GIAP Journals

Green Chemistry & Technology Letters
Vol 1, No 1, November 2015, pg 77-81
DoI: 10.18510/gctl.2015.1112

BINDING OF RUTHENIUM(II)POLYPYRIDYL COMPLEXES WITH POLYPHENOLS IN AQUEOUS MEDIUM

Sheeba Daniela and G. Allen Gnana Rajb*
a. Department of Chemistry, Holy Cross College (Autonomous), Nagercoil-629 004, Tamil Nadu.
b. Department of Chemistry and Research Centre, Scott Christian College (Autonomous), Nagercoil-629 003, Tamil Nadu.
E-mail:gallengraj@gmail.com

Article History: 22nd July, Revised on 25th November, Published on 05th January 2016

Abstract

The binding of three Ru(II)-polypyridyl complexes with polyphenols (gallic acid and quercetin) have been studied in aqueous medium at pH 11 by means of absorption spectral technique. The absorption and emission maximum of this complexes are in the range of 451-457 nm and 612-626 nm respectively. The binding constant (Kb) for these reactions are determined from the Benesi-Hildebrand equation using absorption intensity data. The observed binding constant values are sensitive to the nature of the ligand and the structure of the gallic acid and quercetin. Quercetin binds strongly with Ru(II) complexes than gallic acid owing to the presence of more phenolic –OH groups. Structural effect seems to play a vital role on the binding of the antioxidants with these complexes.

Keywords: Benesi-Hildebrand equation; binding constant; polyphenols; ruthenium (II)-polypyridyl complexes; structural effect

INTRODUCTION

Phenolic acids and flavonoids constitute one of the most common and widespread groups of substances in flowering plants, occurring in all vegetative organs and fruits. Polyphenols have considerable interest in the field of food chemistry, pharmacy and medicine due to a wide range of favourable biological effects including antioxidant properties. The antioxidant property of polyphenols is mainly due to their redox properties. They act as reducing agents (free radical terminators), hydrogen donors, singlet oxygen quenchers and metal chelators [1]. The antioxidant activity of polyphenols depends on the number of hydroxyl groups that are strengthened by steric hindrance [2]. In addition to antioxidant and free-radical scavenger properties, polyphenols have numerous other biological activities, such as antihistamine activity, as well as anti-inflammatory, protecting against cardiovascular diseases and anticancer activity [3].

The development of transition metal complexes that target and interact non-covalently with proteins and antioxidants is an emerging field that links inorganic chemistry with chemical and synthetic biology [4,5]. Metal complexes play an essential role in agriculture, pharmaceutical and industrial chemistry. The used metal complexes as therapeutic agents for treatment of different diseases have been extensively studied [6,7]. As they generally have different mechanism of activity from the organic compounds, the development of metal complexes provides an alternative route of novel drug [8]. Many researchers have proved that binding of a drug to metalloelement enhances its activity and in many cases the complex possesses even more significant activity than the parent compound [9]. Among the transition metal complexes ruthenium(II)-polypyridyl complexes ([Ru(NN)3]2+) have particularly drawn significant interest for developing new diagnostic and therapeutic agents that can recognize and cleave DNA. Ru(II)-ploypyridyl complexes undergo binding with DNA, RNA and proteins and act as therapeutic agents [10,11]. Polyphenols with gallol or catechol groups are generally the most potent antioxidants, primarily because of the large iron-binding stability constants for these groups. Polyphenols containing catechol (quercetin) and gallol (gallic acid) groups have very different activities, depending on the metal ion [12,13]. Based on the literature survey, the present study concentrates on the binding studies of gallic acid and quercetin on tris(4,4′-dialkyl-2,2′-bipyridine)ruthenium(II) complexes in aqueous medium at pH 11.

