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Triorganotin(IV) complexes of pyruvic acid-*N*(4)-cyclohexylthiosemicarbazone (HPACT): Synthesis, characterization, crystal structure and *in vitro* antibacterial activity

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ABSTRACT

The reaction of triorganotin(IV) chloride with pyruvic acid-*N*(4)-cyclohexylthiosemicarbazone (HPACT) afforded the complexes [Bu_3Sn(PACT)] (**1**) and [Ph_3Sn(PACT)] (**2**). The ligand HPACT and its two triorganotin(IV) complexes **1** and **2** have been characterized by elemental analyses, UV–Vis, FT-IR, ^1H and ^{13}C NMR spectroscopy. The structure of the tributyltin(IV) complex **1** was also investigated by X-ray crystallography. The crystal structure of complex **1** revealed that the ligand is coordinated to the tin(IV) moiety as a uninegative monodentate ligand *via* the carboxylato-O atom. The tin(IV) atom exists in a distorted tetrahedral geometry defined by three *ipso*-C atoms of the butyl groups and a carboxylato-O atom of the ligand. The compound crystallizes into a monoclinic lattice with the space group *P*21. The ligand and its triorganotin(IV) complexes **1** and **2** were assayed for *in vitro* antibacterial activity against two Gram-positive bacterial strains (*Bacillis subtilis* and *Staphylococcus aureus*) and two Gram-negative bacterial strains (*Escherichia coli* and *Salmonella typhi*). The screening results have shown that the triorganotin(IV) complexes **1** and **2** have better antibacterial activity than the free ligand. Furthermore, it has been shown that the triphenyltin(IV) derivative exhibits significantly better activities than the tributyltin(IV) derivative.

1. Introduction

Thiosemicarbazones derivatives have recently attracted considerable attention because of their potential biological (*viz*., antibacterial and antitumor) activities [1–3]. Organotin(IV) complexes have been extensively studied owing to their structural diversity and their beneficial biological activities (*viz*., antiviral and antitumor) as well as their wide industrial and agricultural applications [4–6]. For the past few years, a large amount of work on the synthesis and chracterization of transition metal complexes with thiosemicarbazones has been reported [7–10] but very little work has been reported on tin(IV) complexes with substituted thiosemicarbazone ligands. In addition to their biological activities, the coordination chemistry of thiosemicarbazone complexes has been studied to some extent; the reports include monomeric, dimeric and trimeric structures [11–14]. Usually triorganotin(IV) compounds display higher biological activity than their di and monoorganotin(IV) analogues due to their ability to bind with proteins [15,16]. Wiecek et al. [17] have reported organotin(IV) complexes of pyruvic acid thiosemicarbazone which have five-membered chelate rings containing ONS-donor atoms. It was found that all the compounds were highly active against MCF-7 and T-24 cancer cell lines. Our research group has published the crystal structures of pyruvic acid-*N*(4)-cyclohexylethiosemicarbazone and its mono organotin(IV) complex [18,19]. In this complex, the pyruvic acid-*N*(4)-cyclohexylethiosemicarbazone ligand acted in a dinegative tridentate nature and coordinates to the tin(IV) atom through S, O and imine N atoms, whereas in the present triorganotin(IV) complexes, it functions as a uninegative monodentate ligand with oxygen as the donor atom. This is probably due to the steric and electronic effects of the bulky alkyl/aryl groups. Herein, we report the synthesis, spectroscopic characterization, X-ray structure of complex **1** and the biological studies of two triorganotin(IV) complexes of a substituted thiosemicarbazone. The two triorganotin(IV) complexes **1** and **2** showed greater antibacterial activity than the free ligand, but this was lower than the reference drug.

2. Experimental

2.1. Materials and methods

All reagents were purchased from Fluka, Aldrich and JT Baker. All solvents were purified according to standard procedures [20].

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UV–Vis spectra were recorded in $CHCl_3$ solution with a Perkin Elmer Lambda 25 UV–Vis spectrophotometer. Infrared spectra were recorded on KBr discs using a Perkin Elmer Spectrum GX Fourier-Transform spectrometer in the range 4000–370 cm^{-1} at room temperature. ^1H and ^{13}C NMR spectra were recorded on a JEOL 500 MHz-NMR spectrophotometer relative to $SiMe_4$ using $CDCl_3$ as the solvent. CHN analyses were obtained with a Flash EA 1112 series CHN elemental analyzer. Molar conductivity measurements were carried out with a Jenway 4510 conductivity meter using a DMF solvent mode. The crystallographic data and structure refinement parameters for complex **1** are given in Table 1. A colorless block crystal of compound **1** was measured at 150 K on a CrysAlispro CCD diffractometer with graphite monochromated Cu Kα radiation (λ = 1.5418 Å). The structure was solved by direct methods using SHELXL-97 and refined by full-matrix least-squares refinement on F^2 using SHELXL-97. Positional and anisotropic atomic displacement parameters were refined for all non-hydrogen atoms. Hydrogen atoms were placed in calculated positions.

