J Chem Crystallogr (2009) 39:157–162
DOI 10.1007/s10870-008-9446-3

ORIGINAL PAPER

Structures of Three Chalcones Derived from 6-Methoxy-2-naphthaldehyde

Jerry P. Jasinski · Ray J. Butcher · Anil N. Mayekar · H. S. Yathirajan · B. Narayana

Received: 9 March 2008 / Accepted: 10 July 2008 / Published online: 25 July 2008

Abstract In the molecular structures of three new structurally related chalcone derivatives, namely (2E)-1-(2-hydroxyphenyl)-3-(6-methoxy-2-naphthyl)prop-2-en-1-one, $C_{20}H_{16}O_3$, **I**, (2E)-1-(2-chloropyridin-4-yl)-3-(6-methoxy-2-naphthyl)prop-2-en-1-one, $C_{19}H_{14}ClNO_2$, **II**, and (2E)-3-(6-methoxy-2-naphthyl)-1-pyridin-4-ylprop-2-en-1-one, **III**, $C_{19}H_{15}NO_2$, the configuration of the keto group is *syn* with respect to the olefinic double bond. In all three structures the molecules pack with weak intermolecular C–H···O interactions utilizing both the methoxy and keto oxygen's in **I**, the methoxy oxygen in **II** and the keto oxygen in **III**. These interactions link the molecules into chains diagonally along the (011) plane of the unit cell in **I** and **III** and along the (010) plane in **II**. The dihedral angle between the phenyl and 2-napthyl rings in **I** is 31.7(3)°. In **II** and **III** the dihedral angle between the pyridyl and 2-naphthyl rings is 14.4(9)° and 1.8(9)°, respectively. C–H···O hydrogen bonding interactions influence these twist angles of these rings in **I**–**III** while weak π–π stacking interactions between naphthyl rings in **I** and **III** and also between pyridyl and naphthyl rings in **II** help stabilize crystal packing. [**I**: $P2_1/c$, $a = 7.6635(4)$ Å, $b = 11.8047(6)$ Å, $c = 16.7584(7)$ Å, $\beta = 99.271(5)°$, $V = 1496.25(13)$ Å^3; **II**: $Pbca$, $a = 14.1424(4)$ Å, $b = 6.0957(2)$ Å, $c = 33.1458(11)$ Å, $V = 2857.43(16)$ Å^3; **III**: $P2_1/c$, $a = 11.5155(4)$ Å, $b = 6.0020(2)$ Å, $c = 22.4645(8)$ Å, $\beta = 103.002(4)°$, $V = 1512.85(9)$ Å^3].

Keywords Chalcones · Crystal structure · Hydrogen bonds · Naphthyl · Pyridyl · Phenyl · Syn · Trans

Introduction

The present investigation is a continuation of our broad programme work on the synthesis and structural study of chalcones and its derivatives and to understand the geometrical features and the underlying intermolecular interactions which hold the assembly of molecules in the crystalline lattice. Chalcones exhibit various biological activities like insecticidal, antimicrobial, antichorniviral, antipicorniviral and bacteriostatic properties. Azachalcones, the derivatives of chalcones with an annular nitrogen atom in the phenyl ring, were reported to have a wide range of biological activities, such as antibacterial, antituberculostatic and anti-inflammatory. The 4-azachalcones and their N-alkyl derivatives were reported to be the most potent of the chalcone series as inhibitors of myeloperoxidase release from rat polymorphonuclear leukocytes and microtubule polymerization inhibitors which bind to the colchicines-binding site of microtubules [1–5]. We report here the crystal structures of three chalcones derived from 6-methoxy-2-naphthaldehyde, namely, (2E)-1-(2-hydroxyphenyl)-3-(6-methoxy-2-naphthyl)prop-2-en-1-one, $C_{20}H_{16}O_3$,

J. P. Jasinski (✉)
Department of Chemistry, Keene State College, 229 Main Street, Keene, NH 03435-2001, USA
e-mail: jjasinski@keene.edu

