Journal of the Iranian Chemical Society
https://doi.org/10.1007/s13738-023-02746-5

ORIGINAL PAPER

Synthesis, spectroscopy and biological studies of triphenyltin(IV) derivatives with carboxylated Schiff bases

Shabbir Hussain[1] · Rabia Kiran[2] · Muhammad Ahmad[3] · Muhammad Saqib[1] · Khurram Shahzad Munawar[4,5] · Muhammad Shahid[6] · Muhammad Waqas[2] · Shazma Massey[7] · Rifat Jawaria[1] · Rabia Baby[8]

Received: 24 August 2022 / Accepted: 6 January 2023

Abstract

Schiff bases (**S1**–**S8**) were prepared by the reaction of 4-aminophenylacetic acid/5-aminoisophthalic acid with benzaldehyde/acetophenone/benzophenone/anthraquinone in ethanol. The sodium salts (**NaS1**–**NaS8**) of the Schiff bases were reacted further with triphenyltin(IV) chloride in methanol for 4 h to produce the organotin derivatives (**C1**–**C8**). The structures of the synthesized products (**S1**–**S8** and **C1**–**C8**) were verified by elemental analysis, FT-IR analysis, ^{1}H NMR spectroscopy, and thermogravimetry. Elemental analysis (CHN) data agreed well with the chemical composition of compounds. FT-IR spectroscopy demonstrated the isobidentate coordination mode of the carboxylate moiety and a trigonal bipyramidal geometry of Sn(IV) in the solid state of complexes. Proton NMR spectra displayed the signals of the Schiff base skeleton as well as the triphenyltin(IV) moieties in the complexes **C1**–**C8** in their anticipated regions. The thermogravimetric analysis has shown a good agreement between the observed percentages of the evolved contents and residues and the theoretically calculated values. The Schiff bases have shown higher thermal stabilities as compared to their organotin(IV) derivatives, owing to stronger hydrogen bonding in the former case. The complexes exhibited higher antibacterial potential as compared to their free ligand precursors against the tested bacteria (*Bacillus subtilis* and *Escherichia coli*). The biological activities were dependent upon the structures of investigated products, nature of incorporated ligand and type (gram-positive or gram-negative) of the bacterial strains. The compounds were also tested for their in vitro hemolytic effects on human red blood cells while using PBS as a negative control (0% lysis) and triton X-100 as a positive control (100% lysis). Cytotoxicity values lie in the range of 1.5–7.9%, which is an acceptable range and renders the safe medicinal uses of all the synthesized products.

Keywords Schiff bases · Triphenyltin(IV) · Spectroscopy · Thermogravimetry · Antibacterial · Hemolytic

Introduction

Schiff bases are compounds that contain a –C=N (azomethine) linkage [1]. When an aromatic/aliphatic aldehyde or ketone undergoes the condensation reaction with an aromatic/aliphatic amine, Schiff bases are formed with the removal of water molecules [2]. Aliphatic Schiff bases are readily polymerized and less stable while aromatic Schiff bases show good stability due to their impressive conjugation system [3]. Schiff bases can be synthesized under different reaction conditions of reflux (e.g., the reaction of 2-hydroxybenzaldehyde with *m*-phenylenediamine)

✉ Shabbir Hussain
shabchem786@gmail.com; shabbir.hussain@kfueit.edu.pk

[1] Institute of Chemistry, Khwaja Fareed University of Engineering and Information Technology, Rahim Yar Khan 64200, Pakistan

[2] Department of Chemistry, Lahore Garrison University, Lahore, Pakistan

[3] Department of Chemistry, Division of Science and Technology, University of Education, Lahore 54770, Pakistan

[4] Department of Chemistry, University of Mianwali, Mianwali 42200, Pakistan

[5] Institute of Chemistry, University of Sargodha, Sargodha 40100, Pakistan

[6] Department of Chemistry and Biochemistry, University of Agriculture, Faisalabad, Pakistan

[7] Department of Chemistry, Forman Christian College (A Chartered University), Lahore 54600, Pakistan

[8] Department of Education, Sukkur IBA University, Sukkur 65200, Pakistan

Published online: 13 January 2023

[4], ultra-sonication (e.g., the reaction of 2-aminopyridine derivatives with 3-ethoxysalicylaldehyde) and microwave irradiation (e.g., the reaction of *p*-toluidine with 3,4,5-trimethoxybenzaldehyde) [5]. Their formation at room temperature has also been reported through mixing the precursors as an aqueous slurry or simple grinding of the reactants together [6].

Schiff bases can form metal complexes with numerous metals [7–9] including tin [10]. Schiff bases and their metal complexes are widely used in photodynamic treatment, immunoassay, DNA hybridization, the medical field, and clinical analysis [11]. Manganese(III) Schiff base complexes act as catalysts in the oxidation of sulfides to sulfoxides and sulfones with sodium periodate [12]. Schiff base ligands of 2-hydroxy-5-bromobenzaldehyde with 3-amino-4-methylbenzoic acid, 3-aminobenzoic acid and 4-aminobenzoic acid have shown interaction with salmon sperm DNA depending upon the extent of the electron-donating nature of their substituents and hydrogen bonding [13]. Schiff bases of 3,5-dihalosalicylaldehyde (halo = I, Br, and Cl) with polymethylenediamines have been found effective against gram-negative (*Pseudomonas aeruginosa* and *Escherichia coli*) and gram-positive (*Bacillus cereus* and *Staphylococcus aureus*) bacterial strains [14]. The zinc(II), copper(II), and nickel(II) complexes of some Schiff bases have also been found effective against the same bacteria [7]. Schiff bases play a great part in polymer chemistry and coordination chemistry [15]. Schiff bases may be monodentate, bidentate, tridentate, polydentate and some of them can stabilize the central metal in various oxidation states through their coordination [16].

Organotin compounds have at least one organic substituent linked directly to the tin atom via the carbon atom of the organic substituent [17]. They have a wide range of structural diversities [18, 19] and find a lot of non-biological [20, 21], as well as biological applications [22–24] in industry and agriculture [25]. Organotins exist in two oxidation states, Sn(II) and Sn(IV); however, organotin(II) compounds are unstable, polymerize quickly [26], and are easily oxidized to organotin(IV) products, which are more stable [27]. Mostly, organotin complexes are obtained by the condensation reaction of a ligand and a tin salt at a suitable temperature in the presence of a volatile solvent, i.e., ethanol, methanol, chloroform, acetone, etc. Different tin salts like trimethyltin(IV) chloride, tributyltin(IV) chloride, and triphenyltin(IV) chloride, etc., may be used to produce organotin(IV) products [28].

Organtoin(IV) derivatives of Schiff bases are commonly investigated due to their biological/non-biological potential [29–31]. Keeping in view their broad range of applications [32, 33], we have synthesized the Schiff bases (**S1**–**S8**) and their triphenyltin(IV) complexes (**C1**–**C8**). The synthesized products were analyzed by elemental analysis, FT-IR spectroscopy, H^1 NMR analysis, and thermogravimetry. They were also screened for their antimicrobial potential and toxic hemolytic effects.

Experimental

Materials and methods

4-Aminophenyl acetic acid, benzaldehyde, benzophenone, acetophenone, anthraquinone, methanol, and ethanol were purchased from Sigma Aldrich. 5-aminoisophthalic acid from Merck, Germany, was used. Melting points were determined by placing a sample in a small capillary tube and recording the reading in a digital Gallenkamp melting point apparatus. Elemental analysis (CHN) was carried out using the EuroEA Elemental Analyzer. Fourier transform infrared (FT-IR) spectra were recorded by PerkinElmer FT-IR Spectrum B and Thermo FT-IR Nicolet IS 10. Nuclear magnetic resonance (NMR) spectra were recorded by the FT-NMR spectrometer Bruker ARC 300 MHz using deuterated DMSO/H_2O. Thermogravimetric analysis was done by a TGA-7 instrument from PerkinElmer, USA, under the nitrogen atmosphere.

The Schiff bases and their organotin products were tested for their antimicrobial potential by the disk diffusion method [34, 35]. They were also evaluated for their toxic hemolytic effects by a reported procedure [36, 37].

