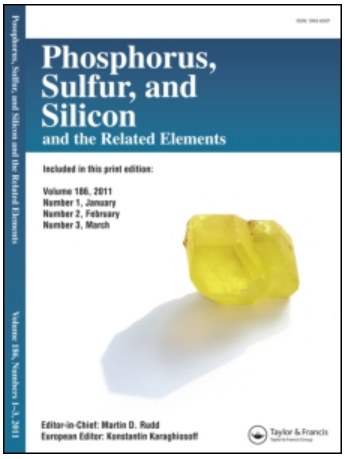

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Synthesis, Spectroscopic Characterization, and In Vitro Antimicrobial Potency of Sulfur-Bonded Complexes of Boron(III)

Monika Swami,[1] Karuna Mahajan,[1] Neeti Gupta,[1] R. V. Singh,[1] Sunita Arya,[2] and Sonalika Kushwah[2]
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The present article describes the synthesis and characterization of tetracoordinated boron (III) complexes with monobasic bidentate ligands (L^1H, L^2H, L^3H, L^4H, L^5H, and L^6H) having the general formulae PhB(L)(OH) and $PhB(L)_2$. The 1:1 and 1:2 reactions of phenyl boronic acid with monobasic bidentate ligands resulted in the formation of colored solids. The complexes have been characterized by elemental analysis, molecular weight determinations, and IR and NMR (^1H, ^{13}C and ^{11}B) spectroscopy, as well as UV-vis spectral studies. Based on these studies, a tetrahedral geometry has been proposed for the resulting complexes. The ligands, along with their complexes, have been screened in vitro against a number of pathogenic fungal and bacterial strains. The studies indicate that the boron chelates are more potent than the parent ligands.

Keywords Antimicrobial potency; biological aspects; hydrazinecarbodithioic acid phenyl methyl esters; phenylborane complexes; thiosemicarbazone

INTRODUCTION

Thiosemicarbazones and S-benzyldithiocarbazates play an important role in inorganic chemistry, as they easily form stable complexes with metal ions. The development in the field of bioinorganic chemistry has increased the interest in these complexes, since it has been recognized that many of these complexes may serve as models for biologically important species.[1–3] There is currently a resurgence of interest in

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the coordination chemistry of boron, mainly due to the involvement of the element in a number of biological systems[4] that have created and necessarily maintain our environment. An understanding of it represents one of the greatest challenges to bio-inorganic chemists. The element boron is a micronutrient for plants, and traces of it have also been reported in some bacterial cells.[5] Boron may play an active role in human brain function and cognitive performance, and there may be additional evidence that boron is an essential nutrient for humans.[6] Considerable interest in the studies of compounds containing intramolecular B-N coordination[7] is due to the remarkable degree of hydrolytic and oxidative stability. The synthetic flexible characteristic of boron, which has a wide range of applications in various disciplines, has attracted a number of investigators in the field.[8] Several organoboranes find promising applications in the synthesis of insect pheromones.[9] Organoboron compounds are attracting attention because of their importance as synthetic[10,11] intermediates, as well as a source of radicals.[12] The mechanism of action for these compounds is believed to arise from the ability of the boron atom to coordinate through its empty p-orbitals to the active hydroxyl groups of the enzyme.

Interest in metal complexes of sulfur–nitrogen chelating agents, especially those formed from thiosemicarbazide[13–17] and S-alkyl/benzyl esters of dithiocarbazic acid,[18–22] has been stimulated by their interesting physicochemical properties and potentially useful pharmacological properties.[13,17,19,23]

Boron complexes of dihiocarbazates have aroused considerable interest in view of their industrial, biological,[24] and pharmacodynamic importance.[25] The applications of boron compounds in cancer therapy have invoked considerable interest due to the unique nuclear property.[26,27]

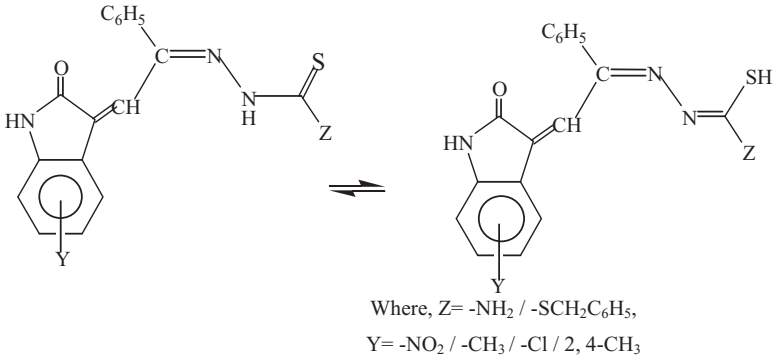
Boron complexes of thiosemicarbazones with N∩S donor system are gaining enormous importance on account of their inherent biological potential.[28] Boron complexes of such ligands are known to function as antimicrobial and antifertility agents.[29–31] The focus of our present communication is on the exploration of the studies on the synthetic, structural, and biological aspects of boron complexes of some stereochemical as well as biological interest with monobasic bidentate thiosemicarbazone and hydrazinecarbodithioic acid phenyl methyl ester ligands. Antifungal and antibacterial activities of these boron complexes have also been carried out to study the role of the coordinated boron atom.

