MICROWAVE ASSISTED SYNTHESIS, CHARACTERIZATION AND BIOLOGICAL STUDIES OF ISONICOTINOYL-HYDRAZONES AND THEIR MANGANESE (II) COMPLEXES

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The Schiff base ligands 1-(2-furanyl) ethanone isonicotinoylhydrazone (L^5H), 1-(2-thienyl)ethanone isonicotinoylhydrazone (L^6H), 1-(2-pyridyl)ethanone isonicotinoylhydrazone (L^7H), 1-(2-naphthyl)ethanone isonicotinoylhydrazone (L^8H), were prepared by the condensation reaction of isonicotinic acid hydrazide with corresponding ethanons in 1:1 molar ratio, respectively, in ethanol under microwave exposure. The Mn (II) complexes have been prepared by mixing $MnCl_2.4H_2O$ in 1:1 and 1:2 molar ratios with monofunctional bidentate ligands. The structure of the ligands and their transition metal complexes were confirmed by the elemental analysis, molecular weight determinations, IR, electronic and EPR spectral studies. On the basis of these studies it is clear that the ligands coordinated to the metal atom in a monobasic bidentate mode, by O∩N donor system. Thus a tetrahedral environment around the Mn(II) ion has been proposed. The antimicrobial activity of Schiff base ligands and their respective Mn(II) complexes were tested against some of pathogenic bacterial and fungal strains. The results indicated that the complexes showed higher activity than the parent ligands.

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Introduction

Coordination compounds are the backbone of modern inorganic and bio-inorganic chemistry and chemical industry. These compounds provide critical insights into the functioning and structures of vital components of biological systems. Coordination compounds also find extensive applications in metallurgical process, analytical and medicinal chemistry.[1] Amongst the coordination compounds, Schiff base complexes are of considerable importance and have been known since the mid nineteenth century.[2,3] Metal-complexes of Schiff bases have occupied a central place in the development of coordination chemistry after the work of Jorgensen and Werner.[4]

Chelating ligands containing N and O donor atoms show broad biological activity and are of special interest because of the variety of ways in which they are bonded to metal ions. It is known that the existence of metal ions bonded to biologically active compounds may enhance their activities.[5-6] There has been considerable interest in coordination chemistry of manganese(II) compounds because of their potential utilities as model compounds of manganese containing proteins which would show significant involvement of manganese in various biological systems. Manganese(II) complexes with Schiff base ligands are becoming increasingly important as biochemical, analytical and antimicrobial reagents, in the design of molecular ferromagnets, in materials chemistry and so on.[8-10] The biological importance of Schiff base complexes of Mn(II) has been referred by number of studies.[11-13]

Green chemistry is the effort of reducing or eliminating the use or generation of hazardous substances during chemical procedures[14,15] to keep environment pollution free. Microwave chemistry as a green method of synthesis has an edge over conventional heating methods for conducting chemical reactions for lead development by pharmaceutical and biotechnology companies.[16] Nowadays the microwave technology is being used for the synthesis of organic and inorganic compounds, as well as for thermal treatment of many materials at laboratorial and industrial scales.[17]

Due to the growing interest of pharmacological properties of nitrogen and oxygen containing Schiff base ligands and their metal complexes, a systematic study of the stereochemical and biological aspects of the Mn(II) complexes of substituted isonicotinylhydrazone have been undertaken. In the present investigation and as synthesized ligands and their complexes have also been tested *in vitro* for antifungal and antibacterial activity.

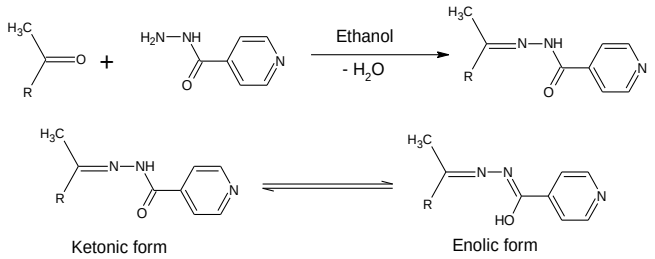
Experimental

All the chemicals and reagents used were of AR grade and dried and distilled before use. The $MnCl_2.4H_2O$ was purchased from Alfa Caesar. 1-(2-furanyl)ethanone, 1-(2-thienyl)ethanone, 1-(2-pyridyl)ethanone and 1-(2-naphthyl)ethanone and isonicotinic acid hydrazide were purchased from Sigma Aldrich. Apparatus fitted with Quickfit interchangeable joints was used to carry out the reactions under completely anhydrous conditions.

