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Some tricyclohexyltin carboxylates containing germanium: synthesis, spectral and crystallographic characterization

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Six tricyclohexyltin triorganogermyl (substituted) propionates have been synthesized and their structures characterized by IR, multinuclear magnetic resonance (^{1}H, ^{13}C, ^{119}Sn) and Mössbauer spectroscopies. Three of them have been characterized crystallographically by X-ray diffraction. The crystal structures of [(*p*-$CH_3C_6H_4$)$_3$GeCH(*p*-$CH_3C_6H_4$)$CH_2COOSn(C_6H_{11})_3$] (1) and [$(C_6H_5)_3$GeCH(C_6H_5)CH(CH_3)$COOSn(C_6H_{11})_3$] (3) indicate that the tin possesses a tetrahedral geometry. The crystal structure of [(*p*-$CH_3C_6H_4$)$_3$GeCH(*p*-$CH_3OC_6H_4$)$CH_2COOSn(C_6H_{11})_3]H_2O$ (2) shows trigonal bipyramidal geometry around the tin with water of hydration enhancing the coordination sphere of the metal. Some of these compounds demonstrated positive antibacterial, antifungal and lethality bioassays. Copyright © 2003 John Wiley & Sons, Ltd.

KEYWORDS: synthesis; tricyclohexyltin carboxylates; germylpropanoic acids; crystal structure; spectroscopy; biological studies

INTRODUCTION

Organotin compounds having three direct tin–carbon bonds are important commercially as biocidally active agents.[1] Tricyclohexyltin hydroxide is highly effective in the control of phytophagus mites.[2] Triorganotin compounds demonstrate an interesting range of structural variations, leading to an identifiable activity–structure relationship.[3] In recent years, some germanium-containing organic compounds have received considerable attention because of their potential clinical applications.[4] There has been an established link between the biological properties of active organotin and organogermanium compounds.[5] It has been reported[6] that triorganotin carboxylates containing the biologically active germyl groups in the carboxylate ligands exhibit good acaricidal activity against *Tetraanychus urticae* Koch and *Culicidae* and the results of bioassay have shown that all these compounds have poor fungicidal activity on the *Aphis craccivora*. Biological testing of germanium–tin compounds has demonstrated that these can be used against bacterial, viral and fungal ailments found in both humans and in animals. Some of these compounds were found to be more active for certain bacteria, such as *Bacillus cerus* and *Klebsiella pneumoniae*, than the reference drugs were.[7] In a continuation of our previous reports,[8,9] we have synthesized some triorganotin carboxylates containing triorganogermyl groups as part of the carboxylate ligands and report their structures, antibacterial, antifungal and lethality bioassays.

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DISCUSSION

Six tricyclohexyltin carboxylates derived from substituted triorganogermyl propanoic acids $(^1R)_3GeCH(^2R)CH(^3R)CO_2H$ have been prepared in a conventional way by reaction with $(C_6H_{11})_3SnOH$, with removal of water effected by use of a Dean and Stark apparatus:

$$(C_6H_{11})_3SnOH + (^1R)_3GeCH(^2R)CH(^3R)COOH \longrightarrow (C_6H_{11})_3SnO_2CCH(^3R)CH(^2R)Ge(^1R)_3$$

^1R = p–$CH_3C_6H_4$, *m*–$CH_3C_6H_4$

^2R = CH_3, C_6H_5, *p*–$CH_3C_6H_4$, *p*– $CH_3OC_6H_4$

^3R = H, CH_3

Triorganotin derivatives **1–6** were obtained in good yields (Table 1). The compounds are water- and air-stable because of the relatively low polarity of the E–C bond (E = Ge, Sn), and they are soluble in chloroform, toluene and dimethylsulfoxide (DMSO). Compound **2** appears to be formed initially as an anhydrous compound, on the basis of microanalysis data; the Mössbauer quadrupole splitting (QS) values of all the compounds studied are also similar. It would appear that, during the recrystallization process, a monohydrate of **2** is produced.

The main IR spectral data are listed in Table 2. The assignments of ν(Sn–C), ν(Sn–O) and ν(Ge–C) are consistent with the values reported in the literature.[10] The $\Delta\nu$ value [$\nu(COO)_{asy} - \nu(COO)_{sym}$] is indicative of the coordination number around the tin.[11] All the values of $\Delta\nu$ are between 272 and 296 cm^{-1}, which clearly suggests four-coordinated tin. Compound **2** shows a $\Delta\nu$ value of 296 cm^{-1}, also demonstrating the presence of a monodentatate carboxylate ligand. There are a number of organotin derivatives reported in the literature that exhibit one water of hydration in their structures similar to **2**.[12,13]