2.2. Synthesis of pyruvic acid-N(4)-cyclohexylthiosemicarbazone (HPACT)

Cyclohexylisothiocyanate (1.41 g, 10 mmol) in 4 mL of ether was added dropwise into 4 mL of an ether solution of hydrazine hydrate (2 g, 40 mmol). The mixture was stirred vigorously for 5 h, then, 5 mL petroleum ether was added into the resulting solution and stirred for another 1 h. The white product, *N*(4)-cyclohexylthiosemicarbazide, that formed was filtered off, washed with a small amount of cold diethyl ether and dried. *N*(4)-Cyclohexylthiosemicarbazide (0.51 g, 3 mmol) was dissolved in absolute methanol (10 mL) and mixed with 10 mL of an absolute methanolic solution of pyruvic acid (0.261 g, 3 mmol). The resulting mixture was refluxed for 4 h (Scheme 1) and cooled to room temperature. White microcrystals were formed and filtered off. The microcrystals were washed several times with small amounts of cold methanol and subsequently with cold hexane. The microcrystals were recrystallised from methanol and dried *in vacuo* over silica gel. Yield: 0.68 g, 87%; M.p.: 188–190 °C; UV–Vis ($CHCl_3$) λ_{max}/nm: 327; FT-IR (KBr disc, cm^{-1}) ν_{max}: 3322 (br, OH), 3197 (s, NH), 2922, 2851 (s, cyclohexyl), 1702 (m, C=O), 1619 (m, C=N), 980 (m, N–N), 1249, 870 (w, C=S); ^1H NMR ($CDCl_3$) δ: 12.21 (s, 1H, COOH), 9.49 (s, 1H, N2–H), 8.08 (d, 2H, 1H of N1–H, 1H of CyC6–H), 2.21 (s, 3H, N=C–CH_3), 2.05–2.03 (m, 10H, CyC–H), 1.8 (s, 1H, SH); ^{13}C NMR ($CDCl_3$) δ: 180.01 (NH–C=S), 165.71 (COOH), 143.05 (C=N), 52.37–25.44 (cyclohexyl), 10.24 (CH_3); *Anal.* Calc. for $C_{10}H_{17}N_3O_2S$: C, 49.36; H, 7.04; N, 17.26. Found: C, 49.31; H, 7.01; N, 17.18%.

Table 1
Crystal data and structure refinement parameters for complex **1**.

Compound	$[Bu_3Sn(PACT)]$ (**1**)
CCDC No.	828342
Empirical formula	$C_{44}H_{86}N_6O_4S_2Sn_2$
Formula weight	1064.75
T (K)	150
λ (Å)	1.5418
Crystal system	monoclinic
Space group	*P*21
Unit cell dimensions	
a (Å)	9.2810(5)
b (Å)	20.1595(10)
c (Å)	14.0785(7)
α (°)	90.00
β (°)	94.259(5)
γ (°)	90.00
V (Å^3)	2626.8(2)
Z	4
D_{calc} (mg/m^3)	1.346
Radiation type λ (Å)	Cu Kα
F(000)	1112
Crystal size (mm)	0.3388 × 0.1833 × 0.1322
Crystal colour	colourless
Scan range θ (°)	3.84–74.82
Absorption coefficient (μ) (mm^{-1})	8.634
Maximum and minimum transmission	0.459 and 0.197
Goodness-of-fit (GOF) on F^2	1.045
Data/restrains/parameters	6889/7/526
Final R indices [$I > 2\sigma(I)$]	R_1 = 0.0504, wR_2 = 0.1313
R indices (all data)	R_1 = 0.0549, wR_2 = 0.1345