R. J. Butcher
Department of Chemistry, Howard University, 525 College Street NW, Washington, DC 20059, USA

A. N. Mayekar · H. S. Yathirajan
Department of Studies in Chemistry, University of Mysore, Manasagangotri, Mysore 570 006, India

B. Narayana
Department of Studies in Chemistry, Mangalore University, Mangalagngotri, Mangalore 574 199, India

I, (2E)-3-(6-methoxy-2-naphthyl)-1-pyridin-4-ylprop-2-en-1-one, **II**, $C_{19}H_{15}NO_2$, and (2E)-1-(2-chloropyridin-4-yl)-3-(6-methoxy-2-naphthyl)prop-2-en-1-one, $C_{19}H_{14}ClNO_2$, **III**.

Experimental

Synthesis of compounds **I–III** were carried out by adding to a mixture of 6-methoxy-2-naphthaldehyde (0.01 mol) and substituted ethanones (0.01 mol) in 40 mL of ethyl alcohol, 10–15 mL of 25% KOH drop wise with vigorous stirring for about 6–10 h. The crude products obtained in all three cases (Fig. 1) were filtered and recrystallized. The molecular formulae, compositions (Calculated), melting points and recrystallization solvents of each of the three chalcones are: Chalcone **I**: $C_{20}H_{16}O_3$, C: 78.86(78.93); H: 5.26(5.30); 371–373 K, Ethyl acetate; Chalcone **II**: $C_{19}H_{14}ClNO_2$, C: 70.39(70.48); H: 4.30(4.36.00);N: 4.28(4.33), 437–439 K, THF:Acetonitrile (1:1); Chalcone **III**: $C_{19}H_{15}NO_2$, C: 78.80(78.87); H: 5.18(5.23); N:4.39 (4.44), 450–452 K, THF: acetonitrile (1:1). The elemental analysis was measured using the instrument ELEMENTAR VARIO EL III, Hanau, Germany.

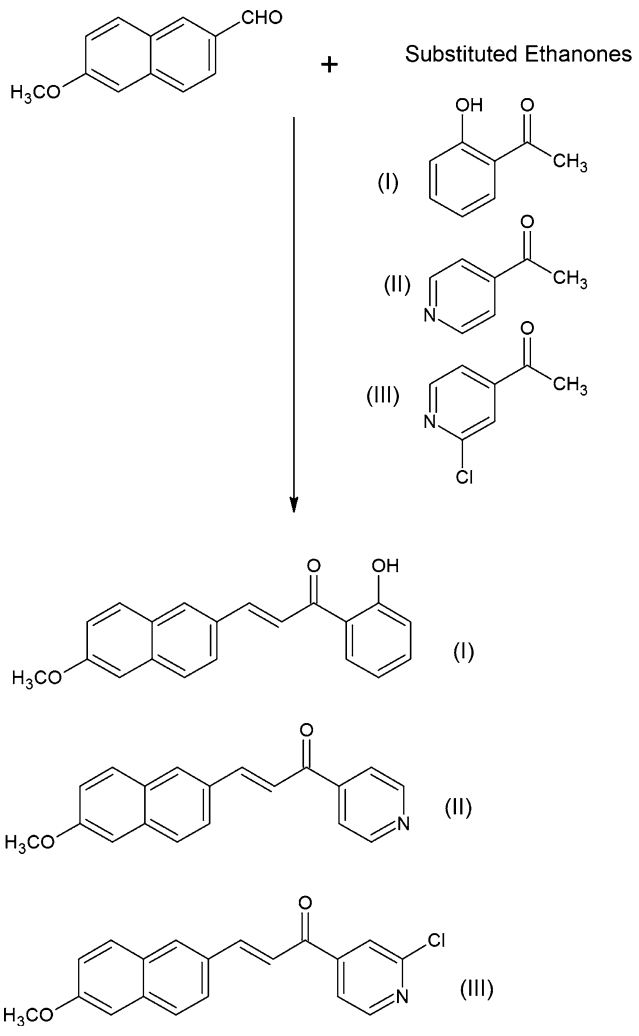

Fig. 1 Scheme for (**I**), (**II**) and (**III**)