The ^{1}H NMR data of compounds **1–6** are listed in Table 3. All the protons in the compounds have been identified by intensity and multiplicity patterns and the total number of

Table 1. Physical data and elemental analysis of $(C_6H_{11})_3SnO_2CCH(^3R)CH(^2R)Ge(^1R)_3$

Compound	^{1}R	^{2}R	^{3}R	Melting point (°C)	Yield (%)	Analysis found (calc.) (%) C	H
1	*p*-$CH_3C_6H_4$	*p*-$CH_3C_6H_4$	H	155–156	68	66.4 (67.1)	7.40 (7.31)
2	*p*-$CH_3C_6H_4$	*p*-$CH_3OC_6H_4$	H	162–163	65	65.8 (65.9)[a]	7.31 (7.17)[a]
3	C_6H_5	C_6H_5	CH_3	147–148	58	66.4 (66.1)	7.14 (6.95)
4	*p*-$CH_3C_6H_4$	C_6H_5	H	110–111	54	66.9 (66.8)	7.29 (7.19)
5	C_6H_5	CH_3	H	154–155	76	63.6 (63.3)	7.36 (7.12)
6	*m*-$CH_3C_6H_4$	C_6H_5	H	131–133	62	67.5 (66.8)	7.28 (7.19)

[a] Calculated values for anhydrous **2**.

Table 2. IR data (cm^{-1}) for $(C_6H_{11})_3SnO_2CCH(^3R)CH(^2R)Ge(^1R)_3$

Compound	$\nu(COO)_{asym}$	$\nu(COO)_{sym}$	$\Delta\nu$	ν(Ge–C)	ν(Sn–O)	ν(Sn–C)
1	1651	1362	289	659	472	584
2	1650	1354	296	662	478	587
3	1642	1370	272	654	485	570
4	1654	1360	294	682	462	565
5	1633	1338	295	670	466	560
6	1648	1365	283	676	464	568

Table 3. The ^{1}H NMR data (ppm) for $(C_6H_{11})_3SnO_2CCH(R^3)CH(R^2)Ge(R^1)_3$

Compound	C_6H_{11}	HC–^{3}R[a]	HC–^{2}R	^{2}R	^{1}R
1	1.18–1.76 (m, 33H)	2.92 (m, 2H)	3.42 (m, 1H)	6.82–6.94 (m, 4H) 2.23 (s, 3H)	7.14–7.21 (m, 12H) 2.34 (s, 9H)
2	1.17–1.71 (m, 33H)	2.89 (m, 2H)	3.60 (m, 1H)	6.62–6.86 (m, 4H), 3.73 (s, 3H)	7.10–7.20 (m, 12H), 2.35 (s, 9H)
3	1.12–1.94 (m, 33H)	3.38 (m, 1H), 1.30 (d, 3H)	3.75 (m, 1H)	6.84–6.95 (m, 5H)	7.12–7.28 (m, 15H)
4	1.14–1.78 (m, 33H)	2.90 (m, 2H)	3.80 (m, 1H)	6.86–6.98 (m, 5H)	7.18–7.25 (m, 12H), 2.34 (s, 9H)
5	1.25–1.92 (m, 33H)	2.34 (m, 2H)	2.76 (m, 1H)	1.25 (d, 3H)	7.35–7.52 (m, 15H)
6	1.14–1.74 (m, 33H)	2.93 (m, 2H)	3.68 (m, 1H)	6.92–7.03 (m, 5H)	7.07–7.24 (m, 12H), 2.30 (s, 9H)

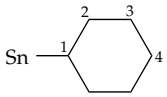
[a] ^{3}R = H for **1**, **2**, **4–6** and CH_3 for **3**.

protons calculated from the integration curve agrees well with that expected from the molecular formulae. The data are in consonance with similar types of compound previously reported.[6,13] In **1**–**6**, the GeCH is a chiral centre, the CH_2 is a prochiral centre and the unit $GeCHCH_2$ comprises three hydrogen atoms that appear as two multiplets in the regions of 3.38–3.80 and 2.34–2.93 ppm.[9] The two (diastereotopic) protons of the CH_2 have become nonequivalent because of the chiral centre and these two protons would have geminal coupling as well as vicinal coupling with the GeCH proton, i.e. these CH_2 protons appear as a multiplet.

