ORIGINAL RESEARCH

The construction of versatile azido-bridged Schiff base Copper(II) complexes with xanthine oxidase inhibitory activity

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Abstract Three new versatile azido-bridged Schiff base Copper(II) complexes, $[Cu_2(L^1)_2(\mu_{1,1}-N_3)_2] \cdot 2CH_3OH$ (1), $[Cu(L^2)(\mu_{1,3}-N_3)]_n$ (2), and $[Cu_2(L^3)(\mu_{1,1}-N_3)_2(N_3)]_2$ (3), where L^1, L^2 , and L^3 are the deprotonated form of the Schiff bases 5-diethylamino-2-[(2-isopropylaminoethylimino)methyl] phenol (HL¹), 5-methoxy-2-[(2-morpholin-4-ylethylimino) methyl]phenol (HL²), and 5-methoxy-2-[(2-piperidin-1ylethylimino)methyl]phenol (HL³), respectively, have been prepared and structurally characterized by elemental analysis, IR spectra, and single-crystal X-ray crystallography. Complex 1 is a crystallographic centro-symmetric end-on azido-bridged dinuclear Copper(II) compound, with the Cu-Cu distance of 3.512(1) Å. Complex 2 is an end-to-end azido-bridged polymeric Copper(II) compound, with the Cu···Cu distance of 5.716(2) Å. Complex **3** is a phenolato-O and end-on azido-bridged tetranuclear Copper(II) compound, with the Cu-Cu distances of 3.122(1) and 3.108(1) Å. The Cu atoms in 1 and 2, and the inner two Cu atoms in 3 are in square-pyramidal coordination. The outer two Cu atoms in 3 are in square planar coordination. The azide ligands are dramatic bridging groups for the construction of versatile polynuclear Copper complexes with Schiff bases. The xanthine oxidase inhibitory activity of the complexes was evaluated.

Introduction

Polymeric complexes with bridging groups are currently attracting much attention for their interesting structures and wide applications [1-3]. The Schiff bases derived from salicylaldehyde and its derivatives are a kind of versatile ligands in coordination chemistry. The rational design and construction of polymeric complexes with Schiff bases are of particular interest in coordination and structural chemistry. Although many bridging groups and metal ions have been employed for the construction of polymeric complexes, the Copper-azide system is one of the most popular among them [4-6]. A number of azido-bridged Copper complexes have been reported [7-11], however, the search in the Cambridge Crystallographic Database (CSD; version 5.32 with addenda up to May 2011) [12] has revealed that only 74 azido-bridged polynuclear Copper complexes with Schiff bases derived from salicylaldehyde and its derivatives have been reported. Recently, we found that the Schiff base Copper complexes have xanthine oxidase (XO) inhibitory activity [13]. In order to enrich the azido-bridged Schiff base Copper(II) complexes, as well as further investigate the XO inhibitory activity, in this article, three new polymeric complexes, $[Cu_2(L^1)_2(\mu_{1,1}-N_3)_2] \cdot 2CH_3OH$ (1), $[Cu(L^2)(\mu_{1,3}-N_3)]_n$ (2), and $[Cu_2(L^3)(\mu_{1,1}-N_3)_2(N_3)]_2$ (3), where L^1 , L^2 , and L^3 are the deprotonated form of the Schiff bases 5-diethylamino-2-[(2-isopropylaminoethylimino) methyl]phenol (HL¹), 5-methoxy-2-[(2-morpholin-4-ylethylimino)methyl]phenol (HL²), and 5-methoxy-2-[(2-piperidin-1-ylethylimino)methyl]phenol (HL³) (Scheme 1),

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respectively, were prepared and evaluated for their XO inhibitory activity.

Experimental

Materials and measurements

Starting materials, reagents and solvents with AR grade were purchased from commercial suppliers and were used without further purification. Elemental analyses were performed on a Perkin-Elmer 240C elemental analyzer. The IR spectra were recorded on a Jasco FT/IR-4000 spectrometer as KBr pellets in the 400–4,000 cm⁻¹ region. Single-crystal structural X-ray diffraction was carried out on a Bruker SMART 1000 CCD area diffractometer. Molar conductivities of the complexes were measured at 25 °C with a DDS-11 molar conductor.

Caution Sodium azide is potentially explosive, only small quantity should be used and handled with great care.