Structure Determination and Refinement

X-ray analysis including data collection, cell refinement and data reduction was carried out with an Oxford Diffraction Gemini CCD using the *CrysAlisPro* software package [6]. Non-H atoms were refined anisotropically by full-matrix least-squares on F^2. Structure solution and refinement was completed with SHELXS97 [7] and SHELXL97 [7] and molecular graphics were carried out with SHELXTL [8]. In all three compounds [**I**, **II** and **III**] the H atoms were placed in their geometrically calculated places and refined using a riding model with C–H = 0.95 Å, and $U_{iso}(H) = 1.18–1.21U_{eq}(C)$ for aromatic, CH_3 (AFIX 137 in SHELXTL) and CH. This worked well for normal C–H bonds since most of the geometric parameters for these molecules are very similar to standard values [9]. In **I** the hydroxyl hydrogen, H10, was located in a difference map and then refined using a riding model with O–H = 0.84 Å, and with $U_{iso}(H) = 1.19U_{eq}(O)$ as this gives a true location of the atom bonded to a sp^3 hybridized oxygen (Table 1).

Results and Discussion

In the title compounds **I** ($C_{20}H_{16}O_3$), **II** ($C_{19}H_{15}NO_2$), and **III** ($C_{19}H_{14}ClNO_2$), the configuration of the keto group is *syn* with respect to the olefinic double bond [C7–C8–C(9)–C10 (II, III) = + 10.3(3); −0.69(19), C8–C9–C10–C11 (I) = − 13.68(16)°] (Figs. 2–4). The dihedral angle between the phenyl and 2-naphthyl rings in **I** is 31.7(3)°. The six-membered pyridyl ring in **II** is disordered with the slightly less predominant component (N–C3A–C2A–C1–C5A–C4A) forming a distorted chair configuration with Cremer & Pople [10] puckering parameters Q, θ and φ of 0.053(1)Å, 23.9(7)° and 314.954(5)°, respectively. In **II** and **III** the dihedral angle between the pyridyl (A component in **II**) and 2-naphthyl rings is 14.4(9)° and 1.8(6)° respectively. Geometric parameters are in normal ranges [9] (Table 2). Among the three compounds, weak intramolecular O–H···O interactions are only seen in **I** (Fig. 2). In all three structures the molecules pack with weak intermolecular C–H···O interactions utilizing both the methoxy and keto oxygen's in **I**, the methoxy oxygen in **II** and the keto oxygen in **III**, respectively (Table 3). These link the molecules into chains diagonally along the (011) plane of the unit cell in **I** and **III** and along the (101) plane

Table 1 Crystal and Experimental Data for **I**, **II** and **III**

	I	II	III
Formula	$C_{20}H_{16}O_3$	$C_{19}H_{15}NO_2$	$C_{19}H_{14}ClNO_2$
Formula weight	304.33	289.32	323.76
Crystal color, habit	Yellow-orange, chunk	Colorless, prism	Colorless, prism
Crystal size (mm)	0.48 × 0.37 × 0.25	0.51 × 0.45 × 0.22	0.49 × 0.44 × 0.31
Crystal System	Monoclinic	Orthorhombic	Monoclinic
Space Group	*P* $2_1/c$	*Pbca*	*P* $2_1/c$
Temperature (K)	200 (2)	200 (2)	200 (2)
a (Å)	7.6635 (4)	14.1424 (4)	11.5155 (4)
b (Å)	11.8047 (6)	6.0957 (2)	6.0020 (2)
c (Å)	16.7584 (7)	33.1458 (11)	22.4645 (8)
α (°)	90	90	90
β (°)	99.271 (5)	90	103.002 (4)
γ (°)	90	90	90
Volume Å^3	1496.25 (13)	2857.43 (16)	1512.85 (9)
Z	4	8	4
D_{calc} (g cm^{-3})	1.351	1.345	1.421
F (0 0 0)	640	1216	672
No. of Reflections [I > 2σ(I)]	4952	4870	4985
$2\theta_{max}$/° with Mo K_a	64.84	65.04	64.98
R,R_w [I > 2σ(I)]	0.0435, 0.1092	0.0715, 0.1757	0.0391, 0.1053
Goodness of fit on F^2	0.925	1.060	1.031
$(\Delta\sigma)_{max}$	0.000	0.000	0.000
$(\Delta\rho)_{max}$/e Å^{-3}	0.259	0.206	0.361
$(\Delta\rho)_{min}$/e Å^{-3}	−0.231	−0.327	−0.198
Measurement	GEMINI (Oxford Diffraction, 2007)		
Program System	CrysAlisPro		
Structure Determination	SHELXS97		
Refinement	Full-matrix least-squares on F^2 (SHELXL97)		

