Antimicrobial Studies of N-Heterocyclic Carbene Silver Complexes Containing Benzimidazol-2-ylidene Ligand

Yetkin Gök,¹ Yakup Sarı,¹ Senem Akkoç,² İ lkın Özdemir,¹ and Selami Günal³

¹ Department of Chemistry, Faculty of Science and Arts, İnönü University, 44280 Malatya, Turkey
² Department of Chemistry, Faculty of Science, Erciyes University, 38039 Kayseri, Turkey
³ Department of Microbiology, Faculty of Medicine, İnönü University, 44280 Malatya, Turkey

Correspondence should be addressed to Senem Akkoç; senemakkoc@erciyes.edu.tr

Received 24 July 2014; Accepted 1 October 2014; Published 10 November 2014

Academic Editor: Hakan Arslan

Copyright © 2014 Yetkin Gök et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

Seven novel 4-vinylbenzyl substituted N-heterocyclic carbene (NHC) silver complexes were synthesized from different benzimidazolium salts and silver (I) oxide in dichloromethane at room temperature. These new 4-vinylbenzyl substituted NHC silver complexes were characterized by spectroscopic (NMR, IR) and elemental analysis techniques. Using the agar dilution procedure, the antimicrobial activities of these synthesized new compounds were investigated against Gram (+)/(-) bacterial and fungal strains. These NHC silver complexes showed effective activities against Escherichia coli, Pseudomonas aeruginosa (Gram-negative bacterial strains), Enterococcus faecalis, Staphylococcus aureus (Gram-positive bacterial strains), and Candida tropicalis and Candida albicans (fungal strains).

1. Introduction

N-Heterocyclic carbones (NHCs) are cyclic constructions which are generally derived from deprotonation of salts of ligands such as imidazolium, benzimidazolium, diazepinium, pyrimidium. Since isolation of first free carbene in 1991 [1], NHCs which are strong σ donor, low π acceptor ability, and transition metal carbene complexes obtained by using carbene precursors have had a wide application area in organometallic chemistry [2–4]. Among various transition metal carbene complexes, NHC silver complexes have played a significant role in the development of N-heterocyclic carbene chemistry because of their structural diversity and their wide spread successful application as effective carbene transfer reagents in transmetallation reactions to make other NHC metal complexes, like nickel [5], copper [6], platinum [6], iridium [6], ruthenium [5], rhodium [6, 7], palladium [6–10], and gold [6, 10, 11] carbene complexes. Also, the prominent biological activity of many NHC silver complexes as antimicrobial and anticancer agents has been confirmed [12–18]. Therefore, many studies on silver complexes have been made by different research groups for many years [19–24].

Herein, we report the synthesis, characterization, and antibacterial and antifungal activity studies of seven novel symmetrically and unsymmetrically p-vinylbenzyl-substituted NHC silver complexes which were prepared starting from 1-(4-vinylbenzyl)-3-alkyl benzimidazolium salts and silver (I) oxide in dichloromethane. The characterization of the NHC silver complexes is consistent with the proposed formula. Using the agar dilution procedure, the antimicrobial activities of these compounds are investigated against Gram (+)/(-) bacterial and fungal strains. NHC silver complexes in the antimicrobial study were observed to have higher activity against fungal strains than against Gram-positive and Gram-negative bacterial strains.

2. Experimental

2.1. Materials and Methods. In this study, the synthesis of silver (I) complexes was pursued in a dark medium under an inert atmosphere. All solvents and reagents were commercially bought. The solvents used in the synthesis, diethyl ether over Na, and dichloromethane over P₄O₁₀ were
2.2. General Method for the Synthesis of 1-(4-Vinylbenzyl)-3-alkylbenzimidazol-2-ylidene Silver Complexes, **la-g**. 1-(4-Vinylbenzyl)-3-alkylbenzimidazolium salts containing symmetrical and unsymmetrical groups were synthesized by reaction of 1-(4-vinylbenzyl)benzimidazole with various aryl halides in DMF according to the literature [25, 26]. Under an inert atmosphere, Ag₂O (0.5 mmol), 1-(4-vinylbenzyl)-3-alkylbenzimidazolium salt (1.0 mmol) and activated 4 Å molecular sieves were put in CH₂Cl₂ which was distilled prior to use over P₂O₅ (20 mL) and were stirred in darkness at ambient temperature for one day. The Schlenk-type flask used was covered with aluminum foil to avoid exposure to light. The resulting solution was filtered through celite and the solvent was removed under reduced pressure. The crude product was washed with diethyl ether which was distilled prior to use over Na (3 x 10 mL) and was crystallized from dichloromethane/diethyl ether at room temperature.