Synthesis of the Schiff bases

The Schiff bases were synthesized by the same method as described here. To the methanolic solution (50 mL) of the carbonyl-containing compounds (1.0 mmol each) was added a methanolic solution (50 mL) of amines (1.0 mmol each) with stirring. The mixtures were stirred for 30 min at room temperature to give yellow solution. The solvent was evaporated to give yellow gummy product of the Schiff bases.

For HL¹: yield 79%. Characteristic IR data: 1,616 cm⁻¹. Anal. calc. for $C_{16}H_{27}N_3O$: C, 69.3; H, 9.8; N, 15.2; found: C, 69.1; H, 9.9; N, 15.3%. For HL²: yield 83%. Characteristic IR data: 1,613 cm⁻¹. Anal. calc. for $C_{14}H_{20}N_2O_3$: C, 63.6; H, 7.6; N, 10.6; found: C, 63.5; H, 7.6; N, 10.5%. For HL³: yield 76%. Characteristic IR data: 1,613 cm⁻¹. Anal. calc. for $C_{15}H_{22}N_2O_2$: C, 68.7; H, 8.4; N, 10.7; found: C, 68.5; H, 8.5; N, 10.6%.



Scheme 1 The Schiff bases

Synthesis of $[Cu_2(L^1)_2(\mu_{1,1}-N_3)_2] \cdot 2CH_3OH$ (1)

To the methanolic solution (10 mL) of HL¹ (0.028 g, 0.1 mmol) was added a methanolic solution (10 mL) of CuCl₂·2H₂O (0.017 g, 0.1 mmol) and sodium azide (0.012 g, 0.2 mmol) with stirring. The mixture was stirred for 30 min at room temperature to give a deep blue solution. After keeping the solution in air for a few days, blue block-shaped crystals of **1**, suitable for X-ray crystal structural determination, were formed at the bottom of the vessel on slow evaporation of the solvent. The crystals were isolated, washed three times with methanol and dried in air. Yield 45%. IR data (cm⁻¹): 3248 (sh, w), 2036 (s), 1599 (s), 1510 (m), 1407 (w), 1334 (m), 1248 (m), 1141 (m), 1077 (w), 1012 (w), 827 (w), 777 (m), 700 (w), 633 (w), 576 (w), 538 (w), 447 (w). Anal. calc. for C₃₄H₆₀Cu₂N₁₂O₄: C, 49.3; H, 7.3; N, 20.3; found: C, 49.1; H, 7.5; N, 20.1%.

Synthesis of $[Cu(L^2)(\mu_{1,3}-N_3)]_n$ (2)

Complex **2** was synthesized by the similar method as that described for **1**, with HL¹ replaced by HL² (0.026 g, 0.1 mmol). The blue block-shaped single crystals of **2** were isolated, washed three times with methanol and dried in air. Yield 61%. IR data (cm⁻¹): 3366 (sh, w), 2043 (s), 1633 (s), 1604 (s), 1530 (m), 1461 (m), 1433 (m), 1319 (w), 1239 (m), 1170 (m), 1137 (m), 1027 (w), 931 (w), 851 (m), 754 (w), 646 (w), 583 (w), 554 (w), 475 (w). Anal. calc. for $C_{14}H_{19}CuN_5O_3$: C, 45.6; H, 5.2; N, 19.0; found: C, 45.4; H, 5.3; N, 18.9%.

Synthesis of $[Cu_2(L^3)(\mu_{1,1}-N_3)_2(N_3)]_2$ (3)

Complex **3** was synthesized by the similar method as that described for **1**, with HL¹ replaced by HL³ (0.026 g, 0.1 mmol), and with CuCl₂·2H₂O replaced by Cu(NO₃)₂· $3H_2O$ (0.024 g, 0.1 mmol). The blue block-shaped single crystals of **3** were isolated, washed three times with methanol and dried in air. Yield 27%. IR data (cm⁻¹): 3446 (br, m), 2085 (s), 2068 (s), 2044 (s), 1627 (s), 1610 (s), 1532 (m), 1440 (m), 1286 (m), 1223 (s), 1169 (m), 1123 (m), 1027 (w), 977 (w), 853 (m), 755 (w), 638 (w), 577 (w), 561 (w), 473 (w). Anal. calc. for C₁₅H₂₁Cu₂N₁₁O₂: C, 35.0; H, 4.1; N, 29.9; found: C, 35.1; H, 4.1; N, 29.7%.

