The phenolic compound used in this study is p-coumaric acid, which is the derivative of phenolic acid playing a role in giving color, odor and taste to the plants. The p-coumaric acid is an organic compound derived from cinnamic acid. There are three isomers of this structure as ortho-, meta- and para- depending on the location of the hydroxyl group within the structure. In this study, metal complexes of p-coumaric acid ligand with the transition metal cations (Co\textsuperscript{II}, Ni\textsuperscript{II}, Cu\textsuperscript{II}, Zn\textsuperscript{II}) were synthesized. The structure of the synthesized complexes was studied via elemental analysis, infrared and ultraviolet-visible spectroscopy, magnetic measurements, melting point and thermal analysis. Furthermore the biological properties of these new molecules were studied.

**Key Words:**
P-coumaric Acid; Metal Complexes; Thermal Analysis; Spectroscopy; Biological Activity.

**ABSTRACT**

The phenolic compound used in this study is p-coumaric acid, which is the derivative of phenolic acid playing a role in giving color, odor and taste to the plants. The p-coumaric acid is an organic compound derived from cinnamic acid. There are three isomers of this structure as ortho-, meta- and para- depending on the location of the hydroxyl group within the structure. In this study, metal complexes of p-coumaric acid ligand with the transition metal cations (Co\textsuperscript{II}, Ni\textsuperscript{II}, Cu\textsuperscript{II}, Zn\textsuperscript{II}) were synthesized. The structure of the synthesized complexes was studied via elemental analysis, infrared and ultraviolet-visible spectroscopy, magnetic measurements, melting point and thermal analysis. Furthermore the biological properties of these new molecules were studied.
the molecular weight of 164.15 g·mol⁻¹, has melting point of 210-213°C. Exists much in orange [14], cherry, coffee, chocolate and wine [15]. The ability to kill tumor cells, the oxidative damage of p-coumaric acid on DNA was reported. It shows the toxic effects when taken in high amounts [16]. It is also known that the p-coumaric acid is particularly effective against gastric cancer [17].

P-coumaric acid has the capability to fight against antibacteria, antifungal and also parasites [18]. The p-coumaric acid the most important derivatives of the cinnamic acid is among the notable pharmaceuticals with the properties such as reducing high blood pressure, preventing stroke (antiaggregant) and being an anti-tumor agent [19].

The structural characterization of p-coumaric acid complexes with transition metals such as lanthanum [20], europium [21], cerium [22], zinc [23], manganese [24], copper [24] and cadmium [24,25] and various chemical and physicochemical properties with alkali metals (Li, Na, K, Rb) [26] were studied in the literature.

In this study, metal complexes of p-coumaric acid ligand with the transition metal cations (CoII, NiII, CuII, ZnII) were synthesized. The structure of the synthesized complexes was studied via elemental analysis, infrared and ultraviolet-visible spectroscopy, magnetic measurements, melting point and thermal analysis. Furthermore the biological properties of these new molecules were studied.

**MATERIAL AND METHOD**

**Synthesis**

In the synthesis of complexes, cobalt (II) nitrate hexahydrate (Co(NO₃)₂·6H₂O), nickel (II) nitrate hexahydrate (NiSO₄·6H₂O), copper (II) nitrate trihydrate (Cu(NO₃)₂·3H₂O), zinc (II) nitrate heptahydrate (ZnSO₄·7H₂O), sodium bicarbonate (NaHCO₃) and p-coumaric acid, all bought from Sigma-Aldrich, were used.

As the first step in the synthesis of the complexes, p-coumaric acid and sodium bicarbonate, 0.02 moles each, were dissolved separately in the medium of 50:50 (v/v) EtOH:H₂O and reacted with each other. The reaction medium was stirred continuously up to all carbon dioxide formed during the reaction fully removed from the environment. Related metal salts were added on the sodium p-coumarate salt remaining purely in the solution media in the ratio of 1:2 mole (metal: ligand) and stirred on a hot plate at 60°C to obtain clear solution. The solution obtained at the end of the process was kept at reflux for about a day at 75°C. The samples were allowed to crystallize at room temperature for 3 to 6 weeks, and filtered after crystallization to dry at the same condition.

