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Synthesis, structural characterization and biological activities of organotin(IV) complexes with 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone

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Abstract. The organotin(IV) complexes [MeSnCl(L)] (**2**), [BuSnCl(L)] (**3**), [PhSnCl(L)] (**4**) and [Me_2Sn(L)] (**5**) were synthesized by reacting organotin(IV) chloride(s) with 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone [H_2L], (**1**)] in presence of KOH in 1:2:1 molar ratio (metal salt: base:ligand). All the complexes have been characterized by elemental analyses, UV-Vis, FT-IR, ^{1}H, ^{13}C and ^{119}Sn NMR spectral studies. The molecular structure of complex **5** has been confirmed by single crystal X-ray diffraction analysis. The ligand, H_2L coordinates to Sn(IV) in thiolate form through phenoxide-O, azomethine-N and thiolate-S atoms. The C-Sn-C angle measured from coupling constant $^1J(^{119}\text{Sn}, ^{13}\text{C})$ for dimethyltin(IV) complex **5** is 123.4°. The $^2J(^{119}\text{Sn}, ^1\text{H})$ coupling constant values for complex **2** and **5** are 72.4 and 76.3 Hz, respectively. Proposed geometry for five coordinated Sn(IV) atom is a strongly distorted trigonal bipyramid. Biological studies were preformed *in vitro* against four bacterial strains which have shown better activities and potential as antibacterial agents.

Keywords. 4-thiosemicarbazone; Organotin(IV) complexes; synthesis; characterization; crystal structure; antibacterial activity.

1. Introduction

Thiosemicarbazones have been the subject of interest due to their medicinal and biological applications as antioxidant, DNA binding, anti-proliferative, antimalarial, antitumor and antibacterial agents.[1–6] Generally, the biological activity of thiosemicarbazones is influenced significantly upon coordination to metal ions.[7,8] Organotin(IV) complexes with ligands containing ON, OS, ONS and NNS donors are notable for their wonderful biological activities as fungicides, bacteriocides and anti-inflammatory agents.[9,10] Tin complexes are also established for their various biological applications as antibacterial, antifungal, biocidal and cytotoxic agents.[11–13] Mostly, biological activity of metal-thiosemicarbazones is influenced by the metal coordination number and structure of the molecule.[14–16] In particular, complexes with thiosemicarbazones derived from ONS dianionic tridentate ligand have been extensively reported.[17–19] Sousa *et al.*, have reported structural studies of organotin(IV) complex with ONS-tridentate thiosemicarbazone and X-ray structure revealed that tin atom is penta-coordinated in a distorted trigonal bipyramidal geometry.[20] Recently, Mouyed *et al.,* have reported synthesis and structural studies of molybdenum(VI) complexes with ONS-donors thiosemicarbazone ligands. These complexes have been shown to exhibit significant antitumour activities.[21,22] Coordination of certain metal complexex with thiosemicarbazone derivatives have been studied along with a structural review of the main group metal complexes with thiosemicarbazoenes.[23–25] However, most of the work that have been reported still involves complexes of thiosemicarbazones with transition metal ions. Though organotin(IV) complexes with thiosemicarbazone derivatives have potential biological activities,[26–28] very few reports are available regarding the mode of interaction between organotin(IV) moieties and ONS tridentate thiosemicarbazone ligands and the nature of these complexes in solution and solid state. In the present work, we report the synthesis spectroscopic characterization and antibacterial activity of new organotin(IV) complexes of 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone. X-ray crystal structure of one representative complex is also reported.

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2. Experimental

2.1 *Materials and methods*

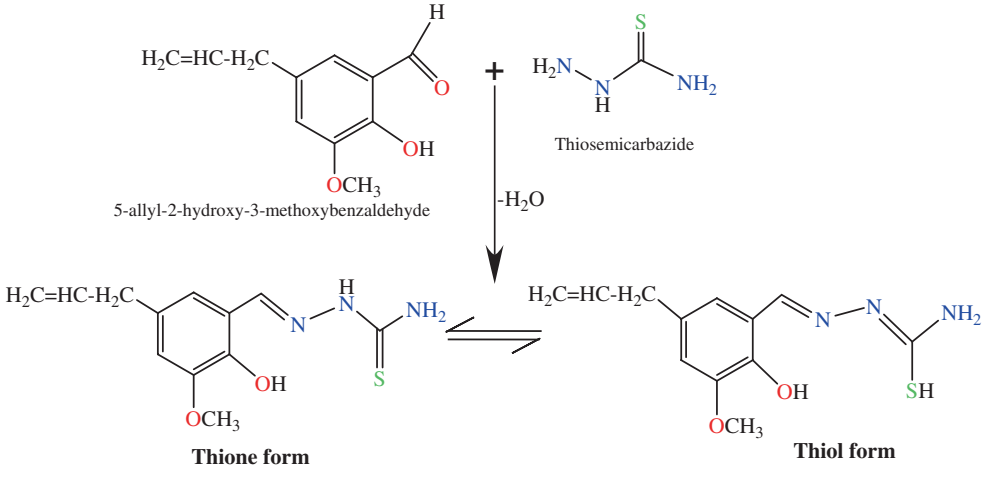
All reagents were purchased from Fluka, Sigma and Aldrich. All solvents were received as reagent grade and used without further purification. Melting point was measured on Stuart Scientific SMP1 melting point apparatus. UV–Vis spectra were recorded in DMSO with a Perkin Elmer Lambda 25 UV-Vis spectrophotometer. FT-IR spectra were recorded on a Perkin Elmer System 2000 spectrophotometer in KBr pellet in the 4000–400 cm^{-1} range at room temperature. ^{1}H, ^{13}C and ^{119}Sn NMR spectra were recorded on a Bruker 500 and 400 MHz NMR spectrophotometer and δ is relative to $SiMe_4$ and $SnMe_4$ in DMSO-d_6. Elemental analysis was conducted with a Perkin Elmer 2400 Series-11 CHN analyzer. X-ray crystallographic data were recorded on a Bruker SMART APEXII CCD area-detector diffractometer using graphite monochromated MoKα radiation (λ = 0.71073 Å) at 100 K. The data were collected and reduced using APEX2 and SAINT programs. The structures were solved by direct methods and refined by full-matrix least-squares method on F^2 using the SHELXTL program.[29] All non-H atoms were anisotropically refined. The molecular graphics were created using SHELXTL-97.