X-ray data collection and structure determination

Diffraction intensities for the complexes were collected at 298(2) K using a Bruker SMART 1000 CCD area-detector diffractometer with MoK α radiation ($\lambda = 0.71073$ Å). The collected data were reduced with the SAINT program [14], and multi-scan absorption correction was performed using the SADABS program [15]. The structures were solved by

direct methods. The complexes were refined against F^2 by full-matrix least-squares method using the SHELXTL package [16]. All of the non-hydrogen atoms were refined anisotropically. The amino H atom in 1 was located from a difference Fourier map and refined isotropically, with N-H distance restrained to 0.90(1) Å. The remaining hydrogen atoms were placed in calculated positions and constrained to ride on their parent atoms. The crystallographic data for the complexes are summarized in Table 1. Selected bond lengths and angles are given in Table 2.

XO inhibitory test

The XO inhibition test was carried out in triplicate. Xanthine oxidase from cow's milk was purchased from Sigma-Aldrich (St. Louis, MO, USA). The XO activities with xanthine as the substrate were measured spectrophotometrically, based on the procedure reported by Kong et al. [17], with modification. The activity of XO was measured by uric acid formation monitored at 295 nm. The assay was performed in a final volume of 1 mL 50 mM K₂HPO₄ pH 7.8 in a quartz cuvette. The reaction mixture contained 200 µL of 84.8 µg/mL xanthine in 50 mM K₂HPO₄. The reaction was started by addition of 66 µL 37.7 mU/mL XO. The reaction was monitored for 6 min at 295 nm and the product is expressed as μ mol uric acid per minute. The kinetics of the reactions were linear during the 6 min of monitoring. The test compounds dissolved initially in DMSO were incorporated in the enzyme assay to assess their inhibitory activity at different concentrations, in comparison with allopurinol as the standard reference. The final concentration of DMSO in the assay was 5%. Control experiments showed that DMSO, at a final concentration of 5%, did not affect the enzyme assay. XO inhibitory activity was expressed as the percentage inhibition of XO in the above assay mixture system or as the concentration resulting in half-maximal enzyme velocity (IC₅₀).

Results and discussion

The Schiff bases HL¹, HL², and HL³ were synthesized by the reaction of equimolar quantities of 4-diethylaminosalicylaldehyde with N-isopropylethane-1,2-diamine,

Table 1 Crystallographic data for complexes	Complex	1	2	3
I I I I	Formula	C34H60Cu2N12O4	C14H19CuN5O3	C ₁₅ H ₂₁ Cu ₂ N ₁₁ O ₂
	Mr	828.0	368.9	514.5
	<i>T</i> (K)	298(2)	298(2)	298(2)
	Crystal shape/color	Block/blue	Block/blue	Block/blue
	Crystal size (mm ³)	$0.21\times0.18\times0.17$	$0.20\times0.20\times0.18$	$0.20 \times 0.20 \times 0.18$
	Crystal system	Monoclinic	Orthorhombic	Triclinic
	Space group	$P2_{1}/c$	$P2_{1}2_{1}2_{1}$	P-1
	<i>a</i> (Å)	13.231(3)	9.658(3)	8.3552(2)
	b (Å)	13.802(3)	6.877(2)	9.7810(2)
	<i>c</i> (Å)	11.834(2)	23.201(3)	12.7226(3)
	α (°)	90	90	97.1360(10)
	β (°)	105.510(2)	90	91.7410(10)
	γ (°)	90	90	103.9940(10)
	$V(\text{\AA}^3)$	2082.3(7)	1541.0(7)	999.07(4)
	Ζ	2	4	2
	$D_{\rm c} ~({\rm g~cm^{-3}})$	1.321	1.590	1.710
	μ (Mo-K α) (mm ⁻¹)	1.071	1.440	2.167
	<i>F</i> (000)	876	764	524
	Independent reflections	4543	3362	4179
	Observed reflections $(I \ge 2\sigma(I))$	3128	2919	3521
	Min. and max. transmission	0.806 and 0.839	0.762 and 0.782	0.671 and 0.696
	Parameters	244	209	272
	Restraints	1	0	0
	Goodness-of-fit on F^2	1.016	1.065	1.031
^a $R_1 = F_o - F_c / F_o$,	$R_1, wR_2 [I \ge 2\sigma(I)]^a$	0.0383, 0.0950	0.0321, 0.0736	0.0278, 0.0692
$wR_{2} = \left[\sum_{v} w(F_{o}^{2} - F_{c}^{2})/\right]^{1/2}$ $\sum_{v} w(F_{o}^{2})^{2} = \frac{1}{2} \left[\sum_{v} w(F_{o}^{2} - F_{c}^{2})/\right]^{1/2}$	R_1 , wR_2 (all data) ^a	0.0689, 0.1112	0.0400, 0.0762	0.0364, 0.0743