2.3. Synthesis of the complex $[Bu_3Sn(PACT)]$ (**1**)

HPACT (0.243 g, 1.0 mmol) was dissolved in absolute methanol (10 mL) in a Schlenk round bottom flask under a nitrogen atmosphere, then a 10 mL methanolic solution of tributyltin(IV) chloride (0.325 g, 1.0 mmol) was added dropwise. The resulting reaction mixture was refluxed for 6 h (Scheme 2) and cooled to room temperature. The microcrystals that formed were filtered off, washed with a small amount of cold methanol and dried *in vacuo* over silica gel. Colourless crystals suitable for X-ray diffraction were obtained by slow evaporation of a chloroform/methanol (1:1 ratio) solution after 15 days at room temperature. Yield: 0.59 g, 79%; M.p.: 206–208 °C; molar conductance (DMF) Ω^{-1} cm^2 mol^{-1}: 11.3; UV–Vis ($CHCl_3$) λ_{max}/nm: 328, 368; FT-IR (KBr disc, cm^{-1}) ν_{max}: 3190 (s, NH), 2932, 2854 (s, cyclohexyl), 1674 [m, ν_{asy} (COO^-)], 1454 [m, ν_{sym} (COO^-)], 1626 (m, C=N), 980 (m, N–N), 1250, 868 (w, C=S), 592 (w, Sn–C), 477 (w, Sn–O); ^1H NMR ($CDCl_3$) δ: 9.50 (*s*, 1H, N2–H), 8.05 (d, 2H, 1H of N1–H, 1H of CyC6–H), 2.24 (s, 3H, N=C–CH_3), 2.17–2.06 (m, 10H, CyC–H), 2.05–2.01 (t, 2H, Sn–CH_2–CH_2–CH_2–CH_3), 1.68–1.61 (m, 2H Sn–CH_2–CH_2–CH_2–CH_3), 1.55–1.29 (m, 2H, Sn–CH_2–CH_2–CH_2–CH_3), 0.88–0.85 (t, 3H, Sn–CH_2–CH_2–CH_2–CH_3); ^{13}C NMR ($CDCl_3$) δ: 180.88 (NH–C=S), 172.52 (COO^-), 143.42 (C=N), 52.11–32.32 (cyclohexyl), 11.98 (CH_3), 27.33, 25.98, 23.24, 17.36 [^1J (^{13}C–^{119}Sn): 386 Hz, Sn–Bu]. *Anal.* Calc. for $C_{22}H_{43}N_3O_2SSn$: C, 49.63; H, 8.14; N, 7.89. Found: C, 49.58; H, 8.11; N, 7.85%.

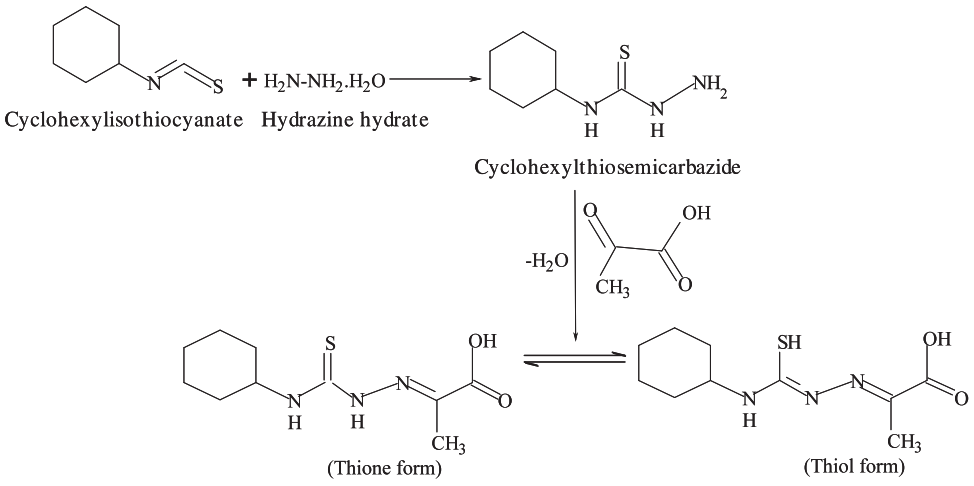
The triphenyltin(IV) complex **2** was synthesized using a similar procedure to **1** using triphenyltin(IV) chloride.

