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Structural study of diarylazoles related to Rimonabant

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ABSTRACT

The structures of three diarylazoles (two pyrazoles and one 1,2,4-triazole) related to Rimonabant have been determined by X-ray crystallography. The conformation of both aryl groups in the new structures is discussed with regard to other related compounds reported in the Cambridge Structural Database. The secondary structure of the three compounds is very different. Compound **2** forms a helix, compound **3** forms a structure with the hydrocarbon layers parallel and compound **4** crystallizes forming a double chain. In the solid state, the conformation of both aryl groups, the *N*-aryl and the *C*-aryl, was compared with similar compounds reported in the literature. GIAO calculations afford absolute shieldings that were compared with experimental chemical shifts.

1. Introduction

Rimonabant (**1**) is the first selective CB_1 receptor blocker used in many countries for patients with metabolic syndrome and related illnesses, like diabetes and dyslipidaemia [1–3]. Our group has been active in this field preparing and evaluating a large series of compounds related to **1** [4–11]. During these studies we have determined the X-ray molecular structure of intermediates **2, 3** and **4** (Scheme 1).

A search in the CSD [12] on 1,5-diarylpyrazoles and 1,5-diaryl-1,2,4-triazoles was carried out to explore their conformation and to confirm that the structure of Rimonabant **1** was not known, reason why we have determined it [13]. It is worth mentioning that there is a great interest on the polymorphism of **1** and related compounds [14–18].

2. Results and discussion

2.1. Crystallography: literature results

We have collected in a Table (see Supplementary data) the pertinent information on 1,5-diarylpyrazoles and 1,5-diaryl-1,2,4-triazoles including the nature of the substituents and the torsion angles of both phenyl rings retrieved from the CSD [12]. The data of Rimonabant **1** [13] are also included.

2.2. Crystallographic results concerning compounds *2–4*

We have represented the three studied molecules in Figs. 1 and 2 (two independent molecules in the unit cell) and 3 (two independent molecules in the unit cell).

The single crystal X-ray structures of compounds **2–4** are listed in Table 1 and the hydrogen-bonding geometries in Tables 2–4 (compound **2**), 3 (compound **3**) and 4 (compound **4**), respectively.

The molecular structure of compound **2** is shown in Fig. 1. The crystal packing for compound **2** shows a helix type propagation along the *c* axis shown in Fig. 4a. The helical structure is supported by a weak H-bond involving nitrogen (N2) and carbon (C10–H10).

The molecular structure of compound **3** is shown in Fig. 2. The molecular packing of compound **3** is made up of a network of hydrogen bonding interactions stabilizing hydrocarbon layers parallel to the *bc* plane. Every layer contains two molecules connected to another molecule of the neighbor layer. Within the layers the aromatic rings are stacked. This molecular packing is shown in Fig. 4b.

The molecular structure of compound **4** is shown in Fig. 3. Compound **4** contains two forms of hydrogen bonds: the O···H bonds along the chain (O03–H14A) and the O···H bonds between chains (O01···H11A) packing like a double chain (Figs. 5 and 6). The double chain is packed by Van der Waals interactions (Fig. 7). Chains

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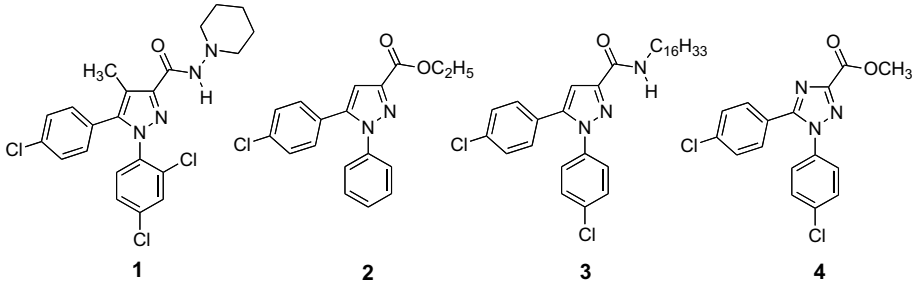


Scheme 1. Rimonabant and related compounds.

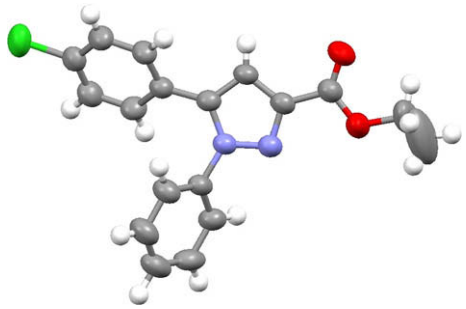


Fig. 1. X-ray molecular structure of compound **2**.