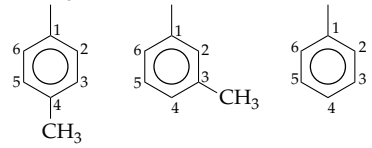
The ^{13}C NMR data for **1**–**6** along their $^{n}J[^{119}Sn,^{13}C]$ are given in Table 4. Resonances due to all the unique carbon atoms in each compound have been located.[14] The aromatic carbon resonances were assigned by comparison of the experimental chemical shifts with those calculated using the incremental method.[15] The methoxy group attached to the aromatic ring in **2** resonates at very low field due to

Table 4. The ^{13}C NMR data (ppm) for $(C_6H_{11})_3SnO_2CCH(^3R)CH(^2R)Ge(^1R)_3$; $^{n}J[^{110}Sn-^{13}C]$ (H_3)

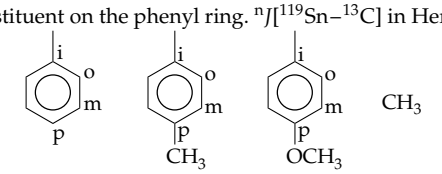
		1	**2**	**3**	**4**	**5**	**6**
Sn–C[a]	1	33.92	33.84	33.80	33.82	33.01	33.78
		^{1}J [314.87]	[316.53]	[314.60]	[312.46]	[324.60]	[312.89]
	2	31.34	31.28	31.68	31.27	31.52	31.28
		^{2}J [14.12]	[13.60]	[14.05]	[13.27]	[14.49]	[13.68]
	3	29.37	29.30	29.46	29.30	29.35	29.29
		^{3}J [65.20]	[64.47]	[64.98]	[64.96]	[64.91]	[64.86]
	4	27.40	27.27	27.48	27.26	27.33	27.23
^{3}R–CH[b]		37.94	38.11	41.94	37.82	38.89	37.80
CH		32.60	33.84	44.53	33.83	34.07	33.86
^{1}R[c]	1	138.26	138.80	142.14	142.15	136.23	142.31
	2	135.46	135.74	135.26	135.72	135.58	135.76
	3	128.14	129.61	128.52	128.68	128.43	133.02
	4	136.01	134.22	129.64	132.18	129.10	128.24
	5						128.97
	6						130.08
		21.94[d]	21.94[d]		21.94[d]		21.94[d]
^{2}R[e]	*i*	136.40	132.36	137.56	138.84	16.91	137.72
	o	128.63	129.08	130.00	127.98		128.08
	m	129.12	113.40	128.72	129.08		130.08
	p	134.00	157.34	126.13	125.24		125.45
		22.42[f]	55.43[g]				
^{3}R[b]		H	H	19.0	H	H	H
C=O		179.14	178.11	181.51	178.02	178.90	178.29

[a] 

[b] ^{3}R = H, CH_3.

[c] ^{1}R = 

[d] Substituent on the phenyl ring. $^{n}J[^{119}Sn-^{13}C]$ in Hertz.

[e] ^{2}R = 

[f] Substituent on the phenyl ring.

[g] Substituent on the phenyl ring.

a strong electron-withdrawing group. The carbon atoms of the cyclohexyl group attached to tin resonate in the range 27.2–33.9 ppm. The coupling constants $^{n}J[^{119}Sn,^{13}C]$ are consistent with a four-coordinate monomeric species characteristic for tricyclohexyltin derivatives.[16] The ^{119}Sn chemical shifts (in $CDCl_3$) were found at *ca* 12 ppm; this confirmed the tetrahedral geometry around tin, as reported earlier.[17]

The ^{119}Sn Mössbauer QS and isomer shift (IS) data for selected compounds are listed in Table 5. The QS values for **1**–**5** are in the range 2.72–2.76 mm s^{-1}. The IS values range from 1.45 to 1.47 mm s^{-1}, indicating a tetrahedral environment around the tin atom.[16] The structures of the compounds in the solid state can be derived from Mössbauer spectroscopy. The ρ values (QS/IS) also provide information about the coordination status of tin in these compounds.[18,19] As $\rho < 2.1$, four coordination at tin can be predicted. Note that the QS value for **2** is the same as the other species; thus, when first made, this compound is anhydrous with a coordination number of four at tin.

The crystal structure of (*p*-$CH_3C_6H_4$)GeCH($C_6H_4CH_3$-*p*)$CH_2CO_2Sn(C_6H_{11})_3$ (**1**) is presented in Fig. 1. Both tin and germanium atoms assume somewhat distorted tetrahedral geometries in this structure. The average bond angles around germanium and tin are 109.44° and 108.91° respectively, but the variation in bond angles is markedly greater for the latter (97.12–121.21° verso 106.79–112.96°), presumably as a consequence of the mixed-ligand coordination sphere. The Sn–O(2) bond length (3.01 Å) is too long for any meaningful interaction, and this is supported by the large difference in C–O bond lengths within the carboxylate group: 1.310(3)° and 1.218(3) Å, which are in agreement with single and double bond lengths respectively. Non-bonding Sn···O separations in related species[6,20] lie in the range 3.11(4)–3.269(3) Å. The carbonyl group C(19)═O(2), which is sterically hindered by the three cyclohexyl groups attached to the tin atom and by the germyl substitution in the carboxylate group, prevents the carbonyl oxygen from approaching the tin in the neighbouring molecule to form an associated polymeric structure. Polymeric structures for compounds of the type Cy_3SnO_2CR do not appear to have been reported; however, there are numerous compounds