2.4. Synthesis of complex $[Ph_3Sn(PACT)]$ (**2**)

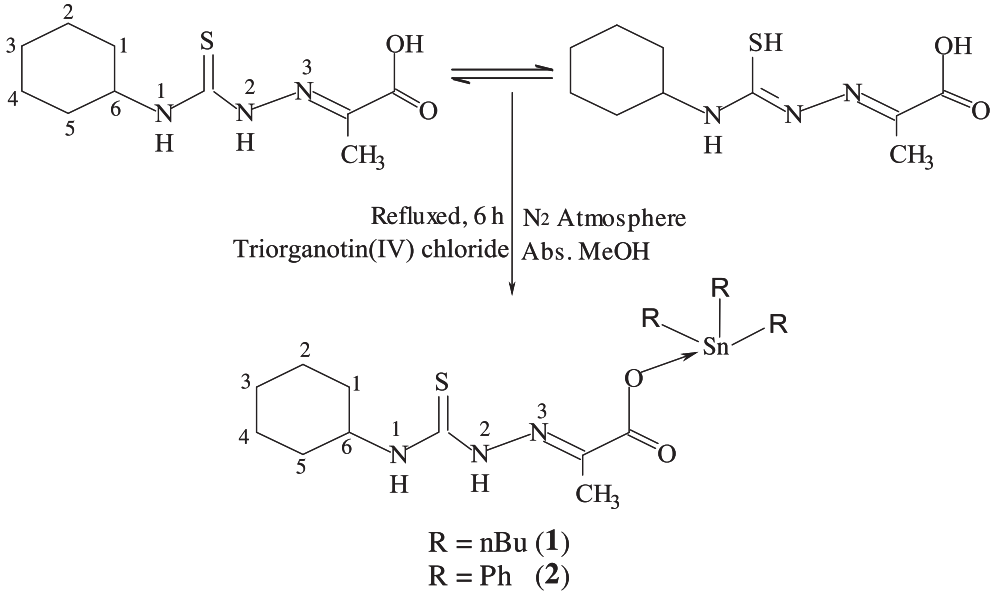
Yield: 0.51 g, 81%; M.p.: 218–220 °C; molar conductance (DMF) Ω^{-1} cm^2 mol^{-1}: 14.7; UV–Vis ($CHCl_3$) λ_{max}/nm: 328, 372; FT-IR (KBr disc, cm^{-1}) ν_{max}: 3114 (s, NH), 2935, 2859 (s, cyclohexyl), 1668 [m, ν_{asy} (COO^-)], 1458 [m, ν_{sym} (COO^-)], 1622 (m, C=N), 987 (m, N–N), 1246, 865 (w, C=S), 593 (w, Sn–C), 482 (w, Sn–O); ^1H NMR ($CDCl_3$) δ: 10.17 (s, 1H, N2–H), 8.31 (d, 2H, 1H of N1–H, 1H of CyC6–H), 7.82–7.80 (m, 15H of phenyl ring), 2.26 (s, 3H, N=C–CH_3), 2.08–2.05 (m, 10H, CyC–H); ^{13}C NMR ($CDCl_3$) δ: 180.32 (NH–C=S), 170.55 (COO^-), 143.33 (C=N), 51.11–28.68 (cyclohexyl), 11.71 (CH_3), 144.88, 143.56, 142.36, 138.36 [^1J (^{13}C–^{119}Sn): 661.5 Hz, Sn–Ph]. *Anal.* Calc. for $C_{28}H_{31}N_3O_2SSn$: C, 56.77; H, 5.28; N, 7.09. Found: C, 56.72; H, 5.25; N, 7.07%.

2.5. Antibacterial test

The synthesized ligand (HPACT) and its triorganotin(IV) complexes **1** and **2** were screened *in vitro* for their antibacterial activity against two Gram-positive (*Bacillis subtilis* and *Staphylococcus aureus*) and two Gram-negative (*Escherichia coli* and *Salmonella typhi*) bacterial strains using the agar-well diffusion method [21]. Wells (of the size 6 mm in diameter) were dug in the media with the help of a sterile metallic borer, with centers at least 24 mm apart. Eight hours old bacterial inoculums containing 10^4–10^6 colony forming units (CFU)/mL were spread on the surface of the



Scheme 1. Synthesis of the pyruvic acid-*N*(4)-cyclohexylthiosemicarbazone (HPACT) ligand.



Scheme 2. Synthesis of the triorganotin(IV) complexes **1** and **2**.

nutrient agar using a sterile cotton swab. The recommended concentration of the test sample (200 mg/mL in DMSO) was introduced in the respective wells. Other wells supplemented with DMSO and reference antibacterial drug (imipenem) served as negative and positive controls, respectively. The plates were incubated immediately at 37 °C for 20 h. 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

Pyruvic acid-*N*(4)-cyclohexylthiosemicarbazone (HPACT) was synthesized by the condensation reaction of pyruvic acid and 4-cyclohexylthiosemicarbazide in absolute methanol in a 1:1 mole ratio. It has two tautomers within the structure, existing as either the thione or thiol tautomer (Scheme 1). The present triorganotin(IV) complexes (**1** and **2**) were obtained by the direct reaction of tributyltin(IV)/triphenyltin(IV) chloride and HPACT in absolute methanol under a nitrogen atmosphere (Scheme 2). The physical properties and analytical data of HPACT and its triorganotin(IV) complexes **1** and **2** are given in the experimental section. The ligand and its complexes **1** and **2** are stable under a N_2 atmosphere and are soluble in $CHCl_3$, CH_2Cl_2, DMF, DMSO and MeCN solvents, and are insoluble in methanol, ethanol, hexane, pentane, THF and ether. The molar conductance values of complexes **1** and **2** are 11.3 and 14.7 Ω^{-1} cm^2 mol^{-1}, respectively, which indicate that the complexes behave as non-electrolytes [22].