**Determination of Antimicrobial and Total Antioxidant Capacity**

Escherichia coli (ATCC 25922), Staphylococcus aureus (ATCC 25923), Enterococcus faecalis (ATCC 29212), Pseudomonas aeruginosa (ATCC 27853), Candida albicans (ATCC 10231) were used as test microorganisms. All strains were obtained from the culture collection at Hitit University, Faculty of Science and Arts, Department of Molecular Biology and Genetics, Molecular Microbiology and Biotechnology Research Laboratory. The antimicrobial activities were evaluated by disc-diffusion method. The total antioxidant capacity (TAC) was determined using an automated colorimetric measurement method.

**RESULTS AND DISCUSSION**

In this study, metal complexes of p-coumaric acid ligand
with the transition metal cations (Co$^{II}$, Ni$^{II}$, Cu$^{II}$, Zn$^{II}$) were synthesized. The structure of the complexes synthesized was studied via the elemental analysis, infrared and ultraviolet-visible spectroscopy, magnetic measurements, melting point and thermal analysis. Theoretical and experimental results summarized in Table 1 showing chemical composition analysis are consistent with each other. Magnetic susceptibilities of complexes in terms of the Bohr Magneton are also consistent with octahedral structures [27].

### Infrared Spectroscopy

The infrared spectra of complexes recorded at 450-4000 cm$^{-1}$ is given in Figure 2. For p-coumaric acid, the strong and broadband at 3000-2900 cm$^{-1}$ corresponds to -OH group, in the same way the other spectra data obtained can be given as; C=O group originating from carboxylic acid at 1688 cm$^{-1}$, supportive C-O peaks at 1260-1100 cm$^{-1}$ and the aromatic C-H stretching at 2879 cm$^{-1}$. In addition, the peak at 973 cm$^{-1}$ refers to the -OH substituent at the para position. The strong and the broad band obtained at 3600-3000 cm$^{-1}$ for the complexes obtained is originating from –OH group of water included in the structure. In our complex, there are stretching vibrations at 2590 and 2860 cm$^{-1}$ corresponding aromatic C-H bands. The C=O group originating from carboxylic acid in Co$^{II}$, Ni$^{II}$, Cu$^{II}$ and Zn$^{II}$ metal complexes gives valence vibrations at 1635, 1632, 1613 and 1638 cm$^{-1}$, respectively. The asymmetric and symmetric absorption bands of COO$^-$ in carboxylic acid correspond to stretching vibration at 1505-1515 cm$^{-1}$ and 1385-1398 cm$^{-1}$. The absorption bands corresponding to the M-O bindings underlying the complex have stretching vibrations at 510 and 531 cm$^{-1}$ for Co$^{II}$ complex; at 514 and 535 cm$^{-1}$ for Ni$^{II}$ complex; at 499 and 571 cm$^{-1}$ for Cu$^{II}$ complex; at 515 and 533 cm$^{-1}$ for Zn$^{II}$ complex. Some stretching and bending vibrations of the complexes are summarized in Table 2.

### Thermal Analysis

It can be determined from the differential thermogravimetric (DTG) analysis of the complexes between Co$^{II}$ and p-coumaric acid ligand that it decomposes at four stages corresponding to maximum temperatures of 58, 84, 228, 314°C. The first decomposition step is the removal of 1 mole of crystal water from the structure.

$$\text{Co(C}_2\text{H}_3\text{O}_7)(\text{H}_2\text{O})\text{H}_2\text{O}\rightarrow \text{Co(C}_2\text{H}_3\text{O}_7)(\text{H}_2\text{O})_2 + \text{H}_2\text{O}$$

It is the complete removal of 2 moles of water molecules of ligand within the coordination sphere from the structure at the decomposition step of 84°C within the temperature range of 79-152°C.

$$\text{Co(C}_2\text{H}_3\text{O}_7)(\text{H}_2\text{O})_2\rightarrow \text{Co(C}_2\text{H}_3\text{O}_7)(\text{H}_2\text{O}) + 2\text{H}_2\text{O}$$

