Uşak Üniversitesi Fen ve Doğa Bilimleri Dergisi
Usak University Journal of Science and Natural Sciences

http://dergipark.gov.tr/usufedbid
https://doi.org/10.47137/usufedbid.1480103

Research Article (Araştırma Makalesi)

Synthesis, Characterization, and Investigation of Antimicrobial Properties of Salt and Metal Complexes of 2,6-Pyridinedicarboxylic Acid and 2-Amino-4,6-dimethylpyridine

Elif YURT[1], Halil İLKİMEN[1], Beyza YILMAZ[1], Ayşe POLAT[1] and Aysel GÜLBANDILAR[2]*

[1]Department of Chemistry, Faculty of Arts and Sciences, Kütahya Dumlupinar University, 43100, Kütahya, Türkiye
[2]Department of Food Engineering, Department of Agricultural Engineering, Eskişehir Osmangazi University, 26000 Eskişehir, Türkiye

Geliş: 8 Mayıs 2024 *Revizyon: 5 Ağustos 2024* *Kabul: 15 Ağustos 2024*
Received: 8 May 2024 *Revised: 5 August 2024* *Accepted: 15 August 2024*

Abstract

A new salt (adpH) of 2,6-pyridinedicarboxylic acid (pdcH2) and 2-amino-4,6-dimethylpyridine (adp) and the metal complexes of the salt {(Hadp)x[M(pdc)2].nH2O, M = Fe (III), x = 1, n = 3 (FeadpH); M = Co(II), x = 2, n = 4 (CoadpH); M = Ni(II), x = 2, n = 5 (NiadpH); M = Cu(II), x = 2, n = 4 (CuadpH)} were synthesized. The structures of the compounds were characterized by AAS, IR, UV, magnetic susceptibility and molar conductivity methods. As a result of spectroscopic analysis, it was observed that all metal complexes had an ionic and octahedral structure. All substances were susceptible to *Candida albicans* (ATCC 14053) (yeast), *Pseudomonas aeruginosa* (ATCC 27853), *Staphylococcus aureus* (NRRL-B 767), *Listeria monocytogenes* (ATCC 7644), *Bacillus subtilis*, *Enterococcus faecalis* (ATCC 29212), and *Escherichia coli* (ATCC 25922) bacteria were examined. Antimicrobial activity results were compared with Fluconazole, Ketoconazole, Chloramphenicol, Levofloxacin, Vancomycin and Cefepime. In the activity results, the best values were observed adpH (31.25 µg/mL) in *B. subtilis* bacteria, NiadpH and CuadpH (31.25 µg/mL) in *S. aureus* bacteria, CoadpH, NiadpH and CuadpH (31.25 µg/mL) in *P. aeruginosa* bacteria, all compounds (62.50 µg/mL) in *L. monocytogenes* bacteria, all compounds (except adp) (62.50 µg/mL) in *E. coli* bacteria, adp (31.25 µg/mL) in *E. faecalis* bacteria and FeadpH (31.25 µg/mL) in *C. albicans* yeast.

Keywords: 2,6-Pyridinedicarboxylic acid, 2-amino-4,6-dimethylpyridine, salt, metal complex, antimicrobial activity.

*Corresponding author: Elif YURT
E-mail: elif.yurt0@ogr.dpu.edu.tr (ORCID ID: 0009-0000-7309-3963)
E-mail: halil.ilkimen@dpu.edu.tr (ORCID ID: 0000-0003-1747-159X)
E-mail: beyzaylmz20.2021@gmail.com (ORCID ID: 0009-0007-0756-6305)
E-mail: ayse.polaty@gmail.com (ORCID ID: 0009-0003-6048-7850)
E-mail: Aysel.gulbandilar@ogu.edu.tr (ORCID ID: 0000-0001-9075-9923)

2,6-Piridindikarboksilik Asit ile 2-Amino-4,6-dimetilpiridinin Tuzu ve Metal Komplekslerinin Sentezi, Karakterizasyonu ve Antimikrobiyal Özelliklerinin İncelenmesi

