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Research Article

A New Palladium(II) Complex With 3-Picoline and Diclofenac: Synthesis, Crystal, Spectroscopic, Thermal and DFT Studies

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Abstract

A novel palladium(II) complex with 3-picoline and diclofenac ligands was synthesized using $[PdCl_2(3\text{-pic})_2]$ as the precursor**.** The synthesized complex is characterized by elemental and thermal and spectroscopic methods. Single X-Ray analysis confirms that the complex has square plane geometry and the compound of formula is $[Pd(dicl)_2(3\text{-pic})_2]$. Electronic properties of the complex have been probed by natural bond orbital (NBO) population analyses. Furthermore, relative stabilities of the complexes have been also compared in theoretical insight based on DFT computations since complex $[PdCl_2(3\text{-pic})_2]$ is the precursor of $[Pd(dicl)_2(3\text{-pic})_2]$. Thermal analysis shows that the complex is stable up to 200 ^oC.

Keywords: Diclofenac, Palladium, DFT, 3-Picoline

3-Pikolin ve Diklofenak İçeren Yeni Diklofenak Kompleksinin Sentezi, Kristal, Spektroskopik, Termik ve DFT Çalışmaları

Öz

$[PdCl_2(3\text{-pic})_2]$ kompleksi kullanılarak, 3-pikolin ve diklofenak ligandları içeren yeni bir palladyum(II) kompleksi sentezlendi. Sentezlenen kompleks, elementel, termik ve spektroskopik yöntemler ile karakterize edildi. X-Işını tek kristal analizi, kompleksin kare düzlem geometriye sahip olduğunu ve bileşiğinin formülünün $[Pd(dicl)_2(3\text{-pic})_2]$ olduğunu doğrulamaktadır. Kompleksin elektronik özellikleri, doğal bağ orbital (NBO) popülasyon analiziyle araştırılmıştır. Ayrıca, $[Pd(dicl)_2(3\text{-pic})_2]$ kompleksi, $[PdCl2(3\text{-pic})_2]$ kompleksinden sentezlendiğinden ötürü; komplekslerin bağıl kararlılıkları, DFT hesaplamalarında elde edilen teorik bulgularla karşılaştırılmıştır. Termik analiz tekniği, kompleksin 200 ^oC'ye kadar kararlı olduğunu göstermektedir.

Anahtar Kelimeler: Diklofenak, Palladyum, DFT, 3-pikolin

1. Introduction

Metal complexes have a lot of applications in synthesis chemistry, pharmacy, catalysis, optical systems, cosmetology, microbiology, dyes and pigments (Chan and Wong, 2013; Psomas and Kessissoglou, 2013; Jain and Jain, 2005; Tzeng et al., 2001). Especially, silver, platinum, palladium and gold complexes have been widely used in bioinorganic and medicinal chemistry (Anacona and Bastardo, 1999; Lai et al.,

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2000; Ma et al., 2013; Njogu et al., 2015; Wang and Cohen, 2009; Zhang et al., 2009; Misaki et al., 2000). Especially, the use of the cisplatin complex as an anticancer drug has led scientists to work in this area. Furthermore, the synthesis of Pd(II) and Pt(II) complexes with various ligands has attracted great interest from researchers since they show well anticancer, antifungal, and antibacterial activities (Al-Allaf et al., 1990; Romerosa et al., 2004; Garoufis et al., 2009). Scientists specially prefer nitrogen-based ligands due to their major biochemical activities in their complexation with palladium (Moro et al., 2012; Carvalho et al., 2015; Lustri et al., 2012; Patel et al., 2012).

Non-steroidal anti-inflammatory drugs (NSAIDs) find many application areas as pharmaceutical agents. NSAIDs prevent the formation of the prostaglandins enzyme, resulting in lower production of prostaglandins. As a result, inflammation and pain are decreased. But NSAIDs have many side effects in clinical practice. Therefore, much studies have been done to reduce these side effects. Hence, studies on d-block metal complexes with NSAIDs have become important. The most NSAIDs contain the carboxyl group for example diclofenac, naproxen, flufenamic acid, mefenamic acid and tolfenamic acid. They have at least two potential coordination sites to bind metal ions so that they act as a good ligand.

Diclofenac [2-[(2,6-dichlorophenyl) amino] phenyl] acetate] is one of the most widely used inhibitors against pain and acute migraines (Etcheverry et al., 2002; Kyropoulou et al., 2013; Quirinia et al., 1997; Housby et al., 1999; Beck et al., 2003; Tunçay et al., 2000). It is also a good ligand for binding to the metal ions (such as copper, manganese, nickel, cobalt, zinc) and its complexes have been reported by some research groups (Kyropoulou et al., 2013; Kovala-Demertziet al., 1993; Dimiza et al., 2011; Kovala-Demertzi et al., 1997; Castellari et al., 1997; Kourkoumelis et al., 2004; Caglar et al., 2013; Caglar et al., 2014). These studies demonstrated that diclofenac-metal complexes showed more effective biological properties and antioxidant activities as compared to free Nadicl (Kyropoulou et al., 2013; Dimiza et al., 2011; Zampakou et al., 2015). But diclofenac-palladium(II) complexes are not studied much by research groups (Konstandinidou et al., 1998). In the literature, diclofenac-palladium(II) complex indicated more important non-steroidal anti-inflammatory activity than free ligand.

Another important organic material 3-picoline ligand has a wide range of applications such as; medicine and cosmetics, dyes, rubber chemicals, explosives, disinfectants, adhesives and solvent (Srinivas et al., 2000; Kalevaru et al., 2009; Martin et al., 2010).

In the present study, we have synthesized a novel palladium-diclofenac-3-picoline complex by utilizing the palladium-3-picoline as an intermediate compound. The structural and thermal properties of the complex were investigated by using X-Ray, FTIR, elemental and TG-DTG and DTA analyses. The ground state electronic properties of the complex were investigated by Population analysis performed through DFT calculations. Also relative stabilities of both the precursor and the novel complex were comparatively examined based on thermodynamic parameters computed indirectly through DFT calculations.