EXPERIMENTAL SECTION

$RuCl_3.3H_2O$, ligands (2,2′-bipyridine (bpy), 4,4′-dimethyl-2,2′-bipyridine (dmbpy), 4,4′-di-tert-butyl-2,2′-bipyridine (dtbpy)) and the polyphenols (gallic acid, quercetin) were procured from Sigma–Aldrich. HPLC grade solvents were used throughout the study for the synthesis of complex as well as for binding studies. The double-distilled deionized water was used for the binding studies. The three $[Ru(NN)_3]^{2+}$ complexes {where NN = 2,2′-bipyridine (bpy), 4,4′-dimethyl-2,2′-bipyridine (dmbpy), 4,4′-di-t-butyl-2,2′-bipyridine (dtbpy)} were synthesized by reacting $RuCl_3.3H_2O$ with the corresponding ligands according to the procedure previously described [14,15].

The absorption spectral measurements were carried out using SYSTRONICS 2203 double beam spectrophotometer. Emission intensity measurements were carried out and the emission spectra were recorded using ELICO SL 174 spectrofluorometer. Excited state lifetime of the complex was made with laser flash photolysis technique using an Applied Photophysics SP-Quanta Ray GCR-

GIAP Journals
Green Chemistry & Technology Letters
Vol 1, No 1, November 2015, pg 77-81
DoI: 10.18510/gctl.2015.1112

2(10) Nd:YAG laser as the excitation source. The structure of the polyphenols used in the present study was shown in **Fig. 1**. The binding of $[Ru(NN)_3]^{2+}$ complexes with various concentrations (2 x 10^{-5} - 1.4 x 10^{-4} M) of gallic acid and quercetin in aqueous medium at pH 11 has been studied by absorption spectral technique. Phenolate ions of the gallic acid and quercetin for the binding studies were prepared by mixing the corresponding polyphenols with NaOH and the pH of the solution was maintained at 11 to confirm that the quencher was present as phenolate ions. The binding constant (K_b) of the $[Ru(NN)_3]^{2+}$ complex with gallic acid and quercetin were determined from the Benesi-Hildebrand equation using absorption intensity data [16].

$$1/\Delta A = I/K_b \, \Delta\varepsilon \, [H] + 1/\Delta\varepsilon \, [G]$$

where ΔA is the change in absorption of the complex with different concentrations ([G]) of polyphenols. The plots of 1/ΔA versus 1/[G] give a straight line, K_b can be obtained from the ratio of Y-intercept to the slope of the straight line.

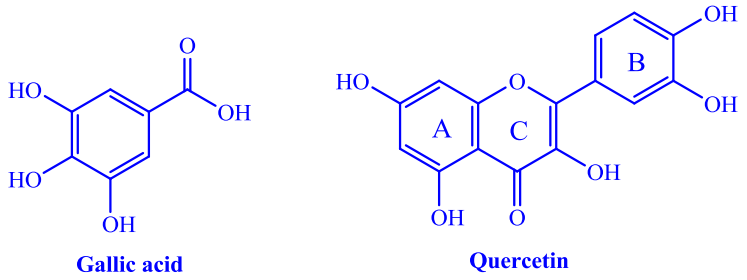

Figure 1: Structure of polyphenols

RESULT AND DISCUSSION

The absorption maximum, emission maximum and excited state lifetime of $[Ru(NN)_3]^{2+}$ complexes in aqueous medium at pH 11 are shown in **Table 1**. The absorption spectral studies of $[Ru(NN)_3]^{2+}$ complex with the incremental addition of gallic acid and quercetin shows a slight increase in the MLCT absorption maximum, indicates the formation of ground state complex (**Fig. 2**). Gallic acid and quercetin have weak absorption at 454 and 426 nm [17]. Gallic acid and quercetin bind with the $[Ru(NN)_3]^{2+}$ complexes in aqueous medium, since gallic acid and quercetin have weak absorption close to the region where Ru(II) complex have strong MLCT absorption. The absorption spectra of $[Ru(NN)_3]^{2+}$ complexes with the antioxidants, gallic acid and quercetin shows a hypsochromic shift of 2 to 3 nm, which may be due to the formation of ground state complex. The K_b of $[Ru(NN)_3]^{2+}$ complexes with gallic acid and quercetin in aqueous medium calculated from Benesi-Hildebrand plot (**Fig. 3**) at pH 11 is shown in **Table 2**. The K_b obtained for gallic acid and quercetin with $Ru(NN)_3]^{2+}$ complexes are in the order of 10^3 - 10^4 M^{-1}.