2.2.1. Iodo [1-(4-Vinylbenzyl)]-3-methyl benzimidazol-2-ylidene silver(I), **1a**. 1-(4-Vinylbenzyl)-3-methyl benzimidazolium salt (1.0 mmol) and Ag₂O (0.5 mmol) in dichloromethane (20 mL) were put in a Schlenk-type flask which was covered with aluminum foil. The resulting solution was stirred for 24 h. Then, it was filtered through celite and the solvent was removed under reduced pressure. The crude product was washed with diethyl ether and was crystallized from dichloromethane/diethyl ether at room temperature. Yield: 81%, m.p.: 146-148°C. FT-IR  ν(CN); 1445.5 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ; 4.02 (s, 3 H, CH₃); 5.23 and 5.81 (dd, 2 H, CH₃C₆H₄CH=CH₂, J: 9.6 Hz); 5.69 (s, 2 H, CH₃C₆H₄CH=CH₂); 6.65 (dd, 1 H, CH₃C₆H₄CH=CH₂, J: 11.4 Hz); 7.21-7.77 (m, 8 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ; 36.1 (CH₃); 52.0 (CH₃C₆H₄CH=CH₂); 112.5, 115.3, 115.6, 124.4, 124.5, 125.8, 126.3, 126.9, 127.4, 128.2, 129.6, 133.6, 134.6, 136.4, 136.6, 137.2, 137.4 and 138.0 (Ar-C and CH=CH₂); 189.0 (C-Ag). Anal. Calcd. for C₂₅H₂₃N₂AgI (481.95 g/mol): C, 42.27; H, 3.34; N, 5.80. Found: C, 42.35; H, 3.29; N, 5.76%.

2.2.2. Chloro[1-(4-vinylbenzyl)-3-benzimidazol-2-ylidene silver(I), **1b**. With a similar method to that used for compound 1a, compound 1b was prepared from 1-(4-vinylbenzyl)-3-benzimidazolium salt (1.0 mmol) and Ag₂O (0.5 mmol) in dichloromethane (20 mL). Yield: 76%, m.p.: 127-129°C. FT-IR  ν(CN); 1443.45 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ; 5.29 and 5.77 (dd, 2 H, CH₃C₆H₄CH=CH₂, J: 8.11 Hz); 5.71 (s, 2 H, CH₃C₆H₄CH=CH₂); 6.65 (dd, 1 H, CH₃C₆H₄CH=CH₂, J: 8.4 Hz); 7.16-7.43 (m, 13 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ; 53.4 (CH₃C₆H₄H₂); 53.6 (CH₃C₆H₄CH=CH₂); 112.2, 114.8, 115.1, 124.5, 125.0, 126.3, 126.9, 127.2, 127.5, 128.6, 129.2, 129.4, 133.9, 134.2, 134.8, 135.2, 135.5, 136.0, 136.1, 137.9 and 138.5 (Ar-C and CH=CH₂). Anal. Calcd. for C₂₅H₂₀N₂AgCl (466.04 g/mol): C, 59.06; H, 4.31; N, 5.99. Found: C, 59.01; H, 4.23; N, 5.97%.

2.2.3. Chloro[1-(4-vinylbenzyl)-3-(2-methylbenzyl)benzimidazol-2-ylidene silver(I), **1c**. With a similar method to that used for compound 1a, compound 1c was prepared from 1-(4-vinylbenzyl)-3-(2-methylbenzyl)benzimidazolium salt (1.0 mmol) and Ag₂O (0.5 mmol) in dichloromethane (20 mL). Yield: 86%, m.p.: 210-211°C. FT-IR  ν(CN); 1444.25 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ; 2.42 (s, 3 H, CH₃C₆H₄H₂); 5.28 and 5.78 (dd, 2 H, CH₃C₆H₄CH=CH₂, J: 11.1 Hz); 5.66 (s, 2 H, CH₃C₆H₄CH=CH₂); 5.73 (s, 2 H, CH₃C₆H₄CH=CH₂); 6.67 (dd, 1 H, CH₃C₆H₄CH=CH₂, J: 10.8 Hz); 7.01-7.53 (m, 12 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ; 19.7 (CH₃C₆H₄H₂); 51.6 (CH₃C₆H₄H₂); 53.5 (CH₃C₆H₄CH=CH₂); 112.2, 114.8, 124.5, 125.6, 126.7, 126.9, 127.4, 128.5, 131.0, 132.2, 133.8, 134.2, 135.5, 136.0, 137.9 and 143.4 (Ar-C and CH=CH₂). Anal. Calcd. for C₂₅H₂₀N₂AgCl (480.06 g/mol): C, 59.83; H, 4.60; N, 5.81. Found: C, 59.71; H, 4.69; N, 5.79%.

