Crystal structure and Hirshfeld surface analysis of ethyl (3E)-5-(4-fluorophenyl)3-[(4-methoxyphenyl)formamido]imino]-7-methyl-2H,3H,5H-[1,3]-thiazolo[3,2-a]pyrimidine-6-carboxylate 0.25-hydrate

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In the title compound, C24H23FN4O4S·0.25H2O, the dihydropyrimidine ring is distinctly non-planar, with the flap C atom deviating by 0.297 (2) Å from the least-squares plane. In the crystal, zigzag chains are formed by N—H···C=C=C=C···N hydrogen bonds parallel to [010] and are connected into layers parallel to (100) by O—H···C=C=C=C···O, O—H···F, C—H···C=C=C=C···O and C—H···N hydrogen bonds. Additional C—H···O hydrogen bonds connect the layers into a three-dimensional network. A Hirshfeld surface analysis indicates that the most significant contributions to the crystal packing are from N—H···C=C=C=C···N (42.6%), O—H···C=C=C=C···O (16.8%) and C—H···C=C=C=C···C (15.5%) contacts.

1. Chemical context

Interest in the anticancer activities of dihydropyrimidines (DHPMs) has been increasing since 1999, when monastrol was discovered (Mayer et al., 1999; Leizerman et al., 2004). In addition, 1,3,4-oxadiazole has been reported to exhibit a significant anticancer activity (Yadagiri et al., 2015; Valente et al., 2014; El-Din et al., 2015). Since the combination of two or more pharmacophoric structural moieties can possibly augment the bioactivity, it was of interest to hybridize the DHPM moiety with 1,3,4-oxadiazole, hoping to discover potent anticancer agents.

In this context, a target compound was designed through the condensation of 6-methyl-4-aryl-1,2,3,4-tetrahydropyrimidine-2(1H)-thione derivatives and 2-(chloromethyl)-5-aryl-1,3,4-oxadiazole derivatives (Ragab et al., 2017). Unexpectedly, an intramolecular cyclization and ring opening of 1,3,4-
oxadiazole occurred. The resulting product was chosen as an example of this series for further structural elucidation through X-ray crystallography. Herein we report the crystal structure and Hirshfeld analysis of the title compound, C₂₄H₂₃FN₄O₄S·0.25H₂O.

2. Structural commentary

In the title compound (Fig. 1), the dihydropyrimidine portion (N₁/C₃/C₂/C₁/N₂/C₄) of the central ring is planar to within 0.0286 (9) Å (r.m.s. deviation of the fitted atoms = 0.0211 Å), with the flap C₁ atom being 0.297 (2) Å out of this plane towards the bonded 4-fluorophenyl group. A puckering analysis (Cremer & Pople, 1975) of this ring yielded the parameters Q = 0.2074 (15) Å, Q = 112.1 (4)° and Q = 3.5 (4)°.

The dihedral angle between the C₅–C₁₀ phenyl ring and the least-squares plane of the dihydropyrimidine plane is 88.76 (5)°. The C₄/N₂/C₁₅/C₁₆/S₁ ring is planar to within 0.0191 (8) Å (r.m.s. deviation of the fitted atoms = 0.0140 Å) and is inclined to the N₁/C₃/C₂/C₁/N₂/C₄ plane by 3.99 (9)°. The dihedral angle between the C₄/N₂/C₁₅/C₁₆/S₁ ring and the C₁₈–C₂₃ phenyl ring is 9.28 (8)°.

3. Supramolecular features

In the crystal, molecules are connected into zigzag chains running parallel to [010] by N₄—H₄···N₁ hydrogen bonds (Table 1). The chains are connected into (100) layers by O₅—

![Figure 1](image1.png)

The title molecule with the labelling scheme and displacement ellipsoids drawn at the 30% probability level.

![Figure 2](image2.png)

View of the molecular packing along [100]. O—H···O, O—H···F, C—H···O, C—H···N and C—H···F hydrogen bonds are shown as dashed lines.

![Figure 3](image3.png)

View of the molecular packing along [010]. Hydrogen bonds are depicted as in Fig. 2.

Table 1
Hydrogen-bond geometry (Å, °).

| D—H···A   | D—H | H···A | D···A | D—H···A |
|-----------|------|-------|-------|---------|
| N₄—H₄···N₁ | 0.885 (19) | 2.164 (19) | 2.9888 (17) | 154.8 (16) |
| Cl—H₁···O₅ | 0.987 (17) | 2.345 (18) | 3.307 (5) | 164.7 (13) |
| C₇—H₇···O₄ | 0.97 (2) | 2.41 (2) | 3.285 (2) | 148.7 (17) |
| C₁₃—H₁₃···F₁ | 0.98 (3) | 2.49 (3) | 3.386 (2) | 153.0 (19) |
| C₁₆—H₁₆···N₁ | 0.98 (2) | 2.58 (2) | 3.4019 (19) | 142.4 (15) |
| C₁₆—H₁₆···O₅ | 0.98 (2) | 2.57 (2) | 3.282 (5) | 154.6 (16) |
| C₂₄—H₂₄···O₁ | 0.99 (2) | 2.53 (2) | 3.450 (3) | 156.6 (18) |
| C₂₄—H₂₄···O₁ | 0.95 (2) | 2.57 (2) | 3.504 (2) | 167.8 (17) |
| O₅—H₅···F₁ | 0.87 | 1.76 | 2.479 (5) | 138 |
| O₅—H₅···O₁ | 0.87 | 2.00 | 2.863 (5) | 174 |

Symmetry codes: (i) x+1, y+1/2, z+1/2; (ii) x, y+1/2, z+1/2; (iii) x+1, y+1/2, z+1/2; (iv) x+1, y+1/2, z+1/2; (v) x+1, y+1, z+1; (vi) x+1, y+1, z+1; (vii) x, y+1/2, z+1/2.
H5B···O3 and O5—H5A···F1 hydrogen bonds involving the water molecule, as well as by C13—H13···F1, C16—H16···N1 and all of the C—H···O hydrogen bonds listed in Table 1, except for the C24—H24···O1 hydrogen bond (Figs. 2, 3 and 4) that serves to link the layers into a three-dimensional network.

