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Synthesis, characterization and antimicrobial investigation of Rh(III), Ru(III) and Ag(I) complexes with some derivatives of 3-amino-2-thioxo-2,3-dihydroquinazolin-4(1*H*)-ones

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ABSTRACT

The reaction of 2,3-disubstituted mercapto quinazolines with 2-hydroxy benzaldehyde (HBAMQ) (1), 2-hydroxy naphthaldehyde (HNAMQ) (2), pyridine-2-carboxaldehyde (PMAMQ) (3) and thiophen-2-carboxaldehyde (TMAMQ) (4), and with metals like Rh(III), Ru(III), and Ag(I) in the presence of piperidine resulted in the formation of their respective complexes by physicochemical methods. The newly synthesized complexes were characterized by elemental analysis, magnetic data, and spectroscopic techniques like UV-Visible, IR and ^{1}H NMR, respectively. These compounds were also evaluated for their antimicrobial activities.

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1. Introduction

Although several classes of antimicrobial compounds are presently available, the resistance of microorganisms to these drugs has been constantly emerging. In order to address this serious medical problem, the medicinal chemists have focused their attention on organic compounds and natural products but not on metallo-organic entities in search of a new drug. Quinazolines are bicylic compounds which play an important role in the synthetic organic chemistry. Among which, particularly those which are C-2 and N-3 di-substituted quinazoline-(3*H*)-4-ones are reported to be physiologically and pharmacologically active and find applications in the treatment of several diseases such as leprosy, mental disorders etc. These compounds are also used as antibacterial, antifungal, antitubercular, anticonvulsant, antipyretic, anti-amoebic, antifertile and plant growth regulating agents [1-6]. In analytical chemistry, quinazolines also find applications by acting as multidentate ligands with metals usually from the transition group [7].

Schiff bases constitute an important class of organic compounds for which they are endowed with synthetic flexibility and can be obtained with varied substitutions widely by the selection of appropriate reactions. These compounds have also been projected as promising pesticides, fungicides and bacteriocides [8-10]. They possess a wide spectrum of medicinal properties as they are active against tuberculosis, leprosy, viral infections and certain types of tumors *etc*. [11-19]. Various studies have also shown that the azomethine group, having a lone pair of electrons in either a *p* or sp^2 hybridized orbital on triagonally hybridized nitrogen has considerable biological importance. It was often been thought that the biological activity of these compounds is due to their ability to chelate metal ions. The synthesis and characterization of metal complexes with bioactive organic ligands, particularly the Schiff bases, is one among the promising fields for the research, as the metal ion association exerts a synergistic effect on the activity of the free ligands [20-24].

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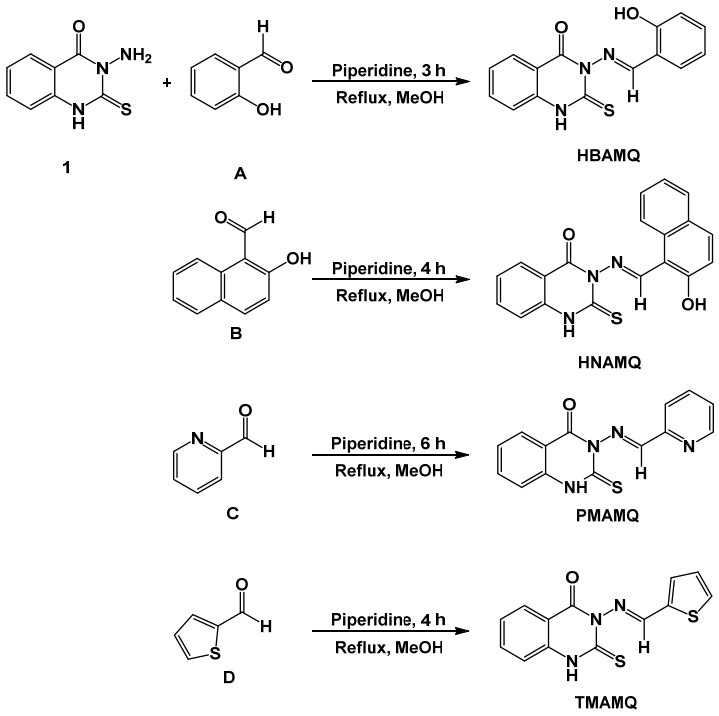


