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Synthesis, characterization and antimicrobial activity of diorganotin(IV) derivatives of some bioactive bifunctional tridentate Schiff base ligands

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Abstract: Some new organotin(IV) complexes of the type $R_2Sn[OC(R')$:$CH(CH_3)C$:$NR''O]$ ($R=CH_3$, C_4H_9, C_6H_5; $R'=CH_3$, C_6H_5; and $R''=(CH_2)_2$, $(CH_2)_3$) have been synthesized by the reactions of diorganotin dichloride with the sodium salt of the corresponding bifunctional tridentate Schiff base ligands in unimolar ratio in refluxing tetrahydrofuran (THF). All these compounds have been characterized by elemental analyses, and their probable structures, in which the central tin atom is pentacoordinated, have been proposed on the basis of infrared (IR) and ^{1}H, ^{13}C and ^{119}Sn NMR and fast atom bombardment mass spectroscopic studies. The ligands, metal precursors and their corresponding diorganotin complexes have also been screened for antimicrobial activities.

Keywords: antimicrobial activities; diorganotin(IV) Schiff base derivatives; FAB mass spectrometry; NMR spectroscopy; pentacoordinated tin.

Introduction

Organotin(IV) complexes have been the subject of interest for some time because of their biomedical and commercial applications (Pellerito and Nagy, 2002). The syntheses of organotin(IV) complexes derived from Schiff bases have been extensively studied in the past decade (Dey et al., 2009; Sedaghat et al., 2012a,b,c). In recent years, interest is growing widely as a result of their antimicrobial, antiviral and antitumor activities (Joshi et al., 2005; Singh et al., 2009; Nath et al., 2013). Schiff base complexes also provide synthetic models for active sites in biological systems (Baul et al., 2008) and offer opportunities for enhancing solubility and stability of their metal complexes (Borisova et al., 2007). During the last decade, metal complexes of group 14 have made a major contribution with their antimicrobial activity, and it is well reported that the activity of Schiff bases are often enhanced due to chelation with metal (Sharma et al., 2007; Singh et al., 2011).

In view of the above facts, we have synthesized and characterized some new diorganotin(IV) complexes with Schiff bases derived from β-diketones and amino alcohols. These compounds have been screened for antimicrobial activities. The antimicrobial activities of these tin compounds have been compared with the corresponding free Schiff bases and metal precursors.

Results and discussion

Syntheses of organotin(IV) derivatives

Ligands have been synthesized by the condensation reaction of β-diketones and selected amino alcohols in unimolar ratio. These ligands may exist in various forms (Scheme 1). The structure (C) seems to be more likely in view of the spectroscopic studies and the single crystal X-ray diffraction analysis of organotin compounds of similar ligands reported in the literature (Dey et al., 2009).

The reactions of R_2SnCl_2 with the sodium salt of Schiff base ligands (synthesized by the reaction of Schiff bases and freshly prepared sodium methoxide) in 1:1 molar ratio in refluxing tetrahydrofuran (THF) yield organotin complexes.

Spectroscopic studies

Infrared spectra

In the infrared (IR) spectra of these derivatives, disappearance of the broad band indicates the deprotonation

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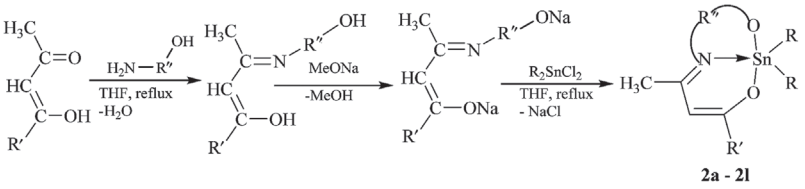

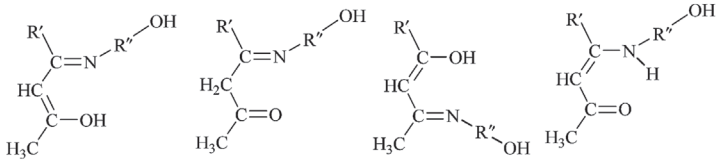

R′= CH_3, R″= -$(CH_2)_2$- (**1a**)
R″= -$(CH_2)_3$- (**1b**)
R′= C_6H_5, R″= -$(CH_2)_2$- (**1c**)
R″= -$(CH_2)_3$- (**1d**)

R= CH_3, R′= CH_3, R″= -$(CH_2)_2$ - (**2a**)
R″= -$(CH_2)_3$ - (**2b**)
R′= C_6H_5, R″= -$(CH_2)_2$ - (**2c**)
R″= -$(CH_2)_3$ - (**2d**)
R= C_4H_9, R′= CH_3, R″= -$(CH_2)_2$ - (**2e**)
R″= -$(CH_2)_3$ - (**2f**)
R′= C_6H_5, R″= -$(CH_2)_2$ - (**2g**)
R″= -$(CH_2)_3$ - (**2h**)
R= -C_6H_5, R′= -CH_3, R″= -$(CH_2)_2$- (**2i**)
R″= -$(CH_2)_3$ - (**2j**)
R′= C_6H_5, R″= -$(CH_2)_2$- (**2k**)
R″= -$(CH_2)_3$ - (**2l**)

Scheme 1: Syntheses of bifunctional tridentate Schiff bases (**1a–1d**) and diorganotin derivatives (**2a–2l**) and schematic drawings of the different forms of ligands (**A–D**).

of -OH group, observed in the spectra of parent ligands at 3300–3600 cm^{-1} and assigned to aminol OH. This is further supported by the appearance of a new band at 512–536 cm^{-1} due to $\nu_{(Sn\text{-}O)}$ stretching vibrations. In the IR spectra of all complexes, the azomethine $\nu_{(C=N)}$ band appears at 1571–1602 cm^{-1} (appeared at 1617–1625 cm^{-1} in free ligands). Considerable shifts to the lower wave number in its position may be due to the involvement of >C=N group nitrogen in coordination with the tin atom. The appearance of a new band in the IR spectra of these complexes in the region 441–448cm^{-1} and assigned to $\nu_{(Sn\text{-}N)}$ supports the formation of a Sn-N bond (Sedaghat et al., 2011).