Preparation of the ligands

All ligands L^5H, L^6H, L^7H and L^8H were prepared by the condensation reaction of isonicotinic acid hydrazide with 1-(2-furanyl)ethanone, 1-(2-thienyl)ethanone, 1-(2-pyridyl)-

ethanone and 1-(2-naphthyl)ethanone in 1:1 molar ratio respectively using ethanol as solvent (Scheme 1). The reaction mixture was subjected under microwave radiations for 5-10 minutes. Reaction progress monitored by TLC and after completion of reactions, the solution was concentrated under reduced pressure, which on cooling gave dark yellow crystalline precipitates (Approx 90 % yield). These were washed and recrystallized in alcohol.



where R= 2-furanyl, 2-thienyl, 2-pyridyl and 2-naphthyl

Preparation of the complexes

Microwave method was employed for the synthesis of the metal complexes of the as- synthesized ligands. A fixed amount of hydrated manganese dichloride ($MnCl_2.4H_2O$) in dry methanol was mixed with a methanolic solution of the synthesized ligands in 1:1 and 1:2 molar ratios. The reaction mixture was subjected under microwave radiations for 7-9 minutes. The resulting mixture was then concentrated under reduced pressure. The resulting compounds were washed with methanol followed by drying in *vacuum* for about one hour to get the final product. The low value of molar conductivity (7.0-11.5 ohm^{-1} cm^2 mol^{-1}) of $1x10^{-3}$ M solutions of the resulting manganese(II) complexes in anhydrous dimethylformamide adequately supports their non-electrolytic nature.

Physical measurements and analytical methods

The molecular weights were determined by the Rast Camphor method.[18] The metal contents were analysed gravimetrically. Sulfur and nitrogen were determined by Messenger's[19] and Kjeldahl's methods,[20] respectively. Carbon and hydrogen analyses were performed at the CDRI, Lucknow. Infrared spectra were recorded on a Nicolet Magna FTIR-550 spectrophotometer using KBr pellets. The electronic spectra were recorded on a Varian–Cary/5E spectrophotometer at Central University Gujarat. EPR spectra of the complexes were monitored on Varian E-4X band spectrometer at Central University Gujarat.

Antimicrobial studies

Bioefficiacies of the synthesized compounds were checked *in vitro*. The *in vitro* antifungal activities of the ligands and their complexes have been evaluated against two pathogenic fungi, *Candida albicans* and *Aspergillus niger* using by the agar plate technique.[21] The potato dextrose agar (PDA) medium was prepared in the laboratory to maintain the fungal growth. For PDA preparation, 20 g potato was extracted with distilled water (100 mL) at 100 ºC for 1 h and it was filtered off by cotton filter. The potato juice was then mixed with 2 g dextrose and 1.5g agar and finally the pH of the prepared PDA media was adjusted at 7. Solutions of the test compounds in methanol at 50, 100 and 200 ppm concentrations were prepared and then were mixed with the medium. The medium was then poured into petri plates and the spores of fungi were placed on the medium with the help of inoculum's needle. These petri plates were wrapped in the polythene bags containing a few drops of alcohol and were placed in an incubator at 25±2 °C. The activity was determined after 96 h of incubation at room temperature (25 ºC). The controls were also run and three replicates were used in each case The linear growth of the fungus was obtained by measuring the diameter of the fungal colony after four days and the percentage inhibition was calculated as 100x(*C*-*T*)/*C*, where *C*=diameter of the fungus colony in the control plate after 96 h and *T*=diameter of the fungal colony in the test plates after the same period. The antifungal screening data of compounds were compared with the standard (Fluconazole).