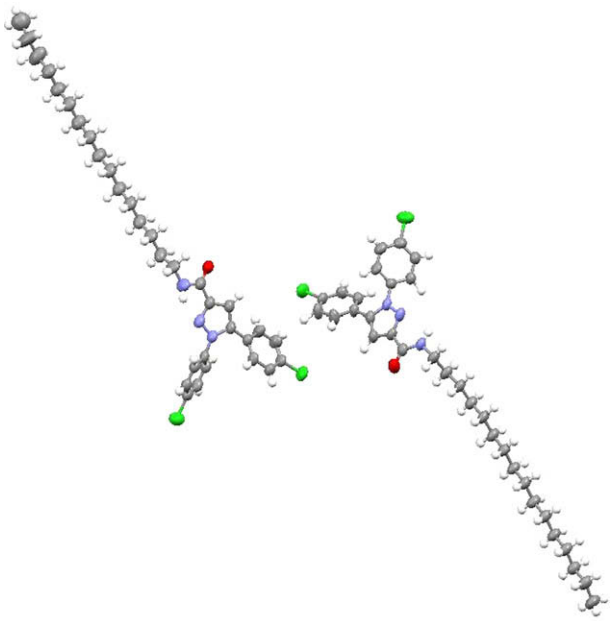


Fig. 2. X-ray molecular structure of compound **3**.

are growing in the direction of *c* axis. The hydrogen-bonding geometries, which give the molecular packing, are shown in Table 4.

2.3. Discussion of the dihedral angles ϕ_1 and ϕ_5

We have always considered the dihedral angles to be $\leqslant 90°$, both being positive because the rings adopt a parallel disposition in all cases save when the angles are 0° or 90° (GEMNIW). The 0°/90° situation evokes the T-shaped structure of benzene dimer while all others are similar to the parallel-displaced structure. A plot of ϕ_1 vs. ϕ_5 is shown in Fig. 8a.

The three compounds that deviate from the general trend in Fig. 9 (when ϕ_1 increase ϕ_2 decrease and reciprocally) are represented in Scheme 2. They correspond to compounds with both angles being large, which is understandable for the congested GEWQUU but not for CILLOY and FETRIG. Note that Rimonabant **1** is also close to these compounds.

The complementarity of the ϕ_1 and ϕ_5 angles means that in the interval 0° ($\phi_1 = \phi_5 = 0°$) to 180° ($\phi_1 = \phi_5 = 90°$) the most common situation is $\phi_1 + \phi_5 = 90°$. Deviations are much more frequent towards situations with both phenyl rings almost perpendicular (see Fig. 9).

When a phenyl ring adjacent to a pyridine-like N atom bears an *o*-hydroxy group (no example in the pyrazole series) then an intramolecular O–H···N hydrogen bond is formed and the corresponding torsion angle is small. This happens in the 1,2,4-triazole series for the 5-aryl group (ϕ_5, Scheme 3) with the notable exception of SAJFIT, where the OH of the 5-aryl group is involved in intermolecular HBs.

It was expected that the dihedral angle ϕ_2 would depend on the substituent at position 4: in the absence of substituent (1,2,4-triazoles) or when this substituent is an H atom (several pyrazoles), the angle should be lower than for 4-substituted pyrazoles. Fig. 8b

Table 1
Crystal data and structure refinement for compounds **2, 3** and **4**.

	Compound **2**	Compound **3**	Compound **4**
CCDC [12]	664037	664038	700182
Empirical formula	$C_{18}H_{15}ClN_2O_2$	$C_{32}H_{43}Cl_2N_3O$	$C_{16}H_{11}N_3O_2Cl_2$
Formula weigh	326.77	556.59	348.188
Crystal system	Monoclinic	Triclinic	Triclinic
Space group	$P2_1/c$ (14)	P-1(2)	P-1(2)
a (Å)	10.6740(7)	9.7627(3)	9.4194(2)
b (Å)	8.3670(5)	10.0704(4)	10.9035(3)
c (Å)	19.7420(15)	33.6580(10)	16.1944(5)
α (°)	90.0	97.110(2)	105.339(2)
β (°)	111.669(2)	93.353(2)	95.656(2)
γ (°)	90.0	104.335(2)	93.277(2)
V (Å^3)	1638.55(19)	3167.68(18)	1590.16(8)
Z	4	4	4
μ (mm^{-1})	2.154	2.047	3.786
F(000)	680	1192	712
Temperature (K)	293(2)	293(2)	293(2)
Wavelength (Å)	1.54184	1.54184	1.54184
Reflections collected	3006	9431	50751
Unique reflections	3006	9431	5727
R_{int}	0.019	0.098	0.0416
$R_1[I > 2\sigma(I)]$	0.053	0.053	0.0443
wR_2 (all data)	0.152	0.150	0.1448

Table 2
Hydrogen-bonding geometry (Å, °) for **2**.

D–H···A	D–H (Å)	H···A (Å)	D···A (Å)	D–H···A (°)	Symmetry[a]
C17–H172···O2	0.97	2.25	2.687(5)	106.5	1
C10–H10···N2	0.93(3)	2.50(3)	3.318(3)	147(2)	2
C6–H6···O2	0.93(3)	2.52(3)	3.412(3)	161(2)	3

[a] Symmetry codes: (1) *x*, *y*, *z*; (2) $-x$, $y - 1/2$, $-z + 1/2$; (3) $-x$, $-y + 1$, $-z + 1$.

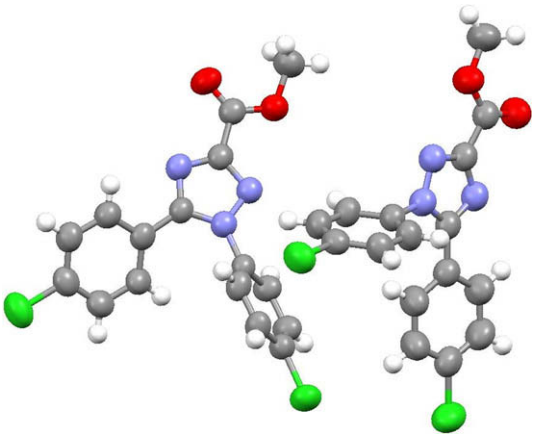


Fig. 3. X-ray molecular structure of compound **4**.