Özet

2,6-Piridindikarboksilik asit ($pdcH_2$) ile 2-amino-4,6-dimetilpiridinin (adp) yeni tuz (adpH) ve tuzun metal kompleksleri {$(Hadp)_x[M(pdc)_2].nH_2O$, M = Fe (III), x = 1, n = 3 (FeadpH); M = Co(II), x = 2, n = 4 (CoadpH); M = Ni(II), x = 2, n = 5 (NiadpH); M = Cu(II), x = 2, n = 4 (CuadpH)} sentezlenmiştir. Bileşiklerin yapıları, AAS, IR, UV, manyetik duyarlılık ve molar iletkenlik metotları ile önerilmiştir. Spektroskopik analizler sonucunda tüm metal komplekslerinin iyonik ve oktahedral yapıya sahip olduğu gözlenmiştir Tüm maddelerin *Candida albicans* (ATCC 14053) mayasına, *Listeria monocytogenes* (*ATCC 7644)*, *Staphylococcus aureus* (NRRL-B 767), *Bacillus subtilis, Enterococcus faecalis* (*ATCC 29212*), *Pseudomonas aeruginosa* (*ATCC 27853), ve Escherichia coli* (ATCC 25922) bakterilerine karşı antimikrobiyal aktiviteleri incelenmiştir. Antimikrobiyal aktivite sonuçları Flukonazol, Ketokonazol, Kloramfenikol, Levofloksasin, Vankomisin ve Sefepim ile kıyaslanmıştır. Aktivite sonuçlarında en iyi değerler *B. subtilis* bakterisinde adpH (31.25 µg/mL), *S. aureus* bakterilerinde NiadpH ve CuadpH (31.25 µg/mL), *P. aeruginosa* bakterisinde CoadpH, NiadpH ve CuadpH (31.25 µg/mL), *L. monocytogenes* bakterisinde tüm bileşikler (62.50 µg/mL), *E. coli* bakterisinde tüm bileşikler (**2** hariç) (31.25 µg/mL), *E. faecalis* bakterisinde adp ve *C. albicans* mayasında FeadpH (31.25 µg/mL) gözlenmiştir.

Anahtar Kelimeler: *2,6-Piridindikarboksilik asit, 2-amino-4,6-dimetilpiridin, tuz, metal kompleksi, antimikrobiyal aktivite.*

1. Introduction

Hydrogen bonding is a prominent type of non-covalent interactions in the field of chemistry, known for its exceptional ability to intricately and selectively organize molecules in a directional manner [1,2]. The process of salt generation occurs through the transfer of a proton engaged in a hydrogen bond interaction from the donor (acid) to the acceptor (base), a mechanism commonly referred to as proton transfer. The outcomes of proton transfer reactions, wherein a proton from a specific species relocates to the basic center, are denoted as proton transfer compound [3], charge transfer complex [4], and H-bonded complex [5]. Proton transfer reactions have garnered significant attention within the domains of chemistry and biochemistry, assuming a crucial role in various chemical and biological processes including the stabilization of biomolecular structures, regulation of enzymatic reaction rates, and the assembly of supramolecular structures through ionic hydrogen bonding [6,7]. Notably, the realm of active pharmaceutical additives has witnessed advancements through the formulation of novel products rooted in proton transfer reactions.

2,6-Pyridinedicarboxylic acid (1) used as acid in proton transfer salt synthesis present in the oxidative breakdown of vitamins, coenzymes, and alkaloids in natural systems, are emphasized due to its minimal toxicity and amphiphilic structure [8,9]. It serves as a versatile, potent, nitrogen-oxygen, multimodal donor ligand forming stable complexes with different metal ions, occasionally in unconventional oxidation states [10]. Derivatives of 2-aminopyridine used as bases in proton transfer salt synthesis exhibit a broad spectrum of pharmacological effects such as antifungal, antiviral, anti-inflammatory, antihistamine, antibacterial, antiparasitic, anticonvulsant, anti-alzheimer, antidiabetic, and analgesic characteristics [11]. Their capability to interact with metal ions either as a monodentate or bidentate ligand using the pyridine ring and the nitrogen atom within the amino group is noteworthy [12,13]. The synthesis and characterization of salt and metal

complexes of 2,6-pyridinedicarboxylic acid and 2-aminopyridine derivatives, such as 2-aminopyridine [14-22], 2,3-diaminopyridine, 2,6-diaminopyridine [23-49], 2-amino-3-hidroksipiridin [50], 2-amino methylpyridine derivatives [51-61] were conducted through various methods. In the contemporary context, the emergence of microbial resistance stands out as a global problem leading to increased mortality and morbidity rates. It is necessary to develop the spectrum effectiveness of new compounds that can combat resistant microorganisms in a wide range.

In this study, the salt (adpH) of 2,6-pyridinedicarboxylic acid (pdcH2) and 2-amino-4,6-dimethylpyridine (adp) and the metal complexes (FeadpH, CodpH, NiadpH and CuadpH) of adpH were synthesized. The structures of all compounds were characterized by NMR, AAS, IR, UV, molar conductivity and magnetic susceptibility methods. The antibacterial activities against *P. aeruginosa*, *E. coli*, *E. faecalis*, *L. monocytogenes*, *S. aureus* and *B. subtilis* bacteria and the antifungal activities of all substances against *C. albicans* yeast were examined. Their antimicrobial activities were compared with Fluconazole, Ketoconazole, Chloramphenicol, Levofloxacin, Vancomycin and Cefepime.

2. Experimental Section

2.1. Material and Methods

Chemicals used were analytical reagents and were commercially purchased from Merck. AAS analyses for Perkin Elmer AAS PinAAcle 900T, NMR spectra studies for Agilent Premium Compact 14.1 Tesla, FT-IR spectra for Bruker Optics, Vertex 70 FT-IR spectrometer using KBr, UV–Vis spectra for SHIMADZU UV-2550 spectrometer in the range of 200–900 nm, magnetic susceptibility measurements for Sherwood Scientific Magway MSB MK1 and molar conductances for WTW Cond 315i/SET Model conductivity meter were used.