Synthesis of Schiff base ligands (S1–S8)

The Schiff bases **(S1–S8)** were prepared by the condensation reaction of equimolar quantities of 4-aminophenyl acetic acid (0.01 mol, 0.151 g) or 5-aminoisophthalic acid (0.01 mol, 0.181 g) with benzaldehyde (0.01 mol, 0.106 g, 0.101 mL)/benzophenone (0.01 mol, 0.82 g)/anthraquinone (0.01 mol, 0.208 g)/acetophenone (0.01 mol, 0.120 g) after the addition of a few drops of sulfuric acid in 60 mL of ethanol for 2 h under reflux conditions [38]. The reaction mixture was left overnight and then evaporated by a rotary evaporator to leave behind the solid residue of Schiff base ligands **(S1–S8)** (Scheme 1).

Synthesis of sodium salts of Schiff bases (S1Na–S8Na)

Equimolar quantities of sodium bicarbonate and Schiff base ligands **(S1–S8)** were stirred together in 20 mL of ethanol for 1 h [39]. The resulting solution was left overnight and then rotary evaporated to leave behind the solid residue of sodium salt **(S1Na–S8Na)** of Schiff bases (Scheme 2).

Synthesis of organotin complexes (C1–C8)

Organotin complexes **(C1–C8)** were prepared by the reaction of triphenyltin(IV) chloride (0.01 mol, 0.386 g) with equimolar quantities of the sodium salt of a Schiff base **(S1Na–S8Na)**. The reaction mixture was refluxed for 4 h in 100 mL of methanol [40]. It was left overnight and then filtered off to remove the insoluble NaCl. The filtrate was then evaporated by a rotary evaporator to leave behind the solid residue of organotin complexes **(C1–C8)** (Scheme 3).

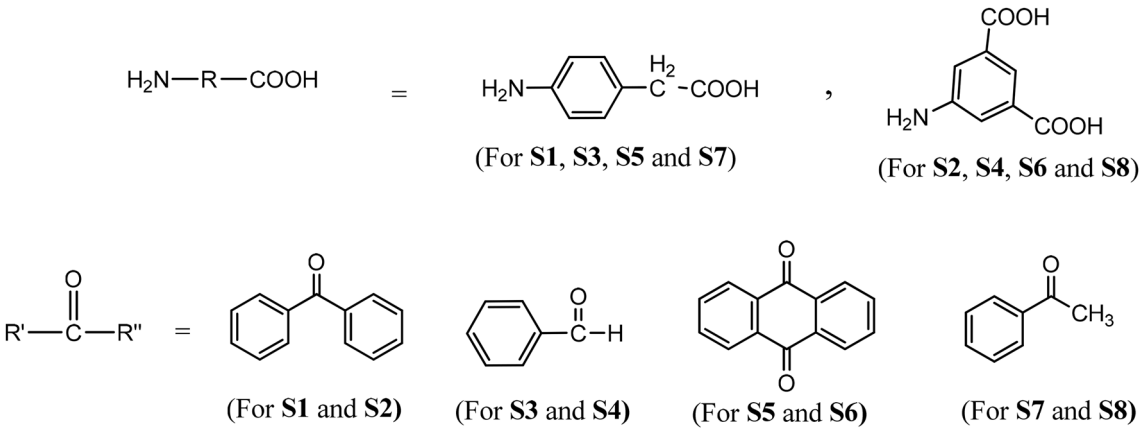
Results and discussion

Schiff bases (**S1–S8)** were prepared by the condensation reaction between 4-aminophenyl acetic acid/5-aminoisophthalic acid and benzaldehyde/acetophenone/benzophenone/anthraquinone. These Schiff bases were further treated with sodium bicarbonate to prepare sodium salts (**S1Na–S8Na**) of Schiff bases, which were finally reacted with triphenyltin(IV) chloride to give organotin complexes (**C1–C8**).

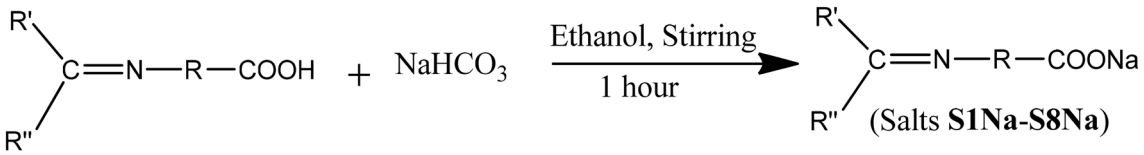
All the Schiff bases (**S1–S8)** and coordinated products (**C1–C8**) have shown sharp melting points and are stable in the air. They are white crystalline solids that are soluble in common organic solvents. Elemental analysis (CHN) data agrees well with the molecular composition of the products. The physical data of the Schiff bases (**S1–S8)**, their salts (**S1Na–S8Na)**, and their complexes (**C1–C8**) are summarized in Tables 1, 2, and 3, respectively. The IUPAC names of **S1–S8** and **C1–C8** are displayed in Table S1 (Supplementary material).

FT-IR spectroscopy

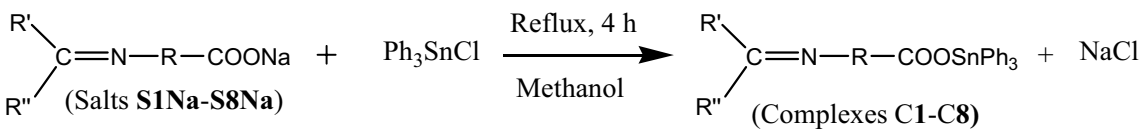
The FT-IR spectra of complexes and ligands were recorded in the range of 4000–500 cm^{-1}; the obtained data are displayed in Table 4. The Schiff base ligands (**S1–S8**) displayed a weak to medium intensity band at 1640–1649 cm^{-1}, which was assigned to azomethine ν(C=N) linkage [41]. There was



Scheme 1 Synthesis of Schiff base ligands (**S1–S8**)



Scheme 2 Synthesis of Sodium Salts (**S1Na–S8Na**) of the Schiff base ligands (**S1–S8**)



Scheme 3 Synthesis of Triphenyltin(IV) derivatives (**C1–C8**) of the Schiff bases

Table 1 Physical data of Schiff bases (**S1**–**S8**)

Schiff bases	Molecular formula	Molar mass (g/m)	Melting point (°C)	Elemental analysis % observed (% calculated)			Solubility	% yield
				C	H	N		
S1	$C_{21}H_{17}O_2N$	315	145	80.21 (79.98)	5.40 (5.43)	4.53 (4.44)	Ethanol, methanol, water, DMSO, acetone, and ethyl acetate	78
S2	$C_{21}H_{15}O_4N$	345	170	72.99 (73.03)	4.32 (4.38)	4.13 (4.06)	Ethanol, methanol, acetone, and DMSO	72
S3	$C_{15}H_{13}O_2N$	239	160	75.31 (75.30)	5.45 (5.48)	5.29 (5.85)	Water, ethanol, methanol, acetone, DMSO, and ethyl acetate	68
S4	$C_{15}H_{11}O_4N$	269	158	66.88 (66.91)	4.08 (4.12)	5.21 (5.20)	Water, ethanol, methanol, and DMSO	81
S5	$C_{22}H_{15}O_3N$	341	268	77.24 (77.41)	4.33 (4.43)	4.07 (4.10)	Methanol, ethanol, acetone, and DMSO	73
S6	$C_{22}H_{13}O_5N$	371	280	71.26 (71.16)	3.45 (3.53)	3.86 (3.77)	Ethanol, methanol, chloroform, acetone, DMSO, and ethyl acetate	79
S7	$C_{16}H_{15}O_2N$	253	185	75.83 (75.87)	6.07 (5.97)	5.51 (5.53)	Ethanol, methanol, DMSO, acetone, and water	68
S8	$C_{16}H_{13}O_4N$	283	236	67.81 (67.84)	4.53 (4.63)	4.87 (4.94)	Water, ethanol, methanol, and DMSO	74

Table 2 Physical data of sodium salts of Schiff bases (**S1Na**–**S8Na**)