CCDC 680465 (**I**), 680467 (**II**), 680466 (**III**) contains supplementary crystallographic data for this paper. These data can be obtained free of charge from The Cambridge Crystallographic Data Centre via www.ccdc.cam.ac.uk/data_request/cif, or by emailing data_request@ccdc.cam.ac.uk, or by contacting The Cambridge Crystallographic Data Centre, 12, Union Road, Cambridge CB2 1EZ, UK; fax: +44-1223-336033

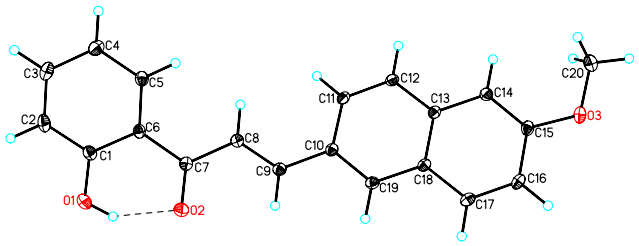

Fig. 2 Molecular structure of (**I**), drawn with 50% probability displacement ellipsoids and showing the atom labeling scheme. The dashed line indicates an intramolecular hydrogen bond, O1–H10···O2

in **II** (Figs. 5–7). In addition weak π–π stacking interactions are observed between naphthyl rings in **I** and **III** and also between pyridyl and naphthyl rings in **II**. The distance between the centroids of interacting rings is Cg2(**I**)···Cg2(**I**) = 3.644(9) Å (−x, 1−*y*, 1−*z*), Cg1(**III**)···Cg1(**III**) = 3.998(3) Å (2−*x*, 1−*y*, −*z*) and Cg1(**III**)···Cg2(**III**) = 3.797(8) Å (1−*x*, 1−*y*, −*z*), respectively [Cg2(**I**) = center of gravity of the 1st 2-naphthyl ring in **I** (C10–C11–C12–C13–C18–C19); Cg1(**III**) & Cg2(**III**) = center of gravity of the pyridyl and 1st 2-naphthyl ring in **III** (N–C3–C2–C1–C5–C4 and C9–C10–C11–C12–C17–C18)].

In contrast, the crystal structures of related chalcone derivatives $C_{18}H_{14}O_2S$ [11], $C_{20}H_{16}O_2$ [12], and $C_{27}H_{25}NO_4$ [13], show that these compounds are essentially planar with the central C=C double bond *trans*-configured and geometric parameters in normal ranges. In $C_{20}H_{16}O_2$ [12], its two C=C atoms are slightly twisted out of the naphthyl plane with the dihedral angle between the

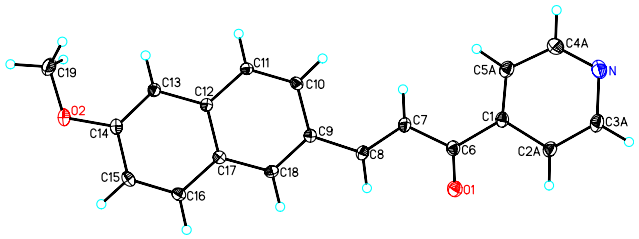

Fig. 3 Molecular structure of (**II**), drawn with 50% probability displacement ellipsoids and showing the atom labeling scheme. Disordered C2–C3, C4–C5 atoms in the pyridine ring are shown as PART A (C2A, C3A, C4A, C5A)