3.1. UV–Vis spectra

The UV–Vis spectra of the ligand HPACT and its triorganotin(IV) complexes **1** and **2** were carried out in $CHCl_3$ solution (10^{-4} mol L^{-1}) at room temperature. The UV–Vis spectra of these compounds are shown in Fig. 1. The UV–Vis spectrum of HAPCT exhibits only one band at 327 nm, assigned to the HOMO/LUMO transition. The HOMO orbital has a π bonding character located on the S=C–NH–cyclohexyl system; The LUMO orbital is a π* orbital (antibonding) located on the S=C–N–N=C–Me system. After complexation, complexes **1** and **2** showed two absorption bands

in the regions 328–335 and 368–377 nm. The absorption bands which appeared at 328–335 nm are due to an intra ligand transition. In the spectra of complexes **1** and **2**, one new absorption band appeared at 368–377 nm which is assigned to a ligand → metal (Sn) charge transfer (LMCT) band [23]. The shift of the HOMO/LUMO band from HPACT to the tin(IV) complexes is a clear indication that coordination occurred between tin(IV) and the ligand HPACT.

3.2. IR spectra

In its IR spectrum, HPACT displayed absorption bands at 3322 and 3197 cm^{-1} attributed to the OH group and the NH moiety linked to the cyclohexyl group, respectively. The other absorption bands observed in the spectrum at 2922 and 2851, 1702, 1619, 980, 1249 and 873 cm^{-1} are due to ν(cyclohexyl), ν(C=O), ν(C=N), ν(N–N) and ν(C=S), respectively. The characteristics absorption frequencies, e.g., ν(C=O) and ν(Sn–O), provide valuable information about the formation of tin(IV) complexes and the coordination mode of the ligand. The assignment of IR bands of these triorganotin(IV) derivatives have been determined by a comparison with the IR spectrum of the free ligand. The free ligand shows a broad OH absorption band at 3322 cm^{-1}, which is absent in the spectra of complexes **1** and **2**, suggesting that the ligand is coordinated to the tin(IV) atom through the carboxylate oxygen after deprotonation of OH. A new absorption band at 477–482 cm^{-1} is assigned to the stretching mode of the Sn–O linkage, indicating the formation of a complex, and this value is comparable with the published literature [24]. The ν(C=O) band of the COOH group is observed at 1702 cm^{-1} in the infrared spectrum of the free ligand, and is absent in the IR spectra of complexes **1** and **2**. In the IR spectra of complexes **1** and **2**, two new absorption bands were observed at 1668–1674 and 1454–1458 cm^{-1}, which are attributable to $\nu_{asy}(COO^-)$ and $\nu_{sym}(COO^-)$, respectively. The magnitude of $\Delta[\nu_{asy}(COO^-)-\nu_{sym}(COO^-)]$ is 220 and 210 cm^{-1} for complexes **1** and **2**, respectively, and this can be used to determine the type of bonding between the tin(IV) centre and the carboxyl group. This information also indicates that the carboxylate group is monodentate [25]. The absorptions at 592 and 593 cm^{-1} in the spectra of complexes **1** and **2** are assigned to the band characteristic for ν(Sn–C). The ν(NH), ν(C=N) and ν(C=S) absorption bands were found at similar positions to the ligand absorption bands, indicating the azomethine nitrogen and thione sulfur atoms are not coordinate to the tin(IV) moiety. The information obtained from the infrared spectra of complexes **1** and **2** supports the X-ray data of complex **1**.