^{1}H NMR spectra

In the ^{1}H NMR spectra (Table 1) of ligand enolic and aminol, -OH signals were observed at δ 11.3–12.2 and δ 3.4–4.4, respectively. Absence of these signals in the spectra of diorganotin(IV) derivatives reveals the deprotonation and bonding of these groups with tin atom. Aromatic protons appeared as a multiplet in the region δ 7.9–7.3 in the spectra of ligands as well as their tin complexes. ^{1}H NMR signals due to butyl group attached to tin appeared in the region δ 1.9–1.2 (**2e–2h**). The singlet for CH_3–Sn appeared in the region δ 0.57–1.9, and $^2J(^{119}Sn\text{-}^1H)$ value is observed in the range 69.4–80.2 Hz for **2a–2d** derivatives. These values are found larger than for non-complexed Me_2SnCl_2 (68.7 Hz) (Sedaghat et al., 2011) and found to be in the range of pentacoordinated tin atom (64–79 Hz) (Lockhart et al., 1986) for these dimethyltin(IV) complexes. The $^2J(^{119}Sn\text{-}^1H)$ coupling constant value could not be observed for butyl tin(IV) derivatives as these signals are merged with alkyl and phenyl protons of ligand moieties. There is also no $^2J(^{119}Sn\text{-}^1H)$ coupling for Sn-Ph moieties as the Ph group does not carry any alpha hydrogen.

Substitution of $^2J(^{119}Sn\text{-}^1H)$ coupling constant values (**2a–2d**) in the Lockhart-Manders equation gives the value 125.2°–131.1° for the Me-Sn-Me angle. The observed values for Me-Sn-Me angle further support the pentacoordinated tin (Lockhart et al., 1985) having trigonal bipyramidal geometry in all these derivatives.

Table 1: NMR spectroscopic data (δ) of the Schiff bases **1a–1d** (^{1}H) and the diorganotin(IV) derivatives **2a–2l** (^{1}H, ^{119}Sn).

