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Synthesis, characterization, spectroscopic studies and antimicrobial activity of three new Schiff bases derived from Heterocyclic moiety

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ABSTRACT

Three new Schiff-bases compounds (**I-III**) were synthesized by a condensation reaction in 1:2 M ratios of 4,4′-diaminodiphenyl sulfide and pyrrol/thiophene/furan-2-carboxaldehyde in ethanol. The structural determinations of the Schiff-bases were identified with the help of elemental analysis then confirmed by UV–Vis, FT-IR and ^{1}H NMR. The products were obtained in excellent yields. On the other hand, the in vitro antibacterial and antifungal activities of the synthesized compounds were investigated using disc diffusion method. Schiff bases synthesized individually exhibited varying degrees of inhibitory effects on the growth of the tested microbial species.

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1. Introduction

Compounds containing the –C═N– (azomethine group) structure are known as Schiff bases, usually synthesized from the condensation of primary amines and active carbonyl groups [1], and generally take place under acid, base catalysis or with heat. Schiff bases are considered as a very important class of organic compounds, having wide ranges of applications, such as hydrogenation, oxidation catalysts [2–13], a reagent of analysis [14], and as industrial dyes [15,16]. Schiff bases are especially studied due to their synthetic flexibility, selectivity and sensitivity towards the metallic ions [17–20]. Schiff base metal complexes have a variety of biological applications in clinical, pharmacological areas [21,22], and several derivatives have been used as drugs and their affectivities have been proved as bacteriocides, pesticides, fungicides and insecticides [23,24]. Some of them which have structural similarities with natural biological substances have been used as models in biological macro systems, radiopharmaceuticals for cancer targeting, oxygen carriers, medical substrates and catalyst [25,26]. Furthermore, Schiff base Heterocyclic containing nitrogen, oxygen and sulfur atoms constitute a class of compounds which shows momentous biological activities [27], such as antiviral activity [28], antifungal [29], antioxidant [30], anti-inflammatory [31], antitumor [32,33], anticancer [34,35], antibacterial activities [36,37], and antipyretic applications [38].

With the sensitizing of the human being to the pathogenic effect, there is an increasing need for antibacterial materials in many application areas such as medical devices, health care, hygienic application, water purification system, hospital, dental surgery equipment, textiles, food packaging and storage [39,40].

In this work, we present the synthesis of three new Schiff bases derived from condensation of pyrrole-2-carboxaldehyde, thiophene-2-carboxaldehyde and furan-2-carboxaldehyde with 4,4′-diaminodiphenyl sulfide. The structures of synthesized compounds were characterized by UV–Vis, FT-IR and ^{1}H NMR. Further support for their structures was derived from elemental analyses. These Schiff bases were investigated for their antibacterial and antifungal properties.

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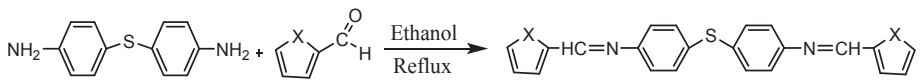

I: X= NH, **II**: X= S, **III**: X= O.

Fig. 1. Synthesis and structure of Schiff bases **I-III**.

2. Experimental

All materials were commercially available, were obtained from Sigma-Aldrich or Fluka, were used as received and without any further purification.

2.1. Synthesis of Schiff base *I*

Schiff base 4,4′- Bis (2-pyrrole carboxaldehyde) diphényl diiminosulfide (compound **I**) was synthesized by condensation of pyrrole-2-carbaxaldehyde (2.16 g, 10 mmol) with 4,4′-diaminodiphenyl sulfide (20 mmol) taken in a molar ratio of 1:2. The absolute ethanol was used as a solvent. The dissolved aldehyde was added drop wise to the hot solution of 4,4′-diaminodiphenyl sulfide and stirred well using a magnetic stirrer. The color of the reaction mixture turns yellow. The mixture was heated and kept at reflux for 3 h and then was cooled overnight at room temperature. Pale yellow product was precipitated out, it was filtered, washed and recrystallized with ethanol. The yield and melting point of the product were determined. The reaction scheme is shown in Fig. 1.

2.2. Synthesis of Schiff base *II*

4,4′- Bis (2-thiophène carboxaldehyde) diphényl diiminosulfide (compound **II**) was synthesized by the same method as for **I,** using thiophene-2-carbaxaldehyde as the reactant and sketched in Fig. 1. After The mixture was refluxed for 3 h to give a yellow precipitate. The precipitate was isolated by filtration washed with ethanol.

2.3. Synthesis of Schiff base *III*

Furane-2- carbaxaldehyde was dissolved in absolute ethanol (20 ml) added dropwise to a solution of 4,4′-diaminodiphenyl sulfide (20 mmol) in absolute ethanol (20 ml). The appropriate reaction mixtures were stirred and refluxed for 3 h under nitrogen. The red brick precipitate formed after 3 days upon cooling at room temperature was collected by filtration and then washed with ethanol, purified product 4,4′- Bis (2-furane carboxaldehyde) diphényl diiminosulfide (compound **III**) was obtained (Fig. 1).

The yields and melting points of the three products were determined.

2.4. Characterization

All reactions were monitored using thin layer chromatography (TLC) carried out on 0.25-mm E Merck silica gel plates (60F-254) and the spots were visualized by UV light. Melting points were determined on a digital apparatus Koefler Banc while elemental analyses were carried out with a Perkin-Elmer 240 elemental analyzer. The UV–Visible spectra were recorded in dichloromethane between 200 and 800 nm using JASCO V– 650 spectrophotometer with quartz cells of 1 cm path length. A Perkin Elmer Spectrum one FT-IR spectrometer with the diffuse reflectance attachment (Miracle Attenuated Total Reflectance Attachment) at a 4 cm^{-1} resolution in the region 4000-600 cm^{-1} was employed to record the infrared spectrum to analyze the functional groups present in the Schiff bases compounds. Proton NMR spectrum of these compounds was recorded in $CDCl_3$-d using Me4Si (TMS) as internal standard on a Bruker Avance III HD 400 NMR spectrometer at room temperature to confirm its molecular structure.

2.5. Biological activity

2.5.1. Antibacterial activity (in vitro)

The synthesized Schiff bases **I-III** were screened in vitro for their antibacterial activity against three referential strains namely, *Escherichia coli* ATCC 25922 and *Pseudomonas aeruginosa* ATCC 27853 Gram-negative, *Staphylococcus aureus* ATCC 25923 Gram-positive, and three clinical strains namely *Klebsiella pneumoniae*, *Proteus mirabilis* and *Serratia marcescens* Gram-negative, isolated in the microbiology laboratory of the UHC Sétif, using the disc diffusion method [41–43].

