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Araştırma Makalesi / Research Article

Synthesis and Characterization of Metal-Saccharin Complexes Containing *N,N'*-Bis(2-hydroxyethyl)piperazine

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Abstract

New complexes containing Co(II), Ni(II), Cu(II), and Zn(II) ions with *N,N'*-bis(2-hydroxyethyl)piperazine (bheppz) and saccharinate (sac) ligands were synthesized. The characterization of the complexes with the proposed formula $[M_2(sac)_4(bheppz)(H_2O)_4]$ was performed using elemental analysis, magnetic susceptibility measurements, FT-IR spectroscopy, and thermal analysis methods. The FT-IR spectra displayed specific absorption bands corresponding to both the bheppz and saccharinate ligands. Thermal analysis indicated that the initial decomposition step involves the release of coordinated water molecules, followed by the breakdown of the bheppz ligand in subsequent stages. In the final stage, the decomposition of the saccharinate ligand leads to the formation of metal oxides.

Keywords: Thermal Analysis, *N,N'*-bis(2-hydroxyethyl)piperazine, Saccharin Complexes.

N,N'-Bis(2-hidroksietil)piperazin İçeren Metal-Sakarin Komplekslerinin Sentezi ve Karakterizasyonu

Öz

Co(II), Ni(II), Cu(II) ve Zn(II) iyonları ile *N,N'*-bis(2-hidroksietil)piperazin (bheppz) ve sakkarinat (sac) ligandlarını içeren yeni kompleksler sentezlenmiştir. $[M_2(sac)_4(bheppz)(H_2O)_4]$ formülüne sahip olduğu önerilen bu komplekslerin karakterizasyonu elementel analiz, manyetik duyarlılık ölçümleri, FT-IR spektroskopisi ve termal analiz yöntemleriyle yapılmıştır. FT-IR spektrumları, hem bheppz hem de sac ligandlarına özgü karakteristik absorpsiyon bantlarını göstermiştir. Termal analiz sonuçları, komplekslerin ilk bozunma evresinin koordine olan su moleküllerinin uzaklaşmasına karşılık geldiğini göstermektedir. Bunu takiben, bheppz ligandı ayrılmakta, son aşamada ise sac ligandının bozunmasıyla metal oksitler oluşmaktadır.

Anahtar Kelimeler: Termal Analiz, *N,N'*-bis(2-hidroksietil)piperazin, Sakkarin Kompleksleri.

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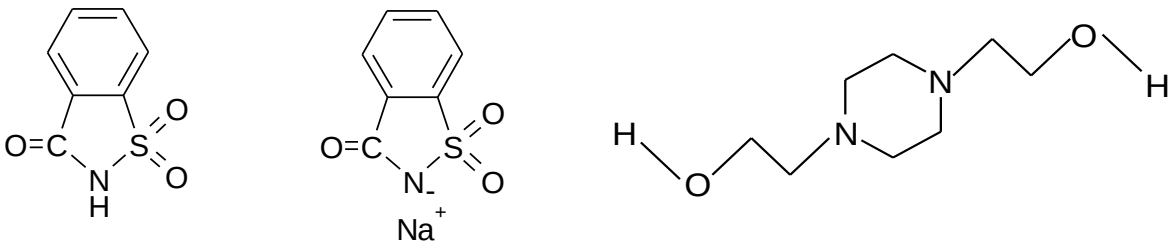
1. Introduction

Saccharin (Figure 1.a), first discovered accidentally in 1879 by Remson and Fahlberg at Johns Hopkins University, is an artificial sweetener known to be 500–700 times sweeter than sugar. It offers a cost-effective and heat-resistant alternative to sugar (Anderson and Deskins, 1995). Saccharin is not metabolized by the body, which makes it a suitable sweetener for diabetic individuals. Additionally, unlike sugar, it does not lead to weight gain, rendering it a favorable choice for those managing their weight (Anderson and Deskins, 1995).

Saccharin's role as an antidote for metal poisoning, combined with its wide range of uses in food products, beverages, toothpaste, mouthwash, dental fillings, cosmetics, and pharmaceuticals, has greatly increased interest in this compound. Saccharin has also gained attention as a versatile ligand in coordination chemistry due to its multifunctional binding properties.