Compound	R	R′	R″	^{1}H NMR	^{119}Sn NMR
1a		CH_3	-$(CH_2)_2$-	5.521(s)-C**H**CO, 3.284(t)-C**H**$_2$O, 3.115(t)-C**H**$_2$N, 2.010(s)-C**H**$_3$CO, 1.854(s)-C**H**$_3$CN	
1b		CH_3	-$(CH_2)_3$-	5.534(s)-C**H**CO, 3.301(t)-C**H**$_2$O, 3.202(t)-C**H**$_2$N, 2.035(s)-C**H**$_3$CO, 1.915(s)-C**H**$_3$CN	
1c		C_6H_5	-$(CH_2)_2$-	7.152–7.741(m)-C_6**H**$_5$, 5.539(s)-C**H**CO, 3.421(t)-C**H**$_2$O, 3.315(t)-C**H**$_2$N, 1.714(s)-C**H**$_3$CN	
1d		C_6H_5	-$(CH_2)_3$-	7.251–7.811(m)-C_6**H**$_5$, 5.540(s)-C**H**CO, 3.654(t)-C**H**$_2$O, 3.299(t)-C**H**$_2$N, 1.762(s)-C**H**$_3$CN	
2a	CH_3	CH_3	-$(CH_2)_2$-	5.544(s)-C**H**CO, 3.313(t)-C**H**$_2$O(J=7.44 Hz), 3.212(t)-C**H**$_2$N(J=6.12 Hz), 2.056(s)-C**H**$_3$CO, 1.969(s)-C**H**$_3$CN, 1.727(s)-C**H**$_3$, Sn^{2}J(^{119}Sn-^{1}H)=69.4 Hz	-140.7
2b	CH_3	CH_3	-$(CH_2)_3$-	5.582(s)-C**H**CO, 3.472(t)-C**H**$_2$O(J=7.44 Hz), 3.370 (t)-C**H**$_2$N(J=7.44 Hz), 3.204(m)-CH_2-C**H**$_2$-CH_2-, 1.997(s)-C**H**$_3$CO, 1.742(s)-C**H**$_3$CN, 1.216(s)-C**H**$_3$Sn, ^{2}J(^{119}Sn-^{1}H)=72.9 Hz	-142.4
2c	CH_3	C_6H_5	-$(CH_2)_2$-	7.192–7.811(m)-C_6**H**$_5$, 5.554(s)-C**H**CO, 3.714(t)-C**H**$_2$O(J=7.8 Hz), 3.352(t)-C**H**$_2$N(J=6.5 Hz), 1.777(s)-C**H**$_3$CN, 0.774(s)-C**H**$_3$Sn, ^{2}J(^{119}Sn-^{1})=77.8 Hz	-149.2
2d	CH_3	C_6H_5	-$(CH_2)_3$-	7.312–7.775(m)-C_6**H**$_5$, 5.591(s)-C**H**CO, 3.691(t)-C**H**$_2$O(J=7.9 Hz), 3.404(t)-C**H**$_2$N(J=6.14 Hz), 3.389(m)-CH_2-C**H**$_2$-CH_2-, 1.827(s)-C**H**$_3$CN, 1.812(s)-C**H**$_3$Sn, ^{2}J(^{119}Sn-^{1}H)=77.8 Hz	-152.7
2e	C_4H_9	CH_3	-$(CH_2)_2$-	4.909(s)-C**H**CO, 3.680(t)-C**H**$_2$O(J=7.4 Hz), 3.356(t)-C**H**$_2$N(J=7.1 Hz), 1.920(s)-C**H**$_3$CO, 1.908(s)-C**H**$_3$CN, 1.154–1.749(m)-C_4 **H**$_{10}$	-179.3
2f	C_4H_9	CH_3	-$(CH_2)_3$-	4.888(s)-C**H**CO, 3.316(t)-C**H**$_2$O(J=7.44 Hz), 3.003(t) (J=6.78 Hz)-C**H**$_2$N, 3.204(m)-CH_2-C**H**$_2$-CH_2-, 1.910(s)-C**H**$_3$CO, 1.874(s)-C**H**$_3$CN, 1.591–1.184(m)-C_4 **H**$_{10}$	-178.9
2g	C_4H_9	C_6H_5	-$(CH_2)_2$-	7.336–7.753(m)-C_6**H**$_5$, 5.535(s)-C**H**CO, 3.684(t)-C**H**$_2$O(J=9 Hz), 3.332(t)-C**H**$_2$N(J=6.8 Hz), 1.969(s)-C**H**$_3$CN, 1.290–1.175(m)-C_4 **H**$_{10}$	-182.3
2h	C_4H_9	C_6H_5	-$(CH_2)_3$-	7.139–7.656(m)-C_6**H**$_5$, 5.134(s)-C**H**CO, 3.589(t)-C**H**$_2$O(J=7.71 Hz), 3.271(t)-C**H**$_2$N(J=6.5 Hz), 2.998(m)-CH_2-C**H**$_2$-CH_2-, 1.969(s)-C**H**$_3$CN, 1.872–1.183(m)-C_4 **H**$_{10}$	-185.5
2i	C_6H_5	CH_3	-$(CH_2)_2$-	7.569–7.372(m)-C_6**H**$_5$, 5.482(s)-C**H**CO, 3.523(t)-C**H**$_2$O(J=7.41 Hz), 3.295(t)-C**H**$_2$N(J=6.66 Hz), 2.001(s)-C**H**$_3$CO, 1.927(s)-C**H**$_3$CN	-254.8
2j	C_6H_5	CH_3	-$(CH_2)_3$-	7.754–7.275(m)-C_6**H**$_5$, 5.561(s)-C**H**CO, 3.648(t)-C**H**$_2$O(J=7.9 Hz),3.339(t)-C**H**$_2$N(J=7.1 Hz), 3.323(m)-CH_2-C**H**$_2$-CH_2-, 1.951(s)-C**H**$_3$CO, 1.799(s)-C**H**$_3$CN	-255.3
2k	C_6H_5	C_6H_5	-$(CH_2)_2$-	7.856–7.305(m)-C_6**H**$_5$, 5.515(s)-C**H**CO, 3.515(t)-C**H**$_2$O(J=7.81 Hz),3.341(t)-C**H**$_2$N(J=6.44 Hz), 1.774 (s)-C**H**$_3$CN	-269.4
2l	C_6H_5	C_6H_5	-$(CH_2)_3$-	7.671–7.293(m)-C_6**H**$_5$, 5.392(s)-C**H**CO, 3.697(t)-C**H**$_2$O(J=9 Hz),3.317(t)-C**H**$_2$N(J=7.03 Hz), 3.235(m)-CH_2-C**H**$_2$-CH_2-, 1.704(s)-C**H**$_3$CN	-271.1

^{13}C NMR spectra

^{13}C NMR spectral data of these derivatives have been summarized in Table 2. The spectra of all these derivatives (**2a–2l**) exhibit signal for >C-O- enolic group carbon in the range δ 187.5–195.8 in these organotin compounds as well as their corresponding ligands. A small downfield shift is observed in the position of this signal as compared to their corresponding free ligands. Signal for >C=N imine group carbon has been observed in the range δ 162.9–165.9. A downfield shift of ~2–5 ppm has been observed as compared to its position in corresponding free Schiff base ligands. The shifts in the positions of carbon atom adjacent to the imine group nitrogen suggest that nitrogen is involved with tin in these complexes. The signal for CH_2O- group carbon (deprotonated amino alcohol group) appeared in the range of δ 60.7–68.3 having a slight downfield shift (~2 ppm) as compared to their position in free Schiff base moieties. Signals for CH_3-Sn group carbon appeared in the range δ 19.4–20.3 in **2a–2d** derivatives. The ^1J(^{119}Sn-^{13}C) coupling constant values were found in the range 553–596 Hz for **2a–2d** derivatives, which is consistent with pentacoordination range (470–610 Hz) (Lockhart et al., 1985).