2. Experimental

2.1. Materials and Methods

$K_2[PdCl_4]$ (Sigma), 3-picoline (Aldrich, 99.00%) and sodium diclofenac (Sigma, 99.00%) were utilized for the synthesis of the complexes. FT-IR spectra of the complexes

were recorded on a Thermo Nicolet 6700 spectrophotometer in the region 4000-450 cm^{-1} at a resolution of 4 cm^{-1} by using KBr pellet technique. Elemental analysis (C, H and N) of complexes were determined on a LECO CHNS-932 elemental analyzer. Thermal analyses were carried out on a PRIS Diamond TG/DTG/DTA apparatus from 30 to 1000 ^oC at a heating rate of 10 ^oC min^{-1} under a dynamic air atmosphere (platinum crucibles and mass ~10 mg).

Firstly, we give the fundamental definition and properties for this sequence.

2.2. Synthesis of $[Pd(dicl)_2(3\text{-}pic)_2]$ (1)

Firstly, we have synthesized $[PdCl_2(3\text{-}pic)_2]$ complex as the precursor**.** $K_2[PdCl_4]$ (0.06 mmol) was dissolved in water (10 cm^3) with stirring at 60 ^oC. Then 3-pic ligand (20µL, 0.12 mmol) was added drop by drop. The solution was stirred for 3 h. After that the solution was left for slow evaporation at room temperature. Orange crystals of $[PdCl_2(3\text{-}pic)_2]$ (65%) was obtained by filtration after one week. The crystal was filtered, washed with water and dried at room temperature. Analytical data for $[C_{12}H_{14}Cl_2N_2Pd]$ Found: C, 39.62; H, 3.87; N, 7.71 %; calcd: C, 39.65; H, 3.85; N, 7.70 %).

1 was synthesized starting from $[PdCl_2(3\text{-}pic)_2]$ complex. The obtained $[PdCl_2(3\text{-}pic)_2]$ complex was dissolved in methanol. Sodium diclofenac ligand was dissolved in methanol and then the two solutions were mixed at 50 ^oC, 1 h. The resulting solution was left for slow evaporation at room temperature.

Yellow crystals of **1** (60%) suitable for X-ray structure determination were collected after one month. The products were filtered, washed with water and dried at room temperature. Analytical data for $[C_{40}H_{34}Cl_4N_4O_4Pd]$ Found: C, 54.43; H, 3.83; N, 6.35 %; calcd: C, 54.41; H, 3.85; N, 6.34 %.

2.3. X-ray Crystal Structure Determination

Suitable crystals of the synthesized complex were selected for data collection which was performed on a D8-QUEST diffractometer equipped with a graphite-monochromatic Mo-Kα radiation at 296 K. The structure was solved by direct methods using SHELXS-97 (Sheldrick, 1998) and refined by full-matrix least-squares methods on F2 using SHELXL-2013 (Sheldrick, 2015). All non-hydrogen atoms were refined with anisotropic parameters. The H atoms were located from difference maps and then treated as riding atoms with C-H distance of 0.93-0.96 Å and N-H distance of 0.82 Å. The following procedures were implemented in our analysis: data collection: Bruker APEX2 (APEX2, 2013); program used for molecular graphics were as follow: MERCURY programs (Mercury); software used to prepare material for publication: WinGX (Farrugia, 1999).

2.4. Computational procedure

All computations were performed by using Gaussian 09 program suite (Frisch et al., 2009). X-ray geometry of $[PdCl_2(3\text{-}pic)_2]$ and **1** were optimized at B3LYP/3-21G* level under Ci-imposed symmetry constrain using Gaussian 03W program suit. NBO analyses of the optimized structure of the synthesized complex were performed through SPE calculations carried out using general basis set combination of cc-PV4Z for non-metal and ECP LANL2DZ for metal atoms. Obtained NBO data were utilized for the designation and comparison of the magnitude and nature of donor-Pd(II) interactions.

$[PdCl_2(3\text{-pic})_2]$ is the precursor of **$[Pd(dicl)_2(3\text{-pic})_2]$** as understood from experimental section. Therefore relative stabilities of the complexes were compared by calculating the enthalpic parameters of the following ligand exchange equilibrium reaction between $[PdCl_2(3\text{-pic})_2]$ and **$[Pd(dicl)_2(3\text{-pic})_2]$**.

$$\left[PdCl_2\left(3\text{-}pic\right)_2\right](1) + 2dicl^- \rightleftharpoons \left[Pd\left(dicl\right)_2\left(3\text{-}pic\right)_2\right](2) + 2Cl^- \quad (1)$$

For the above equilibrium, only variant thermodynamic quantity is solvation enthalpies of the species. Therefore the species at the side, where the change of solvation enthalpies are negatively higher, are thermodynamically more stable. Solvation enthalpy of each specimen at the above equilibrium was calculated as the differences of total electronic energies between the gas-phase and PCM-solvated optimized geometries.

$$\Delta H_{S(pcm)} = E_{S_{(pcm)}} - E_{S_{(gas)}} \quad (2)$$

Where ΔH_S is solvation enthalpy, $E_{S_{(pcm)}}$ is total electronic energy of the specimen perturbed under PCM continuum solvation, $E_{S_{(gas)}}$ is gas phase total electronic energy of the specimen. Total solvation enthalpy change of the reaction is defined as

$$\Delta H_{S_R} = \left(\Delta H_{S(2)} + 2\Delta H_{S(Cl^-)}\right) - \left(\Delta H_{S(1)} + 2\Delta H_{S(dicl^-)}\right) \quad (3)$$

Negatively magnitude of ΔH_{S_R} denotes to higher stability of complex $[Pd(dicl)_2(3\text{-pic})_2]$ over $[PdCl_2(3\text{-pic})_2]$.

3. Results and Discussion

3.1. Crystal Structures of $[Pd(dicl)_2(3\text{-pic})_2]$

$[PdCl_2(3\text{-pic})_2]$ crystallizes in the triclinic system (P-1) and shows a square planar coordination geometry in which Pd(II) center is coordinated to two 3-pic and chlorine ligands in *trans* positions as introduced in previously reported (Milani et al., 2013). The molecular structure of $[PdCl_2(3\text{-pic})_2]$ is depicted together with the atom numbering scheme in Figure 1.