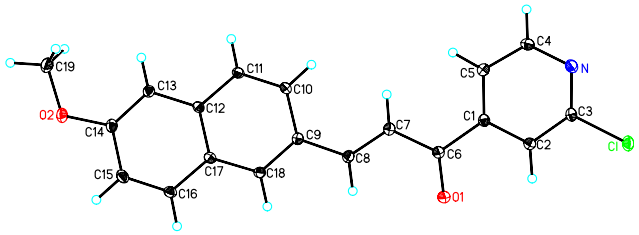

Fig. 4 Molecular structure of (**III**), drawn with 50% probability displacement ellipsoids and showing the atom labeling scheme

aromatic groups being 14.09(8)°. But the chalcone, viz., 1-(3-bromo-2-thienyl)-3-(6-methoxy-2-naphthyl)prop-2-en-1-one, $C_{18}H_{13}BrO_2S$ [14], is chiral due to the twist of the naphthalene and thienyl rings about the chalcone backbone [dihedral angle = 17.75 (10)°]. In addition, there are weak C–H···O interactions which link the molecules into chains along the *b* direction.

The role of the keto group in stabilizing the structure within the crystal environment as well packing effects can be examined by looking at its orientation relative to the methoxy napthaldehyde group and to its twist angles with the phenyl and pyridyl rings when compared to a theoretical semi empirical model based on atom sizes and bonding tendencies such as that provided by *MOPAC* [15].

MOPAC calculations on **I** and **III** were performed with *WebMO Pro*™ as implemented by *WeMO* [16]. The disordered pyridyl ring in **II** did not allow for a converged result, therefore will not be used in the subsequent analysis. The PM-3 (Parametric Model 3) approximation together with the Hartree-Fock closed-shell (restricted) wavefunction was used for **I** and **III** and minimizations were teminnated at an r.m.s. gradient of less than 0.01 kJ mol^{-1} $Å^{-1}$. When the refined atom coordinates in **I** are subjected to a *MOPAC* calculation the angle between the mean planes of the phenyl and 2-naphthyl groups become 54.01° (vs. 31.73° in crystal) and the angle between the mean planes of the keto group (C6–C7–O2–C8) and the phenyl and 2-napthyl groups become 27.24° and 36.26° (vs. 4.62° and 27.83° in crystal), respectively, in the local minimized structure. It is clear that inter and intramolecular hydrogen bonding effects influence these twist angle values for the molecule in this crystal. The repulsion of the H atoms at C8 and C11 is balanced by the π conjugation of the carbonyl and aryl groups as well as from intermolecular hydrogen bonding effects. The slight difference between the C7–O2 bond length (1.2429(13) Å crystal vs 1.245 Å *MOPAC*) indicates only slightly different degrees of conjugation of the sp^3 hybridized O2 atom. In **III,** the angle between the mean planes of the phenyl and 2-naphthyl groups becomes

Table 2 Selected bond lengths (Å), Bond angles (°), and Torsion angles (°) for (**I**), (**II**) and (**III**)