Table 3
Hydrogen-bonding geometry (Å, °) for **3**.

D–H···A	D–H (Å)	H···A (Å)	D···A (Å)	D–H···A (°)	Symmetry[a]
N11–H11···N12	0.86	2.38	2.745(4)	105.7	1
N21–H21···N22	0.86	2.34	2.725(4)	107.5	1
N21–H21···O1	0.86	2.06	2.832(4)	148.1	2
C215–H215···O2	0.93	2.43	3.360(5)	174.3	3

[a] Symmetry codes: (1) x, y, z; (2) $-x+1, -y+2, -z+1$; (3) $x+1, y, z$.

Table 4
Hydrogen-bonding geometry (Å, °) for **4**.

D–H···A	D–H (Å)	H···A (Å)	D···A (Å)	D–H···A (°)	Symmetry[a]
C14A–H14A···O03	0.93	2.56	3.406(3)	151.7	1
C11A–H11A···O01	0.93	2.36	3.275(3)	168.9	2

[a] Symmetry codes: (1) $-x+1, -y+1, -z+2$; (2) $-x+1, -y+1, -z+1$.

shows that this is in general the case, although GEWQUU and SAJFIT clearly deviate. For GEWQUU the explanation is *ortho*-steric effects.

2.4. Computational study

We have calculated compounds **1**, **2**, **3′** (with *n*-propyl instead of hexadecyl as the substituent of the amide) and **4**. First, the geometries were optimized at the B3YP/6-311++G(d,p) level and then, we used these geometries to calculate the absolute shieldings (GIAO).

In what concerns the $\phi_1 + \phi_5$ sum the values are comprised between 81.4 (X-ray **2**) and 90.0 (calculations of **3**, see Table 1) showing that the tendency of Fig. 9 is followed. However, if one considers triazole **4** where the calculated angles are 49.4° and 33.6°, respectively, in the crystal there are two independent molecules, one close (molecule 1°, 53.3° and 29.5°) but other far away (molecule 2°, 74.7° and 9.8°). Thus, the two angles are related and their sum tends to be 90° but there is a large freedom to move away from the 50°/35° average (see Fig. 10).

Using the GIAO approximation, we have calculated the absolute shieldings (σ, ppm) and compared them to the ^{1}H and ^{13}C experimental chemical shifts (δ, ppm, see experimental part) that were assigned through routine 2D experiments [19] and by analogy to similar compounds [20–23]. Carbons bearing halogen substituents deviate [24–26] and to fit them a dummy variable must be added. The three following equations were obtained:

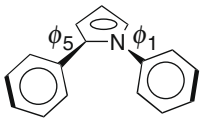
$$\text{Without C—Cl}: \delta^{13}C = (175.5 \pm 0.4) - (0.964 \pm 0.006)\sigma^{13}\text{C}, n = 46, R^2 = 0.998$$

$$\text{With C—Cl}: \delta^{13}\text{C} = (175.1 \pm 0.5) - (0.960 \pm 0.008)\sigma^{13}\text{C} - (8.2 \pm 0.9)\text{C} - \text{Cl}, n = 51, R^2 = 0.996$$

$$\delta^1\text{H} = (30.5 \pm 0.3) - (0.95 \pm 0.01)\delta^1\text{H}, n = 16, R^2 = 0.998$$

These equations are similar to those we reported previously for other compounds [23]. For carbon atoms bearing chlorine substituents a correction of −8.2 ppm should be applied (the correction is −17.6 ppm for bromine substituted carbons [26]). For the last equation we used only the values assigned in the experimental part.

3. Conclusions



The structure of the three compounds we have determined in this work affords new values for the torsion angles ϕ_1 and ϕ_5. Together with those reported in the literature (see Table in the Supplementary data), a relationship between both angles has been found, the two extreme situations for the adjacent phenyl rings being T-shaped and parallel. The secondary structure of the three compounds is very different, forming helices (compound **2**), parallel extended saturated chains (compound **3**) and double chains (compound **4**).

4. Experimental

All reagents and solvents were used as commercially received with exception of CH_2Cl_2 which was distilled from P_2O_5 prior to

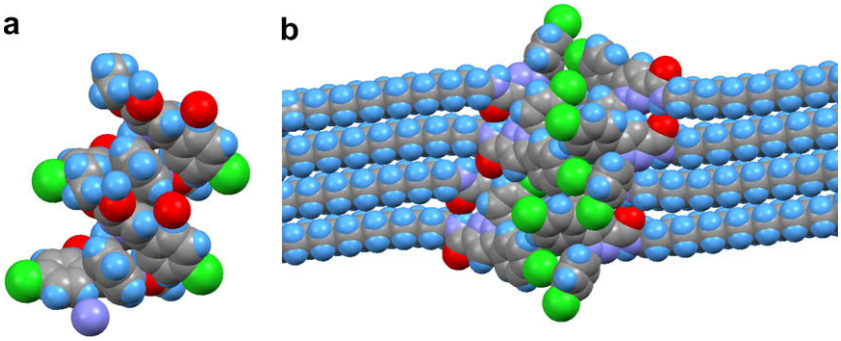


Fig. 4. (a) Helical structure of compound **2** and (b) supramolecular structure of compound **3**.