4. Hirshfeld surface analysis

A Hirshfeld surface analysis was performed, and two-dimensional fingerprint plots were constructed using Crystal Explorer17.5 to quantify the intermolecular interactions in the title molecule (Turner et al., 2017). Fig. 5 depicts the Hirshfeld surface plotted over $d_{norm}$ in the range $-0.7253$ to $+1.4745$ arbitrary units, with red patches indicating putative hydrogen bonding in the crystal structure.

The intensity of the red patches is more pronounced for N4—H4···N1, C1—H1···O5, C16—H16···O5, C24—H24···O1, C24—H24···O1 and O5—H5B···O3, thus revealing the strongest interactions when compared to other red spots on the Hirshfeld surface. Table 2 gives numerical data for close intermolecular contacts. The two-dimensional fingerprint plots (Fig. 6) shows that the largest contributions are from H···H (42.6%; Fig. 6a), O···H/O···O (16.8%; Fig. 6c) and C···H/H···C (15.5%; Fig. 6d) interactions. Other interactions contributing less to the crystal packing are from F···H/H···F (6.7%), N···H/H···N (4.5%), S···H/H···S (3.4%), S···C/C···S (3.4%), C···C (2.8%), S···N/N···S (1.4%), N···C/C···N (1.4%), O···C/C···O (0.7%), N···N (0.5%), O···N/N···O (0.2%) and S···O/O···S (0.1%) interactions.

5. Database survey

A search of the Cambridge Structural Database (CSD, Version 5.42, update of September 2021; Groom et al., 2016)
for compounds most closely related to the 2,3-dihydro-5H-[1,3]thiazolo[3,2-a]pyrimidine unit of the title compound gave the following hits: recodes ZOWXAM (I) (Krishnamurthy et al., 2014); PONVOF (II) (Krishnamurthy & Begum, 2014); AFIZUM (III) (Fatima et al., 2013); YAYHAJ (IV) (Nagarajiah et al., 2012); KUSQUL (V) (Jotani et al., 2010a); PUJRIV (VI) (Jotani et al., 2010b); DIWISIM (VII) (Jotani & Baldaniya, 2008); TICHAP (VIII) (Jotani & Baldaniya, 2007); AWUPAK (IX) (Fun et al., 2011); XETKOX (X) (Sridhar et al., 2006) and XETKOX01 (XI) (Sridhar et al., 2006).

In the crystal of (I), pairs of weak C···H···O hydrogen bonds link molecules related by twofold rotation axes, forming R2(10) rings, which in turn are linked by weak C···H···N interactions to form chains parallel to [010]. In addition, weak C···H···π(arene) interactions link the chains into layers parallel to (001), and π···π interactions connect these layers into a three-dimensional network.

In (II), weak C···H···F and C···H···O hydrogen bonds connect molecules, forming zigzag chains parallel to [010]. In addition, π···π stacking interactions connect these chains into ladders via inversion-related 4-fluorophenyl groups.

In (III), pairs of weak C···H···O hydrogen bonds lead to the formation of inversion dimers. A weak C···H···π interaction and π···π stacking interactions are observed.

In (IV), O···H···N and C···H···S interactions result in (001) layers. The supramolecular assembly is stabilized by π···π stacking interactions between the 2-bromobenzylidene and thiazolopyrimidine rings. In addition, C···H···π interactions are also observed.

In (V), co-operative C···H···O and C···H···π interactions lead to supramolecular chains parallel [100]. These chains are connected via π···π interactions.

The crystal packing of (VI) is influenced by weak intermolecular C···H···π interactions and π···π stacking between the thiazole and phenyl rings, which stack the molecules parallel to [001].

In (VII), in addition to intermolecular C···H···O hydrogen bonding, short intramolecular C···H···S contacts and π···π stacking interactions contribute to the crystal packing.

In (VIII), short intermolecular C···H···O, C···H···π and π···π stacking interactions contribute to the stability of the crystal packing.

In (IX), molecules are linked into a three-dimensional network by intermolecular C···H···O and C···H···F hydrogen bonds. The crystal structure is further stabilized by a C···H···π interaction.

Compounds (X) and (XI) crystallize in two polymorphic forms having the same space-group type, viz. P1, with Z′ = 2 and Z′ = 1. In both polymorphs, the molecules are linked by N···H···O and C···H···O hydrogen bonds.

