Structural studies of some push–pull *N*-arylbenzazoles†‡

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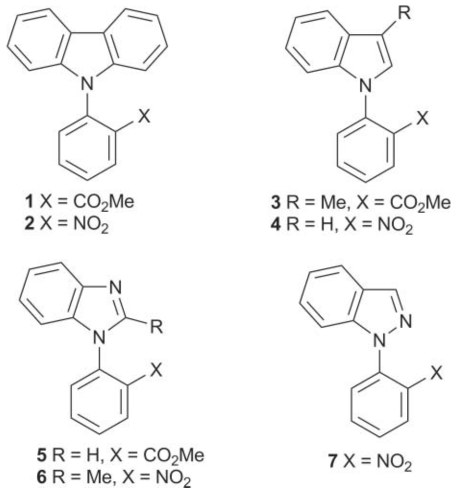
X-Ray crystal structures, and calculated structures (at B3LYP/6-31G level) are reported for seven *N*-arylbenzazoles (two carbazoles, indoles and benzimidazoles, and one indazole) bearing electron withdrawing groups in the 2-position of the *N*-aryl ring. The structures are markedly non-planar by rotation around the *N*-aryl bond, with the substituent in most cases lying s-*E* in relation to the *N*-aryl bond; intermolecular electrostatic interactions in the crystal rationalise the two examples in which an s-*Z* conformation is observed. A large interplanar angle between the benzazole and the *N*-aryl planes is associated with a small interplanar angle between the planes of the *N*-aryl group and the substituent and *vice versa*.

Introduction

We report an analysis of the X-ray crystal structures of a range of push–pull benzazole derivatives **1–7**. These compounds all have a benzazole core [either carbazole (**1** and **2**), indole (**3** and **4**), benzimidazole (**5** and **6**) or indazole (**7**)] with an *N*-aryl group bearing a strong electron withdrawing group [either carbomethoxy (**1**, **3** and **5**) or nitro (**2**, **4**, **6** and **7**)] in the 2-position of the *N*-aryl ring.



1 X = CO_2Me
2 X = NO_2

3 R = Me, X = CO_2Me
4 R = H, X = NO_2

(1)

5 R = H, X = CO_2Me
6 R = Me, X = NO_2

7 X = NO_2

For maximum delocalisation of the azole nitrogen atom lone pair, through to the electron withdrawing group, the systems would ideally be planar. In compounds **1–7**, this ideal state is impossible owing to the *peri*-interactions of the *N*-aryl group and the fused benzene ring of the benzazole, exacerbated by the presence of a bulky *ortho*-substituent. It was therefore of interest to correlate the way in which the systems cope with these competing influences. In the solid-state, crystal packing forces can provide a further complication, and so the X-ray crystallographic studies have been complemented by calculations of the gas-phase structures, made at B3LYP/6-31G level.[1]

Results and discussion

General

Compounds **1–4** and **6–7** were made from the corresponding azole by standard S_NAr procedures.[2–6] Compound **5** required a three-step procedure in which the final step was cyclisation of *N*-(2-carbomethoxyphenyl)-*o*-phenylenediamine[7] with formic acid.[8] This compound shows unusual ^1H NMR behaviour (ESI‡) in which broadened areas of the spectrum are sharpened both at higher and lower temperatures. This may be due to exchange between two identical sites.

Plots of the X-ray crystal structures of **1–7** are given in Fig. 1–7, respectively, and diagrams of corresponding calculated structures are reported in the ESI.‡ All are significantly non-planar, suggesting that push–pull conjugation is not a significant feature in their structures. The solid-state structure of **1** shows eight molecules in the unit cell at atmospheric pressure and its pressure dependent polymorphism has been previously reported.[2] The structure of **3** is disordered with *ca*. 10% showing an s-*E* configuration around the *N*-aryl bond (ESI‡).