In vitro antibacterial screening is generally performed by disc diffusion method[22] for primary selection of the compounds as therapeutic agents. The antibacterial activity of the ligands and their manganese complexes were evaluated against of two bacteria including Gram-positive (*Bacillus subtilis)* and Gram-negative (*Escherichia coli)*. The nutrient agar medium having the composition peptone 5 g, beef extract 5 g, NaCl 5 g, agar-agar 20 g and distilled water 1000 mL was pipetted into the Petri dish. When it solidified, 5.0 mL of warm seeded agar was applied. The seeded agar was prepared by cooling the molten agar to 40 °C and then added the 10 mL of bacterial suspension. The compounds were dissolved in methanol in 500 and 1000 ppm concentrations. Paper discs of Whatman No.1 filter paper measuring diameter of 5mm were soaked in these solutions. The discs were dried and placed on the medium previously seeded with organisms in Petri plates at suitable distance. The Petri plates were stored in an incubator at 28±2 °C for 24 h. The diameters of the zone of inhibition produced by the compounds were compared with the standard antibiotic (Streptomycin). The zone of inhibition thus formed around each disc containing the test compounds was measured accurately in mm.

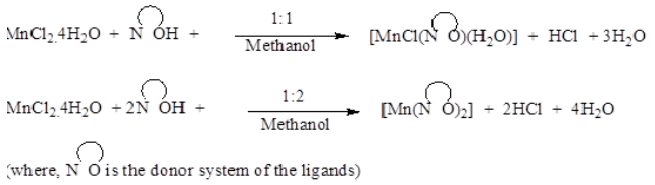
Determination of minimum inhibitory concentration (MIC)

Minimum Inhibitory Concentration, MIC, is the lowest concentration of test agent that inhibited visible growth of bacteria after 18 h incubation at 37 °C. The determination of the MIC involves a semiquantitative test procedure, which gives an approximation to the least concentration of an antimicrobial needed to prevent microbial growth. The minimum inhibitory concentration was determined by liquid dilution method.[23] Stock solutions of Mn(II) complexes with 10-50 mg mL^{-1} concentrations were prepared with aqueous methanol solvent. Inoculum of the overnight culture was prepared. In a series of tubes, 1 mL each of Mn(II) complex solutions with different concentrations were taken and 0.4 mL of the inoculum was added to each tubes. Further 3.5 mL of the sterile water was added to each of the test tubes. These test tubes were incubated for 24 h and observed for the presence of turbidity. The absorbance of the suspension of the inoculum was observed with

spectrophotometer at 555 nm. The end result of the test was the minimum concentration of antimicrobial (test materials) which gave a clear solution, i.e., no visual growth.[24]

Results and Discussion

The elemental analysis and spectral data are consistent with the formulation of compounds as $[MnCl(L)(H_2O)]$ and $[Mn(L)_2]$. Molecular weight determinations indicate their monomeric nature. The reactions of $MnCl_2.4H_2O$ with the synthesized ligands were carried out in unimolar and bimolar ratios in methanol solution proceed with the formation of M←N and M-O bonds yielding the substitution products. The reactions proceed as shown in Scheme 2.



Scheme 2. Preparation route of the complexes

The reason for synthesizing metal complexes by microwave method is due to its ecofriendly nature. The microwave mediated reactions occur more safely, reduce the amount of waste products and increases the yield of pure required products. The physical properties and analytical data of the synthesized ligands and their metal complexes are enlisted in Table 1. The bonding pattern and the geometry of these complexes have been deduced on the basis of IR, UV and ESR spectral studies.

Infrared spectral data

A comparison of the characteristic IR absorption bands of the ligand and corresponding metal complexes reveal important features for establishing the facts that the ligands (L^5H, L^6H, L^7H and L^8H) behave as monofunctional bidentate N∩O donor for bonding to the metal atom. The broad band due to ν_{NH} vibrations disappears in the spectra of manganese(II) complexes, indicating the deprotonation of this group on coordination with the metal atom. In the IR spectra of the complexes appropriate shifts of ligand bands was noted due to complex formation. The $\nu_{C=O}$ and $\nu_{C=N}$ stretching bands that appeared in the free ligands at 1715-1705 cm^{-1} and 1600-1590 cm^{-1}, respectively, are shifted to lower frequency in the complexes and observed in the ranges 1700–1690 cm^{-1} and 1580–1570 cm^{-1} for $\nu_{C=O}$ and $\nu_{C=N}$, respectively.