### Table 1. The elemental analysis data of complexes.

| Complex | MW g/mol | Yield | Contents % Found (calc.) | Color | d.p. °C | $\mu_{eq}$ BM |
|---------|----------|-------|--------------------------|-------|---------|--------------|
| [Co(C$_7$H$_6$O$_7$)(H$_2$O)$_3$H$_2$O] | 439.28 | 92 | C: 49.84 (49.22), H: 5.32 (4.59), O: 44.85 | pink | 186 | 3.77 |
| [Ni(C$_7$H$_6$O$_7$)(H$_2$O)$_3$H$_2$O] | 457.05 | 87 | C: 49.11 (48.30), H: 4.17 (4.25), O: 46.72 | green | 191 decomp | 2.65 |
| [Cu(C$_7$H$_6$O$_7$)(H$_2$O)$_3$H$_2$O] | 426.88 | 93 | C: 51.63 (50.76), H: 5.17 (4.25), O: 43.20 | blue | 189 | 2.62 |
| [Zn(C$_7$H$_6$O$_7$)(H$_2$O)$_3$H$_2$O] | 445.73 | 82 | C: 49.13 (48.50), H: 3.97 (4.25), O: 47.13 | white | 186 | Dia. |

### Figure 2. The infrared spectra of p-coumaric acid (a) and Co$^{II}$ (b), Ni$^{II}$ (c), Cu$^{II}$ (d) vs Zn$^{II}$ (e) complexes.
The pca (p-coumaric acid) which is the ligand in the complex was removed from the medium by decomposing at the temperature range of 155-385°C. The black colored compound of CoO was remained as the decomposition products.

\[
\text{[Co(C}_9\text{H}_7\text{O}_3\text{)]}_2}\rightarrow\text{CoO}_2\text{+ 2 decomposition products of pca}
\]

It can be determined from the DTG curve of the complexes between Ni\textsuperscript{II} and p-coumaric acid ligand that it decomposes at four stages corresponding to maximum temperatures of 76, 139, 219 and 398; 775°C. The first decomposition step is the removal of 2 moles of crystal water from the structure.

\[
\text{[Ni(C}_9\text{H}_7\text{O}_3\text{)]}_2(\text{H}_2\text{O})_2\rightarrow[\text{Ni(C}_9\text{H}_7\text{O}_3\text{)]}_2+2\text{H}_2\text{O}_\text{g}}
\]

It is the complete removal of 2 moles of aqua ligand within the coordination sphere from the structure at the decomposition step of 139°C within the temperature range of 130-162°C.

\[
\text{[Ni(C}_9\text{H}_7\text{O}_3\text{)]}_2(\text{H}_2\text{O})_2\rightarrow[\text{Ni(C}_9\text{H}_7\text{O}_3\text{)]}_2+2\text{H}_2\text{O}_\text{g}}
\]

The pca (p-coumaric acid) which is the ligand in the complex was removed from the medium by decomposing at the temperature range of 156-790°C. The black colored compound of NiO was remained as the decomposition products.

\[
\text{[Ni(C}_9\text{H}_7\text{O}_3\text{)]}_2\rightarrow\text{NiO}_2\text{+ 2 decomposition products of pca}
\]

It can be determined from the DTG curve of the (VII) complexes between Cu\textsuperscript{II} and p-coumaric acid ligand that it decomposes at three stages corresponding to maximum temperatures of 83, 223; 260, 856°C. The first decomposition step is the removal of 2 moles of ligand water from the structure.

\[
\text{[Cu(C}_9\text{H}_7\text{O}_3\text{)]}_2(\text{H}_2\text{O})_2\rightarrow[\text{Cu(C}_9\text{H}_7\text{O}_3\text{)]}_2+2\text{H}_2\text{O}_\text{g}}
\]

The pca (p-coumaric acid) which is the ligand in the complex was removed from the medium by decomposing at the temperature range of 138-871°C. The black colored compound of CuO was remained as the decomposition products.
It can be determined from the DTG curve of the (VIII) complexes between Zn$^{II}$ and p-coumaric acid ligand that it decomposes at four stages corresponding to maximum temperatures of 62; 86, 113; 150, 178, 285°C. The first decomposition step is the removal of 1 mole of crystal water from the structure.