Table 1: Absorption maximum, emission maximum and excited state lifetime of [Ru(NN)3]2+ complexes in aqueous medium at pH 11

Complex	Absorption maximum (nm)	Emission maximum (nm)	Excited state lifetime (ns)
$[Ru(bpy)_3]^{2+}$	451	612	614
$[Ru(dmbpy)_3]^{2+}$	457	625	380
$[Ru(dtbpy)_3]^{2+}$	457	626	510

Table 2: Binding constant, K_b (M^{-1}) for gallic acid and quercetin with $Ru(NN)_3]^{2+}$ complexes in aqueous medium at pH 11

Complex	Binding constant, K_b (M^{-1})	
	Gallic acid	Quercetin
$[Ru(bpy)_3]^{2+}$	2.9 x 10^3	4.0 x 10^4
$[Ru(dmbpy)_3]^{2+}$	8.2 x 10^3	5.7 x 10^4
$[Ru(dtbpy)_3]^{2+}$	8.9 x 10^3	9.0 x 10^4

GIAP Journals

Green Chemistry & Technology Letters
Vol 1, No 1, November 2015, pg 77-81
DoI: 10.18510/gctl.2015.1112

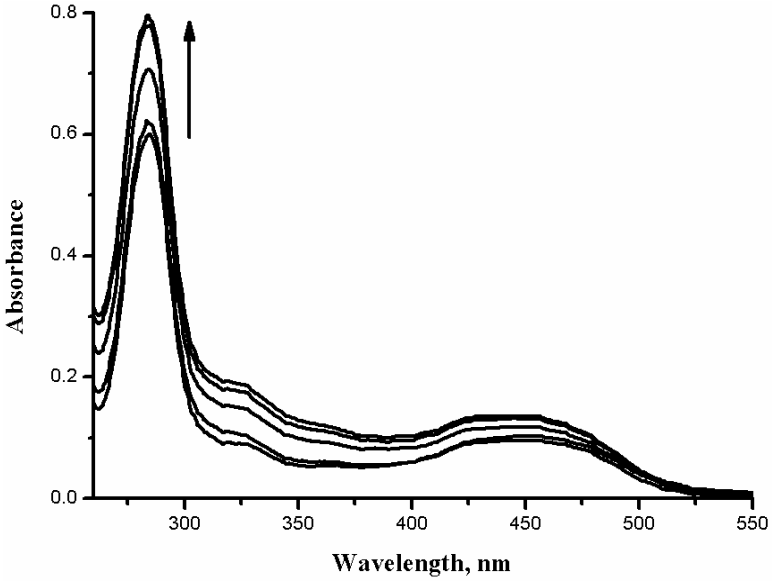

Figure 2: Absorption spectrum of [Ru(bpy)3]2+ with incremental addition of quercetin in aqueous medium at pH 11

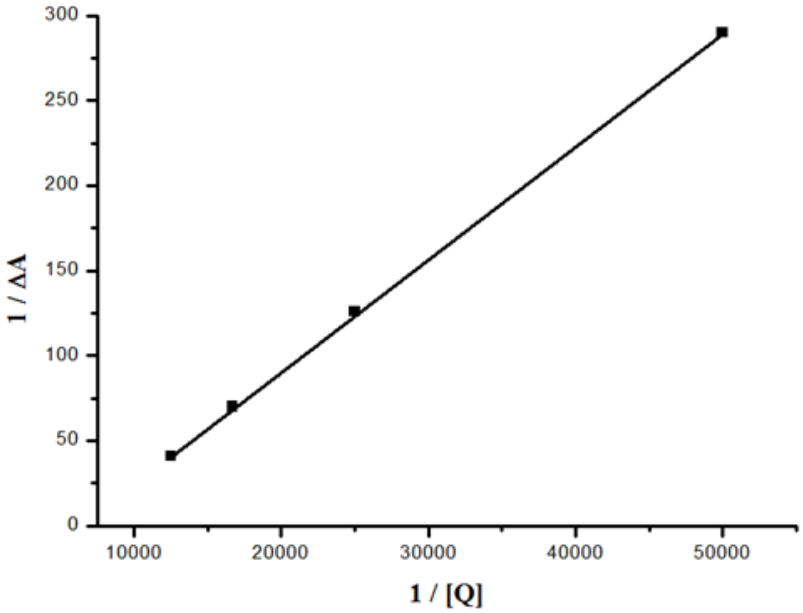

Figure 3: Benesi-Hildebrand plot of [Ru(dmbpy)3]2+ with incremental addition of gallic acid in aqueous medium at pH 11