Table 1. Analytical data and physical properties of the ligands and their complexes

Synthesized compounds	Colour	Melting Point (^{0}C)	Found (Calculated) (%)			Mol. Wt. Found (calculated)
			N	S	Mn	
L^5H	Yellow	160-165	18.2 (18.32)	-	-	228.35 (229.23)
L^6H	Light yellow	199-205	18.74 (17.12)	13.93 (13.07)	-	244.5 (245.29)
L^7H	Light yellow	130-134	22.74 (23.31)	-	-	239.3 (240.24)
L^8H	Light yellow	220(d)	15.4 (14.52)	-	-	289.5 (290.33)
$[MnCl(L^5)(H_2O)]$	Pink	165	12.10 (12.48)	-	15.84 (16.31)	334.81 (336.63)
$[Mn(L^5)_2]$	Light pink	173(d)	16.77 (16.43)	-	10.39 (10.74)	509.64 (511.39)
$[MnCl(L^6)(H_2O)]$	Light pink	225(d)	11.54 (11.91)	10.01 (9.09)	15.24 (15.57)	350.27 (352.69)
$[Mn(L^6)_2]$	Light pink	248(d)	16.07 (15.46)	9.94 (10.10)	11.27 (11.79)	542.51 (543.52)
$[MnCl(L^7)(H_2O)]$	Light pink	199(d)	16.72 (16.11)	-	15.17 (15.80)	345.56 (347.62)
$[Mn(L^7)_2]$	Light pink	187(d)	20.81 (21.00)	-	10.89 (10.29)	530.80 (533.44)
$[MnCl(L^8)(H_2O)]$	Light pink	235(d)	10.23 (10.60)	-	14.24 (13.86)	398.50 (397.73)
$[Mn(L^8)_2]$	Light pink	212(d)	13.60 (13.30)	-	8.08 (8.69)	632.54 (633.59)

d = decomposition

These bands are assigned to a $\nu_{C=O}$ and $\nu_{C=N}$ stretches of reduced bond order. This can be attributed to delocalisation of metal electron density (t_{2g}) to the π-system of the ligand,[25] indicating coordination of oxygen of C=O and nitrogen of the C=N moieties to the metal atoms.[26] The IR spectra of the ligands display two sharp bands around 3230-3200 cm^{-1} and 3455-3380 cm^{-1} assignable to ν_{sym} and ν_{asym} vibrations of the NH_2 group, respectively. These bands remain unchanged in the manganese(II) complexes of the ligands, indicating non-involvement of the NH_2 group in coordination. In the spectra of (1:1) manganese(II) complexes, a band observed at 830-860 cm^{-1} was assigned to the rocking mode of the coordinated water molecule. The band due to the ν_{Mn-Cl} appears in the region 335-322 cm^{-1}. These bands are absent in the spectra of manganese(II) complexes synthesized in (1:2) molar ratio. Some bands of low intensity appearing in the spectra of manganese(II) complexes in the region 439-420 cm^{-1} and 600-585 cm^{-1} can be assigned to ν(Mn←N) and ν(Mn-O)[27] vibrations, respectively, which do not appear in the spectra of ligands confirming that the chelation takes place through the bidentate (N∩O) donor system.

Table 2. IR spectral data of the ligands and their Mn(II) complexes

Synthesized compounds	IR spectral data (cm^{-1})				
	***ν*(C=O)**	**ν(C=N)**	**ν(M-O)**	**ν(M←N)**	**ν(M-Cl)**
L^4H	1715	1600	-	-	-
L^5H	1710	1593	-	-	-
L^9H	1709	1596	-	-	-
$L^{10}H$	1705	1600	-	-	-
$[MnCl(L^5)(H_2O)]$	1690	1570	585	439	322
$[Mn(L^5)_2]$	1700	1575	597	438	330
$[MnCl(L^6)(H_2O)]$	1697	1580	600	420	325
$[Mn(L^6)_2]$	1695	1573	592	437	333
$[MnCl(L^7)(H_2O)]$	1699	1975	589	438	330
$[Mn(L^7)_2]$	1700	1578	595	422	328
$[MnCl(L^8)(H_2O)]$	1700	1576	590	426	332
$[Mn(L^8)_2]$	1698	1579	600	438	335

Table 3. Electronic spectral data of the Mn(II) complexes.