2.2 *Synthesis of 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone (H_2L) (**1**)*

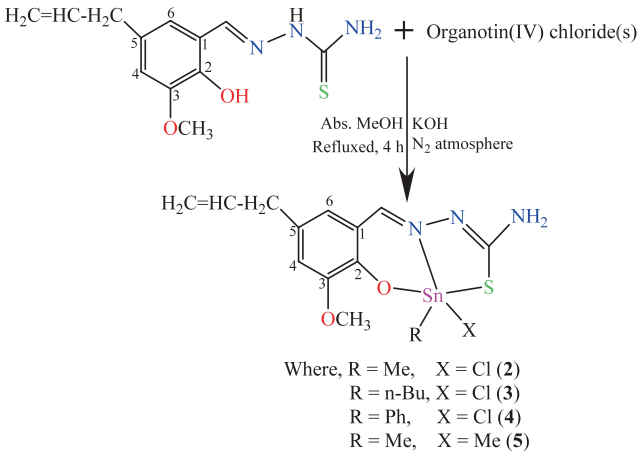
A solution of 5-allyl-3-methoxy-2-hydroxybenzaldehyde (0.57 g, 3.0 mmol) in 10 mL absolute ethanol was treated with 10 mL absolute ethanolic solution of thiosemicarbazide (0.27 g, 3.0 mmol). The resulting colorless solution was refluxed with stirring for 4 h (scheme 1). White solid product was formed when the solution cooled down to room temperature, then filtered, washed with ethanol and dried in desiccators over silica gel. Yield: 0.68 g, 80%: M.p.: 189-191°C: UV–Vis (DMSO)λ_{max}/nm: 260, 328, 366: FT-IR (KBr) ν_{max}/cm^{-1}: 3411 (s, OH), 3335 (s, NH_2), 3185 (s, NH), 1620 (m, C=N), 1562 (s, C_{aro}-O), 998 (m, N-N), 1363, 859 (w, CS). ^{1}H NMR (DMSO-d_6, ppm): 11.40 (s, 1H, OH), 10.14 (s, 1H, NH), 9.13 (s, 2H, NH_2), 8.28 (s, 1H, N=CH), 7.34 (s, 1H, PhC4-H), 7.10 (s, 1H, PhC6-H), 5.98 (m, 1H, CH_2 =CH-CH_2-Ph), 5.02 (m, 2H, CH_2 =CH-CH_2-Ph), 3.76 (d, 2H, CH_2 =CH-CH_2-Ph, J = 6.5 Hz), 3.28 (s, 3H, OCH_3). ^{13}C NMR (DMSO-d_6, ppm): 191.23 (C=S), 152.81 (C=N), 136.14-120.28 (Ph-C), 117.40 (=CH), 115.47 (CH_2 =), 113.19 (CH_2-Ph), 55.79 (O-CH_3). Anal. Calc. (%) for $C_{12}H_{15}N_3O_2S$: C, 54.32; H, 5.70; N, 15.84. Found: C, 54.35; H, 5.52; N, 16.01.

2.3 *Synthesis of [MeSnCl(L)] (**2**)*

The ligand, H_2L (**1**) (0.265 g, 1.0 mmol) was dissolved in absolute methanol (10 mL) under a nitrogen atmosphere in a round-bottomed reaction flask. Potassium hydroxide (0.11 g, 2.0 mmol) in methanol (10 mL) was added dropwise to the ligand solution. The reaction mixture was refluxed for 1 h. Then, a methanolic solution of methyltin(IV) trichloride (0.24 g, 1.0 mmol) was added dropwise and resulted in a yellow solution. The resulting reaction mixture was refluxed with stirring for 4 h (scheme 2). The yellow solid product was obtained by slow evaporation of the resulting solution at room temperature. The yellow product was filtered off, washed with methanol, and dried in *vacuo* over silica gel. Yield: 0.38 g, 75%: M.p.: 232–234°C. UV–Vis (DMSO)λ_{max}/nm: 272, 337, 380, 429: FT-IR (KBr) ν_{max}/cm^{-1}: 3285 (s, NH_2), 1587 (m, C=N), 1531 (s,



Scheme 1. Synthesis of 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone [H_2L, **1**].



Scheme 2. Reaction scheme for synthesis of organotin(IV) complexes (**2-5**).

C_{aro}-O), 1020 (w, N-N), 1329, 830 (m, C-S), 582 (w, Sn-C), 541 (w, Sn-O), 450 (w, Sn-N). ^{1}H NMR (DMSO-d_6, ppm): 9.08 (s, 2H, NH_2), 8.17 (s, 1H, N=CH), 7.38 (s, 1H, PhC4-H), 7.14 (s, 1H, PhC6-H), 5.95 (m, 1H, CH_2 =CH-CH_2-Ph), 5.05 (m, 2H, CH_2 =CH-CH_2-Ph), 3.70 (d, 2H, CH_2 =CH-CH_2-Ph, J = 6.8 Hz), 3.25 (s, 3H, OCH_3), 1.07 (s, 3H, $^2J_{Sn-H}$ = 72.4 Hz, Sn-CH_3). ^{13}C NMR (DMSO-d_6, ppm): 182.11 (C=S), 161.75 (C=N), 142.32-125.62 (Ph-C), 117.45 (=CH), 115.50 (CH_2 =), 113.25 (CH_2-Ph), 55.75 (O-CH_3), 18.31 ($^1J_{Sn-C}$ = 531.82 Hz, Sn-CH_3). ^{119}Sn NMR (DMSO-d_6, ppm): –154.48. Anal. Calc. (%) for $C_{13}H_{16}ClN_3O_2SSn$: C, 36.10; H, 3.73; N, 9.72. Found: C, 36.26; H, 3.86; N, 9.87%.