The crystal structure of the **$[Pd(dicl)_2(3\text{-pic})_2]$** is demonstrated in Figure 2. Crystal data and structure refinement parameters, selected bond distances and angles are given in Table 1 and 2, respectively. Complex crystallizes in the monoclinic system (P21/n). The asymmetric unit of the complex contains one mononuclear **$[Pd(dicl)_2(3\text{-pic})_2]$** unit in which Pd(II) center is coordinated to two 3-pic and two dicl ligands to form square-planar geometry in trans-orientation of the ligands. Weak nonconventional hydrogen bonds between ring hydrogens and chlorine/carboxylate oxygens are only effective in crystal packing and in the formation of 3D assembly. Packing diagram of the complex along with b-c plane is shown in Figure 3 and unit cell content is given in Figure 4. The deprotonated dicl ligands are coordinated in trans position to palladium atom via the hydrogen bonded carboxylato oxygens. No significant π interactions and intermolecular hydrogen bonds were detected. Intramolecular hydrogen bond with a distance of H2A···O1=2.17(2) Å and an angle of N2–H2A–O1=134.76(8) as indicated in Figure 2 stabilizes the monomer

complex formation and is almost same with that in free diclofenac anion only with a distal and angular difference of ≈ 0.003 Å and 2-3° respectively. However, carboxylate C7–O1 distance of 1.295(1) Å is significantly longer than that in free diclofenac with a difference of 0.035 Å as a result of coordination to Pd(II) center.

Pd-$N_{3\text{-pic}}$ bond length is 2.025(2) Å, this value is closer to the value in $[Pd(phen)(L)_2][PF_6]_2$ (L: 2.030(4) Å for pyridine; L: 2.021(6) - 2.016(6) Å for 2-picoline) (Chen et al., 1997) and $[Pd(3\text{-picoline})_4]Cl_2.2H_2O$ (2.024 (2) Å) (Hallıgudı et al., 1996). But Pd-$N_{3\text{-pic}}$ bond length is longer than $[Pd(acetato)_2(3\text{-pic})_2]$ (2.011(3) Å) (Tessier and Rochon, 1999).

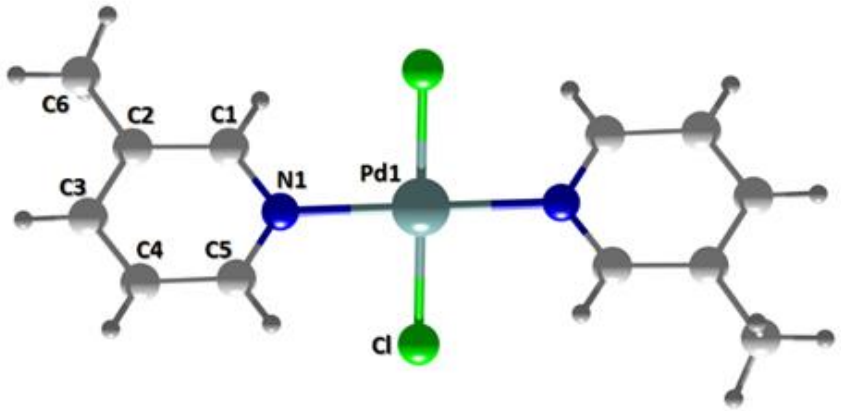

Fig. 1. X-ray symmetric unit structure of 1

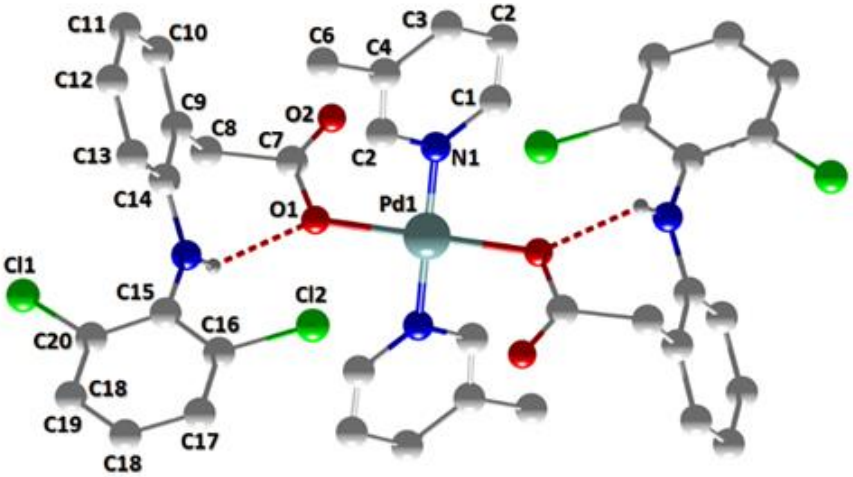

Fig. 2. X-ray symmetric unit structure of $[Pd(dicl)_2(3\text{-pic})_2]$ with intramolecular H-bond interaction

