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# Imino Diels–Alder adducts. XII. Two pyrano[3,2-c]quinolines

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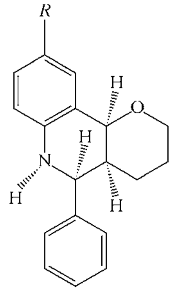
The crystal structures of pyranoquinolines 9-fluoro-5-phenyl-3,4,4a,5,6,10b-hexahydro-2*H*-pyrano[3,2-*c*]quinoline, $C_{18}H_{18}FNO$, and 9-methyl-5-phenyl-3,4,4a,5,6,10b-hexahydro-2*H*-pyrano[3,2-*c*]quinoline, $C_{19}H_{21}NO$, are isomorphous. In both structures, the pyran ring is *exo* to the six-membered N-heterocyclic ring formed in the cycloaddition step. The torsion angles across the phenyl linkage for the two structures are −91.2 (1) and −88.3 (2)°. The striking feature in both crystal packings is that they do not contain the expected conventional hydrogen bonds, in spite of the presence of good hydrogen-bonding functionalities. Possible C—H$\cdots\pi$ interactions are, however, observed.

## Comment

Pyranoquinoline systems are of interest because they constitute the parent ring structure of pyranoquinoline alkaloids, such as khaplofoline, simulenoline and zanthodiaoline. A range of biological activities have been reported for pyranoquinolines and their derivatives (Yamada *et al.*, 1992; Nesterova *et al.*, 1995), and these compounds are used as building blocks for the synthesis of various bridgehead N-heterocycles (Faber *et al.*, 1984). Pyranoquinolines possess a diverse array of structural patterns in linear or angular forms, which provide to the organic chemist a challenging field for investigations of their structures and accomplishment of their syntheses. Imino Diels–Alder reactions catalyzed by Lewis acids are a powerful and efficient methodology for the construction of nitrogen-containing heterocyclic compounds. Recently, the synthesis of disubstituted pyrano- and furoquinolines by the application of imino Diels–Alder reactions between *N*-benzylideneanilines as dienes and 3,4-dihydropyran or 2,3-dihydrofuran as dienophiles, using $ZrCl_4$ as a catalyst, have been reported (Mahesh *et al.*, 2004). We have been investigating how the formation of *endo*/*exo* isomers *via* Diels–Alder cycloadditions depends on the relative orientation of the diene and the dienophile. In the course of these studies, the crystal structures of the title compounds, (I*a*) and (I*b*), have been determined.



(I*a*) *R*=F
(I*b*) *R*=Me

Compounds (I*a*) and (I*b*) have isomorphous crystal structures (Figs. 1 and 2), despite one having F (electron withdrawing) and the other having $CH_3$ (electron donating) substituents; the difference in volume is also significant (9.6 Å$^3$ for F and 23.5 Å$^3$ for $CH_3$; Kitaigorodsky, 1973; Bertault *et al.*, 1998). The geometries of the molecules are very similar; differences ranging from 1.7 to 4.9° in bond angles involving atom C9 (Tables 1 and 2) may be attributed to the nature of the substituent (F or $CH_3$). The C—F bond distance in (I*a*) [1.3691 (15) Å] agrees well with the mean value for C—F distances for monofluoroarenes tabulated by Allen *et al.* (1987) [1.363 (8) Å].

The structures reveal that the dihydropyran ring is attached to the central N-heterocyclic ring in an *exo* (*trans*) fashion [C5—C4—C12—O1 = 178.2 (1)° for (I*a*) and 179.6 (1)° for (I*b*)]. The H4—C4—C12—H12 torsion angle of 51.3° in (I*a*) and 52.6° in (I*b*) indicates that the junction between the pyran and quinoline rings is *cis*. Similarly, the orientation of atoms H5 and H4, defined by the H5—C5—C4—H4 torsion angle