Table 5. Mössbauer and ^{119}Sn NMR data for selected compounds

Compound	Mössbauer data			^{119}Sn NMR
	QS (mm s^{-1})	IS (mm s^{-1})	ρ	δ (ppm)
1	2.76	1.47	1.88	13.02
2	2.76	1.45	1.90	
3	2.74	1.47	1.86	
4	2.72	1.47	1.85	12.01
5	2.72	1.47	1.85	
6				12.36

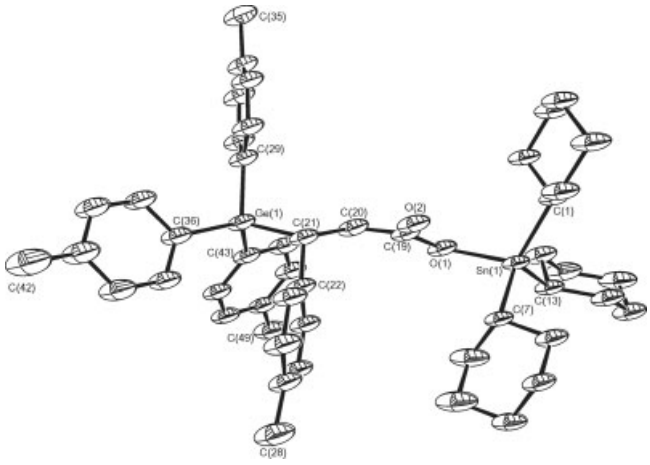


Figure 1. The asymmetric unit of **1**; thermal ellipsoids are at the 30% level. Selected metrical data: Sn(1)–O(1) 2.073(2), Sn(1)–C(1) 2.155(3), Sn(1)–C(7) 2.146(3), Sn(1)–C(13) 2.169(3), Ge(1)–C(21) 1.992(3), Ge(1)–C(29) 1.941(3), Ge(1)–C(36) 1.951(3), Ge(1)–C(43) 1.958(3), O(1)–C(19) 1.310(3), O(2)–C(19) 1.218(3) Å; O(1)–Sn(1)–C(7) 102.24(9), O(1)–Sn(1)–C(1) 108.95(9), C(7)–Sn(1)–C(1) 121.21(11), O(1)–Sn(1)–C(13) 97.12(9), C(7)–Sn(1)–C(13) 112.73(11), C(1)–Sn(1)–C(13) 111.23(11), C(29)–Ge(1)–C(36) 108.22(13), C(29)–Ge(1)–C(43) 111.63(13), C(36)–Ge(1)–C(43) 112.96(12), C(29)–Ge(1)–C(21) 106.79(12), C(36)–Ge(1)–C(21) 108.63(12), C(43)–Ge(1)–C(21) 108.40(12)°.

with other hydrocarbon groups attached to tin that show a polymeric chain structure of triorganotin units linked by carboxylate bridges.[21,22] The comparable structure is that of $Ph_3GeCH(o\text{-}C_6H_4Cl)CH_2COOSn(CH_2(CH_3)_2CPh)_3$, in which tin also possesses tetrahedral geometry.[6]

The crystal structure of (*p*-$CH_3C_6H_4$)GeCH($C_6H_4OCH_3$-*p*)$CH_2CO_2Sn(C_6H_{11})_3 \cdot H_2O$ (**2**) is given in Fig. 2. The germanium atom has distorted tetrahedral geometry with a range of <C–Ge–C similar to that of **1** (107.71–111.37°). The tin atom has distorted *trans*-O_2SnC_3 trigonal bipyramidal geometry with three cyclohexyl groups in the equatorial plane. The Sn–C distances lie in the range 2.162(2)–2.222(8) Å and are in agreement with the corresponding values reported in related structures.[21,22] The Sn–O bonds in the axial positions involve the carbonyl oxygen atom [Sn(1)–O(2) = 2.158(1) Å] and a more weakly bound water [Sn(1)–O(1) = 2.476(2) Å]. The O(2)–Sn–O(1) bond angle approaches linearity [170.34(6)°]. Intermolecular hydrogen bonding occurs between H(1B) and O(3) [O(3)–H(1B) = 1.81(2) Å; O(3)–O(1) = 2.653(2) Å; <O(3)–H(1B)–O(1) = 172(2)°] to generate a polymeric chain (Fig. 3). Despite the apparent strength of this H - bond, as judged by the above atomic separations and bond angle, the C(19)═O(3) bond, is the same length, within experimental error, as the corresponding 1.224(3) Å C═O bond in **1** [C(19)═O(2) = 1.218(3) Å]. The crystal structure of **2** is