EXPERIMENTAL

All the chemicals were dried and purified before use, and the purity was checked by thin layer chromatography (TLC).

Preparation of Thiosemicarbazones(L^1H, L^2H, and L^3H)

The reaction of an EtOH solution of 5-nitro, 6-nitro, and 7-nitro isatin (synthesized by the Sandmeyer isonitrosoacetanilide method[32]) and PhCOMe was carried out in an equimolar ratio. The reaction mixture was refluxed for 2–3 h at 60°C. The resulting substituted product was dried and recrystallized from EtOH. This substituted product was then condensed with thiosemicarbazide in EtOH. This mixture was then refluxed on a water bath for 3–4 h and allowed to stand overnight. Upon cooling, the ligands were separated out, then collected, dried, and recrystallized in ethanol (Scheme 1).



SCHEME 1

Preparation of Hydrazinecarbodithioic Acid Phenyl Methyl Esters (L^4H, L^5H, and L^6H)

The reactions of an EtOH solution of 5-methyl, 5-chloro, and 5,7-dimethyl isatin and PhCOMe were carried out in an equimolar ratio. The reaction mixture was refluxed for 2–3 h at 60°C. The resulting substituted product was dried and recrystallized from EtOH. This substituted product was then condensed with S-benzyldithiocarbazates in EtOH. These mixtures were then refluxed on a water bath for 3–4 h

TABLE I Analytical Data and Physical Properties of Hydrazinecarbothioamides and Hydrazinecarbodithioic Acid Phenyl Methyl Ester

S. No.	Ligand	Empirical Formula	Color and State	Mp (°C)	Analyses (%) Found/(Calcd.) C	H	N	S	Mol. Wt. Found (Calcd.)
1.	L^1H	$C_{17}H_{13}N_5O_3S$	Gray, Solid	255	55.72 (55.57)	3.63 (3.56)	18.98 (19.06)	8.79 (8.72)	380.92 (367.37)
2.	L^2H	$C_{17}H_{13}N_5O_3S$	Dark brown, Solid	236	55.84 (55.57)	3.62 (3.56)	19.92 (19.00)	13.14 (13.06)	381.72 (367.37)
3.	L^3H	$C_{17}H_{13}N_5O_3S$	Gray, Solid	244	55.62 (55.57)	3.73 (3.56)	19.14 (19.06)	13.27 (13.06)	352.86 (367.37)
4.	L^4H	$C_{25}H_{21}N_3O_3S$	Light brown, Solid	162	67.60 (67.65)	4.82 (4.77)	9.36 (9.47)	14.39 (14.45)	430.73 (443.57)
5.	L^5H	$C_{24}H_{18}N_9O_2OCl$	Gray, Solid	165	62.31 (62.12)	3.84 (3.91)	9.24 (9.05)	13.75 (13.82)	478.55 (463.99)
7.	L_6H	$C_{26}H_{23}N_3O_2O$	Brown, Solid	171	68.62 (68.24)	5.19 (5.06)	9.04 (9.18)	14.32 (14.02)	441.76 (457.60)

and allowed to stand overnight. Upon cooling, the ligands were separated out (Table I), then collected, dried, and recrystallized in ethanol (Scheme 1).

The resulting ligands are herein described:

L^1H: 5-Nitro-1,3-dihydro-3-[2-(phenyl)-ethylidene]-2H-indol-2one-hydrazinecarbothioamide.
L^2H: 6-Nitro-1,3-dihydro-3-[2-(phenyl)-ethylidene]-2H-indol-2one-hydrazinecarbothioamide.
L^3H: 7-Nitro-1,3-dihydro-3-[2-(phenyl)-ethylidene]-2H-indol-2one-hydrazinecarbothioamide.
L^4H: 5-Methyl-1,3-dihydro-3-[2-(phenyl)-ethylidene]-2H-indol-2one-hydrazinecarbodithioic acid phenyl methyl ester.
L^5H: 5-Chloro-1,3-dihydro-3-[2-(phenyl)-ethylidene]-2H-indol-2one-hydrazinecarbodithioic acid phenyl methyl ester.
L^6H: 5,7-Dimethyl-1,3-dihydro-3-[2-(phenyl)-ethylidene]-2H-indol-2one-hydrazinecarbodithioic acid phenyl methyl ester.

