Spectrochimica Acta Part A 81 (2011) 184–198

Contents lists available at ScienceDirect

Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy

journal homepage: www.elsevier.com/locate/saa

Antioxidant, electrochemical, thermal, antimicrobial and alkane oxidation properties of tridentate Schiff base ligands and their metal complexes

Gökhan Ceyhan[a], Cumali Çelik[b,*], Serhan Uruş[c], İbrahim Demirtaş[d], Mahfuz Elmastaş[d], Mehmet Tümer[a]

[a] Kahramanmaraş Sütçü Imam University, Chemistry Department, 46100 K.Maras, Turkey
[b] Yalova University, Polymer Engineering, 77100 Yalova, Turkey
[c] K.Maraş Sütçü Imam University, University-Industry-Public Collaboration, Research-Development-Application Centre, 46100 K.Maraş, Turkey
[d] Gaziosmanpasa University, Department of Chemistry, 60240 Tokat, Turkey

ARTICLE INFO

Article history:
Received 22 December 2010
Received in revised form 26 May 2011
Accepted 30 May 2011

Keywords:
Schiff bases
Antimicrobial
Antioxidant
Catalysis
Electrochemical
Alkane-oxidation

ABSTRACT

In this study, two Schiff base ligands (HL^1 and HL^2) and their Cu(II), Co(II), Ni(II), Pd(II) and Ru(III) metal complexes were synthesized and characterized by the analytical and spectroscopic methods. Alkane oxidation activities of the metal complexes were studied on cyclohexane as substrate. The ligands and their metal complexes were evaluated for their antimicrobial activity against *Corynebacterium xerosis*, *Bacillus brevis*, *Bacillus megaterium*, *Bacillus cereus*, *Mycobacterium smegmatis*, *Staphylococcus aureus*, *Micrococcus luteus* and *Enterococcus faecalis* (as Gram-positive bacteria) and *Pseudomonas aeruginosa*, *Klebsiella pneumoniae*, *Escherichia coli*, *Yersinia enterocolitica*, *Klebsiella fragilis*, *Saccharomyces cerevisiae*, and *Candida albicans* (as Gram-negative bacteria). The antioxidant properties of the Schiff base ligands were evaluated in a series of in vitro tests: 1,1-diphenyl-2-picrylhydrazyl (DPPH•) free radical scavenging and reducing power activity of superoxide anion radical generated non-enzymatic systems. Electrochemical and thermal properties of the compounds were investigated.

1. Introduction

Free radicals contain one or more unpaired electrons, produced in normal or pathological cell metabolism. Reactive oxygen species (ROS) react easily with these free radicals to become radicals themselves. ROS are various forms of activated oxygen, which include free radicals such as superoxide anion radicals (O_2^-) and hydroxyl radicals (OH•), as well as non-free radical species (H_2O_2) and the singled oxygen (O_2) [1,2]. They are formed in living organisms in different ways, including normal aerobic respiration, stimulated polymorphonuclear leukocytes and macrophages, and peroxisomes. They are natural by-products of our body's metabolism. They are dangerous; however, when present in excess, they can attack biological molecules such as lipids, proteins, enzymes, DNA and RNA, leading to cell or tissue injury [3]. The cells experience an oxidative stress which contributes in a various clinical disorders such as cancer, heart diseases, neurogenerative diseases like multiple sclerosis, Parkinson's disease, autoimmune disease, stroke, arthritis, ischemia, reperfusion injury, acute hypertension, haemorrhagic shock, emphysema, cirrhosis, diabetes mellitus, hepatitis, cancer, atherosclerosis as well as other ailments [4–7].

Schiff bases form an important class of organic compounds with a wide variety of biological properties [8]. Development of a new chemotherapeutic Schiff bases is now attracting the attention of medicinal chemist [9]. Many studies have been reported regarding the biological activities of Schiff bases, including their anticancer [10], antibacterial [11], antifungal, and herbicidal activities. Schiff bases derived from various amine and carbonyl derivatives were reported to possess genotoxicity [12,13], antimicrobial [14], and antifungal activities [15]. A number of Schiff bases [16] have been tested for antibacterial [17], antifungal [18], anticancer [19], and herbicidal [20] activities. Although many studies have investigated the antioxidant properties of resveratrol [21], there have been only a few reports of antioxidant and antiproliferative effects of hydroxyl-substituted Schiff bases.

