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Synthesis, spectral and antimicrobial activity of Zn(II) complexes with Schiff bases derived from 2-hydrazino-5-[substituted phenyl]-1,3, 4-thiadiazole and benzaldehyde/2-hydroxyacetophenone/indoline-2,3dione

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HIGHLIGHTS

- Zn(II) complexes with Schiff bases containing 1,3,4-thiadiazole ring have been synthesized and characterized.
- Schiff bases and their corresponding Zn(II) complexes are bactericidal in nature.
- Isatin derived compound 10 showed maximum activities against all microbes.
- MIC value of compound 10 was comparable to any commercial synthetic pesticide.

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ABSTRACT

Zn(II) complexes have been synthesized by reacting zinc acetate with Schiff bases derived from 2-hydrazino-5-[substituted phenyl]-1,3,4-thiadiazole and 2-hydroxyacetophenone/benzaldehyde/indoline-2, 3-dione. All these complexes are soluble in DMF and DMSO; low molar conductance values indicate that they are non electrolytes. Elemental analyses suggest that the complexes have 1:2 metal to ligands stoichiometry of the types [ZnL₂(H₂O)₂](L = monoanionic Schiff bases derived from 2-hydrazino-5-[substituted phenyl]-1,3,4-thiadiazole and 2-hydroxyacetophenone/indoline-2,3-dione) [ZnL₂(OOCCH₃)₂(H₂O)₂] (L' = neutral Schiff bases derived from 2-hydrazino-5-[substituted phenyl]-1,3,4-thiadiazole and benzaldehyde), and they were characterized by IR, ¹H NMR, and ¹³C NMR. Particle sizes of synthesized compounds were measured with dynamic light scattering (DLS) analyser which indicates that particle diameter are of the range ca. 100-200 nm. All these Schiff bases and their complexes have also been screened for their antibacterial (Bacillus subtilis (B. subtilis), Escherichia coli (E. coli) and antifungal activities (Colletotrichum falcatum (C. falcatum), Aspergillus niger (A. niger), Fusarium oxysporium (F. oxysporium) Curvularia pallescence (C. pallescence). The antimicrobial activities have shown that upon complexation the activity increases.

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Introduction

1,3,4-Thiadiazole derivatives are important class of biological active compounds showing anti-inflammatory, antimicrobial,

antitumor properties [1-4], and other useful application are conducting polymer [5,6], solar cell [7], sensor [8,9], enzymatic application [10], energy storage [11], electrodes [12], anxiolytic activity [13], etc. Schiff base ligands are able to coordinate many elements

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| Table | 1 |
|-------|---|
| Physi | cal properties and analytical data of Zn(II) complexes. |