Preparation of Boron(III) Complexes

To a calculated amount of the ligands dissolved in dry benzene, the dihydroxyphenylborane in unimolar and bimolar ratios was added. The

reaction mixture was refluxed for 10–12 h on a fractionating column, and the progress of the reaction was monitored by the liberation of the azeotrope of water and benzene. After the completion of the reaction, excess of the solvent was distilled off and the products were dried. The resulting products were washed with dry cyclohexane and then finally dried in vacuo for 3–4 h. The physical properties and analytical data of these derivatives are recorded in Tables II and III.

Analytical Methods and Physical Measurements

Nitrogen and sulfur were estimated by the Kjeldahl's and Messenger's methods,[33] respectively. Boron was estimated volumetrically as boric acid. The UV spectra were recorded on a Hitachi-U-2000 spectrophotometer. The IR spectra with KBr optics were obtained using the Perkin–Elmer 577 grating spectrophotometer. The ^{1}H (89.55 MHz) and ^{13}C NMR spectra (at 22.49 MHz) were recorded in DMSO-d_6 using TMS as the standard on a JEOL AL 300 FT NMR. ^{11}B NMR spectra (at 28.69 MHz) were recorded using $BF_3.Et_2O$ as an external standard. The molecular weights of the compounds were determined by the Rast Camphor[34] method.

MICROBIAL ASSAY

Fungicidal and bactericidal activities of the ligands and their corresponding boron complexes against different fungi and bacteria have been carried out by the methods reported earlier.[35] On the basis of these studies, it may be concluded that fungitoxicity and bacteriostatic properties of a compound may be slightly enhanced upon chelation with the boron atom. The antifungal activity was tested against *Fusarium oxysporum* and *Macrophomina phaseolina* and bacterial activity against *Klebsilla aeurogenous*, and *Pseudomonas cepacicola* (-). Proper temperature (25–30°C), necessary nutrients, and growth media free from other microorganisms were employed for the preparation of culture media of fungi and bacteria using aseptic techniques.

In Vitro Study

Bactericidal Screening (Inhibition Zone Technique)[36]

For the evaluation of degree of inhibitory effects on the growth of a wide spectrum of microorganisms, antibacterial activity was performed, and the results are summarized in Table IV. The compounds were dissolved in methanol at 500 and 1000 ppm concentrations.

TABLE II Reactions of Phenylboronic Acid with Hydrazinecarbothioamides and Physical Characteristics of Boron(III) Complexes

S. No.	Reactant $PhB(OH)_2$ (g)	Ligand (g)	Molar ratio	Product (g)	Color, State, Mp (°C)	Analyses (%) Found/(Calcd.) B	C	H	N	S	Mol. Wt. Found (Calcd.)
1.	$PhB(OH)_2$ (0.45)	L^1H (1.38)	1:1	$PhB(OH)(L^1)$ (1.05)	Gray, Solid, 260	2.74 (2.29)	58.24 (958.61)	3.55 (3.84)	14.70 (14.85)	6.71 (6.80)	487.75 (471.29)
2.	$PhB(OH)_2$ (0.67)	L^1H (4.07)	1:2	$PhB(L^1)_2$ (2.24)	Brown, Solid, 267	1.34 (1.31)	58.37 (58.54)	3.74 (3.56)	17.22 (17.06)	7.64 (7.81)	808.73 (820.65)
3.	$PhB(OH)_2$ (0.55)	L^2H) (1.66)	1:1	$PhB(OH)(L^2)$ (1.18)	Brown, Solid, 257	2.79 (2.29)	58.67 (58.61)	3.64 (3.84)	14.73 (14.85)	6.67 (6.80)	457.82 (471.29)
4.	$PhB(OH)_2$ (0.59)	L^2H (3.59)	1:2	$PhB(L^2)_2$ (1.98)	Dark brown, Solid, 263	1.37 (1.31)	58.32 (58.54)	3.85 (3.56)	17.43 (17.06)	7.74 (7.81)	833.42 (820.65)
5.	$PhB(OH)_2$ (0.71)	L^3H (2.15)	1:1	$PhB(OH)(L^3)$ (1.86)	Gray, Solid, 226	2.34 (2.29)	58.73 (58.61)	3.61 (3.84)	14.55 (14.85)	6.73 (6.80)	458.03 (471.29)
6.	$PhB(OH)_2$ (0.36)	L^3H (2.20)	1:2	$PhB(L^3)_2$ (1.75)	Dark brown Solid, 239	1.53 (1.31)	58.37 (58.54)	3.67 (3.56)	17.28 (7.81)	7.66 (7.81)	809.75 (820.65)

TABLE III Reactions of Phenylboronic Acid with S-Benzyldithiocarbazates and Physical Characteristics of Boron(III) Complexes