\[
\text{[Zn(C}_9\text{H}_7\text{O}_3)_2\text{H}_2\text{O}_2\text{]}.\text{H}_2\text{O}} \rightarrow [\text{Zn(C}_9\text{H}_7\text{O}_3)_2\text{H}_2\text{O}_2\text{]} + \text{H}_2\text{O}^\oplus
\]

It is the complete removal of 2 moles of aqua ligand within the coordination sphere from the structure at the decomposition step of 113; 150°C within the temperature range of 91-152°C.

\[
[\text{Zn(C}_9\text{H}_7\text{O}_3)_2\text{H}_2\text{O}_2\text{]} \rightarrow [\text{Zn(C}_9\text{H}_7\text{O}_3)_2\text{]} + 2\text{H}_2\text{O}^\oplus
\]

The pca (p-coumaric acid) which is the ligand in the complex was removed from the medium by decomposing at the temperature range of 153-442°C. The grey colored compound of ZnO was remained as the decomposition products.

\[
[\text{Zn(C}_9\text{H}_7\text{O}_3)_2\text{]} \rightarrow \text{ZnO} + 2\text{decomposition products of pca}
\]

Complex decomposition steps and decomposition products are summarized in detail in Table 3.

**Solid-State UV-vis Spectroscopy**

The electronic transition values of complexes obtained according to the visible region spectroscopy (UV-vis) Figure 4.
of compounds recorded in the interval of 900-200 nm were deduced from the spectral pattern (Figures 4.23 - 4.26). According to these data; d-d transitions could be related to the Co$^{3+}$ (V) complexes that were observed at the wavelength of 564.12 nm ($\tilde{t}_\text{T}_{1g} \rightarrow \tilde{t}_\text{T}_{2g}$) (F) and 509.61 nm ($\tilde{t}_\text{T}_{1g} \rightarrow \tilde{t}_\text{T}_{2g}$) (P) (Figure 4.23). The three spin-allowed d-d transition belonging to the Ni$^{3+}$ (VI) complex were corresponded to the wavelengths of 836.35 nm ($\tilde{t}_\text{T}_{1g} \rightarrow \tilde{t}_\text{T}_{1g}$) (P), 641.24 nm ($\tilde{t}_\text{T}_{1g} \rightarrow \tilde{t}_\text{T}_{1g}$) (F) and 397.72 nm ($\tilde{t}_\text{T}_{1g} \rightarrow \tilde{t}_\text{T}_{1g}$) (F). Therefore, these transition bands confirmed the splitting of d orbitals of Ni$^{3+}$ metal cation supporting the octahedral (Figure 4.24). The multiple absorption bands of Cu$^{2+}$ (VII) are formed by overlapping peaks and had a broad shape in a wide range corresponding to the interval of 837.95 - 527.37 nm (Figure 4.25). In the light of these spectral data, it can be thought that Cu$^{2+}$ metal cation confirms "pseudo-octahedral" structure under the influence of the Jahn-Teller effect. The maximum adsorption band of broadened spectrum owned by Cu$^{2+}$ (VII) complex corresponded to the wavelength of approximately 677.49 nm ($\tilde{t}_\text{T}_{1g} \rightarrow \tilde{t}_\text{T}_{2g}$) [28,29]. There was no any d-d electronic transition for an octahedral splitting possible to occur because fully occupied d orbitals in the last orbit of Zn$^{2+}$ (VIII) complex with the diamagnetic feature as seen from the magnetic susceptibility data (Figure 5) [30-32].

Biologic Applications

The antimicrobial activity and the total antioxidant activity (TAA) of the complexes synthesized are given in Table 4 and 5 respectively.

The antioxidant activity of metal complexes were shown in Table 5. Although the antioxidant values were found to very close to each other, Co$^{3+}$ containing molecule has the lowest and the Zn$^{2+}$ containing molecules had the highest value. In the case of evaluation of the antimicrobial activities of the complexes (Table 4), it was determined that the most effective metal is zinc. In addition, the metal complexes were found to be effective especially on yeasts and gram negative bacteria according to the inhibition zones obtained for the complexes between transition metal cations (Co$^{3+}$, Ni$^{3+}$, Cu$^{2+}$, Zn$^{2+}$) and p-coumaric acid, especially yeasts and gram-negative bacteria appears to be effective.