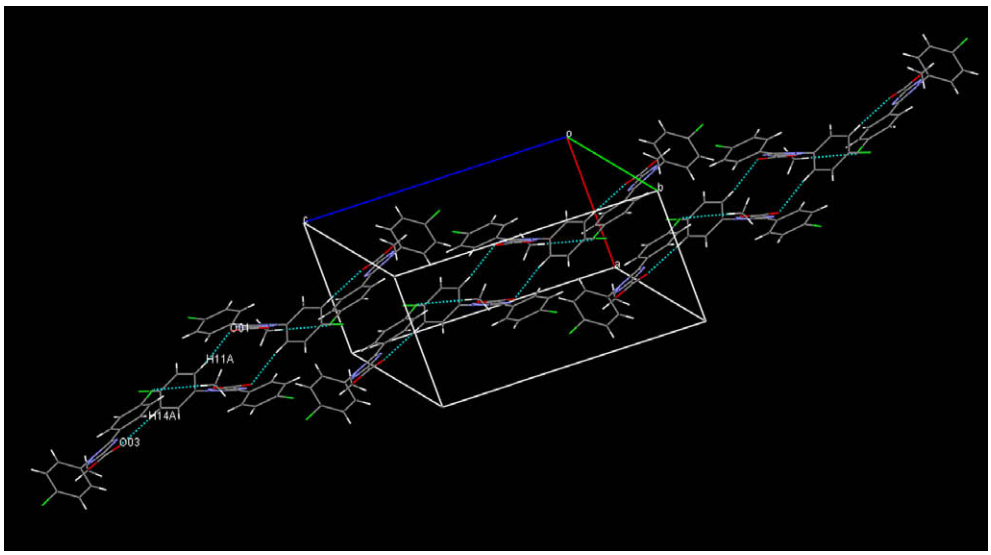


Fig. 5. Hydrogen bonded chain of compound **4** view along *c* axis.

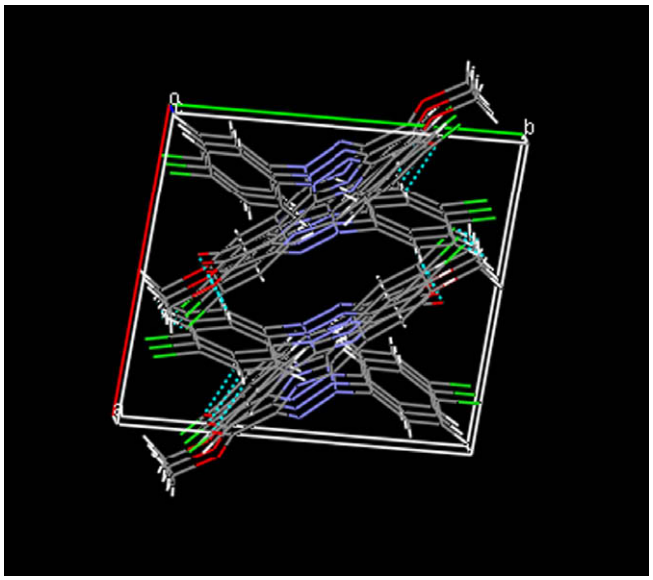


Fig. 6. Hydrogen bonded chain of compound **4**, down *ab* plane.

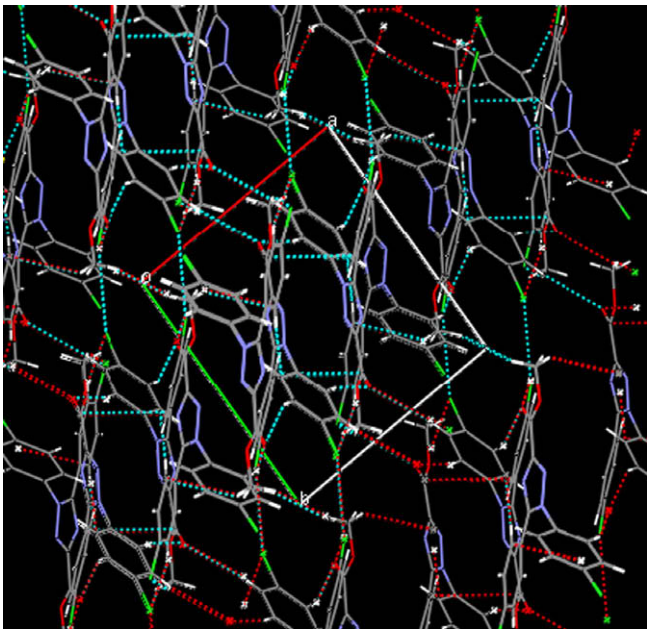


Fig. 7. Van der Waals interactions in compound **4**.

use. TLC: precoated silica-gel *60* F_{254} plates (Merck), detection by UV light (254 nm). Flash-column Chromatography (FC): *Kieselgel 60* (230–400 mesh; *Merck*). Melting points (mp) were determined in open capillaries with a *Gallenkamp* capillary melting-points apparatus and are uncorrected.

^{1}H and ^{13}C NMR spectra were recorded on Bruker Advance 300 spectrometer operating at 300.13 and 75.47 MHz, respectively, in $CDCl_3$ as solvent and Me_4Si as the internal standard. Chemical shifts are reported in ppm on the δ scale. The mass spectra (EI-MS; 70 eV) were determined on a MSD 5973 Hewlett Packard instrument. Elemental analyses were performed on a Heraeus CHN–O Rapid Analysis at the Centro de Química Orgánica "Manuel Lora Tamayo" (CSIC).

