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# Synthesis, spectroscopic characterization and quantum chemical computational studies on 1-acetyl-3,5-di(4-methylphenyl)-1*H*-pyrazole

Ersin İnkaya<sup>a,\*</sup>, Muharrem Dinçer<sup>a</sup>, Elif Korkusuz<sup>b</sup>, İsmail Yıldırım<sup>c</sup>, Orhan Büyükgüngör<sup>a</sup>

<sup>a</sup> Department of Physics, Faculty of Arts and Sciences, Ondokuz Mayıs University, 55139 Kurupelit, Samsun, Turkey
 <sup>b</sup> Erciyes University, Kayseri Vocational College, 38039 Kayseri, Turkey
 <sup>c</sup> Department of Chemistry, Faculty of Arts and Sciences, Erciyes University, 38039 Kayseri, Turkey

# HIGHLIGHTS

▶ Pyrazole, X-ray single crystal diffraction.

► Density functional theory (DFT) and Hartree–Fock (HF).

▶ Molecular electrostatic potential (MEP) distribution and non-linear optical properties (NLO).

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# ABSTRACT

The pyrazole compound 1-acetyl-3,5-di(4-methylphenyl)-1*H*-pyrazole, ( $C_{19}H_{18}N_2O$ ), was characterized by X-ray single crystal diffraction technique, IR–NMR spectroscopy and quantum chemical computational methods as both experimental and theoretically. The compound crystallizes in the monoclinic space group C 2/c with *a* = 32.5334 (1) Å, *b* = 5.8060 (1) Å, *c* = 23.6519 (8) Å, *β* = 134.572 (2)°, and *Z* = 8. The molecular geometry was also optimized using the Hartree–Fock (HF) and density functional theory (DFT/B3LYP) methods with the 6-311G(d,p) basis set and compared with the experimental data. To determine conformational flexibility, molecular energy profile of the tittle compound was obtained by semi-empirical (AM1) with respect to selected degree of torsional freedom, which was varied from –180° to +180° in steps 10°. From the optimized geometry of the molecular vibrational frequencies, gauge-independent atomic orbital (GIAO) <sup>1</sup>H and <sup>13</sup>C NMR chemical shift values, molecular electrostatic potential (MEP) distribution, non-line ar optical properties, frontier molecular orbitals (FMOs) of the title compound have been calculated in the ground state theoretically. The theoretical result showed good agreement with the experimental values © 2012 Elsevier B.V. All rights reserved.

#### 1. Introduction

Many natural products have the pyrazole unit as the core structure [1]. Pyrazole derivatives exhibit important biological properties such as antitumor [2], anticoagulant [3], anti-hyperglycemic, analgesic, anti-inflammatory, anti-pyretic, antibacterial, hypoglycemic and sedative-hypnotic activity [4–6]. These derivatives have attracted significant attention because of the application in drug development [7]. Particularly, arylpyrazoles are important in medicinal and pesticidal chemistry [8]; a number of herbicides with pyrazole moieties have been commercialized [9]. Recent literature shows that, some arylpyrazoles were reported to have non-nucleoside HIV-1 reverse transcriptase inhibitory activity [10,11]. They are also useful intermediates for many industrial products [12–14]. Due to the importance of the pyrazole nucleus, we believed it worthwhile to design and synthesize new pyrazole derivatives. In this paper, 1-acetyl-3,5-di(4-methylphenyl)-1*H*-pyrazole was like prepared chloride by the reaction of 3,5-bis(4-methyphenyl)-1*H*-pyrazole with acetyl chloride and characterized by elemental analysis, FT-IR, <sup>1</sup>H, <sup>13</sup>C-NMR and elemental analysis, and the product is completely original. The title compound is a novel compound synthesized firstly in our laboratories by us.

Investigations into the structural stability of these compounds using both experimental techniques and theoretical methods have been of interest for many years. With recent advances in computer hardware and software, it is possible to correctly describe the physico-chemical properties of molecules from first principles using various computational techniques [15]. In recent years, density functional theory (DFT) has been the shooting star in theoretical modeling. The development of ever better exchange–correlation functionals has made it possible to calculate many molecular properties with accuracies comparable to those of traditional correlated *ab initio* methods, at more favorable computational costs [16].

<sup>\*</sup> Corresponding author. Tel.: +90 362 3121919/5256; fax: +90 362 4576081. *E-mail address:* ersin.inkaya@oposta.omu.edu.tr (E. İnkaya).

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Literature surveys have revealed the high degree of accuracy of DFT methods in reproducing the experimental values in terms of geometry, dipole moment, vibrational frequency, etc. [17–22].

In this study, we present results of a detailed investigation of the synthesis and structural characterization of the title compound using single crystal X-ray diffraction, IR and NMR spectroscopy and quantum chemical methods. The geometrical parameters, fundamental frequencies and GIAO <sup>1</sup>H and <sup>13</sup>C NMR chemical shift values of the title compound in the ground state have been calculated by using the HF/6-311G(d,p) and B3LYP/6-311G(d,p) methods. This calculation is valuable for providing insight into molecular parameters and the vibrational spectrum and NMR spectrum. The aim of this work is to explore the molecular dynamics and the structural parameters that govern the chemical behavior, and to compare predictions made from theory with experimental observations.