1			
Cu1–O1	1.942(2)	Cu1–N1	1.937(2)
Cu1–N2	2.064(2)	Cu1–N4	1.988(2)
Cu1–N4A	2.479(2)		
N1–Cu1–O1	92.1(1)	N1-Cu1-N4	171.9(1)
O1–Cu1–N4	92.3(1)	N1-Cu1-N2	83.4(1)
O1–Cu1–N2	156.9(1)	N4-Cu1-N2	95.2(1)
N1–Cu1–N4A	95.2(1)	O1-Cu1-N4A	110.7(1)
N4–Cu1–N4A	76.8(1)	N2-Cu1-N4A	92.2(1)
2			
Cu1–O1	1.897(2)	Cu1–N1	1.932(2)
Cu1–N2	2.085(2)	Cu1–N3	1.965(2)
Cu1–N5A	2.847(2)		
O1–Cu1–N1	93.2(1)	O1-Cu1-N3	90.8(1)
N1–Cu1–N3	170.6(1)	O1-Cu1-N2	176.6(1)
N1–Cu1–N2	84.7(1)	N3-Cu1-N2	90.8(1)
O1–Cu1–N5A	96.8(1)	N1-Cu1-N5A	82.5(1)
N2–Cu1–N5A	85.6(1)	N3-Cu1-N5A	105.5(1)
3			
Cu1–O1	2.333(2)	Cu1–N3	2.016(2)
Cu1–N6	1.941(2)	Cu1–N9A	2.014(2)
Cu1–N9	2.040(2)	Cu2–O1	1.915(2)
Cu2–N1	1.934(2)	Cu2–N3	2.016(2)
Cu2–N2	2.058(2)		
N6–Cu1–N9A	156.5(1)	N6-Cu1-N3	93.8(1)
N9–Cu1–N3A	96.5(1)	N6-Cu1-N9	90.1(1)
N9–Cu1–N9A	79.9(1)	N3vCu1–N9	176.0(1)
N6-Cu1-O1	111.3(1)	N9-Cu1-O1A	91.9(1)
N3–Cu1–O1	73.3(1)	N9-Cu1-O1	105.1(1)
O1-Cu2-N1	93.4(1)	O1-Cu2-N3	83.1(1)
N1-Cu2-N3	171.6(1)	O1-Cu2-N2	168.7(1)
N1–Cu2–N2	84.5(1)	N3-Cu2-N2	97.4(1)

Table 2 Selected bond lengths/Å and angles/° for the complexes

Compound 1 Symmetry code for A: -x, -y, 1 - z; Compound 2 Symmetry code for A: -1/2 + x, -1/2 - y, -z; Compound 3 Symmetry code for A: -x, 1 - y, 1 - z

4-methoxysalicylaldehyde with 2-morpholin-4-ylethylamine, and 4-methoxysalicylaldehyde with 2-piperidin-1-ylethylamine, respectively, in methanol. The air-stable yellow gummy product of the Schiff bases is soluble in DMSO, DMF, methanol, ethanol, acetonitrile, and chloroform. The elemental analyses are in good agreement with the chemical formulae proposed for the compounds. The three complexes were synthesized by the reaction of the Schiff bases, Copper salts, and sodium azide in methanol at ambient condition (Scheme 2). All the complexes are stable in air at room temperature for at least 2 months. The molar conductivities of **1**, **2**, and **3** at concentrations of 10^{-3} M are 11, 8, and $17 \ \Omega^{-1} \ cm^2 \ mol^{-1}$, respectively, indicate that the azide groups in the complexes are coordinated to the metal center and are not dissociated in solution.