1 A B C D

Scheme 1

As the Schiff base derivatives of quinazolines and their metal complexes play an important role in many biological processes, and our earlier research work involved the synthesis, characterization, and bioactivity evaluation of quinazolyl based Schiff bases [25-27], their metal complexes, and based on the encouraging results obtained with regard to the biological activity of these systems, through this paper, we report the synthesis and characterization of the ligand systems obtained by the reaction of 2,3-disubtituted mercaptoquinazoline with A, B, C, D to result 3-((2-hydroxy benzylidene) amino)-2-thioxo-2, 3-dihydroquinazolin-4(1*H*)-one (1), 3-(((2-hydroxynaphthalen-1-yl)methylene)amino)-2-thioxo-2, 3-di hydroquinazolin-4(1*H*)-one (2), 3-((pyridin-2-ylmethylene) amino)-2-thioxo-2, 3-dihydroquinazolin-4(1*H*)-one (3) and 3-((thiophen-2-ylmethylene)amino)-2-thioxo-2,3-dihydroquinazolin-4(1*H*)-one (4) and their Rh(III), Ru(III), and Ag(I) complexes by physicochemical methods (Scheme 1) and their antimicrobial activity against different types of bacteria and fungal species.

2. Experimental

2.1. Instrumentation

The process of elemental analyses was carried out by means of Perkin Elmer 2400 CHN elemental analyzer at Osmania University, Hyderabad, India. The magnetic susceptibility studies of the metal complexes were recorded by using magnetic susceptibility meter MS_2G, single frequency sensor Barington Company, India. The infrared spectra of the ligands and the metal complexes were recorded in KBr pellets in the range 4000-400 cm^{-1} on Perkin Elmer-BX spectrophotometer at central instrumentation center, Kakatiya University, Warangal, India. The electronic spectra of the metal complexes in DMF were recorded on ELICO SL-159 UV-VIS spectrophotometer and Systronics Double beam UV-VIS spectrophotometer, 2201 at Chaitanya Degree and Post Graduate College, Hanamkonda, Warangal, India. ^1H NMR and ^{13}C NMR were recorded in DMSO-d_6 (Bruker Aspect AM-400 instrument) at 400 and 100 MHz, respectively. The chemical shift values (δ) are given in ppm.

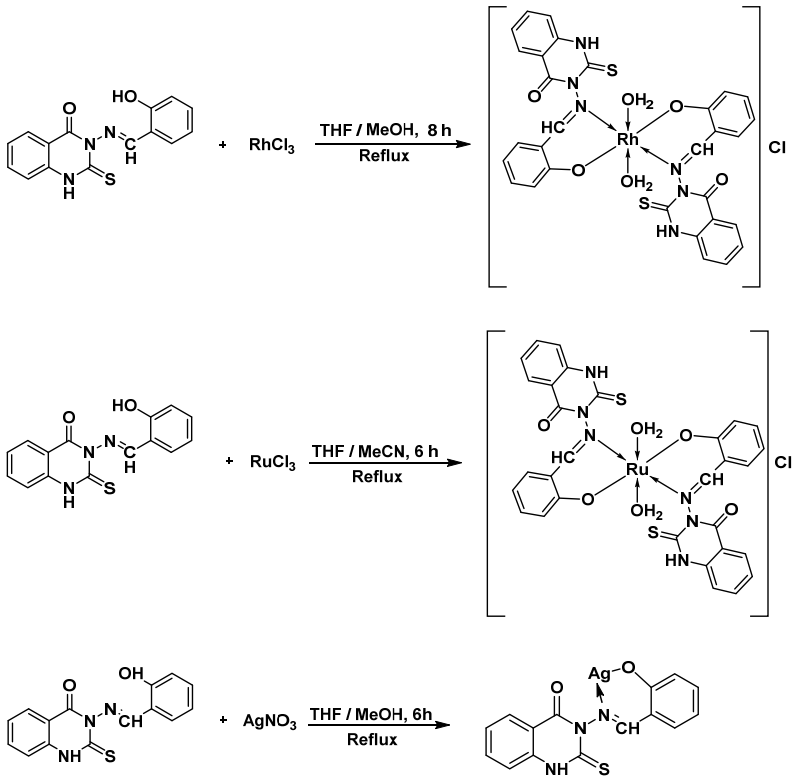
2.2. Synthesis of ligands

All the chemicals used were AR and BDH grade. 3-Amino-2-mercapto-quinazoline-4-(3*H*)-ones (**1**) was prepared as reported earlier [28]. The ligands HBAMQ, HNAMQ, PMAMQ, and TMAMQ were synthesized by refluxing equimolar methanolic solutions of 3-amino-2-thioxo-2,3-dihydro quinazolin-4(1*H*)-one (**1**) and the respective aldehydes in presence of few drops of piperidine for 3 to 6 h. The solids that separated during reflux were filtered, washed with methanol and recrystallized from hot dry methanol.