2.2.4. Chloro[1-(4-vinylbenzyl)-3-(4-methylbenzyl)benzimidazol-2-ylidene silver(I), **1d**. With a similar method to that used for compound 1a, compound 1d was prepared from 1-(4-vinylbenzyl)-3-(4-methylbenzyl)benzimidazolium salt (1.0 mmol) and Ag₂O (0.5 mmol) in dichloromethane (20 mL). Yield: 83%, m.p.: 216-217°C. FT-IR  ν(CN); 1439.17 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ; 2.24 (s, 3 H, CH₃C₆H₄H₂); 5.25 and 5.83 (dd, 2 H, CH₃C₆H₄CH=CH₂, J: 10.8 Hz); 5.71 (s, 2 H, CH₃C₆H₄H₂); 5.75 (s, 2 H, CH₃C₆H₄CH=CH₂); 6.69 (dd, 1 H, CH₃C₆H₄CH=CH₂, J: 7.2 Hz); 7.01-8.18 (m, 12 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ; 21.13 (CH₃C₆H₄H₂); 52.2 (CH₃C₆H₄CH=CH₂); 114.8, 136.0, 112.9, 124.5, 126.5, 126.9, 128.5, 131.0, 132.6, 133.8, 134.2, 135.5 and 137.9 (Ar-C and CH=CH₂). Anal. Calcd. for C₂₅H₂₀N₂AgCl (480.06 g/mol): C, 59.83; H, 4.60; N, 5.81. Found: C, 59.95; H, 4.66; N, 5.84%.
2.2.5. Chloro[1-(4-vinylbenzyl)-3-(2,4,6-trimethylbenzyl)benzimidazol-2-ylidene]silver(I), 1e. With a similar method to that used for compound 1a, compound 1e was prepared from 1-(4-vinylbenzyl)-3-(2,4,6-trimethylbenzyl)benzimidazolium salt (1.0 mmol) and AgO (0.5 mmol) in dichloromethane (20 mL). Yield: 75%, m.p.: 230-231°C. FT-IR ν (cm⁻¹): 1403.38 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ: 2.19 and 2.26 [s, 9 H, CH₂C₆H₄(CH₃)₂]; 5.25 and 5.82 (dd, 2 H, CH₂C₆H₄CH₂CH₃, J = 10.8 Hz); 5.57 [s, 2 H, CH₂C₆H₄(CH₃)₂]; 5.62 (dd, 2 H, CH₂C₆H₄CH₂CH₃, J = 3.26 Hz); 6.65 (dd, 1 H, CH₂C₆H₄CH₂CH₃, J = 11.0 Hz); 6.93-8.10 (m, 10 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ: 19.8 and 21.1 [CH₂C₆H₄(CH₃)₂]; 52.1 [CH₂C₆H₄(CH₃)₂]; 52.2 (CH₂C₆H₄CH₂CH₃); 112.9, 114.8, 124.5, 126.5, 126.7, 126.9, 128.5, 131.0, 132.6, 133.8, 134.2, 135.5, 136.0 and 137.9 (Ar-C) (ve CH=CH₂). Anal. Calcld. for C₆₀H₄₃N₂AgCl (508.09 g/mol): C, 61.25; H, 5.14; N, 5.49. Found: C, 61.33; H, 5.09; N, 5.45%.