^{119}Sn NMR spectra

^{119}Sn NMR spectra of tin complexes exhibit one sharp singlet in the range δ -140.7 to δ -271.1. These chemical shifts are observed at lower frequency as compared to $SnMe_2Cl_2$ (137 ppm), $SnBu_2Cl_2$ (122 ppm) and $SnPh_2Cl_2$ (-32 ppm) (Sedaghat et al., 2012a,b,c) and depict the presence of five coordinated tin atoms in these derivatives.

Table 2: ^{13}C NMR spectroscopic data (δ) of some new diorganotin(IV) Schiff base derivatives.

Compound	=C-OH-	>C=N	Phenyl carbon				Alkylene carbon
			C_1 $C_{1'}$	C_2 $C_{2'}$	C_3 $C_{3'}$	C_4 $C_{4'}$	
1a			–	–	–	–	93.6(=**C**H-), 62.1(**C**H_2O), 57.6(**C**H_2N), 33.3(**C**H_3CO), 25.8(**C**H_3CN)
	191.1	162.6	–	–	–	–	
1b			–	–	–	–	94.1(=**C**H-), 61.3(**C**H_2O), 57.7(**C**H_2N), 40.5(**C**H_2), 32.5(**C**H_3CO),
	193.5	163.4	–	–	–	–	26.2(**C**H_3CN)
1c			–	–	–	–	94.3(=**C**H-), 61.7(**C**H_2O), 58.2(**C**H_2N), 26.6(**C**H_3CN)
	188.2	161.7	140.9	135.1	130.5	126.1	
1d			–	–	–	–	95.8(=**C**H-), 62.4(**C**H_2O), 58.5(**C**H_2N), 41.2(**C**H_2), 26.3(**C**H_3CN)
	187.1	163.8	140.5	135.4	129.4	126.9	
2a			–	–	–	–	94.9(=**C**H-), 62.2(**C**H_2O), 58.1(**C**H_2N), 33.9(**C**H_3CO), 26.4(**C**H_3CN),
	194.2	164.2	–	–	–	–	19.4(**C**H_3Sn), $^1J(^{119}Sn\text{-}^{13}C)$=553 Hz
2b			–	–	–	–	96.6(=**C**H-), 68.3(**C**H_2O), 51.2(**C**H_2N), 41.2(**C**H_2), 31.2(**C**H_3CO),
	195.8	165.0	–	–	–	–	24.3(**C**H_3CN) 20.3(**C**H_3Sn), $^1J(^{119}Sn\text{-}^{13}C)$=561 Hz
2c			–	–	–	–	94.7(=**C**H-), 67.2(**C**H_2O), 57.7(**C**H_2N), 28.0(**C**H_3CN)
	189.7	164.3	140.2	135.7	130.1	126.5	19.9(**C**H_3Sn), $^1J(^{119}Sn\text{-}^{13}C)$=578 Hz
2d			–	–	–	–	92.2(=**C**H-), 70.1(**C**H_2O), 59.5(**C**H_2N), 39.9(**C**H_2), 26.4(**C**H_3CN)
	187.6	165.4	140.4	136.0	129.9	126.8	19.4(**C**H_3Sn), $^1J(^{119}Sn\text{-}^{13}C)$=596 Hz
2e			–	–	–	–	95.7(=**C**H-), 67.6(**C**H_2O), 52.4(**C**H_2N), 33.2(**C**H_3CO), 27.4,(**C**H_3CN),
	194.8	164.2	–	–	–	–	23.1–19.2(**C**$_4H_{10}$)
2f			–	–	–	–	94.6(=**C**H-), 62.7(**C**H_2O), 56.2(**C**H_2N), 38.9(**C**H_2), 31.6(**C**H_3CO),
	194.1	162.9	–	–	–	–	28.3(**C**H_3CN), 26.0–17.8(**C**$_4H_{10}$)
2g			–	–	–	–	94.9(=**C**H-), 62.0(**C**H_2O), 51.9(**C**H_2N), 27.4(**C**H_3CN), 25.4–19.6(**C**$_4H_{10}$)
	187.9	165.8	140.3	135.7	129.8	126.7	
2h			–	–	–	–	95.2(=**C**H-), 60.9(**C**H_2O), 53.6(**C**H_2N), 39.8(**C**H_2), 28.5(**C**H_3CN)
	194.5	163.8	140.4	136.2	130.1	126.1	21.8–15.7(**C**$_4H_{10}$)
2i			139.4	136.6	129.1	125.8	94.2(=**C**H-), 65.2(**C**H_2O), 57.2(**C**H_2N), 35.2(**C**H_3CO), 27.6(**C**H_3CN)
	194.2	163.6	–	–	–	–	
2j			139.4	135.9	129.5	126.5	92.2(=**C**H-), 66.3(**C**H_2O), 59.3(**C**H_2N), 40.1(**C**H_2), 32.1(**C**H_3CO),
	187.5	165.7	–	–	–	–	27.1(**C**H_3CN)
2k			138.1	135.0	129.1	125.8	95.7(=**C**H-), 60.7(**C**H_2O), 53.6(**C**H_2N), 39.9(CH_2), 24.8(CH_3CN)
	192.9	164.9	139.3	136.8	130.4	126.3	
2l			139.2	135.9	128.9	126.2	94.6(=**C**H-), 64.6(**C**H_2O), 60.2(**C**H_2N), 44.5(**C**H_2), 26.2(**C**H_3CN)
	193.7	162.9	140.9	137.1	130.3	127.0	

C_1, C_2, C_3 and C_4 denote the phenyl carbons of group R. $C_{1'}$, $C_{2'}$, $C_{3'}$ and $C_{4'}$ denote the phenyl carbons of group R′.