*4.1. General procedure for the preparation of ethyl 1,5-diarylpyrazole-3-carboxylates (**2** and **8**) (Scheme 4)*

To a solution of ethyl 4-(4-chlorophenyl)-2,4-dioxobutanoate **7** in glacial acetic acid, obtained through condensation of acetophenone and diethyl oxalate in basic medium [27], was added an amount equimolar of the arylhydrazine. The reaction mixture was refluxed and later poured into water. The yellowish oil was separated by extraction with ether (3 × 50 mL) and the organic extract was washed with $NaHCO_3$ solution (10%) (3 × 15 mL) and water (3 × 15 mL). The extract was dried (Na_2SO_4) and the solvent was removed under reduced pressure to give predominantly the 1*H*-pyrazole-3-carboxylate isomer [28–30] as a viscous yellow oil. The residue was purified by flash chromatography (FC) and crystallization.

*4.2. Ethyl 5-(4-chlorophenyl)-1-phenylpyrazole-3-carboxylate (**2**)*

The title compound was prepared according to the previously described general procedure by refluxing 4-(4-chlorophenyl)-2,4-dioxobutanoate **7** (3.0 g, 11.8 mmol) and phenylhydrazine (1.27 g, 11.8 mmol) in glacial acetic acid (10 mL) during 24 h. The

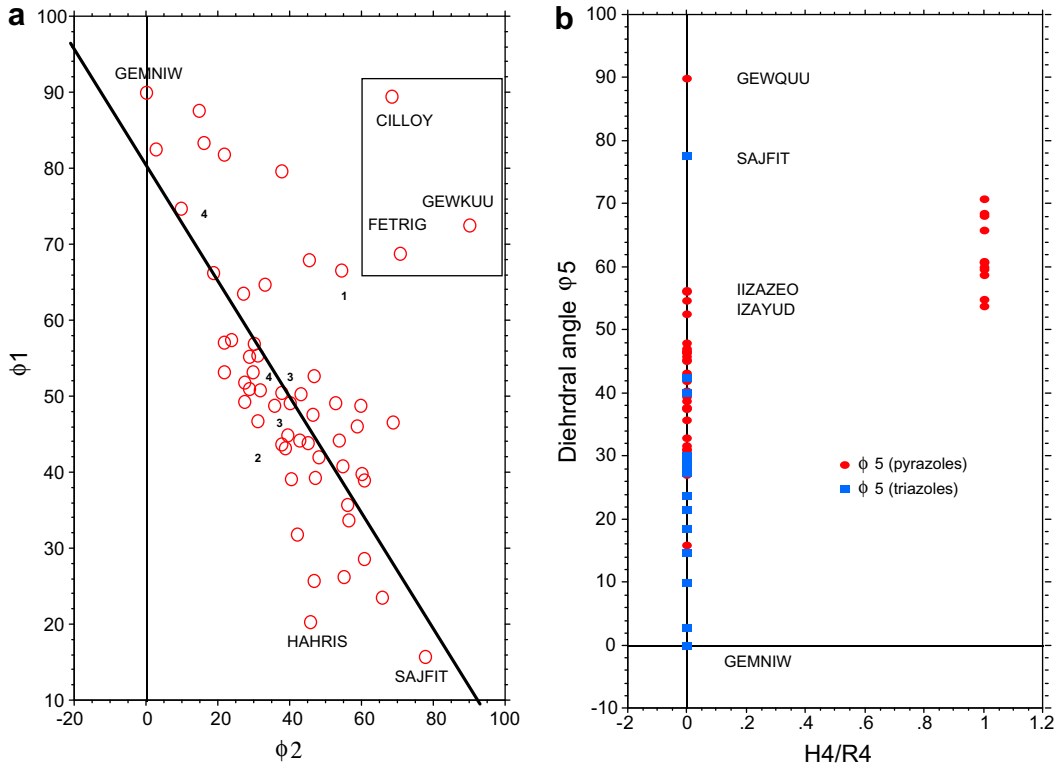


Fig. 8. (a) The straight line (excluding CILLOY, FETRIG and GEWQUU) corresponds to $\phi_1 = (81 \pm 4) - (0.77 \pm 0.09)\,\phi_2$, $n = 55$, $R^2 = 0.58$. (b) H4 or N in position 4 (triazoles) = 0; R^4 in position 4 = 1.