The reactions of aryl aldehydes like A, B, C, D (1 mmol) with 3-amino-2-mercapto-quinazolin-4(3*H*)-one in the presence of few drops of piperidine as a base catalyst were carried out in methanol and refluxed on hot water bath for 3-6 h (Scheme 1). The crude products obtained were purified from methanol and recrystallized by hot dry methanol.

3-((2-Hydroxybenzylidene)amino)-2-thioxo-2, 3-dihydro quinazolin-4(1H)-one (**HBAMQ**): Color: Yellow solid. Yield: 78%. M.p.: 188-190 °C. FT-IR (KBr, ν, cm^{-1}): 3200 (NH), 3455 (OH), 1718 (C=O), 1583 (C=N). ^1H NMR (400 MHz, DMSO-d_6, δ, ppm): 6.90-6.96 (m, 2H, Ar-H), 7.21-7.30 (m, 2H, Ar-H), 7.30-7.40 (d, 2H, Ar-H), 7.64-7.84 (m, 1H, Ar-H), 8.02 (d, 1H, Ar-H), 8.70 (s, 1H, N=CH), 11.43 (s, 1H, NH), 11.849 (s, 1H, OH). ^{13}C NMR (100 MHz, DMSO-d_6, δ, ppm): 116.8, 117.8, 119.2, 119.6, 123.1, 124.4 125.7, 126.6, 130.2, 131.2, 134.7, 147.8, 148.2, 157.7, 161.6. Anal. calcd. for $C_{15}H_{11}N_3O_2S$: C, 60.59; H, 3.73; N, 14.13; Found: C, 60.26; H, 3.69; N, 14.02%.

3-(((2-Hydroxynaphthalen-1-yl)methylene)amino)-2-thioxo-2,3-dihydroquinazolin-4(1H)-one (**HNAMQ**): Color: Mustard yellow solid. Yield: 82%. M.p.: 226-228 °C. FT-IR (KBr, ν, cm^{-1}): 3242 (NH), 3450 (OH), 1723 (C=O), 1586 (C=N). ^1H NMR (400 MHz, DMSO-d_6, δ, ppm): 7.24-7.27 (m, 2H, Ar-H), 7.37-7.42 (m, 2H, Ar-H), 7.57-7.60 (t, 1H, Ar-H), 7.67-7.80 (t, 1H, Ar-H), 7.86-



Scheme 2

7.91 (m, 2H, Ar-H), 8.01-8.03 (d, 1H, Ar-H), 8.14-8.16 (d, 1H, Ar-H), 9.70 (s, 1H, N=CH), 13.2 (s, 1H, OH), 11.5 (s, 1H, NH). ^{13}C NMR (100 MHz, DMSO-d_6, δ, ppm): δ 109.3, 117.93, 119.56, 120.83, 123.32, 123.90, 125.85, 126.64, 127.99, 128.20, 129.36, 132.12, 132.43, 134.84, 145.61, 148.18, 148.66, 157.95, 161.7. Anal. calcd. for $C_{19}H_{13}N_3O_2S$: C, 65.69; H, 3.77; N, 12.10. Found: C, 65.39; H, 3.67; N, 11.98%.

3-((Pyridin-2-ylmethylene)amino)-2-thioxo-2, 3-dihydro quinazolin-4(1H)-one (**PMAMQ**): Color: Light brown solid. Yield: 80%. M.p.: 130-132 °C. FT-IR (KBr, ν, cm^{-1}): 3447 (NH), 1685 (C=O), 1584 (C=N). ^{1}H NMR (400 MHz, DMSO-d_6, δ, ppm): 7.21-7.26 (m, 2H, Ar-H), 7.31-7.32 (m, 2H, Ar-H), 7.40-7.42 (d, 2H, Ar-H), 7.52-7.54 (m, 1H, Ar-H), 7.94 (d, 1H, Ar-H), 8.72 (s, 1H, N=CH), 11.3 (s, 1H, NH). ^{13}C NMR (100 MHz, DMSO-d_6, δ, ppm):118.2, 123.4, 124.4, 125.8, 126.5, 134.6, 137.0, 137.1, 148.6 134.7, 149.0, 149.7, 152.2, 154.1, 161.6. Anal. calcd. for $C_{14}H_{10}N_4OS$: C, 59.56; H, 3.57; N, 19.85. Found: C, 59.37; H, 3.53; N, 19.69%.