Other organotin(IV) complexes (**3-5**) were synthesised following the same procedure by using the appropriate organotin(IV) chloride(s) (scheme 2).

2.4 *Synthesis of [BuSnCl(L)] (**3**)*

Yield: 0.40 g, 73%: M.p: 240–242°C. UV–Vis (DMSO)λ_{max}/nm: 270, 339, 387, 442: FT-IR (KBr) ν_{max}/cm^{-1}: 3291 (s, NH_2), 1590 (m, C=N), 1527 (s, C_{aro}-O), 1018 (w, N-N), 1330, 834 (m, C-S), 578 (w, Sn-C), 549 (w, Sn-O), 432 (w, Sn-N). ^{1}H NMR (DMSO-d_6, ppm): 9.05 (s, 2H, NH_2), 8.25 (s, 1H, N=CH), 7.39 (s, 1H, PhC4-H), 7.15 (s, 1H, PhC6-H), 5.93 (m, 1H, CH_2 =CH-CH_2-Ph), 5.10 (m, 2H, CH_2 =CH-CH_2-Ph), 3.72 (d, 2H, CH_2 =CH-CH_2-Ph, J = 6.7 Hz), 3.23 (s, 3H, OCH_3), 1.61-1.55 (t, 2H, Sn-CH_2-CH_2-CH_2-CH_3), 1.40-1.34 (m, 2H Sn-CH_2-CH_2-CH_2-CH_3), 1.21-1.15 (m, 2H, Sn-CH_2-CH_2-CH_2-CH_3), 0.94-0.85 (t, 3H, Sn-CH_2-CH_2-CH_2-CH_3). ^{13}C NMR (DMSO-d_6, ppm): 177.25 (C=S), 165.82 (C=N), 140.02-124.21 (Ph-C), 117.42 (=CH), 115.40 (CH_2 =), 113.20 (CH_2-Ph), 55.82 (O-CH_3), 38.01, 32.32, 26.81, 22.65 (Sn-Bu). ^{119}Sn NMR (DMSO-d_6, ppm): –162.37. Anal. Calc. (%) for $C_{16}H_{22}ClN_3O_2SSn$: C, 40.49; H, 4.67; N, 8.85. Found: C, 40.76; H, 4.77; N, 8.99%.

2.5 *Synthesis of [PhSnCl(L)] (**4**)*

Yield: 0.41 g, 72%: M.p: 246-248°C. UV–Vis (DMSO)λ_{max}/nm: 274, 344, 382, 422: FT-IR (KBr) ν_{max}/cm^{-1}: 3288 (s, NH_2), 1588 (m, C=N), 1522 (s, C_{aro}-O), 1026 (w, N-N), 1335, 840 (m, C-S), 588 (w, Sn-C), 561 (w, Sn-O), 443 (w, Sn-N). ^{1}H NMR (DMSO-d_6, ppm): 9.10 (s, 2H, NH_2), 8.23 (s, 1H, N=CH), 7.40-7.12 (m, 7H, Ph-H), 5.90 (m, 1H, CH_2 =CH-CH_2-Ph), 5.03 (m, 2H, CH_2 =CH-CH_2-Ph), 3.78 (d, 2H, CH_2 =CH-CH_2-Ph, J = 6.6 Hz), 3.27 (s, 3H, OCH_3). ^{13}C NMR (DMSO-d_6, ppm): 179.72 (C=S), 162.33 (C=N), 141.22–126.40 (Ph-C), 117.32 (=CH), 114.98 (CH_2 =), 113.35 (CH_2-Ph), 55.85 (O-CH_3). ^{119}Sn NMR (DMSO-d_6, ppm): –167.02. Anal. Calc. (%) for $C_{18}H_{18}ClN_3O_2SSn$: C, 43.71; H, 3.67; N, 8.50. Found: C, 43.88; H, 3.80; N, 8.65%.

2.6 *Synthesis of [Me_2 Sn(L)] (**5**)*

Yield: 0.36g, 74%: M.p: 235–237°C. UV–Vis (DMSO)λ_{max}/nm: 271, 340, 377, 418: FT-IR (KBr) ν_{max}/cm^{-1}: 3293 (s, NH_2), 1582 (m, C=N), 1524 (s, C_{aro}-O), 1030 (w, N-N), 1321, 842 (m, C-S), 591 (w, Sn-C), 550 (w, Sn-O), 462 (w, Sn-N). ^{1}H NMR (DMSO-d_6, ppm): 9.04 (s, 2H, NH_2), 8.08 (s, 1H, N=CH), 7.41 (s, 1H, PhC4-H), 7.21 (s, 1H, PhC6-H), 5.99 (m, 1H, CH_2=CH-CH_2-Ph), 5.08 (m, 2H, CH_2 =CH-CH_2-Ph), 3.79 (d, 2H, CH_2 =CH-CH_2-Ph, J = 6.4 Hz), 3.30 (s, 3H, OCH_3), 1.10 (m, 6H, $^2J_{Sn-H}$ = 76.3 Hz, Sn-$(CH_3)_2$). ^{13}C NMR (DMSO-d_6, ppm): 178.35 (C=S), 168.72 (C=N), 140.26-133.38 (Ph-C), 118.55 (=CH), 116.11 (CH_2 =), 112.24 (CH_2-Ph), 54.83 (O-CH_3), 17.87 ($^1J_{Sn-C}$ = 531.82 Hz, Sn-$(CH_3)_2$). ^{119}Sn NMR (DMSO-d_6, ppm): –171.35. Anal.

Calc. (%) for $C_{14}H_{19}N_3O_2SSn$: C, 40.80; H, 4.65; N, 10.20. Found: C, 40.93; H, 4.72; N, 10.33%.