6. Synthesis and crystallization

A mixture of ethyl 4-(4-fluorophenyl)-6-methyl-2-thioxo-1,2,3,4-tetrahydropyrimidine-5-carboxylate (2 mmol), 2-(chloromethy1)-5-(4-methoxyphenyl)-1,3,4-oxadiazole (2 mmol), potassium iodide (2 mmol) and triethyl amine (2.5 mmol), was refluxed for 4 h in absolute ethanol (20 ml). The reaction mixture was poured onto crushed ice (40 g) and acidified with acetic acid (2 ml). The deposited precipitate was filtered off, washed with cold water, dried and recrystallized from a methanol/DMF mixture.

Yield: 95%; melting point: 493–495 K; IR (KBr) νmax/cm−1: 3390, 3178, 1693, 1654. 1H NMR (400 MHz, DMSO-d6) δ 10.60 (s, 1H, NH), 7.81 (d, J = 8.7 Hz, 2H, Ar—H), 7.44 (t, J = 7.7 Hz, 2H, Ar—H), 7.15 (t, J = 7.7 Hz, 2H, Ar—H), 7.03 (d, J = 8.7 Hz, 2H, Ar—H), 6.13 (s, 1H, C4—H), 4.45 (d, J = 17.4 Hz, 1H, S—CH2), 4.35 (d, J = 17.3 Hz, 1H, S—CH2), 4.03 (q, J = 7.1 Hz, 2H, CH2—CH3), 3.82 (s, 3H, OCH3), 2.34 (s, 3H, C6—CH3), 1.11 (t, J = 7.1 Hz, 3H, CH2—CH3). 13C NMR (125 MHz, DMSO-d6) δ 165.59, 163.23, 163.20, 162.65, 153.92, 153.58, 130.57, 130.50, 130.03, 125.90, 115.64, 115.47, 114.05, 105.95, 60.28, 55.87, 54.89, 28.56, 23.06, 14.45. Analysis calculated for C24H23FN4O4S (482.53): C 59.74, H 4.80, N 11.61. Found: C 60.02, H 4.89, N 11.87.

7. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 3. The H atoms were found in difference-Fourier maps; all C and N-bound H atoms were refined freely. The water molecule was found to be occupationally disordered and was refined with a fixed site occupa-

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**Table 3**

| Crystal data | Chemical formula | C24H23FN4O4S·0.25H2O | 487.03 |
|--------------|-----------------|---------------------|--------|
| Crystal system, space group | Monoclinic, P21/c | | |
| Temperature (K) | 14.4316 (3), 10.8518 (2), 15.5940 (3) |
| F (mm) | 109.941 (1) |
| V (Å³) | 2295.74 (8) |
| Z | 4 |
| Radiation type | Cu Kα |
| μ (mm⁻¹) | 1.68 |
| Crystal size (mm) | 0.15 x 0.14 x 0.11 |

**Data collection**

Diffractometer | Bruker D8 VENTURE PHOTON 100 CMOS |
Absorption correction | Multi-scan (SADABS: Krause et al., 2015) |
Tmin, Tmax | 0.75, 0.84 |
No. of measured, independent and observed [F > 2σ(F)] | 17597, 4576, 4142 |
| | 0.029 |
| (sin θ)/λmax (Å⁻¹) | 0.625 |
| Refinement | |
| R[F² > 2σ(F²)], wR(F²), S | 0.035, 0.088, 1.04 |
| No. of reflections | 4576 |
| No. of parameters | 409 |
| H-atom treatment | H atoms treated by a mixture of independent and constrained refinement |
| Δρmax, Δρmin (e Å⁻³) | 0.34, −0.56 |

Computer programs: APEX3 and SAINT (Bruker, 2016), SHELX (Sheldrick, 2015), SHELXL (Sheldrick, 2015a), SHELXL (Sheldrick, 2015b), DIAMOND (Brandenburg & Putz, 2012) and publCIF (Westrip, 2010).
tion factor of 1/4. The H atoms of the water molecules were located in a difference-Fourier map, their bond lengths set to an ideal value of 0.87 Å, and were refined with $U_{iso}(H) = 1.5 U_{eq}(O)$ using a riding model.

Acknowledgements

Author contributions are as follows: synthesis and organic chemistry parts preparation, AMA, FAFR, SKM; conceptualization and study guide, AMA, SKM; financial support, MAA MAU; crystal data production and validation, JTM; paper preparation and Hirshfeld study, MA, SKM.

Funding information

The support of NSF-MRI grant No. 1228232 for the purchase of the diffractometer and Tulane University for support of the Tulane Crystallography Laboratory are gratefully acknowledged.

