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Crystal structure and Hirshfeld surface analysis of 3-cyano-4-hydroxy-2-(4-methylphenyl)-6-oxo-*N*-phenyl-4-(thiophen-2-yl)cyclohexane-1-carboxamide 0.04-hydrate

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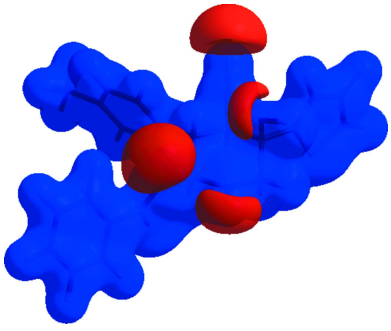
Supporting information: this article has supporting information at journals.iucr.org/e

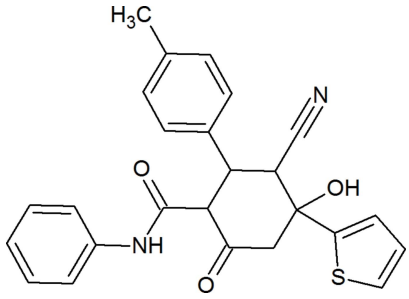
In the title compound, $C_{25}H_{22}N_2O_3S\cdot0.04H_2O$, the central cyclohexane ring adopts a chair conformation. In the crystal, molecules are linked by N—H···O, C—H···O, and C—H···N hydrogen bonds, forming the molecular layers parallel to the *bc* plane, which interact by the van der Waals forces between them. A Hirshfeld surface analysis indicates that the contributions from the most prevalent interactions are H···H (41.2%), C···H/H···C (20.3%), O···H/H···O (17.8%) and N···H/H···N (10.6%).

1. Chemical context

The significance of β-carbonyl compounds in organic chemistry is difficult to overestimate. They are valuable building blocks in organic synthesis and coordination complexes (Shokova *et al.*, 2015; Ma *et al.*, 2015; Gurbanov *et al.*, 2017, 2018; Mittersteiner *et al.*, 2020). Cyclocondensation reactions of β-diketones with various reagents mainly lead to the formation of carbocyclic and heterocyclic compounds (Mamedov *et al.*, 2013, 2019; Naghiyev *et al.*, 2019; Naghiyev, 2020). Being a carbocyclic system, cyclohexanone derivatives are scaffolds in many synthetic and natural products. They possess a broad spectrum of biological assets, such as anthelmintic, anti-inflammatory, antibacterial, anticancer, anticonvulsant, antitubercular, antitumor, antileukemic, antiviral, analgesic, herbicidal and enzyme inhibitory activities (Holland *et al.*, 1990; Fu & Ye, 2004; Liu *et al.*, 2009; Gein *et al.*, 2015; Mamedov *et al.*, 2017; Nosova *et al.*, 2020). The methods used most widely for the synthesis of these functionalized cyclohexanones involve the condensation of aldehydes with β-carbonyl compounds (Gein *et al.*, 2015; Nosova *et al.*, 2020).

As part of our studies on the chemistry of β-dicarbonyl compounds, as well as taking into account our ongoing structural studies (Naghiyev, Akkurt *et al.*, 2020; Naghiyev, Cisterna *et al.*, 2020; Naghiyev, Mammadova *et al.*, 2020; Naghiyev *et al.*, 2021), we report here the crystal structure and Hirshfeld surface analysis of the title compound, 3-cyano-4-hydroxy-2-(4-methylphenyl)-6-oxo-*N*-phenyl-4-(thiophen-2-yl)-cyclohexane-1-carboxamide 0.04-hydrate.





2. Structural commentary

In the title compound, (Fig. 1), the central cyclohexane ring (C1–C6) adopts a chair conformation with puckering parameters (Cremer & Pople, 1975) Q_T = 0.570 (2) Å, θ = 5.1 (2)° and φ = 226 (2)°. The thiophene (S1/C22–C25), phenyl (C8–C13) and benzene (C14–C19) rings make dihedral angles of 68.05 (10), 46.41 (9) and 87.95 (10)°, respectively, with the mean plane of the central cyclohexane ring. The thiophene ring forms dihedral angles of 21.88 (10) and 73.64 (10)°, respectively, with the phenyl and benzene rings, which subtend a dihedral angle of 80.91 (10)°. The C2—C7—N1—C8 torsion angle is 178.99 (18)°.