2.2. Preparation of Salts and Cu(II) Complexes

For a 1:1 acid and base solution, pdcH2 (10 mmol, 1.6712 g) was dissolved under reflux in 25 mL of pure ethanol, and adp (10 mmol, 1.2247 g) was also dissolved in ethanol (25 mL). The mixture was stirred at reflux temperature for five hours. The white powder solid (adpH, 4.0628 g, 90% yield) precipitated in the reaction was filtered and dried (Fig. 1).

1 mmol metal(II) salt [0.556 g $FeSO_4.7H_2O$ for FeadpH, 0.498 g $Co(CH_3COO)_2.4H_2O$ for CoadpH, 0.496 g $Ni(CH_3COO)_2.4H_2O$ for NiadpH, 0.400 g $Cu(CH_3COO)_2.H_2O$ for CuadpH] and 0.4514 g (1 mmol) adpH was dissolved in water:ethanol solution (1:1) (75 mL) with magnetically stirring one week. Yellow power solid (0.1690 g, 60% yield) for FeadpH, pink power solid (0.1946 g, 55% yield) for CoadpH, green power solid (0.1995 g, 55% yield) for NiadpH and turquoise power solid (0.2136 g, 60% yield) for CuadpH were obtained from the mixtures (Fig. 1).

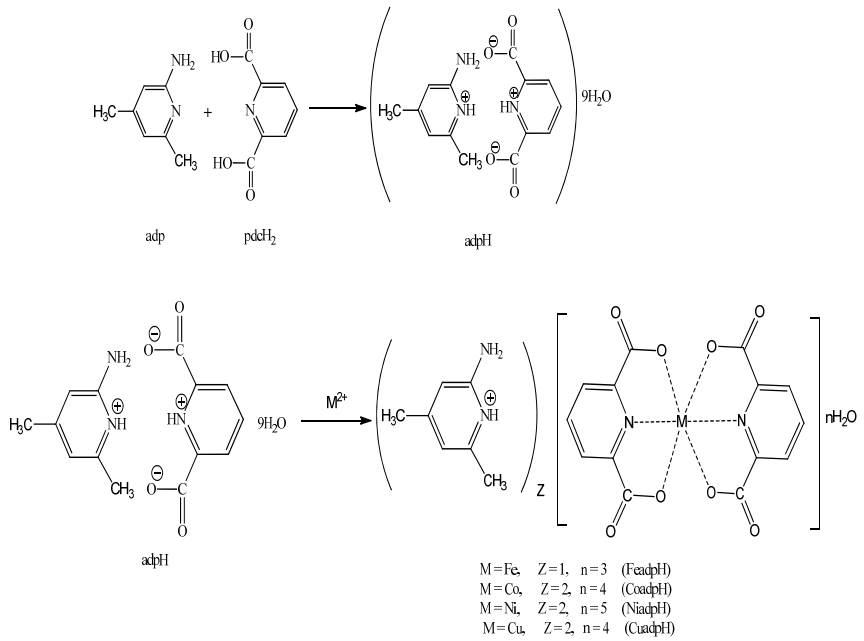


Figure 1. Syntheses of all compounds

2.3. Anti-Microbial Assay

The evaluation of the antimicrobial properties of the substances was conducted through the utilization of a microbroth dilution susceptibility test. Stock solutions were prepared using dimethyl sulfoxide. Each compound, totaling 4 mg, was dissolved in 2 mL of dimethyl sulfoxide. Bacteria and yeast suspensions, grown overnight, were standardized to 108 colony forming units/mL using McFarland No. 0.5 standard solution in double-strength Mueller-Hinton broth. Subsequently, 100 µL of each microbe suspension was added to the wells. A well-chain devoid of microbes served as the negative control. The positive growth control consisted of the medium and sterile distilled water. The minimum inhibitory concentration (MIC) was determined as the first well without turbidity after 18-24 hours of incubation at 37 °C.

3. Results and Discussion

3.1. Results of Elemental Analysis and AAS

Elemental analysis was performed for all compounds, while AAS was carried out for FeadpH, CodpH, NiadpH and CuadpH. The obtained results indicated a the adp:pdcH_2 ratio for adpH and the metal:adp:pdcH_2 ratios for metal complexes were observed to be 1:1:2 for FeadpH and 1:2:2 for CodpH, NiadpH and CuadpH (Table 1).