**CONCLUSION**

It was determined as a result of the elemental analysis of the complexes synthesized that the metal: ligand ratio was 1:2 for single ligand and 1:2:2 for multi ligand complexes. According to the elemental analysis results (Table 1), the formula of the complexes were determined to be as follows.

$[\text{Co}(\text{C}_6\text{H}_5\text{O}_3)_2(\text{H}_2\text{O})_2]\text{H}_2\text{O}$

$[\text{Ni}(\text{C}_6\text{H}_5\text{O}_3)_2(\text{H}_2\text{O})_2]2\text{H}_2\text{O}$

$[\text{Cu}(\text{C}_6\text{H}_5\text{O}_3)_2(\text{H}_2\text{O})_2]$  

$[\text{Zn}(\text{C}_6\text{H}_5\text{O}_3)_2(\text{H}_2\text{O})_2]\text{H}_2\text{O}$

It is estimated that the complexes have metal cation coordination sphere in the shape of octahedral geometry. The complexes obtained from transition metal cations of Co$^{3+}$, Ni$^{3+}$, Cu$^{2+}$ and Zn$^{2+}$ synthesized have the infrared spectrum (Table 4).

---

**Table 4.** The in vitro antimicrobial activity of complexes synthesized.

| Complexes | S. aureus ATCC 25923 | E. faecalis ATCC 29212 | E. coli ATCC 25922 | P. aeruginosa ATCC 27853 | C. albicans ATCC 10231 |
|-----------|----------------------|------------------------|----------------------|------------------------|------------------------|
| p-coumaric acid | 9,0±1,0 | 10,5±1,5 | 0,79 | 11,0±1,0 | 0,84 |
| +Co | - | - | - | 9,0±1,0 | - |
| +Ni | - | - | - | 11,5±0,5 | - |
| +Cu | 7,5±0,5 | 8,0±2,0 | 10,0±0,1 | 11,5±0,5 | - |
| +Zn | 11,0±1,0 | 10,5±1,5 | 11,5±0,5 | - | - |

(*: no inhibition, the amount of complex used: 25µL.)

**Table 5.** The total antioxidant activity results of complexes synthesized.

| Metal Complexes | Total Antioxidant Values (mmol Trolox Eq./ L) |
|-----------------|---------------------------------------------|
| Co$^{3+}$ (V) complex | 0,79 |
| Ni$^{3+}$ (VI) complex | 0,84 |
| Cu$^{2+}$ (VII) complex | 0,81 |
| Zn$^{2+}$ (VIII) complex | 0,89 |

---

Figure 5. The UV-vis spectrum of [Zn(C$_6$H$_5$O$_3$)$_2$(H$_2$O)$_2$]H$_2$O complex.
2) in concordance with the binding model proposed in this study. It was determined from symmetric and asymmetric stretching vibrations of carboxylic acid that the binding of p-coumaric acid providing the charge balance of complexes is monoanionic bidentate binding [29,33]. The differences between the symmetric and asymmetric stretching vibrations of the \( \text{COO}^- \) group were obtained as 128 cm\(^{-1}\) for Co\(^{II}\), 119 cm\(^{-1}\) for Ni\(^{II}\), 107 cm\(^{-1}\) for Cu\(^{II}\) and 128 cm\(^{-1}\) for Zn\(^{II}\) complexes. The differences between symmetric and asymmetric stretching vibrations belonging to the \( \text{COO}^- \) group of p-coumaric acid sodium salt is 145 cm\(^{-1}\) and thus the binding is monoanionic bidentate for the p-coumaric acid containing transition metal complexes.

The estimated structural formula of the complexes, with respect to the results of analysis and similar metal complexes stated previously in the literature [11,29] was proposed as follows:

ACKNOWLEDGEMENTS

We are thankful to Asoc. Prof. Gulcin ALP AVCI of Hitit University for cultivation of bacterias used in this study. This research was supported by the Science Research Department of Hitit University (Project no: FEF.19004.13.002).