| Complex | Mol. formula | % yield/color | Decomp. Temp. | Molecular weight | % Analysis found(Cal.) | | | | | |
|---------|--|------------------------|-------------------------------|------------------|------------------------|----------------|--------------|------------|------------|--|
| | | | $(^{\circ}C)/\lambda_{M}^{*}$ | found(Cal.) | С | Н | Ν | S | Zn | |
| 1 | C34H34N8O6S2Zn | 64/Light green | 204/18 | 780(780.22) | 52.22(52.34) | 4.16(4.39) | 14.12(14.36) | 8.10(8.22) | 8.11(8.38) | |
| 2 | C ₃₄ H ₃₂ N ₈ O ₆ Cl ₂ S ₂ Zn | 67/Yellow | 270/19 | 849(849.11) | 47.84(48.09) | 3.45(3.80) | 13.05(13.20) | 7.34(7.55) | 7.35(7.70) | |
| 3 | $C_{34}H_{32}N_8O_6Cl_2$ S ₂ Zn | 71/Yellow | 260/19 | 848(849.11) | 47.80(48.09) | 3.55(3.80) | 13.07(13.20) | 7.32(7.55) | 7.45(7.70) | |
| 4 | C ₃₄ H ₃₂ N ₁₀ O ₁₀ S ₂ Zn | 74/Greenish- yellow | 240/20 | 870(870.21) | 46.84(46.93) | 3.47(3.71) | 16.02(16.10) | 7.24(7.37) | 7.37(7.52) | |
| 5 | $C_{32}H_{30}N_8O_4S_2Zn$ | 70/White | 280/12 | 719(720.17) | 53.24(53.37) | 4.12(4.20) | 15.24(15.56) | 8.45(8.90) | 8.65(9.08) | |
| 6 | $C_{32}H_{28}N_8O_4Cl_2S_2Zn$ | 72/Yellow | 220/13 | 788(789.06) | 48.44(48.71) | 3.33(3.58) | 14.04(14.20) | 8.01(8.13) | 8.11(8.29) | |
| 7 | $C_{32}H_{28}N_8O_4Cl_2S_2Zn$ | 68/Yellow | 280/13 | 788(789.06) | 48.52(48.71) | 3.48(3.58) | 14.01(14.20) | 8.07(8.13) | 8.09(8.29) | |
| 8 | $C_{32}H_{28}N_{10}O_8S_2Zn$ | 63/Brown | 220/14 | 810(810.16) | 47.21(47.44) | 3.15 (3.48) | 17.11(17.29) | 7.64(7.92) | 7.90(8.07) | |
| 9 | C32H24N10O4S2Zn | 75/Orange | 170/7 | 742(742.13) | 51.48(51.79) | 3.16(3.26) | 18.55(18.87) | 8.44(8.64) | 8.63(8.81) | |
| 10 | $C_{32}H_{22}N_{10}O_4Cl_2$ S_2Zn | 67/Brown | 230/8 | 810(811.02) | 47.19(47.39) | 2.58(2.73) | 17.04(17.27) | 7.55(7.91) | 7.71(8.07) | |
| 11 | $C_{32}H_{22}N_{10}O_4Cl_2$ S ₂ Zn | 62/Chocolate | 210/8 | 810(811.02) | 47.14(47.39) | 2.41(2.73) | 17.14(17.27) | 7.66(7.91) | 7.71(8.07) | |
| 12 | $\bar{C_{32}}H_{22}N_{12}O_8S_2Zn$ | 72/Light orange | 220/10 | 831(832.13) | 46.03(46.19) | 2.44(2.66) | 20.02(20.20) | 7.45(7.71) | 7.41(7.86) | |

 * Ohm⁻¹ cm⁻¹ mol⁻¹ (in DMSO).

and to stabilize them in various oxidation states. Furthermore, Schiff bases have been known to be used in the preparation of many potential drugs, and are known to possess a broad spectrum of biological activities such as antiviral [14], antifungal [15], antiparasitic [16], antibacterial [17], anti-inflammatory [18], antitumor [19], anti-HIV [20], and anticancer [21]. Schiff bases derived from 1,3,4-thiadiazole have been synthesized and extensively studied because they have some typical properties such as manifestations of original structures, thermal stability, significant biological properties, high synthesis flexibility and therapeutic utility [22]. Previously, many scientists reported that after complexation of transition metal complexes to Schiff bases microbial activity was generally increased [23].

Because of interesting observations on synthetic routes and applicability of zinc(II) complexes and Schiff bases, it was thought be of interesting to study the coordination behaviour of Schiff bases containing thiadiazole ring and to study their antimicrobial properties.

Experimental

Materials and reagents

The solvents and used chemicals were purchased from Merck and used without further purification. Zinc acetate dihydrate was purchased from Sigma–Aldrich.

Instruments

Melting points/decomposition temperature were determined on a Buchi 530 apparatus in open capillary tubes. FAB mass spectra were obtained on a JEOL SX-120/DA6000 spectrometer using argon (6 kV, 10 mA) as the FAB gas. FT-IR spectra were recorded on a Shimadzu 8201 PC model FT-IR spectrophotometer as KBr disks. ¹H and ¹³C NMR spectra were recorded on a Bruker DRX-300 spectrometer using DMSO-*d*₆ as solvent. Chemical shifts (δ) are reported in parts per million (ppm) relative to an internal standard of Me₄Si. Elemental Analyses were recorded by Elementar Vario EL III Carlo Erba 1108 models. Dynamic radiuses of synthesized complexes were measured with help of Nano BioChem DLS analyser. Powdered XRD were scanned by Philips Xpert X-ray diffractometer with CuK α (1.54056) radiation. Elemental analysis (C, H, N, Zn) indicates that the found and calculated values were within acceptable limits (±0.5). Molar conductance of 10^{-3} M solutions of the complexes in DMSO was recorded on a Hanna EC 215 conductivity meter by using 0.01 M KCl water solution as calibrant. The purity of compounds was checked by thin layer chromatography on silica gel plate using ether and ethyl acetate as a solvent system. Iodine chamber was used as a developing chamber.