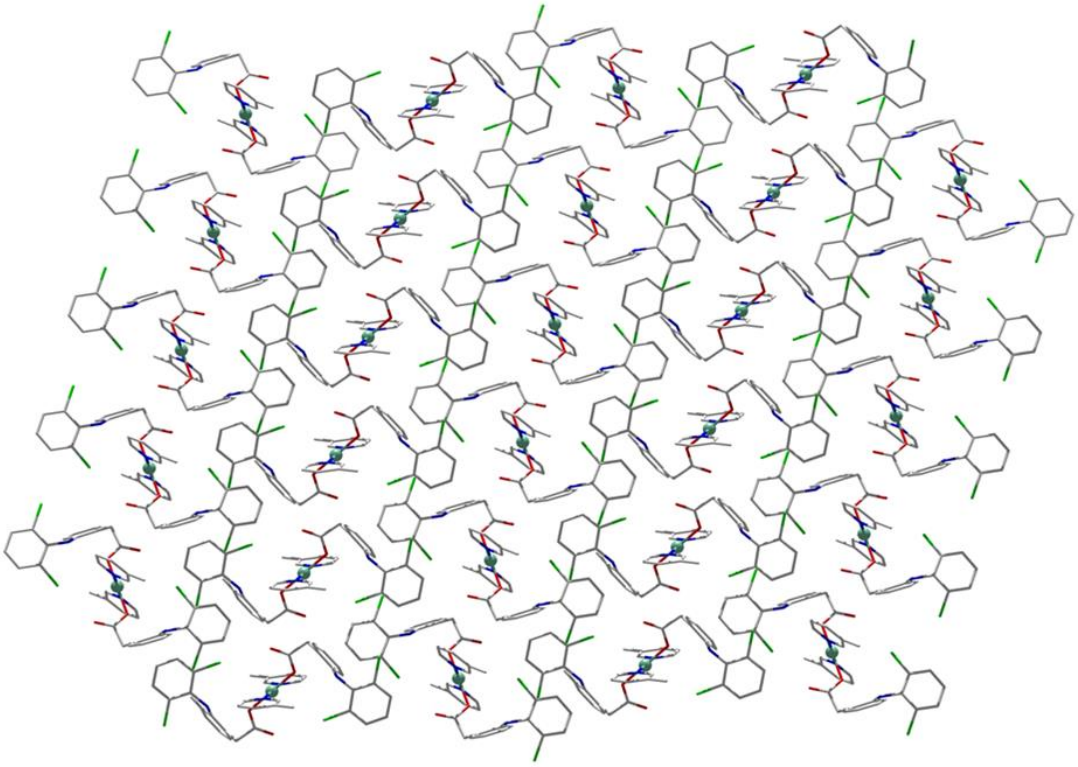

Fig. 3. 2D stacking of $[Pd(dicl)_2(3\text{-}pic)_2]$ through b-c plane

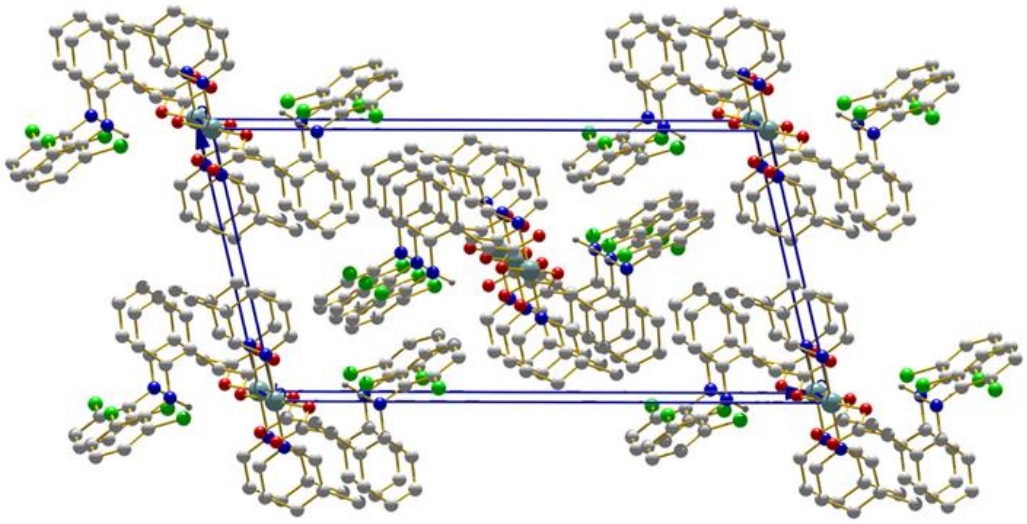

Fig. 4. Unit cell content of $[Pd(dicl)_2(3\text{-}pic)_2]$

Table 1. Crystal data and structure refinement parameters for $[Pd(dicl)_2(3\text{-pic})_2]$

Empirical formula	$C_{40}H_{34}Cl_4N_4O_4Pd$
Formula weight	882.91
Temperature (K)	296
Wavelength (Å)	0.71073
Crytal system	monoclinic
Space group	P 21/n
Unit cell dimensions	
a (Å)	11.2248(12)
b (Å)	7.8397(8)
c (Å)	22.386(2)
α^o)	90
β^o)	103.435(4)
γ^o)	90
V $(Å)^3$	1916.0(3)
Z	2
A. coefficient (mm^{-1})	0.810
D_{calc} (mg m^{-3})	1.530
Crystal size (mm)	0.11;0.12;0.16
Theta range for data collection (^{o})	2.987; 28.338
Measured reflections	4765
Indepen. reflections	3986
Absorpt. correction	Integration
Refinement method	Full-matrix least-squares on F^2
Final R indices $[F^2 > 2\sigma(F^2)]$	0.0538
Goodness-of-fit on F^2	1.172

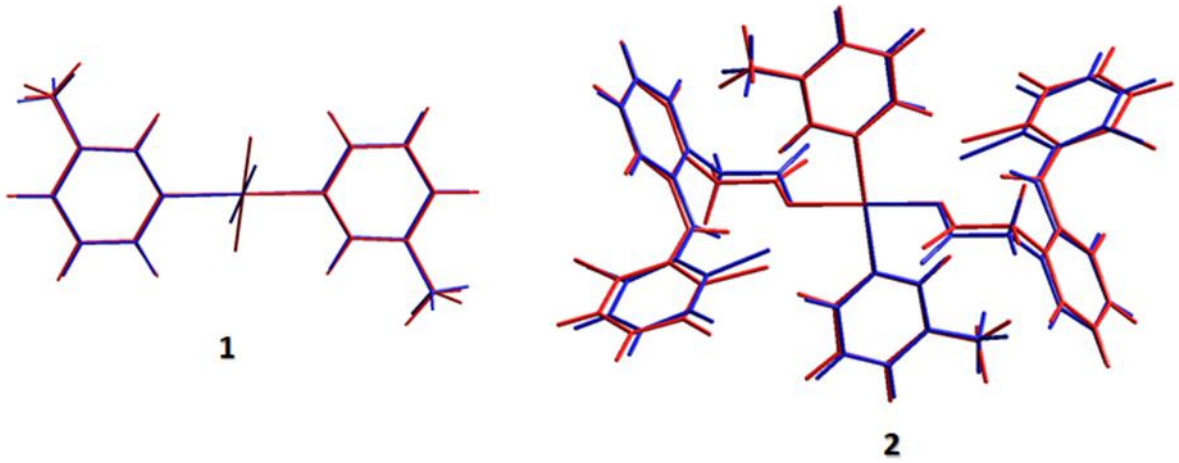

Fig. 5. Superimpostions of the X-ray (red) and optimized (blue) geometries of $[PdCl_2(3\text{-pic})_2]$ (1) and **1** (2)

Table 2. Selected bond distances (Å) and angles (°) for $[Pd(dicl)_2(3\text{-pic})_2]$