(**I**) $C_{20}H_{16}O_3$			
C6–C7	1.4817 (15)	C7–O2	1.2429 (13)
C7–C8	1.4612 (15)	C8–C9	1.3342 (14)
C9–C10	1.4559 (15)	C15–O3	1.3674 (13)
C1–O1	1.3473 (14)	C20–O3	1.4272 (14)
(**II**) $C_{19}H_{15}NO_2$			
C1–C6	1.503 (2)	C6–O1	1.226 (2)
C6–C7	1.472 (2)	C7–C8	1.335 (2)
C8–C9	1.457 (2)	C14–O2	1.369 (2)
(**III**) $C_{19}H_{14}ClNO_2$			
C1–C6	1.5096 (16)	C6–O1	1.2219 (14)
C6–C7	1.4727 (16)	C7–C8	1.3430 (16)
C8–C9	1.4568 (15)	C14–O2	1.3670 (14)
(**I**) $C_{20}H_{16}O_3$			
C5–C6–C7	122.34 (9)	C7–C8–C9	121.85 (10)
C9–C10–C11	121.82 (9)	C6–C7–C8	119.38 (9)
O2–C7–C6	119.75 (10)	O2–C7–C8	120.85 (10)
C15–O3–C20	117.38 (8)	C14–C15–O3	124.53 (10)
O1–C1–C2	117.56 (10)	O1–C1–C6	122.19 (10)
(**II**) $C_{19}H_{15}NO_2$			
C5A–C1–C6	125.9 (2)	C1–C6–C7	118.82 (16)
C8–C9–C10	122.48 (15)	C9–C10–C11	120.86 (15)
O1–C6–C1	119.27 (16)	O1–C6–C7	121.91 (17)
C14–O2–C19	117.80 (15)	C13–C14–O2	125.15 (16)
(**III**) $C_{19}H_{14}ClNO_2$			
C5–C1–C6	124.17 (10)	C1–C6–C7	119.22 (10)
C8–C9–C10	122.72 (10)	C9–C10–C11	121.21 (10)
O1–C6–C1	118.60 (10)	O1–C6–C7	122.18 (11)
C14–O2–C19	117.78 (10)	C13–C14–O2	124.90 (11)
(**I**) $C_{20}H_{16}O_3$			
C5–C6–C7–C8	−4.82 (15)	C8–C9–C10–C11	−13.68 (16)
C5–C6–C7–O2	173.88 (10)	C14–C14–O3–C20	−3.63 (16)
O1–C1–C6–C5	179.63 (10)	O1–C1–C6–C7	−2.48 (15)
(**II**) $C_{19}H_{15}NO_2$			
C5A–C1–C6–C7	−23.7 (4)	C7–C8–C9–C10	10.3 (3)
C5A–C1–C6–O1	155.9 (3)	C13–C14–O2–C19	7.6 (3)
(**III**) $C_{19}H_{14}ClNO_2$			
C5–C1–C6–C7	6.03 (18)	C7–C8–C9–C10	−0.69 (19)
C5–C1–C6–O1	−174.4 (12)	C13–C14–O2–C19	−4.96 (18)

Table 3 Hydrogen bonds for (**I**) $C_{20}H_{16}O_3$, (**II**) $C_{19}H_{15}NO_2$ and (**III**) $C_{19}H_{14}ClNO_2$ [Å and °]

D–H…A	d(D–H)	d(H···A)	d(D···A)	<(DHA)
I				
O(1)–H(1O)…O(2)	0.84	1.80	2.5403(11)	146.0
C(8)–H(8A)…O(3)#1	0.95	2.56	3.4810(13)	163.0
C(11)–H(11A)…O(3)#1	0.95	2.59	3.5381(13)	173.6
C(20)–H(20C)…O(2)#2	0.98	2.63	3.3164(16)	127.6
II				
C(3A)–H(3AA)…O(2)#3	0.95	2.52	3.314(4)	141.5
III				
C(8)–H(8A)…O(1)#4	0.95	2.58	3.4518(15)	153.2

Symmetry transformations used to generate equivalent atoms: (**I**) #1 x, −y + 3/2, z − 1/2, #2 −x,−y + 2,−z, (**II**) #3 x, −y + 3/2, z + 1/2, (**III**) #4 −x + 1,−y + 2,−z

58.43° (vs. 1.86° in crystal) and the angle between the mean planes of the keto group (C1–C6–O1–C7) and the phenyl and 2-naphthyl groups becomes 56.78° and 1.60° (vs. 56.78° and 1.60° in crystal), respectively, in the local minimized structure when subjected to the *MOPAC* calculation. These results indicate a pattern of similar effects due to hydrogen bonding interactions on the twist angle of these groups. The difference between the C6–O1, bond length [1.2219(14) Å crystal vs 1.218 Å MOPAC] also indicates only slightly different degrees of conjugation of the hydrogen bonded sp^3 hybridized O1 atom.