Synthesis of 5-[substituted phenyl] 2- mercapto-1,3,4-thiadiazole

5-[Substituted phenyl]-2-mercapto-1,3,4-thiadiazoles were prepared according to the method of Mishra et al. [24].

Preparation of 5-(substituted phenyl)-2-hydrazino-1,3,4-thiadiazole

A mixture of 5-[substituted phenyl]-2-mercapto-1,3,4-thiadiazole and hydrazine hydrate in 1:1 molar ratio in ethanol was refluxed for about 4–5 h on water bath. The reaction mixture was cooled to room temperature; within an hour the compound precipitated from the clear solution. It was filtered off, washed and recrystallized in ethanol.

Synthesis of Schiff bases $(L_1-L_{12}H)$

A mixture of 5-[substituted phenyl]-2-hydrazino-1,3,4-thiadiazole and benzaldehyde/2-hydroxyacetophenone/indoline-2, 3-dione in 1:1 molar ratio was refluxed in ethanol (25 cm³) containing few drops of conc. HCl for 5–6 h. The product was separated out on evaporation of the ethanol which was recrystallized in ethanol/ether (1:1).

Synthesis of zinc(II) complexes

Zn(*II*) complexes with ligands L_1 – L_4

An ethanolic solution (30 cm^3) of Zn(II) acetate dihydrate (0.01 mol) was added to a refluxing solution of appropriate Schiff base (L_1-L_4) (0.02 mol) in ethanol (30 cm³). The reaction mixture was refluxed for about 8–11 h. The colored complex was obtained. The complex was filtered off, washed thoroughly with ethanol and dried under *vacuo* at room temperature. The complexes were obtained as powdered material.



Fig. 1. Reaction scheme for the preparation of Schiff base and their Zn(II) complexes (R = C_6H_5 (1); R = $2-ClC_6H_4$ (2); R = $4-ClC_6H_4$ (3); R = $4-NO_2C_6H_4$ (4); R' = C_6H_5 (5); R' = $2-ClC_6H_4$ (6); R' = $4-ClC_6H_4$ (7); R' = $4-NO_2C_6H_4$ (8); R'' = $2-ClC_6H_4$ (10); R'' = $4-ClC_6H_4$ (11); R'' = $4-NO_2C_6H_4$ (12).

| Table 2 | | | | |
|------------------|-------------|-------------|-----------|------------|
| The important IR | frequencies | (cm^{-1}) | of Zn(II) | complexes. |

1,

| Complexes | IR frequency (cm ⁻) | | | | | | | | | | | |
|-----------|---------------------------------|--------|---------|------------------|--------|--------|----------------------|-----------------|--------|---------|---------|---------|
| | υ(Ο —Η) | υ(N—H) | v(Ar–H) | v(— COO) | v(C=N) | v(C=C) | v(-NO ₂) | Phenolic v(C–O) | υ(N—N) | v(C—Cl) | v(Zn-O) | υ(Zn—N) |
| 1 | 3432s | 3180m | 3050w | 1730m | 1590s | 1575w | - | - | 1195m | - | 415m | 420m |
| 2 | 3436s | 3195m | 3070w | 1745m | 1585s | 1580w | - | - | 1200m | 775w | 410m | 430m |
| 3 | 3345s | 3182m | 3075w | 1755m | 1610s | 1610w | - | - | 1210m | 765w | 420m | 435m |
| 4 | 3440s | 3190m | 3080w | 1740m | 1595s | 1585w | 1535m | - | 1215m | - | 414m | 432m |
| 5 | 3430s | 3200m | 3065w | - | 1585s | 1570w | - | 1375s | 1217m | - | 445m | 440m |
| 6 | 3434s | 3195m | 3078w | - | 1605s | 1578w | - | 1350s | 1220m | 769w | 460m | 445m |
| 7 | 3430s | 3205m | 3087w | - | 1600s | 1595w | - | 1343s | 1223m | 774w | 465m | 450m |
| 8 | 3440s | 3202m | 3088w | - | 1615s | 1598w | 1540m | 1380s | 1227m | - | 466m | 442m |
| 9 | 3420s | 3190m | 3110w | - | 1590s | 1576w | - | 1355s | 1225m | - | 464m | 455m |
| 10 | 3436s | 3195m | 3121w | - | 1596s | 1585w | - | 1350s | 1222m | 780w | 470m | 450m |
| 11 | 3437s | 3186m | 3112w | - | 1595s | 1592w | - | 1310s | 1224m | 775w | 475m | 440m |
| 12 | 3446s | 3195m | 3125w | - | 1615s | 1580w | 1545m | 1340s | 1221m | - | 480m | 452m |