Sodium salts of **S1**–**S8**	Molecular formula	Molecular mass (g/m)	Melting point (°)	Elemental analysis %			Solubility	% yield
				C	H	N		
S1Na	$C_{21}H_{16}O_2NNa$	337	266	73.6 (74.77)	4.73 (4.78)	4.19 (4.15)	Water, ethanol, methanol, and chloroform	91
S2Na	$C_{21}H_{14}O_4NNa$	367	230	68.82 (68.66)	3.58 (3.84)	3.79 (3.81)	Water, ethanol, methanol, and chloroform	94
S3Na	$C_{15}H_{12}O_2NNa$	261	278	68.89 (68.96)	4.61 (4.63)	5.39 (5.36)	Water, ethanol, methanol, and chloroform	89
S4Na	$C_{15}H_{10}O_4NNa$	291	215	62.11 (61.86)	3.39 (3.46)	4.80 (4.81)	Water, ethanol, methanol, and chloroform	92
S5Na	$C_{22}H_{14}O_3NNa$	363	> 350	72.69 (72.72)	3.85 (3.88)	3.79 (3.85)	Water, ethanol, methanol, and chloroform	88
S6Na	$C_{22}H_{12}O_5NNa$	393	280	67.31 (67.18)	2.87 (3.08)	3.49 (3.56)	Water, ethanol, methanol, and chloroform	94
S7Na	$C_{16}H_{14}O_2NNa$	275	> 350	68.98 (69.81)	5.18 (5.13)	5.13 (5.09)	Water, ethanol, methanol, and chloroform	90
S8Na	$C_{16}H_{12}O_4NNa$	305	238	63.18 (62.95)	3.64 (3.96)	4.6 (4.59)	Water, ethanol, methanol, and chloroform	89

a minor decrease in this band to 1633–1641 cm^{-1} in complexes (**C1**–**C8**), which may be owed to small changes in C=N electronic charge density after tin-carboxylate coordination. The carbonyl stretching frequency (asymmetric) of the free ligand (**S1**–**S8**) was appeared at 1680–1710 cm^{-1}; it was decreased to 1660–1691 cm^{-1} in the triphenyltin(IV) derivatives (**C1**–**C8**) due to carboxylate–metal interaction in a bidentate manner through the involvement of the carbonyl oxygen for bonding with tin. The bidentate coordination mode of the carboxylate group was also reflected from the value of $\Delta\upsilon_{(COO)} = \upsilon(COO)_{asym} - \upsilon(COO)_{sym}$. In the FT-IR spectra of organotin(IV) carboxylates, the $\upsilon(COO)_{asym}$ and $\upsilon(COO)_{sym}$ modes are of special interest as they provide information about bonding modes of metal carboxylates, the solid-state geometries and the coordination number of Sn(IV) [18, 37]. According to the literature [42], the value of $\Delta\upsilon_{(COO)}$ decides about monodentate ($\Delta\upsilon > 250$ cm^{-1}), bridging ($\Delta\upsilon = 150$–250 cm^{-1}) or chelating ($\Delta\upsilon < 150$ cm^{-1}) coordination mode. In all the organostannic derivatives (**C1**–**C8**), the value of $\Delta\upsilon_{(COO)}$ was found to be 182–213 cm^{-1}, showing bridging coordinating behavior (isobidentate) of the Schiff base ligands and penta-coordinated (trigonal bipyramidal)

Table 3 Physical properties and elemental analysis data of organotin complexes (**C1**–**C8**)

Complexes **C1**–**C8**	Molecular formula	Molar mass (g/m)	Melting point (°C)	Elemental analysis			Solubility	% yield
				C	H	N		
C1	$C_{39}H_{31}O_2NSn$	664	150	70.4 (69.8)	4.6 (4.4)	2.1 (2.3)	DMSO, methanol, and ethanol	68
C2	$C_{39}H_{29}O_4NSn$	694	290	65.3 (66.2)	3.9 (3.7)	1.95 (2.03)	DMSO and ethyl acetate	70
C3	$C_{33}H_{27}O_2NSn$	588	148	67.3 (66.9)	4.5 (4.6)	2.3 (2.5)	DMSO, ethyl acetate, chloroform, and acetone	73
C4	$C_{33}H_{25}O_4NSn$	618	> 400	62.8 (63.2)	3.75 (3.6)	2.18 (2.2)	DMSO, ethyl acetate, methanol, and acetone	76
C5	$C_{40}H_{29}O_3NSn$	690	> 400	69.5 (70.6)	4.2 (3.9)	2.0 (2.3)	DMSO	65
C6	$C_{40}H_{27}O_5NSn$	720	> 400	64.6 (63.8)	3.5 (3.4)	1.88 (2.3)	DMSO	76
C7	$C_{34}H_{29}O_2NSn$	602	210	67.7 (66.9)	4.8 (4.9)	2.3 (2.4)	DMSO, ethyl acetate, and methanol	73
C8	$C_{34}H_{27}O_4NSn$	632	380	62.3 (61.9)	3.9 (4.5)	2.1 (2.3)	Ethyl acetate	67

Table 4 FT-IR data (cm^{-1}) of ligands (**S1**–**S8**) and organotin complexes (**C1**–**C8**)

Compounds	υ(C=N)	υ(C=O)	$\upsilon(COO)_{Asym}$	$\upsilon(COO)_{Sym}$	$\Delta\upsilon_{(COO)}$	υ(Sn–C)	υ(Sn–O)
S1	1641 w	1699 s	–	–	–	–	–
C1	1638 m	1667 w	1591 s	1409 s	182	597 m	541 m
S2	1644 m	1701 s	–	–	–	–	–
C2	1641 m	1671 w	1588 s	1403 s	185	588 m	538 m
S3	1640 m	1708 s	–	–	–	–	–
C3	1638 w	1668 w	1593 s	1398 s	195	592 w	550 m
S4	1645 m	1698 s	–	–	–	–	–
C4	1633 w	1690 w	1590 s	1388 s	202	598 m	529 w
S5	1646 m	1702 s	–	–	–	–	–
C5	1639 w	1660 w	1592 s	1400 w	192	580 m	526 m
S7	1649 w	1680 m	–	–	–	–	–
C7	1636 s	1680 m	1610 m	1401 s	209	591 m	530 m
S8	1648 m	1710 s	–	–	–	–	–
C8	1637 m	1691 w	1612 s	1399 s	213	582 m	510 s

υSn^1–C = Organotin moiety bonded with oxygen; υSn^2–O = Organotin moiety bonded with oxygen

s strong, *m* medium, *w* weak

solid-state geometries around tin(IV). The formation of the Sn-carboxylate coordination was verified through the appearance of medium to low-intensity Sn–O vibrations at 510–550 cm^{-1} linkage [41]. The peaks at 580–598 cm^{-1} were assigned to Sn–C vibrations [16].

^{1}H NMR spectroscopy

The free Schiff base precursors **S1**–**S8** and the corresponding triphenyltin(IV) complexes (C1–C8) were subjected to ^{1}H NMR analysis in deuterated water and deuterated DMSO, respectively. The numbers of protons calculated by the integration of peaks were found to be in very good agreement with those calculated by the incremental method [18]. Table 5 displays the obtained data, while Scheme 4 displays the proton numbering. The representative proton NMR spectra of the Schiff base ligand (**S6**) and the corresponding complex (**S6**) are shown in Figs. 1 and 2, respectively.