Crystal structure description of 1

The single-crystal X-ray diffraction shows that the compound 1 contains an end-on azido-bridged dinuclear Copper(II) complex molecule (Fig. 1) and two methanol molecules of crystallization. The asymmetric unit of the complex contains one half of the molecule with the other half generated by the inversion symmetry. The Cu-Cu distance is 3.512(1) Å, indicating there exists strong metallophilic interactions. Each Cu atom in the complex is in a squarepyramidal coordination, with the NNO donor set of the Schiff base ligand and the N4 atom of the azide ligand defining the basal plane, and with the N4ⁱ atom [symmetry code for (i): -x, -y, 1 - z] of the other azide ligand occupying the apical position. The deviation of the Cu atom from the least-squares plane defined by the basal donor atoms is 0.128(2) Å. The azide ligands ligate two different but symmetry-related Cu atoms through the end-on bridging mode. Significant distortion of the square pyramid is revealed by bond lengths and angles between the apical and basal donor atoms. The apical Cu-N bond length is much longer than usual; the other bond lengths are within normal ranges and comparable to the corresponding values observed in other Schiff base Copper(II) complexes [18–20]. The bridging azide groups are nearly linear and show bent coordination with Cu atoms $[N4-N5-N6 = 178.2(3)^{\circ}, Cu1-N4-N5 =$ $128.3(2)^{\circ}$, Cu1ⁱ–N4–N5 = $126.6(2)^{\circ}$].

In the crystal structure of the complex, the methanol molecules are linked to the dinuclear Copper complex molecule through intermolecular N2–H2A···O2ⁱⁱ [N2–H2A = 0.90(1) Å, H2A···O2ⁱⁱ = 2.07(2) Å, N2···O2ⁱⁱ = 2.951(4) Å, N2–H2A···O2ⁱⁱ = 165(3)°, symmetry code for (ii): -x, 1 - y, 1 - z], and O2–H2···O1ⁱⁱⁱ [O2–H2 = 0.82 Å, H2···O1ⁱⁱⁱ = 1.88 Å, O2···O1ⁱⁱⁱ = 2.696(3) Å, O2–H2···O1ⁱⁱⁱ = 171°, symmetry code for iii): x, 1 + y, z] hydrogen bonds (Fig. 2).

Crystal structure description of 2

The single-crystal X-ray diffraction shows that the complex **2** is an end-to-end azido-bridged polymeric Copper(II) complex (Fig. 3). The asymmetric unit of the complex contains two [CuL²($\mu_{1,3}$ -N₃)] moieties. The Cu···Cu distance is 5.716(1) Å, which is much longer than that in **1**. This is caused by the different bridging modes of the azide ligands. Each Cu is in a square-pyramidal coordination, with the NNO donor set of the Schiff base ligand and the terminal N3 atom of a bridging azide ligand defining the basal plane, and with the NS^{iv} atom [symmetry code for iv): -x, -y, 1 - z] of another azide ligand occupying the apical position. The deviation of the Cu atom from the least-squares plane defined by the basal donor atoms is 0.097(2) Å. The azide ligands ligate two different but symmetry-related Cu atoms through the end-to-end

Scheme 2 The molecular structures of the complexes





Fig. 1 A perspective view of the molecular structure of **1** with the atom labeling scheme. The thermal ellipsoids are drawn at the 30% probability level. Atoms labeled with the suffix A or unlabeled are at the symmetry position -x, -y, 1 - z. The two methanol molecules were omitted for clarity

bridging mode. Significant distortion of the square pyramid is revealed by bond lengths and angles between the apical and basal donor atoms. The apical Cu–N bond length is much longer than usual; the other bond lengths are within normal ranges and comparable to the corresponding values observed in **1** and other Schiff base Copper(II) complexes [19, 21]. The bridging azide groups are nearly linear and show bent coordination with Cu atoms [N3–N4–N5 = 177.7(3)°, Cu1–N3–N4 = 123.9(2)°, Cu1–N5^{iv}–N4^{iv} = 116.0(2)°]. In the crystal structure of the complex, the molecules are linked through bridging azide groups, forming polymeric chains running along the a axis (Fig. 4).