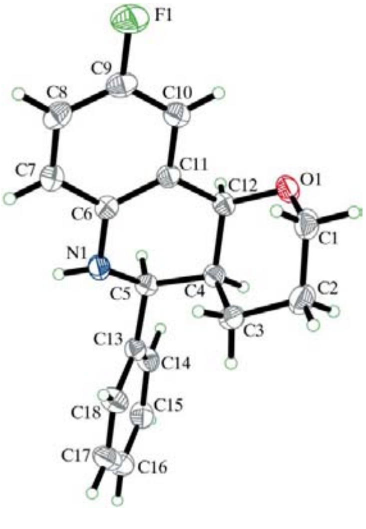


**Figure 1**
A perspective view of the molecule of (I*a*). Displacement ellipsoids are drawn at the 30% probability level and H atoms are drawn as small circles of arbitrary radii.

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[−62.9° in (I*a*) and −61.0° in (I*b*)] is also *cis*. This orientation facilitates the pyran and the phenyl rings being on the same side of the quinoline ring [C3—C4—C5—C13 = −63.4 (1)° in (I*a*) and −61.0 (2)° in (I*b*)]. This configuration is in accordance with the coupling constant $J$ = 5.2 Hz observed between atoms H4 and H5 for compounds (I*a*) and (I*b*).

In both structures, the fusion strain exerted during the quinoline ring formation in the Diels–Alder process can be seen from the twist about the C5$\cdots$C11 vector [C5—C4—C12—C11 = 51.3 (1)° in (I*a*) and 52.4 (2)° in (I*b*); C5—N1—C6—C11 = −20.1 (2)° in (I*a*) and −18.7 (2)° in (I*b*)] The coordination of the quinoline N atom is significantly pyramidal, the sum of the angles at N being 347.6 (2)° in (I*a*) and 349.2 (2)° in (I*b*). The appropriate puckering description for the N-heterocycle ring in the quinoline ring system is half-chair in both structures, with asymmetry parameters (Nardelli, 1983) $\Delta C_2$(C5—C4) of 0.024 (1) in (I*a*) and 0.039 (1) in (I*b*).

The pyran rings in both structures are oriented almost perpendicular to the quinoline ring systems. Atom O1 is displaced above the N1/C6/C11/C12 least-squares plane by 0.686 (1) Å in (I*a*) and 0.651 (1) Å in (I*b*). The conformation of the pyran ring in both structures is a chair, as expected, with atoms C1, C3, C4 and O1 defining the plane, atom C2 being displaced by 0.660 (2) Å in (I*a*) and 0.661 (2) Å in (I*b*), and atom C12 being displaced by −0.614 (1) Å in (I*a*) and −0.623 (2) Å in (I*b*).

The phenyl ring substituted at atom C5 in both compounds is planar and is rotated from the central N-heterocyclic ring about the C5—C13 bond by −91.2 (1)° in (I*a*) and −88.3 (2)° in (I*b*), so as to avoid short non-bonded interactions between the atoms of this ring and the atoms of the N-heterocycle [*e.g.* H1N$\cdots$H18 = 2.70 Å in (I*a*) and 2.62 Å in (I*b*)]

A striking feature is that the structures of (I*a*) and (I*b*) do not contain conventional hydrogen bonds, although in principle hydrogen bonds could be formed. Recently, Bhatt & Desiraju (2006) have reported a similar situation in the crystal structure of desloratadine, where the NH group is not hydrogen bonded in a conventional sense, although two acceptors are available. A similar situation has also been noted in the crystal structures of alloxan (Beyer *et al.*, 2001; Coombes *et al.*, 1997), an oxalic acid–phthalocyanine complex (Liu *et al.*, 2002), and furo- and pyranoquinolines (Ravikumar *et al.*, 2004, 2005). The phenyl ring is the basis of a large volume of experimental material on C—H$\cdots\pi$ hydrogen bonds (Desiraju & Steiner, 1999). In both compounds, geometry calculations show a significant C—H$\cdots\pi$ interaction involving C12—H12 and the centroid (*Cg*1) of the C6–C11 aromatic ring of an inversion-related molecule (Table 3). This interaction for (I*a*) is shown in Fig. 3; that for (I*b*) is similar.