References

Brandenburg, K. & Putz, H. (2012). DIAMOND, Crystal Impact GbR, Bonn, Germany.
Bruker (2016). APEX3 and SAINT. Bruker AXS Inc., Madison, Wisconsin, USA.
Cremer, D. & Pople, J. A. (1975). J. Am. Chem. Soc. 97, 1354–1358.
El-Din, M. M. G., El-Gamal, M. I., Abdel-Maksoud, M. S., Yoo, K. H. & Oh, C.-H. (2015). Acta Cryst. E69, o1262.
Fun, H.-K., Loh, W.-S., Sarojini, B. K., Umesha, K. & Narayana, B. (2011). Acta Cryst. E67, o1913–o1914.
Groom, C. R., Bruno, I. J., Lightfoot, M. P. & Ward, S. C. (2016). Acta Cryst. B72, 171–179.
Jotani, M. M. & Baldaniya, B. B. (2007). Acta Cryst. E63, o1937–o1939.
Jotani, M. M. & Baldaniya, B. B. (2008). Acta Cryst. E64, o739.
Jotani, M. M., Baldaniya, B. B. & Jasinski, J. P. (2010b). Acta Cryst. E66, o599–o600.
Jotani, M. M., Baldaniya, B. B. & Tieckink, E. R. T. (2010a). Acta Cryst. E66, o762–o763.
Krause, L., Herbst-Irmer, R., Sheldrick, G. M. & Stalke, D. (2015). J. Appl. Cryst. 48, 3–10.
Krishnamurthy, M. S. & Begum, N. S. (2014). Acta Cryst. E70, o1270–o1271.
Krishnamurthy, M. S., Nagarajaiah, H. & Begum, N. S. (2014). Acta Cryst. E70, o1187–o1188.
Leizerman, I., Avunie-Masala, R., El-kabets, M., Fich, A. & Gheber, L. (2004). Cell. Mol. Life Sci. 61, 2060–2070.
Mayer, T. U., Kapoor, T. M., Haggarty, S. J., King, R. W., Schreiber, S. L. & Mitchison, T. J. (1999). Science, 286, 971–974.
Nagarajaiah, H., Fathima, N. & Begum, N. S. (2012). Acta Cryst. E68, o1257–o1258.
Ragab, F. A., Abou-Seri, S. M., Abdel-Aziz, S. A., Alfayomy, A. M. & Aboelmagd, M. (2017). Eur. J. Med. Chem. 138, 140–151.
Sheldrick, G. M. (2015a). Acta Cryst. A71, 3–8.
Sheldrick, G. M. (2015b). Acta Cryst. C71, 3–8.
Sridhar, B., Ravikumar, K. & Sadanandam, Y. S. (2006). Acta Cryst. C62, o687–o690.
Turner, M. J., McKinnon, J. J., Wolff, S. K., Grimwood, D. J., Spackman, P. R., Jayatilaka, D. & Spackman, M. A. (2017). CrystalExplorer17. The University of Western Australia.
Valente, S., Trisciuglio, D., De Luca, T., Nebbiioso, A., Labella, D., Lenoci, A., Bigogno, C., Donadio, G., Miceli, M., Brosch, G., Del Bufalo, D., Altucci, L. & Mai, A. (2014). J. Med. Chem. 57, 6259–6265.
Westrip, S. P. (2010). J. Appl. Cryst. 43, 920–925.
Yadagiri, B., Gurrula, S., Bantur, R., Nagarapu, L., Polepalli, S., Srujana, G. & Jain, N. (2015). Bioorg. Med. Chem. Lett. 25, 2220–2224.
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Crystal structure and Hirshfeld surface analysis of ethyl (3E)-5-(4-fluorophenyl)3-[(4-methoxyphenyl)formamido]imino)-7-methyl-2H,3H,5H-[1,3]thiazolo[3,2-a]pyrimidine-6-carboxylate 0.25-hydrate

Crystal data

C24H23FN4O4S·0.25H2O  F(000) = 1018
Mr = 487.03  Dc = 1.409 Mg m−3
Monoclinic, P21/c Cu Kα radiation, λ = 1.54178 Å
a = 14.4316 (3) Å  Cell parameters from 9970 reflections
b = 10.8518 (2) Å  θ = 3.3–74.4°
c = 15.5940 (3) Å  μ = 1.68 mm−1
β = 109.941 (1)°  T = 150 K
V = 2295.74 (8) Å3  Block, colourless
Z = 4  0.15 × 0.14 × 0.11 mm

Data collection

Bruker D8 VENTURE PHOTON 100 CMOS  Tmin = 0.75, Tmax = 0.84
diffractometer  17597 measured reflections
Radiation source: INCOATEC μS micro–focus  4576 independent reflections
source  4142 reflections with I > 2σ(I)
Mirror monochromator  Rint = 0.029
Detector resolution: 10.4167 pixels mm−1  θmax = 74.4°, θmin = 3.3°
ω scans  h = −17→18
Absorption correction: multi-scan  k = −13→12
(SADABS; Krause et al., 2015)  l = −19→18

Refinement

Refinement on F2  S = 1.04
Least-squares matrix: full  4576 reflections
R[F2 > 2σ(F2)] = 0.035  409 parameters
wR(F2) = 0.088  0 restraints
Primary atom site location: structure-invariant direct methods
Secondary atom site location: difference Fourier map
Hydrogen site location: difference Fourier map
H atoms treated by a mixture of independent and constrained refinement

\[ w = \frac{1}{[\sigma^2(F_o^2) + (0.0389P)^2 + 1.1637P]} \]
where \( P = (F_o^2 + 2F_c^2)/3 \)

\[ (\Delta/\sigma)_{\text{max}} < 0.001 \]
\[ \Delta \rho_{\text{max}} = 0.34 \text{ e Å}^{-3} \]
\[ \Delta \rho_{\text{min}} = -0.56 \text{ e Å}^{-3} \]

Extinction correction: \( \text{SHELXL-2018/1} \)
(Sheldrick, 2015b),
\[ F_c^* = kF_c[1+0.001xF_c^2\lambda^3/sin(2\theta)]^{-1/4} \]
Extinction coefficient: 0.00229 (19)

Special details
Geometry. All esds (except the esd in the dihedral angle between two l.s. planes) are estimated using the full covariance matrix. The cell esds are taken into account individually in the estimation of esds in distances, angles and torsion angles; correlations between esds in cell parameters are only used when they are defined by crystal symmetry. An approximate (isotropic) treatment of cell esds is used for estimating esds involving l.s. planes.