Zn(II) complexes with ligands $L_5H-L_{12}H$

The procedure involves the addition of the appropriate Schiff base $(L_5H-L_{12}H)$ (0.04 mol) to an aq. ethanol (~30 cm³) of zinc acetate dihydrate (0.02 mol) and sodium acetate (0.04 mol). The

mixture was refluxed for *ca*.10–11 h on a water bath. Light yellow or brown precipitate obtained was filtered, washed with ethanol and hot water and dried *in vacuo* at room temperature. The complexes were obtained as powdered material.

| Table 3 | | |
|--|----------------|-------------------|
| ¹ H NMR and ¹³ C NMR | spectral bands | Zn(II) complexes. |

| Compound | | | NMR data | | | | | ¹³ C NMR |
|----------|---------|------------|-------------------|----------|-------|---------|-------|--|
| | —NH (s) | $-CH_3(s)$ | Aromatic ring (m) | -HC=N(s) | -COO | $-CH_3$ | -C=N | Aromatic ring |
| 1 | 12.24 | 2.16 | 7.00-8.71 | 8.21 | 182.4 | 23.4 | 155.4 | 135.4, 131.1, 130.8, 130.2, 129.3, 128.7, 128.3, 127.4 |
| 2 | 12.58 | 2.26 | 7.10-8.82 | 8.23 | 182.7 | 23.8 | 155.8 | 137.4, 133.4, 130.7, 130.5, 129.7, 129.4, 128.9, 128.4, 127.7 |
| 3 | 12.23 | 2.31 | 7.15-8.70 | 8.27 | 182.8 | 23.7 | 155.6 | 135.4, 132.2, 131.2, 130.6, 129.4, 128.7, 127.4 |
| 4 | 12.48 | 2.41 | 7.03-8.65 | 8.29 | 182.6 | 23.5 | 155.7 | 148.6, 140.5, 131.2, 129.5, 128.9, 125.4 |
| 5 | 12.60 | 1.25 | 7.17-8.45 | - | - | 12.4 | 158.4 | 152.4, 134.3, 131.4, 130.5, 129.7, 129.1, 122.4, 115.5, 114.6 |
| 6 | 12.66 | 1.27 | 7.07-8.53 | - | - | 12.6 | 158.3 | 152.7, 138.8, 132.5, 131.1, 129.4, 128.7, 121.7, 115.4, 114.8 |
| 7 | 12.67 | 1.21 | 7.09-8.37 | - | - | 12.7 | 158.5 | 152.6, 135.6, 131.6, 129.6, 128.9, 122.2, 115.9, 114.4 |
| 8 | 12.64 | 1.31 | 7.15-8.42 | - | - | 12.5 | 158.3 | 153.0, 149.4, 139.8, 130.4, 129.3, 124.5, 121.7, 115.4, 114.9 |
| 9 | 12.10 | - | 7.13-8.51 | - | - | - | 143.4 | 155.5, 133.6, 131.3, 130.1, 129.7, 128.9, 127.7, 126.4, 122.8 |
| 10 | 12.23 | - | 7.17-8.46 | - | - | - | 143.1 | 155.3, 137.5, 133.6, 131.2, 130.4, 129.7, 129.1, 127.5, 127.3, |
| | | | | | | | | 126.9, 122.2 |
| 11 | 12.20 | - | 7.21-8.57 | - | - | - | 143.2 | 155.7, 135.4, 131.9, 130.4, 129.5, 128.8, 127.6, 126.5, 122.7 |
| 12 | 12.30 | - | 7.22-8.51 | - | - | - | 143.5 | 155.6, 148.4, 138.3, 130.6, 129.8, 128.3, 127.1, 126.4, 122.2 |

The details of the reactions along with the analytical data of the products are given in Table 1. The general reaction scheme is given in Fig. 1.