2.7 *Antibacterial test*

The synthesized compounds **1–5** were screened *in vitro* antibacterial activities against *Staphylococcus aureus* (ATCC 6538), *Enterobacter aerogenes* (ATCC 13048), *Escherichia coli*i (ATCC 15224) and *Salmonella typhi* (ATCC 10749) using the agar well diffusion method.[30] Doxycycline was used as the standard drug. The bacteria from stock culture were lightly inoculated into the Mueller Hinton Broth (MHB) and allowed to grow overnight at 37°C in an ambient air incubator. The culture was diluted with a new MHB in order to achieve an absorbance value of 2.0×10^6 colony forming units (CFU/mL) or 0.168 at 550 nm in the spectrophotometer. Sterile cotton swab was dipped into the broth culture and inoculated on the Mueller Hinton Agar (MHA). Sterile paper discs with 6 mm diameter were placed on the agar in equal distance. The recommended concentration of the test sample (2 mg/mL in DMSO) was introduced individually to each of the discs. The agar plates were incubated immediately at 37°C for 20 h. For each plate, DMSO mixture and reference antibacterial drug such as doxycycline served as negative and positive controls, respectively. The activity was determined by measuring the diameter of zones showing complete inhibition (mm). Growth inhibition was calculated with reference to the positive control.

3. Results and Discussion

3.1 *Synthesis*

The ligand, 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone (H_2L) was prepared by reaction of 5-allyl-2-hydroxy-3-methoxybenzaldehyde with thiosemicarbazide. It exhibits two possible tautomers either as thione or thiol forms (scheme 1). H_2L was treated with corresponding organotin(IV) chloride(s) in presence of KOH to obtain organotin(IV) derivatives (scheme 2). The obtained organotin(IV) compounds are yellow solids stable in air and soluble in methanol, chloroform, THF, DMSO and DMF. Elemental analysis data confirms that the complexes are of good purity. The physical and analytical data are reported in experimental section. The nature of bonding and structures of ligand and its complexes were suggested by spectroscopic studies. The molecular structure of complex **5** is also reported.

3.2 *UV-Visible spectra*

The electronic spectrum of ligand (**1**) has π–π^* band at 260 nm and two n–π^* bands around in the region at 328–366 nm due to the transitions of aromatic ring, thiolate function and azomethine group, respectively. These bands are slightly shifted in energy after complexation. In all the complexes, a moderately intense band was observed in the region at 442–418 nm assigned to ligand-to-metal-charge-transfer transitions (LMCT).[31] The shift of λ_{max} clearly indicates the coordination of the ligand to metal. The UV-Vis spectra of organotin(IV) complexes (**4**-**5**) and the ligand are shown in figure 1.

3.3 *Infrared spectra*

IR spectra clarify the mode of the ligand bonded to the tin moiety and support their proposed structures. The free ligand (**1**) exhibit ν(OH) stretching vibrations at 3411 cm^{-1} which was absent in the spectra of the complexes (**2–5**), indicating deprotonation of phenolic proton and bond formation with Sn(IV) atom. The ν(NH) stretching vibration of free ligand was observed at 3185 cm^{-1}. This band disappeared in the IR spectra of the complexes (**2–5**), which is attributed to the coordination bond of azomethine nitrogen to Sn(V) atom. The absence of ν(S-H) peak around 2700 cm^{-1} in the spectrum of free ligand (**1**) indicates that ligand is in thione form in the solid state.[32,33] The ν(C=N) band which observed at 1620 cm^{-1} in IR spectrum of free ligand shifted to lower frequencies in the complexes, in agreement with coordination of azomethine nitrogen to Sn(IV) atom.[34] The ν(N-N) band in free ligand at 998 cm^{-1} is shifted to higher wave numbers at 1030–1018 cm^{-1} in the complexes, indicating that the azomethine nitrogen atom is involved in coordination. The ν(C-S) stretching and bending vibrations observed at 1363 and 859 cm^{-1} in the free ligand is shifted to lower wave numbers at 1335–1321 and 842–830 cm^{-1} in the complexes, indicating bonding of thiolate sulphur to Sn(IV) atom.[35] Absorption band of $\nu(C_{aro}\text{-}O)$ in free ligand appeared at 1562 cm^{-1} is shifted to

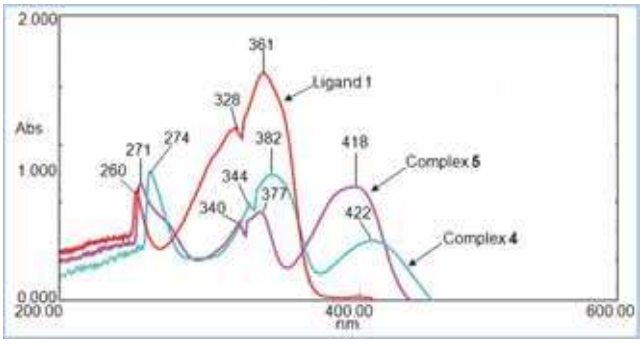


Figure 1. UV-Vis spectra of ligand (**1**) and its complexes (**4** and **5**) in DMSO (1×10^{-4} M).

lower wave numbers at 1531–1522 cm^{-1} in the complexes, suggesting the involvement of phenolic oxygen in coordination.[36] New bands in the region at 561–541 and 462–422 cm^{-1} are assigned to ν(Sn-O) and ν(Sn-N), respectively, supporting coordination of oxygen and nitrogen to Sn(IV) atom.[37–39] The weak band assigned to ν(Sn-C) observed at 591–578 cm^{-1} which confirms that Sn–C bond in their structure.[40] The IR spectral data suggested that thiosemicarbazone ligand (H_2L) act as dinegative ONS tridentate chelating agent coordinated to central tin(IV) atom through phenolic oxygen, azomethine nitrogen and thiolate sulphur atoms. This mode of coordination has been confirmed by the X-ray structure studies of dimethyltin(IV) complex **5**.