Refinement. Refinement of \( F^2 \) against ALL reflections. The weighted R-factor \( wR \) and goodness of fit \( S \) are based on \( F^2 \), conventional R-factors \( R \) are based on \( F \), with \( F \) set to zero for negative \( F^2 \). The threshold expression of \( F^2 > 2\sigma(F^2) \) is used only for calculating R-factors(gt) etc. and is not relevant to the choice of reflections for refinement. R-factors based on \( F^2 \) are statistically about twice as large as those based on \( F \), and R- factors based on ALL data will be even larger. Refinement of the site occupancy factor for the lattice water (O5) converged at ca. 0.25. This was fixed at this value for the remainder of the refinement, the attached hydrogen atoms were located in a difference map and included as riding contributions in idealized positions.

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å²)

|    | x     | y     | z     | Uiso*/*Ueq | Occ. (<1) |
|----|-------|-------|-------|------------|-----------|
| S1 | 0.45709 (2) | 0.29846 (3) | 0.22568 (2) | 0.02637 (11) |
| F1 | 0.81951 (11) | 0.85095 (10) | 0.24433 (11) | 0.0709 (4) |
| O1 | 0.93592 (8) | 0.24379 (11) | 0.47803 (8) | 0.0365 (3) |
| O2 | 0.88439 (7) | 0.41670 (10) | 0.52684 (7) | 0.0294 (2) |
| O3 | 0.55706 (8) | 0.71812 (10) | 0.54550 (7) | 0.0307 (2) |
| O4 | 0.17420 (9) | 0.104606 (11) | 0.46165 (8) | 0.0390 (3) |
| N1 | 0.64445 (8) | 0.22708 (11) | 0.27415 (8) | 0.0220 (2) |
| N2 | 0.60560 (8) | 0.39869 (10) | 0.34918 (8) | 0.0200 (2) |
| N3 | 0.54560 (8) | 0.55654 (10) | 0.41266 (8) | 0.0206 (2) |
| N4 | 0.46512 (8) | 0.62737 (11) | 0.41154 (8) | 0.0209 (2) |
| H4 | 0.4182 (14) | 0.6419 (17) | 0.3587 (13) | 0.032 (5)* |
| C1 | 0.70873 (9) | 0.43284 (13) | 0.40035 (10) | 0.0213 (3) |
| H1 | 0.7122 (12) | 0.4512 (15) | 0.4634 (11) | 0.022 (4)* |
| C2 | 0.77324 (10) | 0.32264 (13) | 0.39918 (10) | 0.0224 (3) |
| C3 | 0.74171 (10) | 0.23233 (13) | 0.33574 (10) | 0.0224 (3) |
| C4 | 0.58287 (10) | 0.30597 (12) | 0.28731 (9) | 0.0207 (3) |
| C5 | 0.73684 (9) | 0.54708 (13) | 0.35807 (10) | 0.0233 (3) |
| C6 | 0.76870 (10) | 0.65331 (14) | 0.40974 (11) | 0.0291 (3) |
| H6 | 0.7696 (14) | 0.6545 (17) | 0.4744 (13) | 0.035 (5)* |
| C7 | 0.79756 (12) | 0.75620 (15) | 0.37183 (14) | 0.0365 (4) |
| H7 | 0.8223 (15) | 0.829 (2) | 0.4092 (14) | 0.048 (6)* |
| C8 | 0.79149 (13) | 0.75033 (15) | 0.28209 (14) | 0.0410 (4) |
| C9 | 0.75793 (15) | 0.64862 (16) | 0.22793 (14) | 0.0420 (4) |
| H9 | 0.7526 (16) | 0.651 (2) | 0.1629 (15) | 0.050 (6)* |
### Atomic displacement parameters (Å²)