It is noted that the length of the *c*-axis of the unit cell of **III** (22.4645(8) Å) is much longer than that in **I** (16.7584(7) Å) even though they have the same space group (*P21/c*). Based on that fact that they both link the molecules into chains diagonally along the (011) plane of the unit cell and with the *a* and *b* axis of similar length, it would appear that this increase could be attributed to the presence of two intermolecular hydrogen bond interactions from the keto oxygen in **I** as well as a methoxy H-bond as compared to one keto oxygen H-bond interaction in **III** along with the presence of a chloro atom bonded to the pryidyl ring in the plane of the linked molecules in the *bc* plane (Figs. 5 and 7).

Further analysis of crystal packing in the title compounds reveals that there are short intermolecular steric contacts in all three structures between atoms of the naphthyl fragments of neighboring molecules in **I** [C(11)···C(19) (−*x*, 1−*y*, 1−*z*) = 2.540(5) Å], between the methoxy oxygen atom and chloro groups in **III** [Cl···O(2) (1 + *x*, ½ − *y*, −1/2 + *z*) = 3.036(2) Å] and between a naphthyl fragment and keto oxygen atom in **II** [C(15)···O(1) (1 − *x*, 1/2 + *y*, 1/2 − *z*) = 3.147(0) Å] [17]. In **II** disordered carbon atoms of pyridyl groups of neighboring molecules also form short interatomic steric interactions [C2A···C2A = 3.393(0) Å; C3A···C3A = 3.113(9) Å; C2A···C3A = 2.897(3) Å; C4B···C4B = 2.871(3) Å (1 − *x*, 1 − *y*, − *z*)]. Therefore it would seem that additional crystal packing effects such as those described here also contribute to the influence of geometric and spatial orientation of the molecules in the unit cells of all three compounds. The remaining geometric parameters in all three structures are similar to standard values [9]. These observations support the data outlined above as well as the conclusions from the *MOPAC* calculations on **I** and **III**.

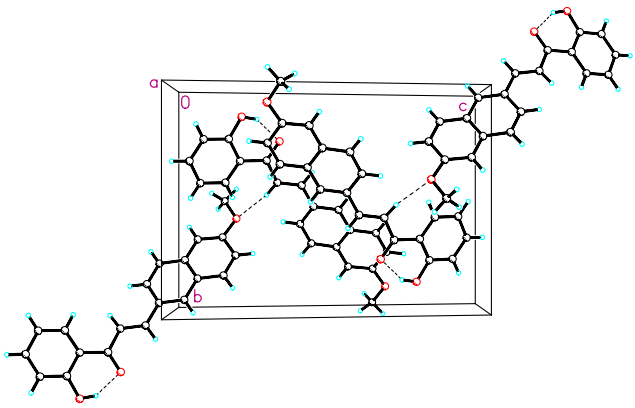

Fig. 5 Packing diagram of (**I**), viewed down the *a* axis. Dashed lines indicate intermolecular (C8–H8A···O3) and intramolecular (O1–H10···O2) hydrogen-bonding interactions

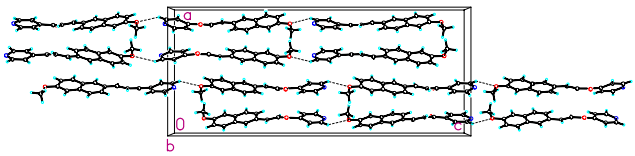

Fig. 6 Packing diagram of (**II**), viewed down the *b* axis. Dashed lines indicate intermolecular (C3A–H3AA···O2) hydrogen-bonding interactions

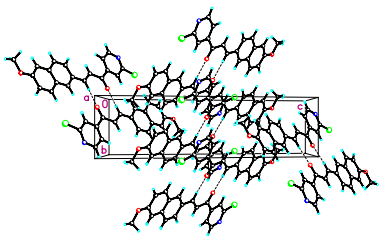

Fig. 7 Packing diagram of (**III**), viewed down the *a* axis. Dashed lines indicate intermolecular (C8–H8A···O1) hydrogen-bonding interactions

Acknowledgements ANM thanks University of Mysore for use of their research facilities. RJB acknowledges the NSF MRI program (grant No. CHE-0619278) for funds to purchase the X-ray diffractometer.

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