REFERENCES

1. Balasundram N, Sundram K, Samman S. Phenolic compounds in plants and agrindustrial by-products: Antioxidant activity, occurrence, and potential uses. Food Chemistry, 99 (2006) 191-203.
2. Swisłocka R, Kowczyk-Śadowski M, Kalinowska M and Lewandowski W. Spectroscopic (FT-IR, FT-Raman, \(^1\)H and \(^{13}\)C-NMR) and theoretical studies of p-coumaric acid and alkali metal p-coumarates. Spectroscopy 27 (2012) 35-48.
3. Kalinowska M, Swisłocka R and Lewandowski W. Journal of Molecular Structure 834-836 (2007) 572-580.
4. Salameh D, Brandam C, Medawar W, Lteif R and Strehaiano P. Food Chemistry 107 (2008) 1661-1667.
5. Nizamłoğlu NM, Nas S. The Phenolic Compounds in Vegetables and Fruit; Structures and Their Importance. Electronic Journal of Food Technologies 5(1) (2010) 20–35.
6. Halvorsen BL, Holte K, Myhrstad MC, Barikmo I, Hvattum E, Remberg SF, Wold AB, Haffner K, Baugerød H, Andersen LF, Moskaugu Ø, Jacobs DR Jr, Blomhoff R. A systematic screening of total antioxidants in dietary plants. The Journal of Nutrition 132(3) (2002) 461-471.
7. Cotelle N, Bernier JL, Catteau JP, Pommery J, Wallet JC, Gaydou EM. Antioxidant properties of hydroxy–flavones. Free Radical Biology and Medicine 20(1) (1996) 35–43.
8. Maure A, Cruz JM, Franco D, Dominguez M, Sineiro J, Nunez MJ, Parajo JC. Natural antioxidants from residual sources. Food Chemistry 72 (2001) 145–171.
9. Jayaprakasha GK, Selvi T, Sakariah KK. Antibacterial and antioxidant activities of grape (Vitis vinifera) seed extracts. Food Research International 36 (2003) 117–122.
10. Nandita S, Rajini PS. Free radical scavenging activity of an aqueous extract of potato peel. Food Chemistry 85 (2004) 611–616.
11. Köse DA, Öztürk B, Şahin O, Büyükgünler O. Mixed ligand complexes of coumarilic acid/nicotinamide with transition metal complexes. Synthesis and structural investigation. Journal of Thermal Analysis and Calorimetry 115(2) (2014) 1515-1524.
12. Rice–Evans C, Miller NJ, Pa姜ga Q. Structure–antioxidant activity relationships of flavonoids and phenolic acids. Free Radical Biology & Medicine 20 (1996) 933–956.
13. Moline J, Bukharovich IF, Wolff MS, Phillips R. Dietary flavonoids and hypertension: is there a link? Medical Hypotheses 55(4) (2000) 306–309.
14. Sousa WR, Rocha C, Cardoso CL, Silva DHS, Zanoni MVB. Determination of the relative contribution of phenolic antioxidants in orange juice by voltammetric methods. Journal of Food Composition and Analysis 17 (2004) 619–625.
15. Abdel–Kader MS. New ester and furcocoumarins from the roots of pituranthos tortuosus. Journal of Chemical Education, 14(1) (2003) 48–51.
16. Labieniecz M, Gabryelak T, Falcioni G. Antioxidant and pro-oxidant effects of Tannins in digestive cells of the freshwater mussel unio tumidus. Mutation Research Genetic Toxicology and Environmental Mutagenesis 539 (2003) 19–28.
17. Kong CS, Jeong CH, Choi JS, Kim KJ, Jeong JW. Antiangiogenic effects of p-coumaric acid in human endothelial cells. Phytotherapy Research 27(3) (2013) 317–23.
18. Burt S, Essential oils: their antibacterial properties and potential applications in foods—a review. International Journal of Food Microbiology 94 (2004) 223–253.
19. Hertoq MG, Kromhout D, Aravanis C, Blackburn H, Buzina R, Fidanza F, Giampaoli S, Giampaoli S, Jansen A, Nedeljkovic N, Wolff MS. The seven countries study: socio-economic factors and cardiovascular disease in the seven countries study. Archives of Internal Medicine 155 (1995) 381–386.