|   | $U^{11}$    | $U^{22}$    | $U^{33}$    | $U^{12}$    | $U^{13}$    | $U^{23}$   |
|---|-------------|-------------|-------------|-------------|-------------|------------|
| S1| 0.01757 (17)| 0.0260 (2)  | 0.0312 (2)  | 0.00125 (12)| 0.00266 (13)| −0.00720 (13)|
| F1| 0.1061 (11) | 0.0263 (6)  | 0.1191 (11)| −0.0171 (6) | 0.0888 (10)| −0.0055 (6) |
| O1| 0.0214 (5)  | 0.0345 (6)  | 0.0476 (7)  | 0.0093 (4)  | 0.0038 (5)  | −0.0055 (5)  |
| O2| 0.0177 (5)  | 0.0313 (6)  | 0.0326 (6)  | 0.0026 (4)  | 0.0002 (4)  | −0.0057 (4)  |
| O3| 0.0271 (5)  | 0.0336 (6)  | 0.0274 (5)  | 0.0038 (4)  | 0.0040 (4)  | −0.0039 (4)  |
| O4| 0.0370 (6)  | 0.0405 (7)  | 0.0400 (6)  | 0.0175 (5)  | 0.0137 (5)  | −0.0051 (5)  |
| N1| 0.0198 (5)  | 0.0194 (6)  | 0.0257 (6)  | 0.0010 (4)  | 0.0064 (5)  | −0.0013 (4)  |
| N2| 0.0151 (5)  | 0.0186 (6)  | 0.0246 (6)  | 0.0011 (4)  | 0.0046 (4)  | −0.0013 (4)  |
|    | 0.0174 (5) | 0.0202 (6) | 0.0246 (6) | 0.0028 (4) | 0.0078 (4) | 0.0011 (4) |
|----|------------|------------|------------|------------|------------|------------|
| N3 | 0.0179 (5) | 0.0216 (6) | 0.0231 (6) | 0.0044 (4) | 0.0069 (5) | 0.0005 (4) |
| C1 | 0.0151 (6) | 0.0211 (7) | 0.0256 (7) | 0.0001 (5) | 0.0042 (5) | −0.0028 (5) |
| C2 | 0.0169 (6) | 0.0208 (7) | 0.0284 (7) | 0.0019 (5) | 0.0062 (5) | 0.0005 (5) |
| C3 | 0.0190 (6) | 0.0205 (7) | 0.0276 (7) | 0.0016 (5) | 0.0079 (5) | 0.0023 (5) |
| C4 | 0.0206 (6) | 0.0181 (7) | 0.0230 (7) | −0.0001 (5) | 0.0067 (5) | 0.0005 (5) |
| C5 | 0.0146 (6) | 0.0199 (7) | 0.0348 (8) | 0.0012 (5) | 0.0077 (5) | −0.0021 (5) |
| C6 | 0.0207 (7) | 0.0237 (8) | 0.0399 (9) | 0.0007 (5) | 0.0066 (6) | −0.0057 (6) |
| C7 | 0.0270 (8) | 0.0204 (8) | 0.0640 (11) | −0.0040 (6) | 0.0179 (8) | −0.0093 (7) |
| C8 | 0.0439 (9) | 0.0204 (8) | 0.0744 (13) | −0.0032 (7) | 0.0406 (9) | 0.0001 (8) |
| C9 | 0.0582 (11) | 0.0270 (9) | 0.0568 (11) | −0.0018 (7) | 0.0402 (10) | −0.0014 (7) |
| C10 | 0.0373 (8) | 0.0227 (8) | 0.0403 (9) | −0.0035 (6) | 0.0212 (7) | −0.0051 (6) |
| C11 | 0.0191 (6) | 0.0238 (7) | 0.0312 (7) | 0.0015 (5) | 0.0064 (6) | −0.0005 (6) |
| C12 | 0.0177 (7) | 0.0431 (10) | 0.0315 (8) | 0.0004 (6) | −0.0005 (6) | −0.0031 (7) |
| C13 | 0.0284 (8) | 0.0560 (12) | 0.0348 (9) | −0.0025 (8) | 0.0053 (7) | −0.0140 (8) |
| C14 | 0.0239 (7) | 0.0252 (8) | 0.0356 (8) | 0.0050 (6) | 0.0083 (6) | −0.0037 (6) |
| C15 | 0.0171 (6) | 0.0186 (7) | 0.0246 (7) | 0.0011 (5) | 0.0068 (5) | 0.0028 (5) |
| C16 | 0.0187 (6) | 0.0254 (8) | 0.0303 (8) | 0.0020 (5) | 0.0038 (6) | −0.0048 (6) |
| C17 | 0.0226 (7) | 0.0217 (7) | 0.0234 (7) | 0.0007 (5) | 0.0090 (5) | 0.0015 (5) |
| C18 | 0.0246 (7) | 0.0235 (7) | 0.0234 (7) | 0.0023 (5) | 0.0113 (6) | 0.0002 (5) |
| C19 | 0.0287 (8) | 0.0288 (8) | 0.0292 (8) | 0.0003 (6) | 0.0098 (6) | −0.0039 (6) |
| C20 | 0.0378 (9) | 0.0286 (8) | 0.0336 (8) | 0.0043 (6) | 0.0134 (7) | −0.0072 (6) |
| C21 | 0.0322 (8) | 0.0313 (8) | 0.0286 (8) | 0.0110 (6) | 0.0155 (6) | 0.0018 (6) |
| C22 | 0.0254 (7) | 0.0341 (8) | 0.0283 (7) | 0.0042 (6) | 0.0114 (6) | −0.0016 (6) |
| C23 | 0.0256 (7) | 0.0274 (8) | 0.0273 (7) | 0.0014 (6) | 0.0121 (6) | −0.0035 (6) |
| C24 | 0.0357 (9) | 0.0540 (12) | 0.0455 (11) | 0.0212 (9) | 0.0119 (8) | −0.0026 (9) |
| O5 | 0.027 (2) | 0.042 (3) | 0.039 (3) | −0.0069 (19) | 0.0036 (19) | 0.006 (2) |

Geometric parameters (Å, º)

|    | 1.7422 (14) | C9—C10 | 1.388 (2) |
|----|-------------|--------|----------|
| S1 | C16         | 1.8130 (15) | 0.99 (2) |
| F1 | C8          | 1.3657 (19) | 0.96 (2) |
| O1 | C11         | 1.2133 (18) | 1.498 (2) |
| O2 | C11         | 1.3522 (18) | 1.00 (2) |
| O2 | C12         | 1.4526 (17) | 0.988 (19) |
| O3 | C17         | 1.2236 (17) | 1.03 (2) |
| O4 | C21         | 1.3680 (18) | 1.00 (2) |
| O4 | C24         | 1.426 (2) | 0.98 (3) |
| N1 | C4          | 1.2996 (18) | 0.97 (2) |
| N1 | C3          | 1.4058 (17) | 0.96 (2) |
| N2 | C4          | 1.3546 (17) | 0.98 (2) |
| N2 | C15         | 1.3963 (17) | 1.5020 (19) |
| N2 | C1          | 1.4762 (16) | 0.98 (2) |
| N3 | C15         | 1.2750 (18) | 0.98 (2) |
| N3 | N4          | 1.3880 (15) | 1.4939 (19) |
| N4 | C17         | 1.3698 (18) | 1.391 (2) |
| N4 | H4          | 0.885 (19) | 1.401 (2) |

