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Synthesis, characterization and biological study of Cu(II) complexes of aminopyridine and (aminomethyl)pyridine Schiff bases

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Abstract: The synthesis, characterization and antimicrobial activity determination of some aminopyridine- and (aminomethyl)pyridine–salicylaldimine copper(II) complexes were realized. The ligands, L^1–L^6, were prepared by condensing salicylaldehyde and *o*-vanillin with 2- and 3-amino- and (aminomethyl)pyridine, respectively. The complexes were characterized by micro-analytical, electronic, infrared and conductivity data. The structures of the Schiff base ligands were further confirmed from ^{1}H- and ^{13}C-NMR spectral data. This study established that salicylaldimine ligands could coordinate as neutral species *via* the imine-N and the undeprotonated phenolic-O. The complexes have the molecular formula: [CuLCl], $[Cu(LH)_2Cl_2]\cdot xH_2O$ or $[Cu(LH)Cl(H_2O)]Cl$. The X-ray crystal structure of $[CuL^6Cl]$ indicated a square planar geometry with the Schiff base ligand coordinated to the Cu(II) ion as a tridentate monobasic, N_2O, ligand. The crystals crystallized in a monoclinic system with $P2_1/c$ space group. All the ligands and their Cu(II) complexes were screened for their antimicrobial activity against *Staphylococcus aureus* subsp. *aureus* ATCC® 6538™*, *Bacillus subtillis* subsp. *spizizenii* ATCC® 6633™*, *Escherichia coli* ATCC® 8739™* and *Candida albicans* ATCC® 2091™* using agar diffusion and broth dilution techniques. The presence of the methoxyl group enhanced the antimicrobial activity of the salicylaldimine Schiff base ligands.

Keywords: salicylaldimine; crystal structure; square planar; Schiff bases; *in vitro*; chelates.

INTRODUCTION

The unwavering interest in the study of Schiff base compounds arises from the ease of their preparation and versatility. They are prepared from one pot con-

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densation of primary amines with aldehydes or ketones.[1,2] Schiff bases are a special class of organic compounds with varying applications in several fields of chemistry and biochemistry, especially as coordinating ligands.[3,4] Schiff bases of aminoalkylpyridines are known to be structurally related to compounds participating in vitamin B6 chemistry.[5] It was demonstrated that they possess significant biological activity, such as antimicrobial,[2,6–12] anti-inflammatory,[13] and antiviral activity.[14] Studies showed that the biological activity of free ligands sometimes become enhanced upon coordination with metal ions.[15–21] Stable chelates are formed with Schiff bases containing multiple donor atoms, notably bis(*ortho*-hydroxybenzylidene)diamines (N_2O_2) ligands.[22,23] The presence of the heterocyclic ring in the Schiff base moiety lends additional stability to the structure of Schiff base metal complexes. This extra stability is possible with aminopyridine-derived Schiff base ligands depending on the position of the imine-N relative to the azine--N. Most *ortho*-hydroxy Schiff bases coordinate as monobasic bidentate ligands *via* the imine-N and the phenoxide ion;[24,25] only a few cases of neutral coordination of salicylaldimines have been reported.[26] It is noteworthy, therefore, to discuss this uncommon coordination mode as observed in the Cu(II) complexes of some aminopyridine derived Schiff base ligands. In this article, therefore, the synthesis, characterization and biological study of Cu(II) complexes of some Schiff base ligands (L^1–L^6) derived from condensing salicylaldehyde and *o*-vanillin (2-hydroxy-3-methoxybenzaldehyde) with 2-aminopyridine, 3-aminopyridine, 2- (aminomethyl)pyridine and 3-(aminomethyl)pyridine, respectively, are reported. In particular, the molecular structure of the 2-(aminomethyl)pyridine based Cu(II) complex is discussed.

