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Synthesis, Characterization and Crystal Structure of (2Z)-3-[(4-Methylphenyl)amino]-1-phenylbut-2-en-1-one

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Abstract The compound (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one was synthesized by the condensation reaction of benzoylacetone with *p*-methylaniline and structurally characterized by ¹H NMR, ¹³C NMR, IR, mass spectrometry, elemental analysis, TGA/DSC and single crystal X-ray diffraction. The title compound crystallizes in the orthorhombic space group *Pccn* (No. 56) with *a* = 17.0042(18) Å, *b* = 11.5826(13) Å, *c* = 14.0514(15) Å, *V* = 2767.5(5) Å³ and *Z* = 8. Data collection on 223(2) K resulted its structure with *R*1 = 0.0449, *wR*2 = 0.0980. The molecules in the unit cell are arranged in layers. The intramolecular hydrogen bonds of the type N–H···O were observed in the structure. The compound exhibits two distinct endothermic peaks at a temperature 94.70 °C and 232.60 °C corresponding to melting and boiling points respectively.

Keywords Synthesis · Spectroscopy · Crystal structure · (2Z)-3-[(4-Methylphenyl)amino]-1-phenylbut-2-en-1-one · Thermogravimetric Analysis

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Introduction

 β -Enaminones have been widely used as key precursors in organic synthesis [1-3], as well as synthons for different important heterocycles [4–6], antibacterial [7], anticonvulsant, anti-inflammatory [8], antitumour agents [9], and naturally occurring alkaloids [10]. Therefore, development of new synthetic methods has received considerable attention. In 1961, Martin [11] reported one of the most important ways to prepare β -enaminones, via the direct condensation of β -dicarbonyl compounds with amines in a refluxing aromatic solvent. In recent years, this reaction was investigated in depth and detail, mainly focusing on improving the reaction conditions. This has led to the development of interesting reaction systems, such as those catalyzed by K-10 clay [12], NaAuCl₄ [13]. $Zn(ClO_4)_2 \cdot 6H_2O$ [14]. ionic liquids [15]. $CeCl_3 \cdot 7H_2O$ [16], $ZrCl_4$ [17], and ytterbium triflate [18]. Nevertheless, the application of these systems suffers from one or more disadvantages, such as using expensive or less readily available reagents, toxic solvents, drastic reaction conditions, long reaction times, unsatisfactory yields and/or low selectivity. Therefore, the development of facile and green synthetic methods is still in high demand.

Formic acid or methanoic acid (HCOOH) is widely used as acid catalyst in organic synthesis since it is relatively inexpensive, and merits high volatility and easy work-up. Accordingly, it has emerged as a key replacement for conventional acidic catalysts in organic synthesis. In this paper, we report the synthesis, characterization and crystal structure of the product derived from 1:1 condensation of benzoylacetone with *p*-methylaniline using formic acid as a catalyst, where the keto- and amino- groups are aromatic substituents.



Scheme 1 Synthesis of (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one

Experimental

General Information on Reagents and Techniques

The reaction was carried out under aerobic conditions. All reagents were of analytical grade; they were purchased and without further purification. Benzovlacetone, used *p*-methylaniline and formic acid were procured commercially from Sigma-Aldrich Chemical Company and were used without further purification. Nuclear magnetic resonance (NMR) spectra were obtained using a 10 to 25% solution in deuterochloroform (CDCl₃). ¹H and ¹³C NMR spectra were recorded on a Varian Mercury 300 MHz spectrometer. Proton and carbon chemical shifts are reported in parts-permillion (δ) with respect to tetramethylsilane (TMS) as internal reference ($\delta = 0.0$ ppm). IR spectra were recorded on a Perkin Elmer Paragon 1000 FT-IR Spectrometer employing a KBr disc. Mass spectra were obtained on a GC-MS instrument operating in TOF-MI⁺ mode. CHN analysis was performed by Atlantic Microlab using an Exeter Analytical CE-440 Elemental Analyzer, and was within $\pm 0.4\%$ of the theoretical values. Thermogravimetric analyses (TGA) and melting/boiling point determinations were made using a TA Q600 simultaneous TGA/DSC instrument. A heating rate of 5 °C min⁻¹ was used, and samples (5–10 mg) were contained in a platinum pan. The sample compartment was purged with dry nitrogen at 50 mL min⁻¹ during analysis. TA Thermal Advantage software was used for data analysis. Single crystals suitable for X-ray diffraction study were obtained from methanol by slow evaporation at room temperature.

