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Research Article

Synthesis, Characterization, and Thermal and Antimicrobial Activities of Some Novel Organotin(IV): Purine Base Complexes

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A new series of organotin(IV) complexes with purine bases theophylline (HL^1) and theobromine (L^2) of the types $R_3Sn(L^1)$, $R_2Sn(L^1)Cl$, $R_3Sn(L^2)Cl$, and $R_2Sn(L^2)Cl_2$(R = $C_6H_5CH_2$–; *p*-$ClC_6H_4CH_2$–) have been synthesized in anhydrous THF. The complexes were characterized by elemental analysis, conductance measurements, molecular weight determinations, UV-vis, IR, ^1H, ^{13}C NMR, and mass spectral studies. Various kinetic and thermodynamic parameters of these complexes have also been determined using TG/DTA technique. The thermal decomposition techniques indicate the formation of SnO_2 as a residue. The results show that the ligands act as bidentate, forming a five-member chelate ring. All the complexes are 1 : 1 metal-ligand complexes. In order to assess their antimicrobial activity, the ligands and their corresponding complexes have also been tested *in vitro* against bacteria (*E. coli, S. aureus*, and *P. pyocyanea*) and fungi (*Rhizopus oryzae* and *Aspergillus flavus*). All the complexes exhibit remarkable activity, and the results provide evidence that the studied complexes might indeed be a potential source of antimicrobial agents.

1. Introduction

Organotin(IV) compounds are characterized by the presence of at least one covalent carbon-organotin bond. The compounds contain tin centres which are tetravalent and are classified as mono-, di-, tri-, and tetraorganotin(IV), depending on the number of alkyl (R) or aryl (Ar) moieties. During the last 65 years, the worldwide production of organotin compounds and their derivatives has increased considerably, owing to their activities as anticancer [1], antifouling [2–4] and bactericidal [5–9], fungicidal [7–13], antifertility [6, 8, 9], and antiviral agents [14]. Since biocidal properties of organotin(IV) compounds are dependent on both the organic group and the ligand attached to the tin [15, 16], an interesting development is introducing ligands which are themselves bioactive [15, 17–19].

Compounds containing purine play a significant role in many biological systems [20], where they exist in nucleic acids, several vitamins, coenzymes, and antibiotics. These provide potential binding sites for metal ions, and any information on their coordinating properties is important as a means of understanding the role of the metal ion in biological systems. Theophylline (1, 3-dimethylxanthine) and theobromine (3, 7-dimethylxanthine) are referred to as purine bases and constitute an important class of anti-inflammatory agents [21]. Theophylline has biological importance as it is structurally related to nucleic acids components [22] and thus can be used as a drug for the treatment of asthmatic bronchitis and chronic obstructive bronchitis under a variety of brand names and as anticancer drugs.

The interest in metal complexes of theophylline and theobromine is stimulated by the fact that certain purine-metal complexes have been found to have therapeutic value as diuretics [23]. It is also important to study the mode of binding of the ligand with the metal [24]. Moreover, the study of the behavior of theophylline as a ligand can be useful for elucidating the metal and interligand interactions involving the purine bases of nucleic acids or their nucleosides, as the theophylline molecule can be considered as a model for the nucleoside guanosine. In continuation of our previous work,

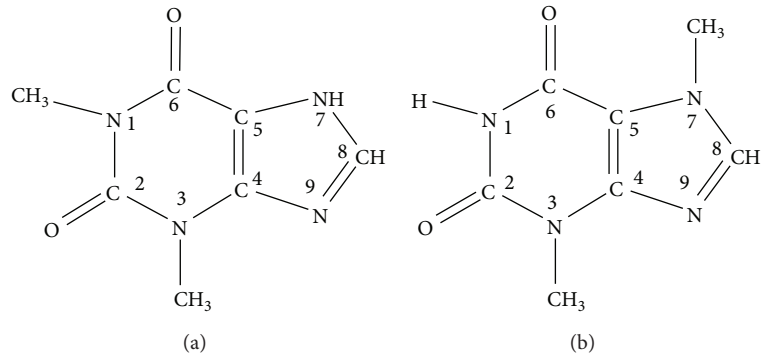


Figure 1: Structure of (a) theophylline and (b) theobromine ligands.

here we present the synthesis, mode of binding, thermal studies, and antimicrobial properties of some organotin(IV) complexes with purine bases theophylline (Figure 1(a)) and theobromine (Figure 1(b)).