Biological activity study

All newly prepared Schiff bases and Zn(II) complexes were screened for their activity against four fungal organisms *Colletotrichum falcatum, Aspergillus niger, Fusarium oxysporium* and *Curvularia pallescence* and two bacteria namely *Bacillus subtilis, and Escherichia coli* by disc-diffusion method [25]. Antifungal and antibacterial activity of each compound was evaluated at three different concentrations, i.e., 1000, 100, 10 μ g/mL and 200, 100, 10 μ g/mL, respectively.

Bacterial zone of inhibition was measured by well forming method. *E. coli* and *B. subtilis* were grown at 37 °C and 32 °C maintained on LB plates (Luria base Hi-media). Well are formed in LB plates with the help of sterilized plastic tips. 10 μ g/mL concentration Zn(II) complexes (2, 6 and 10) were added in separate well and further temperatures were maintained for 24 h, zone of inhibition was measured with help of barmier callipers. Fluconazole was used as standard drug for antifungal and gentamycine was used as standard drugs for antibacterial activity.

Results and discussion

Zn(II) complexes are sparingly soluble in common solvents; however, these complexes are soluble in DMF and DMSO. The conductivity measured in DMSO, showed that the complexes are nonelectrolytes. Magnetic susceptibility measurement showed that they are diamagnetic nature. The presence of water molecules in the complexes has been confirmed by TG studies which show weight loss at ca. 165–180 °C, corresponding to two water molecules.

Infrared spectra

The characteristic IR spectral bands of Zn(II) derivatives are given in Table 2. The IR spectra provide valuable information regarding the coordination behaviour of Schiff bases. Schiff bases derived from indoline-2,3-dione appear to exist in both keto and enol tautomeric forms (Fig. 2) suggested by a broad band (solution spectra) at *ca*. 2600 cm⁻¹, due to intramolecular H-bonded OH group. All the ligands and complexes show band *ca*. 3050–3125 cm⁻¹ assigned for the v(Ar-H). The bands in the IR spectra of complexes 4, 8 and 12 at *ca*. 1535–1545 cm⁻¹ can be assigned to the NO₂ group [26]. The IR spectra of complexes 2, 3, 6, 7, 10 and 11 shows

at 765–780 cm⁻¹ assigned for the C–Cl stretching modes [27]. The spectra of Schiff bases show a medium band at 3175–3200 cm⁻¹ due to v(N-H) which remains almost at the same position in complex indicating the non involvement of N-H group in bond formation. The ligands show one medium intensity band at *ca*. 1630 cm⁻¹ assignable [26,28] to v (C=N) which shifts to 1590-1615 cm⁻¹ in the complexes. This shifting indicates that the coordination of azomethine nitrogen to metal ion [29-32]. The bands at ca. 420–455 cm⁻¹ were assigned [32] to v(Zn-N). L₅H–L₁₂H Schiff bases show broad band at *ca*. 2640 cm⁻¹ due to intramolecular Hbonded OH group. This band disappear in their corresponding Zn(II) complexes indicating the coordination of phenolic oxygen to zinc metal ion through deprotonation. This is further supported by shift in phenolic v(C-O) band from 1285 to 1300 cm⁻¹ (in the free ligand) to *ca*. 1310–1380 cm^{-1} in the complexes. The coordination through phenolic oxygen has been further confirmed by the appearance of band at *ca*. 445–480 cm⁻¹ assignable to v(Zn-O)[33]. The presence of coordinated water in the complexes is indicated by a broad trough band in the region *ca*. 3420-3446 cm⁻¹ and two weaker bands in the region 750-810 and 700-730 $\rm cm^{-1}$ due to v(-OH) rocking and wagging mode of vibrations, respectively [34,35]. The complexes with ligand L₁-L₄ show strong bands in the region 1730–1755 cm⁻¹ which are assigned to v(OOCCH₃). In complexes Zn–O band appears at 410–420 cm⁻¹, which indicates that the acetate molecules are bonded to zinc [36]. Further, the absorption at 1616 and 1410 cm⁻¹, confirm the monodentate nature of the acetate ion in complexes with ligand L_1-L_4 [37].