In this study, two Schiff base ligands and their metal complexes were synthesized and characterized by the analytical and spectroscopic methods. Antioxidant properties of the hydroxyl-substituted Schiff base ligands were investigated. The antimicrobial activities of the ligands and their metal complexes were studied using the bacteria and yeast. The redox properties of the compounds were investigated by the cyclic voltammetry. The catalytic properties of the metal complexes were investigated on

* Corresponding author. Tel.: +90 344 219 10 93; fax: +90 344 219 10 42.
E-mail address: mtumer@ksu.edu.tr (C. Çelik).

1386-1425/$ – see front matter © 2011 Elsevier B.V. All rights reserved.
doi:10.1016/j.saa.2011.05.106

cyclohexane as substrate. Thermal properties of the metal complexes were investigated in the 20–1000 °C temperature range.

2. Experimental

2.1. General

The metal salts $CuCl_2{\cdot}2H_2O$, $CoCl_2{\cdot}6H_2O$, $NiCl_2{\cdot}6H_2O$, $RuCl_3{\cdot}3H_2O$, $Pd(AcO)_2$ and organic substances were purchased from commercial sources and used as received, unless noted otherwise. The Bu_4NBF_4 compound was obtained from Fluka. Elemental analyses (C, H and N) were performed using a LECO CHNS 932 elemental analyser. Infrared spectra of the ligands and their metal complexes were obtained using KBr discs (4000–400 cm^{-1}) with a Perkin Elmer spectrum 400 FT-IR spectrophotometer. FAR spectra of the complexes were recorded using a Perkin Elmer spectrum 400 FT-IR/FT-FAR instrument. The electronic spectra were obtained in the 200–900 nm range by a Perkin Elmer Lambda 45 spectrophotometer. Magnetic measurements were carried out by the Gouy method using $Hg[Co(SCN)_4]$ as a calibrant. Mass spectra of the ligands were recorded on a LC/MS APCI AGILENT 1100 MSD spectrophotometer. ^1H and ^{13}C NMR spectra were recorded on a Bruker 400 MHz instrument. TMS was used as internal standard and $CDCl_3$ as solvent. The thermal analyses studies of the complexes were performed on a Perkin Elmer Pyris Diamond DTA/TG Thermal System under nitrogen atmosphere at a heating rate of 10 °C/min.

Cyclic voltammograms were recorded on an Iviumstat Electrochemical workstation equipped with a low current module (BAS PA-1) recorder. The electrochemical cell was equipped with a BAS glassy carbon working electrode (area 4.6 mm^2), a platinum coil auxiliary electrode and an Ag^+/AgCl reference electrode filled with tetrabutylammonium tetrafluoroborate (0.1 M) in CH_3CN and DMF solvents and adjusted to 0.00 V vs. SCE. Cyclic voltammetric measurements were carried out at room temperature in an undivided cell (BAS model C-3 cell stand) with a platinum counter electrode and an Ag^+/AgCl reference electrode (BAS). All potentials are reported with respect to Ag^+/AgCl. The solutions were deoxygenated by passing dry nitrogen through the solution for 30 min prior to the experiments during the experiments.

The microwave experiments were carried out using a Berghof MWS3+ equipped with pressure and temperature control. Microwave experiments were done in closed DAP 60 vessels. The reaction products were characterized and analyzed by Perkin Elmer Clarus 600 GC equipped with MS dedector fitted with Elite-5 MS and FID detectors with BPX5 capillary columns.