3-((Thiophen-2-ylmethylene)amino)-2-thioxo-2, 3-dihydro quinazolin-4(1H)-one (**TMAMQ**): Color: White solid. Yield: 81%. M.p.: 140-142 °C. FT-IR (KBr, ν, cm^{-1}): 3447 (NH), 1685 (C=O), 1585 (C=N). ^{1}H NMR (400 MHz, DMSO-d_6, δ, ppm): 7.02-7.10 (m, 2H, Ar-H), 7.12-7.14 (m, 2H, Ar-H), 7.24-7.36 (d, 1H, Ar-H), 7.54-7.60 (m, 1H, Ar-H), 7.72 (d, 1H, Ar-H), 8.15 (s, 1H, N=CH), 11.4 (s, 1H, NH). ^{13}C NMR (100 MHz, DMSO-d_6, δ, ppm): 113.7, 116.3, 122.7, 126.7, 128.2, 132.5, 133.90, 134.6, 134.7, 138.8, 143.8, 148.7, 157.2. Anal. calcd. for $C_{13}H_9N_3OS_2$: C, 54.34; H, 3.16; N, 14.62. Found: C, 53.96; H, 3.03; N, 14.52%.

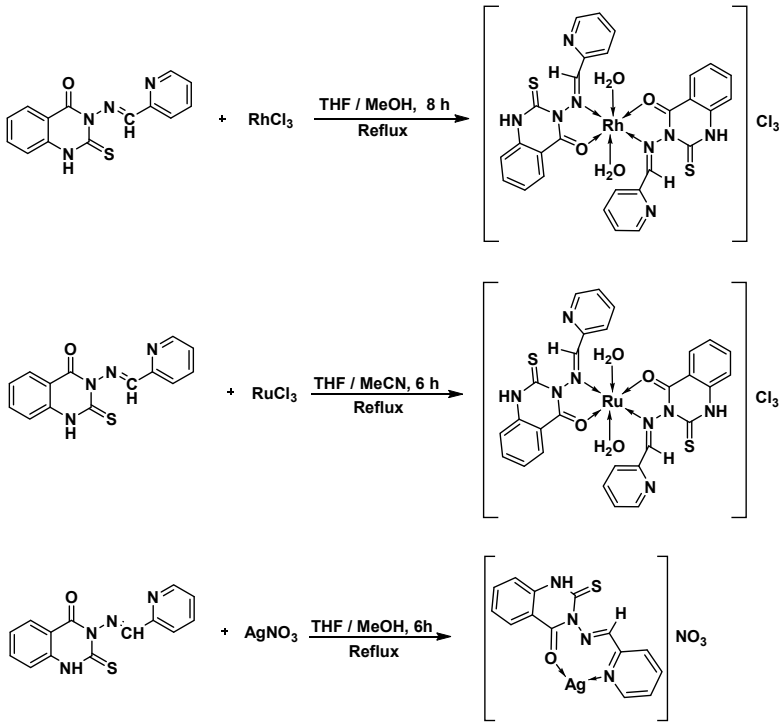
2.3. Synthesis of metal complexes

Rh(III), Ru(III) and Ag(I) complexes were prepared by taking $RhCl_3$, $RuCl_3$ and $AgNO_3$ as their respective salts. In the preparation of all the metal complexes, the metal and the ligand were combined in 1:1 or 1:2 mole ratio (the metal being in slight excess of what the ratio is required) using required quantities of THF, DMSO, hot methanol and/or ethanol for the ligands and metal salts so as to affect their solubility. The contents were refluxed on a water bath for about 8-12 h by maintaining the pH of the solution 8.2-9.5. The solid that separated was filtered, washed with water, hot methanol, ether and vacuum dried over $CaCl_2$.

The reaction of optically active chiral Schiff base ligands that contains potential donor sites *viz*, azomethine nitrogen, phenolic oxygen and carbonyl oxygen with different metal salts like $RhCl_3$, $RuCl_3$ and $AgNO_3$ yielded their respective complexes (Scheme 2 and 3).