EXPERIMENTAL

All the chemicals and reagents were of reagent grade and used as supplied. The ^{1}H- and ^{13}C-NMR spectra were recorded in $CDCl_3$ with TMS as the internal standard on Bruker Avance NMR equipment operating at 400 MHz. The mid-infrared (4000–700 cm^{-1}) absorption spectra were recorded on PerkinElmer Spectrum 100 FT-IR instrument equipped with a universal attenuated total reflectance (ATR) accessory; the far-infrared (700–30 cm^{-1}) spectra were recorded in nujol mull on PerkinElmer Spectrum 400 FT-IR instrument. The electronic spectra were obtained using a PerkinElmer Lambda 25 spectrophotometer. The elemental analysis, CHN, was realized on a Vario Micro V1.6.2 analyzer, Elemental analysen Systeme GmbH, Germany, while the percentage metal content was determined on a PerkinElmer AAnalyst atomic absorption spectrometer. Molar conductivity measurements for the complexes were realized in DMF, using an Az® 86555 pH/ORP/Cond./TDS/salinity meter. The melting points (uncorrected) of the compounds were determined using the Galenkemp melting point apparatus. The micro-organisms were purchased from Microbiologics, Cape Town, South Africa.

Analytical and spectral data are given in Supplementary material to this paper.

Synthesis of the Schiff base ligands

The Schiff base ligands, L^1–L^6 (sal-2-aminopy, sal-3-aminopy, sal-3-pico, ovan-2-aminopy, ovan-3-aminopy and ovan-2-pico) were synthesized by mixing and refluxing equimolar amounts of salicylaldehyde or *o*-vanillin and the appropriate amine in 10 mL ethanol in a round bottom flask equipped with an air-cooled condenser.[2,20,27]

Ligand L[1]. Salicylaldehyde (10 mmol, 1.07 mL) in 10 mL ethanol was mixed with 2-aminopyridine (10 mmol, 0.94 g) in 10 mL ethanol under stirring. The resulting yellow solution was refluxed for 2 h in a 100 mL round-bottom flask equipped with an air-cooled condenser to obtain a yellow precipitate. The precipitate was filtered under suction, washed with ethanol, recrystallized from ethanol and dried over silica gel.

Ligand L[2]. The procedure was the same as that for ligand L^1 using 3-aminopyridine instead of 2-aminopyridine.

Ligand L[3]. The procedure was the same as that for ligand L^1 using 3-(aminomethyl)pyridine instead of 2-aminopyridine.

Ligand L[4]. A hot solution of *o*-vanillin (1.522 g, 10.0 mmol) in 10 mL ethanol was mixed with 2-aminopyridine (0.94 g, 10 mmol) in 10 mL ethanol. The resulting orange solution was refluxed for 2 h in a 100 mL round-bottom flask equipped with an air-cooled condenser to obtain an orange precipitate. The precipitate was filtered under suction, washed with ethanol, recrystallized from ethanol and dried over silica gel.

Ligand L[5]. The procedure was the same as that for ligand L^4 using 3-aminopyridine instead of 2-aminopyridine.

Ligand L[6]. The procedure was the same as that for ligand L^4 using 2-(aminomethyl)-pyridine instead of 2-aminopyridine.

Synthesis of the complexes

All the Cu(II) complexes were prepared similarly by modifying the technique used for the preparation of metal complexes of some aminopyridine Schiff base ligands,[28] as typified below. A hot ethanolic solution of $CuCl_2 \cdot 2H_2O$ of 0.756 mmol (0.129 g) was gradually added to 10 mL ethanolic solution of 1.513 mmol (0.3 g). The resulting solution was stirred for 30 min with slight heating. Diethyl ether was used to induce precipitation of the complexes in cases where the precipitate did not form spontaneously on stirring. The precipitate was filtered under suction, washed with ethanol and dried in a vacuum desiccator over silica gel.

RESULTS AND DISCUSSION

Crystallographic studies

Some single crystals of the 2-(aminomethyl)pyridine Schiff base complex, $[CuL^6Cl]$, were obtained *via* slow evaporation of a saturated DMF solution of the complex. A suitable single crystal of the complex was diffracted using a Bruker Kappa Apex II single crystal X-ray diffractometer, with a 4-circle Kappa goniometer.

The crystallographic data was collected at 266 K and 0.71073 nm (λ) on a sensitive CCD detector with graphite-monochromated MoKα radiation. A total of 3097 reflections were collected of which 2754 were observed ($I > 2\sigma(I)$). The structure was solved by the direct method using the program SHELXS-97[29] and refined anisotropically by full matrix least-squares on F^2 using SHELXL-97.[29] The details of crystallographic parameters, data collection and refinements are

listed in Table S-I of the Supplementary material to this paper. Selected bond lengths and angles are presented in Table I.