Pd1-N1	2.025(2)	Pd1-N1^i	2.025(2)
Pd1-O1	2.0078(19)	Pd1-O1^i	2.008(2)
N1-Pd1-O1	90.65(9)	O1^i-Pd1-O1	180.0
N1-Pd1-O1^i	89.35(9)	N1^i-Pd1-N1	180.0
N1^i-Pd1-O1	89.35(9)	N1^i-Pd1-O1^i	90.65(9)

Symmetry codes: i: 1-x,1-y,1-z

3.2. Population analysis

In order for the computational data to be meaningful in theoretical insight, optimized structures were used for all subsequent calculations including solution phase SPE calculations and NBO analyses. Superimpositions between X-ray and optimized geometries of the complexes were depicted in Figure 5. The RMS errors for the impositions for $[PdCl_2(3\text{-pic})_2]$ and $[Pd(dicl)_2(3\text{-pic})_2]$ are 0.3795 Å and 0.3079 Å respectively. As understood from low total RMS errors, there is a reasonable agreement between X-ray and optimized geometries. Therefore optimized geometries were used confidentially for subsequent calculations. Total electronic population of donor atoms and groups together with central atoms for the complexes $[PdCl_2(3\text{-pic})_2]$ and **1** are given in Table 3. With respect to $[PdCl_2(3\text{-pic})_2]$, the lower electronic population on Pd1 atom of **1** indicates higher positive charge of this center and hence higher electrostatic interaction of metal atom in 1. In carboxylate group of **1**, the higher electron population on hydrogen bonded and metal-coordinated O1 atom compared to uncoordinated O2 atom is an expected result for singly bonded O1 atom in comparison with doubly bonded O2 atom.

Table 3. Electron population of donor and central atoms in complexes according to NBO basis

	Complex	
Atoms	$[PdCl_2(3\text{-pic})_2]$	$[Pd(dicl)_2(3\text{-pic})_2]$
Cl	17.47	-
N1	7.33	7.39
O1	-	8.75*
O2	-	8.59
N2	-	7.61
Pd	45.64	45.27
*: hydrogen bonded atom		

Given in Table 4, Only natural bond orbital of single bond order that is detected between Cl and Pd1 atoms denote to covalent character of Cl-Pd1 bond in $[PdCl_2(3\text{-pic})_2]$. The electron population on Cl-Pd1 bond is 1.90 and bond energy is 70.01 kJ/mol in $[PdCl_2(3\text{-pic})_2]$ according to NBO basis. In the case of $[Pd(dicl)_2(3\text{-pic})_2]$, only natural bond orbital of kJ/mol bond energy is detected in N1-Pd1 bond. Therefore

diclofenac-metal interaction can said to be electrostatic based upon NBO data. Interestingly, second order N2–H2A···O1 hydrogen bond energy is 58.30 kJ/mol and is of same magnitude in energy with that of first order Cl-Pd1 bond in $[PdCl_2(3\text{-pic})_2]$.

Table 4. Major second order energies from NBO analysis

Complex	Donor	Acceptor	E^2 (kcal/mol)
$[PdCl_2(3\text{-pic})_2]$	N14(LP)	Pd16(LP*)	70.01
1	N37(LP)	Pd44(LP*)	29.66

LP: a lone pair valence orbital, LP*: an empty valence orbitals

HOMO and LUMO surfaces of the complexes (Figure 6) denotes to the differences in bonding natures of the complexes and support the findings from population analyses. In HOMO of 1, There is none of MO population between diclofenac and metal center. Therefore bonding between diclofenac and metal center seems electrostatic while LUMO in 1 most partly localized between diclofenac and metal center. In case of $[PdCl_2(3\text{-pic})_2]$, HOMO is localized only between chlorine ligands and metal center while LUMO is delocalized in entire molecule.

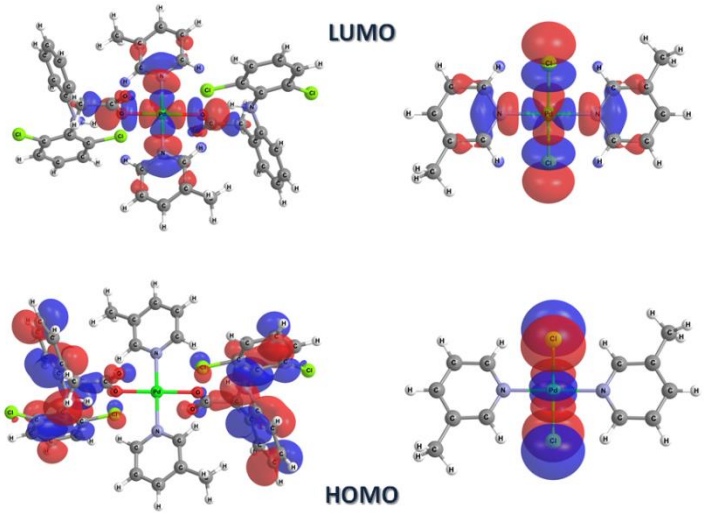

Fig. 6. Frontier molecular orbitals of 1 (left) and $[PdCl_2(3\text{-pic})_2]$ (right) with the isosurfaces of 0.02 e/A^3

3.3. Benchmark for the stabilities of the complexes

For the above ligand exchange equilibrium reaction, Differences of Gibbs free energy changes and entropies between reactants and products are zero, only solvation enthalpies are not. Solvation enthalpies of each specimen calculated based on Eq. 1 are, $\Delta H_{S(dicl^-)}$ = -254 kJ/mol; $\Delta H_{S(Cl^-)}$ = -326.5 kJ/mol; $\Delta H_{S(1)}$ = -79.5 kJ/mol; $\Delta H_{S(2)}$ = -95,13 kJ/mol. Then using Eq. 2, total solvation enthalpy of the reaction is

calculated as ΔH_{S_R} = -160.63 kj/mol and denotes to higher stability of $[Pd(dicl)_2(3\text{-}pic)_2]$ over $[PdCl_2(3\text{-}pic)_2]$. At the above equilibrium, sodium as the counter cation of diclofenac, is solvated at both side of the equilibrium and hence the solvation of it do not effects the total solvation enthalpy of the reaction. Therefore this is excluded in the calculations.