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### Supporting Information

| Bond          | Length (Å)   | Bond          | Length (Å)   |
|---------------|--------------|---------------|--------------|
| C1—C2         | 1.5194 (18)  | C19—C20       | 1.379 (2)    |
| C1—C5         | 1.5226 (19)  | C19—H19       | 0.96 (2)     |
| C1—H1         | 0.987 (17)   | C20—C21       | 1.392 (2)    |
| C2—C3         | 1.356 (2)    | C20—H20       | 0.97 (2)     |
| C2—C11        | 1.4694 (19)  | C21—C22       | 1.390 (2)    |
| C3—C14        | 1.5024 (19)  | C22—C23       | 1.392 (2)    |
| C5—C10        | 1.391 (2)    | C22—H22       | 0.99 (2)     |
| C5—C6         | 1.392 (2)    | C23—H23       | 0.960 (19)   |
| C6—C7         | 1.392 (2)    | C24—H24A      | 0.99 (2)     |
| C6—H6         | 1.004 (19)   | C24—H24B      | 1.00 (2)     |
| C7—C8         | 1.373 (3)    | C24—H24C      | 0.95 (2)     |
| C7—H7         | 0.97 (2)     | O5—H5A        | 0.8700       |
| C8—C9         | 1.374 (3)    | O5—H5B        | 0.8701       |

| Bond          | Angle (°)   |
|---------------|-------------|
| C4—S1—C16     | 112.3 (11)  |
| C11—O2—C12    | 108.7 (16)  |
| C21—O4—C24    | 111.3 (12)  |
| C4—N1—C3      | 107.9 (13)  |
| C4—N2—C15     | 110.2 (18)  |
| C4—N2—C1      | 110.9 (14)  |
| C15—N2—C1     | 107.1 (18)  |
| C15—N3—N4     | 109.4 (19)  |
| C17—N4—N3     | 111.4 (13)  |
| C17—N4—H4     | 112.1 (14)  |
| N3—N4—H4      | 103.9 (18)  |
| N2—C1—C2      | 109.4 (12)  |
| N2—C1—C5      | 109.8 (18)  |
| C2—C1—C5      | 110.1 (18)  |
| N2—C1—H1      | 118.03 (12) |
| C2—C1—H1      | 130.06 (12) |
| C5—C1—H1      | 111.90 (11) |
| C3—C2—C11     | 106.69 (9)  |
| C3—C2—C1      | 111.4 (12)  |
| C11—C2—C1     | 109.4 (11)  |
| C2—C3—N1      | 109.7 (12)  |
| C2—C3—C14     | 109.9 (12)  |
| N1—C3—C14     | 109.8 (16)  |
| N1—C4—N2      | 123.09 (13) |
| N1—C4—S1      | 121.90 (13) |
| N2—C4—S1      | 115.00 (12) |
| C10—C5—C6     | 118.49 (13) |
| C10—C5—C1     | 124.17 (13) |
| C6—C5—C1      | 117.34 (13) |
| C5—C6—H6      | 120.6 (11)  |
| C7—C6—H6      | 118.8 (11)  |
| C8—C7—C6      | 120.16 (15) |
| C8—C7—H7      | 121.9 (13)  |
| Bond | Angle (°)     | Bond | Angle (°)     | Bond | Angle (°)     |
|------|--------------|------|--------------|------|--------------|
| C6—C7—H7 | 119.8 (12) | C21—C20—H20 | 117.9 (13) |
| F1—C8—C7 | 118.48 (16) | O4—C21—C22 | 124.66 (14) |
| F1—C8—C9 | 118.13 (17) | O4—C21—C20 | 115.13 (14) |
| C7—C8—C9 | 123.39 (16) | C22—C21—C20 | 120.20 (14) |
| C8—C9—C10 | 117.76 (17) | C21—C22—C23 | 119.12 (14) |
| C8—C9—H9 | 119.7 (13) | C21—C22—H22 | 120.7 (11) |
| C10—C9—H9 | 122.5 (13) | C23—C22—H22 | 120.2 (11) |
| C9—C10—C5 | 120.96 (15) | C18—C23—C22 | 121.34 (14) |
| C9—C10—H10 | 119.1 (12) | C18—C23—H23 | 120.2 (11) |
| C5—C10—H10 | 119.9 (12) | C22—C23—H23 | 118.4 (11) |
| O1—C11—O2 | 122.00 (13) | C24—H24A—O4 | 110.4 (13) |
| O1—C11—C2 | 127.18 (14) | C24—H24B—O4 | 110.9 (13) |
| O2—C11—C2 | 110.81 (11) | H24A—C24—H24B | 110.1 (18) |
| O2—C12—C13 | 106.88 (13) | O4—C24—H24A | 104.9 (13) |
| O2—C12—H12A | 108.3 (12) | H24A—C24—H24C | 111.1 (18) |
| C13—C12—H12A | 112.1 (12) | H24B—C24—H24C | 109.4 (18) |
| O2—C12—H12B | 108.5 (11) | H5A—O5—H5B | 104.0 |