2. Experimental

2.1. Physical Measurements. All reagents used were AR grade, and the solvents were purified and dried by standard methods, and moisture was excluded from glass apparatus using $CaCl_2$ drying tubes. The elemental analysis was carried out on an Elementar Analysensysteme GmbH Varion EL *III*, Germany. IR and far IR spectra were recorded on KBr and polyethylene discs, respectively, using a Perkin Elmer Spectrum 2000 FTIR spectrometer. The ^{13}C and ^{1}H NMR spectra were recorded in $CDCl_3$, respectively, on a Bruker Spectrospin Advance 300 spectrometer. Tetramethylsilane was used as an internal reference for ^{1}H NMR. Varian Cary 100 UV-VIS spectrophotometer was used to record the electronic spectra of the compounds. Conductance measurements were carried out on Elico Conductivity Bridge (Type CM82T), and mass spectra were obtained using Jeol SX-102(FAB) mass spectrometer. Thermal studies (TG/DTA curves) were recorded on a Rigaku Corporation Thermoflex PTC-10A, in static air at a heating rate of 10°C/min. The Pt crucible was used with alumina as the reference material. Chlorine was determined gravimetrically as silver chloride [25, 26]. Tin was also estimated gravimetrically as SnO_2 [27]. The antibacterial activities were evaluated by the paper-disc plate method [28] and antifungal by agar plate technique [29]. Molecular masses of the complexes were determined by Cottrell's method of boiling point elevation [30].

2.2. Antimicrobial Activity

2.2.1. Antibacterial Activity. For the evaluation of degree of inhibitory effects on the growth of a wide spectrum of microorganisms, antibacterial activity was performed against one Gram-positive (*Staphylococcus aureus*) and three Gram-negative (*Escherichia coli, Pseudomonas aeruginosa,* and *Klebsiella pneumoniae*) bacteria. In order to compare the results obtained the Imipenem was used as standard drug. Determination of the antibacterial activity was carried out by the paper-disc plate method [28]. The compounds were dissolved in DMF at 500 and 1000 ppm concentrations. The Whatman no. 1 papers with a diameter 5 mm were soaked in these solutions. These discs were placed on the appropriate nutrient medium (0.5% peptone, 0.15% yeast, 0.15% beef extract, 0.35% sodium chloride, and 0.13% KH_2PO_4 in 1000 cm^3 distilled water which was autoclaved for 20 min at 15 psi before inoculation), previously seeded with organisms, in Petri dishes and stored in an incubator at 28 ± 2°C. The inhibition zone thus formed around each disc was measured (in mm) after 96 h.

2.2.2. Antifungal Studies. Bioefficacies of the synthesized compounds were checked *in vitro*. The *in vitro* antifungal activities of the ligands and their complexes were evaluated against two pathogenic fungi, *Rhizopus oryzae* (causes zygomycosis) *and Aspergillus flavus* (causing aspergillosis of lungs) by the agar plate technique [29]. In order to compare the results obtained, the *Bavistin* was used as standard drug. The compounds were directly mixed with the medium in 0.01 and 0.1% (in methanol) concentrations. The medium was then poured into Petri plates, and a small disc (0.7 cm) of the fungus culture was cut with a sterile cork borer and transferred aseptically into the centre of a Petri dish containing the medium, with a certain amount of the compound. Suitable checks were kept where the culture discs were grown under the same conditions on PDA without the compound. These Petri dishes were wrapped in polythene bags containing a few drops of alcohol and were placed in an incubator at 25 ± 2°C. Controls were also run, and three replicates were used in each case. The linear growth of the fungus was obtained by measuring the diameter of the fungal colony after four days. The amount of growth inhibition in each of the replicate was calculated by percentage inhibition = $(C - T) \times 100/C$, where C is diameter of the fungus colony in the control plate after 96 h and T is diameter of the fungus colony in tested plates after the same period.

2.3. Preparation of Complexes. $(C_6H_5CH_2)_3SnCl$, $(p\text{-}ClC_6H_4\cdot CH_2)_3SnCl$, $(C_6H_5CH_2)_2SnCl_2$, and $(p\text{-}ClC_6H_5CH_2)_2SnCl_2$ were synthesized by the method given by Sisido et al. [31]. The organotin(IV) complexes of theophylline (HL^1)

and theobromine (L^2) were synthesized according to the procedure reported by Bhatia et al. [32].

A solution of theophylline (HL^1, 1.80 g, 0.01 mol) in 25 mL THF and 5 g NaOH was stirred for about 12 hrs at room temperature. A solution of R_3SnCl or R_2SnCl_2 (0.01 mol) in 25 mL THF was added to it and stirred for 4H at room temperature. The contents were then filtered, and the filtrate was reduced to one-fourth of its original volume. The R_3SnL^1 or $R_2Sn(L^1)Cl$ complexes precipitated out on adding petroleum ether and were recrystallised from acetone. Theobromine complexes were synthesized by simply adding a solution of R_3SnCl or R_2SnCl_2 (0.01 mol) in 25 mL THF to a suspension of theobromine (L^2, 1.80 g, 0.01 mol) in 25 mL THF and stirred for 3 hours at room temperature. The contents were filtered, and volume was reduced to one-fourth of its original volume. The $R_3SnL^2(Cl)$ or $R_2Sn(L^2)Cl_2$ complexes precipitated out on addition of petroleum ether and were recrystallised from acetone.