S. No.	Reactant $PhB(OH)_2$ (g)	Ligand (g)	Molar ratio	Product (g)	Color, State, Mp (°C)	Analyses (%) Found/(Calcd.) B	C	H	N	S	Mol. Wt. Found (Calcd.)
7.	$(Ph)B(OH)_2$ (0.52)	L^4H (1.91)	1:1	$(Ph)B(OH)(L^4)$ (1.72)	Greenish, Solid, 178	1.86 (1.97)	68.32 (68.01)	4.65 (4.78)	7.72 (7.67)	11.55 (11.71)	562.39 (9547.49)
8.	$(Ph)B(OH)_2$ (0.49)	L^4H (3.61)	1:2	$(Ph)B(L^4)_2$ (2.32)	Gray, Solid, 195	1.36 (1.11)	69.34 (69.12)	4.53 (4.66)	8.82 (8.63)	13.54 (13.17)	986.45 (973.05)
9.	$(Ph)B(OH)_2$ (0.67)	L^5H (2.57)	1:1	$(Ph)B(OH)(L^5)$ (1.39)	Dim yellow, Solid, 180	1.84 (1.90)	63.39 (63.44)	4.36 (4.08)	7.48 (7.39)	11.56 (11.29)	583.73 (567.30)
10.	$PhB(OH)_2$ (0.56)	L^5H (4.32)	1:2	$(Ph)B(L^5)_2$ (2.85)	Dim yellow, Solid, 198	1.24 (1.06)	63.74 (63.37)	3.96 (3.87)	8.19 (8.28)	12.85 (12.64)	1016.99 (1013.89)
11.	$(Ph)B(OH)_2$ (0.75)	l^6H (2.82)	1:1	$(Ph)B(OH)(L^6)$ (1.62)	Gray, Solid, 186	1.83 (1.92)	68.17 968.44)	5.15 95.02)	78.32 (7.48)	11.36 (11.41)	578.48 (561.51)
12.	$(Ph)B(OH)_2$ (0.57)	L^6H (4.32)	1:2	$(Ph)B(L^6)_2$ (2.63)	Brown, Solid, 212	1.26 (1.07)	69.44 (69.65)	4.76 (4.93)	8.65 (8.39)	12.59 (12.80)	986.63 (1001.10)

TABLE IV Antibacterial Screening Data of the Ligands and Their Boron(III) Complexes

		% Inhibition after 1 day 25 ± 2°C			
		Klebsilla aeurogenous (Conc. in ppm)		*Pseudomonas cepaciola* (−) (Conc. in ppm)	
S. No.	Complex	500	1000	500	1000
1.	L^1H	7	9	7	10
2.	$[PhB(OH)(L^1)]$	10	14	9	14
3.	$[PhB(L^1)_2]$	12	17	11	19
4.	L^2H	7	8	8	9
5.	$[PhB(OH)(L^2)]$	9	11	9	11
6.	$[PhB(L^2)_2]$	11	14	13	16
7.	L^3H	8	10	7	10
8.	$[PhB(OH)(L^3)]$	10	13	8	13
9.	$[PhB(L^3)_2]$	11	15	12	15
10.	L^4H	9	10	7	8
11.	$[PhB(OH)(L^4)]$	11	13	10	12
12.	$[PhB(L^4)_2]$	14	15	14	16
13.	L^5H	8	9	8	10
14.	$[PhB(OH)(L^5)]$	11	13	10	13
15.	$[PhB(L^5)_2]$	14	16	14	17
16.	L^6H	10	12	9	11
17.	$[PhB(OH)(L^6)]$	12	16	10	14
18.	$[PhB(L^6)_2]$	16	20	15	17

Whatman No. 1 paper discs 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), autoclaved for 20 min at 15 psi before inoculation with previously seeded organisms in Petri dishes and stored in an incubator at 25 ± 2°C. The inhibition zone thus formed around each disc was measured (in mm) after 24 h.

Fungicidal Screening (Poisoned Food Technique)[36]

Potato dextrose agar (PDA) medium was prepared in a flask and autoclaved for 20 min at 15 psi before inoculation. The compounds were directly mixed with the medium in 50, 100, and 200 ppm (in methanol) concentrations. Aliquots of 15 mL medium were poured in sterilized Petri plates. A culture of test fungus was grown on PDA in 24 h at the 25 ± 2°C temperature for growth. A small disc of the fungus culture was cut with a sterile cork borer and transferred aseptically to the center