C15—N3—N4—C17 | 173.45 (12) | C1—C5—C10—C9 | −179.13 (15) |
C4—N2—C1—C2 | −21.62 (17) | C12—O2—C11—O1 | 1.5 (2) |
C15—N2—C1—C2 | 167.22 (11) | C12—O2—C11—C2 | −179.00 (12) |
C4—N2—C1—C5 | 101.08 (14) | C3—C2—C11—O1 | 2.3 (2) |
C15—N2—C1—C5 | −70.08 (15) | C1—C2—C11—O1 | −176.78 (15) |
N2—C1—C2—C3 | 20.41 (18) | C3—C2—C11—O2 | −177.21 (13) |
C5—C1—C2—C3 | −100.69 (15) | C3—C2—C11—O2 | 3.75 (18) |
N2—C1—C2—C11 | −160.54 (12) | C11—O2—C12—C13 | 173.66 (14) |
C5—C1—C2—C11 | 78.36 (15) | N4—N3—C15—N2 | 178.26 (11) |
C11—C2—C3—N1 | 173.50 (13) | N4—N3—C15—C16 | −2.1 (2) |
C1—C2—C3—N1 | −7.5 (2) | C4—N2—C15—N3 | 177.79 (12) |
C11—C2—C3—C14 | −5.0 (2) | C1—C2—C15—N3 | −10.60 (19) |
C1—C2—C3—C14 | 174.03 (14) | C1—C2—C15—C16 | −1.93 (17) |
C4—N1—C3—C2 | −7.2 (2) | C1—C2—C15—C16 | 169.67 (12) |
C4—N1—C3—C14 | 171.48 (13) | N3—C15—C16—S1 | −176.70 (12) |
C3—N1—C4—N2 | 6.2 (2) | N2—C15—C16—S1 | 2.98 (14) |
C3—N1—C4—S1 | −171.99 (10) | C4—S1—C16—C15 | −2.61 (11) |
C15—N2—C4—N1 | −178.53 (13) | N3—N4—C17—O3 | −7.08 (19) |
C1—N2—C4—N1 | 9.9 (2) | N3—N4—C17—C18 | 174.20 (11) |
C15—N2—C4—S1 | −0.18 (15) | O3—C17—C18—C23 | −160.50 (14) |
C1—N2—C4—S1 | −171.74 (10) | N4—C17—C18—C23 | 18.2 (2) |
C16—S1—C4—N1 | −179.84 (12) | O3—C17—C18—C19 | 19.1 (2) |
C16—S1—C4—N2 | 1.73 (11) | N4—C17—C18—C19 | −162.14 (13) |
N2—C1—C5—C10 | −58.95 (16) | C23—C18—C19—C20 | −1.5 (2) |
C2—C1—C5—C10 | 60.97 (17) | C17—C18—C19—C20 | 178.83 (14) |
N2—C1—C5—C6 | 121.37 (13) | C18—C19—C20—C21 | 1.3 (2) |
C2—C1—C5—C6 | −118.72 (14) | C24—O4—C21—C22 | 1.3 (2) |
C10—C5—C6—C7 | −1.9 (2) | C24—O4—C21—C20 | −178.54 (16) |
C1—C5—C6—C7 | 177.79 (13) | C19—C20—C21—O4 | 179.23 (14) |
C5—C6—C7—C8 | 1.4 (2) | C19—C20—C21—C22 | −0.6 (2) |
C6—C7—C8—F1 179.90 (15)  
C6—C7—C8—C9 0.4 (3)  
F1—C8—C9—C10 178.81 (16)  
C7—C8—C9—C10 −1.7 (3)  
C8—C9—C10—C5 1.2 (3)  
C6—C5—C10—C9 0.6 (2)  

Hydrogen-bond geometry (Å, º)

| D—H···A    | D—H   | H···A | D···A   | D—H···A |
|------------|--------|-------|---------|---------|
| N4—H4···N1i | 0.885 (19) | 2.164 (19) | 2.9888 (17) | 154.8 (16) |
| C1—H1···O5ii | 0.987 (17) | 2.345 (18) | 3.307 (5) | 164.7 (13) |
| C7—H7···O4iii | 0.97 (2) | 2.41 (2) | 3.285 (2) | 148.7 (17) |
| C13—H13B···F1iv | 0.98 (2) | 2.49 (3) | 3.386 (2) | 153.0 (19) |
| C16—H16A···N1i | 0.98 (2) | 2.58 (2) | 3.4019 (19) | 142.4 (15) |
| C16—H16B···O5iv | 0.98 (2) | 2.37 (2) | 3.282 (5) | 154.6 (16) |
| C24—H24A···O1v | 0.99 (2) | 2.53 (2) | 3.450 (3) | 154.6 (18) |
| C24—H24C···O1vi | 0.95 (2) | 2.57 (2) | 3.504 (2) | 167.8 (17) |
| O5—H5A···F1    | 0.87 | 1.76  | 2.479 (5) | 138 |
| O5—H5B···O3vii | 0.87 | 2.00  | 2.863 (5) | 174 |

Symmetry codes: (i) −x+1, y+1/2, −z+1/2; (ii) −y+3/2, z+1/2; (iii) −x+1, −y+2, −z+1; (iv) −x+1, y−1/2, −z+1/2; (v) −x+1, −y+1, −z+1; (vi) x−1, y+1, z; (vii) −y+3/2, z−1/2.