Synthesized compounds	Transitions	Spectral bands(cm^{-1})	μ_{eff} (BM)
$[MnCl(L^5)(H_2O)]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16540	5.73
	$^6A_1 \rightarrow {}^4E$ (ν_2)	22800	
$[Mn(L^5)_2]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16880	5.88
	$^6A_1 \rightarrow {}^4E$ (ν_2)	22400	
$[MnCl(L^6)(H_2O)]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16900	5.91
	$^6A_1 \rightarrow {}^4E$ (ν_2)	20000	
$[Mn(L^6)_2]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16740	5.99
	$^6A_1 \rightarrow {}^4E$ (ν_2)	22700	
$[MnCl(L^7)(H_2O)]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16900	5.69
	$^6A_1 \rightarrow {}^4E$ (ν_2)	22650	
$[Mn(L^7)_2]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16830	6.10
	$^6A_1 \rightarrow {}^4E$ (ν_2)	22630	
$[MnCl(L^8)(H_2O)]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	16760	6.05
	$^6A_1 \rightarrow {}^4E$ (ν_2)	22300	
$[Mn(L^8)_2]$	$^6A_1 \rightarrow {}^4T_2$ (ν_1)	17100	6.05
	$^6A_1 \rightarrow {}^4E$ (ν_2)	23600	

Table 4. ESR spectral data of the Mn(II) complexes

Synthesized compounds	H_0	g^{II} value	Temp. (^{0}C)	Frequency (ν)
$[MnCl(L^5)(H_2O)]$	3285.02	1.9900	25	9.38
$[Mn(L^5)_2]$	3350.72	2.0000	25	9.38
$[MnCl(L^6)(H_2O)]$	3294.66	2.0200	25	9.38
$[Mn(L^6)_2]$	3364.57	1.9920	25	9.38
$[MnCl(L^7)(H_2O)]$	3350.25	2.0000	25	9.38
$[Mn(L^7)_2]$	3255.65	1.9994	25	9.38
$[MnCl(L^8)(H_2O)]$	3217.21	2.0130	25	9.38
$[Mn(L^8)_2]$	3175.59	2.0103	25	9.38

Table 5. MIC (μg mL^{-1}) values of the ligands and their complexes

Synthesized compounds	*Bacillus subtilis*	*Escherichia coli*	*Candida albicans*	*Aspergillus niger*
L^5H	34.0±0.3	30.0±0.2	29.0±0.1	38.0±0.2
L^6H	30.0±0.1	31.0±0.2	33.0±0.2	28.0±0.1
L^7H	39.0±0.3	34.0±0.2	33.0±0.4	30.0±0.3
L^8H	32.0±0.1	38.0±0.2	39.0±0.1	32.0±0.2
$[MnCl(L^5)(H_2O)]$	20.0±0.2	20.0±0.3	22.0±0.3	24.0±0.3
$[Mn(L^5)_2]$	20.0±0.2	24.0±0.2	21.0±0.2	20.0±0.1
$[MnCl(L^6)(H_2O)]$	20.0±0.1	22.0±0.2	18.0±0.1	23.0±0.1
$[Mn(L^6)_2]$	19.0±0.1	19.0±0.1	19.0±0.1	22.0±0.1
$[MnCl(L^7)(H_2O)]$	19.0±0.1	21.0±0.3	20.0±0.2	22.0±0.2
$[Mn(L^7)_2]$	20.0±0.4	23.0±0.3	22.0±0.3	22.0±0.2
$[MnCl(L^8)(H_2O)]$	19.0±0.2	20.0±0.3	22.0±0.3	23.0±0.3
$[Mn(L^8)_2]$	20.0±0.2	19.0±0.2	21.0±0.2	18.0±0.1

The significant IR bands of the ligands and their metal complexes along with their tentative assignments are reported in Table 2.

Electronic spectral analysis

Electronic spectral and magnetic susceptibility results have supported to establish the geometry of the metal complexes. The expected tetrahedral geometry of the manganese(II) complexes was supported by the bands at 16540-17100 cm^{-1} and 20000-23600 cm^{-1} due to the $^6A_1 \rightarrow {}^4T_2(\nu_1)$ and $^6A_1 \rightarrow {}^4E(\nu_2)$ transitions, which are characteristics of tetrahedral geometry.[29] The observed magnetic moment value of 5.69-6.10 BM indicates that manganese(II) complexes are paramagnetic in nature consisting five unpaired electrons.