# 2. Experimental and theoretical methods

# 2.1. Experimental

#### 2.1.1. Synthesis

The starting material (3,5-di(4-methylphenyl)-1*H*-pyrazole) was prepared from the reaction of 1,3-di(4-methylbenzoyl)methane [23–25] with hydrazine monohydrate in ethanol by us. An equimolar mixture of 3,5-di(4-methylphenyl)-1*H*-pyrazole (0.5 g, 1.7 mmol) and acetyl chloride (0.15 g, 1.7 mmol) was refluxed in xylene for 3 h by adding 2–3 drops pyridine. The solvent was evaporated, then the oily residue was treated with diethyl ether and the formed crude product was recrystallized from methanol. (Yield: 85%; M.p. 85 °C). Analysis calculated for C<sub>19</sub>H<sub>18</sub>N<sub>2</sub>O (290.36 g/mol): C 78.59, H 6.25, N 9.65%; found: C 78.63, H 6.24, N 9.64% (Scheme.1).

# 2.1.2. General remarks

Melting points were measured on an Electro thermal 9200 apparatus and are uncorrected. Microanalysis for C and H was performed using a Leco-932 CHNS-O elemental analyzer. The IR spectra of the compound were recorded in the range of 400–4000 cm<sup>-1</sup> region using a Shimadzu FT-IR 8400 model spectrometer with KBr pellets. The <sup>1</sup>H and <sup>13</sup>C NMR spectra were measured



Scheme 1. The formation of the title compound.

with Bruker Avance III 400 MHz spectrometers and the chemical shifts were recorded in ppm units. After completion of the reactions, solvents were evaporated with rotary evaporator (Heildolph 4001 G1). All other reagents were purchased from Merck, Fluka, Aldrich and used without further purification.

# 2.1.3. Crystallography

The single-crystal X-ray data were collected on a STOE IPDS II image plate diffractometer at 296 K. Graphite-monochromated Mo K $\alpha$  radiation ( $\lambda$  = 0.71073 Å) and the w-scan technique were used. The structure was solved by direct methods using SHELXS-97 [26] and refined through the full-matrix least-squares method using SHELXL-97 [27], implemented in the WinGX [28] program suite. Non-hydrogen atoms were refined with anisotropic displacement parameters. All H atoms were located in a difference Fourier map and were refined isotropically. Data collection: Stoe X-AREA [29], cell refinement: Stoe X-AREA [29], data reduction: Stoe X-RED [29]. Details of the data collection conditions and the parameters of the refinement process are given in Table 1. The general-purpose crystallographic tool PLATON [30] was used for the structure analysis and presentation of the results.

# 2.2. Theoretical

The molecular structure of the compound in the ground state (*in vacuo*) was optimized using Hartree–Fock (HF) and density functional theory (DFT/B3LYP) [31,32] methods with the 6-311G(d,p) basis set. For modeling, the initial guess of the compound was first obtained from the X-ray coordinates. Then, vibrational frequencies for the optimized molecular structure were calculated with DFT/B3LYP method and then scaled by 0.9669 [33]. The geometry of the compound, together with that of Tetramethylsilane (TMS), is fully optimized. <sup>1</sup>H and <sup>13</sup>C NMR chemical shifts were calculated within GIAO approach [34,35] applying the same methods and the basis set as used for geometry optimization. The predicted <sup>1</sup>H and <sup>13</sup>C NMR chemical shifts were derived from the equation  $\delta = \Sigma_0 - \Sigma$ , where  $\delta$  is the chemical shift,  $\Sigma$  is the absolute shielding



Crystal data and structure refinement parameters for the title compound.

CCDC deposition no.	838,067
Color/shape	Colorless/Prism
Chemical formula	$C_{19}H_{18}N_2O$
Formula weight	290.35
Temperature (K)	296
Wavelength (Å)	0.71073 Μο Κα
Crystal system	Monoclinic
Space group	C2/c
Unit cell parameters	
a, b, c (Å)	32.5334 (1), 5.8060 (1), 23.6519 (8)
α, β, γ (°)	90, 134.572 (2), 90
Volume (Å <sup>3</sup> )	3182.56 (16)
Ζ	8
$D_{\text{calc}}$ (g/cm <sup>3</sup> )	1.212
$\mu (\mathrm{mm}^{-1})$	0.08
F(000)	1232
Crystal size (mm <sup>3</sup> )	$0.62\times0.55\times0.42$
Diffractometer/measurement	STOE IPDS $2/\omega$ scan
Index ranges	40 < b < 40  7 < b < 7
Index ranges	$-40 \le 1 \le 40, -7 \le K \le 7,$
$\theta$ range for data collection (°)	$-25 \leqslant i \leqslant 25$ $1.7 < \theta < 26.5$
Reflections collected	23079
Independent/observed reflections	3304/2752
R <sub>int</sub>	0.050
Refinement method	Full-matrix least-squares on F <sup>2</sup>
Data/restraints/parameters	3304/0/199
Goodness-of-fit on $F^2$	1.08
<i>R</i> indices $[I > 2\sigma(I)]$	$R_1 = 0.0552, wR_2 = 0.1672$
R indices (all data)	$R_1 = 0.0650, wR_2 = 0.1756$
$\Delta  ho_{ m max}$ , $\Delta  ho_{ m min}$ (e/Å <sup>3</sup> )	0.29, -0.26

and  $\Sigma_0$  is the absolute shielding of the standard (TMS), whose values are 32.46 and 196.41 ppm for HF, and 31.99 and 184.79 ppm for B3LYP methods with the 6-311G(d,p) basis set, respectively. All the calculations were performed without specifying any symmetry for the title molecule by using Gauss View molecular visualization program [36] and Gaussian 03 program package [37]. The effect of solvent on the theoretical NMR parameters was included using the default model IEF-PCM (Integral-Equation-Formalism Polarizable Continuum Model) [38] provided by Gaussian 03. Chloroform was used as solvent. In order to describe conformational flexibility of the title molecule, the selected torsion angles *T* (C4–C5–C8–N1) and T (C14–C13–C10–N2), was varied from  $-180^{\circ}$  to  $-180^{\circ}$  in every 10° and the molecular energy profile as a function of the selected torsional degree of freedom is obtained by performing single point calculations on the calculated potential energy surface, and the molecular energy profile was obtained at the AM1 level of theory. For the calculation of MEP [39,40], the same level theory

# 3. Results and discussion

B3LYP/6-311G(d,p), was used.