2.4. Assay of antibacterial activity

In vitro antibacterial activity of the ligands HBAMQ, HNAMQ, PMAMQ, and TMAMQ, and their Rh(III), Ru(III) and Ag(I) complexes were assayed with two concentrations (600 and 900 µg/mL) against six representative Gram-positive bacteria (*Bacillus subtilis*, *Bacillus megaterium*, *Bacillus pumilus*, *Staphylococcus aureus*, *Enterobacter aerogenes* and *Streptococcus pyogenes*) and four representative Gram-negative bacteria (*Escherichia coli, Klebsiella pneumoniae, Proteus vulgaris, Enterococcus faecalis*) using broth dilution method recommended by National Committee for clinical laboratory standards [29]. Bacteria were grown overnight in Luria-Bertani (LB) broth at 37 °C harvested by centrifugation and then washed twice with sterile distilled water. Stock solutions of the total compounds were dissolved in DMSO solvent. Each stock solution was diluted with standard broth method. The inhibition of microbial growth under standardized conditions was utilized to demonstrate antibacterial action of compound. Streptomycin was used as a standard drug for comparison.



Scheme 3

2.5. Assay of antifungal activity

In vitro antifungal activity of the Schiff base ligands and their complexes were assayed against fungal organisms viz, *Candida albicans*, *Fusarium oxysporum*, *Drechslera* and *Colletotrichum falcatum.* The test organisms were grown for 48 h at 25 °C. Yeast Extract-Peptone-Dextrose (YPD) broth (1 % yeast extract, 2 % peptone and 2 % dextrose) harvested by centrifugation and then washed with sterile distilled water. All the newly synthesized compounds were tested in four concentrations, i.e., 300, 600, 900, and 1200 µg/mL. Itrazole was used as a standard drug for comparison.

3. Results and discussion

3.1. Chemistry

The newly synthesized complexes were characterized and supported by elemental analysis, magnetic, IR, ^{1}H NMR, ^{13}C NMR and electronic spectral data. The obtained Schiff base ligands are stable at room temperature, non-hygroscopic, insoluble in water and slightly soluble in methanol and acetone and fairly soluble in DMF. The novel complexes are powdered like, para, diamagnetic, colored and stable in the solid state under normal laboratory conditions. They are soluble in polar solvents such as DMF or DMSO.

3.2. Elemental and analytical data

The analytical data presented in Table 1, confirms the assigned composition of the ligand and the complex. It may be seen from the table that the experimental values are in fair agreement with the calculated ones.

3.3. Magnetic moment

The room temperature magnetic moment data obtained for the present complexes reveals that, the present Rh(III) complexes are found diamagnetic suggesting their low spin nature. The magnetic moment values for the Ru(III) complexes reveals that these are low spin in nature. The low spin complexes with t_{2g}^5 configuration are expected to have orbital contribution to magnetic moment and show a value around 2.0 B.M. The present Ru(III) complexes are found to have values in the range of 1.79-1.80 by indicating them to be of low spin octahedral complex [30]. The magnetic moment values observed for Ag(I) complexes were found with no magnetic moment and hence they are diamagnetic in nature.

3.4. FT-IR spectral data

The ligands HBAMQ, HNAMQ reveals a sharp band around 1718 cm^{-1} and the ligands PMAMQ, TMAMQ around 1680 cm^{-1} due to νC=O of quinazoline ring (Table 2). This band appears unshifted in the metal complexes of HBAMQ and HNAMQ but it is lower shifted in the metal complexes of PMAMQ and TMAMQ, suggesting non-involvement of the group in coordination with respect to HBAMQ and HNAMQ and involvement of the same in coordination with respect to PMAMQ and TMAMQ [31]. It is observed that all these ligands do not reveal a band in the range 2600-2550 cm^{-1} due to νS-H indicating that this group has undergone tautomerism into thione form. Further, these ligands reveal bands corresponding to the thioamide (H-N-C=S) group. These bands remain unshifted in their complexes indicating non-involvement of 'S' in co-ordination.

Further, to report that the HBAMQ and HNAMQ record small intensity bands in the region 3455-3200 cm^{-1}, the one at higher frequency due νO-H and the other at lower frequency due to νN-H. The higher frequency band corresponding νO-H disappears in their metal complexes indicating the involvement of O-hydroxy group in complexation through deprotonation, where as the νN-H band persists at the same frequency in their complexes.

Table 1. Elemental analysis of the synthesized complexes.