Sodium saccharinate (Figure 1.b), the sodium salt of saccharin, is highly water-soluble (830 g/L at 20 °C) and functions as both a ligand and a sweetener. When acting as a ligand, the saccharinate anion coordinates to metal centers through its negatively charged nitrogen atom as well as its CO and SO_2 groups, utilizing these sites as electron donors (Baran and Yılmaz, 2006). Moreover, saccharinate complexes have garnered attention due to their potential anticancer properties, as demonstrated in various studies (Ulukaya et al., 2011; Ari et al., 2013; 2014; Al-Jibori et al., 2014).

The bheppz ligand (Figure 1.c) contains four donor atoms, allowing it to form coordination bonds with metal ions through these sites. In the polymeric $[Ag(\mu\text{-sac})(\mu\text{-bheppz})]_n$ complex, bheppz serves as a bidentate ligand, attaching through one nitrogen and one oxygen atom at each terminal, thereby forming five-membered chelate rings around Ag(I) (Yılmaz et al., 2008). In the $[Pd(bheppz)Cl_2]$ complex, the palladium centre has a typical square-planar geometry with a tetrahedral distortion, and the environment consists of two chlorides in the cis-positions and one ligand coordinated via piperazine nitrogen (Shehata et al, 2016). In the [Pd(bheppz)(CBDCA)] complex (CBDA = cyclobutanedicarboxylate), the bheppz ligand acts as a bidentate chelate, forming a five-membered metallocyclic ring with a distorted twist boat conformation (Shehata, 2019).



a **b** **c**

Figure 1. The molecular structures of Saccharin (a), Sodium saccharinate (b), *N*,*N'*-bis(2-hydroxyethyl)piperazine (c).

In the literature, there are many studies regarding the anticancer and antimicrobial properties of metal saccharinate complexes (İçsel et al, 2024). Piperazine derivatives have gained significant interest due to their biological properties, such as anti-inflammatory, antibacterial, anticancer, cardioprotective agents, antiviral, antituberculosis, antidiabetic, and antihistamine activities (Prasad et al, 2021). In this study, Co(II), Ni(II), Cu(II), and Zn(II) mixed-ligand complexes containing saccharinate and *N*,*N*′-bis(2-hydroxyethyl)piperazine were synthesized and their structures were elucidated using a range of analytical techniques. In the next phase, the anticancer and antimicrobial properties of the synthesized complexes are planned to be investigated.

2. Materials and Methods

2.1. Materials

All chemicals used in this research were obtained from commercial sources and employed without further purification. The precursor complexes $[M(sac)_2(H_2O)_4]\cdot 2H_2O$ were prepared according to methods described in the literature (Biedermann, Rossmann, & Schwarzhan, 1971; Kamenar & Jovanovski, 1982; Haider et al., 1985).

2.2. Physical Measurements

The infrared (IR) spectra were recorded on a Mattson 1000 FTIR spectrophotometer, with samples prepared as KBr pellets, covering a frequency range of 4000–400 cm^{-1}. UV-Vis electronic spectra were obtained in 10^{-3} M aqueous solutions using a Unicam UV2 spectrophotometer, spanning the wavelength range from 200 to 800 nm. Elemental analysis for carbon, hydrogen, and nitrogen was performed with a LECO CHNS 932 Elemental Analyzer. Magnetic susceptibility measurements at room temperature were made with a Sherwood Scientific MXI model Evans magnetic balance. Thermogravimetric (TGA) and differential thermal analysis (DTA) were carried out on a Rigaku TG8110 thermal analyzer under static air conditions, with sample sizes ranging from 5 to 10 mg.

2.3. Synthesis

A solution of bheppz ligand (0.348 g, 2.0 mmol) in 20 ml of methanol was slowly added dropwise to a methanolic solution (20 ml) of tetraaquabis(saccharinato)metal(II)dihydrate (1 mmol) while stirring continuously at room temperature. The mixture was stirred for 1 hour using a magnetic stirrer. After a few days, powdered complexes of Co(II), Ni(II), Cu(II), and Zn(II) were obtained.

3. Findings and Discussion

3.1. Elemental Analysis

The synthesized complexes were characterized by their color and elemental composition, with the results presented in Table 1. From the elemental analysis, the proposed molecular formula for the complexes is $[M_2(sac)_4(bheppz)(H_2O)_4]$, where M represents Co(II) (1), Ni(II) (2), Cu(II) (3), or Zn(II) (4). The experimental data closely match the theoretical values, confirming the validity of the proposed formula. Each complex contains two moles of sac, one mole of bheppz, and two moles of water ligands coordinated to the central metal ion. Thermal analysis confirmed the presence of water molecules, while the coordination modes of the ligands were deduced from IR spectroscopic data. The proposed geometrical structures of the complexes are shown in Figure 2, with all complexes synthesized in high yields.