2.2.6. Chloro[1-(4-vinylbenzyl)-3-(2,3,5,6-tetramethylbenzyl)benzimidazol-2-ylidene]silver(I), 2f. With a similar method to that used for compound 1a, compound 2f was prepared from 1-(4-vinylbenzyl)-3-(2,3,5,6-tetramethylbenzyl)benzimidazolium salt (1.0 mmol) and AgO (0.5 mmol) in dichloromethane (20 mL). Yield: 73%, m.p.: 237-238°C. FT-IR ν (cm⁻¹): 1449.43 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ: 2.10 and 2.19 [s, 12 H, CH₂C₆H₄(CH₃)₂]; 5.23 and 5.81 (dd, 2 H, CH₂C₆H₄CH₂CH₃, J = 10.5 Hz); 5.60 (dd, 2 H, CH₂C₆H₄CH₂CH₃, J = 6.66 (dd, 1 H, CH₂C₆H₄CH₂CH₃, J = 10.5 Hz); 7.04-7.93 (m, 9 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ: 16.4 and 20.8 [CH₂C₆H₄(CH₃)₂]; 46.8 [CH₂C₆H₄(CH₃)₂]; 52.9 (CH₂C₆H₄CH₂CH₃); 112.5, 119.5, 119.3, 124.6, 124.8, 126.9, 127.8, 131.8, 132.6, 133.3, 133.9, 134.7, 134.9, 136.2, 136.4 and 137.5 (Ar-C). Anal. Calcld. for C₆₂H₄₃N₂AgCl (522.11 g/mol): C, 61.91; H, 5.39; N, 5.35. Found: C, 61.82; H, 5.46; N, 5.28%.

2.2.7. Chloro[3-bis(4-vinylbenzyl)benzimidazol-2-ylidene]silver(I), 3g. With a similar method to that used in compound 1a, compound 3g was prepared from 1,3-bis(4-vinylbenzyl)benzimidazolium salt (1.0 mmol) and AgO (0.5 mmol) in dichloromethane (20 mL). Yield: 79%, m.p.: 249-250°C. FT-IR ν (cm⁻¹): 1440.26 cm⁻¹. 1H NMR (300.13 MHz, DMSO-d₆), δ: 5.25 and 5.83 (dd, 4 H, CH₂C₆H₄CH₂CH₃, J = 10.8 Hz); 5.76 (s, 4 H, CH₂C₆H₄CH₂CH₃, J = 6.69 (dd, 2 H, CH₂C₆H₄CH₂CH₃, J = 10.8 Hz); 7.13-7.75 (m, 12 H, Ar-H). 13C NMR (75.47 MHz, DMSO-d₆), δ: 52.2 (CH₂C₆H₄CH₂CH₃); 112.9, 115.1, 124.7, 127.0, 127.8, 128.1, 129.8, 129.3, 133.9, 136.3, 136.5 and 137.4 (Ar-C) and CH=CH₂. Anal. Calcld. for C₆₃H₄₅N₂AgCl (492.06 g/mol): C, 60.81; H, 4.49; N, 5.67. Found: C, 60.71; H, 4.55; N, 5.65%.

3. Results and Discussion

3.1. Synthesis and Characterization of N-Heterocyclic Carbone Silver Complexes, 1a–g. Different 1-(4-vinylbenzyl)-3-alkyl benzimidazolium salts as carbone precursors were synthesized [25, 26]. The intended silver (I) complexes 1a–g were obtained from the interaction of AgO with benzimidazolium salts in CH₃Cl at room temperature after 24 h as white solid crystals in 73–86% yields according to known methods (Scheme 1) [17, 24]. Their structures were characterized using spectroscopic and analytical techniques. The 1H and 13C NMR spectra of these new complexes are consistent with the proposed formula. The spectra of these products in dimethylsulfoxide (DMSO-d₆) supported the formation of the silver complexes because of the loss of proton (NCHN) signal of the benzimidazolium salts. Compound 1a exhibited characteristic a carbene carbon peak in the 13C NMR spectra as singlet at 189.0 ppm. The resonance for carbene carbon was not determined in the 1b–g complexes. This condition has been mentioned in the literature and has been given as a reason for the variable action of the NHC complexes [29–31]. The FT-IR data for NHC silver complexes exhibit a characteristic ν(C=N) band at 1445.13, 1443.45, 1444.25, 1439.17, 1403.38, 1449.43, and 1449.43 and 1440.26 for 1a–g, respectively.