#### 3.1. Description of the crystal structure

The title compound, a DIAMOND [41] view of which is shown in Fig. 1, is a crystallizing in the monoclinic space group  $C 2_1/c$  with eight molecules in unit cell. The asymmetric unit of the compound consists of one independent molecule. The atomic coordinates and thermal parameters for the compound can be obtained from Supplementary material. The selected bond lengths and angles are listed in Table 2. The tittle molecule is composed of a central pyrazole ring, with an acetyl group connected to the 1-position of the ring and two 4-methylphenyl groups in the 3,5-positions. In the crystal structure, two (4-methylphenyl) groups are *cis* position with respect to the pyrazole ring.

The pyrazole ring is planar with a maximum deviation of -0.0025 (12) Å for atom C1. All bond lengths and bond angles for phenyl rings are within a normal range typical for such compounds. There are two obviously different C–N bond distances in the pyrazole ring, *viz*. C1=N2 and C3–N1. The C1=N2 bond length is all longer than and C3–N1 bond length is all shorter than those found in similar structures [C=N 1.381 (2)–1.320 (2) Å, C–N 1.482(2)–1.515(9) Å] [42], resulting from the conjugation of the electrons of atom N with atom C. In this relation, this result is consistent with the respect to different pyrazole derivatives. The C11–O1 bond length is indicative of a significant double bond character. The dihedral angle between pyrazole ring with the phenyl rings (C4–C9) and (C13–C18) are 61.35 (1)° and 10.80 (2)°, respectively. Additionally, the dihedral angle between pyrazole ring with the acetyl group is 7.73 (4)°.



**Fig. 1.** A view of the title compound showing the atom-numbering scheme. Displacement ellipsoids are drawn at the 40% probability level and H atoms are shown as small spheres of arbitrary radii. Hydrogen bonds are indicated by broken lines.

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Experimental and optimized geometrical parameters of the title compound.

Parameters	Experimental	Calculated	
		HF/6-311G(d,p)	B3LYP/6-311G(d,p)
Bond lengths (Å)			
N1-N2	1.373 (2)	1.350	1.366
N1-C3	1.381 (2)	1.375	1.394
N1-C11	1.418 (3)	1.404	1.424
N2-C1	1.320 (2)	1.289	1.322
01–C11	1.203 (2)	1.182	1.204
C10–C7	1.507 (3)	1.509	1.508
C7–C6	1.368 (3)	1.382	1.395
C6-C5	1.387 (3)	1.388	1.392
C5-C4	1.379 (3)	1.383	1.399
C4–C9	1.383 (3)	1.392	1.401
C9–C8	1.374 (3)	1.376	1.386
C11–C12	1.485 (3)	1.506	1.509
C16-C19	1.507 (3)	1.510	1.508
RMSD <sup>a</sup>		0.06	0.01
Bond angles (°)			
N2-N1-C3	111.42 (15)	111.08	115.55
N2-N1-C11	118.70 (15)	118.89	118.49
C1-N2-N1	105.36 (14)	106.80	106.05
N2-C1-C13	120.28 (16)	121.61	121.18
N2-C1-C2	110.63 (16)	110.40	110.48
01-C11-N1	119.58 (18)	121.08	120.99
01–C11–C12	124.4 (2)	123.35	123.93
N1-C11-C12	116.06 (16)	115.55	115.06
C17-C16-C19	121.13 (19)	121.47	120.84
C6-C7-C10	121.4 (2)	121.56	121.39
C4—C5—C6	120.0 (2)	120.70	120.86
C5–C4–C9	118.17 (18)	118.58	118.20
C9–C4–C3	121.51 (18)	122.12	122.93
C3-C2-C1	106.82 (18)	105.77	106.64
RMSD <sup>a</sup>		0.09	1.10
Dihedral angles (°)			
C11-N1-N2-C1	173.39(17)	174.65	173.97
N1-N2-C1-C2	-0.5 (2)	-0.19	-0.25
C9-C4-C3-N1	61.5(3)	58.23	51.16
N2-N1-C11-01	-172.09(19)	-177.34	-177.08

<sup>a</sup> RMSD (root mean of square deviation) computed using theoretical methods and those obtained from X-ray diffraction.

The crystal structure does not exhibit intermolecular,  $X-H\cdots$ Cg ( $\pi$ -ring) (edge-to-face) or  $\pi$ - $\pi$  stacking (face-to-face) interactions. There are, however, one C-H···N intramolecular interaction, details of which is given in Table 3. An intramolecular C12-H···N2 contact leads to the formation of a five-membered ring with graph-set descriptor *S*(5) [43]. The packing is further stabilized by Van der Waals forces.

# 3.2. Optimized structures

The molecular structure of the title compound was also studied theoretically. The starting coordinates were those obtained from the X-ray structure determination. Some selected geometric parameters experimentally obtained and theoretically calculated by using the Hartree–Fock (HF) and density functional theory (DFT/B3LYP) methods with the 6-311G(d,p) basis set are listed in Table 2.