Synthesis of (2Z)-3-[(4-Methylphenyl)amino]-1-phenylbut-2-en-1-one

Benzoylacetone (1.62 g; 10.0 mmol) was dissolved in methanol (35 mL) and to this, *p*-methylaniline (1.07 g; 10.0 mmol) was added, followed by the addition of two drops of formic acid and the solution was refluxed for 6-8 h and cooled. The yellow colored solid formed was filtered and dried in air. The solid was recrystallized from

methanol to get a pure compound. The synthetic pathway described in this work is outlined in Scheme 1. Crystals suitable for X-ray analysis were grown by the slow evaporation method using methanol as the solvent. Overall yield 95%; m.p. 93-95 °C. Compound was analyzed for C₁₇H₁₇NO (calculated C 81.24, H 6.82, N 5.57, O 6.37%; found C 81.19, H 6.79, N 5.59, O 6.35%). ¹H NMR (CDCl₃, 300 MHz) δ: 2.11 (s, 3H, CH₃); 2.35 (s, 3H, CH₃); 5.87 (s, 1H, CH); 7.09-7.05 (m, 2H, ArH); 7.18-7.14 (m, 2H, ArH); 7.46-7.40 (m, 3H, ArH); 7.93-7.89 (m, 2H, ArH); 13.02 (s, 1H, NH). ¹³C NMR (CDCl₃, 75 MHz) δ : 20.3 (CH₃), 20.9 (CH₃), 93.8 (CH₂), 124.8, 126.9, 128.2, 129.7, 130.7, 135.7, 135.9, 140.0 (ArC), 162.6 (C-N), 188.4 (C=O). Mass data (TOF MS EI⁺): calculated for C₁₇H₁₇NO [M⁺] 251.1310, found: 251.1298. IR absorptions (KBr, cm⁻¹): 3445 (w), 3016 (w), 2921 (m), 1603 (s), 1506 (s), 1441 (s), 1323 (s), 1199 (s), 1155 (w), 1068 (s), 931 (m), 834 (s), 770 (s), 694 (m), 645 (w), 559 (m) 507 (s), 452 (w).

Crystal Structure Determination and Refinement

X-ray intensity data of 14993 reflections (of which 2535 unique) were collected at room temperature on a Rigaku XtaLAB mini diffractometer equipped with graphite monochromated Mo K α radiation (k = 0.71075 Å) [19, 20]. The crystal used for data collection was of dimensions $0.32 \times 0.18 \times 0.08$ mm. The intensities were measured by ϕ and ω scan mode for θ ranges 3.14–25.34°. Data were corrected for Lorentz and polarization factors. The structure was solved by direct methods using SHELXS97 [21]. Full-matrix least squares refinement was carried out using SHELXL97 [21]. All the hydrogen atoms bound to carbon atoms were placed at idealized positions and refined as riding atoms. The only H atom which was located on the electron density map is H1 (on N1). The final refinement cycles converged to an R = 0.0449 and wR(F2) = 0.0980for the observed data. Residual electron densities ranged from -0.200 to $0.130 \text{ e} \text{ Å}^{-3}$. The crystal data and the refinement results are given in Table 1. Selected bond lengths and bond angles are summarized in Table 2.