Bond lengths and angles

Bond lengths and angles of **1–7** are generally unexceptional. The bond lengths between the azole nitrogen atoms and the *N*-aryl rings might have been expected to be short due to delocalisation. Those of the eight molecules of **1** fall in the range 1.410(5)–1.445(5) Å (average 1.432 Å); the average is close to the value for *N*-phenylcarbazole itself[9] (1.427 and 1.420 Å, for the two molecules in the unit cell). There is no obvious correlation between the C–N bond lengths and the interplanar angle between the carbazole and the *N*-aryl group. For compounds **2–7**, the C–N bond length is in the range 1.409(5)–1.4282(18) Å.

For compounds **2**, **4** and **6**, the lengths of the two N–O bonds in the nitro group differ by around 1σ or less in the

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† This paper is dedicated to Professor David Rankin, in recognition of his seminal contributions to structural science.

‡ Electronic supplementary information (ESI) available: NMR data for **5**, crystallographic data, Cartesian coordinates, calculated energies. See DOI: 10.1039/c0dt00029a

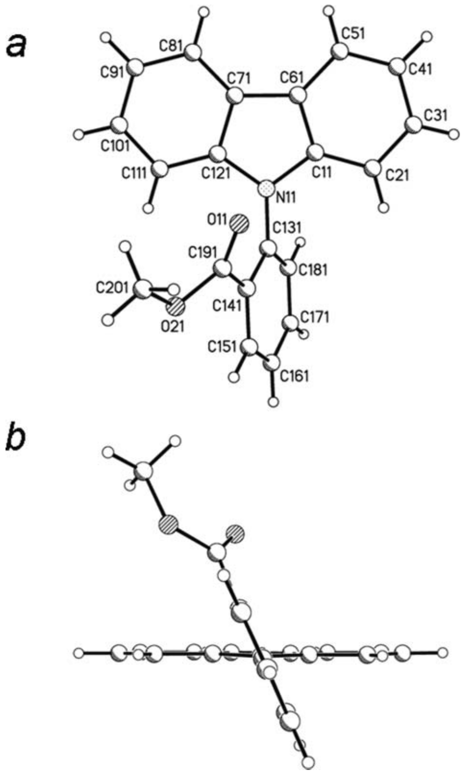

Fig. 1 Plots of one of the eight molecules of **1** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper.

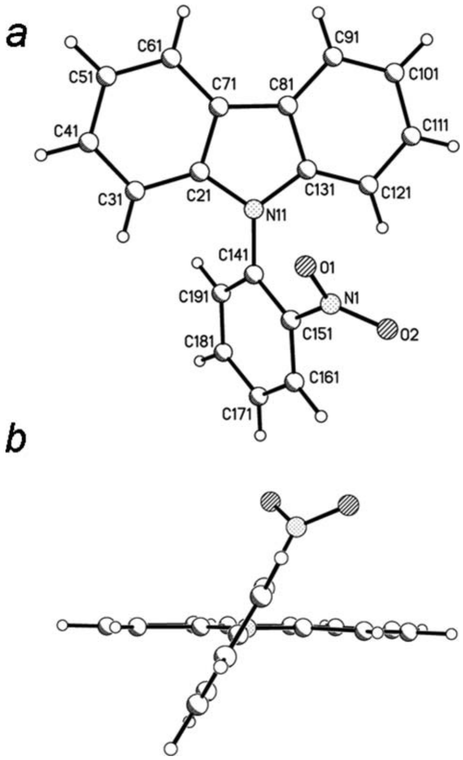

Fig. 2 Plots of **2** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper.

X-ray structure; however the situation is very different for the indazole derivative **7**, in which these parameters differ by some 5σ [1.196(5) Å and 1.231(5) Å]. This difference is not reflected in the calculated structure (N111–O112 1.260 Å; N111–O111 1.265 Å. There are no obvious inter- or intra-molecular interactions to account for this difference in the crystal; indeed, if the two N–O distances are strongly restrained to be equal, R_1 increases by only 0.004. It is possible that the high mosacity in the crystal used for data collection compromised the peak shapes, degrading the accuracy of the integrated intensities. A search of the Cambridge Crystallographic database (ESI‡) reveals that the N–O bonds of nitro groups differ by ≥0.035 Å in less than 1% of hits; although unusual, this situation is therefore not unprecedented.