20. Hui Li, Chang Wen Hu. Novel one-dimensional lanthanide acryllic acid complexes: an alternative chain constructed by hydrogen bonding. Journal of Solid State Chemistry 177 (2004) 4501–4507.
21. Yan J, Guo Y, Li H, Sun X, Wang Z. Structural diversity and luminescent properties of europium(III) complexes with acrylic acid ligands. Journal of Molecular Structure 891 (2008) 298–304.
22. Deacon GB, Forsyth M, Junk PC, Leary SG, Lee WW. Synthesis and Characterisation of Rare Earth Complexes Supported by para-Substituted Cinnamate Ligands. Zeitschrift für anorganische und allgemeine Chemie 635 (2009) 833–839.
23. Biswick T, Park DH, Shul YG, Choy JH. P-coumaric acid-zinc basic salt nanohybrid for controlled release and sustained anti oxidant activity. Journal of Physics and Chemistry of Solids 71 (2010) 647–649.
24. Jia–Yuan Mao, Hong–Xin Fang, Qing–Feng Xu, Qiu–Xuan Zhou, Jian–Mei Lu, Zhang Y. Synthesis and structural characterization of complexes [Cd(hca),(H₂O)]₂H₂O and [Cu(hca).phen]. Chinese Journal of Inorganic Chemistry 7 (2008) 1046–1050.
25. Kalinowska M, Laderiere B, Champagne P, Kowczyk–Sadowy M, Lewandowski W. Mn(II), Cu(II) and Cd(II) p-coumarates: FT–IR, FT–Raman, 'H and 13C NMR and thermogravimetric studies. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 103 (2013) 264–271.
26. Lewandowski W, Kalinowska M, Lewandowska H. The influence of metals on the electronic system of biologically important ligands. Spectroscopic study of benzoates, salicylates, nicotinates and isoorotates. Journal of Inorganic Biochemistry 99 (2005) 1407–1423.
27. Köse DA, Necetoğlu H, İbudak H. Synthesis and characterization of N,N-diethylnicotinamidem-acetylsalicylato complexes of Co(II), Ni(II), Cu(II) and Zn(II). Journal of Coordination Chemistry 61(21) (2008) 3508–3515.
28. Köse DA, Kaya A, Necetoğlu H. Synthesis and characterization of bis(N,N-Diethylnicotinamide) m-hydroxybenzoate complexes of Co(II), Ni(II), Cu(II) and Zn(II). Russian Journal of Coordination Chemistry 33(6) (2007) 422–427.
29. Köse DA, Necetoğlu H. Synthesis and characterization of bis(Nicotinamide) m-hydroxybenzoate complexes of Co(II), Ni(II), Cu(II) and Zn(II). Journal of Thermal Analysis and Calorimetry 93(2) (2008) 509–514.
30. Mihaylov Tz, Trendafilova N, Kostova I, Georgieva I, Bauer G. DFT modeling and spectroscopic study of metal–ligand bonding in La(III) complex of coumarin–3-carboxylic acid. Chemical Physics, 327 (2006) 209–219.
31. Patil SA, Unki SN, Kulkarni AD, Naik VH, Badami PS. Co(II), Ni(II) and Cu(II) complexes with coumarin–8–yl Schiff-bases: Spectroscopic, in vitro antimicrobial, DNA cleavage and fluorescence studies. Spectrochimica Acta Part A: Molecular and Biomolecular Spectroscopy 79 (2011) 1128–1136.
32. Köse DA, Necetoğlu H, Şahin O, Büyükgünler O. Synthesis, structural, spectroscopic characterization and structural comparison of 3-hydroxybenzoate and nicotinamide/ N,N-diethylnicotinamide mixed ligand complexes with Zn(II). Journal of Thermal Analysis and Calorimetry, 110(3) (2012) 1233–1241.
33. Nakamoto K. (2009) Infrared and Raman Spectra of Inorganic and Coordination Compounds, Part B, Applications in Coordination, Organometallic, and Bioinorganic Chemistry. Wiley, ISBN: 978–0–471–74493–1.