Thus, disinfected plates were filled with 12 ml of sterilized Muller–Hinton agar medium). Afterwards, 100 μL of particular bacterium which contained of 0.5×10^6 CFU mL^{-1} (tantamount to 0.5 McFarland standards) was dispersed on the plates surfaces using a sterile swab. The discs which had been impregnated with (10 μL) the Schiff base compounds with (25 mg/ml in DMSO) and were placed on the agar surface. The disc soaked in the DMSO was used as negative control. The plates were incubated at 37 °C for 24 h, and the diameters of the zones of inhibition were measured in millimeters (mm). All sample tests were performed in three replicates to obtain mean ± standard deviation. (S.D.) values.

Table 1
Diagram of the procedure (technique of dilution in liquid medium).

N° tubes	Volume of added antibiotic	Intermediate concentration	Supplemented volume MH	Inoculum	Final concentration
1	100 μl of the solution 25 mg/ml	12.5 mg/ml	280 μl	20 μl	3.125 mg/ml
2	100 μl of the solution 12.5 mg/ml	6.25 mg/ml	280 μl	20 μl	1.562 mg/ml
3	100 μl of the solution 6.25 mg/ml	3.125 mg/ml	280 μl	20 μl	0.781 mg/ml
4	100 μl of the solution 3.125 mg/ml	1.56 mg/ml	280 μl	20 μl	0.39 mg/ml
5	100 μl of the solution 1.56 mg/ml	0.78 mg/ml	280 μl	20 μl	0.195 mg/ml

Table 2
Analytical and physical data of Schiff bases synthesized (**I**–**III**).

Compounds	molecular formula	Color	Yield(%)	M.P.(°C)	Elemental analysis found (Calcl.) (%)				
					C	H	N	S	O
I	$C_{22}H_{18}N_4S$	yellow	83.12	192	71.34(71.31)	4.75(4.91)	15.34(15.1)	8.35(8.65)	–
II	$C_{22}H_{16}N_2S_3$	yellow	83.14	164	65.45(65.30)	4.08(3.99)	7.19 (7.52)	23.36(23.77)	–
III	$C_{22}H_{16}N_2O_2S$	brick red	87.25	142	70.77(70.94)	4.46(4.34)	8.12 (7.52)	7.95 (8.61)	8.16(8.59)

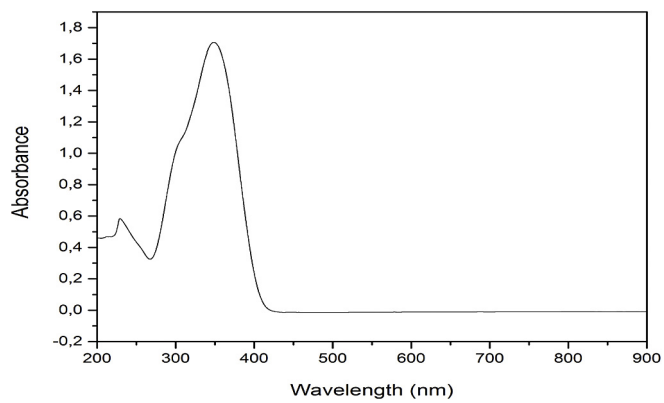

Fig. 2. UV–Vis spectrum of 4,4′- Bis (2-pyrrole carboxaldehyde) diphényl diimino sulfide.

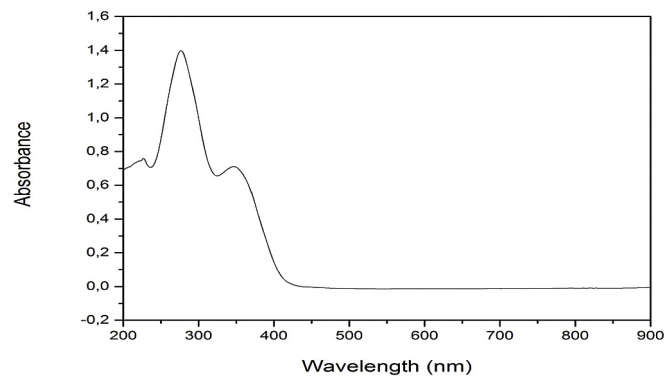

Fig. 4. UV–Vis spectrum of 4,4′- Bis (2-furane carboxaldehyde) diphényl diimino sulfide.

2.5.1.1. Minimum inhibitory concentration (MIC). The MIC values were determined as the second applicable test for the investigation of antibacterial properties of Schiff base compounds, by the method of micro dilution of the compounds to test in liquid Mueller-Hinton (MH) medium. Semi-logarithmic dilutions of reason 2 were carried out starting from the mother solutions, we obtain intermediate concentrations going from 12.5 mg/ml to 0.78 mg/ml. The tubes were inoculated with 20 μL bacterial suspensions containing $0.5.10^5$ CFU/ML of germ, 280 μl of MH was distributed in the tubes, the concentration of azomethine compounds obtained is then of 3.125 mg/ml to 0.195 mg/ml (Table 1), and incubated at 37 °C for 24 h [44]. The lowest concentration that inhibited the ocular growth of bacteria (absence of turbidity in the test tubes after incubation for 24 h) was considered as the MIC value.

2.5.1.2. Minimum bactericidal concentration (MBC). The intrinsic turbidity of compounds in solution necessitated the application of the MBC, the MBC test was used as the third method for the investigation of antibacterial activities. A loop full of broth of dilution used for the MIC tests in Muller Hinton broth medium was spread on agar plates and then incubated at 37 °C for 24 h. For each series, a witness was carried out without Schiff base. The dilutions of the bacterial inoculum at a density of 0.5 MF (1/10, 1/100, 1/1000, 1/10000) were subcultured in streaking on agar Muller-Hinton to serve as a witness [45]. In this method, observation of bacterial growth on the surface of agar medium became possible and therefore recognition of antibacterial activities of Schiff base compounds was easier with respect to the MIC test. MBC was defined as the lowest Schiff base concentration in which 99, 9% of the inoculum were killed in comparing with the witness suspensions.