TABLE I. Selected bond lengths (nm) and bond angles (°) around the Cu atom in [CuL^{6}Cl]

Bond	Bond length, nm	Bond	Bond angle, °
Cu1–Cl1	2.2510 (4)	Cl1–Cu1–O1	89.76 (3)
Cu1–O1	1.912 (1)	Cl1–Cu1–N1	174.24 (4)
Cu1–N1	1.941 (1)	Cl–Cu1–N2	95.94 (4)
Cu1–N2	2.012 (1)	O1–Cu1–N1	92.43 (5)
N1–C8	1.292 (2)	O1–Cu1–N2	174.17 (5)
N1–C9	1.343 (2)	N1–Cu1–N2	82.01 (5)
N2–C10	1.343 (2)	Cu1–O1–C2	127.9 (1)
N2–C14	1.349 (2)	Cu1–N1–C8	126.4 (1)

Elemental analysis and conductivity data

All the compounds were obtained in high yield with a significant degree of purity. The micro-analytical data for the complexes indicated a 1:2 (M:L) coordination for the 3-aminopyridine and 3-(aminomethyl)pyridine ligands (L^2, L^3 and L^5) and 1:1 (M:L) for the 2-aminopyridine and 2-(aminomethyl)pyridine ligands (L^1, L^4 and L^6). The conductivity values for most of the complexes (L^1, L^2, L^3, L^5 and L^6) ranged between 57.95 and 47.80 Ω^{-1} cm^2 mol^{-1} indicating non-electrolytes. However, the value for the L^4 complex corresponds to a 1:1 electrolyte.[30] These values indicate that the complexes, therefore, have the molecular formula [Cu(LH)$_2$Cl$_2$]·xH$_2$O for ligands L^2, L^3 and L^5, [CuLCl] for L^1 and L^6; and [Cu(LH)(H$_2$O)Cl]Cl for L^4, as presented in Figs. 1 and 2. This was further substantiated by the infrared spectral data.

^{1}H- and ^{13}C-NMR studies

The assignment of the main NMR signals of the Schiff base ligands is presented in the Supplementary material. The azomethine proton (HC=N) absorbed downfield in all the Schiff base ligands at 8.68–8.40 ppm as one proton singlet. The hydroxyl proton (OH) was observed far downfield at 14.00–12.80 ppm as a broad singlet due to extensive intra-molecular hydrogen bonding[31–33] between the hydroxyl and the imine groups. A strong signal (3H, *s*) corresponding to the methoxy group of the *o*-vanillin moiety was observed at 3.97–3.94 ppm, while the two protons singlet (2H, *s*) at 2.99 ppm was assigned to the methylene group of the methylpyridine moiety. The ^{13}C-NMR spectra of the compounds consisted of strong signals at 167.25–161.33 ppm, 65.16–61.19 ppm and 56.68–56.60 ppm corresponding to the azomethine (HC=N), methylene (CH$_2$) and the methoxyl (OCH$_3$) groups respectively. The absence of any signal corresponding to the aldehyde (CHO) group at 9–10 ppm and 180–200 ppm confirms the purity of the

compounds. The Cu(II) ion is paramagnetic and so an NMR study of the complexes would be of no significance.

Infrared study

The stretch vibration due to the hydroxyl group of the Schiff base ligands was observed as a broad and weak band at 3200–2100 cm^{-1}. This is a consequence of strong intramolecular hydrogen bonding between the hydroxyl proton and the imine nitrogen (OH···NH).[31–33] The presence of the hydroxyl group was further substantiated with the appearance of the phenolic C–O stretch band at 1299–1196 cm^{-1}.[31,34] The strong band at 1631–1588 cm^{-1} was assigned to the imine $\nu_{C=N}$ of the Schiff base ligands, while the band at 1575–1560 cm^{-1} region corresponds to the $\nu_{C=N}$ band of the pyridine ring. The increase in the $\nu_{C=N}$ values for the (aminomethyl)pyridine Schiff bases may be understood to be due to the presence of the methylene bridge that isolated the pyridine ring from the π conjugation of the rest of the molecule. The $\nu_{C=N}$ values for ligands L^3 (sal-3--pico) and L^6 (ovan-2-pico) were 1627 and 1631 cm^{-1}, respectively.