3. Results and Discussion

Elemental analyses reveal that the complexes are of good purity and are yellow in colour. The complexes were found to be soluble in acetonitrile, THF, DMSO, acetone, and $CHCl_3$. The complexes decomposed before melting. The analytical data of the complexes along with their decomposition temperature is given in Table 1. From the analytical data, it is clear that organotin(IV) derivatives react with these ligands in 1 : 1 molar proportions. Conductance measurements for these complexes in 10^{-2} M nitrobenzene solution are in the range of 0.12–0.40 $ohm^{-1}\ cm^2\ mol^{-1}$, indicating that the complexes are nonelectrolytes.

3.1. Infrared Studies. In case of theophylline complexes, the ligand can chelate with the metal ion either through C(6) carbonyl and N(7) or through N(7) alone [24, 32, 33]. In the present case, the ν(C=O) stretching frequency for free ligand was observed at 1720 and 1660 cm^{-1}. On complexation, the peaks merged and appeared at ca. 1700 cm^{-1}. However, this shift cannot be attributed to the interaction of carbonyl at C(6) with Sn(IV), since the electronic spectra of these complexes rules out this possibility. Further, the disappearance of the band at 3200 cm^{-1} due to ν(N–H) stretching in the complexes indicate that the ligand is linked to Sn(IV) through the deprotonation of N(7).

In case of free theobromine, the ν(C=O) stretching frequency appears at 1700 and 1665 cm^{-1} and remains unaltered on complexation. However, the ν(C=N) + ν(C=C) stretching frequency is shifted from 1595 and 1550 cm^{-1} in free theobromine to ca. 1580 and 1530 cm^{-1} in complexes, indicating that the theobromine is linked to Sn(IV) through N(9) [34].

3.2. Electronic Spectra. In the electronic spectra of theophylline and theobromine, the band corresponding to $\pi \rightarrow \pi^*$ transition of the carbonyl group at 270 nm (logε 3.45) and 272 nm (logε 3.5), respectively, almost remained unperturbed on complexation, confirming the noninvolvement of the carbonyl group of these ligands in complexation [32]. Additional peaks at ~210 nm and ~250 nm corresponding to the phenyl ring of R moiety are observed in case of the UV spectrum of metal complexes. In addition to this, the ligand $\rightarrow$ metal charge transfer band is observed in the region 320–340 nm ($\log \varepsilon \sim 4.2$) in the complexes.

3.3. ^1H and ^{13}C NMR Studies. The ^{1}H NMR data of the complexes are tabulated in Tables 2 and 3. The peaks undergo a slight downfield shift on complexation, due to the change in the electronic environment of the ligand. In theophylline, the broad peak due to –N–H (δ 10.4) disappears on complexation, confirming that the complexation involves the replacement of hydrogen atom in –N–H– group. In theobromine, the peak corresponding to H-8 (δ 7.1) undergoes significant downfield shift on complexation, confirming the involvement of N-9 in complexation [35]. ^{13}C NMR data have been recorded for both the ligands and their corresponding organotin(IV) complexes, and these spectra also support the authenticity of the proposed structures. $(C_6H_5CH_2)_3Sn(L^1)$ ^{13}C NMR, ppm: theophyllinato, C(2), 155.8; C(3), 149.5; C(5), 107.3; C(6), 162.3; C(8), 141.1; 1-Me, 28.4; 3-Me, 30.1; Sn–CH_2, 17.87; aromatic: 141.8, 130.6, 128.8, 131.7, 127.9, 131.6. $(C_6H_5CH_2)_3Sn(L^2)Cl$: theobromine, C(2), 151.1; C(4), 149.5; C(5), 106.3; C(6), 161.2; C(8), 136.5; 3-Me, 29.1; 7-Me, 28.4; Sn–CH_2, 19.56, aromatic: 142.8, 131.6, 129.8, 132.7, 128.9, 132.6.

3.4. Mass Studies. The fragmentation pattern of the complexes has been analysed on the basis of mass spectra. The $RSn^{+\cdot}$, R^+, and Sn^+ ions dominate the mass spectra. The carbonium ion R^+ constitutes the base peak in the mass spectra of all the complexes. Schemes 1 and 2 represent the fragmentation pattern for theophylline and theobromine moieties, respectively, in the organotin(IV) complexes.