Fast atom bombardment mass spectra

Fast atom bombardment (FAB) mass spectral data of three diorganotin(IV) derivatives (**2a**), (**2e**) and (**2i**) have been recorded. The spectra reveal the monomeric nature of these compounds, and their fragmentation patterns are being summarized in the Experimental section. The mass peaks indicate the formation of a variety of fragments during the course of decomposition. In these three compounds, molecular ion peaks are observed at m/z 291, 374 and 414, respectively. Base peaks for these compounds are observed at 278 (**2a**), 361(**2e**) and 401(**2i**). In all these three compounds, molecular ion peaks are not observed as base peak and fragmentation initiate in same manner by the loss of ethylenic (=CH) carbon. After the formation of base ion peak in these compounds **2a**, **2e** and **2i**, the decomposition takes place through the fragmentation of Schiff base moiety.

The $[R\text{-}Sn]^+$ fragment is formed as a final decomposition product in all these three compounds, showing strong R-Sn bonding.

Structural elucidation

In view of the above mentioned spectroscopic data, the following structures having bifunctional tridentate Schiff bases with pentacoordinated tin may be proposed in solution for these diorganotin(IV) derivatives **2a–2l** (see drawing in Scheme 1). According to the Bent's rule, both the R- groups will occupy equatorial positions. Pentacoordination around tin atom (bond angle of 124°–131°) is

Table 3: Antibacterial studies of the ligands and their organotin derivatives (**2a–2l**).

Compound	Concentration (mg/mL)	Zone size (mm)			
		S. aureus	*B. subtilis*	*E. coli*	*P. aeruginosa*
Me_2SnCl_2	2	7	6	6	5
	4	8	9	8	7
Bu_2SnCl_2	2	7	7	5	6
	4	10	10	9	9
Ph_2SnCl_2	2	9	8	8	7
	4	12	11	10	10
LH_2 (**1a**)	2	6	7	5	7
	4	8	9	7	9
LH_2 (**1b**)	2	7	8	6	8
	4	10	10	9	10
LH_2 (**1c**)	2	6	7	6	7
	4	8	12	8	11
LH_2 (**1d**)	2	7	9	7	9
	4	11	14	10	12
2a	2	11	9	8	7
	4	14	15	13	11
2b	2	13	12	11	10
	4	17	15	16	14
2c	2	10	12	10	9
	4	13	16	13	12
2d	2	14	13	12	8
	4	17	17	16	11
2e	2	12	12	12	9
	4	17	19	13	13
2f	2	15	17	14	12
	4	19	20	18	17
2g	2	13	14	13	10
	4	19	19	17	13
2h	2	16	16	11	12
	4	20	19	14	19
2i	2	14	14	12	13
	4	19	20	15	18
2j	2	17	17	13	15
	4	21	20	19	18
2k	2	15	14	12	14
	4	18	16	18	16
2l	2	17	18	11	13
	4	20	21	16	15

confirmed by ^{1}H, ^{13}C and ^{119} Sn NMR spectroscopic data, and the opening of the bond may be explained by the solvent effect.

Antimicrobial activity

Diorganotin derivatives (**2a–2l**) with their corresponding free Schiff bases (**1a–1d**) and metal precursors were screened against bacteria (Table 3: Figures S1, S2, S3 and S4) and fungi (Table 4: Figures S5 and S6) to examine their growth inhibitory potential towards the test organisms. Apparently, the complexes are more toxic towards Gram-positive strains (*Staphylococcus aureus* and *Bacillus subtilis*) than Gram-negative strains (*Escherichia coli* and *Pseudomonas aeruginosa*). The reason probably lies in the difference between the structures of the cell walls. The relatively more complex walls of Gram-negative cells may prevent the diffusion of chemicals into the cytoplasm of the organisms, which may not be the case of Gram-positive cells. The results indicate that the metal chelates have higher activity than the free ligands as well as metal precursors. This increased activity of the metal chelates can be explained by Tweedy's chelation theory (Tweedy, 1964) and Overtone's concept. According to Overtone's concept of cell permeability, the lipid membrane that surrounds the cell favors passage of only lipid-soluble material due to liposolubility, which is an important factor that controls

Table 4: Antifungal studies of the ligands and their organotin derivatives (**2a**–**2l**).

Compound	Concentration (mg/mL)	Zone size (mm)			
		F. oxysporum	*T. reesei*	*P. funiculosum*	*A. niger*
Me_2SnCl_2	2	7	6	6	5
	4	8	9	8	7
Bu_2SnCl_2	2	9	8	7	6
	4	11	12	11	10
Ph_2SnCl_2	2	11	10	9	8
	4	13	12	13	12
LH_2 (**1a**)	2	6	5	5	6
	4	7	9	8	9
LH_2 (**1b**)	2	7	8	6	7
	4	9	11	9	10
LH_2 (**1c**)	2	8	7	7	8
	4	10	11	10	11
LH_2 (**1d**)	2	7	9	7	8
	4	11	12	12	10
2a	2	8	7	8	9
	4	12	11	10	13
2b	2	10	9	14	13
	4	13	12	16	17
2c	2	11	13	11	14
	4	15	14	15	16
2d	2	12	15	16	17
	4	15	18	20	20
2e	2	11	11	13	14
	4	13	14	17	19
2f	2	13	12	14	17
	4	15	16	18	24
2g	2	16	17	17	17
	4	19	19	21	22
2h	2	18	19	20	18
	4	20	22	23	22
2i	2	12	10	15	16
	4	18	16	21	20
2j	2	13	12	14	18
	4	17	16	19	22
2k	2	14	17	17	19
	4	19	19	21	22
2l	2	15	16	19	20
	4	18	20	24	23