TABLE V Antifungal Screening Data of The Ligands and Their Boron(III) Complexes

		% Inhibition after 4 days at 25 ± 2°C					
		Fusarium oxysporum (Conc. in ppm)			*Macrophomina phaseolina* (Conc. in ppm)		
S. No.	Complex	50	100	200	50	100	200
1.	L^1H	28	39	48	27	38	49
2.	$[PhB(OH)(L^1)]$	35	43	58	36	45	59
3.	$[PhB(L^1)_2]$	36	43	56	34	44	57
4.	L^2H	25	35	49	23	31	43
5.	$[PhB(OH)(L^2)]$	36	47	61	35	42	54
6.	$[PhB(L^2)_2]$	39	50	65	37	47	62
7.	L^3H	24	36	45	23	32	43
8.	$[PhB(OH)(L^3)$	35	42	58	32	43	56
9.	$[PhB(L^3)_2]$	38	46	60	37	47	59
10.	L^4H	46	59	68	45	62	75
11.	$[PhB(OH)(L^4)]$	57	61	79	55	59	78
12.	$[PhB(L^4)_2]$	58	63	81	57	61	79
13.	L^5H	42	56	65	39	54	62
14.	$[PhB(OH)L^5)]$	53	61	71	48	61	64
15.	$[:PhB(L^5)_2$	55	64	74	50	36	69
16.	L^6H	48	60	79	46	64	79
17.	$[PhB(OH)(L^6)]$	59	70	81	57	74	83
18.	$[PhB(L^6)_2$	61	72	83	59	76	84

of a Petri disc containing the medium and incubated for 4 days at 25 ± 2°C. The colony diameter was measured after the incubation period of growth. The results are summarized in Table V. The percentage inhibition of growth was calculated by,

$$(C - T)\, C^{-1} \times 100$$

Where, C = growth in control, T = growth in treatment.

RESULTS AND DISUSSION

Reactions of phenylboronic acid with monobasic bidentate ligands have been carried out in refluxing benzene. These reactions may be represented as follows:

$$PhB(OH)_2 + N^{\cap}SH \rightarrow PhB(OH)(N^{\cap}S) + H_2O$$

$$PhB(OH)_2 + 2N^{\cap}SH \rightarrow PhB(N^{\cap}S)_2 + 2\,H_2O$$

$N^{\cap}S$ is the donor system of the reacting ligand moiety.

The resulting colored solids are soluble in DMF and DMSO. The UV, IR, and NMR spectra support the proposed structures. Their low molar conductance values (10–15 ohm^{-1} cm^2 mol^{-1}) show that they are nonelectrolytes in nature.

SPECTROSCOPIC STUDIES

UV Spectra

The UV spectra of the ligands (L^1H, L^2H, L^3H) and (L^4H, L^5H, L^6H) show two maxima at ca. 274, 316 nm and 264, 328 nm, respectively, assignable to π–π^* transitions. These remain almost unchanged in the complexes.[37] Another band due to >C=N is observed at 336 and 344–360 nm in the spectra of the ligands (L^1H, L^2H, L^3H) and (L^4H, L^5H, L^6H), respectively. This is due to n–π^* transitions and shows bathochromic shifts of 20–30 nm in the complexes, due to donation of a lone pair of electrons by the nitrogen of the ligands to the central boron atom, indicating the delocalization of the electronic charge within the chelate ring, thus stabilizing the resulting complexes.

IR Spectra

The IR spectra of the ligands (L^1H, L^2H, L^3H) display two sharp bands around 3360 cm^{-1} and 3500 cm^{-1}, assignable to ν_{sym} and $\nu_{asym}NH_2$ vibrations, respectively. The spectra of the ligands (L^1H, L^2H, L^3H) and (L^4H, L^5H, L^6H) show medium intensity bands at 3280 and 3395–3100 cm^{-1} due to ν NH vibrations, which disappear in the spectra of the complexes. The absorption at ca. 1615 cm^{-1}, characterstics of the azomethine (>C=N)[38] group in the spectra of the ligands, get split into two sharp bands at *ca.* 1595 cm^{-1} and 1625 cm^{-1} in 1:2 complexes. This splitting of the bands suggests that azomethine group is in different chemical environments. The splitting of the bands at ca. 1625 cm^{-1} (higher wave number side) suggests the coordination of the azomethine nitrogen to the boron atom, whereas the band at ca. 1595 cm^{-1} is assigned to the uncoordinated azomethine group. The νOH band in case of 1:1 boron complexes appears at ca. 3450 cm^{-1}. Another ν(NH) band, which exists in the ring, appears at 3250 cm^{-1} in the free ligands as well as in their complexes. It indicates noninvolvement of this group in complexation. New bands in the complexes, which appeared in the regions, 835–840 cm^{-1}, 1525–1545 cm^{-1}, and 1235–1250 cm^{-1}, are due to ν(B—S),[39] ν(B←N),[40] and ν(Ph—B) frequencies, respectively, and indicate that the azomethine nitrogen and thiolo sulfur are in coordinative interaction at the boron center. The free ligands displayed bands at

2900 and 2960 cm^{-1} are attributed to symmetric and asymmetric vibration of $–CH_2$ of SCH_2 C_6H_5 grouping and are reduced to a weak doublet in the spectra of the complexes.[41]