3.4. FT-IR Analyses

The $\nu(C\text{-}H)_{aro}$ and $\nu(C\text{-}H)_{alf}$ bands of dicl and 3-pic ligands are appeared at about 3065-2900 cm^{-1}. Sodium dicl molecule is including a secondary amino group [υ(NH)] and this band is observed at 3236 cm^{-1} in free sodium dicl. υ(NH) band is seen at 3380 cm^{-1} in the complex. There is no interaction between the palladium ion and N-H group so there is none of observed systematic shift of the υ(N-H) group. The bands around at 1578, 1506 and 1473 cm^{-1} originates from the $\nu(C{=}C)_{pyr}$ and $\nu(C{=}N)_{pyr}$ vibrations of ligands. In the FT-IR spectrum of the complex, two bands ascribed to the $\upsilon_{asym}(COO^-)$ and $\upsilon_{sym}(COO^-)$ vibrations are monitored at 1620 and 1412 cm^{-1}, respectively. The $\Delta\upsilon(COO^-)$ has a value of 208 cm^{-1} which is indicative of monodentate binding mode. The asymmetric deformations bands $\delta_{as}(CH_3)$ of the methyl group appear at 1450 cm^{-1}. The bands around at 1032 cm^{-1} are attributed to the methyl group rocking modes. The ν(C-N) bands are observed around at 1287 cm^{-1}. The υ_{asym}(C-N-C) and υ_{sym}(C-N-C) stretching bands of dicl ligand are seemed at 1305 cm^{-1} and 1252 cm^{-1}. The band assigned to in plane deformation vibration of the C-H groups occurs in 941 cm^{-1}. The bands around at 802 cm^{-1} correspond to υ(C-Cl) vibration of dicl ligand (Figure 7).

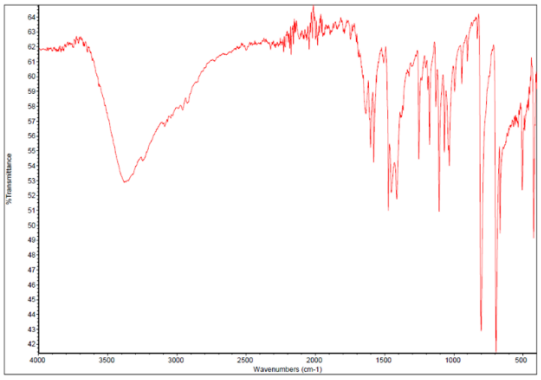

Fig. 7. FT-IR spectrum of $[Pd(dicl)_2(3\text{-}pic)_2]$

3.5. Thermal Analyses

The thermal analyses result shows that the complex displays two decomposition stages. The first mass loss stages start at 30 °C, ends at 310 °C and correspond to the loss of two 3-pic ligand from the complex (DTG_{max}: 240 and 284 °C; DTA: 240 °C (endo), 284 °C (endo)). The experimental mass loss is 23.2 %; and the calculated mass loss is 21.1 %. The second mass loss stages between 310-991 °C correspond to the loss of two dicl ligands (DTG_{max}: 475, 762, 978 °C; DTA: 477(exo), 770(exo), 978(exo) °C; exp. mass loss 62.2%, calcd. 66.8%). The final decomposition product is PdO (exp. mass loss 13.86%, calcd. 14.70%) (Figure 8).

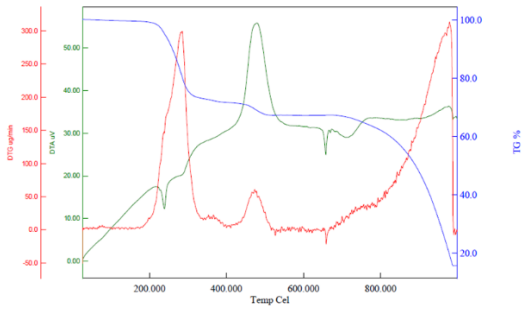

Fig. 8. TG/DTG/DTA curves of $[Pd(dicl)_2(3\text{-}pic)_2]$

4. Conclusion

The synthesis of the Pd(II) complex with the non-steroidal anti-inflammatory drugs

diclofenac was using $[PdCl_2(3\text{-pic})_2]$ as the precursor and obtained novel complex was characterized by various techniques. The monodentate coordination of diclofenac molecule through the oxygen atom of the carboxylate group was revealed by FT-IR spectroscopic and X-ray data. Considering X-ray data, the complex is in square planar coordination geometry with trans direction of ligands. Trans direction of the ligands in the complex can readily be attributed to steric strain of bulk diclofenac and 3-pic ligands rather than trans effect of chloro ligands. The increased stability upon substitution of chloro ligands by diclofenac ligands was approved in computational insight by computing the total solvation enthalpy of ligand exhange reaction between the intermediate compound and the novel complex. Reasonably negative magnitude of total solvation enthalpy indicates that the $[Pd(dicl)_2(3\text{-pic})_2]$ can be rationally prepared from the precursor compound. We can conclude from these data that DFT-thermodynamical calculations can be simply applied to that kind of ligand exchange reactions which are in equilibrium (zero Gibbs free energy change) and with equimolar amounts of reactants and products (zero entropy change).

Supplementary Material

Supplementary data CCDC 1569286 contain the supplementary crystallographic data for $[Pd(dicl)_2(3\text{-pic})_2]$. These data can be obtained free of charge via http://www.ccdc.cam.ac.uk/ conts/retrieving.html, or from the Cambridge Crystallographic Data Centre, 12 Union Road, Cambridge CB2 1EZ, UK; fax: (+44) 1223-336-033; or e-mail: deposit@ccdc.cam.ac.uk.

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5. References

Al-Allaf, T.A.K., Ayoub, M.T., Rashan, L.J. 1990. Synthesis and characterization of novel biologically active platinum(II) and palladium (II) complexes of some β-carboline alkaloids. J. Inorg. Biochem., 38, 47-56.

Anacona, J.R., Bastardo, E. 1999. Manganese(II) and palladium(II) complexes containing a new macrocyclic Schiff base ligand: antibacterial properties. Transition Met. Chem., 24, 478-480.

APEX2. 2013. Bruker AXS Inc. Madison Wisconsin USA.

Beck, A., Krischak, G., Sorg, T., Augat, P., Farker, K., Merkel, U., Kinzl, L., Claes, L. 2013. Influence of diclofenac (group of nonsteroidal anti-inflammatory drugs) on fracture healing. Arch Orthop Trauma Su, 123, 327-332.