**Figure 2**
A perspective view of the molecule of (I*b*). Displacement ellipsoids are drawn at the 30% probability level and H atoms are drawn as small circles of arbitrary radii.

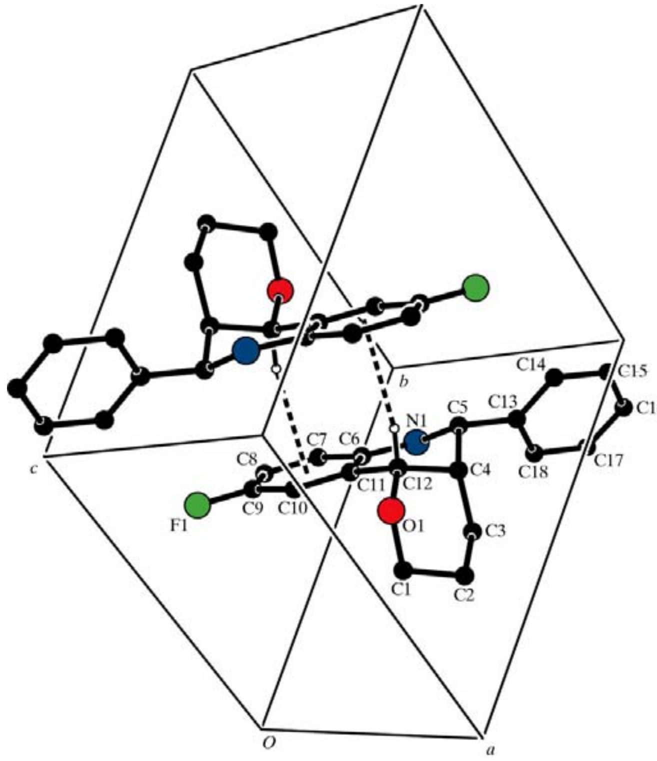

**Figure 3**
The crystal packing of (I*a*), showing the formation of centrosymmetric dimers through C—H$\cdots\pi$ hydrogen-bonding interactions (dashed lines). H atoms not involved in hydrogen bonding have been omitted for clarity.

## Experimental

To a solution of the appropriate *N*-benzylideneaniline (5.5 mmol) in dichloromethane (5 ml) at room temperature were added $ZrCl_4$ (10 mol%) and 3,4-dihydropyran (5.5 mmol) and the mixture stirred for 90 min. The completed reaction was quenched with water and the crude product was purified by column chromatography using 2% ethyl acetate and hexane to yield the title compounds. Crystals suitable for X-ray study were obtained by recrystallization from a mixture of methanol and water (3:1) in both cases.

## Compound (I*a*)

*Crystal data*

$C_{18}H_{18}FNO$
$M_r = 283.33$
Triclinic, $P\bar{1}$
$a = 8.3005\ (9)$ Å
$b = 9.6401\ (11)$ Å
$c = 10.0400\ (11)$ Å
$\alpha = 66.154\ (2)^\circ$
$\beta = 79.666\ (2)^\circ$
$\gamma = 79.880\ (2)^\circ$
$V = 718.11\ (14)$ Å$^3$
$Z = 2$
$D_x = 1.310$ Mg m$^{-3}$
Mo $K\alpha$ radiation
$\mu = 0.09$ mm$^{-1}$
$T = 273\ (2)$ K
Block, colorless
0.20 × 0.15 × 0.10 mm

*Data collection*

Bruker SMART APEX CCD area-detector diffractometer
$\omega$ scan
6884 measured reflections
2504 independent reflections
2276 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.017$
$\theta_{\rm max} = 25.0^\circ$

*Refinement*

Refinement on $F^2$
$R[F^2 > 2\sigma(F^2)] = 0.039$
$wR(F^2) = 0.113$; $S = 1.08$
2504 reflections
194 parameters
H atoms: see below
$w = 1/[\sigma^2(F_o^2) + (0.0612P)^2 + 0.1136P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.20$ e Å$^{-3}$
$\Delta\rho_{\rm min} = -0.23$ e Å$^{-3}$