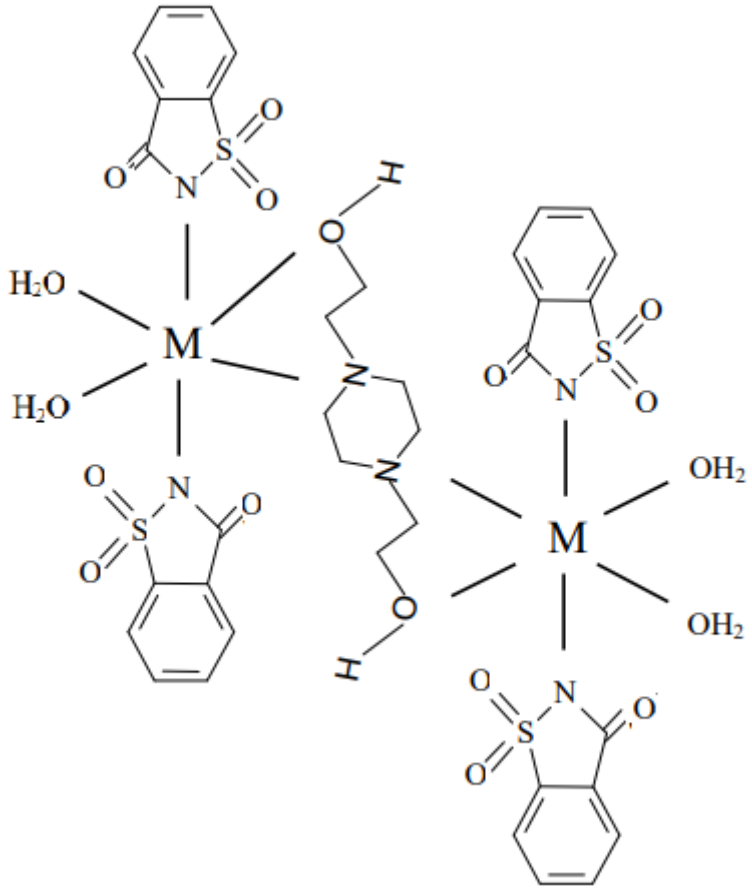


Figure 2. Suggested molecular arrangements for the synthesized compounds.

Table 1. Analytical data for the compounds

Compounds	Empirical Formula	Colour	*Anal. Found (calc.)(%)*		
			C	**H**	**N**
1	$C_{22}H_{30}N_4O_{10}S_2Co$	Red	41,42(41,71)	5,01(4,77)	8,73(8,84)
2	$C_{22}H_{30}N_4O_{10}S_2Ni$	Green	40,91(41,72)	4,60(4,77)	8,50(8,84)
3	$C_{22}H_{30}N_4O_{10}S_2Cu$	Green	40,23(41,40)	4,56(4,74)	8,11(8,78)
4	$C_{22}H_{30}N_4O_{10}S_2Zn$	White	40,40(41,29)	4,58(4,72)	8,31(8,75)

3.2. Spectral and Magnetic Properties

The IR spectra of the complexes are presented in Figure 3, and the observed significant vibration frequencies are given in Table 2. The O-H stretching bands were observed in a broad range from 3446 to 3286 cm^{-1}, indicating the coordination of water molecules. The N-H stretching bands of bheppz overlap with the O-H band. C-H stretching vibrations were observed in the 3039–2800 cm^{-1} range. A strong band corresponding to the C=O group of sac appeared between 1630 and 1668 cm^{-1}. Except for the Cu(II) complex, the C=O stretching vibration frequencies closely match those of the starting material $[M(sac)_2(H_2O)_4]\cdot 2H_2O$, suggesting N-coordination of sac in these complexes.

C=N stretching vibrations of the pyridine ring around 1600 cm^{-1} were indistinguishable due to overlapping with the C=O bands. Symmetric and asymmetric SO_2 vibrations were observed in the ranges 1257–1290 cm^{-1} and 1146–1153 cm^{-1}, respectively. CNS stretching vibrations appeared at 1330–1348 cm^{-1} (symmetric) and 947–970 cm^{-1} (asymmetric).