Caglar, S., Aydemir, I.E., Adıgüzel, E., Caglar, B., Demir, S., Buyukgungor, O. 2013. Four copper (II) diclofenac complexes with pyridine derivatives: Synthesis, crystal structures, spectroscopic properties, thermal analysis and catechol oxidase activities. Inorg. Chim. Acta, 408, 131-138.

Caglar, S., Aydemir, I.E., Cankaya, M., Kuzucu, M., Temel, E., Buyukgungor, O. 2014. Four diclofenac complexes with cobalt(II) and nickel(II) ions: synthesis, spectroscopic properties, thermal decompo-sitions, crystal structures, and carbonic anhydrase activities. J. Coord. Chem., 67, 969-985.

Carvalho, M.A., Souza, B.C., Paiva, R.E.F., Bergamini, F.R.G., Gomes, A.F., Gozzo, F.C. 2015. Synthesis and crystal structure of a palladium (II) complex with the amino acid L-citrulline. Powder Diffr., 30, 357-361.

Castellari, C., Feroci, G., Ottani, S. 1999. Diclofenac interactions: tetrakis[[μ]-2-(2,6-dichloroanilino)phenylacetato]-1:2[κ]^{8}O:O'-diacetone-1[κ]O,2[κ]O-dicopper(II)(Cu--Cu) acetaldehyde solvate. Acta Crystallogr. Sect. C, 55, 907-910.

Chan, W.T.K., Wong, W.T. 2013. A brief introduction to transition metals in unusual oxidation states. W.T. Polyhedron, 52, 43-61.

Chen, W., Liu, C.M., Xiong, R.G., You, X.Z. 1997. 4:1 Lewis Base Adducts of Palladium Dichloride: [Pd(3-picoline)$_4$]Cl$_2$.2H$_2$O. Acta Crystallogr. Sect. C, 53, 1218-1220.

Dimiza, F., Perdih, F., Tangoulis, V., Turel, I., Kessissoglou, D.P., Psomas, G. 2011. Interaction of copper (II) with the non-steroidal anti-inflammatory drugs naproxen and diclofenac: Synthesis, structure, DNA- and albumin-binding. J. Inorg. Biochem., 105, 476-489.

Etcheverry, S.B., Barrio, D.A., Cortizo, A.M., Williams, P.A.M. 2002. Three new vanadyl (IV) complexes with non-steroidal anti-inflammatory drugs (Ibuprofen, Naproxen and Tolmetin). Bioactivity on osteoblast-like cells in culture. J. Inorg. Biochem., 88, 94-100.

Farrugia, L.J. 1999. WinGX suite for small-molecule single-crystal crystallography. Apply Cryst., 32, 837-838.

Frisch, M. J., Trucks, G.W., Schlegel, H. B., Scuseria, G. E., Robb, M. A., Cheeseman, J. R., Scalmani, G., Barone, V., Mennucci, B., Petersson, G. A., Nakatsuji, H., Caricato, M., Li, X., Hratchian, H. P., Izmaylov, A. F., Bloino, J., Zheng, G., Sonnenberg, J. L., Hada, M., Ehara, M., Toyota, K., Fukuda, R., Hasegawa, J., Ishida, M., Nakajima, T., Honda, Y., Kitao, O., Nakai, H., Vreven, T., Montgomery, Jr J. A., Peralta, J. E., Ogliaro, F., Bearpark, M., Heyd, J. J., Brothers, E., Kudin, K. N., Staroverov, V. N., Kobayashi, R., Normand, J., Raghavachari, K., Rendell, A., Burant, J C., Iyengar, SS., Tomasi, J., Cossi, M., Rega, N., Millam, J. M., Klene, M.; Knox, J. E., JBCross, Bakken, V., Adamo, C., Jaramillo, J., Gomperts, R., Stratmann, R. E.; Yazyev, O.; Austin, A. J., Cammi, R., Pomelli, C., Ochterski, J. W., Martin, R. L., Morokuma, K., Zakrzewski, V. G., Voth, G, A., Salvador, P., Dannenberg, J. J., Dapprich, S., Daniels, A. D., Farkas, Ö., Foresman, J. B., Ortiz, J. V., Cioslowski, J., and Fox, D. J. 2009. Gaussian 09, Revision A.1, Gaussian, Inc.: Wallingford CT.

Garoufis, A., Hadjikakou, S.K., Hadjiliadis, N. 2009. Palladium coordination compounds as anti-viral, anti-fungal, anti-microbial and anti-tumor agents. Coord. Chem. Rev., 253, 1384-1397.

Hallıgudı, S.B., Bhatt, K.N., Khan, N.H., Kurashy, R.I., Venkatsubramanıan, K. 1996. Synthesis, structural characterization and catalytic carbonylation of nitrobenzene and amines by mononuclear palladium(II) complexes containing substituted pyridine ligands. Polyhedron, 15, 2093-2101.

Housby, J.N., Cahill, C.M., Chu, B., Prevelige, R., Bickford, K., Stevenson, M.A., Calderwood, S.K. 1999. Non-steroidal anti-inflammatory drugs inhibit the expression of cytokines and induce HSP70 in human monocytes. Cytokine, 11, 347-358.

Jain, V.K., Jain, L. 2005. The chemistry of binuclear palladium(II) and platinum(II) complexes, Coord. Chem. Rev., 249, 3075-3197.

Kalevaru,V.N., Raju, B.D., Rao, V.V., Martin, A. 2009. Preparation, characterisation and catalytic evaluation of MgF_2 supported V_2O_5 catalysts for ammoxidation of 3-picoline. Appl. Catal. 352, 223-233.

Konstandinidou, M., Kourounakis, A., Yiangou, M., Hadjipetrou, L., Kovala-Demertzi, D., Hadjikakou, S., Demertzis, M. 1998. Anti-inflammatory properties of diclofenac transition metalloelement complexes. J. Inorg. Biochem., 70, 63-69.

Kourkoumelis, N., Demertzis, M.A., Kovala-Demertzi, D., Koutsodimou, A. Moukarika, A. 2004. Preparations and spectroscopic studies of organotin complexes of diclofenac. Spectrochim. Acta Part A, 60, 2253-2259.

Kovala-Demertzi, D., Mentzafos, D., Terzis, A. 1993. Metal complexes of the anti-inflammatory drug sodium [2-[(2,6-dichlorophenyl) amino]phenyl]acetate (diclofenac sodium). Molecular and crystal structure of cadmium diclofenac. Polyhedron, 12, 1361-1370.