3.3. ^1H and ^{13}C NMR spectra

The characteristic resonance peaks in the ^1H and ^{13}C NMR spectra of the ligand and its triorganotin(IV) complexes **1** and **2** were recorded in $CDCl_3$ and interpreted based on the atomic labelling in Scheme 2. The ^1H NMR spectrum of the free ligand showed a singlet at 12.21 ppm, corresponding to the resonance signal of COOH. The resonance signal at 9.49 ppm is assigned to the N2–H proton. A doublet at 8.08 ppm corresponded to N1–H, which overlaps with CyC6–H. The resonance signal at 2.21 ppm is due to N=C–CH_3. The OH proton signal was absent in the spectra of complexes **1** and **2**, indicating the deprotonation of the carboxylic proton and coordination to the tin(IV) atom. The chemical shift of the N2–H proton was observed at 9.50 and 10.17 ppm for complexes **1** and **2**. The N1–H proton signals, which overlap with proton signal of CyC6–H for complexes **1** and **2**, were observed at 8.05 and 8.31 ppm, respectively. The resonance signal of the phenyl protons in complex **2** appeared as a multiplet at about 7.80–7.82 ppm. The azomethine proton (N=C–CH_3) signal appears at 2.21 ppm in the free ligand, and at 2.24–2.26 ppm in complexes **1** and **2**. These peaks are slightly downfield shifted in the complexes, which might be due to electron delocalization through the S=C–NH–N=C–Me system. The three butyl groups attached to the tin(IV) moiety in complex **1** gave four resonance signals, namely 2.05–2.01 (triplet, Sn–CH_2–CH_2–CH_2–CH_3), 1.68–1.61 (multiplet, Sn–CH_2–CH_2–CH_2–CH_3), 1.55–1.29 (multiplet, Sn–CH_2–CH_2–CH_2–CH_3) and 0.88–0.85 ppm (triplet, Sn–CH_2–CH_2–CH_2–CH_3). The ^1H NMR information also support the IR data of complexes **1** and **2**.

The ^{13}C NMR peaks in the free ligand were observed at 180.01, 165.71, 143.05, 52.07–25.44 and 10.24 ppm due to the δ(NH–C=S), δ(COOH), δ(C=N), δ(cyclohexyl ring) and $\delta(CH_3)$, respectively. After complexation, the position of the carboxylate carbon moved to the lower field region compared to the free ligand, being at 172.52–170.55 ppm for complexes **1** and **2**, indicating coordination of the carboxylate group to the tin(IV) atom [26]. The chemical shifts of

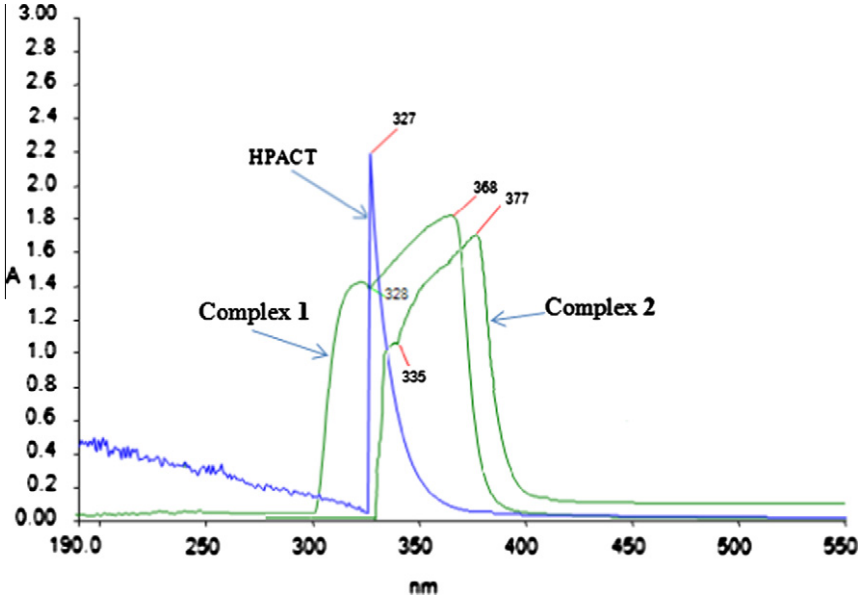


Fig. 1. UV–Vis absorption spectra of the HPACT ligand and its triorganotin(IV) complexes (**1** and **2**).

δ(NH–C=S), δ(cyclohexyl ring) and $\delta(CH_3)$ does not shift significantly in complexes **1** and **2** as compared to the free ligand. The coupling constant, $^{1}J[^{119}Sn, ^{13}C]$ is one of the key parameters in assessing the possible coordination geometries of organotin(IV) compounds in solution. For the tributyltin(IV) (**1**) and triphenyltin(IV) (**2**) compounds, the coupling constants were found to be 386 and 661.5 Hz, respectively, which corresponds to a tetrahedral geometry in $CDCl_3$ solution [26,27].