Crystal structure description of 3

The single-crystal X-ray diffraction shows that the complex 3 is a phenolato-O and end-on azido-bridged tetranuclear Copper(II) complex (Fig. 5). The asymmetric unit of the complex contains one half of the molecule, with the other half generated by the inversion symmetry. The Cu--Cu distances are found to be 3.122(2) Å for Cu1 and Cu2, and 3.108(2) Å for Cu1 and Cu1ⁱⁱ, indicating there exist strong metallophilic interactions. Each asymmetric unit is a dinuclear Copper(II) complex moiety, within which the Cu atoms are connected by two bridging groups: one phenolate O atom, and one $\mu_{1,1}$ -N₃ ligand. The two asymmetric units are further linked through another two $\mu_{1,1}$ -N₃ ligands, forming a tetranuclear complex. Each of the symmetryrelated two outermost Cu atoms is four-coordinated by the NNO donor set of the Schiff base ligand and the N3 atom of an azide ligand, forming a square planar coordination. The Cu2 atom deviates from the least-squares plane defined by the four donor atoms by 0.974(2) Å. Each of the symmetryrelated two central Cu atoms is in a severely distorted square-pyramidal coordination, with the four azide N atoms



Fig. 2 The crystal structure of 1, viewed along the c axis. Hydrogen bonds are shown as *dashed lines*



Fig. 3 A perspective view of the molecular structure of 2 with the atom labeling scheme. The thermal ellipsoids are drawn at the 30% probability level. Atoms labeled with the suffix A or unlabeled are at the symmetry position -1/2 + x, -1/2 - y, -z

defining the basal plane, and with the phenolate O atom occupying the apical position. The deviation of the Cu1 atom from the least-squares plane defined by the basal donor atoms is 0.172(2) Å. Significant distortion of the square pyramid is revealed by bond lengths and angles between the apical and basal donor atoms. The apical Cu–O bond length is much longer than usual; the other bond lengths are within normal ranges and comparable to the corresponding values observed in **1**, **2**, and other Schiff base Copper(II) complexes [22, 23]. The bridging and terminal



Fig. 4 The crystal structure of 2, viewed along the b axis



Fig. 5 A perspective view of the molecular structure of **3** with the atom labeling scheme. The thermal ellipsoids are drawn at the 30% probability level. Atoms labeled with the suffix A or unlabeled are at the symmetry position -x, 1 - y, 1 - z

azide groups are nearly linear and show bent coordination with Cu atoms.

In the crystal structure, molecules are stacked along the *a* axis through $\pi \cdots \pi$ interactions $[Cg1 \cdots Cg2^i = 3.641(2) \text{ Å}, Cg2 \cdots Cg2^i = 3.817(2) \text{ Å}; Cg1 and Cg2 are the centroids of Cu2–O1–C2–C1–C7–N1 and C1–C2–C3–C4–C5–C6 rings, respectively], as shown in Fig. 6.$

IR spectra

The IR spectra of the Schiff bases and the complexes provide information about the metal–ligand bonding. The assignments are based on the typical group frequencies. The weak and sharp absorption at $3,248 \text{ cm}^{-1}$ for **1** is assigned to the vibration of the amino N–H groups. In the



Fig. 6 The crystal structure of 3, viewed along the *a* axis

IR spectra of the complexes, the strong absorption bands at 1606 cm^{-1} (1), 1609 cm^{-1} (2), and 1610 cm^{-1} (3) are assigned to the azomethine stretching frequencies of the Schiff base ligands, whereas for the free Schiff bases the corresponding bands are observed at higher wave numbers of 1627–1638 cm^{-1} . The shift of these bands toward lower frequencies on complexation suggests coordination to the Cu atoms through the imine N atoms. The v(C-O) mode is present as middle bands at 1222 cm^{-1} for **1**, 1233 cm^{-1} for 2, and 1223 cm^{-1} for 3. The intense bands at 2043 cm^{-1} for 1, and 2049 cm^{-1} for 2, as well as 2085, 2068, and 2044 cm^{-1} for **3**, are assigned to the stretching vibration of the azide ligands. There is only one intense absorption for the azide groups in the spectrum of 1 or 2, while there are three distinct intense absorptions for the azide groups in the spectrum of 3. This is in accordance with the different types of azide groups in the complexes. The weak bands indicative of the Cu-O and Cu-N bonds are located in the region 640–450 cm^{-1} .

XO inhibitory activity

The IC_{50} values for the compounds are listed in Table 3. The complexes show stronger XO inhibitory activity than those of the free Schiff bases, but less activity than the allopurinol used as a reference. The activity of the three complexes in this study is comparable to that of the Copper complexes we reported previously [13]. However, when compared with the Zinc(II) complex we reported previously [24], it can be seen that the activity of the Copper(II) complexes are much weak.