As can be seen in Table 2, most of the optimized bond lengths are slightly longer than the experimental values and the optimized bond angles are slightly different from the experimental values due to the difference of the studied molecular states. The isolated molecule is considered in gas phase in the theoretical calculation, while the experimental results are related to the molecular packing in solid state. According to X-ray study, the dihedral angle between the pyrazole ring with the phenyl rings (C4–C9) and (C13–C18) are 61.35 (1)° and 10.80 (2)°, whereas the dihedral angles have been calculated 56.72° and 11.94(2)° for HF and 49.30° and 4.55° DFT/B3LYP methods with 6-311G(d,p) level. The calculated D–H,

Table 3Hydrogen bonding geometry for the title compound.

-					
	D—H····A	D—H (Å)	H···A (Å)	$D \cdots A(Å)$	D−−H···A (°)
	C12—H12A · · · N2	0.96	2.22	2.738 (3)	113
	<i>HF/6-311G(d,p)</i> C12—H12A↔N2	1.08	2.66	2.71	81
	B3LYP/6-311G(d,p) C12—H12A⋯N2	1.09	2.65	2.72	81.76

Note: The atom numbering according to Fig. 1 used.

H···A, D···A and D–H···A values for this interactions are 1.08 Å, 2.66 Å, 2.71 Å and  $81.00^{\circ}$  for HF and 1.09 Å, 2.65 Å, 2.72 Å and  $81.76^{\circ}$  for B3LYP methods with 6-311G (d,p), respectively.

The root mean square deviation (RMSD) values for bond lengths are 0.06 and 0.01 for HF and DFT/B3LYP methods, respectively. Consequently, DFT correlates a little better for the geometrical parameters than the HF method.

#### 3.3. Vibrational spectra

The FT-IR spectrum of the title compound were recorded in the  $4000-400 \text{ cm}^{-1}$  region using KBr pellets on a Shimadzu FT-IR 8400 model spectrometer and given with theoretical ones in Fig. 2. It is

well known that the calculated HF and DFT 'raw' or 'non-scale' harmonic frequencies can significantly overestimate experimental values due to lack of electron correlation insufficient basis sets and anharmonicity. Harmonic vibrational frequencies of the title compound were calculated by using density functional theory (DFT/B3LYP) methods with the 6-311G(d,p) basis set. Frequency calculations revealed no imaginary frequencies, indicating that an optimal geometry at these levels of approximation was found for the title compound. We compared our calculation for the title compound with the experimental results. Theoretical and experimental results of the title compound are shown in Table 4. The vibrational bands assignments have been made by using Gauss View [36] molecular visualization program. The agreement between the experimental and calculated frequencies is satisfactory in general.

In the higher frequency region, almost all of the vibrations belong to CH<sub>3</sub> and ring CH stretching vibrations. The CH and CH<sub>3</sub> symmetrical and asymmetrical stretching vibrations are observed at 2849–3030 cm<sup>-1</sup> range and theoretically these frequencies have been calculated at 2922–3099 cm<sup>-1</sup> region for DFT/B3LYP method with 6-311G(d,p) level.

In the pyrazole ring, the C=N and C=C stretching modes were found at 1585 cm<sup>-1</sup> as experimentally. These modes were calculated at 1566 cm<sup>-1</sup> for same method. The tittle compound shows a strong band at 1742 cm<sup>-1</sup> which is assigned to  $\nu$ C=O stretching.



Fig. 2. (a) Experimental and (b) theoretical FT-IR spectrum of the title compound.

 Table 4

 Comparison of the observed and calculated vibrational spectra of the title compound.

Assignments	Experimental IR with KBr $(cm^{-1})$	Calculate B3LYP/6-	Calculated B3LYP/6-311G(d,p)	
		Scal.	I (km/	
		1104.	-	
$v_{\rm s}C$ —H (R)	3030	3099	6	
$v_{\rm s}C$ —H (R)	-	3093	3	
$v_{\rm s}C$ —H (R)	-	3077	13	
$v_{\rm s}C$ —H (R)	_	3076	11	
$v_{as}C-H(R)$	3010	3055	19	
$v_{as}C-H(R)$	-	3054	18	
$v_{as}C-H(R)$	-	3053	24	
$v_{as}C-H(R)$	-	-	-	
$v_{as}C-H_3$	2928	3052	14	
$v_{as}C-H_3$	-	2999	18	
$v_{as}C-H_3$	-	3000	19	
$v_sC-H_3$	2849	2999	21	
$v_sC-H_3$	-	2922	35	
v C=0	1742	1748	350	
v C—C	1610	1602	16	
v C = C + v C = N	1585	1566	5	
$\theta$ (r)	-	1540	28	
<i>ρ</i> С—Н	1585	-	-	
ν C—N + ρ C—H	1501	1489	72	
$\delta C-H_3$	-	1450	44	
$\delta C - H_3$	-	1446	11	
$\delta$ C—H <sub>3</sub>	-	1435	11	
$\delta C - H_3$	-	1433	6	
ω C—H <sub>3</sub> + $ρ$	-	1430	19	
C—H				
$\omega C-H_3$	-	1420	10	
ω CH <sub>3</sub>	-	1415	4	
ν C—N + ω C—H <sub>3</sub>	-	1266	193	
$\rho$ C—H (R)	-	1201	32	
$\rho$ C—H (R)	-	1193	3	
$\beta$ C—N—N (r)	-	-	-	
v N—N (r)	-	1175	14	
<i>ρ</i> С—Н	-	1150	33	
$\rho$ C—H	-	1106	19	
$\rho$ C—H <sub>3</sub>	-	1089	10	
ho C—H (r)	-	1057	7	
$\beta_{deformation}(\mathbf{r})$	-	922	116	
ω C—H (R)	-	812	16	
ω C—H (R)	-	800	67	

Vibrational modes: v, stretching;  $\delta$ , scissoring;  $\rho$ , rocking;  $\omega$ , wagging;  $\beta$ , in-plane bending;  $\theta$ , ring breathing. Abbreviations: s, symmetric; as, asymmetric; R, benzene ring; r, pyrazole ring.