3.4. X-ray crystallography diffraction analyses

The molecular structure of complex **1** with the atomic numbering scheme is depicted in Fig. 2. The main crystal parameters are reported in Table 1. Selected bond lengths and bond angles are given in Table 2. The compound crystallizes with two molecules per asymmetric unit into the monoclinic crystal system with a space group of *P*21. From Table 2 it is clear that the two molecules in the asymmetric unit are almost identical. So the discussion can be limited to one of the molecules. In one of the molecules a butyl chain was disordered. This was modelled as two parts with a 60:40 occupancy ratio. The atoms involved were refined isotropically as the data did not support anisotropic refinement. The solid state structure of the reported complex **1** showed that the monodeprotonated ligand is coordinated to the tin(IV) atom *via* the carboxylato-O atom. Thus, the coordination geometry about the tin atom is best described as distorted tetrahedral with one O atom and three C atoms which exhibit an R_3SnO geometry. The bond lengths O1A–C2A and O3A–C2A are 1.290(11) and 1.245(12) Å, respectively, which specify delocalized bonding at the carboxylic group, indicating the longer separation being associated with the stronger Sn–O1A interaction [28]. The Sn1–O1A bond distance is 2.139 Å, which is close to the sum of the covalent radii of tin and oxygen (2.10 Å), but is considerably less than the van der Waals radii (2.8 Å), indicating a strong Sn–O bonding interaction. The metal-oxygen bond distance (Sn–O) is similar to other organotin(IV) complexes presented in the literature [29–31]. The most significant differences in the geometric parameters about the tin atom were found in the O–Sn–C and C–Sn–C angles. The major distortion from an ideal tetrahedral configuration is shown by the O1A–Sn1–C1C angle of 92.8(3)°. However it is noteworthy that the C1D–Sn1–C1B angle of 123.2(4)° is the next major distortion from the ideal geometry. This distortion is probably due to the bulky butyl groups attached to the tin(IV) atom. Other bond angles around the tin(IV) centre are O1A–Sn1–C1D = 100.8(4)° and O1A–Sn1–C1B = 95.9(3)°, which deviates from the ideal value, probably due to the ligand constituents. The sum of the bond angles for C1B–Sn1–C1D (123.2(4)°), C1B–Sn1–C1C (116.7(4)°) and C1D–Sn1–C1C (116.2(4)°) is 356.1°, which indicates that the Sn–3C system [Sn1–C(1B)–C(1C)–C(1D)] is basically planar for complex **1**. The Sn–C bond lengths are consistent with those reported in other organotin complexes [31,32]. The N6A–N7A bond length (1.375(11) Å) is closer to a single bond length (1.45 Å) than to a double bond length (1.25 Å) [33]. The C8A–S9A bond distance of 1.695(9) Å is close to that expected for a C=S double bond (1.60 Å) [31] and the C4A–N6A bond length of 1.298(12) Å is nearly the same as that of a C=N double bond (1.28 Å) [34].

Table 2
Selected bond lengths (Å) and angles (°) of [Bu_3Sn(PACT)] (**1**).

Bond lengths (Å)			
Sn1–O1A	2.131(7)	O3A–C2A	1.245(12)
Sn1–C1C	2.154(9)	N6A–C4A	1.298(12)
Sn1–C1D	2.153(11)	N6A–N7A	1.375(11)
Sn1–C1B	2.121(10)	C4A–C2A	1.504(14)
S9A–C8A	1.695(9)	C4A–C5A	1.494(13)
C3D–C2D	1.541(13)	C8A–N10A	1.311(13)
C3D–C4D	1.523(18)	C8A–N7A	1.372(12)
O1A–C2A	1.290(11)	N10A–C11A	1.478(11)
Bond angles (°)			
O1A–Sn1–C1C	92.8(3)	C1B–Sn1–C1D	123.2(4)
O1A–Sn1–C1D	100.8(4)	C2A–O1A–Sn1	123.0(7)
O1A–Sn1–C1B	95.9(3)	C4A–N6A–N7A	118.7(8)
C1D–Sn1–C1C	116.2(4)	N6A–CV4A–C2A	124.7(9)
C1B–Sn1–C1C	116.7(4)	N6A–C4A–C5A	116.6(9)
C5A–C4A–C2A	118.7(8)	N10A–C8A–S9A	124.5(7)
O1A–C2A–C4A	114.5(9)	N10A–C8A–N7A	117.2(8)
O3A–C2A–O1A	124.1(9)	N7A–C8A–S9A	118(7)
O3A–C2A–C4A	121.4(8)	C8A–N10A–C11A	125.2(8)

3.5. Antibacterial activity

The synthesized ligand (HPACT) and its triorganotin(IV) complexes **1** and **2** were tested against *B. subtilis*, *S. aureus*, *E. coli* and *S. typhi* bacterial strains for their antibacterial activity using the agar-well diffusion method, and data are listed Table 3. It was concluded that the triorganotin complexes are more active than the free ligand, which indicates that the metallation increases the antibacterial activity. Based on the results, the free ligand (HAPCT)