The ground-state interactions between polyphenols and the bipyridyl rings of $[Ru(NN)_3]^{2+}$ complexes are hydrophobic or π-stacking in nature [18]. To the extent that π - π stacking interactions exist between the ligands of Ru(II)- complexes and the polyphenols, the binding becomes stronger. The hydrophobic nature of Ru(II)-polypyridyl complexes increases from $[Ru(bpy)_3]^{2+}$ to $[Ru(dtbpy)_3]^{2+}$ complexes due to the presence of bulky alkyl substituted ligands. As the hydrophobic nature of the ligands increases K_b also increases. Hence the binding constant values of $[Ru(NN)_3]^{2+}$ complexes with gallic acid and quercetin increase from $[Ru(bpy)_3]^{2+}$ to $[Ru(dtbpy)_3]^{2+}$ complexes. This results show that K_b is sensitive to the hydrophobic nature of the ligands.

The K_b calculated for gallic acid and quercetin from the absorption spectral data shows that quercetin undergoes strong binding with the $[Ru(NN)_3]^{2+}$ complexes than that of gallic acid. Gallic acid consist of three phenolic–OH groups, in alkaline medium especially above pH 9 the three phenolic–OH groups get ionized. The pK_a values for the three phenolic–OH groups of gallic acid are 8.7, 11.4 and > 13. Quercetin has two different pharmacophores, the catechol group in ring B and the three hydroxyl groups in rings A and C, the pK_a values of quercetin are 5.87 and 8.48. The binding process is highly sensitive to the pH of the medium. The K_b value is largely pH dependent at pH > pK_a whereas the K_b value is little sensitive to the change of pH of the medium at pH < pK_a.

Green Chemistry & Technology Letters
Vol 1, No 1, November 2015, pg 77-81
DoI: 10.18510/gctl.2015.1112

Gallic acid consist of 3 phenolic–OH groups and at pH 11 almost all the phenolic–OH are converted into phenolate ions whereas quercetin consist of 4 phenolic–OH groups. The binding constant depends on the number of phenolic–OH groups. As the number of phenolic –OH groups increases the binding constant also increases. Hence quercetin shows a higher binding constant than gallic acid with $[Ru(NN)_3]^{2+}$ complexes. This indicates that the K_b is not only sensitive to the nature of the ligand but also to the structure of the polyphenols. Thus K_b depends on the substituent present in the ligands and the polyphenols.

CONCLUSION

The binding of gallic acid and quercetin with $[Ru(NN)_3]^{2+}$ complexes in aqueous medium at pH 11 has been studied by absorption spectral techniques. The binding constant of the $[Ru(NN)_3]^{2+}$ complexes with gallic acid and quercetin are determined from the Benesi-Hildebrand plot. The binding constant depends on the hydrophobic nature of the ligands and the number of phenolic–OH groups of the polyphenols. As the number of phenolic–OH groups increases the binding constant also increases. Quercetin shows higher binding constant than that of gallic acid due to the presence of more number of phenolic–OH groups. This study confirms the structural effects on the binding of biologically important phenolate ions with $[Ru(NN)_3]^{2+}$ complexes.