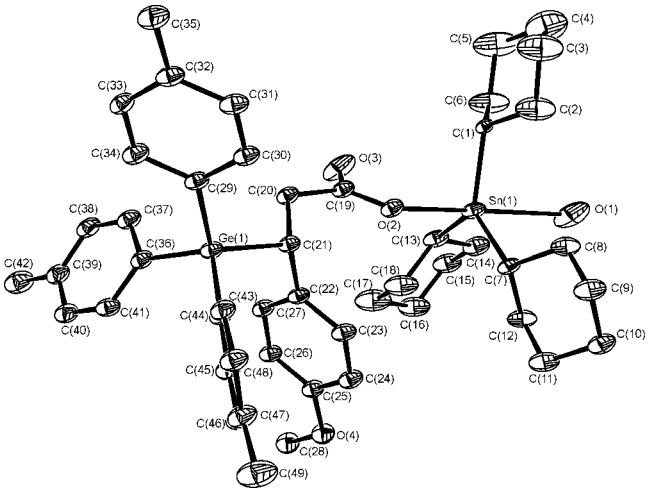


Figure 2. The asymmetric unit of **2**; thermal ellipsoids are at the 30% level. Only one of the disordered cyclohexyl rings (based on C(1)) is shown for clarity. Selected metrical data: Sn(1)–O(1) 2.476(2), Sn(1)–O(2) 2.158(1), Sn(1)–C(1) 2.222(8), Sn(1)–C(7) 2.162(2), Sn(1)–C(13) 2.164(2), Ge(1)–C(21) 1.995(2), Ge(1)–C(29) 1.950(2), Ge(1)–C(36) 1.956(2), Ge(1)–C(43) 1.950(2), O(2)–C(19) 1.280(2), O(3)–C(19) 1.224(3) Å; O(2)–Sn(1)–C(7) 87.52(7), O(2)–Sn(1)–C(13) 96.91(7), C(7)–Sn(1)–C(13) 118.40 (8), O(2)–Sn(1)–C(1) 88.29(16), C(7)–Sn(1)–C(1) 118.91(19), C(13)–Sn(1)–C(1) 122.60(19), O(2)–Sn(1)–O(1) 170.34(6), C(7)–Sn(1)–O(1) 84.49(7), C(13)–Sn(1)–O(1) 91.67(8), C(1)–Sn(1)–O(1) 90.82(17), C(43)–Ge(1)–C(29) 109.37(9), C(43)–Ge(1)–C(36) 111.37(9), C(29)–Ge(1)–C(36) 108.55(9), C(43)–Ge(1)–C(21) 107.71(8), C(29)–Ge(1)–C(21) 110.98(9), C(36)–Ge(1)–C(21) 108.86(9)°.

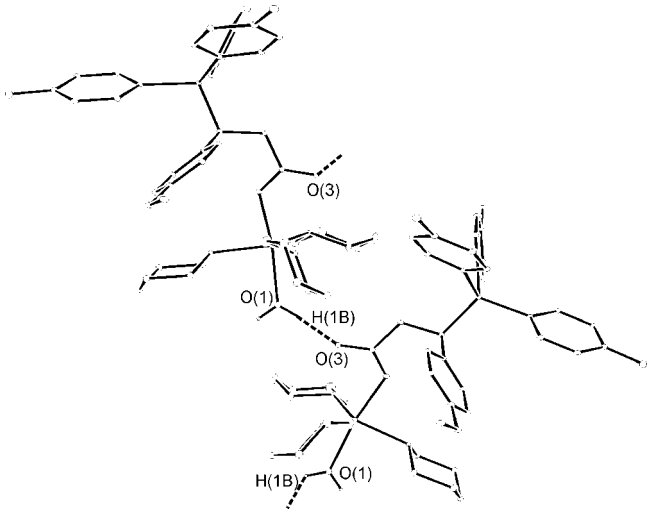


Figure 3. Hydrogen bonding in **2** showing the formation of a one-dimensional chain.