The stretching vC=O vibration gives rise to a band in the experimental infrared spectrum at 1742 cm<sup>-1</sup>, and the calculated value is predicted to be  $6 \text{ cm}^{-1}$  higher at 1748 cm<sup>-1</sup> for B3LYP/6-311G(d,p). The C–C and C–N stretching vibrations are found to be 1601 and 1489 cm<sup>-1</sup> for the same level, respectively. The other calculated vibrational frequencies can be seen in Table 4.

# 3.4. NMR spectra

The characterization of the compound was further enhanced by the use of <sup>1</sup>H and <sup>13</sup>C NMR spectroscopy. The <sup>1</sup>H and <sup>13</sup>C NMR spectra of the compound recorded in chloroform (CDCl<sub>3</sub>) solution at 298 K are shown in Fig. 3. In addition, theoretical <sup>1</sup>H and <sup>13</sup>C NMR chemical shift values of the compound have been computed using the same methods and the basis set for the two optimized geometries. The results of these calculations are tabulated in Table 5 together with the experimental values. Since experimental <sup>1</sup>H chemical shift values were not available for individual hydrogen atoms of CH<sub>3</sub> groups, we have presented the average of the computed values for these hydrogen atoms.

We have calculated <sup>1</sup>H chemical shift values (with respect to TMS) of 8.76–2.44 ppm for HF and 8.52–2.42 ppm for B3LYP methods with 6-311G(d,p) level, however, the experimental results

were observed to be in the range between 7.82 and 2.40 ppm, and so the proper assignments need careful interpretation. In the <sup>1</sup>H NMR spectra of the compound, the chemical shift values of C—H<sub>3</sub> protons were observed to be 2.40(H10), 2.83(H12) and 2.40(H19) ppm, respectively. These signals have been calculated as 2.50, 2.64 and 2.44 ppm for HF, and 2.46, 2.69 and 2.42 ppm for B3LYP methods with the 6-311G(d,p) level, respectively. The CH hydrogen of the pyrazole ring appears at 6.81 ppm, and these value is determined computationally at 6.80 ppm for HF/6-311G(d,p).

We have calculated <sup>13</sup>C chemical shift values (with respect to TMS) of 174.69–21.53 ppm for HF and 177.23–23.79 ppm for B3LYP methods with the 6-311G(d,p) level, however, the experimental results were observed to be 170.61–21.42 ppm. In the <sup>13</sup>C NMR spectrum, the C10, C2 and C11 signals were observed at 21.42, 109.61 and 170.61 ppm, that have been calculated at 21.61, 110.83 and 174.69 ppm for HF, and at 23.79, 115.12 and 177.23 ppm for B3LYP methods with the 6-311G(d,p) level, respectively.

The root mean square deviation (RMSD) values are 1.296 and 1.011 for HF and DFT/B3LYP methods, respectively. Consequently, DFT correlates a little better for the chemical shifts than the HF method.

# 3.5. Molecular electrostatic potential

The molecular electrostatic potential (MEP) is related to the electronic density and is a very useful descriptor in understanding sites for electrophilic attack and nucleophilic reactions as well as hydrogen-bonding interactions [44–46]. The electrostatic potential V(r) are also well suited for analyzing processes based on the "recognition" of one molecule by another, as in drug–receptor, and enzyme–substrate interactions, because it is through their potentials that the two species first "see" each other [47,48]. Being a real physical property V(r) can be determined experimentally by diffraction or by computational methods [49].

To predict reactive sites for electrophilic and nucleophilic attack for the title molecule, MEP was calculated by applying the DFT/ B3LYP) method and 6-311G(d,p) basis set for the optimized geometry. The negative (red) regions of MEP were related to electrophilic reactivity and the positive (blue) regions to nucleophilic reactivity shown in Fig. S1 (see Supplementary materials).

As can be seen in from the figure, there are two possible sites on the title compound for electrophilic attack. The negative regions are mainly over the O1 atom. The maximum values of negative and positive regions are -0.053 and 0.022 a.u., respectively. For the title compound, negative regions were calculated: the MEP value around O1. These results provide information concerning the region where the compound may have intra- or intermolecular interaction.

#### 3.6. Frontier molecular orbitals

The frontier molecular orbitals play an important role in the electric and optical properties, as well as in UV–Vis spectra and chemical reactions [50]. Fig. S2 (see Supplementary materials) shows the distributions and energy levels of the HOMO -1, HOMO, LUMO and LUMO+1 orbitals computed at the B3LYP/6-311 G(d,p) level for the title compound.

As can be seen from the figure, both the highest occupied molecular orbitals (HOMOs) and the lowest-lying unoccupied molecular orbitals (LUMOs) are delocalized over nearly the entire molecule and they are mostly the  $\pi$ -antibonding type orbitals. The value of the energy separation between the HOMO and LUMO is 4.857 eV. This large HOMO–LUMO gap automatically means high excitation energies for many excited state, a good stability and a high chemical hardness for the tittle compound.



**Fig. 3.** (a) <sup>1</sup>H NMR spectrum of the title compound. (b) <sup>13</sup>C NMR spectrum of the title compound.

 Table 5

 Experimental and theoretical <sup>13</sup>C and <sup>1</sup>H isotropic chemical shifts (ppm) for the title compound.