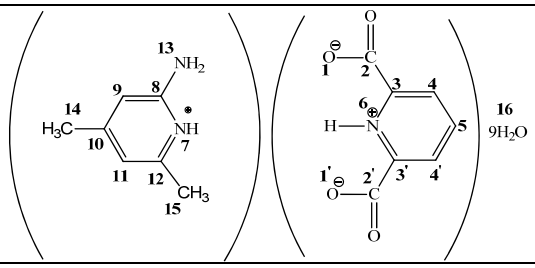
Table 1. Elemental analysis and AAS results of **1-**CoadpH

Compound	Formula	Found% Anal. Cald.%			
		C	H	N	M
adpH	$C_{14}H_{33}N_3O_{13}$	37.35 37.25	7.40 7.37	9.30 9.31	-

FeadpH	$C_{21}H_{23}FeN_4O_{11}$	44.80	4.10	9.90	9.90
		44.78	4.12	9.95	9.91
CoadpH	$C_{28}H_{36}CoN_6O_{12}$	47.50	5.00	11.90	8.30
		47.53	5.13	11.88	8.33
NiadpH	$C_{28}H_{38}NiN_6O_{13}$	46.40	5.20	11.65	8.10
		46.37	5.28	11.59	8.09
CuadpH	$C_{28}H_{36}CuN_6O_{12}$	47.30	5.00	11.90	8.90
		47.22	5.10	11.80	8.92

3.2. NMR Result of adpH

Table 2. Data of NMR spectra of adpH (ppm)



	^{1}H-NMR		^{13}C-NMR
H^4, $H^{4'}$	8.15 (2H, d) [$^3J_{H4/H4'-H5}$ = 7.80 Hz]	C^2, $C^{2'}$	166.940
H^5	8.08 (1H, t) [$^3J_{H5-H4,H4'}$ = 7.80 Hz]	C^3, $C^{3'}$	151.779
H^6	-	C^4, $C^{4'}$	127.193
H^7	-	C^5	113.072
H^9	6.24 (1H, s)	C^8	157.833
H^{11}	6.26 (1H, s)	C^9	151.505
H^{13}, H^{16}	4.50 (20H, s)	C^{10}	107.175
H^{14}	2.24 (3H, s)	C^{11}	139.173
H^{15}	2.13 (3H, s)	C^{12}	149.831
		C^{14}	21.616
		C^{15}	21.247

In the ^{1}H NMR spectrum of adpH (in DMSO, 600 MHz, Fig. 2, Table 2), the protons of adpH were observed at 8.15 ppm (H^4 and $H^{4'}$, doublet, $^3J_{H4/H4'-H5}$ = 7.80 Hz) with 2H intensity, 8.08 ppm (H^5, triplet, $^3J_{H5-H4,H3}$ = 7.80 Hz) with 1H intensity, 6.24 ppm (H^9, singlet) with 1H intensity, 6.26 ppm (H^{10}, singlet) with 1H intensity, 4.50 ppm (H^{13} and H^{16}, singlet) with 20H intensity, 3.24 ppm (H^{14}, singlet) with 3H intensity, and 2.13 ppm (H^{15}, singlet) with 3H intensity.

^{13}C NMR spectrum of adpH (in DMSO, 600 MHz, Fig. 3, Table 2), the carbon peaks of adpH were observed at 166.940 ppm (C^2, $C^{2'}$), 151.779 ppm (C^3, $C^{3'}$), 127.193 ppm (C^4, $C^{4'}$), 113.072 ppm (C^5), 157.833 ppm (C^8), 151.505 ppm (C^9), 107.175 ppm (C^{10}), 139.173 ppm (C^{11}), 149.831 ppm'de (C^{12}), 21.616 ppm'de (C^{14}) and 21.247 ppm'de (C^{15}).