Empirical formula	C ₁₇ H ₁₇ NO
Formula weight	251.32
Temperature (K)	223 (2)
Wavelength (Å)	0.71075 Å
Crystal system	Orthorhombic
Space group	Pccn (No.56)
Unit cell dimensions	
a (Å)	17.0042 (18)
b (Å)	11.5826 (13)
c (Å)	14.0514 (15)
α (°)	90
β (°)	90
γ (°)	90
Volume (Å ³)	2767.5 (5)
Z	8
Density (calculated) (Mg m^{-3})	1.206
Absorption coefficient (mm ⁻¹)	0.075
F ₀₀₀	1,072
Crystal size	$0.32 \times 0.18 \times 0.08 \text{ mm}^3$
θ range for data collection	3.14–25.34°
Index ranges	$\begin{array}{l} -20 \leq h \leq 17, -13 \leq k \leq 13, \\ -15 \leq l \leq 16 \end{array}$
Reflections collected	14,993
Independent reflections	2535[R(int) = 0.0586]
Refinement method	Full-matrix least-squares on F^2
Completeness to θ_{\max}	99.8%
Max. and min. Transmission	0.9941 and 0.9765
Data/restraints/parameters	2535/0/180
Goodness-of-fit on F2	1.033
Final <i>R</i> indices $[I > 2\sigma(I)]$	R1 = 0.0449, wR2 = 0.0980
R indices (all data)	R1 = 0.0747, wR2 = 0.1087
Largest diff. peak and hole (e $Å^{-3}$)	0.130 and -0.200

 Table 1
 Crystal data and structure refinement of (2Z)-3-[(4-methyl-phenyl)amino]-1-phenylbut-2-en-1-one

Table 2 Selected bond lengths (Å) and bond angles (°) of (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one

Bond length	(Å)
O(1)–C(11)	1.2598(19)
N(1)-C(9)	1.345(2)
N(1)-C(5)	1.415(2)
C(1)–C(2)	1.507(2)
C(8)–C(9)	1.504(2)
C(9)–C(10)	1.373(2)
C(10)–C(11)	1.425(2)
C(11)–C(12)	1.494(2)
Bond angle	(°)
C(9)-N(1)-C(5)	131.02(15)
C(7)–C(2)–C(3)	117.22(17)
C(7)–C(2)–C(1)	121.52(16)
C(3)-C(2)-C(1)	121.24(16)
C(6)-C(5)-C(4)	118.99(16)
C(6)-C(5)-N(1)	124.45(16)
C(4)–C(5)–N(1)	116.42(15)
N(1)-C(9)-C(10)	119.63(16)
N(1)-C(9)-C(8)	120.21(16)
C(10)-C(9)-C(8)	120.13(16)
C(9)-C(10)-C(11)	124.63(16)
O(1)-C(11)-C(10)	123.14(16)
O(1)-C(11)-C(12)	118.30(15)
C(10)-C(11)-C(12)	118.53(15)
C(13)-C(12)-C(17)	118.71(16)
C(13)-C(12)-C(11)	122.06(15)
C(17)-C(12)-C(11)	119.23(15)

amino]-1-phenylbut-2-en-1-one is displayed in Fig. 2. The analysis of the crystal structure of (2Z)-3-[(4-methylphenyl) amino]-1-phenylbut-2-en-1-one evidences that it is coplanar. The title compound (2Z)-3-[(4-methylphenyl)amino]-1phenylbut-2-en-1-one has two aromatic rings and a central linkage. The crystal structure analysis shows that the angle between ring A [C(12)-C(13)-C(14)-C(15)-C(16)-C(17)]and ring B [C(4)–C(5)–C(6)–C(7)–C(2)–C(3)] is 1.73° (almost coplanar), the angle of ring A and central linkage [O(1)-C(11)-CC(10)-C(9)-N(1) is 32.75° and the angle between ring B and central linkage is 33.44°. The O(1)-C(11) and C(9)-C(10) bond distances [1.2598(19) and 1.373(2) Å, respectively] confirm the existence of the enamino-ketone [24]. The O=C-C=C-N linkage of the molecule (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one is planar; the bond lengths [C(9)-C(10) = 1.2598(19) and N(1)-C(9) = 1.345(2) Å] indicate electron delocalization. The C-C bond distances in both phenyl rings are in the normal range of 1.38-1.41 Å, which is characteristic of delocalized phenyl rings. The C-C-C bond angles are around 120°, with the variation being less than 2°, which is characteristic of sp²-hybridized carbons. A strong