antimicrobial activity. On chelation, the polarity of the metal ions is reduced to a greater extent due to the overlap of the ligand orbital and partial sharing of the positive charge of the metal ion with a donor group. Enhanced activity may be due to the coordination of ligand to tin leading to electron delocalization and therefore increasing the lipophilic character and efficient diffusion of the metal complexes into bacterial cells. It has been observed that a small structural change, such as change of alkyl group present, increases the activity of compounds in the order $R=CH_3<C_4H_{10}<C_6H_5$ (Sonika and Malhotra, 2011).

The concentration of a compound is another important factor on which the inhibition growth is affected. At lower concentration (2 mg/mL) growth will be slowed down, while at higher concentration more enzymes will become inhibited, leading to a quicker death of organism.

Conclusion

The organotin(IV) derivatives reported here have been characterized by elemental analyses, IR, NMR and FAB mass spectral data. Schiff bases behave as a bifunctional tridentate moiety. ^{1}H, ^{13}C and ^{119}Sn NMR values support the pentacoordinated tin having distorted trigonal bipyramidal geometry. The metal derivatives were found to be more inhibitory than corresponding Schiff bases in the result

Table 5: Synthetic and analytical data of some new diorganotin (IV) Schiff base derivatives (**2a–2l**).

Compd	Reactants g/(mmol)			NaCl found (calcd.)	Empirical formula (Yield %)	Color, physical state (m.p., °C)	Analyses % found (calcd.)			
	R_2SnCl_2	LNa_2	LH_2				Sn	C	H	N
2a	1.505	1.280	0.98	0.792	$C_9H_{17}O_2NSn$ (83)	Creamish white, solid (155)	40.87	37.11	5.85	4.77
	(6.84)	(6.84)	(6.84)	(0.803)			(40.94)	(37.28)	(5.90)	(4.83)
2b	1.439	1.315	1.028	0.753	$C_{10}H_{19}O_2NSn$ (79)	Dark brown, viscous	38.95	39.74	6.21	4.48
	(6.54)	(6.54)	(6.54)	(0.766)			(39.05)	(39.51)	(6.29)	(4.60)
2c	1.248	1.413	1.163	0.649	$C_{14}H_{19}O_2NSn$ (78)	Creamish white, solid (162)	33.61	47.53	5.33	3.87
	(5.67)	(5.67)	(5.67)	(0.662)			(33.72)	(47.76)	(5.44)	(3.99)
2d	1.195	1.429	1.190	0.627	$C_{15}H_{21}O_2NSn$ (76)	Dark brown, viscous	32.31	48.98	5.61	3.85
	(5.43)	(5.43)	(5.43)	(0.636)			(32.43)	(49.22)	(5.78)	(3.83)
2e	1.622	1.00	0.764	0.613	$C_{15}H_{29}O_2NSn$ (82)	Light brown, solid (168)	31.67	48.25	7.91	3.76
	(5.34)	(5.34)	(5.34)	(0.625)			(31.73)	(48.16)	(7.81)	(3.74)
2f	1.564	1.036	0.809	0.591	$C_{16}H_{31}O_2NSn$ (81)	Brown, viscous	30.50	49.26	8.11	3.52
	(5.15)	(5.15)	(5.15)	(0.602)			(30.58)	(49.51)	(8.04)	(3.60)
2g	1.388	1.139	0.938	0.523	$C_{20}H_{31}O_2NSn$ (78)	Brown, solid (171)	27.07	55.18	7.10	3.11
	(4.57)	(4.57)	(4.57)	(0.536)			(27.21)	(55.07)	(7.16)	(3.21)
2h	1.349	1.168	0.973	0.501	$C_{21}H_{33}O_2NSn$ (75)	Brown, viscous	26.15	55.91	7.29	3.16
	(4.44)	(4.44)	(4.44)	(0.519)			(26.36)	(56.02)	(7.38)	(3.11)
2i	1.656	0.901	0.689	0.551	$C_{19}H_{21}O_2NSn$ (81)	Creamish white, solid (182)	28.32	55.43	5.13	3.27
	(4.81)	(4.81)	(4.81)	(0.564)			(28.67)	(55.11)	(5.11)	(3.38)
2j	1.605	0.939	0.734	0.538	$C_{20}H_{23}O_2NSn$ (80)	Brown, viscous	27.57	56.02	5.47	3.33
	4.67	4.67	4.67	(0.546)			(27.73)	(56.11)	(5.41)	(3.27)
2k	1.440	1.041	0.857	0.479	$C_{24}H_{23}O_2NSn$ (79)	Creamish white, solid (189)	24.81	60.43	4.78	2.86
	4.18	4.18	4.18	(0.491)			(24.93)	(60.54)	(4.86)	(2.94)
2l	1.395	1.068	0.890	0.465	$C_{25}H_{25}O_2NSn$ (76)	Dark brown, viscous	24.18	61.47	5.06	2.71
	4.06	4.06	4.06	(0.477)			(24.22)	(61.25)	(5.14)	(2.85)

of antimicrobial activities, and the activity increases with the concentration and depend on the nature of the group attached to the tin atom.