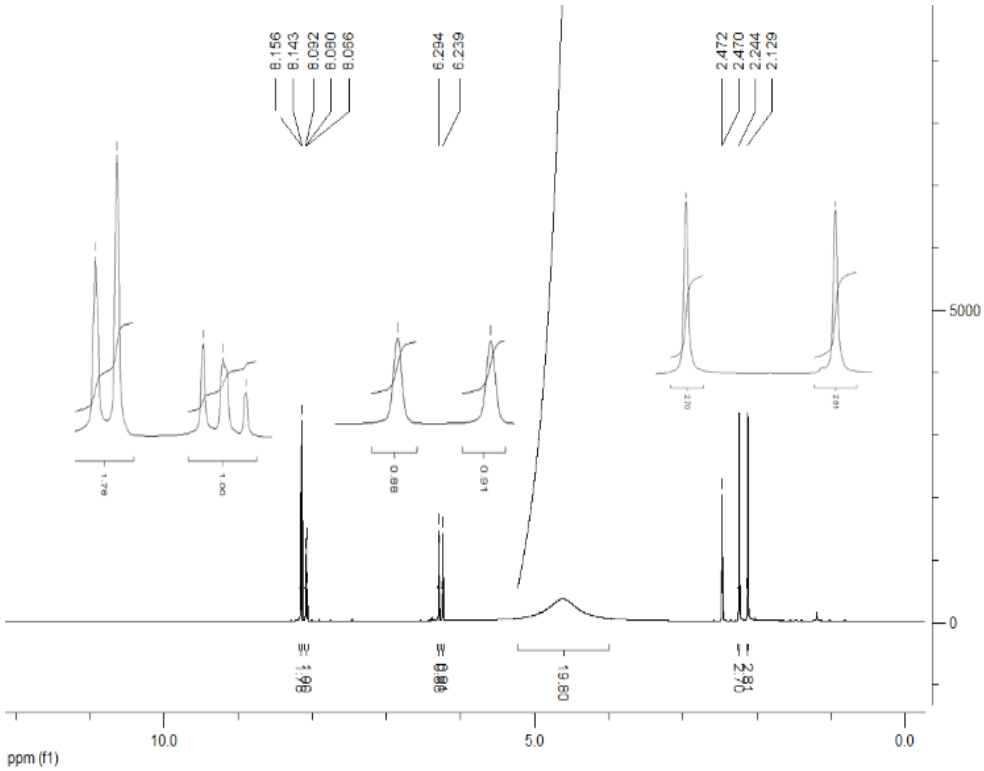


Figure 2. ^{1}H NMR spectrum of adpH.

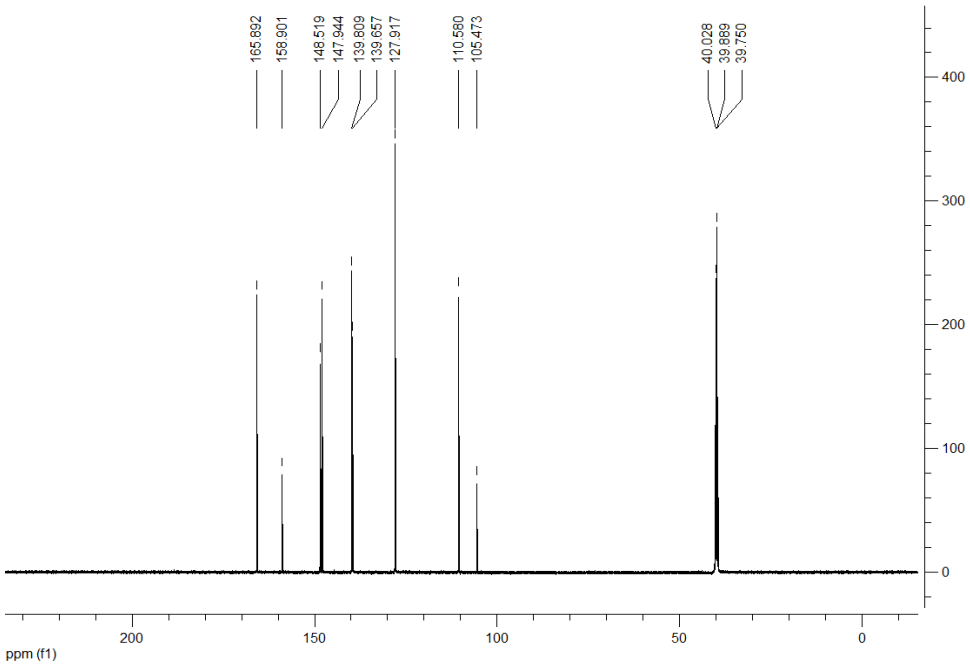
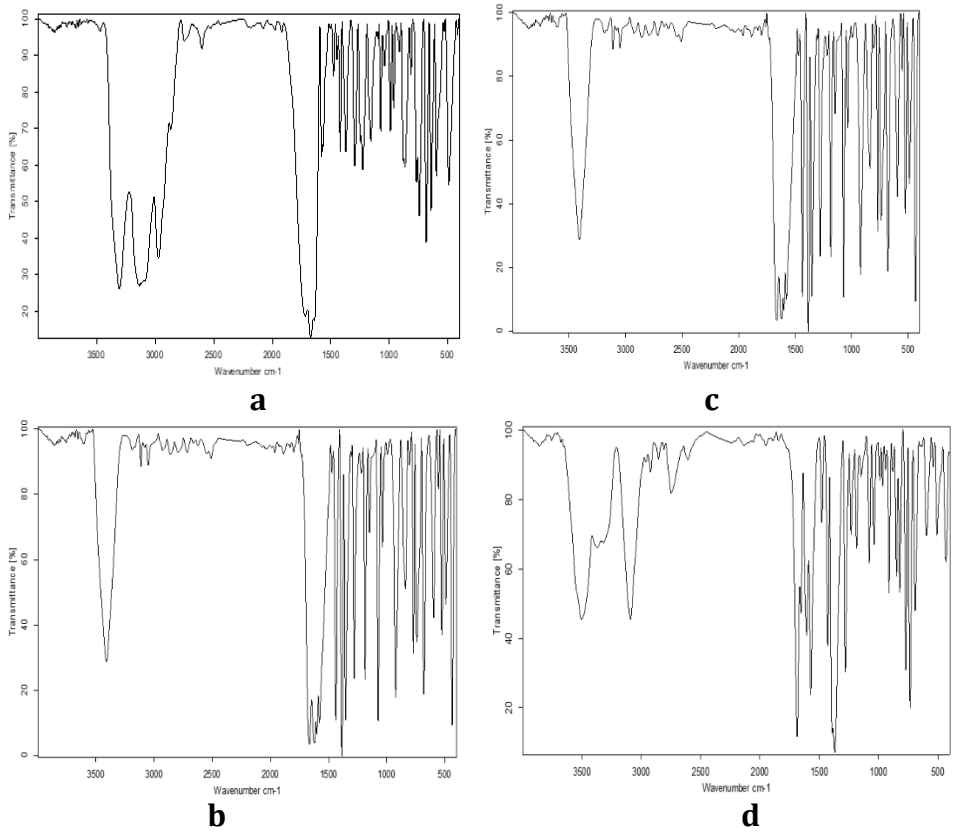
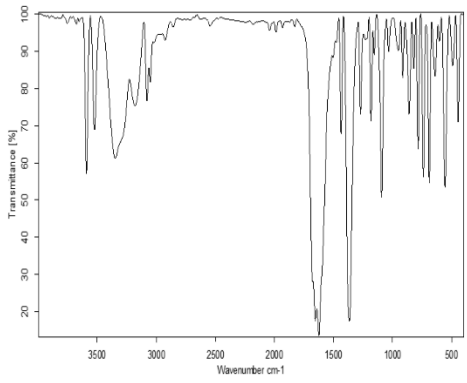