2.5.2. Antifungal activity

Antifungal activities of three Schiff base compounds were checked against two fungal strains (*Microsporum canis* and *Candida albicans*) isolated in the microbiology laboratory of the UHC Sétif. For estimation of the antifungal properties of

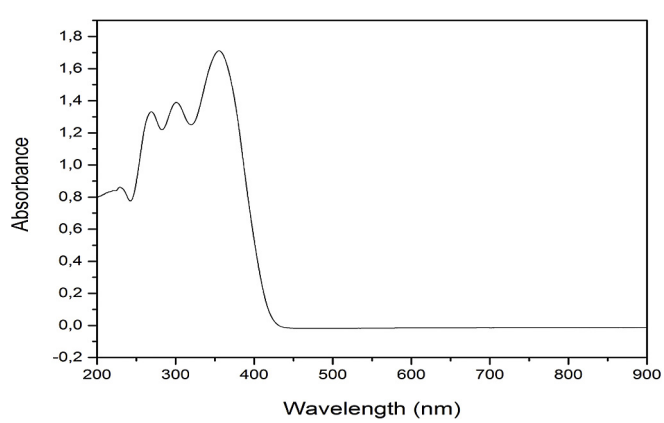

Fig. 3. UV–Vis spectrum of 4,4′- Bis (2-thiophène carboxaldehyde) diphényl diimino sulfide.

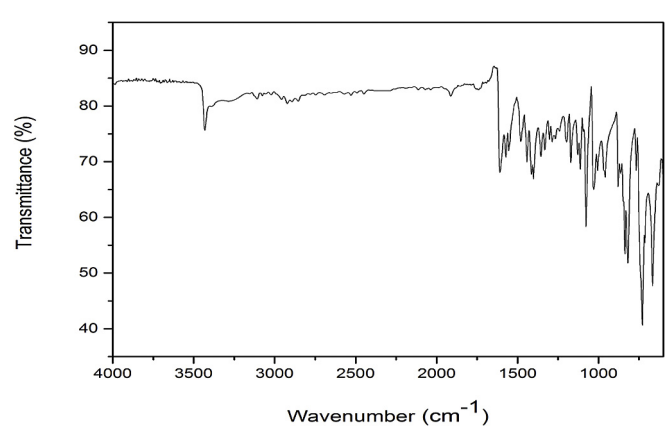

Fig. 5. FT-IR spectrum of 4,4′- Bis (2-pyrrole carboxaldehyde) diphényl diimino sulfide.

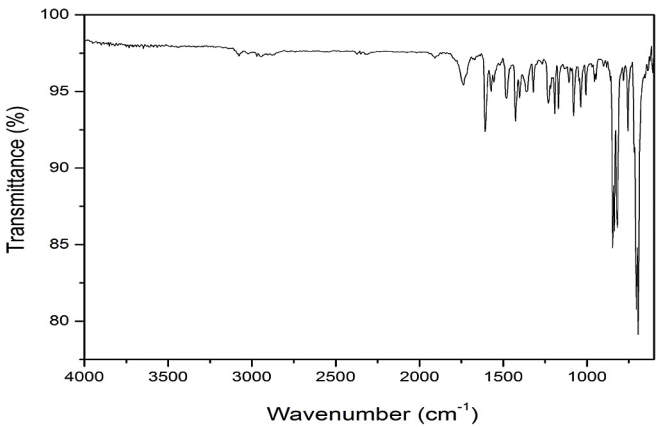

Fig. 6. FT-IR spectrum of 4,4′- Bis (2-thiophène carboxaldehyde) diphényl diimino sulfide.

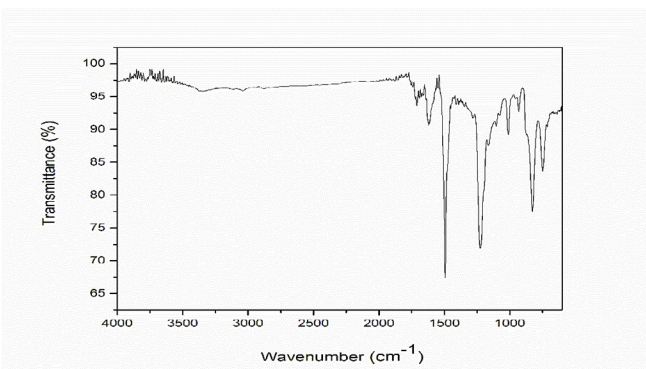

Fig. 7. FT-IR spectrum of 4,4′- Bis (2-furane carboxaldehyde) diphényl diimino sulfide.

compounds, blank sterile disks (6 mm in diameter) were saturated with the test compounds and then the constructed disks with 25 mg of active compound per disk were situated on distinctive locations of Petri plates containing Sabouraud dextrose agar (SDA) medium impregnated with 100 μL of fungal spore suspensions adjusted to a turbidity equivalent to a 0.5 × 10^6 CFU mL^{-1}for *C. albicans* and 10^5 CFU mL^{-1} for *M. cannis*. The prepared plates were incubated at 27 °C for 7 days for *M. canis*, and at 37 °C for 48 h for *C. albicans* [44]. DMSO as a solvent was used as a negative control. Mention again that all sample tests were reproduced in three replicates to obtain the mean ± standard deviation. (S.D.) values.

3. Results and discussion

The synthesized Schiff bases (**I-III**) are colored solids, non-hygroscopic, insoluble in water, partially soluble in ethanol but soluble in DMF, DMSO and $CHCl_3$. The compounds are stable and have sharp melting point that indicate the purity of these latter.

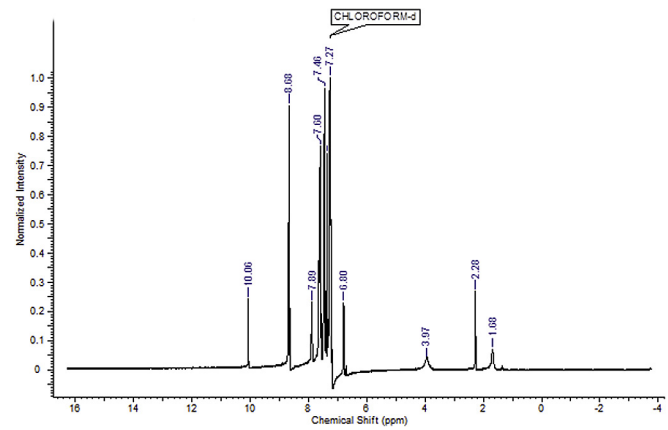

Fig. 8. ^{1}H NMR spectrum of 4,4′- Bis (2-pyrrole carboxaldehyde) diphényl diimino sulfide.

