to terminal bound as well as bridging bromides in the region 227 and 190 cm$^{-1}$ respectively. $v_{\text{Pd-N}}$ for the complex was found at 256 cm$^{-1}$ (Fig. 2).

**Fig. (1).** Thermogram of [Pd$_{2}$Br$_{4}$(m-APB)$_{2}$]2H$_{2}$O complex.

**Fig. (2).** Far IR of [Pd$_{2}$Br$_{4}$(m-APB)$_{2}$]2H$_{2}$O.
The $^1$H NMR spectrum of the complex displayed positive c.i.s ($\delta_{\text{complex}} - \delta_{\text{ligand}}$). The resonance signal of N-H appearing in the range 12.64 ppm in free ligand showed a downfield shift on complexation and appeared at 13.5 ppm. The proton at position 4- of benzimidazole ring also displayed a downfield shift on complexation indicating coordination to central palladium ion through the imine (C=N) nitrogen of benzimidazole ring. The resonance signal of NH$_2$ protons in the ligand was found at 5.29 ppm. On complexation, this proton exhibited a downfield shift of 0.36 ppm. The c.i.s value for other protons also calculated and given in Table 1. The $^{13}$C NMR spectrum of the complex exhibited both positive and negative coordination induced shifts (Table 1). The negative c.i.s. may be attributed to greater metal-to-ligand $\pi$- back donation whereas positive c.i.s. to ligand-to-metal $\sigma$ donation.

The electronic spectrum of the ligand and the complex were recorded in DMF/nujol mull. The spectrum of the ligand exhibited absorption bands at 300 and 309 nm which were assigned to $n \rightarrow \pi^*$ transitions and a band at 332 nm was due to $n \rightarrow \pi^*$ transition. The spectrum of the complex exhibited weak absorption band at 430 nm and molar extinction coefficient $\varepsilon$ was 450 dm$^3$ mol$^{-1}$ cm$^{-1}$ which was assigned to $^1A_{1g} \rightarrow ^1B_{1g}$ transition arising for square planar geometry of d$^8$ Pd (II) metal ion (Fig. 3).

Fig. (4). Structure of di-$\mu$-bromodi[2-(3'-aminophenyl) benzimidazole] dibromodipalladium(II) complex.

FAB Mass spectrum of the complex displayed molecular ion peak at 951 and supporting the binuclear nature of the complex. From this data and considering the thermogravimetric/elemental analysis, the molecular formula of the complex was assigned as [Pd$_2$Br$_4$(m-APB)$_2$]$_2$H$_2$O. Based on all the above studies, the complex was assigned binuclear structure as shown in Fig. (4), wherein the ligand displayed monodentate behavior coordinating through imine (C=N) nitrogen of benzimidazole group.

3.1. Sonogashira Cross Coupling Reaction of Aryl Bromides Using [Pd$_2$Br$_4$(m-APB)$_2$]$_2$H$_2$O as Catalyst

In continuation of our studies on the synthesis and reactions of some silyl based reagents, we screened the novel catalyst prepared for Sonogashira reaction of aryl bromides. Recently, we reported the synthesis of some novel terminal trimethylsilylacetylene benzoate derivatives showing liquid crystalline property by employing the Sonogashira reaction [20].

In our preliminary experiments we chose the cross coupling reaction of 1.2 mmol 4-bromoindanone with 1.8 mmol trimethylsilylethyne in the presence of 2.0 mol% [Pd$_2$Br$_4$(m-APB)$_2$]$_2$H$_2$O catalyst as model reaction under sealed tube condition. We attempted to investigate the optimization of the reaction conditions regarding the base, solvent and temperature and in order to find optimum reaction conditions. When the reaction was carried out by changing the solvent from water to acetonitrile, the desired product was obtained but the reaction took 12 h for completion with 15-20% yields. Replacing the inorganic bases
Table 2. Optimization of Sonogashira cross coupling reaction of 1a with trimethylsilyl ethyne.

<table>
<thead>
<tr>
<th>Entry</th>
<th>Solvent</th>
<th>Base</th>
<th>Temp °C</th>
<th>Time (h)</th>
<th>Yield</th>
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<td>CH₃CN</td>
<td>K₂CO₃</td>
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<td>15</td>
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<tr>
<td>2</td>
<td>CH₃CN</td>
<td>Cs₂CO₃</td>
<td>95</td>
<td>12</td>
<td>20</td>
</tr>
<tr>
<td>3</td>
<td>THF</td>
<td>Et₃N</td>
<td>95</td>
<td>9</td>
<td>60</td>
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<tr>
<td>4</td>
<td>CH₃CN</td>
<td>Et₃N</td>
<td>95</td>
<td>7</td>
<td>85</td>
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<tr>
<td>5</td>
<td>-</td>
<td>Et₃N</td>
<td>95</td>
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<td>95</td>
</tr>
</tbody>
</table>

Scheme (1). Sonogashira Cross-coupling reaction using [Pd₂Br₄(m-APB)₂]2H₂O complex as catalyst.

Scheme (2). Schematic representation of a plausible mechanism for Sonogashira reaction.

like K₂CO₃ and Cs₂CO₃ by an organic base triethylamine in acetonitrile solvent in a sealed vessel, showed a progress in lowered reaction time from 12 h to 7 h and increased product yield (Table 2).

We further investigated the reaction by using different mol% of catalyst [Pd₂Br₄(m-APB)₂] 2H₂O. For this, we examined the synthesis of 2a in the presence different mol% of catalyst at various temperatures. We found that 1.4 mol% of [Pd₂Br₄(m-APB)₂]2H₂O was the most appropriate amount of catalyst for achieving the desired conversion (Table S1). Further the reaction was repeated with ten different aryl bromides 1a-j (Scheme 1, Table 3) and the corresponding pure products 2a-j were isolated by column chromatography and characterized using IR, ¹H-NMR, ¹³C-NMR and ES-MS.

The most probable mechanism for the cross coupling reaction is outlined in Scheme (2). The catalyst precursor [Pd₂Br₄(m-APB)₂]2H₂O is converted to (m-APB)-Pd (0) in situ [6]. Oxidative addition of (m-APB)-Pd (0) by aryl bromide will form a Pd (II) intermediate. The bromide ion is then be substituted by the trimethylsilyl acetylide group. Reductive elimination forms the products: aryl substituted trimethylsilylacetylene.

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Table 3. Synthesis of Aryl substituted trimethylsilylthene (2a-j), their yield and reaction time.

<table>
<thead>
<tr>
<th>Entry</th>
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<th>Yield (%)</th>
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CONCLUSION

The synthesis and characterization of [Pd_{2}Br_{4}(m-APB)]_{2} a novel complex is reported. The synthesized complex exhibited good catalytic activity towards Sonogashira coupling reaction with ten different aryl bromides and trimethylsilylthiophen. The method is simple, efficient and involves copper and solvent free reaction conditions for the synthesis of a diverse range of trimethylsilyl aryl acetylenes.


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