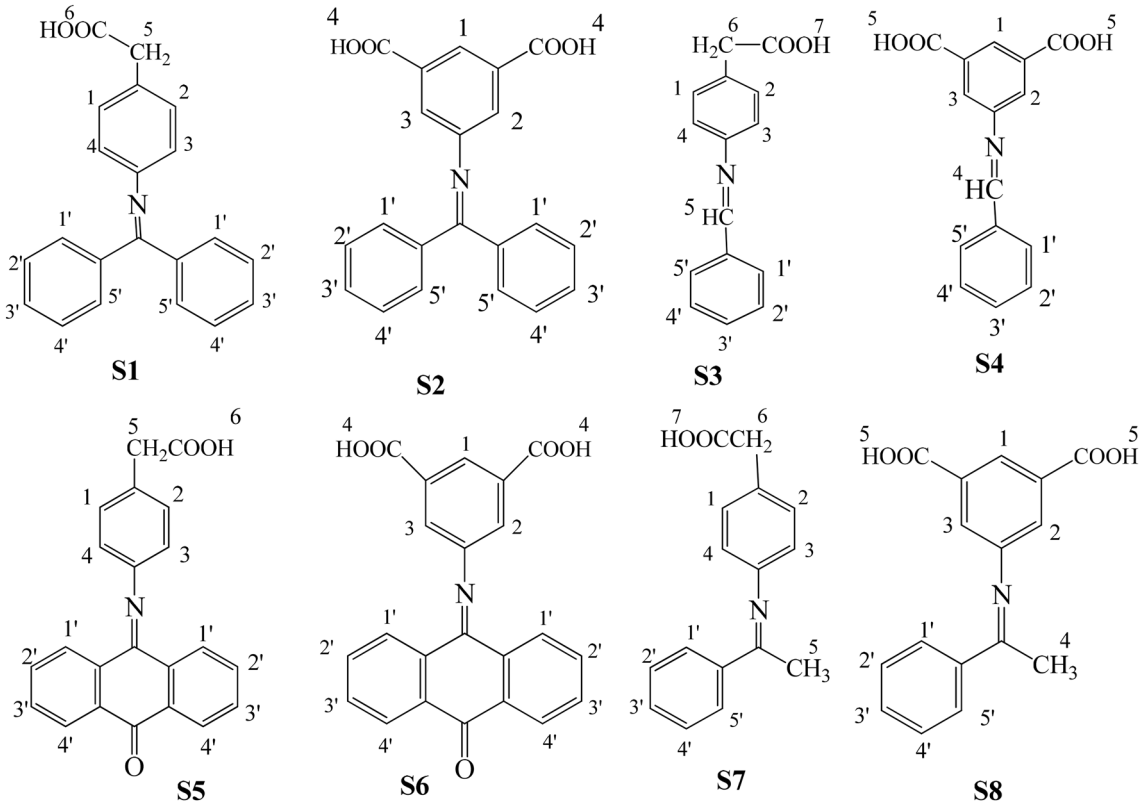
A complex pattern of peaks (especially for phenyl protons) was also observed in the spectra. However, the results were interpreted by comparing the proton NMR spectra of the ligand precursors with their respective triphenyltin(IV) derivatives (Table 5). The absence of carboxylic acid protons in the spectra of **S1**, **S3**, **S5**, **S6,** and **S7** may be the result of the exchange of carboxylic proton with that of deuterated water (used for NMR analysis); this exchange may be owed to the role of their precursor (4-aminophenyl acetic acid) in reactivity because the remaining Schiff bases, i.e., **S2**, **S4**, and **S8** exhibit the –COOH signals as a broad band at 12.88 ppm, 12.88 ppm, and 12.30 ppm, respectively. No signal for the carboxylic acid proton has appeared in the spectra of **C1**–**C8**; it is due to the deprotonation of the carboxylic acid moiety of

Table 5 ^{1}H NMR data (ppm) of Schiff base ligands (**S1**–**S8**) and the complexes (**C1**–**C8**); The NMR numbering patterns are given in Scheme 4

Comp. no	Proton number (Scheme 4)	Schiff base ligands (**S1**–**S8**)	Triphenyltin(IV) derivatives (**C1**–**C8**)
S1 and **C1**	1, 2, 3, 4	7.56–7.71 (m)	7.59–7.80 (m)
	1′, 2′, 3′, 4′, 5′	6.50–6.94 (m)	6.21–6.43 (m)
	5	3.35 (s)	2.91 (s)
	6	–	–
	Sn-Ph_3	–	7.23- 7.47 (m)
S2 and **C2**	1, 2, 3	7.64–7.75 (m)	7.67–7.71 (m)
	1′, 2′, 3′, 4′, 5′	7.56–7.58 (m)	7.56–7.59 (m)
	4	12.88 (b)	–
	Sn-Ph_3	–	7.72–7.75 (m)
S3 and **C3**	1, 2, 3, 4	7.79–7.86 (m) and 7.21–7.64 (m)	7.79–7.83 (m)
	1′, 2′, 3′, 4′, 5′	6.47–6.51 (m) and 6.79–7.00 (m)	6.45–6.47 (m)
	5	7.63 (s)	7.67 (s)
	6	3.35 (s)	3.34 (s)
	7	–	–
	Sn-Ph_3	–	7.35–7.53 (m)
S4 and **C4**	1	7.94 (s)	7.94–7.96 (m)
	2, 3, 1′, 2′, 3′, 4′, 5′	7.36–7.38 (d) and 7.44–7.53 (m)	7.35–7.37 (m)
	4	7.65 (s)	7.68 (s)
	5	12.88 (b)	–
	Sn-Ph_3	–	7.63–7.65 (m)
S5 and **C5**	1, 2, 3, 4	6.55–6.98 (m)	6.94–6.97 (m)
	1′, 2′, 3′, 4′	8.01–8.31 (m)	7.69–7.71 (m)
	5	3.54 (s)	3.31 (s)
	6	–	–
	Sn-Ph_3	–	7.59–7.63 (m)
S6 and **C6**	1, 2, 3	7.65 (s) and 7.36 (s)	6.54 (s)
	1′, 4′	8.22–8.26 (m)	8.22–8.24 (m)
	2′, 3′	7.94–7.98 (m)	7.89–7.96 (m)
	4	–	–
	Sn-Ph_3	–	7.29–7.30 (m) and 7.34–7.37 (m)
S7 and **C7**	1, 2, 3, 4	6.88–6.90 (m)	6.88 (d)
	1′, 2′, 3′, 4′, 5′	6.48–6.51 (m)	6.49 (d)
	5	3.44–3.48 (m)	3.59 (s)
	6	3.32 (s)	3.34 (s)
	7	–	–
	Sn-Ph_3	–	7.84–8.05 (m) and 7.32–7.37 (m)
S8 and **C8**	1, 2, 3	7.65 (s)	i8.05 (s)
	1′, 2′, 3′, 4′, 5′	7.36–7.56 (m)	i7.24–7.65 (m)
	4	3.44 (s)	i3.32 (s)
	5	12.30 (b)	–
	Sn-Ph_3	–	i7.86–7.65 (m)

Multiplicity is given as: b = broad, s = singlet, d = doublet, m = multiplet; The NMR numbering pattern (1, 2, 3, 4, 5, 6, 7, 1′, 2′, 3′, 4′, and 5′) is given in Scheme 4

the free Schiff base precursors (**S1**–**S8**) to develop COO-$SnPh_3$ coordination. The spectra of the coordinated products (**C1**–**C8**) exhibited the chemical shifts for protons of triphenyltin(IV) moieties; these peaks were absent in the spectra of the Schiff base ligand precursors (**S1**–**S8**). The azomethine (–N=CH–) protons appeared at 7.63 ppm and 7.65 ppm in the spectra of **S3** and **S4**, respectively; these signals were shifted to 7.67 ppm and 7.68 ppm in the spectra of the respective coordinated products **C3** and **C4**, respectively.



Scheme 4 The ^{1}H NMR numbering Scheme

Thermogravimetric analysis (TGA)

Thermogravimetric analysis is commonly used for the structural elucidation of metal complexes [43–45]. The Schiff bases (**S4**, **S5**, **S7**, and **S8**) and their respective complexes (**C4**, **C5**, **C7**, and **C8**) were subjected to thermogravimetric analysis in order to determine their modes of decomposition and thermal stabilities. The obtained data, including the evolved components and their residues, are summarized in Table 6, while the representative thermograms of a Schiff base ligand **S4** and its organotin(IV) derivative **C4** are given in Figs. 3 and 4, respectively.

The thermogravimetric analysis has shown a close agreement between the observed percentages of the evolved/residual contents and those of the theoretically calculated values (Table 6). All the Schiff bases exhibited almost the same degradation pattern, leaving behind only the carbon residue [16]. However, a big difference was observed between the modes of thermal decomposition of ligands and the consequent complexes. The Schiff base ligands (**S4**, **S5**, **S7**, and **S8**) displayed 44–53% evolution of volatile fragments in the form of CO_2, CO, HCN, H_2, and CH_4, leaving behind the carbon residue (47–56%). Whereas, the coordination products (**C4**, **C5**, **C7**, and **C8**) also deposited SnO_2/SnO_3 residues in addition to the carbon. The percentage of residual components (90.14–92.4%) observed in complexes (**C4**, **C5**, **C7**, and **C8**) was significantly higher compared to that (47–56%) observed in Schiff base precursors. The results thus verify the coordination of the triphenyltin(IV) moiety in the products **C4**, **C5**, **C7**, and **C8**.