The imine stretch vibration was, however, observed at lower frequencies in the Cu(II) chelates than in the free ligands (1631–1588 cm^{-1} to 1624–1584 cm^{-1}), indicating coordination of the Schiff base ligands *via* the imine nitrogen.[24,35] The higher $\nu_{C=N}$ value for the ligand L^2 complex indicates the possibility of M → L π bonding; which increases the bond order and consequently leads to a higher frequency of absorption. In addition, the ν_{C-O} values for the complexes undergo a blue shift, 1284–1258 cm^{-1} to 1328–1284 cm^{-1},in all the complexes,[28,34] implying coordination *via* the hydroxyl OH of the Schiff base ligands. The medium broad band at 3413 cm^{-1} indicated the presence of a coordinated water molecule in the *o*-vanillin-2-aminopyridine complex, $[Cu(L^4H)(H_2O)Cl]Cl$. This is corroborated by the presence of a band at 720–800 cm^{-1}, which is characteristic of coordinated water.[25]

However, the weak OH band of the Schiff base ligands was still evident in the spectra of most of the complexes, undergoing a blue or red shift upon chelation with the Cu(II) ions.[3] This indicates that the phenolic OH was not deprotonated in the metal complexes but rather coordinates as neutral species.[26] Proposed structure for ligand L^2 (sal-3-ampy) complex is presented as Fig. 1a.

Furthermore, the bending vibration of the pyridine ring was observed at a lower frequency in the complexes of ligands L^1, L^4 and L^6, indicating coordination *via* the azine-N. Ligands L^1 and L^6 coordinated as monobasic tridentate ligands while L^4 exhibits neutral coordination as indicated by the molar conductivity values. The broad ν_{OH} band of ligands L^1 and L^6, which appeared at 3104––2152 cm^{-1}, was absent in the spectra of the complexes. The proposed structures of $[CuL^4Cl]$ and the molecular structure of $[CuL^6Cl]$ are presented as Figs. 1b and 2, respectively.

The coordination of the Schiff base ligands to the Cu(II) ions was further substantiated by the appearance of new bands in the far-infrared spectra of the complexes. The bands at 501–419 cm^{-1} and 427–388 cm^{-1} were assigned to ν_{Cu-O} and ν_{Cu-N},[34] respectively, which corroborates the coordination of the Schiff base ligands *via* the imine-N and the phenolic-O. In addition, the band at 358–351 cm^{-1} region corresponds to the ν_{Cu-Cl} of coordinated chlorine atoms.[25]

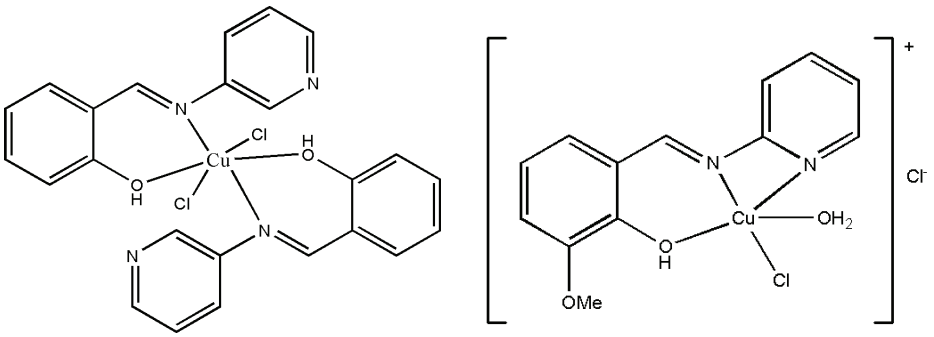

Fig. 1. Proposed structures for: a) ligand L^2 in Cu(II) complex and b) the ligand L^4 complex (1:1).

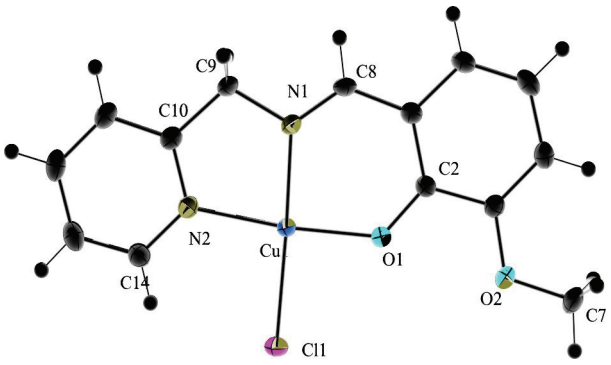

Fig. 2. Labelled diagram of the ORTEP view of $[CuL^6Cl]$ showing 50 % probability ellipsoids.