3.4 *^1H, ^{13}C and ^{119}Sn NMR spectra*

The ^{1}H and ^{13}C spectra of ligand (**1**) and its complexes (**2**–**5**) and of the ^{119}Sn NMR spectra of the complexes (**2**–**5**) were recorded in DMSO. The free ligand displayed signal at 11.40 ppm is attributed to OH proton and the sharp signal at 10.14 ppm is assigned to NH proton. The absence of these two signals upon complexation indicating deprotonation of these groups and coordinated with tin(IV) atom. The appearance of a sharp resonance peak at 9.10–9.04 ppm is due to the NH_2 group in all complexes. The chemical shifts of N=CH proton for ligand appears at 8.28 ppm which is shifted upfield region at 8.25–8.08 ppm due to complex formation. The resonance signals due to aromatic 4-H and 6-H protons were found to be downfield region in the complexes with compared to those of the free ligand. This downfield shift might be due to the donation of electron density from ring to Sn(IV) The allyl group (-CH_2–CH=CH_2) inside the aromatic ring exhibit three signals at the region 5.98–3.70 ppm as multiplet and doublet. However, methyl protons of both methyltin(IV) (**2**) and dimethyltin(IV) (**5**) complexes showed a singlet at 1.10–1.07 ppm. The ^2J (^{119}Sn,^{1}H) coupling constant of complexes **2** and **5** are 72.4 and 76.3 Hz in agreement with five-coordinate tin(IV) centre.[41] The calculated C9-Sn1–C10 angles by the Lockhart-Manders equations[41] as 122.22° and 126.41° for complexes **2** and **5**, respectively, support the proposed geometry.

The C=S carbon signal is shifted to upfield region in the complexes compared with the free ligand, supported coordination through thiolate sulphur to tin(IV) atom. The chemical shift due to the C=N is observed at downfield (168.72–161.75 ppm) in the complexes compared with the ligand (152.81 ppm), clearly indicate the coordination of the azomethine nitrogen to tin(IV). The carbon signal due to aromatic ring carbons at 136.14–120.28 ppm in free ligand is shifted slightly downfield upon complexation. These observations also support coordination through phenolic oxygen to tin(IV) atom. The chemical shifts due to carbons in allyl group (-CH_2–CH=CH_2) and (-OCH_3) did not change upon complexation. The signals due to butyl carbon in complex **3** bonded to tin (Bu-Sn) appeared at 38.01–22.65 ppm. The value of the coupling constant ^1J[^{119}Sn, ^{13}C] for complex **5** is 531.82 Hz which consistent with five-coordinate geometry around tin.[42] The determination of C–Sn–C angle using the Lockhart–Manders equation[41] θ (C-Sn-C) = [$|^1J(^{13}C - ^{119}Sn)| + 875]/11.4$ provided C–Sn–C angle of 123.4° for complex **5**. The observed value of C–Sn–C angle corresponds with the C_{methyl}-Sn-C_{methyl} angle obtained from X-ray crystal analysis of dimethyltin(IV) complex **5**.

The ^{119}Sn NMR spectra of complexes (**2**–**5**) showed a sharp single resonance supported that only one single species is present. The ^{119}Sn NMR resonances were found to be in the range of −154.48 to −171.35 ppm for all complexes (**2**–**5**). The occurrences of chemical shift values for all complexes in this region suggested that five coordination environment around the central Sn(IV) atom.[43,44]

3.5 *Crystal structure of [Me_2Sn(L)] (**5**)*

Yellow crystals suitable for X-ray diffraction analysis of the [Me_2Sn(L)] (**5**) were obtained by slow evaporation of methanol at room temperature. The molecular structure of [Me_2Sn(L)] (**5**) along with the atomic numbering scheme and its packing in the crystal lattice are given in figures 2 and 3, respectively. Summary of crystal data and structure refinement results are given in table 1. Important bond lengths (Å) and angles (°) are compiled in table 2.

The compound crystallizes into monoclinic crystal system with a space group of $P2_1/c$. The molecular structure of complex **5** revealed that the ligand (H_2L) is coordinated to central tin(IV) atom through phenolic oxygen, azomethine nitrogen and thiolate sulphur atoms. The Sn(IV) is penta-coordinated and adopts a distorted trigonal bipyramidal geometry, with the oxygen and thiol sulphur atoms occupying axial positions while azomethine nitrogen atom and two methyl groups occupy the equatorial position. The two methyl groups and azomethine nitrogen are equatorial sites having angles C9–Sn1–C10 = 128.20(6)° C9–Sn1–N1 = 103.24(5)° and N1–Sn1–C10 = 128.47(6)°. The sum of bond angles between Sn atom and equatorial atoms is 360° indicating that they are completely coplanar with the Sn atom lying in the plane. The phenolic oxygen

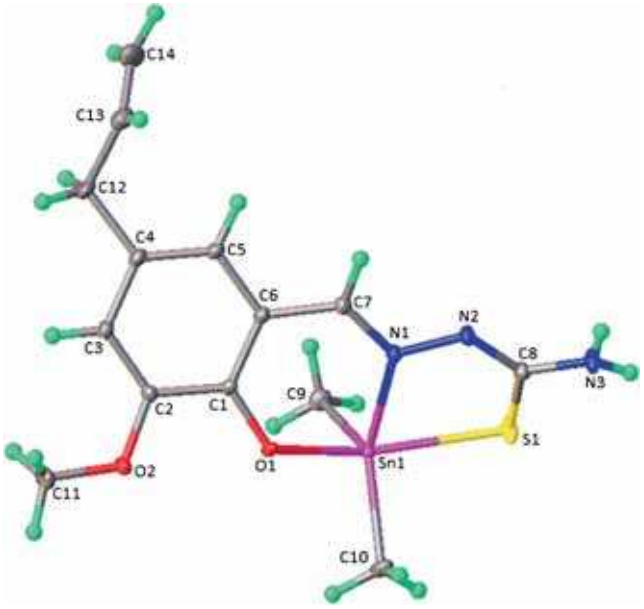


Figure 2. Molecular structure of [$Me_2Sn(L)$] (**5**) showing displacement ellipsoids at the 50% probability level.