¹H NMR spectra

The proton magnetic resonance spectra of these complexes have been recorded in DMSO- d_6 . Chemical shifts for protons in different environments have been given in Table 3. The intensities of all the resonance lines were determined by planimetric integration. The following conclusions can be derived by comparing the spectra of ligands with their corresponding complexes. The spectra of Schiff bases (L_1-L_4) exhibit signals at *ca*. 12.10 and 8.00 ppm due to NH and azomethine protons, respectively. In zinc(II) complexes (1-4), the first signal remains almost at the same position but the second signal shifts to downfield. The downfield shift indicates the deshielding effect due to the coordination of azomethine nitrogen to central metal ion. Complexes of type (1-4) show signal at 2.16-2.41 ppm due to methyl protons of acetate [32]. Schiff base and their corresponding Zn(II) complexes show multiplet at 7.00-8.82 ppm due to aromatic protons. Zn(II) complexes (1-4) show new signal at *ca*. 5.5 ppm due to the water protons.

Schiff bases derived from 2-hydroxyacetophenone (L_5H-L_8H) exhibit signals at 12.60–12.65 and 10.45 ppm due to hydrazino



Fig. 2. Tautomeric forms of Schiff bases (L₉H-L₁₂H).



Fig. 3. DLS analysed results of compounds 6 and 10.

NH and phenolic —OH protons, respectively. The signal due to phenolic —OH at *ca.* 10.45 ppm disappears in the spectra of complexes (5–8); this confirms that the hydroxyl group reacted with metal ion *via* deprotonation. Multiplet is observed at *ca.* 7.07–8.53 ppm due to aromatic protons in the Schiff bases and their corresponding Zn(II) complexes. Schiff bases (L₅H–L₈H) and their corresponding Zn(II) complexes also exhibit a signal at *ca.* 1.21–1.31 ppm due to methyl protons. Zn(II) complexes (5–8) show new signal at *ca.* 5.6 ppm due to the water protons.

Schiff bases derived from indoline-2,3-dione of type $(L_9H-L_{12}H)$ exhibit signals at 12.16 and 5.55 ppm due to hydrazino NH proton and indoline-2,3-dione NH proton, respectively. In Zn(II)

Table 4

Antifungal screening data of Zn(II) complexes at concentration ($\mu g/mL$).

complexes indoline-2,3-dione NH signal disappears. Multiplet is observed at 7.13–8.57 ppm due to aromatic protons in the Schiff base and their corresponding Zn(II) complexes. Complexes (9–12) also show new signal at *ca*. 5.4 ppm due to the water protons.

¹³C NMR

The ¹³C NMR spectra were recorded (Table 3) in DMSO- d_6 . Schiff bases derived from benzaldehyde (L_1-L_4) show signals at *ca*. δ 175 ppm for their azomethine carbon which shift downfield in their corresponding Zn(II) complexes (δ 155 ppm) due to coordination through the azomethine nitrogen. The complexes of type (1–4) show signals at *ca*. δ 23 ppm (CH₃) and *ca*. δ 182 ppm (–COO) due to the presence of coordinated acetate molecules.

Schiff bases derived from 2-hydroxyacetophenone (L_5H-L_8H) show signal at *ca*. δ 173 ppm for azomethine carbon and which shift downfield in zinc metal complexes (*ca*. δ 158 ppm) due to coordination through the azomethine nitrogen. For –CH₃ carbon, a signal appears at *ca*. δ 12.0 ppm in ligands and their corresponding complexes of type (5–8).

Schiff bases $(L_9H-L_{12}H)$ show signals at *ca*. δ 148 ppm due to azomethine carbon which shift downfield in their corresponding Zn(II) complexes (*ca*. δ 143 ppm) due to the coordination through azomethine nitrogen. Schiff bases of type L_1-L_4 , $L_5H-L_{12}H$ and their corresponding Zn(II) complexes show signals at *ca*. 172 ppm and *ca*. 167 ppm assignable for thiadiazole ring carbons. For aromatic ring, a number of signals appear these are given in Table 3.