3.5. Thermal Studies. Thermal studies have been carried out for all the complexes. The thermogravimetric (TG) studies reveal that only two of the prepared complexes $(C_6H_5CH_2)_3Sn(L^1)$ and $(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$ undergo decomposition in two steps, whereas the rest undergo decomposition in three steps. The first step (423–673 K) involves the loss of R groups, the second step corresponds to the loss of chlorine atom(s), and the final step involves the formation of SnO_2. The mass loss data is given in Table 4. The DTA curves reveal that all the decomposition steps, except the step corresponding to the formation of SnO_2, are exothermic in nature. The last step corresponding to the formation of SnO_2 is endothermic in nature.

The order (n) and activation energy (E_a) have been elucidated for the various steps using Coats-Redfern [36] as well as Horowitz-Metzger [37] methods. The values of activation energy and entropy of the reaction have been calculated using both methods and found to be in close agreement. The order of reaction in each case is one. ΔH (enthalpy of reaction) have been calculated, using the TG [38] and DTA curves, respectively [39, 40]. The kinetic parameters

Table 1: Physical characteristics and analytical data of theophylline and theobromine complexes.

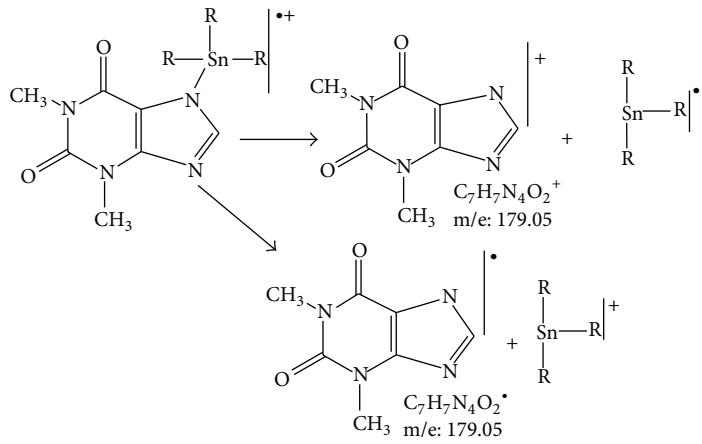
Complex	Empirical formula	Mol. Wt. found (cal)	Decp. temp (/°C)	Λb $(C - 1.59 \times 10^{-2}$ M)	Found (cal.) %				
					Sn	Cl	N	C	H
$(C_6H_5CH_2)_3Sn(L^1)$	$C_{28}H_{28}N_4SnO_2$	570.76 (571.24)	210	0.21	20.19 (20.77)	—	9.61 (9.80)	58.64 (58.87)	4.61 (4.94)
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$	$C_{28}H_{25}N_4SnO_2Cl_3$	673.21 (673.98)	170	0.19	17.05 (17.61)	15.22 (15.69)	7.98 (8.31)	49.62 (49.89)	3.21 (3.73)
$(C_6H_5CH_2)_2Sn(L^1)Cl$	$C_{21}H_{21}N_4SnO_2Cl$	514.91 (515.36)	240	0.24	22.62 (23.03)	6.29 (6.84)	10.38 (10.87)	48.69 (48.94)	3.92 (4.10)
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^1)Cl$	$C_{21}H_{21}N_4SnO_2Cl$	582.61 (583.85)	210	0.39	20.06 (20.32)	17.68 (18.11)	9.26 (9.59)	42.99 (43.20)	3.02 (3.28)
$(C_6H_5CH_2)_3Sn(L^2)Cl$	$C_{28}H_{29}N_4SnO_2Cl$	606.81 (607.50)	200	0.21	19.16 (19.53)	5.34 (5.80)	9.06 (9.22)	55.01 (55.35)	4.51 (4.81)
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^2)Cl$	$C_{28}H_{26}N_4SnO_2Cl_4$	709.29 (710.24)	150	0.29	16.21 (16.71)	19.31 (19.85)	7.62 (7.88)	47.11 (47.35)	3.29 (3.69)
$(C_6H_5CH_2)_2Sn(L^2)Cl_2$	$C_{21}H_{22}N_4SnO_2Cl_2$	551.00 (551.62)	220	0.30	21.12 (21.51)	12.21 (12.78)	9.98 (10.15)	45.54 (45.72)	3.65 (4.02)
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^2)Cl_2$	$C_{21}H_{20}N_4SnO_2Cl_4$	619.79 (620.11)	200	0.32	18.69 (19.14)	22.19 (22.73)	8.89 (9.03)	40.21 (40.67)	3.02 (3.25)

Table 2: ^{1}H and ^{13}C NMR data (δ ppm) of theophylline complexes.