(O1) and thiolate sulphur (S1) atoms bonded with Sn1 have axial positions O1-Sn1–S1 angle of 151.41(3)°. The distortion from trigonal bipyramidal geometry is evident from the bond angle O1-Sn1–N1 79.63(4)° and N1–Sn1–S1 75.95(3)° as the sum of bond angles is 155.58° significantly deviated from 180°. Furthermore, the bond angle of N1-Sn1-C10 is 128.47(6)° which is smaller than 180°. Most probably, the distortion is owing to the participation of the N1 atom in five member chelate rings and also large covalent radius of Sn(IV). The C9–Sn1–C10 angle (128.20(6)°) is slightly larger than 120° indicating that the two methyl groups also contribute for deviation. The deviation from the ideal trigonal bipyramidal geometry can be assigned from stretch exploited by the non-planar five member (Sn1–S1–C8–N2–N1) and six member (Sn1–O1–C1–C6–C7–N1) chelate rings upon complexation. The bond angles between the planes of the two rings are C10–Sn1–C9 (128.20°), C10–Sn1–N1 (128.47°) and C9–Sn1–N1 (103.24°) for C10, C9 and N1 placed at the three edges of the trigonal plane which is evidence for the distortion from the perfect TBP geometry. The Sn1-S1 [2.5497(4) Å] and Sn1-N1 [(2.2212(11) Å] bond lengths are similar to those of other five-coordinate distorted trigonal tin complexes of tridentate ONS donors ligand.[45,46] The Sn1-O1 bond distance [2.1181(10) Å] is almost similar to the covalent radii of Sn–O (2.10 Å), considering significant bonding interaction and comparable with reported article.[47] The Sn1–N1 distance [2.2212(11) Å] is a little longer than the sum of Sn-N covalent radii (2.15 Å),[48] considered as strong bonding and consistence with those reported literature.[49] The bond distances of Sn1–C9 (2.1243 Å) and Sn1-C10 (2.1200 Å) are comparable with those found in other reported organotin(IV) compounds.[50,51] The packing of the molecules in the crystal structure is stabilized by intra and intermolecular hydrogen bonding interactions. The most important feature of the crystal packing is the formation of N3H···N2, N3H...O1 and C10–H···N2 hydrogen bonds. Centrosymmetric dimers in the crystal packing are conciliated by N-H....S hydrogen bonds.

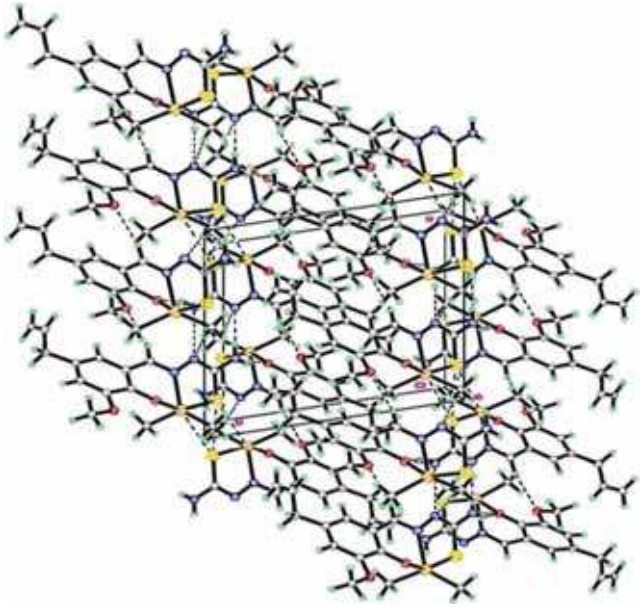


Figure 3. The packing diagram of [$Me_2Sn(L)$] (**5**) in the crystal lattice, viewed along the *a* axis.

3.6 *Antibacterial Activity*

Antibacterial studies of all compounds were carried out *in vitro* against *Staphylococcus aureus, Escherichia coli*, *Enterobacter aerogenes* and *Salmonella typhi*. In this experiments, inhibition zone in millimetre units were presented in table 3. From table 3, it can be concluded that all compounds showed high activity against different bacterial strains but slightly low activity with compared to standard drug (Doxycycline). The ligand showed moderate activity might be due to the presence of OH/NH groups within the parent ligand.[52] Comparison of the antibacterial activity of the free ligand and its organotin(IV) complexes showed that ligand (H_2L) exhibits less activity. The increase in activity of the complexes might be due to the chelation of ligand with tin(IV) leading to electron delocalization and

Table 1. Crystal data and structure refinement parameters for [Me_2Sn(L)] (**5**).

Compound	[Me_2Sn(L)] (**5**)
Empirical formula	$C_{14}H_{19}N_3O_2SSn$
Formula weight	412.07
Temperature (K)	100
Wavelength (Å)	0.71073
Crystal system	Monoclinic
Space group	$P2_1/c$
Unit cell dimensions	
a (Å)	11.5023(7)
b (Å)	13.6747(8)
c (Å)	11.1597(7)
α (°)	90
β (°)	100.3584(8)
γ (°)	90
Volume (Å^3)	1726.71(18)
Z	4
Calculated density (mg/m^3)	1.585
Radiation type λ(Å)	M_0K/a
F(000)	824
Crystal size (mm)	0.14 × 0.40 × 0.47
Crystal colour	Orange
Scan range θ (°)	2.78–30.22
Absorption coefficient (μ) (mm^{-1})	1.607
Max. and min. transm	0.805 and 0.522
Goodness-of-fit on F^2	1.142
Data/Restrains/ parameters	5076/0/201
Final R indices [$I > 2\sigma$ (I)]	$R_1 = 0.0183$, $wR_2 = 0.0191$
R indices (all data)	$R_1 = 0.0551$, $wR_2 = 0.0558$

potent diffusion of the metal complexes into bacterial cell.[53,54] Based on the results, dimethyltin(IV) complex **5** exhibits highest antibacterial activity with inhibition zone rangeing 29.4–27.5 mm. Phenyltin(IV) complex **4** exhibits significantly better activity with inhibition zones in the range of 27.5–26.4 mm against all bacterial strains MeSnCl(L) (**2**) complex exhibits higher activity than BuSnCl(L) (**3**) complex against all bacteria. Therefore, nature of the organo groups (phenyl, methyl and butyl) attached to the tin(IV) centre might

Table 2. Selected bond lengths (Å) and angles (°) of [Me_2Sn(L)] (**5**).