**Table 1**
Selected bond angles (°) for (I*a*).

| | | | |
|---|---|---|---|
| C9—C8—C7 | 118.08 (13) | C8—C9—C10 | 122.45 (13) |
| F1—C9—C8 | 118.62 (13) | C9—C10—C11 | 119.79 (12) |
| F1—C9—C10 | 118.93 (13) | | |

**Table 2**
Hydrogen-bond geometry (Å, °) for (I*a*) and (I*b*).

*Cg*1 is the centroid of the C6–C11 ring.

| $D$—H···$A$ | $D$—H | H···$A$ | $D$···$A$ | $D$—H···$A$ |
|---|---|---|---|---|
| C12—H12···*Cg*1$^{\rm i}$ | 0.98 | 2.68 | 3.647 (2) | 170 |
| C12—H12···*Cg*1$^{\rm i}$ | 0.98 | 2.73 | 3.682 (2) | 165 |

Symmetry code: (i) $-x+1, -y+1, -z+1$.

## Compound (I*b*)

*Crystal data*

$C_{19}H_{21}NO$
$M_r = 279.37$
Triclinic, $P\bar{1}$
$a = 8.2596\ (7)$ Å
$b = 10.0084\ (9)$ Å
$c = 10.1134\ (9)$ Å
$\alpha = 66.435\ (1)^\circ$
$\beta = 81.927\ (2)^\circ$
$\gamma = 77.141\ (1)^\circ$
$V = 745.85\ (11)$ Å$^3$
$Z = 2$
$D_x = 1.244$ Mg m$^{-3}$
Mo $K\alpha$ radiation
$\mu = 0.08$ mm$^{-1}$
$T = 273\ (2)$ K
Needle, colorless
0.20 × 0.11 × 0.08 mm

*Data collection*

Bruker SMART APEX CCD area-detector diffractometer
$\omega$ scan
7067 measured reflections
2615 independent reflections
2329 reflections with $I > 2\sigma(I)$
$R_{\rm int} = 0.016$
$\theta_{\rm max} = 25.0^\circ$

**Table 3**
Selected bond angles (°) for (I*b*).

| | | | |
|---|---|---|---|
| C7—C8—C9 | 121.15 (14) | C10—C9—C19 | 122.14 (15) |
| C8—C9—C10 | 117.52 (14) | C9—C10—C11 | 122.59 (14) |
| C8—C9—C19 | 120.34 (14) | | |

*Refinement*

Refinement on $F^2$
$R[F^2 > 2\sigma(F^2)] = 0.043$
$wR(F^2) = 0.112$
$S = 1.05$
2615 reflections
195 parameters
H atoms treated by a mixture of independent and constrained refinement
$w = 1/[\sigma^2(F_o^2) + (0.0509P)^2 + 0.2075P]$ where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{\rm max} < 0.001$
$\Delta\rho_{\rm max} = 0.20$ e Å$^{-3}$
$\Delta\rho_{\rm min} = -0.15$ e Å$^{-3}$

The H atom attached to the quinoline N atom was located in a difference density map and refined isotropically. All other H atoms were positioned geometrically and were treated as riding on their parent C atoms, with C—H distances of 0.93–0.98 Å, and with $U_{\rm iso}$(H) values of $1.5U_{\rm eq}$(C) for methyl H atoms and $1.2U_{\rm eq}$(C) for the other H atoms.

For both compounds, data collection: *SMART* (Bruker, 2001); cell refinement: *SAINT* (Bruker, 2001); data reduction: *SAINT*; program(s) used to solve structure: *SHELXS97* (Sheldrick, 1997); program(s) used to refine structure: *SHELXL97* (Sheldrick, 1997); molecular graphics: *SHELXTL/PC* (Sheldrick, 1990) and *PLATON* (Spek, 2003); software used to prepare material for publication: *SHELXL97*.

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Supplementary data for this paper are available from the IUCr electronic archives (Reference: FG3027). Services for accessing these data are described at the back of the journal.

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