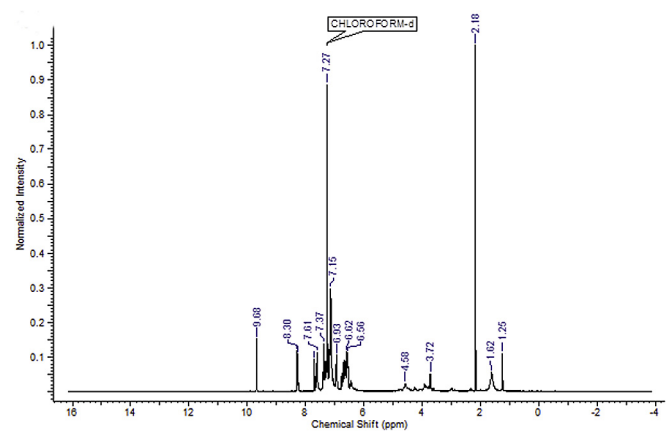

Fig. 9. ^{1}H NMR spectrum of 4,4′- Bis (2-thiophène carboxaldehyde) diphényl diimino sulfide.

Their structures were established through elemental analyses and spectroscopic data (UV–Vis, IR and ^{1}H NMR). Physical measurements and analytical data of these Schiff bases (**I-III**) are given in Table 2, analytical data agree well with the formula of the products obtained and they are confirmed by UV–Vis, IR and ^{1}H NMR spectra.

3.1. Elemental analyses

The formulation of the Schiff bases (**I-III**) synthesized were confirmed by their elemental analysis. Which have been arrived at by estimating the carbon, hydrogen, nitrogen, oxygen and sulfur contents of their structures. The results of C, H, N, O and S percentage are in agreement with the composition suggested for the compounds synthesized.

Table 3
Spectroscopic data (IR) (cm^{-1}) of the Schiff bases synthesized (**I-III**).

Compounds	ν(N–H)	$\nu(CH)_{Ar}$	$\nu(C–H)_{as,s}$	ν(–CH=N–)	δ(N–H)	ν(C=C)	ν(C–N–C)	ν(C–S–C)	ν(C–O–C)	ν(S–C)
I	3429	3114	2960–2840	1612	1565	1551	1079	–	–	730
II	–	3074	2940–2886	1615	–	1571	–	847	–	699
III	–	3047	2920–2813	1619	–	1504	–	–	1222	747

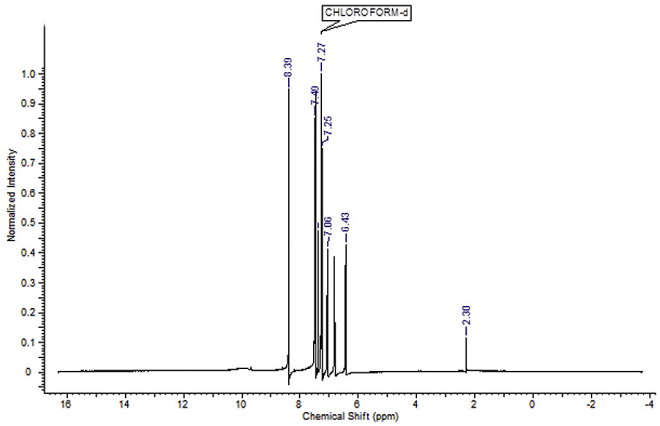

Fig. 10. ^{1}H NMR spectrum of 4,4′- Bis (2-furane carboxaldehyde) diphényl diimino sulfide.

3.2. Spectroscopic studies

3.2.1. UV–vis analysis

The UV–Vis spectra of Schiff bases (**I-III**) synthesized are presented in Figs. 2–4 respectively. The electronic absorption spectra of compound synthesized **I** showed two bands in the UV region. The former band at 229 nm is assigned to transitions $\pi \rightarrow \pi^*$ of the aromatic rings and latter at 349 nm corresponding to $n \rightarrow \pi^*$ transition within the azomethine group [26,46,47]. Similarly, bands observed at 229 nm, 356 nm in **II** and at 228 nm, 347 nm in **III.** The absorption two bands at 268 and 300 nm are observed in the spectra of the Schiff base **II**, are which are assigned to $\pi \rightarrow \pi^*$ and $n \rightarrow \pi^*$, transition respectively. While the compound **III** exhibit band at 275 nm, which may be attributable to the $\pi \rightarrow \pi^*$ transition. It is seen also from the absorption spectra that the compounds (**I-III)** absorb weakly in the visible region at low concentrations.

3.2.2. FT-IR analysis

The IR spectra of Schiff bases (**I-III**) synthesized are presented in Figs. 5–7 respectively, the significant infrared bands of the compounds synthesized are given in Table 3. The IR spectrum of **I** shows a new strong band assigned to azomethine (HC=N) stretching vibrations appeared at 1612 cm^{-1} confirming the formation of Schiff base. Similarly, the bands at 1615 cm^{-1} and 1619 cm^{-1} in **II** and **III** correspond to (HC=N) linkage respectively [48–52]. A weak absorption bands in the region 3120-3040 cm^{-1} assigned to the CH aromatic stretching vibrations, in addition the symmetric stretching vibrations of (C–H) all bands occurred in the regions 2960-2810 cm^{-1} in all compounds respectively. The band at 3429 cm^{-1} in **I** is assigned to (–NH) stretching vibrations of the pyrrole rings and at 1079 cm^{-1} is due to (C–N–C) [52]. The IR spectra of **II** exhibits band at 847 cm^{-1} which ascribed to (C–S–C) stretching vibrations of the thiophane rings [30,54], while the band at 1022 cm^{-1} in compound **III** correspond to (C–O–C) stretching vibrations of the furan rings [55]. The various absorption bands in the range

Table 4
Antibacterial activity of Schiff bases synthesized (**I-III**), against Gram-positive and Gram-negative bacteria [zone of inhibition (mm)].

compounds	*E. coli*	*P. aeroginosa*	*S. aureus*	*k. pneumoniae*	*P. mirabilis*	*S. marcescens*
I	10.00 ± 0.00	0.00	8.00 ± 0.50	7.00 ± 0.00	7.00 ± 0.50	7.00 ± 0.00
II	13.00 ± 0.50	0.00	8.00 ± 1.00	8 00 ± 0.50	7.00 ± 1.00	7 0.00 ± 0.50
III	13.00 ± 0.50	0.00	8.00 ± 0.00	7.00 ± 0.50	7 0.00 ± 0.50	7.00 ± 0.00
DMSO	0.00	0.00	0.00	0.00	0.00	0.00

All of the data are expressed as the means ± standard deviation (SD) of triplicate measurements.