Results and Discussion

Description of the Crystal Structure

The title compound (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one has been shown by ¹H NMR spectroscopy to exist in solution in the enamino-ketone and not the enol-imine form [22, 23]. IR spectroscopy shows only the enamino-ketone form in the solid state; this has been further confirmed in this study of its crystal structure. Compound (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one crystallizes in the orthorhombic space group *Pccn* (No. 56) and the structure with the corresponding atomic numbering scheme is shown in Fig. 1. The molecular packing diagram of (2Z)-3-[(4-methylphenyl)



Fig. 1 ORTEP diagram of (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one showing atom labeling scheme. 50% probability amplitude displacement ellipsoids are shown. Hydrogen atoms are omitted for clarity



Fig. 2 Perspective view of the molecular packing of (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one (hydrogen atoms not involved in H-bonds have been omitted)

intramolecular hydrogen bond between the enamine N atom and carbonyl O atom stabilizes the enamino-ketone. The molecular packing diagram (Fig. 2) shows three layers of molecules, which are independently arranged in the unit cell. In each layer, the molecules are alternatively parallel and perpendicular to each other in a *zig-zag* array.

¹H NMR and ¹³C NMR Spectroscopy

¹H NMR and ¹³C NMR spectra of the title compound (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one was recorded in CDCl₃ solvent and the spectra are presented in Figs. 3 and 4, respectively. The ¹H-NMR spectrum of



Fig. 3 ¹H NMR spectrum of (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one

the (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one exhibits four singlets at 13.02, 5.87, 2.35 and 2.11 ppm, which are due to NH, CH_2 , CH_3 (benzoylacetone) and CH_3 (*p*-methylaniline) protons respectively. Four multiplets at 7.09–7.05, 7.18–7.14, 7.46–7.40 and 7.93–7.89 ppm are attributed to the nine aromatic protons.

In ¹³C-NMR spectrum of the (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one, the carbonyl (C=O) carbon is observed at 188.4 ppm. Peaks at 162.6 and 93.8 ppm are due to carbons of the C–NH and CH groups, respectively. The methyl (CH₃) carbons of benzoylacetone and *p*-methylaniline appear at 20.9 and 20.34 ppm, respectively. Peaks at 124.8, 126.9, 128.2, 129.7, 130.7, 135.7, 135.9 and 140.0 ppm are attributed to the aromatic carbons.



Fig. 4 ¹³C NMR spectrum of (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one



FT-IR Spectrum

The FT-IR spectrum for the compound (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one is recorded in the region from 400 to 4000 cm^{-1} . It shows strong characteristic absorptions near 1603 (v_{as}) and 1545 cm⁻¹ (v_s) for the carbonyl group (C=O) and the weak absorption at 3445 $\text{cm}^{-1}(v)$ is typical of the NH group. Weak to medium absorptions around 3100-3000 cm⁻¹ observed, corresponding to the =C-H stretch of aromatic ring.

Mass Spectrum and Thermogravimetric Analysis

The mass spectrum of title compound (2Z)-3-[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one was analyzed by GC-MS. The peak observed at m/z 251.1298 suggested the molecular formula $C_{17}H_{17}NO$ of the title compound. The mass spectrum of the compound is shown in Fig. 5.

[(4-methylphenyl)amino]-1-phenylbut-2-en-1-one has been investigated using thermogravimetric techniques in the temperature range from 0 to 1000 °C at a heating rate of $10 \,^{\circ}\text{C min}^{-1}$. We observed a sharp endothermic peak at a temperature 94.70 °C from the temperature difference curve; it indicates that the compound melts at 94.70 °C as was expected from the melting point analysis (93-95 °C) of the compound. One additional endothermic peak occurred at a temperature of 232.60 °C, corresponding to boiling point of the compound. Onset of mass loss in the compound occurred at 137.47 °C and terminated at 248.34 °C as observed by weight loss curve of the TGA data in Fig. 6.

Supplementary Material

Crystallographic data for the structure reported in this article have been deposited with the Cambridge Crystallographic Data Center with the deposition number 862748. Copy of the data can be obtained free of charge from the Director, CCDC, 12 Union Road, Cambridge CB2 1EZ, UK [Fax: +44-1223-336-033; E-mail: deposit@ccdc.cam.ac.uk].

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