^{1}H NMR Spectra

The ^{1}H NMR spectra of the free ligands and the complexes were recorded in DMSO-d_6. The spectra of the ligands exhibits signals due to the –NH of the isatin ring and the –NH of the thiosemicarbazone (L^1H) and hydrazinecarbodithioic acid phenyl methyl ester (L^4H and L^5H). The disappearance of the –NH signal of the thiosemicarbazones and hydrazinecarbodithioic acid phenyl methyl esters in the complexes indicates coordination of the azomethine nitrogen as well as covalent bond formation between boron and sulfur atom. Further the spectra of the free ligands and their boron complexes show signals due to –NH of the indol ring at δ10.23–11.96 ppm. It shows the noninvolvement of this group in the complexation. The resonance due to the $–SCH_2$ and aromatic protons in the complexes appears in almost the same positions as in the respective free ligands (L^4H and L^5H). The aromatic protons are observed in the range δ6.70–8.28 ppm in the boron complexes as well as in the spectra of the ligands. The –OH proton signal in 1:1 complexes is observed at δ4.22–4.77 ppm. The chemical shift values of all the complexes/ligands are listed in Table VI.

TABLE VI ^{1}H NMR Spectral Data (δ, ppm) of the Ligands L^1H and L^5H and Their Boron(III) Complexes

Compound	—NH_2 (bs)	—NH(1) (bs)	—NH(2) (s)	—CH_3	—OH (s)	Aromatic protons (m)	—SCH_2
L^1H	3.46	11.53	11.82	—	—	6.78–8.23	—
(Ph)B(OH)(L^1)	3.53	—	11.82	—	4.77	6.82–8.25	—
(Ph)B(L^1)$_2$	3.43	—	11.92	—	—	6.80–8.28	—
L^4H	—	12.56	10.26	2.68	—	8.09–7.74	4.85
(Ph)B(OH)(L^4)	—	—	10.23	2.69	4.45	8.42–7.72	4.81
(Ph)B(L^4)$_2$	—	—	10.24	2.66	—	8.26–7.77	4.87
L^5H	—	11.26	11.92	—	—	6.78–8.28	4.60
(Ph)B(OH)(L^5)	—	—	11.96	—	4.22	6.70–8.18	4.66
(Ph)B(L^5)$_2$	—	—	11.94	—	—	6.76–8.22	4.67

bs = broad singlet and m = complex pattern.

^{13}C NMR Spectra

The chemical shift values of the carbon atoms attached to the azomethine nitrogen and thiolic sulfur further support the proposed coordination in these complexes. The considerable shifts in the positions of carbon atoms attached to the azomethine nitrogen (L^1H, δ 154.32 and L^5H, δ 154.13 ppm) and thiolic carbon (L^1H, δ 163.83 and L^5H, δ 161.12 ppm), respectively, for boron complexes of thiosemicarbazones and hydrazinecarbodithioic acid phenyl methyl esters complexes were also observed. The heterocyclic moiety carbon signals, especially those of the carbon atoms directly bonded to the heteroatom, undergo slight upfieldshifts relative to the other carbon atoms, which remain almost unchanged. The upfield shift of the thiolo carbon and azomethine carbon in the complexes indicates participation of these groups in coordination to the boron atom (Table VII).

^{11}B NMR Spectra

The signals in the ^{11}B NMR spectra of the complexes were observed in the range of δ 3.64–4.42 ppm, which suggest a tetracoordinated[42–44] environment around the boron atom and formation of a coordinate bond.

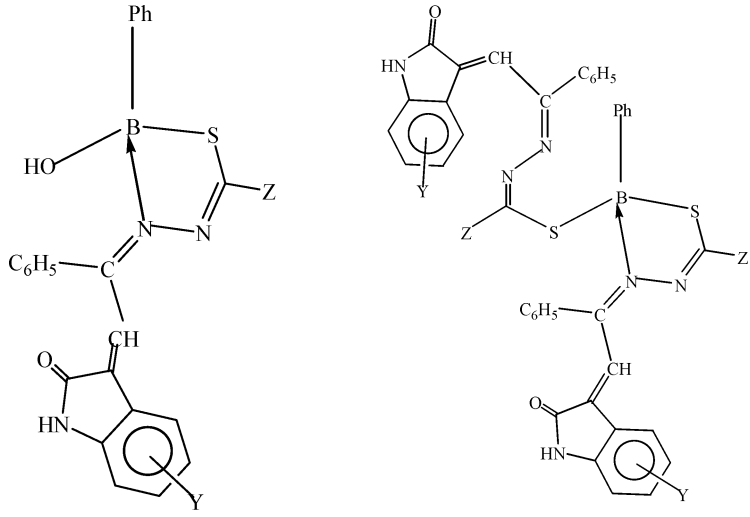
On the basis of the results discussed so far, including analytical and spectroscopic data, a tetracoordinated geometry is suggested for the 1:1 and 1:2 complexes (Scheme 2).