Complex	Molecular formula	Found (Calcd.) %			
		M	C	N	S
$Rh(HBAMQ\text{-}H)_2(H_2O)_2Cl$	$C_{30}H_{24}ClN_6O_6RhS_2$	13.23 (13.42)	46.75 (46.98)	10.75 (10.96)	8.21 (8.36)
$Rh(PMAMQ)_2(H_2O)_2Cl_3$	$C_{28}H_{24}Cl_3N_8O_4RhS_2$	12.35 (12.71)	41.75 (41.52)	13.52 (13.84)	7.40 (7.92)
$Rh(TMAMQ)_2(H_2O)_2Cl_3$	$C_{26}H_{22}Cl_3N_6O_4RhS_4$	12.28 (12.55)	37.86 (38.08)	10.01 (10.25)	15.40 (15.64)
$Rh(HNAMQ\text{-}H)_2(H_2O)_2Cl$	$C_{38}H_{28}ClN_6O_6RhS_2$	11.97 (11.87)	54.24 (52.63)	9.52 (9.69)	6.64 (7.39)
$Ru(HBAMQ\text{-}H)_2(H_2O)_2Cl$	$C_{30}H_{24}ClN_6O_6RuS_2$	13.13 (13.21)	46.87 (47.09)	10.61 (10.98)	8.12 (8.38)
$Ru(HNAMQ\text{-}H)_2(H_2O)_2Cl$	$C_{38}H_{28}ClN_6O_6RuS_2$	11.47 (11.68)	52.45 (52.75)	9.65 (9.71)	7.34 (7.41)
$Ru(PMAMQ)_2(H_2O)_2Cl_3$	$C_{28}H_{24}Cl_3N_8O_4RuS_2$	12.43 (12.51)	41.02 (41.62)	14.01 (13.87)	8.10 (7.93)
$Ru(TMAMQ)_2(H_2O)_2Cl_3$	$C_{26}H_{22}Cl_3N_6O_4RuS_4$	12.24 (12.35)	37.45 (38.17)	. 10.12 (10.27)	15.02 (15.67)
Ag(HBAMQ-H)	$C_{15}H_{10}AgN_3O_2S$	26.23 (26.69)	44.23 (44.57)	10.31 (10.40)	7.58 (7.93)
Ag(HNAMQ-H)	$C_{19}H_{12}AgN_3O_2S$	23.38 (23.75)	49.78 (50.24)	8.89 (9.25)	6.93 (7.06)
$Ag(PMAMQ)(NO_3)$	$C_{14}H_{10}AgN_5O_4S$	23.45 (23.85)	37.02 (37.19)	15.25 (15.49)	7.02 (7.09)
$Ag(TMAMQ)(NO_3)$	$C_{13}H_9AgN_4O_4S_2$	23.21 (23.59)	34.17 (34.15)	12.03 (12.25)	14.98 (14.00)

Table 2. FT-IR spectral data of the synthesized ligands and Rh(III), Ru(III) and Ag(I) complexes.

Compound	νN-H	νO-H	νC=O	νC=N
HBAMQ	3200	3455	1718	1583
Rh-HBAMQ	3206	-	1729	1543
Ru-HBAMQ	3215	-	1724	1550
Ag-HBAMQ	3246	-	1720	1517
HNAMQ	3242	3450	1723	1586
Rh-HNAMQ	3228	-	1724	1569
Ru-HNAMQ	3219	-	1726	1564
Ag-HNAMQ	3216	-	1687	1550
PMAMQ	3447	-	1685	1584
Rh-PMAMQ	3429	-	1662	1572
Ru-PMAMQ	3456	-	1660	1580
Ag-PMAMQ	3469	-	1655	1565
TMAMQ	3447	-	1685	1585
Rh-TMAMQ	3422	-	1666	1565
Ru-TMAMQ	3422	-	1648	1569
Ag-TMAMQ	3448	-	1660	1574

A medium intensity band seems to make its presence in all ligands around ~1586 cm^{-1} due to νC=N has been found lower shifted by about 30 cm^{-1} in all the complexes pointing out that the nitrogen of this group is involved in coordination. In the ligands HBAMQ and HNAMQ, the coordination through oxygen of phenolic group and nitrogen of azomethine group of the ligands in all the complexes is substantiated by the appearance of non-ligand bands in the far infrared region around 500 and 400 cm^{-1} assignable, respectively, to νM-O and νM-N vibrations.

In the ligands PMAMQ and TMAMQ small intensity bands appear at 1380 cm^{-1} due to νC-N (pyridine cyclic) at 780 cm^{-1} due to νC-S (Thiophene cyclic) remain unshifted in their complexes suggesting non-involvement of N and S atom present in the ligands PMAMQ and TMAMQ in coordination.