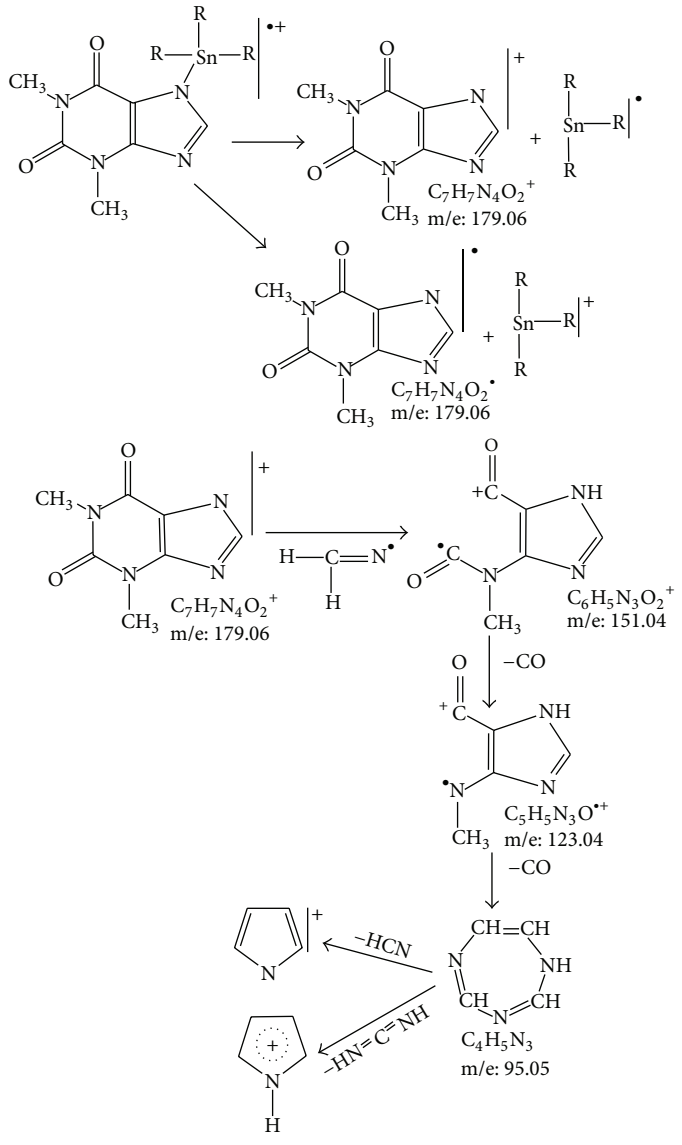
Compound	^{1}H NMR						^{13}C NMR
	–R moiety		Theophylline moiety				
	Ar–H	–CH_2–	H-8	–CH_3 at N-3	–CH_3 at N-1	–NH–	Sn–CH_2
Theophylline (HL^1)	—	—	7.5-7.6 (d,1H)	3.6-3.7 (s,3H)	3.2 (s,3H)	10.4–10.6 (br,2H)	
$(C_6H_5CH_2)_3Sn(L^1)$	7.9–8.1 (m, 15H)	3.6-3.7 (s, 6H)	7.7-7.8 (d,1H)	3.9-4.0 (s,3H)	3.3 (s,3H)	—	17.87
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$	8.0–8.2 (m, 12H)	3.9 (s,6H)	7.6-7.7 (d,1H)	4.1-4.2 (s,3H)	3.4 (s,3H)	—	24.01
$(C_6H_5CH_2)_2Sn(L^1)Cl$	7.9-8.0 (m, 10H)	3.8 (s,4H)	7.5-7.6 (d,1H)	4.0-4.1 (s,3H)	3.3-3.4 (s,3H)	—	17.21
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^1)Cl$	8.0-8.1 (m, 8H)	3.7-3.8 (s,4H)	7.7-7.8 (d,1H)	4.0 (s,3H)	3.4-3.5 (s,3H)	—	23.50

Table 3: ^{1}H and ^{13}C NMR data (δ ppm) of theobromine complexes.