Figure 3. NMR spectrum of adpH.

3.3. IR Measurements

The IR results of all compounds are given in Figure 4 and Table 3. The water molecules in the structure of all compounds were the cause of the ν(O-H) vibrations, which were seen as wide bands between 3407 and 3591 cm^{-1}. The ν(N-H) vibrations are responsible for bands that appear at 3305 and 3135 cm^{-1} for adpH, 3337 and 3185 cm^{-1} for FeadpH, 3408 and 3291 cm^{-1} for CoadpH, 3371 and 3317 cm^{-1} for NiadpH and 3523 and 3300 cm^{-1} for CuadpH. The ν(N^+-H) vibrations observed in the range 2545-2752 cm^{-1} for all compounds [62]. These peaks observation shows that the aminopyridine molecule is present in the complexes as a complimentary ion outside of coordination.





e

Figure 4. IR spectrum of all compounds (**a** for adpH, **b** for FeadpH, **c** for CoadpH, **d** for NiadpH and **e** for CuadpH).

Table 3. IR spectral data of all compounds (cm^{-1}).

	adpH	FeadpH	CoadpH	NiadpH	CuadpH
ν(O-H)	3470(br)	3407(br)	3520(br)	3501(br)	3591(br)
ν(N-H)	3305(m)	3337(m)	3408(m)	3371(m)	3523(m)
	3135(m)	3185(m)	3291(m)	3317(m)	3300(m)
$\nu(C\text{-}H)_{Ar}$	3086(w)	3112(w)	3111(w)	3090(w)	3079(w)
$\nu(C\text{-}H)_{Alf.}$	2972(w)	2924(w)	2958(w)	2960(w)	3052(w)
	2867(w)	2858(w)	2855(w)	2854(w)	2926(w)
	2780(w)	2791(w)	2808(w)	2807(w)	2857v
$\nu(N^{+}\text{-}H)$	2752(w)	2714(w)	2747(w)	2746(w)	2714(w)
	2602(w)	2545(w)	2606(w)	2605(w)	2545(w)
ν(C=O)	1718(s)	1662(s)	1687(s)	1685(s)	1682(s)
	1478(s)	1470(s)	1477(s)	1478(s)	1477(s)
ν(C=N)	1673(s)	1621(s)	1650(s)	1654(s)	1654(s)
ν(C=C)	1638(s)	1601(s)	1616(s)	1605(s)	1624(s)
	1579(s)	1577(s)	1572(s)	1571(s)	1436(s)
	1406(s)	1437(s)	1429(s)	1427(s)	
	1447(s)				
ν(C-O)	1372(s)	1384(s)	11393(s)	1391(s)	1366(s)
	1296(s)	1279(s)	1281(s)	1279(s)	1271(s)
	1098(s)	1073(s)	1077(s)	1078(s)	1093(s)
ν(py)	746(s)	770(s)	768(s)	770(s)	784(s)
ν(M-O)	-	526(w)	534(w)	539(w)	556(w)
ν(M-N)	-	437(w)	428(w)	431(w)	446(w)

br: broad, m: medium, w: weak, s: strong.

The coordination of the COO^{-} group to the metal ion is indicated by the difference (Δυ) between the extensions of its asymmetric and symmetric vibrations. The results of all complexes were calculated to be 192 (1662 and 1470 cm^{-1}) for FeadpH, 210 (1687 and 1477 cm^{-1}) for CoadpH, 210 (1685 and 1478 cm^{-1}) for NiadpH and 205 (1682 and 1477 cm^{-1}) for CuadpH. These observations propose that the carboxylate group is bound to the metal ion in a monodentate manner [63]. The absorption bands in the region of 3079-3112

cm^{-1} for aromatic ν(C-H), 2780-3052 cm^{-1} for aliphatic ν(C-H), 1427-1673 cm^{-1} for ν(C=N)/ν(C=C), 1073-1391 cm^{-1} for ν(C=O), 746-784 cm^{-1} for ν(py), 526-556 cm^{-1} for ν(M-O) (except adpH) and 428-446 cm^{-1} for ν(M-N) (except adpH) are found for all compounds.