These data along with the tentative assignments are presented in Table 3.

ESR spectral analysis and magnetic moment

The ESR spectrum of manganese(II) complexes was recorded at room temperature. The spectrum consists of a single broad peak from which the Lande splitting factor ('*g*' value) has been calculated (Table 4). The '*g*' value lie in the range 1.9900–2.0200, which is characteristic of tetrahedral geometry. Lande splitting factor ('*g*' values) has been calculated by the following formulae:

$$g = \frac{h\nu}{\beta H}$$

where

h= Planck's constant (6.625×10^{-34} J s)

ν = frequency ($\nu = 9.38 \times 10^9$ Hz)

β = Bohr magneton (9.27×10^{-24} J $Tesla^{-1}$)

On the basis of above studies, a tetrahedral environment around the metal atom has been proposed.

Antimicrobial assay

Determination of minimum inhibitory concentration (MIC) of the synthesized ligands and their corresponding metal complexes were carried out on selected fungi, *Candida albicans* and *Aspergillus niger* and two bacteria, Gram-positive (*Bacillus subtilis)*, and Gram-negative (*Escherichia coli)* and the MIC values calculated for the ligands and their manganese(II) complexes as shown in (Table 5).

The results indicated that the ligands and their metal complexes were the most active in inhibiting the growth of the tested organisms between 18-39 μg mL^{-1} MIC values for selected bacteria and fungi. The results showed that all the free ligands were appreciably less active compared to their manganese(II) complexes. This indicated that the complexation to metal enhances the activity of the ligand. This may be explained by Tweedy's chelation theory[28], according to which chelation reduces the polarity of the central metal atom because of partial sharing of its positive charge with the ligand, due to which the lipophilic character of the metal chelate increases and favours its permeation through the lipid layer of cell membrane.

It has also been proposed that the ultimate action of the compounds is the denaturation of one or more proteins of the cell as a result of which normal cellular processes are impaired[29] and deactivation of various cellular enzymes that play a vital role in different metabolic pathways of these microorganisms.

Conclusions

Microwave (MW) irradiation is an efficient and environmentally-benign method to accomplish various inorganic and organic syntheses to afford products in higher yields in shorter reaction periods. Manganese(II) complexes synthesized in 1:1 and 1:2 molar ratios were found to possess tetra-coordinated tetrahedral structure. Biological data of the complexes and the ligands showed that the complexes are more active than the parent ligands.

Table 6. Antifungal and antibacterial screening data for the ligands and their complexes

Synthesized compounds	Antifungal activity, % (conc. in ppm)						Antibacterial activity, % (conc. in ppm)			
	Inhibition after 96 h						Diameter (mm) of inhibition zone after 24 h			
	Candida albicans			*Aspergillus niger*			*Bacillus subtilis*		*Eschirichia coli*	
	50	**100**	**200**	**50**	**100**	**200**	**500**	**1000**	**500**	**1000**
L^5H	23	41	46	22	29	48	10	11	8	9
L^6H	24	44	40	25	31	52	17	13	15	12
L^7H	27	47	42	26	30	53	14	13	10	12
L^8H	25	45	49	23	33	51	13	12	16	14
$[MnCl(L^5)(H_2O)]$	29	49	45	28	35	56	15	13	14	13
$[Mn(L^5)_2]$	32	50	49	29	38	59	12	15	12	14
$[MnCl(L^6)(H_2O)]$	30	52	46	30	40	57	14	16	15	13
$[Mn(L^6)_2]$	32	55	42	31	42	61	16	17	13	15
$[MnCl(L^7)(H_2O)]$	39	57	49	34	49	64	15	18	14	16
$[Mn(L^7)_2]$	42	50	43	37	52	66	17	20	15	18
$[MnCl(L^8)(H_2O)]$	40	52	47	40	50	62	20	18	16	20
$[Mn(L^8)_2]$	39	49	44	42	52	65	15	17	15	19
Flucanazole	60	70	73	55	68	85	-	-	-	-
Streptomycin	-	-	-	-	-	-	19	22	18	21

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