Experimental

Materials and methods

Solvents were purified and dried by standard procedures. Schiff bases (**1a–1d**) were prepared by the condensation reactions of β-diketones with appropriate amino alcohols. Dialkyltin dichloride (Aldrich, USA) was distilled prior to use. Tin was estimated (Vogel, 1989) as tin dioxide in these derivatives. Carbon, hydrogen and nitrogen were analyzed on elemental analyzer Elementar Vario EL III.

^{1}H, ^{13}C and ^{119}Sn NMR spectra were recorded in $CDCl_3$ solution on Bruker FT 400 MHz NMR spectrometer (Brucker coorporation, Billerica, MA, USA). TMS was used as internal reference for ^{1}H and ^{13}C NMR spectra. IR spectra were recorded on 8400 s SHIMADZU FT IR Spectrophotometer (Kyoto, Japan) as nujol mull in KBr disk in the range 4000–400 cm^{-1}. The FAB mass spectra of three representative compounds were recorded on Jeol-SX 102/Da-600 mass spectrometer (Jeol coorporation, Akishima, Tokyo, Japan).

As the synthetic procedure for all these compounds is the same, for the sake of brevity details of only one compound are given, and the analytical as well as preparative details of the rest of compounds are summarized in Table 5.

Syntheses of $(CH_3)_2Sn[OC(CH_3):CH(CH_3)C:N(CH_2CH_2)O]$

The sodium salt of Schiff base has been synthesized by the reaction of sodium methoxide [prepared by the reaction of sodium (0.316 g, 6.84 mmol) in dry methanol (~10 mL)] and THF solution (~15 mL) of Schiff base (0.98 g, 6.84 mmol). The mixture was heated at reflux for half an hour.

To this solution, a THF solution (~40 mL) of dimethyltindichloride (1.505 g, 6.84 mmol) was mixed, and the reaction mixture was refluxed for ~6 h. NaCl thus precipitated was filtered off, and the excess of solvent was removed under reduced pressure to yield a creamish white solid (m.p. 155°C). The compound was recrystallized from THF/*n*-hexane mixture. Percent analyses for $C_9H_{17}O_2NSn$; found (calculated) Sn, 40.72 (40.79) C, 54.96 (55.07) H, 5.65 (5.88) N, 4.73% (4.81) FAB mass spectral data; fragments, m/z (relative intensity) $[C_9H_{17}O_2NSn]^+ \cdot$ 291 (37.83%), $[C_8H_{16}O_2NSn]^+ \cdot$ 279 (100%), $[C_6H_{13}O_2NSn]^+ \cdot$ 251 (30.01%), $[C_4H_{10}ONSn]^+ \cdot$ 208 (6.17%), $[C_3H_8SnO]^+ \cdot$ 180 (8.54%), $[C_2H_6SnO]^+ \cdot$ 166 (4.62%), $[CH_3Sn]^+ \cdot$ 135 (50.80%).

Mass spectral data of compound $(C_4H_{10})_2Sn[OC(CH_3):CH(CH_3)C:N(CH_2CH_2)O]$

FAB mass spectral data; fragments, m/z (relative intensity) $[C_{15}H_{29}O_2NSn]^+ \cdot$ 374 (29.11%), $[C_{14}H_{28}O_2NSn]^+ \cdot$ 361 (100%), $[C_{12}H_{25}O_2NSn]^+ \cdot$ 334 (18.81%), $[C_{10}H_{22}ONSn]^+ \cdot$ 291 (7.19%), $[C_9H_{20}SnO]^+ \cdot$ 263 (3.54%), $[C_8H_{18}SnO]^+ \cdot$ 249 (9.21%), $[C_4H_9Sn]^+ \cdot$ 176 (48.07%).

Mass spectral data of compound

$(C_6H_5)_2Sn[OC(CH_3):CH\ (CH_3)C:N(CH_2CH_2)O]$

FAB mass spectral data; fragments, m/z (relative intensity) $[C_{19}H_{21}O_2NSn]^+$ · 414 (30.25%), $[C_{18}H_{20}O_2NSn]^+$ · 401 (100%), $[C_{16}H_{17}O_2NSn]^+$ · 374 (16.47%), $[C_{14}H_{14}ONSn]^+$ · 331 (5.11%), $[C_{13}H_{12}SnO]^+$ · 287 (3.89%), $[C_{12}H_{10}SnO]^+$ · 273 (8.52%), $[C_6H_5Sn]^+$ · 180 (46.45%).

Antimicrobial activity

The ligands (**1a–1d**) and their corresponding diorganotin derivatives have been screened for the growth inhibitory activity *in vitro* against bacteria (i.e. *S. aureus*, *B. subtilis*, *E. coli* and *P. aeruginosa*) and fungi (i.e. *Fusarium oxysporum*, *Trichoderma reesei*, *Penicillium funiculosum* and *Aspergillus niger*). For both bactericidal and fungicidal assays, *in vitro* disc diffusion method was adopted because of reproducibility and precision. In this method, the different test organisms were processed separately using a sterile swab over previously sterilized culture medium plates, and the zones of inhibition were measured around sterilized dried discs of Whatman paper no.1 (6 mm in diameter) in two different (2 mg/mL, 4 mg/mL) concentrations of the test solution. Dimethyl sulfoxide was used as solvent, and discs were air dried at room temperature to remove any residual solvent. After this, they were sterilized and inoculated. The plates were initially placed at low temperature for 1 h, so as to allow maximum diffusion of the compounds from the test discs into the plate, and later incubated for 24 h at 34°C in the case of bacteria and 48 h at 27°C for fungi, after which the zones of inhibition could be easily observed. The inhibition zone diameters in each case were recorded and shown in Tables 3 and 4. In account of antimicrobial activity, some images are given in the online supplementary material as Figures S1–S6.