Based on all these observations, it may be concluded that HBAMQ and HNAMQ ligands behave towards the metal ions as mononegative bidentate ligands coordinating through phenolic oxygen and azomethine nitrogen where as PMAMQ and TMAMQ behave towards the metal ions as neutral bidentate ligands coordinating through quinazoline carbonyl group and azomethine nitrogen.

3.5. UV-Visible spectral data

The UV-Visible spectra of all the complexes were obtained in methanolic solution. The Rh(III) complexes of all the ligands each show three peaks in their electronic spectra around 24,890 and 33,333 cm^{-1} which may be assigned respectively to the transitions $^1A_{1g} \rightarrow {}^1T_{1g}$ and $^1A_{1g} \rightarrow {}^1T_{2g}$ and the other band appearing at 39,215 cm^{-1} is due to charge transfer transitions of octahedral geometry The present Ru(III) complexes of all the ligands reveal three peaks in the region 11,490-25,000 cm^{-1} which may be assigned in the increasing order of frequency to the transitions $^2T_{2g} \rightarrow {}^4T_{1g}$, $^2T_{2g} \rightarrow {}^4T_{2g}$, $^2T_{2g} \rightarrow {}^2A_{2g}$, $^2T_{1g}$ of octahedral geometry. These observations coupled with the other data, which suggest an octahedral geometry for Rh(III), Ru(III) complexes. On the basis of analytical, magnetic, IR, ^1H NMR and ^{13}C NMR data the Ag(I) complexes have been assigned linear geometry.

3.6. Antibacterial activity

The results of the antibacterial screening of the ligands and their metal complexes are incorporated in Table 3. Based on the observations, it was revealed that the activity profiles of the ligands and their metal complexes screened against the microorganisms are varying as some of the compounds are active either significantly or marginally while others are not. The results indicate that most of the compounds are ineffective in inhibiting the growth of Gram +ve and Gram -ve bacteria. Where the compounds are active, they exert relatively more activity on some species of Gram +ve and on some species of Gram -ve bacteria. All the ligands exert significant activity against the microorganisms though in different level. The compounds Rh-PMAMQ, Ru-HMAMQ and Ag-TMAMQ exert relatively good activity.

Table 3. *In vitro* antibacterial activity of the synthesizd ligands *.

Microorganism	Conc. (µg/mL)	Compound and zone of inhibition in mm												
		Rh(III) complex				Ru(III) complex				Ag(I) complex				Streptomycin
		L1	L2	L3	L4	L1	L2	L3	L4	L1	L2	L3	L4	
Escherichia	600	2.8	1.5	2.5	1.8	2.8	2.8	2.1	2.3	NA	1.8	1.2	NA	3.0
coli	900	5.6	3.0	4.9	3.6	4.9	4.8	4.2	4.6	NA	3.6	2.4	NA	6.1
Proteus	600	2.1	3.0	4.1	1.9	2.4	4.2	2.9	2.1	1.8	1.5	1.6	1.2	8.9
vulgaris	900	4.2	6.2	8.2	3.8	4.8	8.4	6.0	4.2	3.6	3.0	3.2	2.4	16.0
Enterococcus	600	1.9	3.1	2.2	2.0	2.0	3.0	3.1	1.8	3.7	1.2	3.0	4.8	12.8
faecalis	900	4.0	6.2	4.1	4.2	4.0	6.0	6.2	3.6	7.2	2.4	6.0	9.2	20.3
Klebsiella	600	2.0	3.1	2.1	1.2	3.1	1.8	2.0	NA	1.7	1.8	1.2	1.2	3.2
pneumoniae	900	4.0	6.2	4.2	2.4	6.2	3.6	4.2	NA	3.4	3.6	2.4	3.0	6.5
Enterobacter	600	NA	2.0	3.0	1.5	2.1	1.9	1.5	1.2	3.0	3.5	1.2	3.8	4.4
aerogenes	900	NA	4.2	6.0	3.0	4.2	3.8	3.0	2.4	6.0	7.0	2.4	7.6	8.7
Bacillus	600	1.2	2.1	3.7	1.8	6.1	4	6.5	2.0	2.1	NA	1.8	1.5	8.4
subtilis	900	4.2	4.4	7.2	3.6	12.0	8.0	12.9	4.0	4.2	NA	3.6	3.0	16.2
Bacillus	600	NA	1.8	3.0	NA	5.8	5.2	3.5	1.5	2.8	1.2	3.0	2.0	6.2
megaterium	900	NA	3.6	6.0	NA	10.6	10.4	7.0	3.0	5.6	2.5	6.0	4.0	12.8
Bacillus	600	1.5	2.0	1.5	2.8	6.0	4.9	2.8	3.0	3.1	3.0	1.5	4.1	7.2
pumilus	900	3.0	4.1	3.0	5.2	12.0	10.0	5.0	6.1	6.2	6.0	3.0	8.2	14.5
Staphylococcus	600	3.0	4.8	3.0	1.8	2.4	1.8	1.5	1.8	3.0	1.5	4.8	5.2	10.3
aureus	900	6.1	9.2	6.0	3.6	4.8	3.6	3.0	3.7	6.0	3.0	9.6	10.1	20.0
Streptococcus	600	1.5	NA	2.2	2.8	1.8	NA	2.5	6.0	NA	3.0	2.2	NA	8.1
pyogenes	900	3.1	NA	4.4	5.6	3.6	NA	3.0	12.1	NA	6.0	4.4	NA	16.4