Kovala-Demertzi, D., Theodorou, A., Demertzis, M.A., Raptopoulou, C.P., Terzis, A. 1997. Synthesis and characterization of tetrakis-μ-2-[(2,6dichlorophenyl) amino] benzeneacetodiaquodicopper(II) dihydrate and tetrakis-μ-2-[(2,6dichlorophenyl)amino] benzeneaceto dimethylformamidodicopper (II). J. Inorg. Biochem., *65*, 151-157.

Kyropoulou, M., Raptopoulou, C.P., Psycharis,V., Psomas, G. 2013. Ni (II) complexes with non-steroidal anti-inflammatory drug diclofenac: Structure and interaction with DNA and albumins. Polyhedron, 61, 126-136.

Lai, S.W. Cheung, T.C., Chan, M.C.W., Cheung, K.K., Peng, S.M., Che, C.M.2000. Luminescent mononuclear and binuclear cyclometalated palladium(II) complexes of 6-Phenyl-2,2′-bipyridines: spectroscopic and structural comparisons with platinum(II) analogues 1,2. Inorg. Chem., 39, 255-262.

Lustri, W.R., Formiga, A.L.B., Rigatto, G., Corbi, P.P. 2012. Synthesis, spectroscopic characterization, DFT studies, and initial antibacterial assays in vitro of a new palladium(II) complex with tryptophan. J. Coord. Chem., 65, 1700-1711.

Ma, D.Y., Zhang, L.X., Rao, X.Y., Wu, T.L., Li, D.H., Xie, X.Q. 2013. Synthesis, characterization, luminescence, antibacterial, and catalytic activities of a palladium(II) complex involving a Schiff base. J. Coord. Chem., 66, 1486-1496.

Martin, A., Janke,C., Kalevaru,V.N. 2010. Ammoxidation of 3-picoline to nicotinonitrile over VPO catalysts. Appl. Catal., 376, 13-18.

Mercury, version 3.3; CCDC, available online via ccdc.cam.ac.uk/products/mercury.

Milani, B., Scarel, A., Zangrando, E., Mestroni, G., Carfagna,C., Binotti. B. 2003. Cationic palladium complexes with mono- and bidentate nitrogen-donor ligands: synthesis, characterization and reactivity in CO/styrene copolymerization reaction. Inorg. Chim. Acta, 350, 592-602.

Misaki, Y., Tani, Y., Taniguchi, M., Maitani, T., Tanaka, K., Bechgaard, K. 2000. Preparation and Properties of Gold Complexes with TTF Dithiolato Ligands. Mol. Cryst .Liq. Cryst., 343, 59-64.

Moro, A.C., Urbaczek, A.C., De Almeida, E.T., Pavan, F.R., Leite, C.Q.F., Netto, A.V.G., Mauro, A.E. 2012. Binuclear cyclopalladated compounds with antitubercular activity: synthesis and characterization of [{Pd(C2,N-dmba)(X)}2(μ-bpp)]. J. Coord. Chem., 65, 1434-1442.

Njogu, E.M., Omondi, B., Nyamori, V.O. 2015. Review: Multimetallic silver(I)-pyridinyl complexes: coordination of silver(I) and luminescence. J. Coord.Chem., 68, 3389-3431.

Patel, M.N., Dosi, P.A., Bhatt, B.S. 2012. Square planar palladium (II) complexes of bipyridines: synthesis, characterization, and biological studies. J. Coord. Chem., 65, 3833-3844.

Psomas, G., Kessissoglou, D.P. 2013. Quinolones and non-steroidal antiinflammatory drugs interacting with copper(II), nickel(II), cobalt(II) and zinc(II): Structural features, biological evaluation and perspectives. Dalton Trans, 42, 6252-6276.

Quirinia, A., Viidik, A. 1997. Diclofenac and indomethacin influence the healing of normal and ischemic incisional wounds in skin. J. Plast. Reconstr. Hand. Surg., 31, 213-219.

Romerosa, A., Bergamini, P., Bertolasi, V., Canella, A., Cattabriga, M., Gavioli, R., Mañas, S., Mantovani, N., Pellacani, L. 2004. Biologically active platinum complexes containing 8-thiotheophylline and 8-(methylthio) theophylline. Inorg. Chem., 43, 905-913.

Sheldrick, G.M. 2015. Crystal structure refinement with SHELXL. Acta Cryst. C, 71, 3-8.

Sheldrick, G.M.. 2008. A short history of SHELX.2008. Acta Cryst. A, 64, 112-122.

Srinivas, N., Radha Kishan, M., Kulkarni, S.J., Raghavan, K.V. 2000. Ammoxidation of picolines over modified silicoaluminophosphate molecular sieves. Microporous Mesoporous Mater., 39, 125-134.

Tessier, C., Rochon, F.D. 1999. Multinuclear NMR study and crystal structures of complexes of the types cis- and trans-$Pt(Ypy)_2X_2$, where Ypy=pyridine derivative and X=Cl and I. Inorg. Chim. Acta, 295, 25-38.

Tunçay, M., Çaliş, S., Kaş, H.S., Ercan, M.T., Peksoy, I., Hincal, A.A. 2000. Diclofenac sodium incorporated PLGA (50: 50) microspheres: formulation considerations and in vitro/in vivo evaluation. Int. J. Pharm., 195, 179-188.

Tzeng, B.C., Chan, S.C., Chan, M.C.W. Che, C.M., Cheung, K.K., Peng, S.M.2001. Palladium(II) and platinum(II) analogues of luminescent diimine triangulo complexes supported by triply bridging sulfide ligands: structural and spectroscopic comparisons. Inorg. Chem., 40, 6699-6704.

Wang, Z., Cohen, S.M. 2009. Postsynthetic modification of metal-organic frameworks Chem. Soc. Rev., 38, 1315-1329.

Zampakou, M., Hatzidimitriou, A.G., Papadopoulos, A.N., Psomas, G. 2015. Neutral and cationic manganese (II)-diclofenac complexes: structure and biological evaluation. J. Coord. Chem., 68, 4355-4372.

Zhang, J.P., Huang, X.C., Chen, X.M. 2009. Supramolecular isomerism in coordination polymers. Chem. Soc. Rev., 38, 2385-2396.