In terms of thermal stabilities, decomposition begins in all ligands and complexes between 60 and 100 °C. However, the thermal stabilities of Schiff base ligands **S4** (approx. 100 °C), **S7** (approx. 85 °C), and **S8** (approx. 100 °C) were slightly higher than those of their respective complexes **C4** (approx. 70 °C), **C7** (approx. 70 °C), and **S8** (approx. 60 °C). The thermal stabilities of Schiff bases **S4** and **S8** (up to 100 °C) were found to be the highest as compared to those of **S5**, **S8**, **C4**–**C5**, and **C7**–**C8** (up to 60–85 °C). The higher thermal stabilities of the Schiff base precursors as compared to the investigated complexes may be associated with the strong hydrogen bonding (owing to the presence of –COOH groups of free ligand precursors) in the former case as compared to the latter (deprotonation of carboxylic –OH by an organotin moiety).

Antibacterial activities

Schiff bases and their metal complexes are commonly investigated for their antibiological activities [4, 46]. The

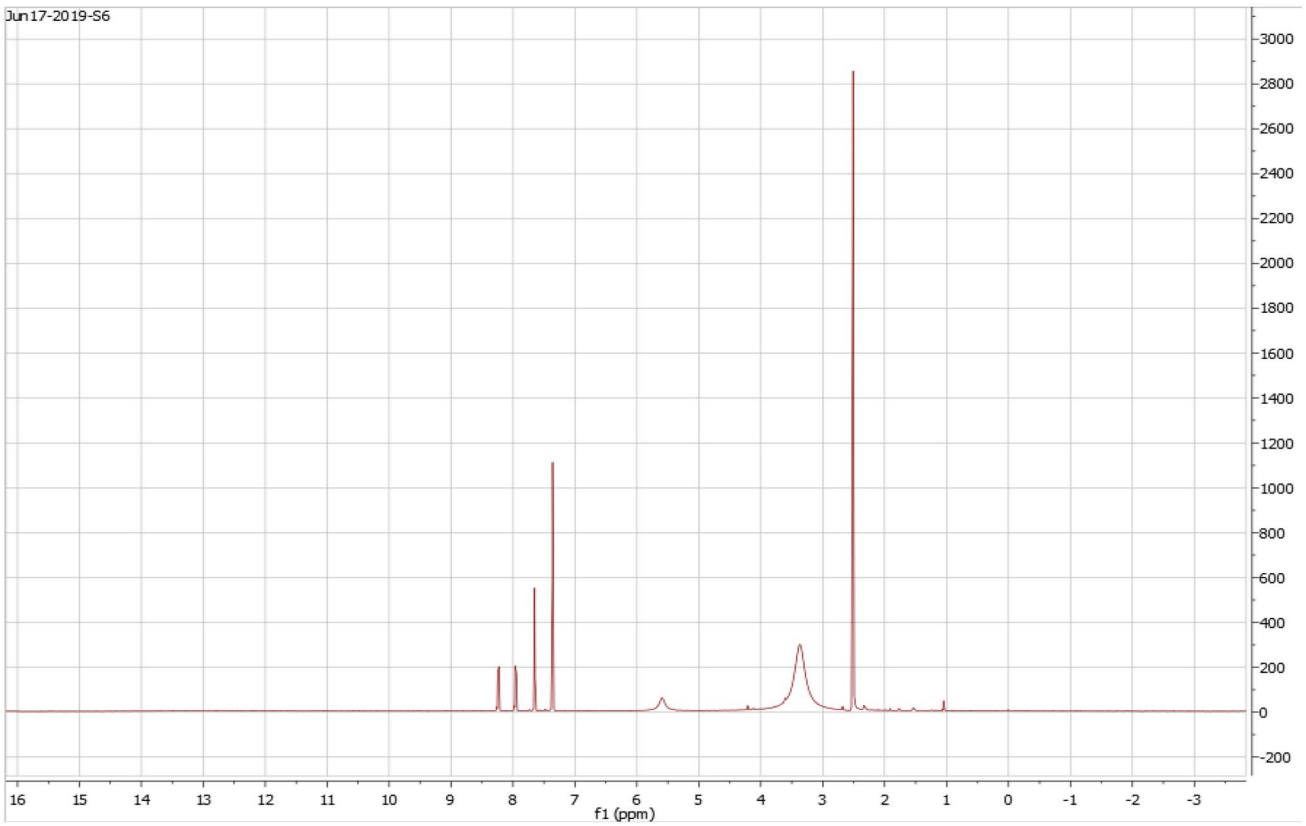


Fig. 1. ^{1}H NMR spectrum of **S6** recorded in deuterated water

synthesized Schiff base ligands (**S1**–**S8**) and complexes (**C1**–**C8**) were tested for their antibacterial potential against *Bacillus subtilis* (gram-positive) and *Escherichia coli* (gram-positive) by the disk diffusion method; ampicillin was used as a standard positive control. The activities were performed using a concentration of 1 mg/mL in the solvent; water was used as a solvent for the ampicillin and Schiff bases (**S1**–**S8**), while DMSO was used as a solvent for the coordinated products (**C1**–**C8**). The zones of inhibition were measured in mm by a zone reader [16]. The obtained antibacterial data are displayed in Table 7. The photographs are shown in the supplementary material as Figures S1–S4.

All the compounds have shown significant antibacterial potential. However, the antibacterial activities of the tested compounds were comparatively lower as compared to those of the standard drug (ampicillin). A close relationship was observed between the structures and antibacterial activities of the products. The biological activities were found to depend on the nature and structure of the Schiff bases and the coordination products. The biological activities of organotin derivatives **(C1**–**C8)** varied greatly depending upon the substitution pattern at tin [22, 47]. The zones of inhibition of the free ligand precursors (**S1**–**S8**) were observed to be 14–22 mm and 25–30 nm against *B. subtilis* and *E. coli*, respectively. The inhibition zones for the complexes (**C1**–**C8**) were found to be 14–22 mm and 24–31 nm against *B. subtilis* and *E. coli*, respectively. Both the Schiff base ligands (**S1**–**S8**) as well as coordination products (**C1**–**C8**) have shown large inhibition zones (25–30 nm and 24–31 nm by **S1**–**S8** and **C1**–**C8**, respectively) against *E. coli* as compared to those (14–22 nm by **S1**–**S8** as well as **C1**–**C8**) observed against *B. subtilis*. So, it was demonstrated that the investigated Schiff bases and their triphenyltin derivatives are more active against *E. coli* as compared to those against *B. subtilis*. The results are in agreement with the literature that metal complexes may possess higher activity against Gram-negative bacteria (*E. coli*) as compared to Gram-positive bacteria (*B. subtilis*) in some cases [48] depending upon their structures. However, based on their structures and the nature of the target bacterial strains, complexes can be concluded to be selective in their action against tested microorganisms.

The antibacterial activities were increased in most cases in going from free Schiff base precursors (**S1**–**S8**) to their corresponding coordination products (**C1**–**C8**). It is due to an increase in lipophilic character upon metal–ligand coordination. According to Tweedy's theory, the polarity of the central metal (e.g., tin) is increased due to the partial sharing