Atom	Experimental (CDCl <sub>3</sub> )	Calculated (CDCl <sub>3</sub> )	
		HF/6-311G(d,p)	B3LYP/6-311G(d,p)
C1	153.41	160.63	159.04
C2	109.61	110.83	115.12
C3	147.26	160.12	157.71
C4	126.14	134.29	135.80
C5	128.41	137.42	135.23
C6	129.04	132.52	133.79
C7	138.72	148.06	147.20
C8	129.04	133.27	133.61
C9	128.41	140.14	137.71
C10	21.42	21.61	23.79
C11	170.61	174.69	177.23
C12	22.30	26.03	27.67
C13	129.52	133.99	135.55
C14	128.88	134.95	131.43
C15	128.62	133.74	134.92
C16	139.15	148.37	147.49
C17	128.62	135.07	135.43
C18	128.88	134.00	130.85
C19	21.42	21.53	23.92
H2	6.81	6.80	6.89
H5	7.43	7.86	7.63
H6	7.30	7.69	7.56
H8	7.28	7.80	7.63
H9	7.40	8.00	7.89
H10 <sup>a</sup>	2.40 <sup>a</sup>	2.50 <sup>a</sup>	2.46 <sup>a</sup>
H12 <sup>a</sup>	2.83 <sup>a</sup>	2.64 <sup>a</sup>	2.69 <sup>a</sup>
H14	7.80	8.16	7.93
H15	7.20	7.73	7.58
H17	7.23	7.90	7.67
H18	7.82	8.76	8.52
H19 <sup>a</sup>	2.40 <sup>a</sup>	2.44 <sup>a</sup>	2.42 <sup>a</sup>
RMSD		1.296	1.011

*Note*: The atom numbering according to Fig. 1 used in the assignment of chemical shifts.

<sup>a</sup> Average.

# 3.7. Conformational analysis

Based on HF/6-311 G(d,p) and B3LYP/6-311 G(d,p) optimized geometry, the total energy of the title compound has been calculated

by these two methods. In order to define preferential position of 1*H*-pyrazole system with respect to two (4-methylphenyl) groups, a preliminary search of low-energy structures was performed using AM1 computation as a function of selected torsion angles *T* (C4—C5—C8—N1) and *T* (C14—C13—C10—N2). The respective value of selected torsion angles are  $-122.8^{\circ}$  and 168° in the X-ray structure, whereas corresponding value in optimized geometries is  $-126.19^{\circ}$  and  $168.18^{\circ}$  for HF/6-311G(d,p) and  $-133.96^{\circ}$  and  $175.53^{\circ}$ for B3LYP/6-311G(d,p).

Molecular energy profiles with respect to rotations about selected torsion angles are presented in Fig. S3 (see Supplementary materials). According to the results the low energy domains for *T* (C4–C5–C8–N1) are located at  $-160^{\circ}$  – $20^{\circ}$  and 20° having energy of 3.205, 3.206 and 3.205 eV., respectively, while they are located at  $-130^{\circ}$ ,  $-50^{\circ}$  and 50° having energy of 3.206, 3.206 and 3.207 eV, respectively, for *T* (C14–C13–C10–N2). The energy difference between the most favorable and most unfavorable conformers, which arises from the rotational potential barrier calculated with respect to the selected torsion angle, was calculated as 0.17660 eV for *T* (C4–C5–C8–N1) and as 0.0658 eV for *T* (C14–C13–C10–N2), when both selected degrees of torsional freedom are considered.

# 3.8. Non-linear optical effects

Non-linear optical (NLO) effects arise from the interactions of electromagnetic fields in various media to produce new fields altered in phase, frequency, amplitude or other propagation characteristics from the incident fields [51]. NLO is at the forefront of current research because of its importance in providing the key functions of frequency shifting, optical modulation, optical switching, optical logic, and optical memory for the emerging technologies in areas such as telecommunications, signal processing, and optical interconnections [52–54].

The calculations of the mean linear polarizability ( $\alpha_{tot}$ ) and the mean first hyperpolarizability ( $\beta_{tot}$ ) from the Gaussian output have been explained in detail previously and DFT has been extensively used as an effective method to investigate the organic NLO materials [55]. The total molecular dipole moment ( $\mu_{tot}$ ), linear polarizability ( $\alpha_{tot}$ ) and first-order hyperpolarizability ( $\beta_{tot}$ ) of the title compound were calculated at the B3LYP/6-311G(d,p) level. The

calculated values of  $\mu_{tot}$ ,  $\alpha_{tot}$  and  $\beta_{tot}$  are 1.46 D, 36.1399 Å<sup>3</sup> and 5.788 × 10<sup>-30</sup> cm<sup>5</sup>/esu. Urea is one of the prototypical molecules used in the study of the NLO properties of molecular systems. Therefore it was used frequently as a threshold value for comparative purposes. The values of  $\mu_{tot}$ ,  $\alpha_{tot}$  and  $\beta_{tot}$  of urea are 3.53 D, 4.1446 Å<sup>3</sup> and 0.5883 × 10<sup>-30</sup> cm<sup>5</sup>/esu obtained at the same level. Theoretically, the first-order hyperpolarizability of the title compound is of 9.8 times magnitude of urea. According to these results, the title compound is a good candidate of NLO material.

# 4. Conclusions

In this study, 1-acetyl-3,5-di(4-methyphenyl)-1H-pyrazole was synthesized and characterized by spectroscopic (FT-IR and NMR) and structural (single-crystal X-ray diffraction) techniques. To support the solid state structure, the geometric parameters, vibrational frequencies and <sup>1</sup>H and <sup>13</sup>C NMR chemical shifts of the title compound have been calculated using the density functional theory (DFT/B3LYP) method with the 6-311G(d,p) basis set, and compared with the experimental findings. As a consequence, it is found a good correlation between the experimental and computed values. It was noted here that the experimental results belong to solid phase and theoretical calculations belong to gaseous phase. In the solid state, the existence of the crystal field along with the intramolecular interactions and Van der Waals forces have connected the molecules together, which result in the differences of bond parameters between the calculated and experimental values. The MEP map agrees well with the solid state interactions. More commonly, however, the NMR spectrum is used in conjunction with other forms of spectroscopy and chemical analysis to determinate the structures of complicated organic molecules. Nonlinear optical properties of the title compound have also been investigated. We hope the results are of assistance in the quest of experimental and theoretical evidence for the title compound as a reaction intermediate, nonlinear optical and photoelectronic material.