3.4. Results of UV/Vis Measurements

The electronic spectra of all compounds (Fig. 5, in DMSO), π-π^* and n-π^* transitions are observed 290 nm (30180 $Lmol^{-1}cm^{-1}$) for $pdcH_2$, 318 nm (26500 $Lmol^{-1}cm^{-1}$) for adp, 304 nm (26240 $Lmol^{-1}cm^{-1}$) for adpH, 302 nm (21830 $Lmol^{-1}cm^{-1}$) and 290 nm (24640 $Lmol^{-1}cm^{-1}$) for FeadpH, 318 nm (32740 $Lmol^{-1}cm^{-1}$) and 302 nm (32740 $Lmol^{-1}cm^{-1}$) for CoadpH, 302 nm (30310 $Lmol^{-1}cm^{-1}$) and 290 nm (31740 $Lmol^{-1}cm^{-1}$) for NiadpH and 318(32740 $Lmol^{-1}cm^{-1}$) and 302(32740 $Lmol^{-1}cm^{-1}$) for CuadpH. The d-d transitions are observed at 674 nm (210 $Lmol^{-1}cm^{-1}$) for CoadpH, 734 nm (130 $Lmol^{-1}cm^{-1}$) for NiadpH and 756 nm (210 $Lmol^{-1}cm^{-1}$) for CuadpH [51].

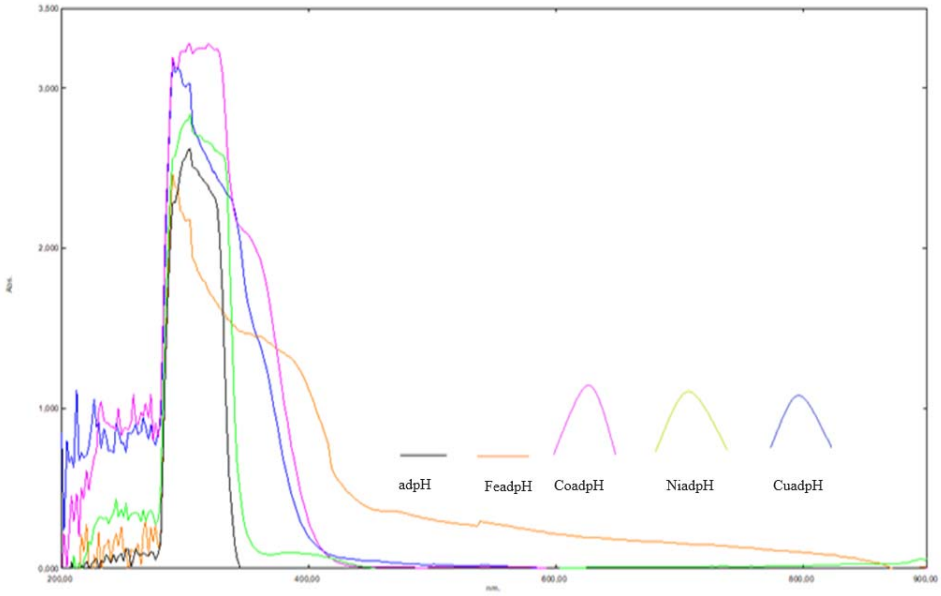


Figure 5. UV–Vis spectra of all compounds

3.5. Results of Magnetic Susceptibility

Magnetic susceptibility results of FeadpH, CodpH, NiadpH and CuadpH were found between 5.80, 3.70, 2.70 and 1.60 BM. These values say that there are five, three, two and one unpaired electrons in the complexes, respectively. The magnetic moment for the metal ion obtained in the octahedral geometry is also consistent with this value [51].

3.6. Results of Molar Conductivity Measurements

Conductivity measurements of all complexes (in DMSO) were observed as 65.50 for FeadpH, 50.20 for CoadpH, 50.60 for NiadpH and 50.10 µS/cm for CuadpH and these results are 1:1 ionic for FeadpH and 2:1 ionic for CoadpH, NiadpH and CuadpH [64].

3.7. Antimicrobial Activity

The antibacterial and antifungal activities of all compounds, Chloramphenicol, Ketoconazole, Fluconazole, Vancomycin, Levofloxacin and Cefepime were investigated by microdilution method. MIC values of all compounds showing activity against bacteria and yeast are given in Table 4. The observed activity results are similar to 2-aminopyridine derivatives, salt and metal complexes found in the literature [12,13,51,65,66].