Interplanar angles

Compounds **1–7** are composed of three, essentially planar, sub-units, *viz* the benzazole (or dibenzazole) ring, the *N*-aryl group and the nitro (or carbomethoxy) substituent. It is clear from the side views shown in Fig. 1–7, that there are substantial angles between the planes of the benzazole and the *N*-aryl group, and between those of the *N*-aryl group and the substituent (Table 1). These results are broadly supported by the calculations (ESI‡).

Table 1 Interplanar angles (°) for **1–8**

	Benzazole-*N*-aryl (X-ray)	Benzazole-*N*-aryl (calc.)[a]	*N*-aryl-substituent (X-ray)	*N*-aryl-substituent (calc.)[a]
1[b]	65.78(13)	63.96	33.6(2)	18.64
	78.09(14)		21.8(2)	
	59.81(14)		39.3(2)	
	60.04(13)		38.9(2)	
	62.42(13)		38.4(2)	
	80.77(13)		21.7(2)	
	81.12(13)		21.7(2)	
	74.05(14)		20.7(2)	
2	61.11(5)	56.70	40.48(9)	32.94
3[c]	115.13(8)	54.72	37.21(6)	10.75
4	47.17(4)	70.54	41.11(6)	33.77
5[d]	116.40(3)	66.59	34.49(3)	21.86
6	68.64(5)	64.25	47.31(17)	24.66
7	40.29(11)	47.00	47.35(27)	35.55

[a] Dihedral angles reported; calculated at B3LYP/6-31G level. [b] Eight independent molecules in the unit cell. [c] Major conformer; substituent is s-*Z*. [d] Substituent is s-*Z*.

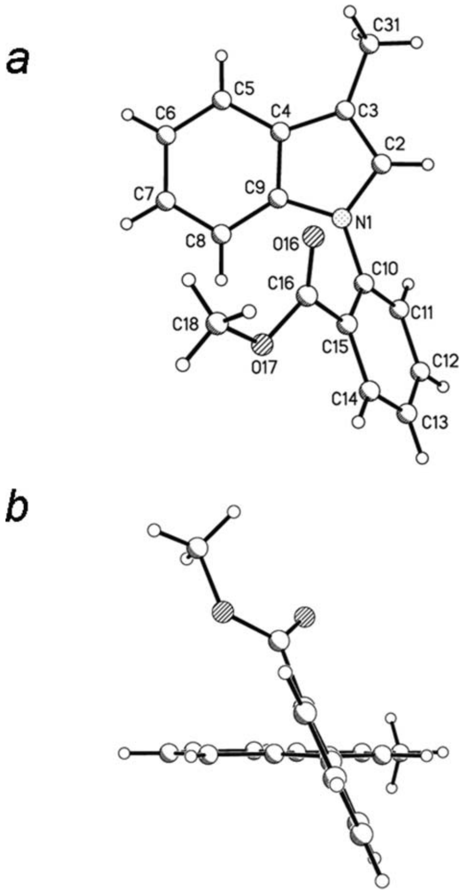

Fig. 3 Plots of the major rotamer of **3** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper. The coordinates plotted in this figure have been inverted relative to the asymmetric unit for consistency with other figures in this paper. This operation is consistent with the space group.

In all cases except **7** (which has only a lone pair on the site adjacent to the *N*-aryl group) the angle between the benzazole and the *N*-aryl ring is greater than that between the *N*-aryl group and the substituent. The carbazole **1** and the 2-methylbenzimidazole **6**, with non-hydrogen substituents on the site adjacent to the *N*-aryl group, correspondingly have the largest benzazole-*N*-aryl angle.

Although the same trends are evident, there is little quantitative correspondence between the calculated and X-ray interplanar angles.