# Appendix A. Supplementary material

The figures related to the molecular electronic potential map, molecular orbital surfaces and molecular energy profile of the title compound are given in the supplementary material. CCDC 838067 contains the supplementary crystallographic data for the compound reported in this paper. These data can be obtained free of charge at www.ccdc.cam.ac.uk/conts/retrieving.html [or from the Cambridge Crystallographic Data Centre (CCDC), 12 Union Road, Cambridge CB2 1EZ, UK; fax: +44 (0)1223 336033; e-mail: deposit@ccdc.cam.ac.uk]. Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/ 10.1016/j.molstruc.2012.06.013.

#### References

- J. Elguero, in: A.R. Katrinsky, C.W. Rees, E.F.V. Scriven (Eds.), Comprehensive Heterocyclic Chemistry, vol. 7, Pergamon, Oxford, 1996, p. 1.
- [2] F. Wei, B.-X. Zhao, B. Huang, L. Zhang, C.-H. Sun, W.-L. Dong, D.-S. Shin, J.-Y. Miao, Bioorg. Med. Chem. Lett. 16 (2006) 6342.
- [3] Y. Xia, Z.-W. Dong, B.-X. Zhao, X. Ge, N. Meng, D.-S. Shin, J.-Y. Miao, Bioorg. Med. Chem. 15 (2007) 6893.
- [4] B. Cottineau, P. Toto, C. Marot, A. Pipaud, J. Chenault, Bioorg. Med. Chem. Lett. 12 (2002) 2105.
- [5] K.Y. Lee, J.M. Kim, J.N. Kim, Tetrahedron Lett. 44 (2003) 6737.
- [6] Z.J. Jia, Y. Wu, W. Huang, P. Zhang, Y. Song, J. Woolfrey, U. Sinha, A.E. Arfsten, S.T. Edwards, A. Hutchaleelaha, S.J. Hollennbach, J.L. Lambing, R.M. Scarborough, B.-Y. Zhu, Bioorg. Med. Chem. Lett. 14 (2004) 1229.
- [7] M.P. Donohue, D.A. Marchuk, H.A. Rockman, J. Am. Coll. Cardiol. 48 (2006) 1289.
- [8] W.L. John, R.M. Patera, M.J. Plummer, B.P. Halling, D.A. Yuhas, Pest. Sci. 42 (1994) 29.