3.2. Antimicrobial Activity of N-(4-Vinylbenzyl) Substituted Silver Complexes, 1a–g. Using an agar dilution procedure, the antimicrobial activities of the synthesized silver (I) complexes were determined. Antimicrobial activities were found to be effective in the tested complexes (1a–g) against both fungi and bacteria strains with MIC values between 200 and 25 μg/mL⁻¹. It was seen that these complexes are more effective against fungi strains than against bacteria strains. The obtained results are summarized in the Table 1. The silver carbone complexes showed effective activities against Escherichia coli, Pseudomonas aeruginosa (gram-negative bacterial strains), Enterococcus faecalis, Staphylococcus aureus (gram-positive bacterial strains), and Candida tropicalis and Candida albicans (fungal strains). Most of benzimidazolium salts containing both electron withdrawing and electron donating groups demonstrated antimicrobial activity. The 1b, 1e, and 1f silver carbone complexes which were containing benzyl, 2,4,6-trimethylbenzyl and 2,3,5,6-tetramethylbenzyl groups and fungal strains (C. tropicalis and C. albicans). Their turbidities matched that of a McFarland number 0.5 turbidity standard. The stock solutions of all silver complexes were prepared in dimethylsulfoxide. All dilutions were carried out using distilled water. The concentrations of the tested silver (I) complexes were 6.25, 12.5, 25, 50, 100, 200, 400, and 800 μg/mL. Fluconazole, ciprofloxacin, and ampicillin were used as the antifungal and antibacterial standard drugs. A loopful (0.01 mL) of the standardized inocula of the yeasts and bacteria (10⁶ CFUs/mL) was spread over the surface of agar plates. All the samples were inoculated after 16–20 h of incubation for bacteria and 48 h for yeasts. The lowest concentration of the NHC silver complexes that prevented visible growth was considered to be the MIC.
showed better antibacterial activity than the 1a, 1c, 1d, and 1g complexes which were including methyl, 2-methylbenzyl, 4-methylbenzyl, and 4-vinylbenzyl groups. Generally, results of this study showed that compound containing sterich effect on the nitrogen atom were more effective on antimicrobial activity. The NHC silver complexes including both symmetrical (1g) and unsymmetrical (1c, 1d) groups indicated the same activities against all bacteria and fungus. Also, these compounds (1c, 1d, and 1g) exhibited low activity for all bacteria and fungi strains. Among the NHC silver complexes, the 1a, 1b, 1e, and 1f complexes showed high activity against *C. tropicalis* at 25 $\mu$g/mL. As positive control, ampicillin, ciprofloxacin, and fluconazole were used. It is seen from the obtained data in this work that the substituents on the *N*-atoms play an important role in antimicrobial activity.

4. Conclusions

The seven new 4-vinylbenzyl substituted benzimidazol-2-ylidene silver complexes were prepared by the reaction of different benzimidazolium salts with silver (I) oxide in...
Table 1: MICs (µg mL⁻¹) of silver-NHCs for test microorganisms.

| Compound | E. coli | S. aureus | E. faecalis | P. aeruginosa | C. albicans | C. tropicalis |
|----------|---------|-----------|-------------|---------------|-------------|--------------|
| 1a       | 50      | 100       | 100         | 100           | 25          | 25           |
| 1b       | 50      | 50        | 50          | 50            | 50          | 25           |
| 1c       | 200     | 200       | 200         | 200           | 200         | 200          |
| 1d       | 200     | 200       | 200         | 200           | 200         | 200          |
| 1e       | 50      | 50        | 50          | 50            | 25          | 25           |
| 1f       | 50      | 50        | 50          | 50            | 25          | 25           |
| 1g       | 200     | 200       | 200         | 200           | 200         | 200          |
| Ampicillin | 3.12  | 3.12      | 1.56        | —             | —           | —            |
| Ciprofloxacin | 1.56  | 0.39      | 0.78        | 3.12          | —           | —            |
| Fluconazole  | —     | —         | —           | —             | 3.12        | 3.12         |

Ampicillin, Ciprofloxacin, and Fluconazole (fungal strains).

Conflict of Interests
The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgment
The authors would like to thank the Inonu University Research Fund (BAP 2011/25) for financial support.

