Synthesis and catalytic activities of bimetallic Ru (II) arene complexes bearing bis-benzimidazoles

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Abstract
In this study, bis-benzimidazole ligands (1a-d) were synthesized using linker groups and they were evaluated as catalyst generated in situ from [RuCl₂(p-cymene)]₂ for transfer hydrogenation (TH) of acetophenone. The bimetallic Ru (II) arene complex (2b) synthesized from ligand 1b which showed the best activity among the ligands in the catalytic TH reaction. The obtained ligands and 2b complex were characterized by ¹H- and ¹³C-NMR, elemental analysis and IR spectroscopy. The catalytic activities of complexes having different chain lengths and Y (CH₃ or H) groups were compared. The highest conversion (99%) was obtained with 2b.

Keywords: Bis-benzimidazole; ruthenium; transfer hydrogenation.

1. Introduction
Benzimidazole is a heterocyclic aromatic organic compound consisting of fusion of benzene and imidazole. Transition metal complexes of benzimidazole ligands are frequently used because of their unique properties such as biological activity, high thermal stability and good catalytic performance (1-4).

The benzimidazole can be easily modified due to its pyrole-type nitrogen. For example, they are alkylated with alkyl halides so as to give 1-alkylbenzimidazoles. Bis-benzimidazoles can also be synthesized when 1,4- and / or 1,6-dialkyl halides are used as linker groups (5-15). Reduction of carbonyl bonds by catalytic transfer hydrogenation using Ru (II) catalyst is of interest due to its simplicity and safety (16-19). Hydrogenation of substrates using a source of H₂ in combination with the catalyst is a highly economical and preferred method.

In this study, primarily a series of bis-benzimidazole ligands were synthesized (1a-d) and the catalytic performance of these obtained ligands [RuCl₂(p-cymene)]₂ for transfer hydrogenation of acetophenone in situ conditions was investigated. The catalytic activity of the Ru (II) (2b) complex synthesized from the ligand (1b) showing the highest activity was compared with the in situ test results. The structures of the synthesized ligands and complexes were characterized using different spectroscopic techniques.

2. Materials and Methods
Reactions involving air-sensitive components were carried out under argon atmosphere conditions and standard Schlenk techniques of vacuum-line systems were employed during the experiments. For this reason, the glass containers used in the reaction were heated under vacuum, moisture and oxygen were removed and then filled with dry argon gas before the reaction. The solvents and reagents were dried before use and purified in an inert atmosphere.

¹H- (400 MHz) and ¹³C-NMR (100 MHz) spectra were recorded by Varian AS 400 NMR spectrometer, the chemical shift values (δ) of the compounds in ppm and the coupling constants (J) were given in Hertz. In NMR measurements, CDCl₃ and DMSO-d₆ were used as the solvents and TMS was used as the internal standard. ¹H NMR signal cleavages were abbreviated as s= singlet, d= doublet, t= triplet, q= quartet, m= multiplet. FTIR measurements were taken in the Perkin Elmer Spectrum 100 spectrophotometer on the ATR unit in the range of 4000-400 cm⁻¹. Elemental analysis was recorded with Perkin Elmer 2400 element analyzer.

2.1. Synthesis and Characterization of Ligands (1a-d, 2a-d)
1a-d were synthesized by N-alkylation using 1,4- and/or 1,6-dialkylhalides in the alkaline solution (Figure 1).
The obtained structures were characterized by elemental analysis, NMR and IR techniques. All spectra are consistent with the proposed structures.

Figure 1. Synthesis of bis-benzimidazole ligands (1a-d).

2.2. General Procedure for the Synthesis of (1a-d)

Benzimidazole (236 mg; 2 mmol) or 5,6-dimethyl benzimidazole (292 mg; 2 mmol) in a Schlenk was dissolved in acetone in the presence of KOH (112 mg; 2 mmol) with heating under reflux for 1 hour. Subsequently, 1,4-dibromobutane (215 mg; 1 mmol) or 1,6-dichlorohexane (155 mg; 1 mmol) was added and refluxed for 6 hours. Then the solvent was removed in vacuum, the residue was dissolved with dichloromethane (5 mL) and filtered. Diethyl ether (10 mL) was added to the solution. The crystals obtained were filtered and dried under vacuum.