2.2. Preparation of the ligands (HL^1 and HL^2)

The amine compound, 2,6-di-tert-butyl-4-hydroxy aniline, and two carbonyl compounds (2,6-di-formyl-4-isopropyl phenol (A) and 2,6-di-formyl-4-tert-butyl phenol (B)) were synthesized to the reported methods [22,23]. The carbonyl compounds (1 mmol, 0.192 g for A and 0.206 g for B) in ethanol (20 mL, absolute) and amine compound (2 mmol, 0.443 g) in ethanol (20 mL) were mixed and refluxed for about 4 h at 80 °C. The color of the solution changed to light yellow. After cooling the solution, the resulting precipitate was filtered, and washed with cold ethanol. The ligands were recrystallized from ethanol.

Analytical and spectroscopic data of the Schiff base ligands are given below:

HL^1: Elemental analyses, found (calcd. %): C, 78.76 (78.22); H, 9.29 (9.19); N, 4.33 (4.68). ^1H NMR ($CDCl_3$ as solvent, δ in ppm): 9.90–10.50 (s, 3H, OH), 8.60 (s, 2H, CH=N), 7.0–8.0 (m, 6H, Ar–H), 2.40 (m, 1H, –CH), 1.10–1.70 (m, 18H, $-C(CH_3)_3$), 1.60 (d, 6H, $-HC(CH_3)_2$). ^{13}C NMR (DMSO-d6 as solvent, δ in ppm): δ 169.0 (CH=N), 115.0–145.0 (Ar–C), 24,09 (CH), 40,75 (t-CH_3), 40.54 (quaternary C), 34.6 (–CH), 21.5 ($-CH_3$). Mass spectrum (LC/MS APCI): m/z 599 $[M]^+$ (10%), 466 $[M-144]^+$ (100%), 430 $[M+2]^{+2}$ (30%). UV–vis (λ_{max}, nm, DMF as solvent): 213, 277, 381, 386, 392, 394, 397. FT-IR (KBr, cm^{-1}): 3430 ν(OH), 2998, 2892 $\nu(CH_2)_{alph}$, 1624 ν(CH=N), 1274 ν(C–OH).

HL^2: Elemental analyses, found (calcd. %): C, 78.15 (78.39), H 9.74 (9.21), N 4.90 (4.78). ^1HNMR ($CDCl_3$, (ppm): 9.80–10.10 (4, 3H, OH), 8.60 (s, 2H, CH=N), 7.40–8.20 (m, 6H, Ar–H), 1.13–1.64 (s, 27H, $-C(CH_3)_3$). ^{13}C NMR ($CDCl_3$, δ ppm) 169.00 (CH=N), 115.00–145.00 (Ar–C), 40,77 (t-CH_3), 40.56 (quaternary C). Mass spectrum (LC/MS APCI): m/z 613 $[M]^+$ (15%), 412 $[M-201]^+$ (100%). UV–vis (λ_{max}, nm, DMF as solvent): 201, 203, 217, 221, 402. FT-IR (KBr, cm^{-1}): 3450 ν(OH), 2975–2900 $\nu(C-H)_{alph}$, 2875 ν(C–H), 1643 ν(C=N), 1290 ν(C–OH), 750 ν(C–H).

2.3. Preparation of the Cu(II), Co(II), Ni(II) and Ru(III) complexes

Copper(II), cobalt(II), nickel(II) and ruthenium(III) complexes were obtained according to a general procedure: $CuCl_2{\cdot}2H_2O$ (2 mmol, 0.241 g) was dissolved in ethanol and stirred under reflux for 30 min, followed by the addition of the Schiff base (1 mmol; 0.599 g for HL^1 and 0.613 g for HL^2) in ethanol and the reaction mixture stirred upon heating for 24 h. The obtained complexes were filtered, washed with methanol and dried in a vacuum desiccator over $CaCl_2$.