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References

Baul, T.; Basu, S. Antimicrobial activity of organotin(IV) compounds: a review. *Appl. Organomet. Chem*. **2008**, *22*, 195–204.

Borisova, N. E.; Reshetova, M. D.; Ustynyuk, Y. A. Metal-free methods in the synthesis of macrocyclic Schiff bases. *Chem. Rev.* **2007**, *107*, 46–79.

Dey, D. K.; Dey, S. P.; Karan, N. K.; Dutta, A.; Lycka, A.; Rosair, G. M. Structural and spectral studies of 3-(2-hydroxyphenylimino)-1-pheylbutan-1-one and its diorganotin(IV) complexes. *J. Organomet. Chem*. **2009**, *694*, 2434–2441.

Joshi, A.; Verma, S.; Gaur, R. B.; Sharma, R. R. Di-n-butyltin(IV) complexes derived from heterocyclic β-diketones and N-phthaloyl amino acids: Preparation, biological evaluation, structural elucidation based upon spectral [IR, NMR (^1H, ^{13}C, ^{19}F and ^{119}Sn)] studies. *Bioinorg. Chem. Appl*. **2005**, *3*, 201–215.

Lockhart, T. P.; Manders, W. F.; Zuckerman, J. J. Strucrural investigation by solid-state ^{13}C NMR. Dependence of ^1J (^{119}Sn, ^{13}C) on the Me-Sn-Me angle in methyltin(IV)s. *J. Am. Chem. Soc*. **1985**, *107*, 4546–4547.

Lockhart, T. P.; Manders, W. F.; Schlemper, E. O.; Zuckerman, J. J. Elucidation of medium effects on molecular structure by solid-state and solution carbon-13 NMR. Identification and X-ray structure of the orthorhombic modification of dimethyltin(I) bis(N,N-diethyldithiocarbamate). *J. Am. Chem. Soc*. **1986**, *108*, 4074–4078.

Nath, M.; Vats, M.; Roy, P. Tri and diorganotin(IV) complexes of biologically important orotic acid: synthesis, spectroscopic studies, in vitro anticancer, DNA fragmentation, enzymes assays and in vivo anti inflammotaory activities. *Eur. J. Med. Chem*. 2013, *59*, 310–321.

Pellerito, L.; Nagy, L. Organotin(IV)n+ complexes formed with biologically active ligands: equilibrium and structural studies, and some biological aspects. *Coordin. Chem. Rev.* **2002**, *224*, 111–150.

Sedaghat, T.; Monajjemzadeh, M.; Motamedi, H. New diorganotin(IV) complexes with some Schiff bases derived from β-diketones: synthesis, spectral properties, thermal analysis, and antibacterial activity. *J. Coord. Chem*. **2011**, *64*, 3169–3179.

Sedaghat, T.; Naseh, M.; Bruno, G.; Rudbari, A. H.; Motamedi, H. New diorganotin(IV) complexes with 3-(2-hydroxy-5-methylphenylamino)-1,3-diphenylprop-2-en-1-one: synthesis, spectroscopic characterization, structural studies and antibacterial activity *J. Mol. Struct*. **2012a**, *1026*, 44–50.

Sedaghat, T.; Naseh, M.; Khavasi, H. R.; Motamedi, H. Synthesis, spectroscopic investigations, crystal structures and antibacterial activity of 3-(3-hydroxypyridin-2-ylamino)-1-phenylbut-2-en-1-one and its diorganotin(IV) complexes. *Polyhedron* **2012b**, *33*, 435–440.

Sedaghat, T.; Habibi, R.; Motamedi, H.; Hamid, K.R. Synthesis, structural characterization and antibacterial activity of diorganotin(IV) complexes with ONO tridentate Schiff bases containing pyridine ring. *Chinese Chem. Lett.* **2012c**, *23*, 1355–1358.

Sharma, S.; Jain, A.; Saxena, S. N-protected amino acids and ketooximes-modified dibutyltin dichloride; synthetic strategy and structural aspects based upon spectral (IR, NMR ^1H, ^{13}C, ^{119}Sn) studies. *Main Group Met.Chem*. **2007**, *30*, 63–73.

Singh, R. V.; Chaudhary, P.; Chauhan, S.; Swami, M. Microwave-assisted synthesis, characterization and biological activities of organotin (IV) complexes with some thio Schiff bases. *Spectrochim. Acta A* **2009**, *72A*, 260–268.

Singh, K.; Puri, P.; Kumar, Y.; Sharma, C.; Rai, A. K. Biological and spectral studies of newly synthesized triazole Schiff bases and their Si(IV), Sn(IV) complexes. *Bioinorg. Chem. Appl.* **2011**, *2011*, 654250.

Sonika, N.; Malhotra, R. Synthesis and structural studies on penta and hexaco-ordinatedorganotin(IV) complexes and alkyl pyruvate aroyl hydrazones. *Der. Pharma Chem*. **2011**, *3*, 305–313.

Tweedy, B. G. Plant extracts with metal ions as potential antimicrobial agents. *Phytopathology* **1964**, *55*, 910–914.

Vogel, A. I. Text Book of Quantitative Chemical Analysis, 5th ed.; Longman: London, 1989.

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