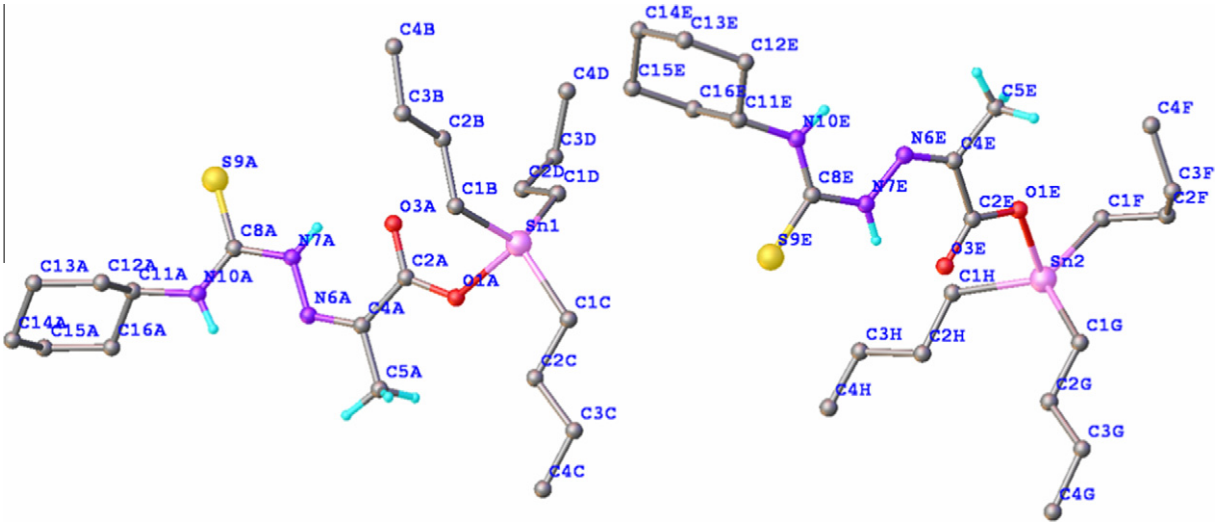


Fig. 2. Molecular structure of the complex [Bu_3Sn(PACT)] (**1**). The hydrogen atoms on the cyclohexyl and butyl groups are omitted for clarity.

Table 3
Results of the antibacterial activity of free HPACT and its triorganotin(IV) complexes (**1** and **2**) (inhibition zone in mm).

Sample	Inhibition zone diameter (mm)			
	Bacteria			
	B. subtilis	*S. aureus*	*E. coli*	*S. typhi*
HPACT	12.2	15.8	13.4	12.7
1	25.7	24.8	20.3	22.8
2	27.3	31.8	24.7	21.1
Imipenem	31.5	38.8	35.2	29.7

shows moderate activity towards the bacteria, and this is might be due to the NH group inside the ligand playing an important role in the antibacterial activity. The screening results exhibited by complexes **1** and **2** showed high activity against all the bacteria strains, but lower activity than the reference drug. The antibacterial activity shown by these compounds against all the bacteria indicates that coupling of HAPCT with the R_3Sn(IV) metal centre results in metallic complexes with important biological properties and better antibacterial activity. Slightly better antibacterial activity was attributed to complex **2** due to the presence of the phenyl groups, which facilitate binding to biological molecules by π–π interactions. The activity might be due to the high lipophilic nature of the complex. Electron delocalization in the chelate ring increases the lipophilic character of metals chelates, which favours the permeation of the complexes through the lipid layer of the cell membrane. It is suggested that the antimicrobial activity of complexes **1** and **2** is due to either killing of the microbes or inhibiting their multiplication by blocking their active site [35].

4. Conclusion

Triorganotin(IV) complexes (**1** and **2**) of pyruvic acid-*N*(4)-cyclohexylthiosemicarbazone (HPACT) have been synthesized and structurally characterized. The ligand (HPACT) exists in the thione form in the solid state, but takes on a thiol form when it is in solution. The triorganotin(IV) complexes of HPACT (**1** and **2**) were proposed to be four coordinated, and the ligand binds to the tin(IV) atom in a uninegative monodentate form. X-ray crystallographic diffraction has revealed that complex **1** is rendered into a distorted tetrahedral geometry. All the compounds have been found to be biologically active, while the triphenyltin(IV) complex (**2**) is more active than the tributyltin(IV) complex (**1**).

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Appendix A. Supplementary data

CCDC 828342 contains the supplementary crystallographic data for compound [Bu_3Sn(PACT)] (**1**). These data can be obtained free of charge via http://www.ccdc.cam.ac.uk/conts/retrieving.html, or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223 336 033; or e-mail: deposit@ccdc.cam.ac.uk.

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