Antimicrobial Studies

Fungicidal and bactericidal screening data show that under identical experimental conditions the compounds possess antimicrobial

TABLE VII ^{13}C NMR Spectral Data (δ, ppm) of Ligands L^1H and L^5H and Their Boron(III) Complexes

Compound	Thiolic carbon	Azomethine carbon	Aromatic carbons carbons	^{11}B Chemical shift
L^1H	163.83	154.32	139.64, 138.38, 138.43, 138.59	—
(Ph)B(OH)(L^1)	171.74	158.41	138.35, 137.63, 138.56, 138.72	3.64
(Ph)B(L^1)$_2$	176.36	157.74	138.15, 137.54, 137.47, 137.54	4.42
L^5H	161.12	154.13	140.62, 138.65, 137.52, 138.31	—
(Ph)B(OH)(L^5)	161.17	155.36	137.32, 136.51, 136.43, 136.92	4.37
(Ph)B(L^5)$_2$	164.54	158.33	137.13, 137.54, 136.45, 137.59	4.36



1:1 Complexes 1:2 Complexes

SCHEME 2

properties. However, a few compounds also possess good activity against microorganisms. It is also noteworthy that the complexes are more active than their parent ligands against the same microorganisms. Giving a closer look at these results reveals a common feature, which is that the bioactivity enhances due to the following points:

1. The chelation reduces the polarity and increase the lipophilic nature of the central boron atom, which subsequently favors its permeation through the lipid layer of the cell membrane. This can be well ascribed to Tweedy's chelation theory.[45]
2. It is also noteworthy that concentration plays an important role in inhibiting the growth of microorganisms. At lower concentration, inhibition is less severe. Due to this fact the activities of the organisms will be slowed down, while at higher concentration, more enzymes will become inhibited leading to a quicker death of the organisms. Lower concentration of compounds can check the sporulation in fungi, and a higher concentration inhibits the growth of organisms almost completely.
3. The toxicity of antibacterial compounds against different species of bacteria depends either on the difference in ribosomes or the impermeability of the cell to the antimicrobial agent.[46]

4. The addition of the boron element to the ligands increases the antimicrobial activity of the complexes.[29]

CONCLUSIONS

1. Thiosemicarbazone and hydrazinecarbodithioic acid phenyl methyl ester ligands behave as monofunctional bidentate with boron atom.
2. Boron complexes obtained by 1:1 and 1:2 molar reactions with different ligands were found to be tetracoordinated.
3. Antimicrobial activity of the complexes and the ligands showed that the former are more active than the parent ligands.
4. The data given in Tables IV and V reveal that $[PhB(L^6)_2]$ and $[PhB(L^1)_2]$ complexes are more toxic than the other complexes.

REFERENCES

[1] Z. H. Chohan and S. K. A. Sheazi, *Synth. React. Inorg. Met.-Org. Chem.*, **29,** 105 (1999).
[2] C. Jayabalakrishnan and K. Natarajan, *Synth. React. Inorg. Met.-Org. Chem.*, **31,** 983 (2001).
[3] T. Jeeworth, H. L. K. Wah, M. G. Bhowon, D. Ghoorhoo, and K. Babooram, *Synth. React. Inorg. Met.-Org. Chem.*, **30,** 1023 (2000).
[4] L. Bolaños, K. Lukaszewski, I. Bonilla, and D. Blevins, *Plant Physio. Biochem.*, **42**(11), 907 (2004).
[5] L. Bolanos, N. J. Brewin, and I. Bonilla, *Plant Physiol.*, **110**(4), 1249 (1996).
[6] J. G. Penland, *Bio. Trace Element Res.*, **66**(1–3), 299 (1998).
[7] V. Barba, R. Santillan, and N. Farfán, *J. Braz. Chem. Soc.*, **16**(3A), 449 (2005).
[8] T. I. Lazarova, L. Jin, M. Rynkiewicz, J. C. Gorga, F. Bibbins, H. V. Meyers, R. Babine, and J. Strickler, *Bioorg. Med. Chem. Lett.*, **16**(19), 5022 (2006).
[9] S. Singh, R. Dhillon, and J. Singh, *Indian J. Chem.*, **30,** 355 (1991).
[10] V. Barba, E. Gallegos, R. Santillan, and N. Farfán, *J. Organomet. Chem.*, **622**(1–2), 259 (2001).
[11] T. N. Bubnov, E. V. Klimkina, A. V. Ignatenko, and I. D. Gridnev, *Tetrahedron Lett.*, **37,** 1317 (1996).
[12] C. Olliver and P. J. Renaud, *J. Am. Chem. Soc.*, **11,** 101 (2001).
[13] D. X. West, A. E. Liberta, S. B. Padhye, R. C. Chikate, P. B. Sonawane, A. S. Kumbhar, and R. G. Yerande, *Coord. Chem. Rev.*, **123,** 49 (1993).
[14] M. B. Ferrari, F. Bisceglie, G. Pelosi, P. Tarasconi, R. Albertini, P. P. Dall'Aglio, A. Bergamo, and S. Fava, *J. Inorg. Biochem.*, **98,** 301 (2004).
[15] N. C. Saha, R. J. Butcher, S. Chaudhuri, and N. Saha, *Polyhedron*, **22,** 383 (2003).
[16] V. B. Arion, M. K. Jakupec, M. Galanski, P. Unfried, and B. K. Keppler, *J. Inorg. Biochem.*, **91,** 298 (2002).
[17] N. C. Kasuga, K. Sekino, M. Ishikawa, A. Honda, M. Yokoyama, S. Nakano, N. Shimada, C. Kuomo, and K. Nomiya, *J. Inorg. Biochem.*, **96,** 298 (2003).
[18] M. A. Ali, A. H. Mirza, C. W. Voo, A. L. Tan, and P. V. Bernhardt, *Polyhedron*, **22,** 3433 (2003).