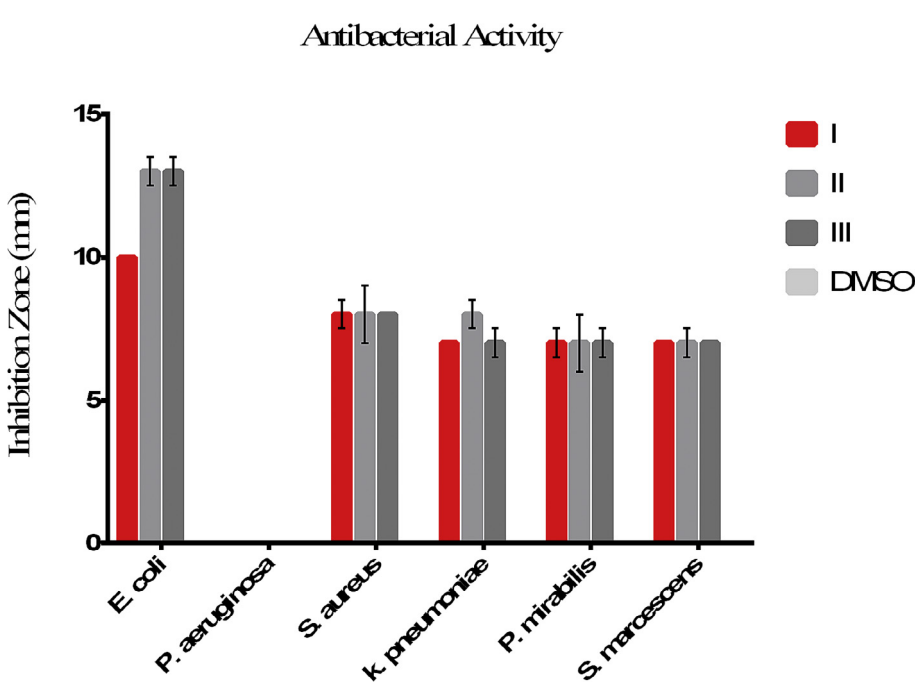

Fig. 11. Antibacterial activity of Schiff bases compounds (**I-III**) against Gram-positive and Gram-negative bacteria.

Table 5
MIC and MBC (mg/mL) inhibitory results of various Schiff bases synthesized (**I-III**).

Compounds	*E. coli*		*P. aeruginosa*		*S. aureus*		*K. pneumoniae*		*P. mirabilis*		*S. marcescens*	
	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC	MIC	MBC
I	N.D.	< 0.195	N.D.	N.A.	N.D.	No MBC	N.D.	N.A.	N.D.	N.A.	N.D.	N.A.
II	N.D.	< 0.195	N.D.	N.A.	N.D.	N.A.	N.D.	No MBC	N.D.	No MBC	N.D.	No MBC
III	N.D.	< 0.195	N.D.	N.A.	N.D.	N.A.	N.D.	No MBC	N.D.	No MBC	N.D.	No MBC

N.A.: no activity; N.D.: not possible to detect.

Table 6
Antifungal activity of Schiff bases synthesized (**I-III**) [zone of inhibition (mm)].

Compounds	*C. albicans*	*M. canis*
I	14.50 ± 0.86	15.33 ± 0.57
II	13.50 ± 0.50	11.00 ± 1.00
III	14.50 ± 0.86	7.00 ± 0.00
DMSO	0.00	0.00

All of the data are expressed as the means ± standard deviation (SD) of triplicate measurements.

1500–1580 cm^{-1} assigned to C=C stretching vibrations of the aromatic rings, moreover (C–S) stretching vibrations observed at 740-690 cm^{-1} in all three Schiff bases (**I-III**).

3.2.3. RMN ^1H analysis

The NMR ^1H spectra confirm the identity of the newly synthesized Schiff bases, in order to identify their structures. The ^1H NMR spectra of compounds **I-III** synthesized (Figs. 8–10) displayed the azomethine protons (–HC=N) at 8.68 ppm, 9.68 ppm, and 8.39 ppm respectively as singlets [30,56] and aromatic protons at 6.42–7.89 ppm range as multiplets [57]. Furthermore, pyrrole –NH proton appear as a singlet at 10.06 ppm for the compound **I** [48]. The appeared signals of all the protons of the Schiff bases **I-III** were found as to be in their expected region.

3.3. Biological activity

3.3.1. Antibacterial activity (in vitro)

The antibacterial properties of news Schiff base compounds against five bacteria strains such as *E. coli*, *P. aeruginosa*, *S. aureus*, *K. pneumoniae*, *P. mirabilis* and *S.* marcescens, were evaluated by disc diffusion method. Muller Hinton agar was used to culture the bacteria.

The experimental details and zone of inhibition in respect antibacterial activity of three synthesized (**I-III**) Schiff bases against the pathogenic bacterial strains which are given in Table 4 and their graphical representations are shown in Fig. 11. These experimental observations indicated that the new compound **I** have been shown moderate inhibition zone in *E. coli*, lower activity in *S. aureus*, *K. pneumonia*, P. *mirabilis* and *S. marcescens*, and whereas they showed no activity in *P. aerugenosa*. While the Schiff base compounds **II** and **III** have a good activity against *E. coli*, lower activity against *S. aureus*, *K. pneumonie*, *P. mabilis* and *S. marcescens*. While it, did not show any activity on *P. aeruginosa*. The MBC values revealed that, the all synthesized compounds (**I-III**) have nearly the same effect bactericidal (≤0.195 mg ml^{-1}) in the case of *E. coli* bacterium, and hadn't bactericidal effect on bacteria that had a lower sensitivity by the disc diffusion method (Table 5).