- [9] K. Hirai, A. Uchida, R. Ohno, in: P. Boger, K. Hirai, K. Wakabyashi, K. Herbicide (Eds.), Classes in Development, Springer-Verlag, Heidelberg, 2002, pp. 279– 289.
- [10] M.J. Genin, C. Biles, B.J. Keiser, S.M. Poppe, S.M. Swaney, W.G. Tarpley, Y. Yagi, D.L. Romero, J. Med. Chem. 43 (2000) 1034.
- [11] D. Rambabu, G.R. Krishna, S. Basavoju, C.M. Reddy, M. Pal, J. Mol. Struct. 994 (2011) 332–334.
- [12] M.G. Mamolo, D. Zampieri, V. Falagiani, L. Vio, E. Banfi, Il Farmaco 56 (2001) 593–599.
- [13] C. Cativiela, J.L. Serrano, M.M. Zurbano, J. Org. Chem. 60 (1995) 3074-3083.
- [14] D. Wang, C.Y. Zheng, L. Fan, J. Mol. Struct. 938 (2009) 311-315.
- [15] Y. Zhang, Z.J. Guo, X.Z. You, J. Am. Chem. Soc. 123 (2001) 9378-9387.
- [16] F.D. Proft, P. Geerlings, Chem. Rev. 101 (2001) 1451-1464.
- [17] G. Fitzgerald, J. Andzelm, J. Phys. Chem. 95 (1991) 10531–10534.
- [18] T. Ziegler, Pure Appl. Chem. 63 (1991) 873-878.
- [19] J. Andzelm, E. Wimmer, J. Chem. Phys. 96 (1992) 1280-1303.
- [20] G.E. Scuseria, J. Chem. Phys. 97 (1992) 7528-7530.
- [21] R.M. Dickson, A.D. Becke, J. Chem. Phys 99 (1993) 3898–3905.
- [22] B.G. Johnson, P.M.W. Gill, J.A. Pople, J. Chem. Phys. 98 (1993) 5612–5626.
   [23] N. Dege, I. Yıldırım, A. Güldeste, H. Inaç, İ. Koca, N. Kahveci, A. Özyetiş, O.
- Büyükgüngör, Acta Cryst. E 61 (2005) o60–o62. [24] İ. Yıldırım, İ. Koca, Kuwait J. Sci. Eng. 32 (2005) 49–60.
- [25] İ. Yıldırım, İ. Koca, M. Dinçer, J. Chem. Soc. Pakistan 30 (2008) 134–141.
- [26] G.M. Sheldrick, SHELXS-97, Program for the Solution of Crystal Structures, University of Göttingen, Germany, 1997.
- [27] G.M. Sheldrick, SHELXL-97, Program for Crystal Structures Refinement, University of Göttingen, Germany, 1997.
- [28] L.J. Farrugia, J. Appl. Crystallogr. 30 (1999) 837-838.
- [29] Stoe and Cie X-AREA (Version 1.18) X-RED32 (Version 1.04) Stoe and Cie, Darmstadt, Germany, 2002.
- [30] A.L. Spek, Acta Crystallogr. D 65 (2009) 148-155.
- [31] C. Lee, W. Yang, R.G. Parr, Phys. Rev. B 37 (1988) 785.
- [32] A.D. Becke, J. Chem. Phys. 98 (1993) 5648.
- [33] K.K. Irikura, R.D. Johnson III, R.N. Kacker, J. Phys. Chem. A 109 (2005) 8430– 8437.
- [34] R. Ditchfield, J. Chem. Phys. 56 (1972) 5688.
- [35] K. Wolinski, J.F. Hinton, P. Pulay, J. Am. Chem. Soc. 112 (1990) 8251.
- [36] R. Dennington II, T. Keith, J. Millam, Gauss View, Version 4.1.2, Semichem Inc., Shawnee Mission, KS, 2007.
- [37] M.J. Frisch, G.W. Trucks, H.B. Schlegel, G.E. Scuseria, M.A. Robb, J.R. Cheeseman, J.A. Montgomery Jr., T. Vreven, K.N. Kudin, J.C. Burant, J.M. Millam, S.S. Iyengar, J. Tomasi, V. Barone, B. Mennucci, M. Cossi, G. Scalmani, N. Rega, G.A. Petersson, H. Nakatsuji, M. Hada, M. Ehara, K. Toyota, R. Fukuda, J. Hasegawa, M. Ishida, T. Nakajima, Y. Honda, O. Kitao, H. Nakai, M. Klene, X. Li, J.E. Knox, H.P. Hratchian, J.B. Cross, V. Bakken, C. Adamo, J. Jaramillo, R. Gomperts, R.E. Stratmann, O. Yazyev, A.J. Austin, R. Cammi, C. Pomelli, J.W. Ochterski, P.Y. Ayala, K. Morokuma, G.A. Voth, P. Salvador, J.J. Dannenberg, V.G. Zakrzewski, S. Dapprich, A.D. Daniels, M.C. Strain, O. Farkas, D.K. Malick, A.D. Rabuck, K. Raghavachari, J.B. Foresman, J.V. Ortiz, Q. Cui, A.G. Baboul, S. Clifford, J. Cioslowski, B.B. Stefanov, G. Liu, A. Liashenko, P. Piskorz, I. Komaromi, R.L. Martin, D.J. Fox, T. Keith, M.A. Al-Laham, C.Y. Peng, A. Nanayakkara, M. Challacombe, P.M.W. Gill, B. Johnson, W. Chen, M.W. Wong, C. Gonzalez, J.A. Pople, Gaussian 03, Revision E.01, Gaussian, Inc., Wallingford CT, 2004.
- [38] E. Cancès, B. Mennucci, J. Tomasi, J. Chem. Phys. 107 (1997) 3032-3041.
- [39] P. Politzer, S.J. Landry, T. Warnheim, Phys. Chem. 86 (1982) 4767, http:// dx.doi.org/10.1021/j100221a024.
- [40] J.S. Murray, P. Lane, T. Brinck, P. Politzer, P. Sjoberg, J. Phys. Chem. 95 (1991) 14.
- [41] K. Brandenburg, DIAMOND, Demonstration Version 3.1.e, Crystal Impact GbR, Bonn, Germany, 2006.
- [42] J. Casanovas, A.M. Namba, S. Leon, G.L.B. Aquino, G.V.J. da Silva, C. Aleman, J. Org. Chem. 66 (2001) 3775.
- [43] J. Bernstein, R.E. Davis, L. Shimoni, N.-L. Chang, Angew. Chem. Int. Ed. Engl. 34 (1995) 1555–1573.
- [44] E. Scrocco, J. Tomasi, Adv. Quant. Chem. 11 (1978) 115-121.
- [45] F.J. Luque, J.M. Lopez, M. Orozco, Theor. Chem. Acc. 103 (2000) 343-345.
- [46] N. Okulik, A.H. Jubert, Internet Electron. J. Mol. Des. 4 (2005) 17–30.
- [47] P. Politzer, P.R. Laurence, K. Jayasuriya, J. McKinney, Environ. Health Persp. 61 (1985) 191.
- [48] E. Scrocco, J. Tomasi, Topics in Current Chemistry, vol. 7, Springer, Berlin, 1973. p. 95.
- [49] P. Politzer, D.G. Truhlar, Chemical Applications of Atomic and Molecular Electrostatic Potentials, Plenum, New York, 1981.
- [50] I. Fleming, Frontier Orbitals and Organic Chemical Reactions, Wiley, London, 1973.
- [51] Y.-X. Sun, Q.-L. Hao, W.-X. Wei, Z.-X. Yu, L.-D. Lu, X. Wang, Y.-S. Wang, J. Mol. Struct.: Theochem. 904 (2009) 74–82.
- [52] C. Andraud, T. Brotin, C. Garcia, F. Pellé, P. Goldner, B. Bigot, A. Collet, J. Am. Chem. Soc. 116 (1994) 2094–2102.
- [53] V.M. Geskin, C. Lambert, J.-L. Brédas, J. Am. Chem. Soc. 125 (2003) 15651– 15658.
- [54] M. Nakano, H. Fujita, M. Takahata, K. Yamaguchi, J. Am. Chem. Soc. 124 (2002) 9648–9655.
- [55] G.A. Babu, P. Ramasamy, Curr. Appl. Phys. 10 (2010) 214-220.