Table 2. Selected IR spectral data for the compounds

Compounds	ν(OH)	ν(CH)	ν(C=O)	$\nu_{asym}(SO_2)$	$\nu_{sym}(SO_2)$	ν_{sym}(CNS)	ν_{asym}(CNS)
1	3297b	2983w- 2800w	1631vs	1257vs	1146vs	1330vs	970vs
2	3286b	3040w- 2829w	1631vs	1261vs	1153vs	1348vs	957vs
3	3446b	2968s- 2852s	1668vs	1290vs	1151vs	1346vs	956vs
4	3375b	3039w- 2843w	1630vs	1273vs	1153vs	1346vs	947vs

b: broad, **vs**: very strong. **s**: strong, **w**: weak

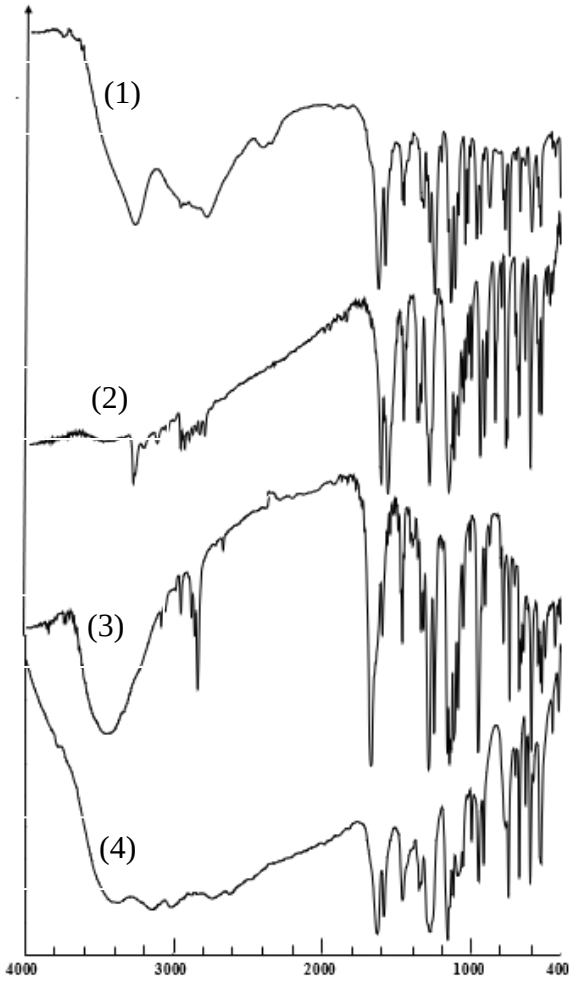


Figure 3. The FT-IR spectra of the compounds.

Table 3 summarizes the electronic spectra and magnetic moment measurements.

Table 3. Electronic spectra and magnetic moment measurements for the synthesized compounds.

Compounds	λ_{max} (nm)		μ_{eff} (B.M.)	
	Ligand	***d-d***	**Found**	**(Calcd.)**
1	237	513	4,02	(3,83)
2	235	391, 662	2,87	(2,83)
3	239, 271	587	1,67	(1,73)
4	236	-	Dia	

Intense π→π* and n→π* transitions associated with sac and bheppz ligands were observed between 235–271 nm, while weaker d-d transitions appeared in the 391–662 nm range. As expected, no d-d transitions were noted for the d^{10}-configured Zn(II) complex. The Zn(II) complex exhibits diamagnetism, as anticipated, whereas the magnetic moment values for the remaining complexes align with those expected for an octahedral structure.

3.3. Thermal Analysis

The thermal analysis of the complexes was performed up to 1000 °C under atmospheric conditions, and the results are presented in Table 4. The DTA and TG curves are shown in Figure 4.

Table 4. Thermal analysis results for the compounds

Compounds	Stage	DTG_{max} (°C) [a]	Species lost	%weight losses	
				Found	Calc.
1	1	131(+)	$4H_2O$	5,5	5,7
	2	250(-)	1bheppz	26,7	27,5
	3	396(-), 512(-)	4sac	57,9	57,5
	Residue		CoO		
2	1	123(+)	$4H_2O$	5,9	5,7
	2	242(-)	1bheppz	26,3	27,5
	3	436(-), 521(-)	4sac	58,0	57,5
	Residue		NiO		
3	1	76(+)	$4H_2O$	5,1	5,6
	2	223(-)	1bheppz	26,6	27,0
	3	497(-)	4sac	57,4	57,1
	Residue		CuO		
4	1	78(+)	$4H_2O$	6,0	5,6
	2	210(+), 352(-)	1bheppz	27,8	27,2
	3	512(-)	4sac	55,8	56,9
	Residue		ZnO		

[a] (+) indicates endothermic, (-) exothermic processes.