Conclusion

In summary, three new azido-bridged Schiff base Copper(II) complexes were prepared and structurally

Table 3 Average IC₅₀ values of the tested materials against XO

Compound	IC ₅₀ (µM)
1	27.3 ± 1.2
2	31.2 ± 0.7
3	23.5 ± 1.5
HL ¹	>100
HL ²	>100
HL ³	>100
Copper complex A [Ref. 10]	25.33
Copper complex B [Ref. 10]	21.27
Zinc complex [Ref. 21]	7.23
Allopurinol	10.2 ± 0.4

characterized by elemental analysis, IR spectra, and single-crystal X-ray crystallography. The azide ligands are dramatic bridging groups for the construction of such complexes. The complexes show moderate xanthine oxidase inhibitory activities.

Supplementary material

CCDC-847218 (1), 847219 (2), and 847220 (3) contain the supplementary crystallographic data for this article. These data can be obtained free of charge at http://www.ccdc. cam.ac.uk/const/retrieving.html or from the Cambridge Crystallographic Data Centre (CCDC), 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44(0)1223-336033 or e-mail: deposit@ccdc.cam.ac.uk.

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References

- 1. Kurkcuoglu GS, Hokelek T, Yesilel OZ, Aksay S (2008) Struct Chem 19:493
- 2. Salmon L, Thuery P, Ephritikhine M (2006) Dalton Trans 30:3629
- 3. Choudhury RR, Choudhury CR, Batten SR, Mitra S (2008) Struct Chem 19:645
- Liu F-C, Zeng Y-F, Jiao J, Bu X-H, Ribas J, Batten SR (2006) Inorg Chem 45:2776
- 5. Hong CS, Koo J, Son S-K, Lee YS, Kim Y-S, Do Y (2001) Chem Eur J 7:4243
- Song X-Y, Li W, Li L-C, Liao D-Z, Jiang Z-H (2007) Inorg Chem Commun 10:567
- 7. Boonmak J, Nakano M, Youngme S (2011) Dalton Trans 40:1254
- Mahendrasinh Z, Kumar SB, Suresh E, Ribas J (2010) Trans Met Chem 35:757
- 9. Bera R, Adhikary C, Lanelli S, Chaudhuri S, Koner S (2010) Polyhedron 29:2166

- 10. Liu G, Jing H, Xue D (2008) Struct Chem 19:81
- 11. Banerjee I, Marek J, Herchel R, Ali M (2010) Polyhedron 29:1201
- 12. Allen FH (2002) Acta Crystallogr B58:380
- Cui Y-Q, You Z-L, Li X-F, Wang X-L, Ma Y-P, Wang C, Zhang C-L (2010) Trans Met Chem 35:159
- 14. Bruker (2007) SMART (Version 5.625) and SAINT (Version 6.01). Bruker AXS Inc., Madison
- 15. Sheldrick GM (1996) SADABS. Program for empirical absorption correction of area detector. University of Göttingen, Göttingen
- Sheldrick GM (1997) SHELXTL V5.1 Software reference manual. Bruker AXS, Inc., Madison
- 17. Kong LD, Zhang Y, Pan X, Tan RX, Cheng CHK (2002) Cell Mol Life Sci 57:500

- Ni L–L, You Z-L, Zhang L, Wang C, Li K (2010) Trans Met Chem 35:13
- 19. You Z-L, Ma X-L, Niu S-Y (2008) J Coord Chem 61:3297
- Mukherjee P, Sengupta O, Drew MGB, Ghosh A (2009) Inorg Chim Acta 362:3285
- Adhikary C, Mal D, Okamoto K, Chaudhuri S, Koner S (2006) Polyhedron 25:2191
- 22. Ray A, Mitra S, Khalaji AD, Atmani C, Cosquer N, Triki S, Clemente-Juan JM, Cardona-Serra S, Gomez-Garcia CJ, Butcher RJ, Garribba E, Xu DJ (2010) Inorg Chim Acta 363:3580
- 23. Dhara K, Saha UC, Dan A, Sarkar S, Manassero M, Chattopadhyay P (2010) Chem Commun 46:1754
- 24. You Z-L, Shi D-H, Zhu H-L (2006) Inorg Chem Commun 9:642