* NA: Not applicable.

Table 4. *In vitro* antifungal activity of the synthesized ligands.

Microorganism	Conc. (µg/mL)	Compound and zone of inhibition												Itrazole
		Rh(III) complex				Ru(III) complex				Ag(I) complex				
		L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4	L_1	L_2	L_3	L_4	
Candida	300	3.9	3.4	2.7	3.2	3.2	3.8	3.0	3.4	3.2	3.0	NA	3.1	2.6
albicans	600	3.0	4.3	4.6	5.0	5.5	4.8	4.1	4.9	4.8	4.6	NA	5.3	5.3
	900	12.0	11.2	11.0	11.5	11.6	12.0	11.3	11.0	12.0	11.3	NA	12.5	12.0
	1200	22.8	23.0	23.0	22.6	21.2	21.6	22.8	21.8	21.6	23.0	NA	22.8	23.0
Fusarium	300	3.9	4.5	4.4	4.0	4.6	5.4	4.4	NA	4.0	NA	4.4	4.9	5.4
oxysporum	600	8.3	8.2	7.6	8.6	9.5	9.7	7.5	NA	6.9	NA	7.9	8.1	10.8
	900	15.8	15.8	16.8	17.0	17.9	19.4	13.3	NA	14.2	NA	15.0	16.8	20.0
	1200	32.0	29.7	32.5	31.8	32.0	33.8	27.8	NA	F.4	NA	30.8	31.3	34.3
Drechslera	300	3.5	NA	3.5	3.5	3.0	3.0	3.9	3.4	2.5	3.6	3.4	3.4	3.5
halodes	600	6.1	NA	7.0	7.1	7.5	6.1	6.2	6.0	5.1	7.0	7.0	6.7	7.5
	900	14.2	NA	14.0	14.6	14.2	13.6	12.3	13.5	12.6	14.0	13.7	12.5	14.7
	1200	26.4	NA	26.7	26.2	21.5	26.2	25.9	21.3	23.2	21.2	21.1	21.2	27.3
Colletotrichum	300	4.4	3.6	2.4	NA	4.2	3.8	3.9	4.3	4.3	5.0	4.1	3.0	4.4
falcatum	600	9.2	9.3	4.9	NA	7.5	7.1	8.2	7.9	8.7	9.3	7.3	6.1	9.3
	900	17.8	18.2	12.0	NA	13.5	15.1	15.3	17.0	17.4	17.0	15.7	12.7	18.2
	1200	23.7	23.5	19.8	NA	27.9	21.4	19.3	23.5	22.9	23.5	23.2	25.4	33.7

* NA: Not applicable.

3.7. Antifungal activity

All the prepared complexes showed good to moderate activity in which Rh-HNAMQ and Ru-HBAMQ showed better activity against maximum strains (Table 4). Due to their polar nature and heterocyclic ring system these compounds exert good activity against certain species of fungi.

4. Conclusions

In conclusion, we have synthesized mercapto quinazoline compounds as ligands and their Rh(III), Ru(III), Ag(I) metal complexes, characterized them, and investigated their antimicrobial activity against different species of microorganisms. The results indicate that the majority of the compounds found to possess interesting antibacterial activities against tested bacterial strains when compared to standard drug streptomycin. Certain of the synthesized compounds found to possess moderate to good antifungal activity when compared to standard drug itrazole.

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