References
[1] A. J. Arduengo III, R. L. Harlow, and M. Kline, "A stable crystalline carbene," Journal of the American Chemical Society, vol. 113, no. 1, pp. 361–363, 1991.
[2] W. A. Herrmann, "N-heterocyclic carbones: a new concept in organometallic catalysis," Angewandte Chemie International Edition, vol. 41, no. 8, pp. 1290–1309, 2002.
[3] D. Bourissou, O. Guerret, F. P. Gabbaï, and G. Bertrand, "Stable carbones," Chemical Reviews, vol. 100, no. 1, pp. 39–92, 2000.
[4] J. C. Garrison and W. J. Youngs, "Ag(I) N-heterocyclic carbene complexes: synthesis, structure, and application," Chemical Reviews, vol. 105, no. 11, pp. 3978–4008, 2005.
[5] V. R. Anna, R. Pallepogu, Z.-Y. Zhou, and M. R. Kollipara, "Novel platinum group metal complexes bearing bidentate chelating pyrimidyl-NHC and pyrimidyl imidazolyl-thione ligands: syntheses, spectral and structural characterization," Inorganic Chemistry Acta, vol. 387, pp. 37–44, 2012.
[6] I. J. B. Lin and C. S. Vasam, "Preparation of N-heterocyclic carbene complexes of Ag(I)," Coordination Chemistry Reviews, vol. 251, no. 5–6, pp. 642–670, 2007.
[7] K. S. Coleman, H. T. Chamberlayne, S. Turberville, M. L. H. Gren, and A. R. Cowley, "Silver(I) complex of a new imino-N-heterocyclic carbene and ligand transfer to palladium(II) and rhodium(I)," Dalton Transactions, no. 14, pp. 2917–2922, 2003.
[8] Q.-X. Liu, L.-X. Zhao, X.-J. Zhao et al., "Silver(I), palladium(II) and mercury(II) NHC complexes based on bis-benzimidazole salts with mesitylene linker: synthesis, structural studies and catalytic activity," Journal of Organometallic Chemistry, vol. 731, pp. 35–48, 2013.
[9] W. A. Herrmann, S. K. Schneider, K. Öfele, M. Sakamoto, and E. Herdtweck, "First silver complexes of tetrahydropropyrimid-2-yldenes," Journal of Organometallic Chemistry, vol. 689, no. 15, pp. 2441–2449, 2004.
[10] H. M. J. Wang and I. J. B. Lin, "Facile synthesis of silver(I)-carbene complexes. Useful carbene transfer agents," Organometallics, vol. 17, no. 5, pp. 972–975, 1998.
[11] J. W. Wang, H. B. Song, Q. S. Li, F. B. Xu, and Z. Z. Zhang, "Macrocyclic dinuclear gold(I) and silver(I) NHCs complexes," Inorganica Chimica Acta, vol. 358, no. 13, pp. 3653–3658, 2005.
[12] L. Mercs and M. Albrecht, "Beyond catalysis: N-heterocyclic carbene complexes as components for medicinal, luminescent, and functional materials applications," Chemical Society Reviews, vol. 39, no. 6, pp. 1903–1912, 2010.
[13] A. Kascatan-Nebioglu, M. J. Panzner, C. A. Tessler, C. L. Cannon, and W. J. Youngs, "N-Heterocyclic carbene-silver complexes: a new class of antibiotics," Coordination Chemistry Reviews, vol. 251, no. 5–6, pp. 884–895, 2007.
[14] T. J. Siciliano, M. C. Deblock, K. M. Hindi et al., "Synthesis and anticancer properties of gold(I) and silver(I) NHCs complexes," Journal of Organometallic Chemistry, vol. 696, no. 5, pp. 1066–1071, 2011.
[15] B. D. Wright, P. N. Shah, L. J. McDonald et al., "Synthesis, characterization, and antimicrobial activity of silver carbene complexes derived from 4,5,6,7-tetrachlorobenzimidazole against antibiotic resistant bacteria," Dalton Transactions, vol. 41, no. 21, pp. 6500–6506, 2012.
[16] D. C. F. Monteiro, R. M. Phillips, B. D. Crossley, J. Fielden, and C. E. Willans, "Enhanced cytotoxicity of silver complexes bearing bidentate N-heterocyclic carbene ligands," Dalton Transactions, vol. 41, no. 13, pp. 3720–3725, 2012.
[17] Y. Gök, S. Akkoç, Ö. Ö. Çelikal, I. Özdemir, S. Günal, and E. Sayın, “N-functionalized benzimidazol-2-ylidene silver complexes: synthesis, characterization, and antimicrobial studies,” *Turkish Journal of Chemistry*, vol. 37, no. 6, pp. 1007–1013, 2013.