Compound	^{1}H NMR						^{13}C NMR
	–R moiety				Theobromine moiety		
	Ar–H	–CH_2–	–CH_3 at N-3	–CH_3 at N-2	H-8	–NH–	Sn–CH_2
Theobromine (L^2)	—	—	3.3 (s, 3H)	3.5 (s, 3H)	7.1 (s, 1H)	13.0–13.2 (br, 1H)	
$(C_6H_5CH_2)_3Sn(L^2)Cl$	7.0–7.4 (m, 15H)	3.8-3.9 (s, 6H)	3.4-3.5 (s, 3H)	3.6-3.7 (s, 3H)	7.7 (s, 1H)	13.2–13.4 (br, 1H)	19.56
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^2)Cl$	7.1–7.3 (m, 12H)	3.9 (s, 6H)	3.3-3.4 (s, 3H)	3.6-3.7 (s, 3H)	7.6 (s, 1H)	13.4–13.6 (br, 1H)	25.34
$(C_6H_5CH_2)_2Sn(L^2)Cl_2$	7.0–7.3 (m, 10H)	3.9-4.0 (s, 4H)	3.4 (s, 3H)	3.7 (s, 3H)	7.5 (s, 1H)	13.3–13.5 (br, 1H)	18.34
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^2)Cl_2$	7.1–7.3 (m, 8H)	3.8 (s, 4H)	3.3-3.4 (s, 3H)	3.6 (s, 3H)	7.8 (s, 1H)	13.3–13.6 (br, 1H)	23.66

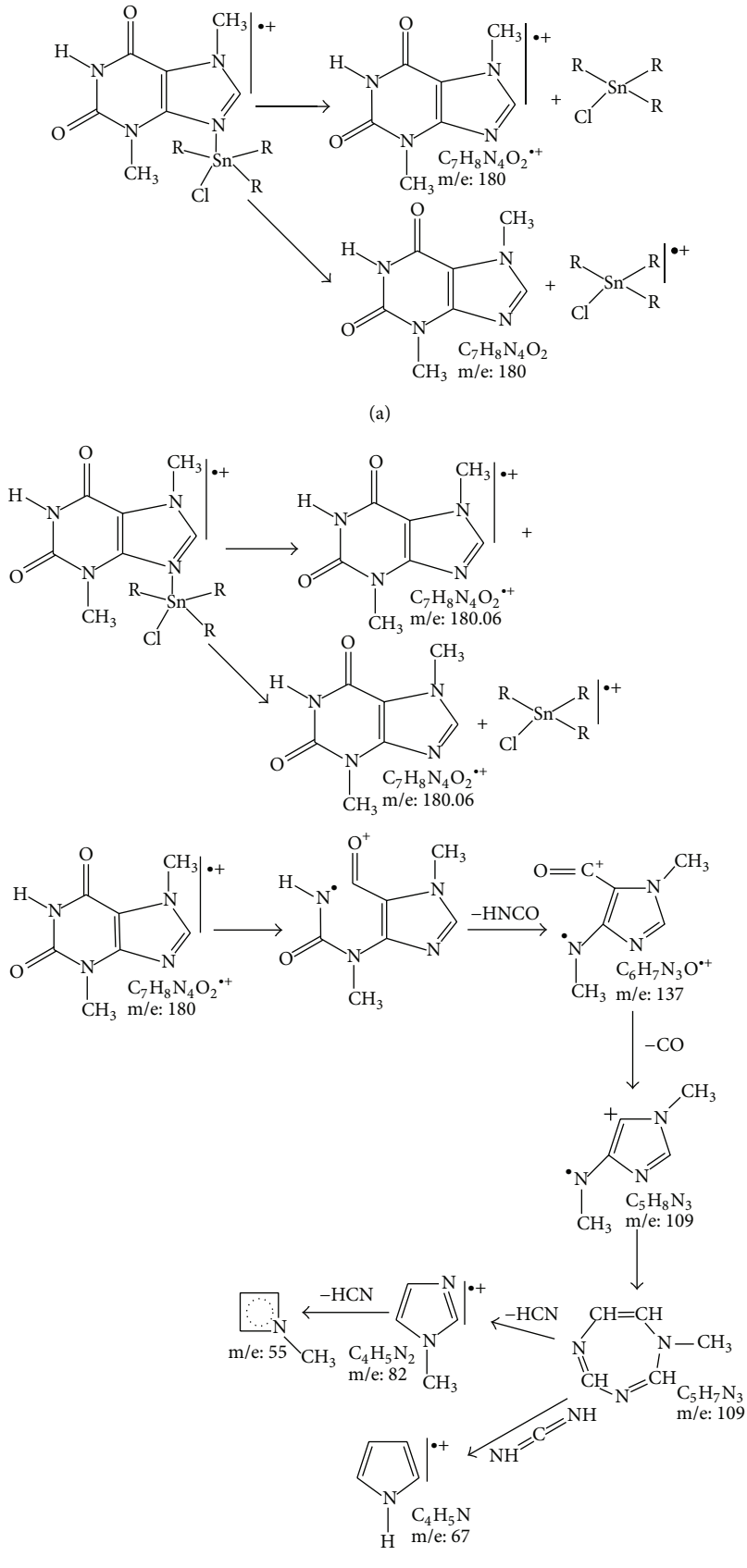


(a)



(b)

Scheme 1: Fragmentation pattern for theophylline complexes.