In all of the calculated structures, and in most of the solid-state structures, the position of the substituent is s-*E* with respect to the *N*-C(aryl) bond. However, in the two carbomethoxy compounds, **3** (major conformer) and **5**, an s-*Z* configuration is adopted so that the substituent lies in the direction of the fused benzene ring (Fig. 3 and 5). Calculations on **3** suggest that the energy surface created by *N*-aryl bond rotation is very flat (ESI‡) (difference of less than 7 kJ mol^{-1} between energy maximum and minimum in the dihedral angle range 30–150°) and so crystal packing could readily account for these differences. Indeed, it is likely that electrostatic interactions are responsible for the conformation of these molecules in the crystal. Thus the Hirshfield surfaces shown in Fig. 8 and 9 demonstrate that **3** and **5** show very similar electrostatic potentials, with an electron rich region close to the s-*Z* carbonyl group creating a pocket for the electron deficient region of the *N*-aryl group, thus controlling the packing forces.

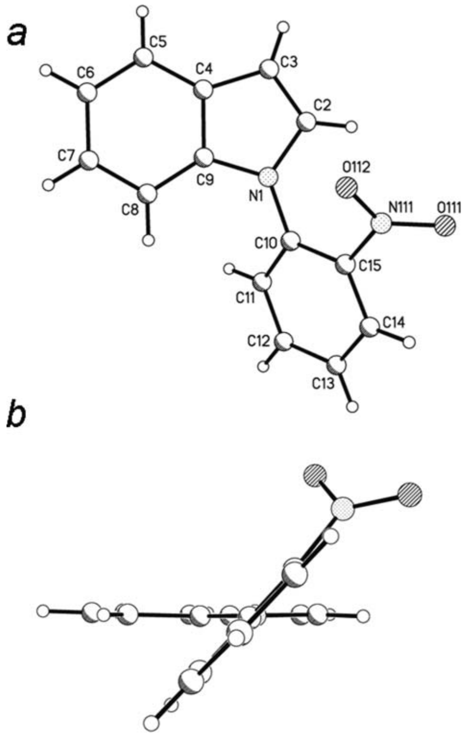

Fig. 4 Plots of **4** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper.

Data for the X-ray structures shown in Table 1 suggest that structures with a large benzazole-*N*-aryl angle tend to show a small *N*-aryl-substituent angle. These parameters are plotted in Fig. 10 and show modest correlation with a straight line fit ($R^2 = 0.64$). The point furthest from the line is for the 2-methylbenzimidazole **6**, where increased steric factors may introduce further complications. If this point is ignored, R^2 improves to 0.85. The correlation is also somewhat better if the eight conformers of **1** are treated separately from **2–7** (R^2 0.91) (ESI‡). Calculations on **1**, in which the benzazole–*N*-aryl angle is fixed, also show a relation between the two interplanar angles though in this case the correlation shows a very good exponential fit (R^2 0.99). Unfortunately, the experimental data do not cover a wide enough range (restricted to benzazole–*N*-aryl interplanar angles of *ca.* 40–80°) for any exponential correlation to become evident. Overall, these results suggest that in the cases where conjugation from the benzazole nitrogen atom is reduced by a large interplanar angle, the systems can compensate by increasing the interaction between the *N*-aryl group and the substituent, by reducing these interplanar angles.

Conclusions

We have shown, by consideration of a range of related *N*-arylbenzazole structures with electron withdrawing substituents in the 2-position of the aryl ring, that the non-planarity