[18] I. Özdemir, N. Gürbüz, Ö. Doğan, and S. Günal, “Synthesis and antimicrobial activity of Ag(I)-N-heterocyclic carbene complexes derived from benzimidazol-2-ylidene,” *Applied Organometallic Chemistry*, vol. 24, no. 11, pp. 758–762, 2010.

[19] P. Kumar and I. Cisarova, “Synthesis and characterization of silver and gold NHC complexes: crystal structures and mass spectral studies,” *Journal of Organometallic Chemistry*, vol. 735, pp. 32–37, 2013.

[20] C.-H. Cheng, D.-F. Chen, H.-B. Song, and L.-F. Tang, “Synthesis and catalytic activity of N-heterocyclic carbene silver complexes derived from 1-[2-(pyrazol-1-yl)phenyl]imidazole,” *Journal of Organometallic Chemistry*, vol. 726, pp. 1–8, 2013.

[21] S. Kumar, M. M. Shaikh, and P. Ghosh, “Palladium complexes of amido-functionalized N-heterocyclic carbenes as effective precatalysts for the Suzuki–Miyaura C–C cross-coupling reactions of aryl bromides and iodides,” *Journal of Organometallic Chemistry*, vol. 694, no. 26, pp. 4162–4169, 2009.

[22] T. Liu, X. Zhao, Q. Shen, and L. Lu, “General and highly efficient fluorinated-N-heterocyclic carbene-based catalysts for the palladium-catalyzed Suzuki-Miyaura reaction,” *Tetrahedron*, vol. 68, no. 32, pp. 6535–6547, 2012.

[23] F. Hackenberg, G. Lally, H. Müller-Bunz et al., “Synthesis and biological evaluation of N-heterocyclic carbene-silver(I) acetate complexes derived from 4,5-ditolyllimidazole,” *Inorganica Chimica Acta*, vol. 395, pp. 135–144, 2013.

[24] Y. Gök, S. Akkoç, S. Albayrak, M. Akkurt, and M. N. Tahir, “N-Phenyl-substituted carbene precursors and their silver complexes: synthesis, characterization and antimicrobial activities,” *Applied Organometallic Chemistry*, vol. 28, no. 4, pp. 244–251, 2014.

[25] Y. Gök, N. Gürbüz, I. Özdemir, B. Çetinkaya, and E. Çetinkaya, “Benzimidazolin-2-ylidene-palladium-catalysed coupling reactions of aryl halides,” *Applied Organometallic Chemistry*, vol. 19, no. 7, pp. 870–874, 2005.

[26] A. Aktaş, S. Akkoç, and Y. Gök, “Palladium catalyzed Mizoroki-Heck and Suzuki-Miyaura reactions using naphthalenomethyl-substituted imidazolidin-2-ylidene ligands in aqueous media,” *Journal of Coordination Chemistry*, vol. 66, no. 16, pp. 2901–2909, 2013.

[27] National Clinical and Laboratory Standards Institute, *Methods for Dilution Antimicrobial Susceptibility Tests for Bacteria that Grow Aerobically: Approved Standard*, CLSI Document M7-A7, National Clinical and Laboratory Standard Institute, Wayne, Pa, USA, 7th edition, 2003.

[28] Clinical and Laboratory Standards Institute, *Reference Method for Broth Dilution Antifungal Susceptibility Testing of Yeasts: Approved Standard*, NCCLS Document M27-A2, National Clinical and Laboratory Standards Institute, Wayne, Pa, USA, 2nd edition, 2002.

[29] D. J. Nielsen, K. J. Cavell, B. W. Skelton, and A. H. White, “Tetrafluoroborate anion B-F bond activation—unusual formation of a nucleophilic heterocyclic carbene: BF3 adduct,” *Inorganica Chimica Acta*, vol. 352, pp. 143–150, 2003.

[30] J. Pytkowicz, S. Roland, and P. Mangeney, “Synthesis of chiral silver(I) diaminocarbene complexes from (R,R)-4,5-di-tert-butylimidazoline,” *Journal of Organometallic Chemistry*, vol. 631, no. 1-2, pp. 157–163, 2001.
Submit your manuscripts at http://www.hindawi.com