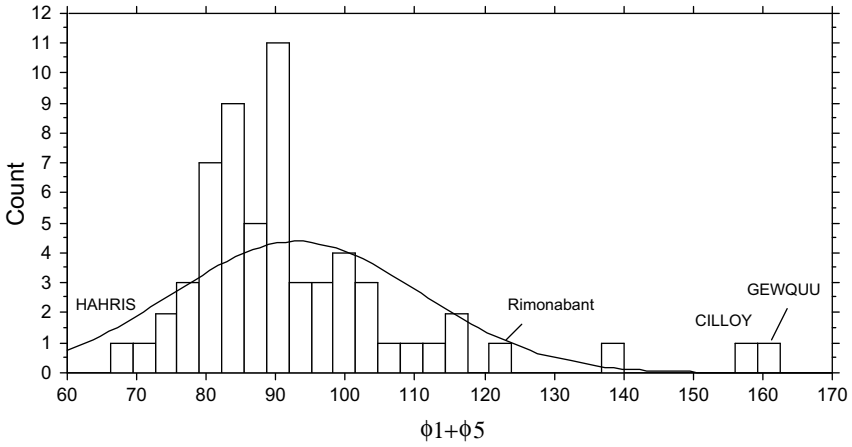
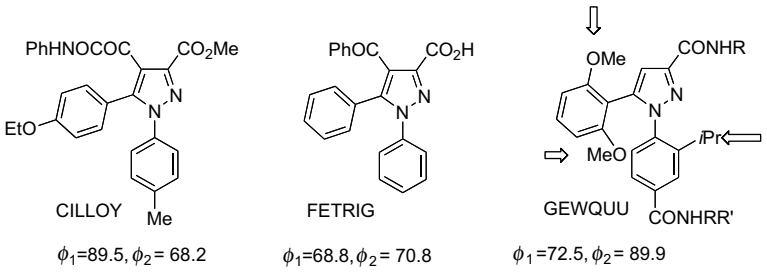


Fig. 9. Histogram of the $\phi_1 + \phi_5$ sum.

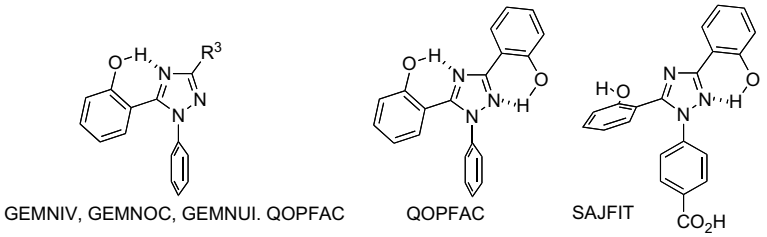
product was purified by FC (SiO_2; EtOAc/*n*-hexane 1:9) and crystallization (79% yield). Yellowish solid, mp: 94–5 °C (EtOH); MS/EI: *m*/*z* (%) = 328 $[M+1]^+$ (34), 326(91), 254(100); ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.29–7.18 (m, 7H), 7.07 (d, J = 8.5 Hz, 2H, *ortho* 5-*p*-ClPh), 6.95 (s, 1H, pyrazole H4), 4.38 (q, J = 7.0 Hz, 2H, CH_2), 1.34 (t, J = 7.0 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 162.2 (CO), 144.3 (C, pyrazole C3), 143.3 (C, pyrazole C5), 139.2 (C, *ipso* 1-Ph), 134.8 (C, *para* 5-*p*-ClPh), 129.8 (CH, *ortho* 5-*p*-ClPh), 129.0 (CH, *meta* 1-Ph), 128.8 (CH, *meta* 5-*p*-ClPh), 128.7 (C, *ipso* 5-*p*-ClPh), 127.9 (C, *para* 1-Ph), 125.6 (CH, *ortho* 1-Ph), 109.9 (CH, pyrazole C4), 61.1 (CH_2), 14.3 (CH_3); elemental analysis calcd (%) for $C_{18}H_{15}ClN_2O_2$ (326.08): C 66.16, H 4.63, N 8.57, found: C: 66.23; H: 4.55; N: 8.52.

4.3. Ethyl 1,5-bis(4-chlorophenyl)pyrazole-3-carboxylate (**8**)

The title compound was prepared by refluxing 4-(4-chlorophenyl)-2,4-dioxobutanoate **7** (3.0 g, 11.8 mmol) and 4-chlorophenyl-hydrazine chlorhydrate (2.1 g, 11.8 mmol) in glacial acetic acid (10 mL) during 48 h. The product was purified by FC (SiO_2; EtOAc/*n*-hexane 1:9) and crystallization (60% yield). Yellowish solid, mp: 120–1 °C (EtOH); MS/EI: *m*/*z* (%) = 362 $[M+1]^+$ (59), 360(94), 288(100); ^{1}H NMR (300 MHz, $CDCl_3$): δ = 7.29–7.23 (m, 4H), 7.20 (d, J = 8.5 Hz, 2H, *ortho* 1-*p*-ClPh), 7.08 (d, J = 8.3 Hz, 2H, *ortho* 5-*p*-ClPh), 6.95 (s, 1H, pyrazole H4), 4.39 (q, J = 7.1 Hz, 2H, CH_2), 1.35 (t, J = 7.1 Hz, 3H, CH_3); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 162.0 (CO), 144.7 (C, pyrazole C3), 143.4 (C, pyrazole C5),



Scheme 2. Compounds with both aryl groups almost perpendicular.



Scheme 3. The ϕ_5 dihedral angle in 1,5-diaryl-1,2,4-triazoles.

137.7 (C, *ipso* 1-*p*-ClPh), 135.1 (C, *para* 5-*p*-ClPh), 134.3 (C, *para* 1-*p*-ClPh), 129.9 (CH, *ortho* 5-*p*-ClPh), 129.3 (CH, *metha* 5-*p*-ClPh), 129.0 (CH, *metha* 1-*p*-ClPh), 127.6 (C, *ipso* 5-*p*-ClPh), 126.7 (CH, *ortho* 1-*p*-ClPh), 110.2 (CH, pyrazole C4), 61.2 (CH_2), 14.3 (CH_3); elemental analysis calcd (%) for $C_{18}H_{14}Cl_2N_2O_2$ (360.04): C 59.85, H 3.91, N 7.76, found: C: 60.02; H: 3.87; N: 7.74.