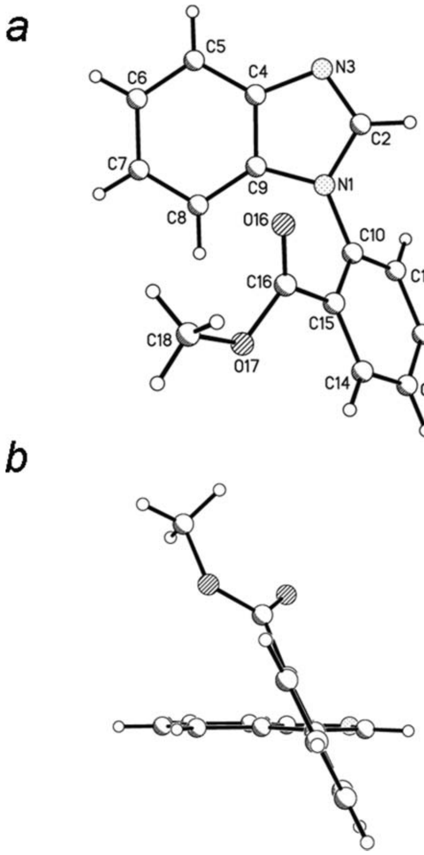

Fig. 5 Plots of **5** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper.

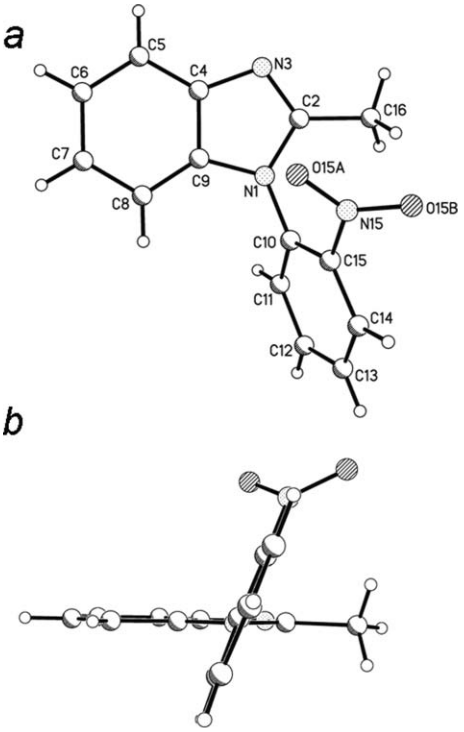

Fig. 6 Plots of **6** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper.

of the systems severely limits push–pull conjugation between the nitrogen atom of the azole and the electron withdrawing substituent. The unexpected s-*Z* configurations of the carbomethoxy compounds **3** and **5** in the solid-state (not reproduced as global minima in the calculated structures) may be explained by intermolecular electrostatic interactions. Interplanar angles between the benzazole and the *N*-aryl group, and between the *N*-aryl group and the substituent are linearly related in the solid-state.

Experimental

NMR spectra were recorded for solutions in $CDCl_3$. Chemical shifts are quoted relative to TMS and coupling constants are given in Hertz. ^{13}C NMR signals refer to one CH resonance unless otherwise stated. Mass spectra were recorded under electron impact conditions.

Compounds **1**,[2] **2**,[3] **3**,[4,5] **4**[4] and **7**[6] were prepared according to literature procedures.

1-(2-Carbomethoxyphenyl)-1*H*-benzimidazole 5

Methyl 2-(2-aminophenylamino)benzoate[7] (1 mmol) and formic acid (10 cm^3) were heated for 2 h at 130 °C. The solution was cooled and ether was added. The solution was extracted with HCl (2 M, 3 × 50 cm^3). The aqueous layer was made alkaline with aqueous potassium carbonate solution and then extracted with ether (3 × 50 cm^3), dried ($MgSO_4$) and the solvent removed under reduced pressure to give **5** (60%) mp 88–89 °C (from toluene) [lit.,[8] 88 °C] δ_H (250 MHz) 8.08 (1H, ddd, ^3J 7.7, ^4J 1.7, ^5J 0.3), 8.00 (1H, br s), 7.85 (1H, br d, ^3J 6.9), 7.70 (1H, td, ^3J 7.5, ^4J 1.6), 7.58 (1H, td, ^3J 7.7, ^{4}J 1.4), 7.14–7.48 (4H, m) and 3.46 (3H, s); δ_C (63 MHz) 165.63 (quat), 143.32, 135.08 (quat), 133.19, 131.82, 128.95, 128.28, 123.46, 122.35, 120.22, 109.68 and 52.29 (CH_3) (3 quaternaries missing – see ESI‡); *m*/*z* 252 (M^+, 100%), 220 (55), 192 (39), 166 (15), 140 (13), 92 (32), 83 (15) and 76 (22). This compound has been reported in a patent.[8]