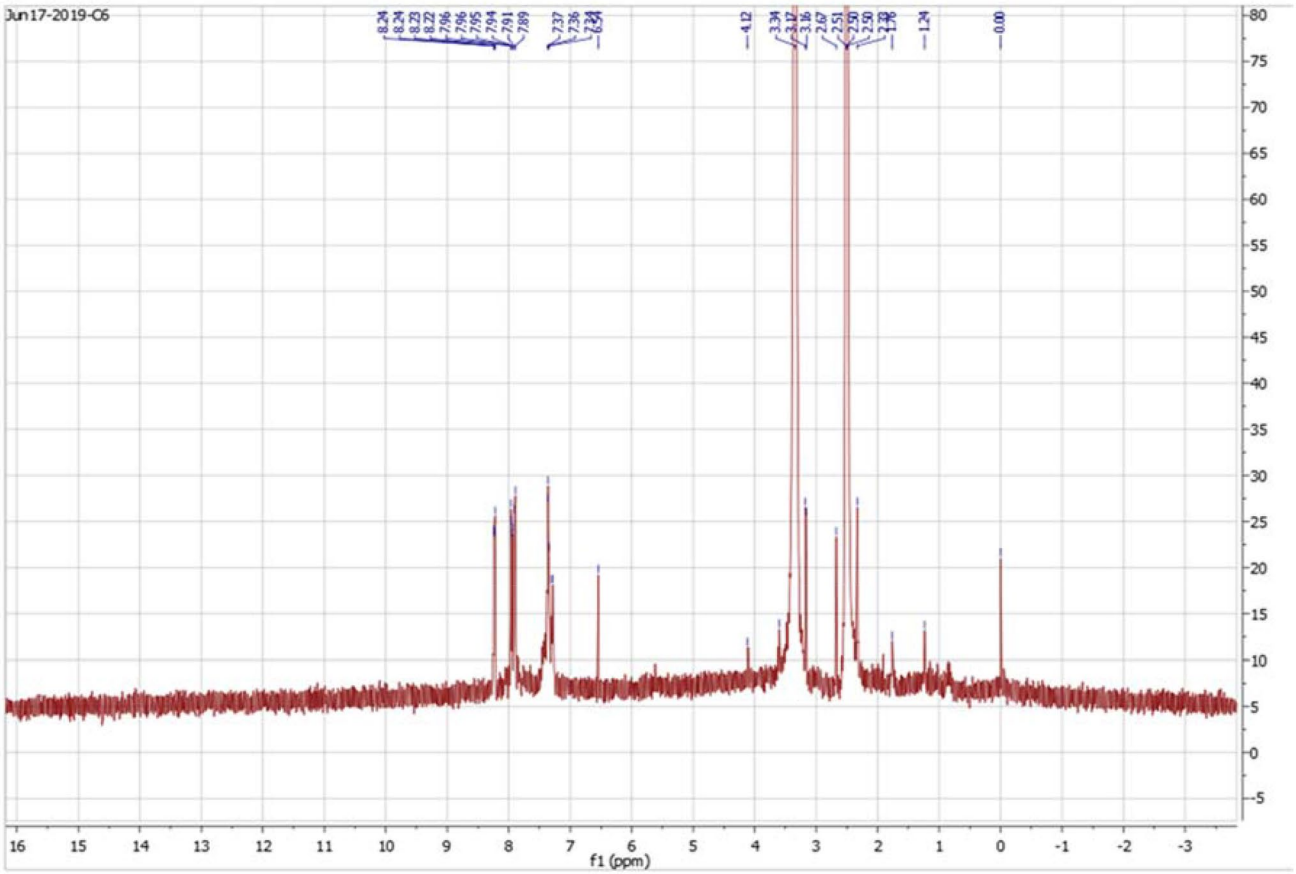


Fig. 2. ^{1}H NMR spectrum of **C6** recorded in deuterated dimethylsulfoxide (DMSO)

Table 6 TGA data of Schiff bases (**S4**, **S5**, **S7**, and **S8**) and the complexes (**C4**, **C5**, **C7**, and **C8**)

Sample code	Molar mass (g/m)	Decomposition range (°C)	Evolved components (observed)	% Loss calculated/observed	Residue left behind	% Residue calculated/observed
S4	269	100–560	$2CO_2$, HCN, $5H_2$	46.5/47	12C	53.5/53
S5	341	65–560	3CO, HCN, H_2, $3CH_4$	47.35/48	15C	52.78/52
S7	253	85–800	CO_2, HCN, $3H_2$, $2CH_4$	43.1/44	12C	56.9/56
S8	283	100–650	4CO, HCN, $6H_2$	53.3/53	11C	46.6/47
C4	618	70–800	$12H_2$, NOH	8.89/7.59	33C, SnO_3	91.11/92.4
C5	690	70–700	$12H_2$, HCN	7.97/8.42	39C, SnO_3	92.13/91.58
C7	602	70–800	$14H_2$, HCN	9.14/9.65	33C, SnO_2	90.85/90.3
C8	632	60–800	$13H_2$, NOH	9.01/9.86	34C, SnO_3	90.98/90.14

of its positive charge with the ligand; which thus facilitates the permeation of the coordination product through the lipid layer of the membrane [49, 50]. The antimicrobial potential was also varied in various coordinated products (**C1**–**C8**) due to differences in the nature (skeleton) of their incorporated ligands because the function of the ligand is to facilitate the transport of the active organotin(IV) moiety into the site of action where it is released by hydrolysis [51]. The organotin(IV) complexes can interact with DNA and proteins and can also damage the mitochondria of microorganisms, ultimately causing their death [52]. It has been well established that organotin(IV) products are biologically active with a few exceptions [53]. However, due to different methodologies and strains assayed, it is highly challenging to compare the antimicrobial results with those reported earlier in literature; yet, because of the biological significance associated with tin, the investigated tin(IV) complexes have shown significant activities