UV–Vis study

The electronic transition study of the compounds was performed in methanol (and/or DMF) and the spectral data are presented in the Supplementary material. The absorption below 250 nm was obscured in the DMF spectra due to solvent absorption. The band at 225–203 nm corresponds to the $\pi \rightarrow \pi^*$ transition of the benzene rings,[36] while the absorptions at 299–256 nm and 345–301 nm were assigned, respectively, to the $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$ transitions of the azomethine

group, HC=N.[7,27,36] The lower energy band at 475–425 nm was attributed to the tautomeric keto–imine form of the Schiff base ligands in the protic solvent.[37] The spectra of the complexes exhibit a prominent band at 513–307 nm due to ligand to Cu(II) charge transfer transition (LMCT),[4] while the broad band at 715–629 nm region corresponds to the d–d transition of the Cu(II) complexes.[4,38]

Molecular structure for [CuL^{6}Cl]

The labelled ORTEP diagram of [CuL^{6}Cl] is presented in Fig. 2; the bond lengths and angles are presented in Table II. The Cu(II) ion is in a square planar environment in which the Schiff base ligand coordinates as tridentate monobasic (N_2O^-) *via* the imine nitrogen, the azine nitrogen and the deprotonated phenolic oxygen. The apical position is occupied by a chlorine atom having a Cu1–Cl bond length of 2.2510 Å; Cl1–Cu1–O1, Cl1–Cu1–N1 and Cl1–Cu1–N2 bond angles of 89.76, 174.24 and 95.94°, respectively, indicate a slight distortion from planarity. The crystals are monoclinic in a space group of $P2_1/c$, with a = = 7.01350, b = 18.1484, c= 10.3959, $\alpha = \gamma = 90°$ and $\beta = 104.2050°$.

TABLE II. Selected bond lengths and bond angles around the Cu atom in [CuL^{6}Cl]

Bond	Bond length, nm	Bond	Bond angle, °
Cu1–Cl1	2.2510 (4)	Cl1–Cu1–O1	89.76 (3)
Cu1–O1	1.912 (1)	Cl1–Cu1–N1	174.24 (4)
Cu1–N1	1.941 (1)	Cl–Cu1–N2	95.94 (4)
Cu1–N2	2.012 (1)	O1–Cu1–N1	92.43 (5)
N1–C8	1.292 (2)	O1–Cu1–N2	174.17 (5)
N1–C9	1.343 (2)	N1–Cu1–N2	82.01 (5)
N2–C10	1.343 (2)	Cu1–O1–C2	127.9 (1)
N2–C14	1.349 (2)	Cu1–N1–C8	126.4 (1)

Biological study

All the Schiff base ligands and the Cu(II) complexes were screened for their *in vitro* antimicrobial activity against *Escherichia coli* ATCC® 8739™*, *Staphylococcus aureus* subsp. *aureus* ATCC® 6538™*, *Bacillus subtilis* subsp. *spizizenii* ATCC® 6633™* and *Candida albicans* ATCC® 2091™*.

The qualitative susceptibility-testing was evaluated using the disc diffusion technique.[39] Each test organism was inoculated onto a nutrient agar plate and incubated at 37 °C for 24 h to obtain the primary culture. Several discrete colonies were harvested from the culture to make a bacterial suspension (10 mL) in a test tube using saline water. The cell density of the suspension was standardized using the 0.5 McFarland barium sulphate turbidity standard. The bacterial suspension (0.1 mL) was inoculated onto a Mueller–Hinton plate, and the sterile discs (6 mm) that had been impregnated with 10 μg of the test compounds were firmly placed on it. The assay was incubated at 37 °C for 16 h and the diameter

of the inhibition zone was measured as millimeters. Ampicillin and dimethylformamide (DMF) were used as the standard antibacterial drug and control solvent, respectively. The test was repeated two more times for those compounds that showed an activity of more than 6 mm. The antibacterial activity of the compounds was recorded as the average inhibition zone and the results are presented in Fig. 3. The fungus, *C. albicans*, was grown on potato disc assay (PDA), and the incubation was realised at 28 °C for 48 h.