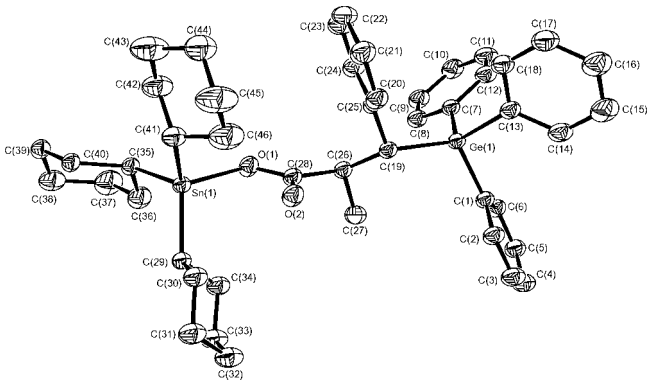


Figure 4. The asymmetric unit of **3**; thermal ellipsoids are at the 30% level. Selected metrical data: Sn(1)–O(1) 2.101(2), Sn(1)–C(29) 2.159(4), Sn(1)–C(35) 2.161(3), Sn(1)–C(41) 2.169(4), Ge(1)–C(1) 1.944(3), Ge(1)–C(7) 1.950(3), Ge(1)–C(13) 1.953(3), Ge(1)–C(19) 1.988(3), O(1)–C(28) 1.293(4), O(2)–C(28) 1.234(4) Å; O(1)–Sn(1)–C(29) 109.96(11), O(1)–Sn(1)–C(35) 90.59(11), C(29)–Sn(1)–C(35) 112.04(13), O(1)–Sn(1)–C(28) 109.0(2), C(40)–Sn(1)–C(35) 114.09(2), C(29)–Sn(1)–C(41) 117.74(15), C(1)–Ge(1)–C(7) 107.13(13), C(1)–Ge(1)–C(13) 107.34(14), C(1)–Ge(1)–C(19) 109.19(13), C(7)–Ge(1)–C(19) 115.35(13), C(13)–Ge(1)–C(14) 118.60(12), C(18)–Ge(1)–C(13) 123.40(3)°.

similar to that of aqua[4-(4-chlorophenyl)-2-phenylthiazole-5-acetato-*O*]trimethyltin(IV).[23]

The crystal structure of $(C_6H_5)_3GeCH(C_6H_5)CH(CH_3)CO_2Sn(C_6H_{11})_3$ (**3**) is depicted in Fig. 4. In this structure the germanium atom possesses slightly distorted tetrahedral geometry with average bond angle 109.42°[107.13(13)–115.35 (13)°]. The tin atom also has a coordination number of four and a distorted tetrahedral geometry, with an average bond angle of 108.91°[90.59(11)–117.74(15)°]. The Sn–C distances lie in the range 2.161–2.169 Å, which are consistent with literature values.[24,25] The bond lengths of two C–O bonds of the carbonyl group, O(1)–C(28) = 1.29(4), O(2)═C(28) = 1.23(4) Å, are comparable with those for **1**. The comparable structure is that of $Ph_3Ge\ CH(m\text{-}CH_3C_6H_4)CH_2CO_2Sn(C_6H_{11})_3$.[26]

The bactericidal properties of some compounds are given in Table 6. The results demonstrate that most of the compounds show insignificant activity against various bacteria, with few exceptions. Compound **3** shows good activity against *B. subtilis*, whereas **5** shows little activity against either *B. subtilis* or *S. typhi*. The brine shrimp lethality bioassays of the compounds are presented in Table 7. Their results show positive lethality, with LD_{50} values ranging from 5.09 to 8.80 μg ml^{-1} for **3**, **4** and **5**, whereas **1** requires 55.88 μg ml^{-1}. The fungicidal screening data for selected compounds are listed in Table 8. The majority of the compounds show poor fungicidal activity. However, **5** indicates significant activity against *T. longiformis*, which is a human pathogen. Compound **4** shows moderate activity and **1** demonstrates poor activity against *F. solani*, which is a plant pathogen.

Table 6. Bactericidal data[a]

Bacterium	Zone of inhibition				
	1	**3**	**4**	**5**	Standard drug (Imipenem)
Escherichia coli	—	9	—	9	30
Bacillus subtilis	10	18	10	12	31
Shigella flexenari	—	—	—	9	35
Staphylococcus aureus	10	10	11	9	45
Pseudomonas aeruginosa	10	10	10	—	29
Salmonella typhi	—	11	—	12	40

Size of well = 6 mm (radius).
[a] *In vitro* concentration 1 mg ml^{-1} of DMSO. Dashes indicates no activity.

Table 7. Lethality bioassay against brine shrimp (*in vitro*)

Compound	LD_{50} (μg ml^{-1})
1	55.88
3	5.99
4	5.09
5	8.80
Etoposide[a]	7.46

[a] Reference drug.