Dynamic light scattering (DLS), powdered XRD

For the compounds 6 and 10, hydrodynamic radiuses were measured by DLS analysis and obtained data presented in Fig. 3. The average dynamic radius of compounds 6 and 10 are 109 and

| Compound | % Fungal inhibition* | | | | | | | | | | | | |
|----------|----------------------|------|------|----------|----------|------|------|---------------|------|------|----------------|------|--|
| | C .falcatum | | | A. niger | A. niger | | | F. oxysporium | | | C. pallescence | | |
| | 1000 | 100 | 10 | 1000 | 100 | 10 | 1000 | 100 | 10 | 1000 | 100 | 10 | |
| 1 | 75.9 | 63.7 | 41.9 | 76.6 | 65.5 | 43.8 | 71.4 | 61.6 | 40.9 | 70.2 | 59.2 | 39.4 | |
| 2 | 81.0 | 69.2 | 55.5 | 82.8 | 70.9 | 54.6 | 80.2 | 69.4 | 52.6 | 78.6 | 66.5 | 50.2 | |
| 3 | 78.2 | 63.9 | 48.9 | 80.0 | 66.7 | 49.0 | 72.6 | 64.5 | 45.8 | 74.4 | 63.7 | 46.6 | |
| 4 | 76.0 | 65.1 | 51.0 | 81.7 | 68.2 | 52.6 | 78.5 | 67.8 | 49.4 | 74.8 | 65.4 | 47.4 | |
| 5 | 73.2 | 64.0 | 47.6 | 78.6 | 63.3 | 47.0 | 72.6 | 63.6 | 44.3 | 73.4 | 62.3 | 42.4 | |
| 6 | 82.6 | 74.1 | 55.2 | 84.7 | 77.8 | 57.4 | 83.5 | 72.4 | 55.5 | 80.5 | 68.8 | 53.3 | |
| 7 | 75.5 | 67.7 | 49.4 | 81.2 | 71.1 | 52.3 | 80.7 | 65.1 | 49.6 | 75.6 | 63.5 | 47.3 | |
| 8 | 79.0 | 68.4 | 53.9 | 82.6 | 69.5 | 55.2 | 81.3 | 66.9 | 51.2 | 74.4 | 65.1 | 49.4 | |
| 9 | 75.6 | 68.8 | 48.9 | 80.7 | 71.6 | 58.8 | 72.9 | 64.0 | 45.3 | 69.2 | 63.1 | 44.2 | |
| 10 | 84.2 | 76.9 | 61.4 | 88.6 | 68.0 | 55.6 | 87.6 | 66.4 | 56.8 | 85.4 | 65.7 | 52.0 | |
| 11 | 78.6 | 70.5 | 58.3 | 83.8 | 69.3 | 57.0 | 82.4 | 67.6 | 53.7 | 79.3 | 61.3 | 49.9 | |
| 12 | 81.4 | 66.1 | 59.1 | 84.0 | 71.1 | 58.2 | 81.3 | 70.5 | 54.5 | 77.2 | 62.8 | 50.1 | |
| 13 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | |

* Each value observed is within the error limits of ±0.1%.

Table 5

Antibacterial screening data of Zn(II) complexes at concentration ($\mu g/mL$).

| | % Bacterial inhibition ^a | | | | | | | | | |
|----------|-------------------------------------|------|------|--------|-------|------|------------------|-------------|--|--|
| Compound | E. coli | | | B. sub | tilis | | MIC ^b | | | |
| | 200 | 100 | 10 | 200 | 100 | 10 | E. coli | B. subtilis | | |
| 1 | 60.4 | 47.3 | 32.1 | 62.7 | 49.8 | 34.5 | >500 | >450 | | |
| 2 | 67.6 | 55.0 | 36.7 | 69.4 | 57.7 | 38.2 | >410 | >385 | | |
| 3 | 65.4 | 51.5 | 35.1 | 67.6 | 53.4 | 36.5 | >445 | >405 | | |
| 4 | 66.3 | 48.8 | 33.4 | 67.9 | 55.6 | 34.7 | >430 | >410 | | |
| 5 | 61.7 | 50.2 | 36.1 | 64.5 | 53.8 | 37.9 | >455 | >425 | | |
| 6 | 68.4 | 57.6 | 42.6 | 70.4 | 59.7 | 44.5 | >370 | >340 | | |
| 7 | 64.2 | 53.0 | 40.5 | 65.6 | 54.3 | 41.1 | >405 | >360 | | |
| 8 | 66.7 | 55.8 | 38.3 | 67.4 | 58.6 | 40.5 | >380 | >350 | | |
| 9 | 62.2 | 52.0 | 40.1 | 63.3 | 55.7 | 42.5 | >350 | >340 | | |
| 10 | 70.9 | 59.1 | 45.4 | 71.7 | 61.1 | 45.3 | >325 | >290 | | |
| 11 | 67.6 | 54.0 | 43.3 | 68.4 | 56.7 | 44.8 | >330 | >315 | | |
| 12 | 69.5 | 57.2 | 41.4 | 67.8 | 60.1 | 40.6 | >340 | >325 | | |