3.3.2. Antifungal activity (in vitro)

The antifungal activity of the compounds was tested against *C. albicans*, and *M. cannis*, and the diameters of the zone of

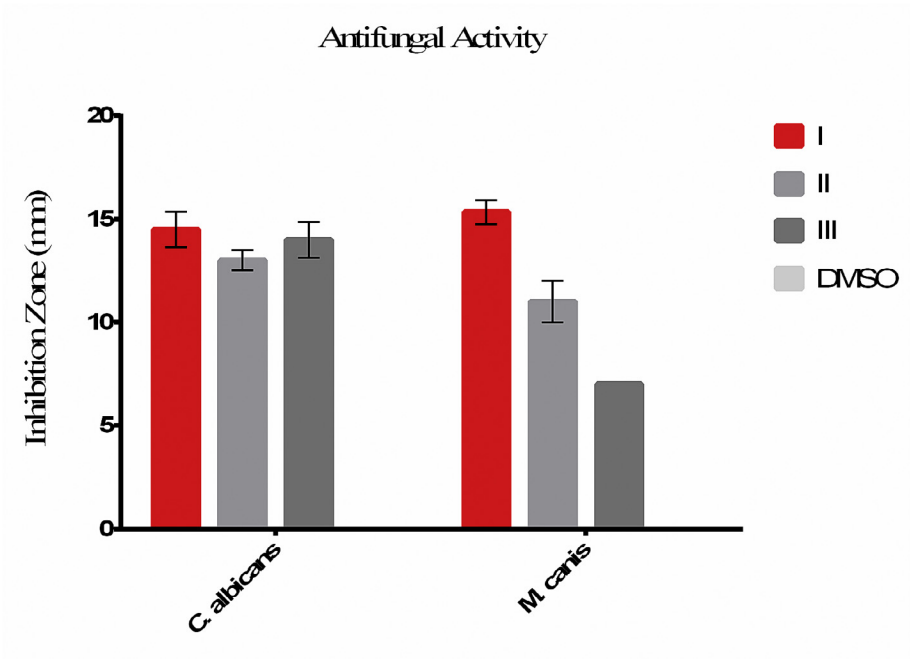

Fig. 12. Antifungal activity of Schiff bases compounds.

inhibition (in mm) of the compounds are listed in Table 6, and their graphical representations are shown in Fig. 12. The compound **I** significantly prevented the growth of *M. cannis* (15.33 mm in diameter), the same activity was shown against *C. albicans* but was lower for *M. cannis*. The compounds **II** and **III** showed the good effect on *C. albicans*. Against *M. cannis* the compound **II** exhibited a medium effect but **III** a low effect.

4. Conclusion

Three new Schiff bases: 4,4′-Bis (2-pyrrole carboxaldehyde) diphényl diimino sulfide (**I**), 4,4′-Bis (2-thiophène carboxaldehyde) diphényl diimino sulfide (**II**) and 4,4′- Bis (2-furane carboxaldehyde) diphényl diimino sulfide (**III**) were synthesized. Their structures were established through UV–Vis, FT-IR and ^{1}H NMR spectral data and elemental analyses. The FT-IR spectra clearly indicated the presence of functional groups in the compounds **I-III** and the IR of each compound synthesized confirms the formation of imines bond (-C=N-). FT-NMR spectra analysis confirmed the molecular structure of these compounds. The elemental analyses of the Schiff bases **I-III** synthesized reveal good agreement with the proposed structures. Furthermore, the new synthesized compounds were tested for their antimicrobial activities against some pathogenic strains. All the compounds exhibited an antibacterial activity against *E. coli*, the strain *Pseudomonas aerugenosa* was not sensitive to any of the compounds. The compound **I** was more active especially on *M. cannis* and **III** show best antifungal activity against the *M. cannis*. The results also indicate that the difference in the chemical structure of the derivative of 2- carboxaldehyde affects the biologic activity of the news compounds. Of this study can be useful to researchers attempting for future work to study the biological activities of the Schiff base complexes.