Analytical and spectroscopic data of the metal complexes are given below:

$Co_2(L^1)(Cl)_3{\cdot}4H_2O$: Elemental analyses, found (calcd. %): C 56.47 (56.98), H 6.40 (6.50), N 2.41 (2.20). UV–vis (λ_{max}, nm, DMF as solvent): 281, 327, 381, 410, 576. FT-IR (KBr, cm^{-1}): 3475 ν(OH), 2950–2800 ν(C–H), 2850 ν(C–H), 1650 ν(C=N), 1365 ν(C–O), 950 ν(C–H), 540 ν(M–O), 475 ν(M–N). μ_{eff} B.M. (298 K): 4.28 (for per metal).

$Cu_2(L^1)(Cl)_3{\cdot}5H_2O$: Elemental analyses, found (calcd. %): C 56.36 (56.35), H 6.04 (6.43), N 3.29 (3.37). UV–vis (λ_{max}, nm, DMF as solvent): 217, 236, 278, 280, 313, 410. FT-IR (KBr, cm^{-1}): 3452 ν(OH), 2960–2930 $\nu(C-H)_{alph}$, 2870 ν(C–H), 1629 ν(C=N), 1300 ν(C–OH), 800 ν(C–H), 575 ν(M–O), 478 ν(M–N). μ_{eff} B.M. (298 K): 1.88 (for per metal).

$Ni_2(L^1)(Cl)_3{\cdot}3H_2O$: Elemental analyses, found (calcd. %): C 56.47 (57.01), H 6.49 (6.50), N 3.33 (3.41). UV–vis (λ_{max}, nm, DMF as solvent): 214, 220, 237, 265, 268, 401, 494, 598. FT-IR (KBr, cm^{-1}): 3431 ν(OH), 2966 $\nu(C-H)_{alph}$, 2877 ν(C–H), 1649 ν(C=N), 1350 ν(C–OH), 887 ν(C–H), 574 ν(M–O), 472 ν(M–N). μ_{eff} B.M. (298 K): diamagnetic.

$Ru(L^1)(Cl)_2{\cdot}6H_2O$: Elemental analyses, found (calcd. %): C 59.00 (59.06), H 6.75 (6.78), N 3.60 (3.62). UV–vis (λ_{max}, nm, DMF as solvent): 201, 212, 217, 206, 209, 214, 399. FT-IR (KBr, cm^{-1}): 3452 ν(OH), 2966 $\nu(C-H)_{alph}$, 2870 ν(C–H), 1643 ν(C=N), 1300 ν(C–O), 846 ν(C–H), 532 ν(M–O), 472 ν(M–N). μ_{eff} B.M. (298 K): 1.74.

$Pd_2(L^1)(AcO)_3{\cdot}4H_2O$: Elemental analyses, found (calcd. %): C 51.05 (50.99), H 6.60 (6.66), N 2.70 (2.64). UV–vis (λ_{max}, nm, DMF as solvent): 214, 218, 220, 226, 232, 236, 252, 418. FT-IR (KBr, cm^{-1}): 3439 ν(OH), 2945 $\nu(C-H)_{alph}$, 2870 ν(C–H), 1622 ν(C=N), 1350 ν(C–O), 812 ν(C–H), 552 ν(M–O), 455 ν(M–N). μ_{eff} B.M. (298 K): diamagnetic.

$Co_2(L^2)(Cl)_3{\cdot}4H_2O$: Elemental analyses, found (calcd. %): C 56.64 (57.46), H 6.62 (6.63), N 3.30 (3.35). UV–vis (λ_{max}, nm, DMF as solvent): 201, 218, 220, 226, 228, 233, 268, 390, 400. FT-IR (KBr, cm^{-1}): 3441 ν(OH), 2972 $\nu(C-H)_{alph}$, 2875 ν(C–H), 1647 ν(C=N), 1400 ν(C–O), 827 ν(C–H), 540 ν(M–O), 467 ν(M–N). μ_{eff} B.M. (298 K): 4.19 (for per metal).

$Cu_2(L^2)(Cl)_3{\cdot}4H_2O$: Elemental analyses, found (calcd. %): C 56.05 (56.83), H 6.90 (6.54), N 3.39 (3.31). UV–vis (λ_{max}, nm, DMF as