Bond lengths (Å)			
Sn1-S1	2.5495(5)	Sn1-O1	2.1181(10)
Sn1-N1	2.2212(11)	Sn1-C9	2.1243(16)
Sn1-C10	2.1200(16)	S1-C8	1.7417(14)
O1-C1	1.3288(16)	O2-C2	1.3704(18)
O2-C11	1.426(2)	N1-N2	1.3837(17)
N1-C7	1.3038(18)	N2-C8	1.3211(18)
N3-C8	1.336(2)	C1-C2	1.4248(19)
Bond angles (°)			
S1-Sn1-O1	151.41(3)	S1-Sn1-N1	75.96(3)
S1-Sn1-C9	102.49(5)	S1-Sn1-C10	93.68(4)
O1-Sn1-N1	79.63(4)	O1-Sn1-C9	97.36(5)
O1-Sn1-C10	89.93(5)	N1-Sn1-C9	103.24(5)
N1-Sn1-C10	128.47(5)	C9-Sn1-C10	128.20(6)
Sn1-S1-C8	96.24(5)	Sn1-O1-C1	123.08(8)
Sn1-N1-N2	122.43(8)	Sn1-N1-C7	122.48(10)
N2-N1-C7	114.79(11)	N1-N2-C8	115.94(11)

Table 3. Antibacterial activity[a] of ligand (**1**) and its organotin(IV) complexes (**2–5**) (inhibition zone in mm).

Compounds	Bacterium			
	S. aureus	*E. coli*	*E. aerogenes*	*S. typhi*
H_2L (1)	14.2	12.4	–	11.8
2	23.8	24.1	25.1	24.3
3	23.2	20.8	22.9	21.2
4	26.4	25.7	26.1	27.5
5	27.8	28.9	27.5	29.4
R	31.6	33.4	32.5	33.1

[a]Concentration used: 2 mg/mL of DMSO, R = standard drug: Doxycycline, dash indicate inactivity.

play an important role in growth inhibitory activity. The organotin(IV) derivatives remarkably inhibit gram-negative/gram-positive bacterial growth. The enhanced antibacterial activity of organotin(IV) derivatives compared to the parent ligand is most possibly due to the reduction in the polarity of the tin(IV) atom upon coordination with the ligand. The antibacterial activities of the studied organotin(IV) compounds are comparable with other reported organotin complexes.[55–57] Hence, organotin(IV) complexes studied in this work may be good candidates to be used as new antibacterial agents. Detailed studies in this research field will be investigated in future biological applications.

4. Conclusion

Four new organotin(IV) complexes of 5-allyl-2-hydroxy-3-methoxybenzaldehyde-4-thiosemicarbazone have been synthesized and their proposed structures are supported by various physico-chemical methods. From the single crystal X-ray molecular structure of complex **5**, it can be concluded that ONS-donor thiosemicarbazone ligand (H_2L) is completely deprotonated and coordinated to the tin(IV) moiety *via* phenolic oxygen, azomethine nitrogen and thiolate sulphur atoms. All the synthesized complexes have shown pronounced biological activities. These organotin(IV) complexes have good antibacterial activity and may be designed as potential drugs in the pharmaceutical field in future

Supplementary Information

UV-Visible, FT-IR and multinuclear NMR (^{1}H, ^{13}C, and ^{119}Sn) spectra of the ligand and its complexes (figures S1–S9) are available at www.ias.ac.in/chemsci. CCDC reference number 1054928 contains the supplementary crystallographic data for [Me_2Sn(L)] (**5**). This data can be obtained free of charge from the Cambridge Crystallographic data center via www.ccdc.ac.uk/data_request/cif or from the Cambridge Crystallographic data center, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or e-mail: deposit@ccdc.cam.ac.uk.

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References

1. Campbell M J M 1975 *Coord. Chem. Rev.* **15** 279
2. Tojal J G, Orad A, Diaz A A, Serra J L, Urtiaga M K, Arriortua M I and Rojo T 2001 *J. Inorg. Biochem.* **84** 271
3. El-Ayaan U, Youssef M M S and Al-Shihry 2009 *J. Mol. Struct.* **936** 213
4. Lukmantara A Y, Kalinowski D S, Kumar N and Richardson D R 2013 *Bioorg. Med. Chem. Lett.* **23** 967
5. Walcourt A, Loyevsky M, Lovejoy D B, Gordeuk V R, Richardson and Des R 2004 *Int. J. Biochem. Cell Biol.* **36** 401
6. Serda M D, Kalinowski S, Wilczkiewicz A M, Musiol R, Szurko A, Ratuszna A, Pantarat N, Kovacevic Z, Merlot A M, Richardson D R and Polanski R 2012 *J. Bioorg. Med. Chem. Lett.* **22** 5527
7. Mendes I C, Moreira J P, Speziali N L, Mangrich A S, Takahashi J A and Beraldo H 2006 *J. Braz. Chem. Soc.* **17** 1571
8. Silva J G, Azzolini L S, Wardell S M S V, Wardell J L and Beraldo H 2009 *Polyhedron* **28** 2301
9. Khoo L E, Xu Y, Goh N K, Chia L S and Koh L L 1997 *Polyhedron* **16** 573
10. Dakternieks D, Basu-Baul T S, Dutta S and Tiekink E R T 1998 *Organometallics* **17** 3058
11. Teoh S G, Ang S H, Fun H K and Ong C W 1999 *J. Organomet. Chem.* **580** 17