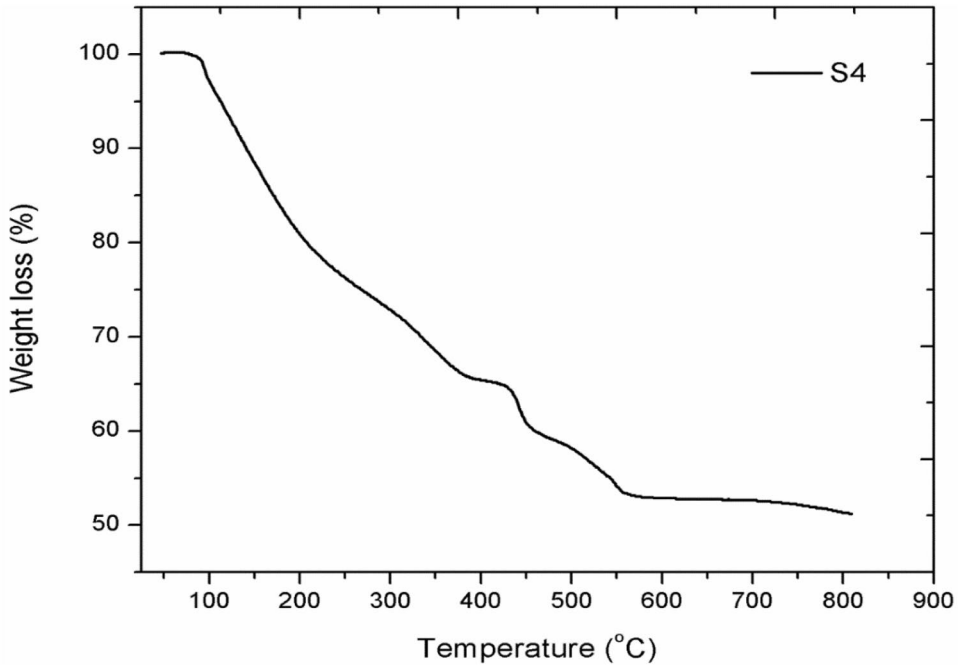


Fig. 3 Thermogram of **S4**

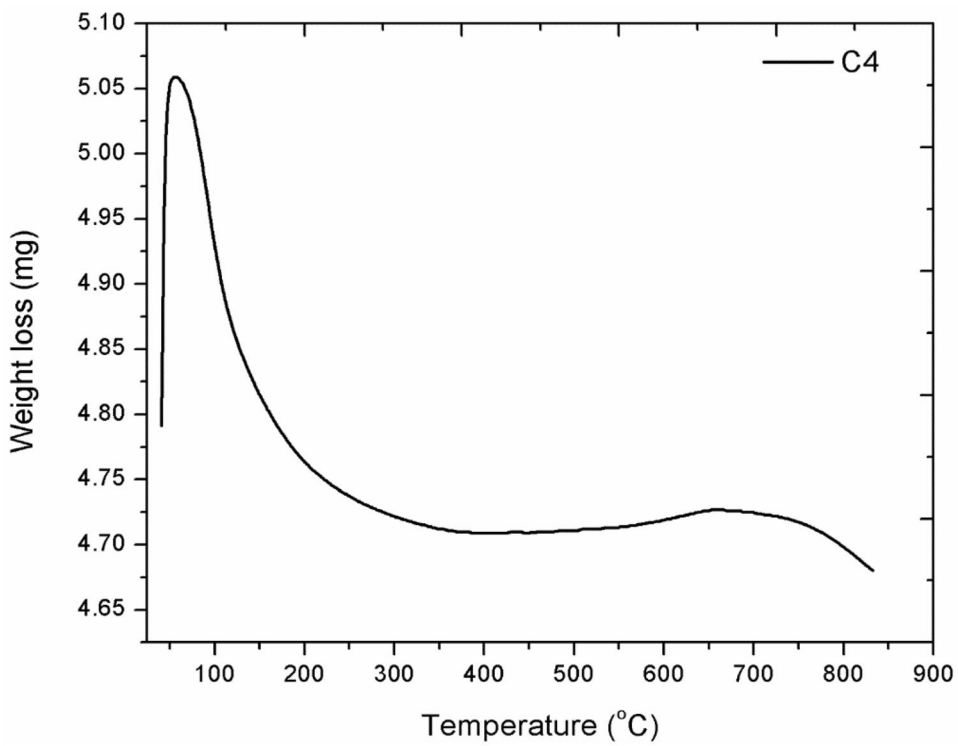


Fig. 4 Thermogram of **C4**

[54]. Earlier studies also support the antimicrobial potential of Schiff base ligands and their complexes with numerous metals. For example, zirconium complexes with Schiff base ligands (1) (3-methoxysalicylidene)-4,5-dimethyl-1,2-phenylenediamine (2) (5-methoxysalicylidene)-4,5-dimethyl-1,2-phenylenediamine (3) (6-methoxysalicylidene)-4,5-dimethyl-1,2-phenylenediamine (4) (4-methoxysalicylidene)-4,5-dimethyl-1,2-phenylenediamine (5) (3-methoxysalicylidene)-2,2-dimethyl-1,3-propanediamine (6) (4-methoxysalicylidene)-2,2-dimethyl-1,3-propanediamine (7) (5-methoxysalicylidene)-2,2-dimethyl-1,3-propanediamine (8) (6-methoxysalicylidene)-2,2-dimethyl-1,3-propanediamine (9) bis(3-ethoxysalicylidene)-4,5-dimethyl-1,2-phe-

Table 7 Antibacterial activity data of the Schiff bases and their triphenyltin(IV) products

Bacterial strains	Zones of inhibition (mm) of Schiff base ligands (**S1**–**S8**)								Ampicillin
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	
B. subtilis	17	20	22	19	18	14	21	16	35
E. coli	30	29	30	27	25	29	26	25	36
Bacterial strains	Zones of inhibition (mm) of triphenyltin(IV) products (**C1**–**C8**)								Ampicillin
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	
B. subtilis	20	18	16	22	21	14	16	19	35
E. coli	30	26	28	29	24	31	27	25	35

nylenediamine (H_2L) and (10) bis(3-ethoxysalicylidene)-2,2-dimethyl-1,3-propanediamine have shown excellent in vitro antibacterial activities against *E. coli* and *S. aureus* [55, 56]. Zinc(II) complexes with ONNO tetradentate Schiff base ligands were found to be the potent inhibitors of *S. aureus*, *E. coli* [57, 58], *B. cereus*, *P. aeruginosa* [57], *B. cereus* and *P. aeruginosa* [58]. A promising antibacterial activity was displayed against *S. aureus* and *E. coli* by copper (II) complexes of bidentate Schiff base ligands derived from 4-aminoantipyrine [59, 60]. Zinc(II), copper(II), and nickel(II) complexes of ONNO donor Schiff base ligands were found effective against Gram-positive (*S. aureus* and *B. cereus*) and Gram-negative (*E. coli* and *P. aeruginosa*) bacteria [61].

Hemolytic activities

The Schiff bases (**S1**–**S8**) and the organotin(IV) complexes (**C1**–**C8**) were tested for their toxicological effects on human red blood cells [36, 37]. In the presence of these effects, the compounds cannot be used as drugs, even if they possess strong antimicrobial potential [34]. The toxicology of the products was tested by a reported hemolytic activity procedure using triton-X100 (100% blood lysis) as a positive control and phosphate buffer (0% blood lysis) as a negative control. It was observed (Table 8) that the investigated compounds display toxicity in the ranges of 1.5–7.9% (**S1**–**S8**) and 1.5–4.5% (**C1**–**C8**), which is an acceptable and safe range. Thus, it was concluded that the synthesized Schiff bases (**S1**–**S8**) and their organotin(IV) complexes (**C1**–**C8**) do not display any toxic hemolytic effects.

Conclusions

4-Aminophenyl acetic acid/5-aminoisophthalic acid was reacted with benzaldehyde/acetophenone/benzophenone/anthraquinone in ethanol at 70 °C for 2 h to produce Schiff bases (**S1**–**S8**). The reaction of sodium salts (**NaS1**–**NaS8**) of Schiff bases with triphenyltin(IV) chloride in methanol at 70 °C for 4 h was used to produce the organotin complexes (**C1**–**C8**). The structures of Schiff bases and their complexes were verified by elemental analysis, FT-IR, ^{1}H NMR spectroscopy, and thermogravimetry. FT-IR spectroscopy demonstrated the isobidentate coordination mode of the carboxylate moiety and a trigonal bipyramidal geometry of Sn(IV) in the solid state of complexes. The numbers of protons observed by ^{1}H NMR spectroscopic data were in good agreement with those of suggested structures of the products. The thermal decomposition data agreed well with the molecular composition of the Schiff bases **(S1–S8)** as well as that of the coordinated products **(C1–C8)**. The Schiff bases and organotin (IV) complexes have shown significant antibacterial activities against *B. subtilis* and *E. coli*. However, all the products (Schiff bases and ligands) have shown higher activities against Gram-negative bacteria (*E. coli*) as compared to Gram-positive bacteria (*B. subtilis*). Their

Table 8 Hemolytic activity data of the Schiff bases and their triphenyltin(IV) products

Hemolytic activities (%) of Schiff base ligands (**S1**–**S8**)								Triton X100
S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**S8**	
2.4	2.9	3.7	2.8	1.5	7.9	3.6	1.5	100
Hemolytic activities (%) of triphenyltin(IV) products (**C1**–**C8**)								Triton X100
C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	
1.8	1.5	4.5	3.2	2.5	1.9	1.5	1.7	100

hemolytic activities were observed to be in the safe range of 1.5–7.9% as compared to those of triton-X100 (100% lysis).

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13738-023-02746-5.

Acknowledgments We gratefully acknowledge the support of Lahore Garrison University, Lahore, Pakistan (practical) and University of Agricultural Faisalabad, Pakistan (for biological activity studies) for this study.

Declarations

Conflict of interest There is no conflict of interest between the authors.