References

[1] H. Puchtler, S. Meloan, On Schiff's bases and aldehyde-Fuchsin: a review from H. Schiff to RD Lillie, Histochem. Cell Biol. 72 (3) (1981) 321–332.
[2] M. Petrus, R. Bouwer, U. Lafont, S. Athanasopoulos, N. Greenham, T. Dingemans, Small-molecule azomethines: organic photovoltaics via Schiff base condensation chemistry, J. Mater. Chem. A 2 (25) (2014) 9474–9477.
[3] T.P. Yoon, E.N. Jacobsen, Privileged chiral catalysts, Science 299 (5613) (2003) 1691–1693.
[4] R. Nair, A. Shah, S. Baluja, S. Chanda, Synthesis and antibacterial activity of some Schiff base complexes, J. Serb. Chem. Soc. 71 (7) (2006) 733–744.
[5] W.G. Hanna, M.M. Moawad, Synthesis, characterization and antimicrobial activity of cobalt (II), nickel (II) and copper (II) complexes with new asymmetrical Schiff base ligands derived from 7-formyanil-substituted diamine-sulphoxine and acetylacetone, Transit. Metal. Chem. 26 (6) (2001) 644–651.
[6] P.A. Vigato, S. Tamburini, The challenge of cyclic and acyclic Schiff bases and related derivatives, Coord. Chem. Rev. 248 (17) (2004) 1717–2128.
[7] S. Ilhan, H. Baykara, M. Seyitoglu, A. Levent, S. Özdemir, A. Dündar, A. Öztomsuk, M. Cornejo, Preparation, spectral studies, theoretical, electrochemical and antibacterial investigation of a new Schiff base and its some metal complexes, J. Mol. Struct. 1075 (2014) 32–42.
[8] M. Gaber, N.A. El-Wakiel, H. El-Ghamry, S.K. Fathalla, Synthesis, spectroscopic characterization, DNA interaction and biological activities of Mn (II), Co (II), Ni (II) and Cu (II) complexes with [(1H-1, 2, 4-triazole-3-ylimino) methyl] naphthalene-2-ol, J. Mol. Struct. 1076 (2014) 251–261.
[9] G. Grivani, G. Bruno, H.A. Rudbari, A.D. Khalaji, P. Pourteimouri, Synthesis, characterization and crystal structure determination of a new oxovanadium (IV) Schiff base complex: the catalytic activity in the epoxidation of cyclooctene, Inorg. Chem. Commun. 18 (2012) 15–20.
[10] K. Gupta, A.K. Sutar, Catalytic activities of Schiff base transition metal complexes, Coord. Chem. Rev. 252 (12) (2008) 1420–1450.
[11] S. Banerjee, C. Adhikary, C. Rizzoli, R. Pal, Single end to end azido bridged adduct of a tridentate schiff base copper (II) complex: synthesis, structure, magnetism and catalytic studies, Inorganica Chim. Acta 409 (2014) 202–207.
[12] X. Yun, X. Hu, Z. Jin, J. Hu, C. Yan, J. Yao, H. Li, Copper-salen catalysts modified by ionic compounds for the oxidation of cyclohexene by oxygen, J. Mol. Catal. A Chem. 327 (1) (2010) 25–31.
[13] G. Grivani, A. Ghavami, M. Kučeráková, M. Dušek, A.D. Khalaji, Synthesis, characterization, crystal structure determination, thermal study and catalytic activity of a new oxidovanadium Schiff base complex, J. Mol. Struct. 1076 (2014) 326–332.
[14] F.A. Carey, R.C. Atkins, Organic Chemistry, fifth ed., McGraw-Hill, New York, 2003.
[15] S.M. Abdallah, G.G. Mohamed, M. Zayed, M.S.A. El-Ela, Spectroscopic study of molecular structures of novel Schiff base derived from o-phthaldehyde and 2-aminophenol and its coordination compounds together with their biological activity, Spectrochim Acta Part A Mol. Biomol. Spectrosc. 73 (5) (2009) 833–840.
[16] H.C. Kim, H.-K. Lee, A. Choi, S.-W. Jeon, Polymeric lead (II)-selective electrode based on N, N'-bis-thiophen-2-ylmethylene-pyridine-2, 6-diamine as an ion carrier, Bull. Korean Chem. Soc. 28 (4) (2007) 538–542.
[17] M.H. Habibi, M. Montazerozohori, A. Lalegani, R.W. Harrington, W. Clegg, Synthesis, structural and spectroscopic properties of a new Schiff base ligand N, N′-bis (trifluoromethylbenzylidene) ethylenediamine, J. Fluor. Chem. 127 (6) (2006) 769–773.
[18] S.A. Abbas, M. Munir, A. Fatima, S. Naheed, Z. Llyas, Synthesis and analytical studies of sulphadimidine-amine Schiff's base complexes Ni (II) and Cu (II), E J. Life Sci. 1 (2) (2010) 37–40.
[19] E. Keskioğlu, A.B. Gündüzalp, S. Cete, F. Hamurcu, B. Erk, Cr (III), Fe (III) and Co (III) complexes of tetradentate (ONNO) Schiff base ligands: synthesis, characterization, properties and biological activity, Spectrochim Acta Part A Mol. Biomol. Spectrosc. 70 (3) (2008) 634–640.
[20] H. Sharghi, M.A. Nasseri, Schiff-base metal (II) complexes as new catalysts in the efficient, mild and regioselective conversion of 1, 2-epoxyethanes to 2-hydroxyethyl thiocyanates with ammonium thiocyanate, Bull. Chem. Soc. Jpn. 76 (1) (2003) 137–142.
[21] W.T. Gao, Z. Zheng, Synthetic studies on optically active Schiff-base ligands derived from condensation of 2-hydroxyacetophenone and chiral diamines, Molecules 7 (7) (2002) 511–516.
[22] M. Shakir, M. Azam, Y. Azim, S. Parveen, A.U. Khan, Synthesis and physicochemical studies on complexes of 1, 2-diaminophenyl-N, N′-bis-(2-pyridinecarboxaldimine),(L): a spectroscopic approach on binding studies of DNA with the copper complex, Polyhedron 26 (18) (2007) 5513–5518.
[23] F. Aydogan, N. Öcal, Z. Turgut, C. Yolacan, Transformations of aldimines derived from pyrrole-2-carboxaldehyde. Synthesis of thiazolidino-fused compounds, Bull. Korean Chem. Soc. 22 (5) (2001) 476–480.
[24] F. Azam, S. Singh, S.L. Khokhra, O. Prakash, Synthesis of Schiff bases of naphtha [1, 2-d] thiazol-2-amine and metal complexes of 2-(2′-hydroxy) benzylideneaminonaphthothiazole as potential antimicrobial agents, J. Zhejiang Univ. Sci. B 8 (6) (2007) 446–452.
[25] V. Reddy, N. Patil, T. Reddy, S. Angadi, Synthesis, characterization and biological activities of Cu (II), Co (II), Ni (II), Mn (II) and Fe (III) complexes with Schiff base derived from 3-(4-chlorophenoxymethyl)-4-amino-5-mercapto-1, 2, 4-triazole, J. Chem. 5 (3) (2008) 529–538.
[26] A.B. Gündüzalp, İ. Özsen, H. Alyar, S. Alyar, N. Özbek, Biologically active Schiff bases containing thiophene/furan ring and their copper (II) complexes: synthesis, spectral, nonlinear optical and density functional studies, J. Mol. Struct. 1120 (2016) 259–266.
[27] D.W. Young, Heterocyclic Chemistry, first ed., Longman group Ltd., London, 1975.
[28] K.S. Kumar, S. Ganguly, R. Veerasamy, E. De Clercq, Synthesis, antiviral activity and cytotoxicity evaluation of Schiff bases of some 2-phenyl quinazoline-4 (3) H-ones, Eur. J. Med. Chem. 45 (11) (2010) 5474–5479.
[29] Ö. Güngör, P. Gürkan, Synthesis and characterization of higher amino acid Schiff bases, as monosodium salts and neutral forms. Investigation of the intramolecular hydrogen bonding in all Schiff bases, antibacterial and antifungal activities of neutral forms, J. Mol. Struct. 1074 (2014) 62–70.
[30] A.A. Shanty, J.E. Philip, E.J. Sneha, M.R.P. Kurup, S. Balachandran, P.V. Mohanan, Synthesis, characterization and biological studies of Schiff bases derived from heterocyclic moiety, Bioorg. Chem. 70 (2017) 67–73.
[31] E. Pontiki, D. Hadjipavlou-Litina, A. Chaviara, Evaluation of anti-inflammatory and antioxidant activities of copper (II) Schiff mono-base and copper (II) Schiff base coordination compounds of dien with heterocyclic aldehydes and 2-amino-5-methyl-thiazole, J. Enzyme Inhib. Med. Chem. 23 (6) (2008) 1011–1017.
[32] S. Amer, N. El-Wakiel, H. El-Ghamry, Synthesis, spectral, antitumor and antimicrobial studies on Cu (II) complexes of purine and triazole Schiff base derivatives, J. Mol. Struct. 1049 (2013) 326–335.
[33] N. El-wakiel, M. El-keiy, M. Gaber, Synthesis, spectral, antitumor, antioxidant and antimicrobial studies on Cu (II), Ni (II) and Co (II) complexes of 4-[(1H-Benzoimidazol-2-ylimino)-methyl]-benzene-1, 3-diol, Spectrochim Acta Part A Mol. Biomol. Spectrosc. 147 (2015) 117–123.
[34] S.M. Bensaber, H. Allafe, N.B. Ermeli, S.B. Mohamed, A.A. Zetrini, S.G. Alsabri, M. Erhuma, A. Hermann, M.I. Jaeda, A.M. Gbaj, Chemical synthesis, molecular modelling, and evaluation of anticancer activity of some pyrazol-3-one Schiff base derivatives, Med. Chem. Res. 23 (12) (2014) 5120–5134.
[35] A. Sinha, K. Banerjee, A. Banerjee, S. Das, S.K. Choudhuri, Synthesis, characterization and biological evaluation of a novel vanadium complex as a possible anticancer agent, J. Organomet. Chem. 772 (2014) 34–41.
[36] H.A. Pramanik, D. Das, P.C. Paul, P. Mondal, C.R. Bhattacharjee, Newer mixed ligand Schiff base complexes from aquo-N-(2′-hydroxy acetophenone) glycinatocopper (II) as synthon: DFT, antimicrobial activity and molecular docking study, J. Mol. Struct. 1059 (2014) 309–319.
[37] C.M. da Silva, D.L. da Silva, L.V. Modolo, R.B. Alves, M.A. de Resende, C.V. Martins, Â. de Fátima, Schiff bases: a short review of their antimicrobial activities, J. Adv. Res. 2 (1) (2011) 1–8.