EXPERIMENTAL

Melting points were determined in a capillary tube using an electrothermal melting point apparatus, model MP.D Mitamura Riken Kogyo (Japan). IR spectra were recorded on Bio-Rad Excalibur FTIR Model FTS 3000 Mx as KBr discs. NMR spectra were recorded on a Bruker 400 spectrometer with $CDCl_3$ as a solvent and the reference was tetramethylsilane. Details of our Mössbauer spectrometer and related procedures are given elsewhere.[27]

All of the organic solvents were dried before use by the standard method.[28] GeO_2, $(C_6H_{11})_3SnOH$ and substituted cinnamic acids were purchased from Aldrich (Germany) and used without further purification. The six precursors, triorganogermyl (substituted) propanoic acids $(^1R)_3GeCH(^2R)CH(^3R)COOH$ were prepared according to literature methods.[14,29]

Synthesis

Compounds **1**–**6** were prepared by the following route: triorganogermyl (substituted) propanoic acid (2.00 mmol) and tricyclohexyltin hydroxide (2.00 mmol) were refluxed in toluene (50 ml) for 8–9 h in Dean and Stark apparatus with continuous removal of water. The contents of the reaction mixture were allowed to cool to room temperature. The solution was filtered and toluene was removed under reduced pressure. The thick residue thus obtained was dried in vacuum and the resulting solid was crystallized from a chloroform–*n*-hexane mixture, which yielded the product as a fine crystalline solid. Yields, analytical and spectroscopic data are given in Tables 1–5.

X-ray crystallography

For each of the three compounds, a crystal suitable for X-ray diffraction was grown by dissolving a 0.5 g sample of compound in a minimum amount of chloroform (5 ml) to yield a saturated solution. A few drops of ethyl acetate or petroleum ether were added and the solution was kept at low temperature in a deep freeze for several days to yield fine crystals. The crystals were washed several times with acetone before X-ray analysis.

Crystallographic and experimental details are given in Table 9. For three compounds (**1**, **2**, **3**) data sets were collected at 150 K on a Nonius Kappa CCD diffractometer; Lp and absorption corrections (semi-empirical from equivalents) were applied in all cases. Refinement was full-matrix least-squares on F^2. In the case of **2**, a 50 : 50 disorder in one of the cyclohexyl rings was modelled, subject to restraints on ring bond distances and anisotropic displacement parameters within each disordered fraction. The asymmetric units of the compounds, along with selected geometric data, are given in Figs 1, 2 and 4. Software used: SHELXS 86,[30] SHELXL 97,[31] ORTEX.[32]

Biological studies

Biological activity tests for representative tricyclohexyltin carboxylates containing germanium were carried out against various bacteria and fungi by the 'agar well diffusion method.'[33] The toxicity of these compounds was measured

Table 8. Antifungal bioassay of selected compounds[a]

	Inhibition after 168 h (%)				
	1	**3**	**4**	**5**	Standard drug miconazole (MIC μg ml^{-1})
Trichophyton longiformis	—	—	—	80	73.25
Fusarium solani	42.10	—	57.80	—	73.25
Candida albicans	—	—	—	—	73.25

[a] *In vitro* concentration 200 μg ml^{-1} of DMSO.

Table 9. Crystallographic data for **1**, **2** and **3**

	1	**2**	**3**
Empirical formula	$C_{49}H_{64}GeO_2Sn$	$C_{49}H_{66}GeO_4Sn$	$C_{46}H_{58}GeO_2Sn$
Formula weight	876.28	910.30	834.20
Crystal system	Monoclinic	Monoclinic	Monoclinic
Space group	$C2/c$	$P2_1/c$	$C2/c$
a (Å)	36.8360(3)	12.2390(1)	16.3516(2)
b (Å)	11.7980(1)	28.6080(4)	13.2210(2)
c (Å)	26.0170(3)	13.6160(2)	19.3576(2)
β (°)	128.296(1)	110.798(1)	103.4850(5)
V (Å^3)	8873.8(2)	4456.8(1)	4069.44(9)
Z	8	4	4
μ(Mo Kα) (mm^{-1})	1.276	1.277	1.388
θ_{max} (°)	29.6	29.6	29.6
Reflections collected	77 724	41 537	92 656
Independent reflections (R_{int})	12 382 (0.084)	12 383 (0.051)	11 420 (0.085)
Reflections observed, $I > 2\sigma(I)$	9999	9036	8213
Max., min. transmission	0.65, 0.46	0.73, 0.68	0.76, 0.61
Goodness-of-fit on F^2	1.04	1.01	1.02
Final R_1, wR_2 [$I > 2\sigma(I)$]	0.043, 0.104	0.037, 0.077	0.049, 0.125
Final R_1, wR_2 (all data)	0.059, 0.114	0.065, 0.086	0.080, 0.140
ρ_{max} (e − Å^{-3})	2.68, −1.41	0.64, −0.58	2.19, −1.28

using the brine shrimp method.[34] Biological studies data are tabulated in Tables 6–8.