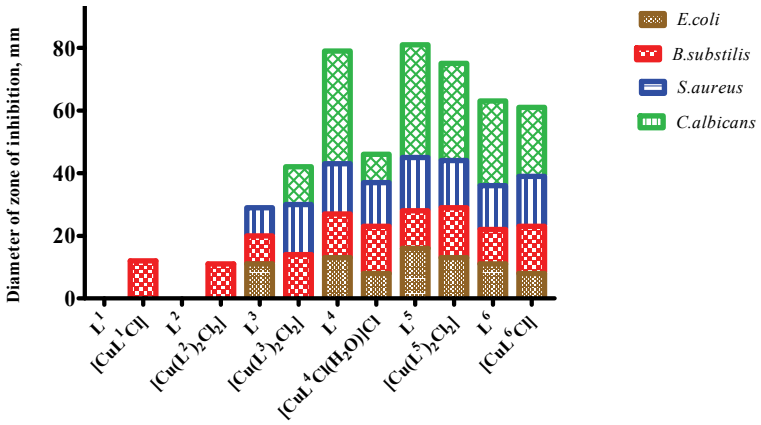

Fig. 3. Disc diffusion results for the Schiff base ligands and the Cu(II) complexes.

*Minimum inhibitory concentration (*MIC*)*

The quantitative antimicrobial activity of the test compounds was evaluated using the macro-dilution broth method. Two-fold serial dilutions of the compounds were prepared in 96 microwell plates using sterile nutrient broth as diluent. The plates were inoculated with 5 µL bacterial suspensions containing 10^6–10^8 CFUs and incubated at 37 °C for 16–18 h. The *MIC* value was defined as the lowest concentration of the compounds giving complete inhibition of visible growth. The *MIC* values for the compounds varied from 1.220×10^{-2}–3.125 mg mL^{-1} and the results are presented in Table III.

TABLE III. *MIC* values for the ligands and the Cu(II) complexes (mg mL^{-1})

Compound	*E. coli*	*B. subtilis*	*S. aureus*
L^3	0.195	0.391	0.781
L^4	1.563	0.195	0.391
L^5	3.125	0.195	0.391
L^6	3.125	0.195	0.781
$[CuL^4Cl(H_2O)]Cl$	0.195	2.441×10^{-2}	0.391
$[Cu(L^5)_2Cl_2]H_2O$	0.781	1.220×10^{-2}	0.391
$[CuL^6Cl]$	3.125	4.883×10^{-2}	1.220×10^{-2}

The *o*-vanillin based ligands were significantly potent against the tested organisms, especially *C. albicans*. They exhibited higher antifungal activity than the commercially available anti-fungal drug, ketoconazole, at 10 μg and thus, may be considered as promising antifungal agent for further study. On chelation, however, the antimicrobial activity of the Schiff base ligands did not increase significantly as expected; the MIC values indicated that the antimicrobial activity of the Cu(II) complexes was similar or slightly higher than the free ligands. Although most free ligands exhibit higher biological activity in the presence of metal ions;[16–21] cases of lower activity upon chelation with metal ions also exist.[40,41] Furthermore, Kowol *et al.*[42] demonstrated that the effect of metal ions on the biological activity of a given bio-active compound is metal specific. The salicylaldehyde-based compounds did not exhibit significant antimicrobial activity against the tested organisms, thus indicating the significance of the methoxyl ($–OCH_3$) substituent on the biological activity of the salicylaldimine derivatives.

CONCLUSIONS

This study established that salicylaldimine ligands could coordinate as neutral species *via* the imine-N and the undeprotonated phenolic-O. In addition, the involvement of the pyridine-N in metal coordination depends largely on its position relative to the imine-N. Thus, the 3-aminopyridine and 3-(aminomethyl)pyridine Schiff bases (L^2, L^3 and L^5) did not afford coordination *via* the azine–N. The presence of the methoxyl group ($–OCH_3$) enhanced the antimicrobial activity of the salicylaldimine ligands. The *o*-vanillin derived Schiff base ligands were significantly active against the tested micro-organism strains, especially *Candida albicans*. Lastly, chelation of the free ligands with Cu(II) ion selectively enhanced the biological activity of the compounds.

SUPPLEMENTARY MATERIAL

Analytical and spectral data of the ligands are available electronically at the pages of journal website: http://www.shd.org.rs/JSCS/, or from the corresponding author on request. X-ray crystallography data of the [CuL^6Cl] complex has been deposited with the Cambridge Crystallographic Data Centre (CCDC) and can be obtained free of charge on request at http://www.ccdc.cam.ac.uk/conts/retrieving.html or from the Cambridge Crystallographic Data Centre (CCDC), 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44(0)1223-336033; e-mail: deposit@ccdc.cam.ac.uk, quoting the CCDC number, 1538384.