Scheme 2: Fragmentation pattern for theobromine complexes.

Table 4: Phenomenological data for the thermal decomposition of the complexes.

Complex	Step number	TG plateaux (K)	Mass loss%		Nature of loss
			Observed	Calc.	
$(C_6H_5CH_2)_3Sn(L^1)$	I	483–673	46.0	47.86	Loss of 3 benzyl groups
	II	893–1003	72.0	73.73	Formation of SnO_2
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$	I	443–633	55.0	55.80	Loss of 3 *p*-chlorobenzyl groups
	II	873–973	75.0	77.73	Formation of SnO_2
$(C_6H_5CH_2)_2Sn(L^1)Cl$	I	513–663	34.7	35.36	Loss of 2 benzyl groups
	II	703–773	42.0	42.20	Loss of chlorine atom
	III	893–973	69.4	70.88	Formation of SnO_2
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^1)Cl$	I	483–673	42.0	42.94	Loss of 2 *p*-chlorobenzyl groups
	II	723–793	47.0	48.98	Loss of chlorine atom
	III	873–973	73.5	74.29	Formation of SnO_2
$(C_6H_5CH_2)_3Sn(L^2)Cl$	I	473–653	45.0	45.0	Loss of 3 benzyl groups
	II	723–813	50.0	50.80	Loss of chlorine atom
	III	893–1003	74.0	75.29	Formation of SnO_2
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^2)Cl$	I	423–623	52.0	52.95	Loss of 3 *p*-chlorobenzyl groups
	II	703–753	57.0	57.92	Loss of chlorine atom
	III	873–973	78.0	78.87	Formation of SnO_2
$(C_6H_5CH_2)_2Sn(L^2)Cl_2$	I	493–653	32.0	33.04	Loss of 2 benzyl groups
	II	703–773	45.0	45.82	Loss of chlorine atoms
	III	873–993	71.0	72.79	Formation of SnO_2
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^2)Cl_2$	I	473–653	40.0	40.43	Loss of 2 *p*-chlorobenzyl groups
	II	723–793	50.0	51.80	Loss of chlorine atoms
	III	873–973	75.0	75.80	Formation of SnO_2

for the thermal decomposition of the complexes are given in Table 5.

On the basis of the above data, it can be concluded that the complexes with R = p-$ClC_6H_4CH_2$– have lower E_a value for step 1 as compared to the complexes with the same number of R groups, but R = $C_6H_5CH_2$– because the electron withdrawing effect of chlorine makes the R–Sn bond weaker and facilitates its thermal degradation. Moreover, tri(*p*-chlorobenzyl)tin derivative has the least activation energy, for the first step, due to the greater steric hindrance.

3.6. In Vitro Antibacterial Studies. The metal complexes were screened versus *E.coli, S. aureus,* and *P. pyocyanea* bacterial strains, using the respective ligands as the standard for comparing the activities. The samples were screened at three different concentrations (25, 50, and 100 $\mu g\,cm^{-3}$) in DMF. The inhibitory power of the metal complexes was observed to be greater than that of the control. The general order of activity versus the three microorganisms is *S.aureus* > *P. pyocyanea* > *E.coli.* The data is presented in Table 6.

3.7. Antifungal Studies. The results reported in Table 7 reveal that the organotin complexes with these ligands are much more active than the parent ligand against the same microorganisms. With increase in concentration of the compounds, there occurs increase in percentage of inhibition. Higher concentration proves inhibitory for fungal growth.

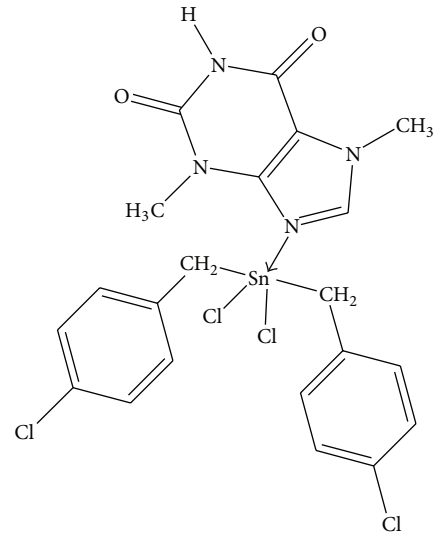


Figure 2

On the basis of spectral evidence, Figure 2 representing coordination has been prepared for one of the complexes synthesized.

Conflict of Interests

The authors declare that they have no conflict of interests.

Table 5: Kinetic parameters for the thermal decomposition of theophylline and theobromine complexes.