^a Maximum error ±0.1%.

^b Maximum error ±5 (μg/mL).



Fig. 4. Bacterial zone of inhibition (mm) by 2-chloro derived Zn(II) complex at concentration $10\,\mu g/mL$

164 nm, respectively indicating the fine particle nature of the compounds. Absence of appropriate peak in powdered XRD measurements indicates that compounds are amorphous in nature.

Microbial activity

The antimicrobial activity of synthesized Zn(II) complexes were carried out by reported method [27] against four fungi (C. falcatum, A. niger, F. oxysporium and C. pallescence) and two bacteria (B. subtilis, and E. coli). Antifungal activity was measured in term of percentage growth inhibition (Table 4), while antibacterial activity was measured in three terms (percentage inhibition, minimum inhibitory concentration (MIC), and zone of inhibition (mm)). Percentage inhibition and MIC results of antibacterial activity are systematised in Table 5 and zone of inhibition results are shown in Fig. 4. The microbial studies suggested that all the synthesized Schiff bases are antimicrobial in nature and their corresponding Zn(II) complexes showed significantly enhanced antimicrobial activities. We observed that with increasing chelation both antifungal and antibacterial activities are enhanced. The actual mechanism for this is unknown byt factors like solubility, dipole moment and cell permeability mechanism and their enzymatic action may be the possible reason. 2-Chloro substituted ligands/compounds are more active than other substituted ligands/ compounds [38]. The compound (10) is more active against all bacteria and fungi because they have additional heterocyclic ring

(indoline-2,3-dione). In antifungal strain we observed that all ligands and Zn(II) complexes are more active against *C. falcatum*. All Schiff bases and Zn(II) complexes are more active against *B. sub-tilis*. It is found that substitution in the ligands increases the activity against bacteria and fungi. Minimum inhibitory measurements (MIC) showed that synthesized compound 10 has lowest concentration (325 μ g/mL for *E. coli* and 290 μ g/mL for *B. subtilis*) needed for complete inhibition.

Standard method was used to established whether the Schiff base and their Zn(II) complexes were bacteriostatic or bactericidal [27], different weighted amount of Schiff base and Zn(II) complexes 10–200 µg/mL, were incubated with bacteria (*B. subtilis* and *E. coli*) in LB broth for 24 h and then 100-µL aliquots were taken from the incubated LB broth and were placed on nutrient soft agar plates and then incubated at for 24 h, colony were counted, the results established that all the Schiff bases and Zn(II) complexes have bactericidal properties. The indoline-2,3-dione derived Schiff base (L₆H) and their Zn(II) complexes (10) have excellent bactericidal properties. *B. subtilis* zone of inhibition measurement showed that complex (10) have nearly same zone (19 mm) of the standard drug streptomycin (20 mm).

Conclusions

Schiff bases (L_1-L_4) act as monodentate ligand coordinating through azomethine nitrogen, while Schiff bases $(L_5H-L_{12}H)$ are monobasic bidentate ligands coordinating through azomethine nitrogen and phenolic oxygen through deprotonation. The octahedral geometry of the complexes has been established by elemental analysis, molecular weight and spectral studies. DLS analysis indicated that compounds are fine particles. Antifungal and antibacterial activities of the ligands and corresponding complexes have also been evaluated, which show that the activities increase on chelation and all Schiff base and Zn(II) complexes are bactericidal in nature.

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