2-Methyl-1-(2-nitrophenyl)-1*H*-benzimidazole 6

2-Methylbenzimidazole (0.01 mol) and 2-fluoronitrobenzene (0.01 mol) were heated at 125 °C for 8 h in DMF (15 cm^3) with stirring, in the presence of anhydrous potassium carbonate (0.01 mol). The reaction mixture was poured into water (100 cm^3) and extracted with dichloromethane (6 × 30 cm^3). The combined organic layers were washed with water (3 × 15 cm^3), dried ($MgSO_4$) and concentrated *in vacuo* to provide **6** (78%), mp 110–111 °C; (Found: C, 66.05; H, 4.25; N, 16.75. $C_{14}H_{11}N_3O_2$ requires C, 66.4; H, 4.35; N, 16.6%); δ_H (360 MHz) 8.21 (1H, dd, ^3J 8.1, ^4J 1.5), 7.87 (1H, td, ^3J 7.8, ^4J 1.6), 7.75–7.80 (2H, m), 7.54 (1H, dd, ^3J 7.8, ^4J 1.5), 7.18–7.32 (2H, m), 6.92 (1H, dd, ^3J 8.1, ^4J 1.1) and 2.47 (3H, s); δ_C (90 MHz) 152.04 (quat), 147.31 (quat), 143.23 (quat), 136.83 (quat), 134.87, 131.53, 131.05, 130.03 (quat), 126.35, 123.54, 123.23, 119.79, 109.43 and 14.47 (CH_3); *m*/*z* 253 (M^+, 57%), 236 (8), 206 (23), 181 (42), 132 (100), 104 (28), 91 (39) and 77 (40).

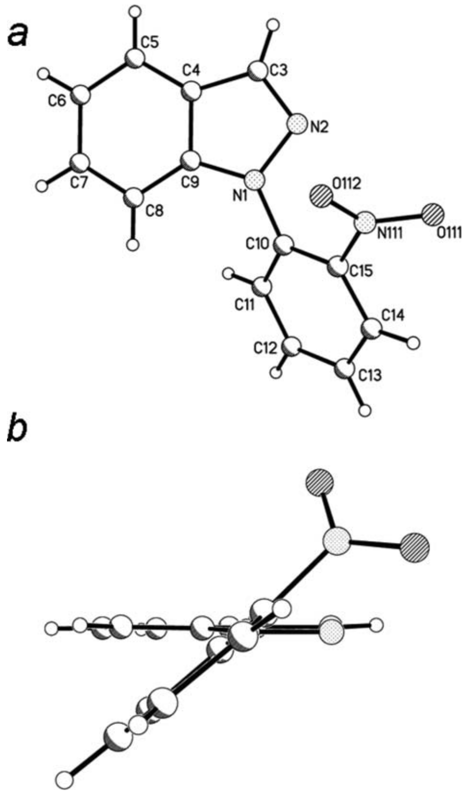

Fig. 7 Plots of **7** showing (a) the crystallographic numbering scheme and (b) a side view in which the heterocyclic ring is approximately orthogonal to the plane of the paper. The coordinates plotted in this figure have been inverted relative to the asymmetric unit for consistency with other figures in this paper. This corresponds to an inversion twinning operation.