2.2.1. 1,1'-butane-1,4-diylbis-1H-benzimidazole (1a)

1a: Yield: 88%. 1H-NMR (400 MHz, CDCl3, TMS, 25 ºC, ppm): 1.91 (bs, 4H, NCH2C2H5), 4.15 (bs, 4H, NCH2), 7.26-7.31 (m, 2H, NCHN, 4H, Benz-H) 7.80-7.82 (m, 4H, Benz-H). 13C-NMR (100 MHz, CDCl3, TMS, 25 ºC, ppm): 27.2, 44.6, 109.4, 120.5, 122.2, 123.0, 133.5, 142.7, 143.8. Elemental analysis: calcd (%) for C18H18N4 (290.36) C 74.46; H 6.25; N 19.30. Found (%): C 74.51; H 6.18; N 19.26. IR (KBr; cm⁻¹): 1493 (νC=N).

2.2.2. 1,1'-butane-1,4-diylbis(5,6-dimethyl-1H-benzimidazole) (1b)

1b: Yield: 86%. 1H-NMR (400 MHz, CDCl3, TMS, 25 ºC, ppm): 1.85 (bs, 4H, NCH2C2H5), 2.37 ( s, 12H, 4xC2H3), 4.08 (bs, 4H, NCH2), 7.05 (s, 2H, Benz-H), 7.55 (s, 2H, NCHN), 7.68 (s, 2H, Benz-H). 13C-NMR (100 MHz, CDCl3, TMS, 25 ºC, ppm): 20.2, 20.5, 27.0, 44.4, 109.6, 120.5, 131.1, 132.0, 132.2, 141.9, 142.5. Elemental analysis: calcd (%) for C22H26N4 (346): C, 76.27; H, 7.56; N, 16.17. Found (%): C, 76.07; H, 7.76; N, 16.09. IR (KBr; cm⁻¹): 1495 (νC=N).

2.2.3. 1,1'-hexane-1,6-diylbis-1H-benzimidazole (1c)

1c: Yield: 85%. 1H-NMR (400 MHz, CDCl3, TMS, 25 ºC, ppm): 1.31-1.34 (m, 4H, NH2C2H3), 1.83-1.86 (bs, 4H, NH2C2H3), 4.12 (t, 4H, J= 7.0 Hz, NCH2), 7.26-7.35 (m, 2H, NCHN, 4H, Benz-H), 7.79-7.82 (m, 4H, Benz-H). 13C-NMR (100 MHz, CDCl3, TMS, 25 ºC, ppm): 26.3, 29.5, 44.8, 109.5, 120.4, 122.0, 122.8, 133.7, 142.8, 143.9. Elemental analysis: calcd (%) for C20H12N2 (318.42) C, 75.44; H, 6.96; N, 17.60. Found (%): C, 75.49; H, 6.92; N, 17.66. IR (KBr; cm⁻¹): 1496 (νC=N).

Figure 2. 1H- and 13C-NMR spectra of 1a.

Figure 3. 1H- and 13C-NMR spectra of 1b.
1d: Yield: 81%. \(^1\)H NMR (400 MHz, CDCl\(_3\), TMS, 25 °C, ppm): 1.28-1.32 (m, 4H, NCH\(_2\)CH\(_2\)H), 1.79-1.82 (bs, 4H, NCH\(_2\)CH\(_2\)), 2.07 (s, 6H, 2xC\(_6\)H\(_3\)), 2.36 (s, 6H, 2xC\(_6\)H\(_3\)), 4.46 (bs, 4H, NCH\(_2\)), 5.77 (dd, 8H, J\(_1\)=17.2, J\(_2\)=6.4 Hz, p-cymene- Ar-H), 7.58 (s, 2H, Benz-H), 7.72 (s, 2H, Benz-H), 9.49 (s, 2H, NCH\(_2\N), 10.5, 106.8, 113.0, 115.0, 129.9, 130.4, 135.7, 136.0, 140.8. Elemental analysis: calcd (%) for C\(_{27}\)H\(_{30}\)N\(_4\)Ru\(_2\)(958.86) Calcd (%): C 52.61; H 5.68; N 5.84. Found (%): C 52.47; H 5.81; N 5.86. IR (KBr; cm\(^{-1}\)): 1512 (\(\nu\)C=N).