[38] R.P. Chinnasamy, R. Sundararajan, S. Govindaraj, Synthesis, characterization, and analgesic activity of novel schiff base of isatin derivatives, J. Adv. Pharm. Technol. Res. 1 (3) (2010) 342.
[39] S. Shahidi, M. Ghoranneviss, B. Moazzenchi, A. Rashidi, M. Mirjalili, Investigation of antibacterial activity on cotton fabrics with cold plasma in the presence of a magnetic field, Plasma Process. Polym. 4 (S1) (2007) S1098–S1103.
[40] M. Hasanzadeh, M. Salehi, M. Kubicki, S.M. Shahcheragh, G. Dutkiewicz, M. Pyziak, A. Khaleghian, Synthesis, crystal structures, spectroscopic studies and antibacterial properties of a series of mononuclear cobalt (III) Schiff base complexes, Transit. Metal. Chem. 39 (6) (2014) 623–632.
[41] R. Cruickshank, J. Duguid, B. Marmion, R. Swain, Textbook of Medical Microbiology, Chirchill, living stone, Edinburgh and NewYork, 1975.
[42] A.H. Collins, Microbiological Methods, second ed., Butterworth, London, 1976.
[43] C. Perez, M. Pauli, P. Bazerque, An antibiotic assay by the agar well diffusion method, Acta Biol. Med. Exp. 15 (1) (1990) 113–115.
[44] M.J. Hearn, M.H. Cynamon, Design and synthesis of antituberculars: preparation and evaluation against Mycobacterium tuberculosis of an isoniazid Schiff base, J. Antimicrob. Chemother. 53 (2) (2004) 185–191.
[45] Z.H. Chohan, S.H. Sumrra, M.H. Youssoufi, T.B. Hadda, Metal based biologically active compounds: design, synthesis, and antibacterial/antifungal/cytotoxic properties of triazole-derived Schiff bases and their oxovanadium (IV) complexes, Eur. J. Med. Chem. 45 (7) (2010) 2739–2747.
[46] S. Sedaghat, S. Ghammamy, R. Hosseinzadeh, Z. Amini, M. Mirrahimi, Synthesis, characterization and antitumor activity of new transition metal and uranyl complexes, in: Proceedings of the 4th International Conference on Energy & Development, Environment & Biomedicine, World Scientific and Engineering Academy and Society (WSEAS), 2010, pp. 83–86.
[47] M. Shakir, A. Abbasi, M. Azam, A.U. Khan, Synthesis, spectroscopic studies and crystal structure of the Schiff base ligand L derived from condensation of 2-thiophenecarboxaldehyde and 3, 3′-diaminobenzidine and its complexes with Co (II), Ni (II), Cu (II), Cd (II) and Hg (II): comparative DNA binding studies of L and its Co (II), Ni (II) and Cu (II) complexes, Spectrochim Acta Part A Mol. Biomol. Spectrosc. 79 (5) (2011) 1866–1875.
[48] R.M. Silverstein, F.X. Webster, D.J. Kiemle, D.L. Bryce, Spectrometric Identification of Organic Compounds, John wiley & sons, 2014.
[49] E. Pretsch, T. Clerc, J. Seibl, W. Simon, Tables of Spectral Data for Structure Determination of Organic Compounds, Springer Science & Business Media, 2013.
[50] A. Vogt, S. Wołowiec, R.L. Prasad, A. Gupta, J. Skarlewski, Synthesis and characterization of nickel (II), copper (II), manganese (III) and iron (III) complexes with new chiral salen-type ligand| N, N′-bis (3, 5-di-tert-butylsalicylidene)-(1R, 3S)-1, 3-diamine-1, 2, 2-trimethylcyclopentane, Polyhedron 17 (8) (1998) 1231–1240.
[51] R. Ramesh, S. Maheswaran, Synthesis, spectra, dioxygen affinity and antifungal activity of Ru (III) Schiff base complexes, J. Inorg. Biochem. 96 (4) (2003) 457–462.
[52] J.R. Zamian, E.R. Dockal, Tetradentate Schiff base oxovanadium (IV) complexes, Transit. Metal. Chem. 21 (4) (1996) 370–376.
[54] Y. Harinath, D.H.K. Reddy, B.N. Kumar, C. Apparao, K. Seshaiah, Synthesis, spectral characterization and antioxidant activity studies of a bidentate Schiff base, 5-methyl thiophene-2-carboxaldehyde-carbohydrazone and its Cd (II), Cu (II), Ni (II) and Zn (II) complexes, Spectrochim Acta Part A Mol. Biomol. Spectrosc. 101 (2013) 264–272.
[55] S. Issaadi, T. Douadi, S. Chafaa, Adsorption and inhibitive properties of a new heterocyclic furan Schiff base on corrosion of copper in HCl 1M: experimental and theoretical investigation, Appl. Surf. Sci. 316 (2014) 582–589.
[56] E. Akila, M. Usharani, R. Rajavel, Metal (II) complexes of bioinorganic and medicinal relevance: antibacterial, antioxidant and dna cleavage studies of tetradentate complexes involving o, n-donor environment of 3, 3′-dihydroxybenzidine-based schiff bases, Int. J. Pharm. Pharm. Sci. 5 (2) (2013) 573–581.
[57] Ü. Ceylan, M.E. Hacıyusufoğlu, Ş.P. Yalçınc, M. Sönmez, M. Aygün, Synthesis, molecular structure and spectroscopic characterization of (E)-1-((2-hydroxynaphthalen-1-yl) methyleneamino)-5-(4-methoxybenzoyl)-4-(4-methoxyphenyl) pyrimidine-2 (1H)-one with experimental techniques and theoretical calculations, J. Mol. Struct. 1109 (2016) 209–219.