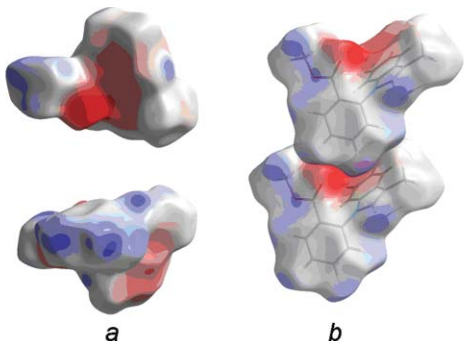

Fig. 8 (a) Views of Hirshfeld surfaces mapped with the individual electrostatic potentials of the main conformer of **3** and (b) a view showing how the electron rich region close to the carbonyl oxygen atom of the ester group creates a pocket suitable for the more electron-deficient area of the *N*-aryl group of an adjacent molecule. Positive regions are shown in blue, and negative in red. The range mapped was ±0.05 au.

Calculations

Calculations were carried out at B3LYP/6-31G level using the Gaussian set of programs.[1] Tables of coordinates and energies are given in the ESI.‡

Hirshfeld surface plots[10] were calculated using the program CrystalExplorer.[10c] Electrostatic potentials were mapped over the range ±0.05 au with red corresponding to net negative charge and blue corresponding to net positive charge. Wavefunctions were calculated using STO-3G basis sets.

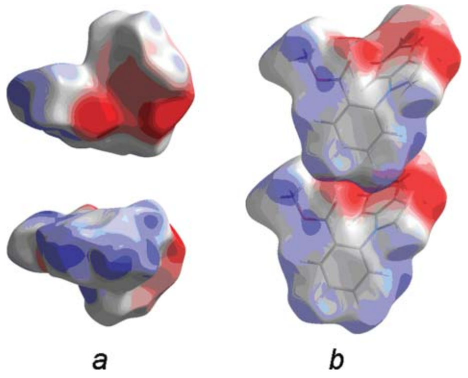

Fig. 9 (a) Views of Hirshfeld surfaces mapped with the individual electrostatic potentials of **5** and (b) a view showing how the electron rich region close to the carbonyl oxygen atom of the ester group creates a pocket suitable for the more electron-deficient area of the *N*-aryl group of an adjacent molecule. Colours and ranges were the same as Fig. 8.

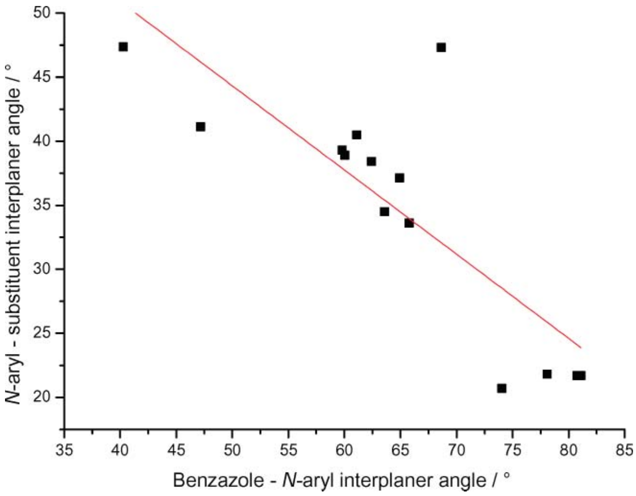

Fig. 10 Plot of benzazole–*N*-aryl interplanar angle *versus* *N*-aryl-substituent interplanar angle for **1** (8 molecules) and **2–7** (X-ray data).

Crystal structures

Crystallographic data for compounds **1–7** are available on the Cambridge Database, having been previously deposited by us. REFCODES are **1** (CARZIF), **2** (SEMTAG), **3** (CARZOL), **4** (PELDUG), **5** (CARZUR), **6** (PELFES) and **7** (PELDOA). Data for **1** have been previously published.[2] Crystal and refinement statistics are recorded as Table 1 in the ESI.‡ Searches of the Cambridge Database[11] used version 5.31 with updates to November 2009. Structures were solved and refined using SHELXTL,[12] and visualised with XP[12] and MERCURY.[13] Structure analyses were accomplished with PLATON.[14]

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