2b: Yield: %78. \(^1\)H-NMR (400 MHz, DMSO-d\(_6\), TMS, 25 °C, ppm): TMS, 25 °C, ppm): 1.17 (d, 12H, J=6.4 Hz, p-cymene- 4xC\(_6\)H\(_3\)), 1.90 (bs, 4H, NCH\(_2\)CH\(_2\)), 2.07 (s, 6H, p-cymene- 2xC\(_6\)H\(_3\)), 2.36 (s, 12H, 4xC\(_6\)H\(_3\)), 2.77-2.85 (m, 2H, p-cymene- 2xC\(_6\)H\(_3\)), 4.46 (bs, 4H, NCH\(_2\)), 5.77 (dd, 8H, J\(_1\)=17.2, J\(_2\)=6.4 Hz, p-cymene- Ar-H), 7.58 (s, 2H, Benz-H), 7.72 (s, 2H, Benz-H), 9.49 (s, 2H, NCH\(_2\)). \(^{13}\)C-NMR (100 MHz, DMSO-d\(_6\), TMS, 25 °C, ppm): 18.3, 20.3, 20.5, 25.8, 30.4, 46.1, 86.0, 86.8, 100.5, 106.8, 113.0, 115.0, 129.9, 130.4, 135.7, 136.0, 140.8. Elemental analysis: calcd (%) for C\(_{35}\)H\(_{38}\)Cl\(_4\)N\(_4\)Ru\(_2\)(958.86) Calcd (%): C 52.61; H 5.68; N 5.84. Found (%): C 52.47; H 5.81; N 5.86. IR (KBr; cm\(^{-1}\)): 1512 (\(\nu\)C=N).

As the obtained complex did not have sufficient solubility in chloroform, NMR data of both 2b complex and 1b ligand were recorded using DMSO-d\(_6\).

1b: \(^1\)H-NMR (400 MHz, DMSO-d\(_6\), TMS, 25 °C, ppm): 1.71 (bs, 4H, NCH\(_2\)CH\(_2\)), 2.26 (s, 12H, 4xC\(_6\)H\(_3\)), 4.17 (bs, 4H, NCH\(_2\)), 7.27 (s, 2H, Benz-H), 7.37 (s, 2H,
Benz-H), 8.02 (s, 2H, NCHN). $^{13}$C NMR (100 MHz, DMSO-$d_6$, TMS, 25 °C, ppm): 20.3, 20.5, 27.1, 43.9, 110.7, 119.9, 130.2, 131.3, 132.7, 142.5, 143.5.

2.2.6. General Procedure of Transfer Hydrogenation (TH) Reactions

A mixture of acetophenone (1 mmol), catalyst (5x10$^{-3}$ mmol, 1 mol%), propan-2-ol (2 mL) and KOH (0.2 mmol) in a two-necked flask was mixed for 1 hour at 82 °C. At reflux temperature. At the desired reaction times, the fractions were withdrawn from the reaction vessel. Yields were determined by $^1$H-NMR.

3. Results and Discussion

Bis-benzimidazole ligands (1a-d) were obtained in high yields (81-88%) by reacting benzimidazole or 5,6-dimethylbenzimidazole with dialkyl halides in acetone at 56 °C for 6 hours. In the $^1$H-NMR spectrum of these ligands, characteristic singlet peaks of N=CH-N group were observed in the range of δ = 7.28-7.55 ppm. In IR spectra, C = N vibrations signal in the range of 1493-1502 cm$^{-1}$. The spectroscopic values of the synthesized ligands were consistent with the proposed structures. Some spectroscopic data of complex 2b and ligand 1b are given in Table 1.

![Figure 7. $^1$H- and $^{13}$C-NMR spectra of 2b.](image)

![Figure 8. $^1$H- and $^{13}$C-NMR spectra of 1b in DMSO-$d_6$.](image)

Table 1. Spectroscopic data of 1b and 2b.

| N=CH-N (ppm) | IR (υ_C=N) (cm$^{-1}$) |
|-------------|-----------------------|
| 1b          | 8.02                  | 1495                  |
| 2b          | 9.49                  | 1512                  |

The catalytic performances of the catalysts formed by the interaction of the obtained ligands (1a-d) in the presence of [RuCl$_2$(p-cymene)]$_2$ in the transfer hydrogenation reaction of acetophenone were investigated. Since the optimum conditions the reaction temperature as 82 °C and the use of KOH as the base were determined in our previous studies [4], therefore in this study same conditions were employed. The obtained results are summarized in Table 2.