References

1. A.M. Asiri, S.A. Khan, Molecules **15**, 6850 (2010)
2. G. Bagihalli, S. Patil, P. Badami, J. Iran. Chem. Soc. **6**, 259 (2009)
3. O. Bekircan, H. Bektas, Molecules **13**, 2126 (2008)
4. M. Diab, G.G. Mohamed, W. Mahmoud, A. El-Sonbati, S.M. Morgan, S. Abbas, Appl. Organomet. Chem. **33**, e4945 (2019)
5. Z. Yang, P. Sun, Molbank **2006**, M514 (2006)
6. M. Zarei, A. Jarrahpour, Iran. J. Sci. Technol. Trans. A Sci. **A3**, 235 (2011)
7. H. Kargar, A. Adabi Ardakani, K.S. Munawar, M. Ashfaq, M.N. Tahir, J. Iran. Chem. Soc. **18**, 2493 (2021)
8. H. Kargar, M. Ashfaq, M. Fallah-Mehrjardi, R. Behjatmanesh-Ardakani, K.S. Munawar, M.N. Tahir, Inorg. Chim. Acta **536**, 120878 (2022)
9. H. Kargar, M. Fallah-Mehrjardi, R. Behjatmanesh-Ardakani, M. Bahadori, M. Moghadam, M. Ashfaq, K.S. Munawar, M.N. Tahir, Polyhedron **213**, 115622 (2022)
10. S. Shujah, N. Muhammad, A. Shah, S. Ali, A. Meetsma, Z. Hussain, J. Organomet. Chem. **759**, 19 (2014)
11. N. Dharmaraj, P. Viswanathamurthi, K. Natarajan, Transit. Met. Chem. **26**, 105 (2001)
12. V. Mirkhani, S. Tangestaninejad, M. Moghadam, I. Mohammadpoor-Baltork, H. Kargar, J. Mol. Catal. A Chem. **242**, 251 (2005)
13. A. Jamshidvand, M. Sahihi, V. Mirkhani, M. Moghadam, I. Mohammadpoor-Baltork, S. Tangestaninejad, H.A. Rudbari, H. Kargar, R. Keshavarzi, S. Gharaghani, J. Mol. Liq. **253**, 61 (2018)
14. A.A. Ardakani, H. Kargar, N. Feizi, M.N. Tahir, J. Iran. Chem. Soc. **15**, 1495 (2018)
15. X.-B. Yang, Q. Wang, Y. Huang, P.-H. Fu, J.-S. Zhang, R.-Q. Zeng, Inorg. Chem. Commun. **25**, 55 (2012)
16. A.R. Bendale, R. Bhatt, A. Nagar, A.G. Jadhav, G. Vidyasagar, Der Pharma Chem. **3**, 34 (2011)
17. V. Barba, E. Vega, R. Luna, H. Höpfl, H.I. Beltrán, L.S. Zamudio-Rivera, J. Organomet. Chem. **692**, 731 (2007)
18. S. Hussain, S. Ali, S. Shahzadi, S.K. Sharma, K. Qanungo, I.H. Bukhari, J. Coord. Chem. **65**, 278 (2012)
19. S. Hussain, S. Ali, S. Shahzadi, C. Rizzoli, Phosphorus Sulfur Silicon Relat. Elem. **188**, 812 (2013)
20. D. Ghazi, Z. Rasheed, E. Yousif, J. Dev. **3**, 4 (2018)
21. A.G. Davies, J. Chem. Res. **34**, 181 (2010)
22. S. Mariam, S. Hussain, S. Ali, S. Shahzadi, S. Ramzan, M. Shahid, Iran. J. Sci. Technol. Trans. A Sci. **42**, 1277 (2018)
23. S. Hussain, Z. Zahid, M. Shahid, M.A. Abid, Arab. J. Sci. Eng. **44**, 6423 (2019)
24. S. Hussain, LGUJLS **2**, 124 (2018)
25. M. Affan, B. Fasihuddin, Y. Liew, S. Foo, J. Ismail, J. Sci. Res. **1**, 306 (2009)
26. Y. Farina, H. Adil, A. Ahmed, A. Graisa, E. Yousif, Aust. J. Basic Appl. Sci. **3**, 1670 (2009)
27. C. Pettinari, F. Marchetti, R. Pettinari, D. Martini, A. Drozdov, S. Troyanov, Inorg. Chim. Acta **325**, 103 (2001)
28. W.T. Piver, Environ. Health Perspect. **4**, 61 (1973)
29. M. Nath, P.K. Saini, Dalton Trans. **40**, 7077 (2011)
30. K. Jamil, R. Wajid, M. Bakhtiar, M. Danish, J. Iran. Chem. Soc. **7**, 495 (2010)
31. Y.-X. Tan, Z.-J. Zhang, Y. Liu, J.-X. Yu, X.-M. Zhu, D.-Z. Kuang, W.-J. Jiang, J. Mol. Struct. **1149**, 874 (2017)
32. H. Kargar, M. Fallah-Mehrjardi, R. Behjatmanesh-Ardakani, K.S. Munawar, M. Bahadori, M. Moghadam, Inorg. Chem. Res. **6**, 76 (2022)
33. H. Kargar, A.A. Ardakani, M.N. Tahir, M. Ashfaq, K.S. Munawar, J. Mol. Struct. **1229**, 129842 (2021)
34. S. Hussain, S. Ali, S. Shahzadi, M. Shahid, Cogent Chem. **1**, 1029038 (2015)
35. T. Riaz, M.A. Abbasi, T. Shazadi, M. Shahid, Pak. J. Pharm. Sci. **32**, 697 (2019)
36. T. Shahzadi, M. Zaib, T. Riaz, S. Shehzadi, M.A. Abbasi, M. Shahid, Arab. J. Sci. Eng. **44**, 6435 (2019)
37. S. Hussain, S. Ali, S. Shahzadi, M.N. Tahir, M. Shahid, J. Coord. Chem. **68**, 2369 (2015)
38. R.K. Agarwal, L. Singh, D.K. Sharma, Bioinorg. Chem. Appl. **2006**, 1–10 (2006)
39. S. Arulmurugan, H.P. Kavitha, B. Venkatraman, Rasayan J. Chem. **3**, 385 (2010)
40. J. Devi, J. Yadav, N. Singh, Res. Chem. Intermed. **45**, 3943 (2019)
41. S. Esmaielzadeh, M. Mohammadi, Bull. Chem. Soc. Ethiop. **33**, 77 (2019)
42. G. Eng, X. Song, A. Zapata, A.C. de Dios, L. Casabianca, R.D. Pike, J. Organomet. Chem. **692**, 1398 (2007)
43. S.M. Morgan, M. Diab, A. El-Sonbati, Appl. Organomet. Chem. **32**, e4305 (2018)
44. S. Hussain, I.H. Bukhari, S. Ali, S. Shahzadi, M. Shahid, K.S. Munawar, J. Coord. Chem. **68**, 662 (2015)
45. H.M. Refaat, H.A. El-Badway, S.M. Morgan, J. Mol. Liq. **220**, 802 (2016)
46. S. Nozha, S.M. Morgan, S.A. Ahmed, M. El-Mogazy, M. Diab, A. El-Sonbati, M. Abou-Dobara, J. Mol. Liq. **1227**, 129525 (2021)
47. S. Hussain, S. Ali, S. Shahzadi, M. Riaz, K. Nazir, M.N. Arshad, A.M. Asiri, Arab. J. Sci. Eng. **45**, 4785 (2020)
48. M. Singh, S. Singh, S. Prasad, I. Gambhir, Dig. J. Nanomater. Biostruct. **3**, 115 (2008)
49. B.G. Tweedy, Phytopathology **55**, 910 (1964)
50. S.S. Konstantinović, B.C. Radovanović, S.P. Sovilj, S. Stanojević, J. Serbian Chem. Soc. **73**, 7 (2008)
51. C. Pellerito, L. Nagy, L. Pellerito, A. Szorcsik, J. Organomet. Chem. **691**, 1733 (2006)
52. M. Carcelli, A. Fochi, P. Pelagatti, G. Pelizzi, U. Russo, J. Organomet. Chem. **626**, 161 (2001)
53. S. Shahzadi, K. Shahid, S. Ali, J. Coord. Chem. **60**, 2637 (2007)
54. N. Sharma, V. Kumar, M. Kumari, A. Pathania, S. Chaudhry, J. Coord. Chem. **63**, 3498 (2010)
55. A. Sahraei, H. Kargar, M. Hakimi, M.N. Tahir, J. Mol. Struct. **1149**, 576 (2017)
56. A. Sahraei, H. Kargar, M. Hakimi, M.N. Tahir, Transit. Met. Chem. **42**, 483 (2017)
57. H. Kargar, M. Fallah-Mehrjardi, M. Ashfaq, K.S. Munawar, M.N. Tahir, R. Behjatmanesh-Ardakani, H. Amiri Rudbari, A. Adabi Ardakani, S. Sedighi-Khavidak, J. Coord. Chem. **74**, 2720 (2021)
58. H. Kargar, M. Fallah-Mehrjardi, R. Behjatmanesh-Ardakani, H.A. Rudbari, A.A. Ardakani, S. Sedighi-Khavidak, K.S. Munawar, M. Ashfaq, M.N. Tahir, Polyhedron **213**, 115636 (2022)

59. H. Kargar, F. Aghaei-Meybodi, R. Behjatmanesh-Ardakani, M.R. Elahifard, V. Torabi, M. Fallah-Mehrjardi, M.N. Tahir, M. Ashfaq, K.S. Munawar, J. Mol. Struct. **1230**, 129908 (2021)
60. H. Kargar, F. Aghaei-Meybodi, M.R. Elahifard, M.N. Tahir, M. Ashfaq, K.S. Munawar, J. Coord. Chem. **74**, 1534 (2021)
61. H. Kargar, A.A. Ardakani, M.N. Tahir, M. Ashfaq, K.S. Munawar, J. Mol. Struct. **1233**, 130112 (2021)