REFERENCES

1. Masoud, M.S., Hagagg, S.S., Ali, A.E., Nasr, N.M., Synthesis and spectroscopic characterization of gallic acid and some of its azo complexes, Journal of Molecular Structure, (1014), 2012, 17–25.
2. Janeiro, P., Novak, I., Seruga, M. Brett, A.M.O., Electroanalytical oxidation of p-coumaric acid, Anal. Lett., (40), 2007, 3309–3321.
3. Dolatabadi, J.E.N., Mokhtarzadeh, A., Ghareghoran, S.M., Dehghan, G., Synthesis, Characterization and Antioxidant Property of Quercetin-Tb(III) Complex, Advanced Pharmaceutical Bulletin, (4), (2), 2014, 101–104.
4. Lo, K.K.W., Louie, M.W., Zhang, K.Y., Design of luminescent iridium(III) and rhenium(I) polypyridine complexes as in vitro and in vivo ion, molecular and biological probes, Coord Chem Rev., (254) 2010, 2603–2622
5. Meggers, E., Targeting proteins with metal complexes, Chem Commun., 2009, 1001–1010
6. Sheikhshoaie, I., Badiei, A., Ghazizadeh, M., Synthesis and characterization of a new poly (amidoamine) dendrimer-like iron (iii) and molybdenum (VI) complexes, Der Chemica Sinica., (3), (1), 2012, 29 –37.
7. Sabastiyan, A., Suvaikin, M.Y., Synthesis, characterization and antimicrobial activity of 2-(dimethylaminomethyl)isoindoline-1,3-dione and its cobalt(II) and nickel(II) complexes, Advances in Applied Science Research, (3), (1), 2012, 45–50.
8. Kostova, I., Momekov, G., New zirconium (IV) complexes of coumarins with cytotoxic activity, Eur. J. Med. Chem., (41), (6), 2006, 717–726.
9. Rajeshirke, M., Shah, R., Yadav, P., Purohit, N.V., Synthesis and antioxidant activity of metal (II) complexes of isocoumarin derivatives, Der Pharmacia Sinica., (3), (2), 2012, 239–248.
10. Maksimoska, J., Feng, L., Harms, K., Yi, C., Kissil, J., Marmorstein, R., Meggers, E., Targeting Large Kinase Active Site with Rigid, Bulky Octahedral Ruthenium Complexes, J Am Chem Soc., (130), 2008, 15764–15765.
11. Babu. E., Mareeswaran, P.M.,, Singaravadivel, S., Bhuvaneswari, J., Rajagopal, S., A selective, long-lived deep-red emissive ruthenium(II) polypyridine complexes for the detection of BSA, Spectrochimica Acta A, (130), 2014, 553–560.
12. Perron, N.R., Brumaghim, J.L., A review of the antioxidant mechanisms of polyphenol compounds related to iron binding cell, Biochem Biophys., (53), 2009, 75–100.
13. Farhan, S.A., Study on the interaction of copper (II) complex of morin and its antimicrobial effect, Int. J. Chem. Sci., (11), (3), 2013, 1247–1255.
14. Thanasekaran, P., Rajendran, T., Rajagopal, S., Srinivasan, C., Ramaraj, R., Ramamurthy, P., Venkatachalapathy, B., Marcus inverted region in the photoinduced electron transfer reactions of ruthenium(II)-polypridyl complexes with phenolate ions, J. Phys. Chem. A, (101), 1997, 8195–8199.

Green Chemistry & Technology Letters
Vol 1, No 1, November 2015, pg 77-81
DoI: 10.18510/gctl.2015.1112

15. Saha, B., Stanbury, D.M., Thermal and photochemical reduction of aqueous chlorine by ruthenium(II) polypyridyl complexes, Inorg. Chem., (39), 2000, 1294–1300.

16. Connors, K.A., Binding Constants: The Measurement of Stability, John Wiley & Sons, Ltd, Chichester, U.K, 1987.

17. Ramešová, S., Sokolová, R., Degano, I., Bulíčková, J., Žabka, J., Gál, M., On the stability of the bioactive flavonoids quercetin and luteolin under oxygen-free conditions, Anal. Bioanal. Chem., (402), 2012, 975–982.

18. Li, C., Hoffman, M.Z., Oxidation of phenol by singlet oxygen photosensitized by the tris(2,2′ bipyridine)ruthenium(II) ion, J. Phys. Chem. A, (104), 2000, 5998–6002.