All antibacterial control compounds (Vancomycin, Levofloxacin, Cefepime and Chloramphenicol) and all compounds ($pdcH_2$, adp, adpH, FeadpH, CodpH, NiadpH and CuadpH) have activity against *B. subtilis;* while adpH showed equally effective, the other compounds were found to have a lower degree of according to Vancomycin and Levofloxacin. adpH showed greater activity than according to Vancomycin and Levofloxacin while adp showed equally effective. The other compounds showed lower activity.

Table 4. MIC values of compounds (µg/mL)

	B. subtilis	***S. aureus***	***P. aeruginosa***	***L. monocytogenes***	***E. coli***	***E. faecalis***	***C. albicans***
Vancomycin	31.25	31.25	62.50	125.00	125.00	31.25	-
Levofloxacin	31.25	62.50	31.25	62.50	31.25	31.25	-
Cefepime	62.50	31.25	31.25	62.50	31.25	62.50	-
Chloramphenicole	62.50	62.50	125.00	62.50	62.50	62.50	
Fluconazole	-	-	-	-	-	-	62.50
Ketoconazole	-	-	-	-	-	-	62.50
$pdcH_2$	62.50	62.50	62.50	62.50	62.50	62.50	125.00
adp	125.00	62.50	62.50	62.50	125.00	31.25	62.50
adpH	31.25	62.50	62.50	62.50	62.50	62.50	62.50
FeadpH	62.50	62.50	62.50	62.50	62.50	125.00	31.25
CoadpH	62.50	62.50	31.25	62.50	62.50	62.50	125.00
NiadpH	62.50	31.25	31.25	62.50	62.50	125.00	125.00
CuadpH	62.50	31.25	31.25	62.50	62.50	62.50	62.50

S. aureus: while NiadpH and CuadpH showed equally effective, the other compounds were found to have a lower degree of according to Vancomycin and Cefepime. NiadpH and CuadpH showed greater activity than according to Chloramphenicol and Levofloxacin while the other compounds showed equally effective.

P. aeruginosa; all compounds showed greater activity than according to Chloramphenicol. CoadpH, NiadpH and CuadpH showed greater activity than according to Vancomycin while the other compounds equally effective. While CoadpH, NiadpH and CuadpH showed equally effective, the other compounds were found to have a lower degree of according to Levofloxacin and Cefepime.

L. monocytogenes; when MIC values are compared; all compounds indicated greater activity than according to Vancomycin. All compounds equally effective according to Chloramphenicol Levofloxacin and Cefepime.

E. coli; all compounds indicated greater activity than according to Vancomycin. All compounds were found to have a lower degree of according to Vancomycin and Cefepime. While all compounds (except adp) showed equally effective, adp was found to have a lower degree of according to Chloramphenicol.

E. faecalis; while adp showed equally effective, the other compounds were found to have a lower degree of according to Vancomycin and Levofloxacin. adp showed greater activity than according to Vancomycin while $pdcH_2$, adpH, CoadpH and CuadpH equally effective according to Chloramphenicol and Cefepime. The other compounds were found to have a lower degree of according to Chloramphenicol and Cefepime

The antifungal control compounds (Ketoconazole and Fluconazole) and all compounds have activity against *C. albicans* when MIC values are compared; FeadpH observed greater activity than according to Ketoconazole and Fluconazole while adp, adpH and CuadpH showed equal effective. $pdcH_2$ and adp were found to have a lower degree of action.

4. Conclusions

In this study, salt (adpH) of 2,6-pyridinedicarboxylic acid ($pdcH_2$) and 2-amino-4,6-dimethylpyridine (adp) and the metal complexes of adpH {$(Hadp)_x[M(pdc)_2].nH_2O$, M = Fe (III), x = 1, n = 3 (FeadpH); M = Co(II), x = 2, n = 4 (CoadpH); M = Ni(II), x = 2, n = 5 (NiadpH); M = Cu(II), x = 2, n = 4 (CuadpH)} were synthesized. The structures of all compounds were characterized by NMR, AAS, IR, UV, magnetic susceptibility, and molar conductivity methods. As a result of spectroscopic analysis, it was observed that all metal complexes had an ionic and octahedral structure. All compounds exhibited antimicrobial efficacy against both bacterial and fungal microorganisms. In the activity results, the best values were observed adpH (31.25 µg/mL) in *B. subtilis* bacteria, NiadpH and CuadpH (31.25 µg/mL) in *S. aureus* bacteria, CoadpH, NiadpH and CuadpH (31.25 µg/mL) in *P. aeruginosa* bacteria, all compounds (62.50 µg/mL) in *L. monocytogenes* bacteria, all compounds (except adp) (62.50 µg/mL) in *E. coli* bacteria, adp (31.25 µg/mL) in *E. faecalis* bacteria and FeadpH (31.25 µg/mL) in *C. albicans* yeast.

Funding

This study was supported within the scope of the TUBITAK 2209-A university students' research projects support program with the application number 1919B012107912.

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

Authors contributed equally to this work.

Ethics Consent

Ethics committee approval is not required for this article.

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