[19] M. T. H. Tarafder, K.-B. Chew, K. A. Crouse, A. M. Ali, B. M. Yamin, and H.-K. Fun, *Polyhedron*, **21,** 2683 (2002).
[20] P. Bera, R. J. Butcher, S. Chaudhuri, and N. Saha, *Polyhedron*, **21,** 1 (2002).
[21] K. Mahajan, N. Fahmi, and R. V. Singh, *Indian J. Chem.*, **46A,** 1221 (2007).
[22] M. A. Ali, S. M. M. H. Majumder, R. J. Butcher, J. P. Jasinski, and J. M. Jasinski, *Polyhedron*, **16,** 2749 (1997).
[23] M. Das and S. E. Livingstone, *Br. J. Cancer*, **37,** 466 (1978).
[24] N. Jayakumar, P. Yogalakshmi, and K. Natarajan, *Synth. React. Inorg. Met.-Org. Chem.*, **20,** 661 (1990).
[25] T. N. Babnov, E. V. Klimkina, A. V. Iqnatenko, and I. D. Gridnev, *Tetrahedron Lett.*, **37,** 1317 (1996).
[26] K. Shelly, C. B. Knobler, and M. R. Howthorne, *Inorg. Chem*., **31,** 2889 (1992).
[27] S. A. Khan, J. H. Morris, M. Haran, and M. B. Hursthouse, *J. Chem. Soc. Dalton Trans.*, 119 (1992).
[28] M. Biyala, N. Fahmi, and R. V. Singh*, Phosphorus, Sulfur, and Silicon*, **180**(2), 425 (2005).
[29] S. Gaur, N. Fahmi, M. Agarwal, and R. V. Singh, *Appl. Organometal. Chem*., **21,** 89 (2007).
[30] P. Nagpal and R. V. Singh, *Appl. Organometal. Chem.*, **18,** 221 (2004).
[31] V. P. Singh, R. V. Singh, and J. P. Tondon, *J. Inorg. Biochem.*, **39,** 893 (1990).
[32] R. Garg, M. K. Saini, N. Fahmi, and R. V. Singh, *Indian J. Chem.*, **44A,** 2433 (2005).
[33] A. I. Vogel, *A Text Book of Quantitative Inorganic Analysis*, 5th ed. (Longman, ELBS, London, 1989).
[34] A. I. Vogel, *A Textbook of Practical Organic Chemistry*, 4th ed. (Longman, ELBS, London, 1978), p. 323.
[35] S. Gaur, S. Maanju, N. Fahmi, and R. V. Singh, *Heterocyclic Commun.*, **11**(5), 411 (2005).
[36] A. Chaudhary, K. Mahajan, and R. V. Singh, *Appl. Organometal. Chem.*, **21,** 117 (2007).
[37] R. V. Singh, S. P. Mittal, M. Swami, and K. Mahajan, *Int. J. Chem. Sci.*, **5**(3), 1417 (2007).
[38] R. V. Singh, S. C. Joshi, S. Kulshreshtha, P. Nagpal, and A. Bansal, *Met. Based Drugs*, **8,** 149 (2001).
[39] C. Saxena and R. V. Singh, *Main Group Met. Chem.*, **15,** 31 (1992).
[40] V. P. Singh, R. V. Singh, and J. P. Tandon, *J. Inorg. Biochem.*, **39,** 237 (1990).
[41] G. H. A. El-Reash, F. Taha, A. M. Shallaby, and O. A. El Gamal, *Indian J. Chem.*, **80A,** 286 (1991).
[42] V. Barba, R. Santillan, and N. Farfan, *J. Mex. Chem. Soc*., **49**(2), 211 (2005).
[43] M. K. Biyala, N. Fahmi, and R. V. Singh, *Indian J. Chem.*, **43A,** 1662 (2004).
[44] R. V. Singh and M. K. Biyala, *Phosphorus, Sulfur, and Silicon*, **181,** 1 (2006).
[45] B. G. Tweedy, *Phytopathology*, **55,** 910 (1964).
[46] P. G. Lawrence, P. L. Harold, and O. G. Francis., *Antibio. Chemother.*, **5,** 1597 (1980).