![Figure 7. $^1$H- and $^{13}$C-NMR spectra of 2b.](image)

![Figure 8. $^1$H- and $^{13}$C-NMR spectra of 1b in DMSO-$d_6$.](image)

Table 2. Optimization table for TH of acetophenone$^a$.

| Entry | Catalyst | Ligand | Yield (%) |
|-------|----------|--------|-----------|
| 1     | [RuCl$_2$(p-cymene)]$_2$ | 1a      | 50        |
| 2     | [RuCl$_2$(p-cymene)]$_2$ | 1b      | 76        |
| 3     | [RuCl$_2$(p-cymene)]$_2$ | 1c      | 45        |
| 4     | [RuCl$_2$(p-cymene)]$_2$ | 1d      | 59        |
| 5     | [RuCl$_2$(p-cymene)]$_2$ | 1e      | 29        |
| 6     | -        | 1b      | 9         |
| 7     | -        | -       | 7         |

$^a$Reaction conditions: KOH (0.2 mmol), 1h, Ketone (1 mmol), 2-PrOH (2 mL).
In the study, the best result was obtained with ligand 1b (Table 2, entry 2). In the case where only [RuCl₂(p-cymene)]₂ was used as catalyst (Table 2, entry 5), a conversion of 29% was achieved, whereas ligand 1b was used only without [RuCl₂(p-cymene)]₂ (Table 2, entry 6) a conversion of 9% was achieved. The preferred KOH as the base showed a 7% conversion after 1 hour (Table 2, entry 7). In view of these results, Ru (II) arene complex (2b) was synthesized in the next step using ligand 1b and the activity of the aromatic ketones in which the complex of 1b ligand as in situ 2b as the catalyst in the same reaction conditions was compared by means of the transfer hydrogenation reaction activities (Table 3).

![Diagram](image)

**Table 3.** Comparison table of TH reaction.

| Entry | Ketone | Product | Yield (%) |
|-------|--------|---------|-----------|
| 1     | O      | 3aa     | 76 in situ: 2b: 93 |
| 2     | Cl     | 3ha     | 88 in situ: 2b: >99 |
| 3     | Br     | 3ca     | 83 in situ: 2b: >99 |
| 4     | H₂C    | 3da     | 67 in situ: 2b: 84 |
| 5     | H₂CO   | 3ea     | 60 in situ: 2b: 78 |

**4. Conclusion**

In this study, the catalytic properties of the synthesized bis-benzimidazole ligands (1a-d) and 2b complex in the transfer hydrogenation reaction of acetophenone were investigated. In the in situ study, the highest results were obtained when 1b was used with 76% yield in 1 hour. The bimetallic 2b complex synthesized using this ligand yielded 93% yield under the same reaction conditions. The results were compared in cases where the 1b ligand in situ and 2b complex were used as catalysts in the transfer hydrogenation reaction using different ketones. Catalytic activity varies depending on the groups in the phenyl ring of acetophenone. In the presence of electron attractive groups it exhibited an increment. The best result was obtained using 4-chloro and 4-bromo acetophenone for a 1 hour reaction time, and when 2b was used as a catalyst, a yield of 99% was achieved.

**Figure 9.** ¹H-NMR spectra of the catalytic products

**Ethics**

There are no ethical issues after the publication of this manuscript.
References

1. Günnaz, S., Özdemir, N., Dayan, S., Dayan, O. Çetinkaya, B. 2011. Synthesis of Ruthenium(II) Complexes Containing Tridentate Triamine (′N’N) and Bidentate Diamine Ligands (N,N): as Catalysts for Transfer Hydrogenation of Ketones, Organometallics, 30(15): 4165-4173.

2. Haneda, S., Adachi, Y., Hayashi, M. 2009. Copper(I)-2-(2'-pyridyl)benzimidazole catalyzed N-arylation of indoles, Tetrahedron, 65(50): 10459-10462.