3. Supramolecular features

In the crystal, N—H···O and C—H···O hydrogen bonds link adjacent molecules, forming molecular ribbons with $R_1^2(6)$ and $R_2^2(10)$ ring motifs (Bernstein *et al.*, 1995) along the *c*-axis direction (Table 1; Figs. 2 and 3). These ribbons are linked by weak C—H···N non-classical hydrogen bonds, forming layers of molecules parallel to the *bc* plane (Table 1; Fig. 4), with only van der Waals interactions between them.

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

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
N1—H1*N*···O2^{i}	0.89 (2)	2.00 (2)	2.886 (2)	174 (2)
C2—H2···O2^{i}	1.00	2.44	3.320 (2)	146
C4—H4···O1^{i}	1.00	2.54	3.434 (2)	149
C9—H9···N2^{ii}	0.95	2.57	3.272 (3)	131

Symmetry codes: (i) $x, -y+\frac{1}{2}, z-\frac{1}{2}$; (ii) $-x+1, y-\frac{1}{2}, -z+\frac{1}{2}$.

4. Hirshfeld surface analysis

The Hirshfeld surface for the title compound and its associated two-dimensional fingerprint plots were calculated using *CrystalExplorer17* (Turner *et al.*, 2017). The oxygen atom of

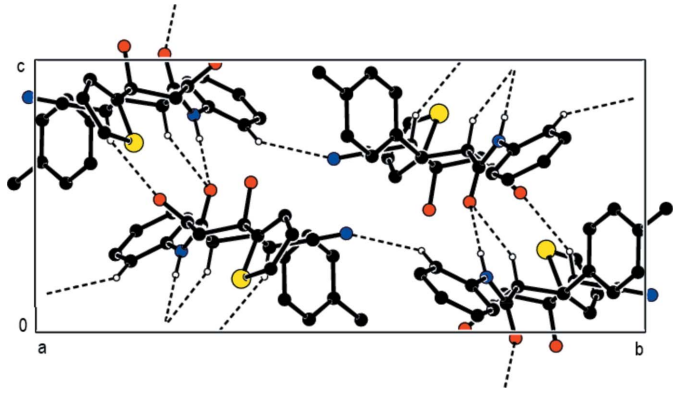


Figure 2
A view down the *a* axis of the intermolecular N—H···O, C—H···O and C—H···N hydrogen bonds of the title compound.

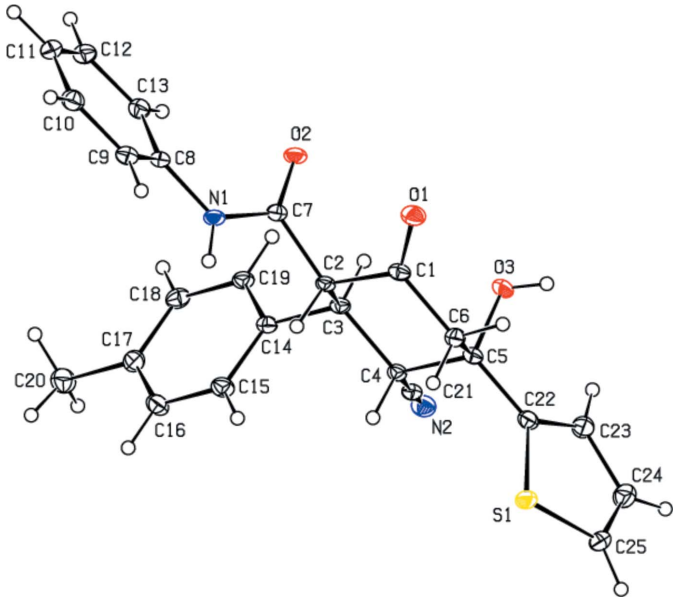


Figure 1
The molecular structure of the title compound. Displacement ellipsoids are drawn at the 30% probability level.