12. Gielen M, Biesemans M and Willen R 2005 *Appl. Organomet. Chem.* **19** 440
13. Chaudhary P, Swami M, Sharma D K and Singh R V 2009 *Appl. Organomet. Chem.* **23** 140
14. Zubita J A and Zukerman J J 1987 *Inorg. Chem.* **24** 251
15. Rebolledo A P, Vieites M, Gambino D, Piro O E, Castellano E E, Zani C L, Souza-Fagundes E M, Teixeira L R, Batista A A and Beraldo H 2005 *J. Inorg. Biochem.* **99** 698
16. West D X, Bain G A, Butcher R J, Jasinski J P, Li Y, Pozdniakiv R Y, Valdes- Martinez J, Toscano R A and Hernandes-Ortega S 1996 *Polyhedron* **15** 665
17. Maurya M R, Kumar A, Abid M and Azam A 2006 *Inorg. Chim. Acta* **359** 2439
18. Alomar K, Khan M A, Allain M and Bouet G 2009 *Polyhedron* **28** 1273
19. Vieites M, Otero L and Santos D 2009 *J. Inorg. Biochem.* **103** 411
20. de Sousa G F, Francisco R H P, Gambardella M T d P, Santos R H d A and Abras A 2001 *J. Braz. Chem. Soc.* **12** 722
21. Hussein M A, Guan T S, Haque R A, Ahamed M B K and Majid A M S A 2015 *Polyhedron* **85** 93
22. Hussein M A, Guan T S, Haque R A, Ahamed M B K and Abdul Majid A M S 2014 *J. Coord. Chem.* **67** 714
23. Gómez-Saiz P, García-Tojal J, Maestro M, Mahía J, Lezama L and Rojo T 2003 *Eur. J. Inorg. Chem.* **2003** 2123
24. López-Torres E, Mendiola M A, Pastor C J and Procopio J R 2003 *Eur. J. Inorg. Chem.* **2003** 2711
25. Casas J S, García-Tasende M S and Sordo J 2000 *Coordination Chemistry Reviews* **209** 197
26. Yang Z Y, Yang R D and Yu K B 1996 *Polyhedron* **15** 3771
27. Garcia-Zarracino R, Ramos-Quinones J and Höpfl H 2003 *Inorg. Chem.* **42** 3835
28. Tsangaris J M and Williams D R 1992 *Appl. Organomet. Chem.* **6** 3
29. Sheldrick G M, SHELXTL Version 5.1 *Software Reference Manual* 1997 Bruker AXS Inc, Madison, Wisconsin, USA
30. Rahman A, Choudry M A and Thomsen M I W J 2001 In *Bioassay Techniques for Drug Development* (Harwood Academic Publishers: The Netherlands)
31. Maurya R M, Jayaswal M N, Puranik V G, Chakrabarti P, Gopinathan S and Gopinathan C 1997 *Polyhedron* **16** 3977
32. Silverstein R M, Bassler G C and Morrill T C 1981 In *Spectrometric Identification of Organic Compounds* 4th ed. (Wiley: New York)
33. Singh S, Bharti N, Naqvi F and Azam A 2004 *Eur. J. Med. Chem.* **39** 459
34. Costa F F, Rebolledo A P, Matencio T, Calado H D R, Ardisson J D, Cortes M E, Rodrigues B L and Beraldo H 2005 *J. Coord. Chem.* **58** 1307
35. Mendes I C, Moreira J P, Mangrich A S, Balena S P, Rodrigues B L and Beraldo H 2007 *Polyhedron* **26** 3263
36. Rajan O A and Chakravarthy A 1981 *Inorg. Chem.* **20** 660
37. Sedaghat T and Shokohi-Pour Z 2009 *J. Coord. Chem.* **62** 3837
38. Saraswat B S, Srivastava G and Mehrotra R C 1979 *J. Organomet. Chem.* **164** 153
39. Teoh S G, Teo S B, Yeap G Y and Declercq J P 1991 *Polyhedron* **10** 2683
40. Mesubi M A and Enemo R E 1982 *Spectrochim. Acta A* **38** 599
41. Lockhart T P and Manders W F 1986 *Inorg. Chem.* **25** 892
42. Nath M, Saini P K and Kumar A 2010 *J. Organomet. Chem.* **695** 1353
43. Yin H D and Chen S W 2006 *Inorg. Chim. Acta* **359** 3330
44. Wrackmeyer B 1985 *Annual Reports on NMR Spectroscopy* **16** 73
45. Chee D N A, Affan M A, Ahmad F B, Asaruddin M R, Sam N, Salam M A, Ismail A and Tan S H 2011 *J. Coord. Chemi.* **64** 4191
46. de Sousaa G F, Franciscob R H P, Gambardellab M T P, Santosb R H deA and Abras A 2001 *Braz. Chem. Soc.* **12** 722
47. Labisbal E, Rodriguez L, Sousa-Pedrares A, Alonso M, Vizoso A, Romero J, Garcia-Vazquez A and Sousa A 2006 *J. Organomet. Chem.* **691** 1321
48. Purcell K F and Kotz J C 1980 In *An Introduction to Inorganic Chemistry* (Saunders College Publishing: Orlando, USA)
49. Pettinari C, Marchetti F, Pettinari R, Martini D, Drozdov A and Troyanov S 2001 *Inorg. Chim. Acta* **325** 103
50. Lopez-Torres E, Mendiola M A, Pastor C J and Procopio J R 2003 *Eur. J. Inorg. Chem.* **2003** 2711
51. Casas J S, Castineiras A, Rodríguez-Arguelles M C, Sanchez A, Sordo J, Vazquez- Lopez A and Vazquez-Lopez E M 2000 *J. Chem. Soc., Dalton Trans.* **2000** 2267
52. Rehman W, Baloch M K and Badshah A 2008 *Eur. J. Med. Chem.* **43** 2380
53. Chohan Z H, Hassan M U I, Khan K M and Supuran C T 2005 *J. Enzyme Inhib. Med. Chem.* **20** 183
54. Dharmaraj N, Vishwanathamurthi V and Natarajan K 2001 *Transition Met. Chem.* **26** 105
55. Ming-Xue L, Dong Z, Li-Zhi Z, Jing-Yang N and Bian-Sheng J 2011 *J. Organomet. Chem.* **696** 852
56. Mendes I C, Moreira J P, Ardisson J D, dos Santos R G, da Silva P R O, Garcia I, Castiñeiras A and Beraldo H 2008 *Eur. J. Med. Chem.* **43** 1454
57. Shujah S, Rehman Z, Muhammada N, Ali S, Khalid N and Tahir M N 2011 *J. Organomet. Chem.* **696** 2772