3. Haneda, S., Gan, Z., Eda, K., Hayashi, M. 2007. Ligand Effects of 2-(2-Pyridyl)benzazole–Pd Complexes on the X-ray Crystallographic Structures, H NMR Spectra, and Catalytic Activities in Mizoroki–Heck Reactions, Organometallics, 26(26): 6551-6555.

4. Done, M., C. Ruther, T. Cavell, K. J., Kilner, M., Peacock, E. J., Braussaud, N., Skelton, B. W., White, A. J. 2000. Novel catonionic and neutral Pd(II) complexes bearing imidazole based chelate ligands: synthesis, structural characterisation and catalytic behaviour, J. Organomet. Chem., 607(1): 78-92.

5. Zhao, X., Liu, D. Li, Y., Cui, G. 2018. Two 3D cadmium (II) coordination polymers modulated by flexible bis(benzimidazole) ligands displaying high photocatalytic activities for degradation of methylene blue and methyl orange, Polyhedron, 156(1): 200-207.

6. Aksenov, A. V., Smirnov, A. N., Aksenov N., A. Bijieva, A. S., Aksenova, I. V., Rubin, M. 2015. Benzimidazoles and benzoxazoles via the nucleophilic addition of amines to nitroalkanes, Org. Biomol. Chem., 13(14): 4289-4295.

7. Zhang, D., Jiang, X., Yang, H., Martinez, A. Feng, M., Donga, Z., Gao, G. 2013. Acridine-based macrocyclic fluorescent sensors: self-assembly behavior characterized by crystal structures and a tunable bathochromic-shift in emission induced by H2PO4⁻ via adjusting the ring size and rigidity, Org. Biomol. Chem., 11(20): 3375-3381.

8. Liu, Q., X. Wei, Q., Zhao, X., J. Wang, H., Li, S., J. Wang, X. G. 2013. Cobalt(II), copper(II), zinc(II) and cadmium(II) complexes based on dibenzimidazolyl bidentate ligands with alkanyl linkers: crystal structure, weak interactions and conformation, Dalton Trans., 42(16): 5902-5915.

9. Iaroshenko, V., O. Ostrovskyi, D., Militina, M., Maalik, A. Villing, A., Tomachev, A., Volochnyuk, D., M. Langer, P. 2012. Design and Synthesis of Polycyclic Imidazole-Containing N-Heterocycles based on C-H Activation/Cyclization Reactions, Adv. Synth. Catal., 354(13): 2495-2503.

10. Kacukbay, H., Yilmaz, U., Sireci, N., Onganer, A. N. 2011. Synthesis and antimicrobial activities of some bridged bis-benzimidazole derivatives, Turk. J. Chem., 35(4): 561-571.

11. Wang, D., E. Deng, K., J. Lv, K., L. Wang, C., G. Wen, L., L., Li, D., F. 2009. Structures, photoluminescence and photocatalytic properties of three new metal–organic frameworks based on non-rigid long bridges, CrystEngComm, 11(7): 1442-1450.

12. Wong, W., W., H. Vickers, M., S., Cowley, A. R., Paul, R., L. Beer, P. D. 2005. Tetraakis(imidazolium) macrocyclic receptors for alan binding, Org. Biomol. Chem., 3(23): 4201-4208.

13. Ma, J. F., Liu, J. F., Liu, Y., C., Xing, Y., Jia, H., Q. Lin, Y. H. 2000. Two new coordination polymers of Co(II) with 1,1’-(1,4-butanediyl)bis(benzimidazole), New J. Chem., 24(10): 759-763.

14. Shi, Z., Thummel, R. P. 1995. N,N-Bridged Derivatives of 2,2'-Bibenzimidazole, J. Org. Chem., 60(18): 5935-5945.

15. Noyori, R., Hashiguchi, S. 1997. Asymmetric Transfer Hydrogenation Catalyzed by Chiral Ruthenium Complexes, Acc. Chem. Res., 30(2): 97-102.

16. Dayan, O., Özdemir, N., Şerbetci, Z., Dinçer, M., Çetinkaya, B., Büyükgüngör, O. 2012. Synthesis and catalytic activity of ruthenium(II) complexes containing pyridine-based tridentate triamines (NNN) and pyridine carboxylate ligands (NO), Inorg. Chim. Acta, 392(1): 246-253.