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ИЗВОД

СИНТЕЗА, КАРАКТЕРИЗАЦИЈА И БИОЛОШКА ИСПИТИВАЊА БАКАР(II) КОМПЛЕКСА СА ШИФОВИМ БАЗАМА АМИНОПИРИДИНА И (АМИНОМЕТИЛ)ПИРИДИНА КАО ЛИГАНДИМА

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Описна је синтеза, карактеризација и антимикробна активност комплекса бакра(II) са аминопиридин- и (аминометил)пиридин-салицилалдимином као лигандима. Лиганди L^1–L^6 су синтетисани кондензацијом салицилалдехида са 2-аминопиридином, 3-аминопиридином и 3-(аминометил)пиридином, као и *o*-ванилина са 2- и 3-аминопиридином и 2--(аминометил)пиридином. Комплекси су окарактерисани на основу елементалне микроанализе, електронске и инфрацрвене спектроскопије и методом кондуктометријских мерења. Поред тога, структура Шифових база као лиганада је потврђена на основу ^{1}H- и ^{13}C-NMR спектроскопије. Нађено је да се салицилалдиминski лиганди координују као неутрални молекули преко иминског атома азота и протонованог фенолног кисеоника. Општа формула испитиваних комплекса је: [CuLCl], $[Cu(LH)_2Cl_2]\cdot H_2O$ или $[Cu(LH)Cl(H_2O)]Cl$. Методом дифракције X-зрака са кристала одређена је квадратно-планрана геометрија $[CuL^6Cl]$ комплекса. Поред тога, на основу кристалографских мерења нађено је да су одговарајуће Шифове базе као лиганди тридентатно координован преко два атома азота и атома кисеоника. Просторна група кристала испитиваног комплекса је $P2_1/c$. Сви лиганди и њихови одговарајући комплекси су испитивани на антимикробну активност на следећим сојевима бактерија и гљива: *Staphylococcus aureus* subsp. *aureus* ATCC® 6538™*, *Bacillus substillis* subsp. *spizizenii* ATCC® 6633™*, *Escherichia coli* ATCC® 8739™* и *Candida albicans* ATCC® 2091™*. Резултати ових испитивања су показали да метокси-групе повећавају антимикробну активност лиганада Шифових база салицилалдимина.

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REFERENCES

1. M. Asadi, S. Torabi, K. Mohammadi, *Spectrochim. Acta, A* **122** (2014) 676
2. D. Sinha, A. K. Tiwari, S. Singh, G. Shukla, P. Mishra, H. Chandra, A. K. Mishra, *Eur. J. Med. Chem.* **43** (2008) 160
3. L. Guofa, N. Chongwu, L. Bin, M. Kunyuan, *Polyhedron* **9** (1990) 2019
4. B. Samanta, J. Chakraborty, C. R. Choudhury, S. K. Dey, D. K. Dey, S. R. Batten, P. Jensen, G. P. A. Yap, S. Mitra, *Struct. Chem.* **18** (2007) 33
5. Z. Cimerman, R. Kiralj, N. Galic, *J. Mol. Struct.* **323** (1994) 7
6. Z. H. Chohan, S. Mushtaq, *Pak. J. Pharm. Sci.* **13** (2000) 21
7. R. Ramesh, S. Maheswaran, *J. Inorg. Biochem.* **96** (2003) 457
8. G. G. Mohamed, M. M. Omar, A. M. Hindy, *Turk. J. Chem.* **30** (2006) 361
9. R. Nair, A. Shah, S. Baluja, S. Chanda, *J. Serb. Chem. Soc.* **71** (2006) 733
10. M. K. Biyala, K. Sharma, M. Swami, N. Fahmi, R. V. Singh, *Transition Met. Chem.* **33** (2008) 377
11. E. A. Elzahany, K. H. Hegab, S. K. H. Khalil, N. S. Youssef, *Aust. J. Basic Appl. Sci.* **2** (2008) 210
12. A. M. Vijey, S. George, V. Vaidhyalingam, *ARKIVOC 2008* (11) (2008) 187
13. S. Bawa, S. Kumar, *Indian J. Chem., B* **48** (2009) 142