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REFERENCES

1. Molloy KC, Purcell TG, Hahn E, Schumann H, Zuckerman JJ. *Organometallics* 1986; **5**: 85.
2. Crowe A. *Appl. Organometal. Chem.* 1987; **1**: 143.
3. Blunden SJ, Smith PJ, Sugavanaman B. *Pestic. Sci.* 1984; **15**: 253.
4. Asai K. *Miracle Cure: Organic—Germanium*. Japan Publications: New York, 1980.
5. Xie QL, San LJ, Liu H. *Appl. Organometal. Chem.* 1994; **8**: 57.
6. Fang XN, Song XQ, Xie QL. *J. Organometal. Chem.* 2001; **619**: 43.
7. Chaudhary MA, Mazhar M, Ali S, Song X, Eng G. *Met. Based Drugs* 2002; **8**: 275.
8. Imtiaz-ud-Din, Mazhar M, Ali S, Dastgir S, Molloy KC, Mahon MF. *Main Group Met. Chem.* 2002; **25**: 315, 319.
9. Chaudhary MA, Mazhar M, Salma U, Ali S, Qinglan X, Molloy KC. *Synth. React. Inorg. Org. Met. Org. Chem.* 2001; **31**: 277.
10. Xie QL, Yang ZQ, Zhang ZX. *Appl. Organometal. Chem.* 1992; **6**: 193.
11. Ho BYK, Zuckerman JJ. *Inorg. Chem.* 1973; **12**: 1552.
12. Huber F, Preut H, Hoffmann E, Gielen M. *Acta Crystallogr. Sect. C* 1989; **45**: 51.
13. Song XQ, Yang ZQ, Xie QL. *J. Organometal. Chem.* 1998; **566**: 103.
14. Xie QL, San LJ, Liu H. *Appl. Organometal. Chem.* 1994; **8**: 57.
15. Kalinowski HO, Berger S, Brown S. ^{13}C *NMR Spectroskie*. Thieme Verlag: Stuttgart, Germany, 1994.
16. Danish M, Alt HG, Badshah A, Ali S, Mazhar M, Islam N. *J. Organometal. Chem.* 1995; **486**: 51.
17. Wrackmeyer B, Kehr G, Süß J. *Chem. Ber.* 1993; **126**: 222.
18. Zuckerman JJ. *Adv. Organometal. Chem.* 1970; **9**: 21.
19. Song XQ, Xie QL, Fang X. *Heteroat. Chem.* 2002; **13**: 592.
20. Calgero S, Ganis P, Peruzzo V, Tagliavini G. *J. Organometal. chem.* 1980; **19**: 381.
21. Tiekink ERT, Sandhu GK, Verma SP. *Acta Crystallogr. Sect. C* 1989; **45**: 1810.
22. Kalsoom A, Mazhar M, Ali S, Mahon MF, Molloy KC, Chaudhary MI. *Appl. Organometal. Chem.* 1997; **11**: 47.
23. Pervez M, Ali S, Mazhar M, Bhatti MH, Khokhar MN. *Acta Crystallogr. Sect. C* 1999; **55**: 1280.
24. Basu Baul TS, Pyke SM, Saima KK, Tiekink ERT. *Main Group Met. Chem.* 1996; **19**: 807.
25. Pervez M, Ali S, Masood T, Mazhar M, Danish M. *Acta Crystallogr. Sect. C* 1997; **53**: 1211.
26. Yang ZQ, Xie QL, Zhou XZ. *Acta Chim. Sin.* 1995; **53**: 721.
27. Molloy KC, Purcell TG, Quill K, Nowell I. *J. Organometal. Chem.* 1984; **267**: 237.
28. Perrin DD, Armarego WLF. *Purification of Laboratory Chemicals*, 3rd edn. Pergamon: Oxford, 1988.
29. Sato R. *Jpn. Kokai Tokyo Koho* 1981; **56**: 218.
30. Sheldrick GM. SHELXS 86, a computer program for crystal structure determination. University of Göttingen, 1986.
31. Sheldrick GM. SHELXL 97, a computer program for crystal structure refinement. University of Göttingen, 1997.
32. McArdle PJ. *J. Appl. Crystallogr.* 1995; **28**: 65.
33. Kazmi SU, Ali SN, Jamal SA, Rehman A. *J. Pharm. Sci.* 1991; **4**: 113.
34. Meyer BN, Ferrigni NR, Putman JE, Jacobson LB, Nichols DE, McLaughlin JL. *J. Medi. Plant. Res.* 1982; **45**: 31.