4.4. Preparation of N-(1-hexadecyl)-1,5-bis(4-chlorophenyl)-1H-pyrazole-3-carboxamide (**3**)

To the *N*-hexadecylamine (0.83 g, 3.5 mmol) dissolved in dry CH_2Cl_2 was added dropwise during 5 min a commercial solution 2 M $Al(CH_3)_3$ in heptane (1.73 mL, 3.5 mmol). [31,32]. The reaction mixture was stirred during 1 h at room temperature. Then, a solution of ethyl 1,5-bis(4-chlorophenyl)pyrazole-3-carboxylate **8** (0.25 g, 0.7 mmol) dissolved in dry CH_2Cl_2 (100 mL) was added and the mixture was heated at reflux during 20 h. The reaction was quenched by slow and careful addition of a solution 2N HCl (50 mL). The organic layer was then separated and washed with a solution 2N HCl (3 × 15 mL), dried (Na_2SO_4) and evaporated to dryness. The product was purified by FC (SiO_2; EtOAc/*n*-hexane 1:4) and crystallization (90% yield). White solid, mp: 78–9 °C (*n*-hexane); MS/EI: *m*/*z* (%) = 557 $[M+1]^+$ (10), 555(15), 315(100); ^1H NMR (300 MHz, $CDCl_3$): δ = 7.30–7.19 (m, 4H), 7.17 (d, *J* = 8.7 Hz, 2H, *ortho* 1-*p*-ClPh), 7.07 (d, *J* = 7.0 Hz, 2H, *ortho* 5-*p*-ClPh), 6.96 (s, 1H, pyrazole H4), 3.38 (q, *J* = 7.0 Hz, 2H), 1.58–1.49 (m, 2H), 1.29–1.17 (m, 26H), 0.82 (t, *J* = 7.0 Hz, 3H); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 161.3 (CO), 147.7 (C, pyrazole C3), 143.7 (C, pyrazole C5), 137.8 (C, *ipso* 1-*p*-ClPh), 135.0 (C, *para* 5-*p*-ClPh), 134.2 (C, *para* 1-*p*-ClPh), 129.9 (CH, *ortho* 5-*p*-ClPh), 129.3 (CH, *meta* 5-*p*-ClPh), 129.0 (CH, *meta* 1-*p*-ClPh), 128.3 (C, *ipso* 5-*p*-ClPh), 126.9 (CH, *ortho* 1-*p*-ClPh), 108.9 (CH, pyrazole C4), 39.6 (CH_2), 32.3 (CH_2), 30.1–29.7 (CH_2), 27.3 (CH_2), 23.0 (CH_2), 14.5 (CH_3); elemental analysis calcd (%) for $C_{32}H_{43}Cl_2N_3O$ (555.28): C 69.05, H 7.79, N 7.55, found: C: 68.89; H: 7.51; N: 7.73.

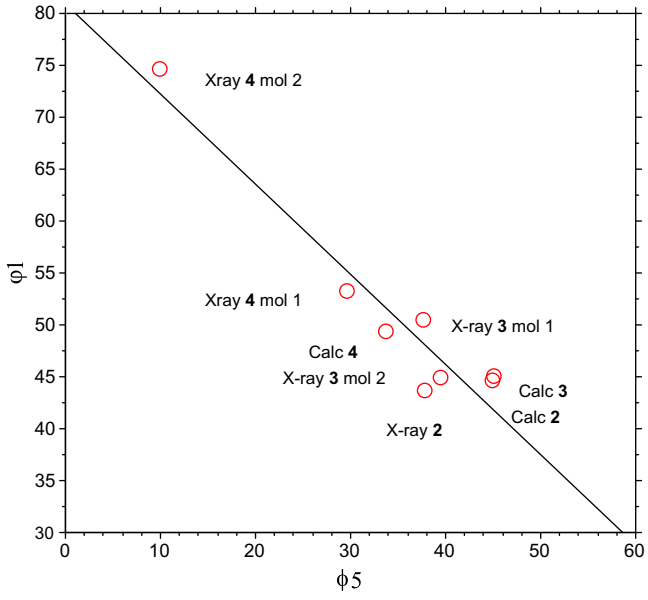
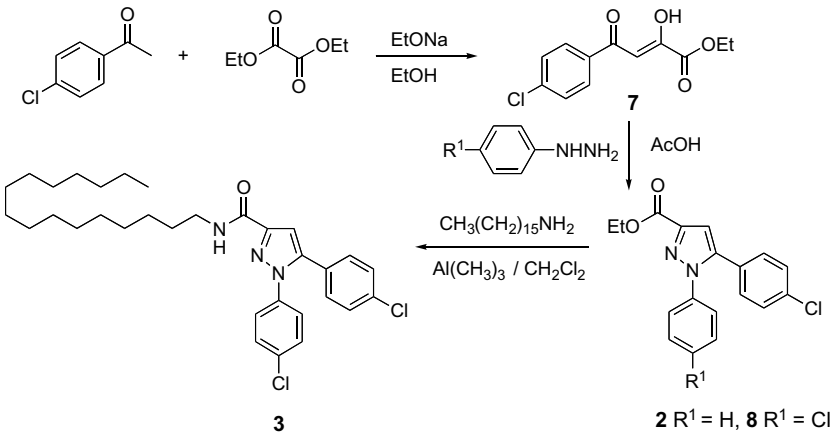