Complex	Step number	Temp./K	Coats-Redfern method		Horowitz-Metzger method		DTA	
			E_a/kJ mol^{-1}	$\Delta S^{\#}$ (JK^{-1} mol^{-1})	E_a/kJ mol^{-1}	$\Delta S^{\#}$ (JK^{-1} mol^{-1})	Thermal effect	ΔH (Jg^{-1})
$(C_6H_5CH_2)_3Sn(L^1)$	1	483–673	51.09	9.41	54.23	10.46	Exo.	−20.42
	2	893–1003	306.35	37.62	310.17	38.01	Endo.	94.46
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$	1	443–633	40.30	8.50	41.84	8.81	Exo.	−17.46
	2	873–973	218.82	27.42	243.23	29.82	Endo.	93.26
$(C_6H_5CH_2)_2Sn(L^1)Cl$	1	513–663	63.82	12.00	65.62	12.33	Exo.	−22.10
	2	703–773	191.54	32.06	211.40	33.26	Exo.	−89.99
	3	893–973	366.98	45.41	353.53	44.3	Endo.	90.42
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^1)Cl$	1	483–673	54.70	10.54	55.23	10.67	Exo.	−21.69
	2	723–793	255.29	39.42	238.49	37.64	Exo.	−92.46
	3	873–973	382.94	47.45	380.48	47.85	Endo.	92.91
$(C_6H_5CH_2)_3Sn(L^2)Cl$	1	473–653	38.29	6.97	40.46	7.95	Exo.	−30.46
	2	723–813	87.03	12.06	95.34	13.83	Exo.	−52.49
	3	893–1003	208.12	24.10	217.31	26.22	Endo.	111.12
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^2)Cl$	1	423–623	31.91	6.20	34.91	7.41	Exo.	−29.62
	2	703–753	255.29	41.62	250.21	40.69	Exo.	−51.62
	3	873–973	239.33	30.41	250.95	31.89	Endo.	113.42
$(C_6H_5CH_2)_2Sn(L^2)Cl_2$	1	493–653	57.44	11.20	58.55	11.35	Exo.	−29.94
	2	703–773	281.57	43.69	274.33	43.44	Exo.	−51.60
	3	873–993	176.32	21.42	178.57	21.57	Endo.	110.21
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^2)Cl_2$	1	473–653	54.44	7.84	56.45	8.26	Exo.	−31.06
	2	723–793	191.47	29.47	192.18	29.71	Exo.	−52.06
	3	873–973	237.53	29.01	243.28	29.99	Endo.	112.26

Table 6: Antibacterial activity of theophylline and theobromine complexes.

Compound	Diameter of inhibition zone (mm) after 24 hr							
	Escherichia coli (−)		*Pseudomonas aeruginosa* (−)		*Klebsiella pneumonia* (−)		*Staphylococcus aureus* (+)	
	500	1000	500	1000	500	1000	500	1000
HL^1	8	10	12	16	9	12	11	14
$(C_6H_5CH_2)_3Sn(L^1)$	10	12	13	17	10	13	10	12
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$	9	10	13	15	12	14	12	13
$(C_6H_5CH_2)_2Sn(L^1)Cl$	9	12	10	13	9	11	10	11
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^1)Cl$	11	14	15	18	12	14	14	16
L^2	9	11	13	17	11	15	12	14
$(C_6H_5CH_2)_3Sn(L^2)Cl$	9	11	15	19	12	16	14	16
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^2)Cl$	10	13	14	17	11	13	13	15
$(C_6H_5CH_2)_2Sn(L^2)Cl_2$	11	15	16	19	13	17	14	16
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^2)Cl_2$	10	11	12	16	10	14	11	13

Table 7: Antifungal activity of theophylline and theobromine complexes.

Compound	Average% inhibition after 96 H			
	Rhizopus oryzae		*Aspergillus flavus*	
	Conc. (0.01%)	Conc. (0.1%)	Conc. (0.01%)	Conc. (0.1%)
HL^1	33	42	39	48
$(C_6H_5CH_2)_3Sn(L^1)$	60	79	63	77
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^1)$	55	61	65	79
$(C_6H_5CH_2)_2Sn(L^1)Cl$	48	61	62	69
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^1)Cl$	51	59	65	72
Bavistin	82	96	84	98
L^2	36	48	42	54
$(C_6H_5CH_2)_3Sn(L^2)Cl$	42	56	50	67
$(p\text{-}ClC_6H_4CH_2)_3Sn(L^2)Cl$	52	64	58	73
$(C_6H_5CH_2)_2Sn(L^2)Cl_2$	58	68	64	76
$(p\text{-}ClC_6H_4CH_2)_2Sn(L^2)Cl_2$	62	73	68	82
Bavistin	82	96	84	98

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