The complexes lack a distinct melting point and show a weight reduction between 65 and 940 °C. Initially, all complexes undergo mass loss due to the evaporation of water molecules, followed by the elimination of bheppz ligands. The remaining metal saccharinates decompose exothermically to form metal oxides, with experimental values closely matching theoretical ones.

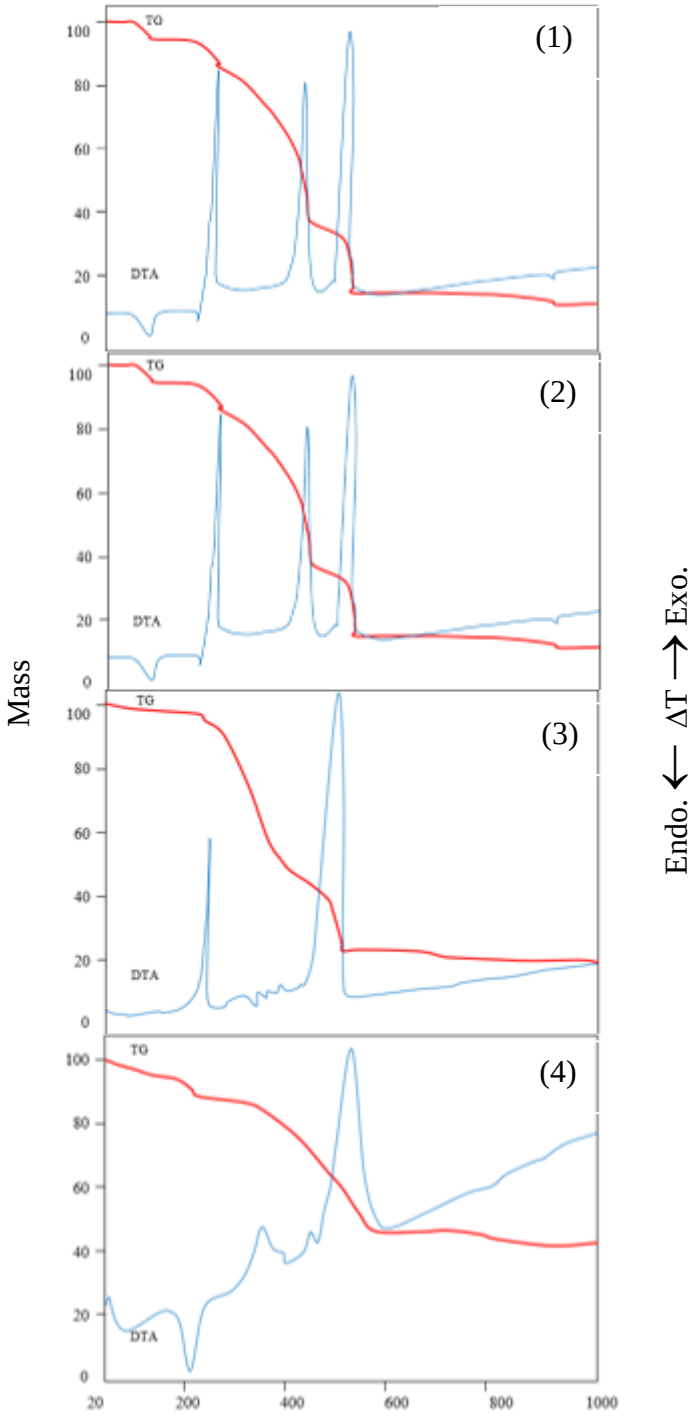


Figure 4. DTA and TG curves of the compounds.

4. Conclusions and Recommendations

In this study, four novel mixed-ligand metal-saccharinate complexes incorporating bheppz were synthesized and analyzed through various techniques, including elemental analysis, magnetic susceptibility measurements, UV-VIS, IR spectroscopy, and thermal evaluation. The complexes are proposed to adopt a dimeric structure with the formula $[M_2(sac)_4(bheppz)(H_2O)_4]$ (M = Co(II), Ni(II),

Cu(II), and Zn(II)). These compounds were synthesized with high yields and exhibited stable behavior in air.

The formation of single crystals for these complexes, which would enable a complete structural determination, could be achieved by optimizing the choice of solvents and environmental factors. Furthermore, exploring the biological activities (such as antimicrobial or anticancer properties) and electrochemical behaviors of the complexes may enhance their potential use in diverse applications.

Statement of Research and Publication Ethics

The author declares that this study complies with Research and Publication Ethics.

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