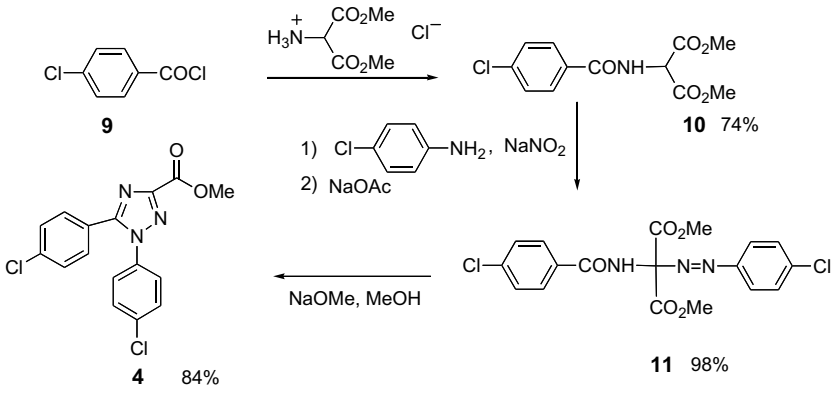
Fig. 10. Calculated and experimental dihedral angles for molecules **2**–**4**. The line corresponds to $\phi_1 = (81 \pm 4) - (0.87 \pm 0.11)\ \phi_5$, $n = 8$, $R^2 = 0.92$.

4.5. Preparation of methyl 1,5-bis(4-chlorophenyl)-1H-1,2,4-triazole-3-carboxylate (**4**) (Scheme 5)

The title compound was obtained [33] by reaction of aroyl chloride **9** with 2-aminodimethylmalonate hydrochloride to give **10** in 74% yield. Diazotation of the 4-chloroaniline followed by reaction with **10** afforded the azo intermediate **11** in high yield, which reacted with sodium methanolate to produce the triazole methyl ester **4**. Product **4** was purified by FC (SiO_2; EtOAc/*n*-hexane 1:3) and crystallization (85% yield). Light pink solid, mp: 144–5 °C (2-Propanol); MS/EI: *m*/*z* (%) = 349 $[M+1]^+$ (47), 347(66), 210(62), 125(100). ^1H NMR (300 MHz, $CDCl_3$): δ = 7.45–7.42 (m, 4H), 7.36–7.31 (m, 4H), 4.04 (s, 3H, Me); ^{13}C NMR (75 MHz, $CDCl_3$): δ = 160.0 (CO), 154.7 (C, triazole C3), 154.5 (C, triazole C5), 137.2 (C, *para* 5-*p*-ClPh), 135.9 (C, *para* 1-*p*-ClPh), 135.7 (C, *ipso* 1-*p*-ClPh), 130.3 (CH, *ortho* 5-*p*-ClPh), 129.9 (CH, *meta* 1-*p*-ClPh), 129.1 (CH, *meta* 5-*p*-ClPh), 126.7 (CH, *ortho* 1-*p*-ClPh), 124.8 (C, *ipso* 5-*p*-ClPh), 53.0 (CH_3); elemental analysis calcd (%) for $C_{16}H_{11}Cl_2N_3O_2$ (347.02): C 55.19, H 3.18, N 12.07, found: C: 55.21; H: 3.46; N: 12.20.



Scheme 4. Synthesis of pyrazoles **2** and **3** (from **8**).



Scheme 5. Synthesis of triazole **4**.

5. Crystallography

Data collection was performed on a Nonius Kappa CCD single crystal diffractometer for compounds **2** and **3** and on a Xcalibur Nova single crystal diffractometer for compound **4**, using Cu Kα (λ = 1.54180 Å) in all cases. The intensities of the three compounds were measured using the CCD rotation images, ω and φ scans. An empirical method was used for the absorption correction in all compounds. The crystal structures were solved by direct methods. The refinements were performed using full-matrix least squares on F^2. All non-H atoms were anisotropically refined. All H atoms were geometrically placed for the three compounds. For compound **2**, H-atoms parameters were mixed refined, that is, some parameters were constrained refined while others parameters were independent refined. For compounds **3** and **4**, H-atoms parameters were refined with constrained geometries.

Crystallographic calculations were made at the University of Oviedo, on the X-ray group computers, using the following programs: Collect [34] for **2** and **3** data collection; CrysAlis CCD [35] for **4** data collection; HKL Denzo and Scalepack [36] for **2** and **3** cell refinement and data reduction; CrysAlis RED [35] for **4** cell refinement and data reduction; SIR92 [37] for structure solutions; SHELXL-97 [38] for structure refinements; XABS2 [39] for absorption corrections; PARST97 [40] and PLATON [41] for the geometrical calculations; ORTEP-3 for windows for molecular graphics [42] and Wingx [43] publication routines to prepare material for publication [44].

6. Computational methods

The optimization of the geometries of the structures were first carried out at the B3LYP/6-31G* and then reoptimized at the B3LYP/6-311++G** computational level [45–50] within the Gaussian-03 package [51] Frequency calculations at both levels were carried out to confirm that the obtained structures correspond to energy minima. GIAO absolute shieldings [52,53] were calculated on the B3LYP/6-311++G** optimized geometries at the same computational level.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at doi:10.1016/j.molstruc.2008.10.020.

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