14. A. Jarrahpour, D. Khalili, C. E. De, C. Salmi, J. M. Brunel, J. Michel, *Molecules* **12** (2007) 1720
15. J. Devi, N. Batra, *Spectrochim. Acta, A* **135** (2015) 710
16. A. F. Santos, D. F. Brotto, L. V. Favarin, N. A. Cabeza, R. Geziel, M. Batistote, M. A. A. Cavalheiro, A. Neves, D. Rodrigues, C. M. Daniela, A. dos Anjos, *Braz. J. Pharmacogn.* **24** (2014) 309
17. K. Dhahagani, S. M. Kumar, G. Chakkaravarthi, K. Anitha, J. Rajesh, A. Ramu, G. Rajagopal, *Spectrochim. Acta, A* **117** (2014) 87
18. M. Shabbir, Z. Akhter, P. R. Raithby, L. H. Thomas, H. Ismail, F. Arshad, B. Mirza, S. J. Teat, K. Mahmood, *J. Coord. Chem.* **70** (2017) 2463
19. A. S. Gaballa, M. S. Asker, A. S. Barakat, S. M. Teleb, *Spectrochim. Acta, A* **67** (2007) 114
20. M. S. Nair, D. Arish, *Trans. Indian Inst. Met.* **64** (2011) 287
21. N. Raman, A. Kulandaisamy, K. Jeyasubramanian, *Pol. J. Chem.* **76** (2002) 1085
22. D. N. Kumar, B. S. Garg, *Spectrochim. Acta, A* **64** (2006) 141
23. H. A. R. Pramanik, P. C. Paul, P. Mondal, C. R. Bhattacharjee, *J. Mol. Struct.* **1100** (2015) 496
24. R. K. Dubey, U. K. Dubey, C. M. Mishra, *Indian J. Chem., A* **47** (2008) 1208
25. R. C. Aggarwal, N. K. Singh, R. P. Singh, *Inorg. Chem.* **20** (1981) 2794
26. M. R. Mahmoud, M. T. El-Haty, *J. Inorg. Nucl. Chem.* **42** (1980) 349.
27. A. O. Sobola, G. M. Watkins, B. van Brecht, *S. Afr. J. Chem.* **67** (2014) 45
28. S. A. Abdel-Latif, H. B. Hassib, Y. M. Issa, *Spectrochim Acta, A* **67** (2007) 950
29. G. M. Sheldrick, *Acta. Crysttallogr., A* **64** (2008) 112
30. W. J. Geary, *Coord. Chem. Rev.* **7** (1971) 81
31. J. E. Kovacic, *Spectrochim. Acta, A* **23** (1967) 183
32. G. C. Percy, D. A. Thornton, *J. Inorg. Nucl. Chem.* **35** (1973) 2319
33. A. M. Ali, A. H. Ahmed, T. A. Mohammed, B. H. Mohammed, *J. Appl. Sci. Res* **3** (2007) 109
34. G. C. Percy, D. A. Thornton, *J. Inorg. Nucl. Chem.* **34** (1972) 3357
35. V. Reddy, N. Patil, S. D. Angadi, *E-J. Chem.* **5** (2008) 577
36. Y. Zhou, X. Ye, F. Xin, X. Xin, *Transition Met. Chem.* **24** (1999) 118
37. H. E. Smith, J. R. Neergaard, E. P. Burrows, F.-M. Chen, *J. Am. Chem. Soc.* **96** (1974) 2908
38. N. S. Youssef, E. El-Zahany, A. M. A. El-Seidy, A. Caselli, S. Fantauzzi, S. Cenini, *Inorg. Chim. Acta* **362** (2009) 2006
39. A. Wanger, in *Antimicrobial susceptibility testing protocols*, R. Schwalbe, L. Steele--Moore, A. C. Goodwin, Eds., CRC Press, Boca Raton, FL, 2007, p. 53
40. K. A. Crouse, K. B. Chew, M. T. H. Tarafder, A. Kasbollah, A. M. Ali, B. M. Yamin, H. K. Fun, *Polyhedron* **23** (2004) 161
41. M. T. H. Tarafder, K. T. Jin, K. A. Crouse, A. M. Ali, B. M. Yamin, H.-K. Fun, *Polyhedron* **21** (2002) 2547
42. C. R. Kowol, R. Trondl, P. Heffeter, V. B. Arion, M. A. Jakupec, A. Roller, M. Galanski, W. Berger, B. K. Keppler, *J. Med. Chem.* **52** (2009) 5032.