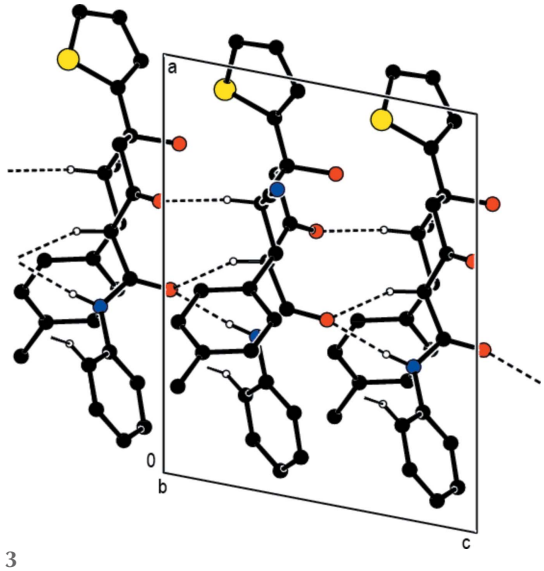


Figure 3
A view down the *b* axis of the intermolecular N—H···O, C—H···O and C—H···N hydrogen bonds of the title compound.

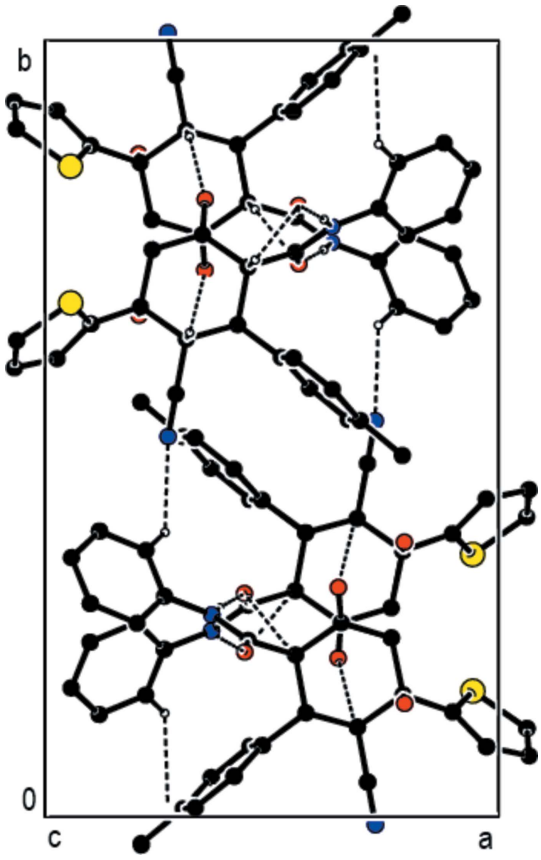


Figure 4
A view down the *c* axis of the intermolecular N—H···O, C—H···O and C—H···N hydrogen bonds of the title compound.

the water molecule with a low occupancy factor of about 4% was not taken into account in the process. The Hirshfeld surface mapped over electrostatic potential (Spackman *et al.*, 2008; Jayatilaka *et al.*, 2005) is shown in Fig. 5. The blue regions indicate positive electrostatic potential (hydrogen-bond donors), while the red regions indicate negative electrostatic potential (hydrogen-bond acceptors).

The overall two-dimensional fingerprint plot, and those delineated into H···H (41.2%), C···H/H···C (20.3%), O···H/H···O (17.8%) and N···H/H···N (10.6%) contacts are illustrated in Fig. 6*a–e*, respectively. The other minor contributions to the Hirshfeld surface are from S···H/H···S (5.5%), O···O (1.9%), C···C (1.1%), S···C/C···S (1.0%), O···C/C···O (0.5%) and O···N/N···O (0.1%) contacts. The large number of H···H, C···H/H···C, O···H/H···O and N···H/H···N interactions suggest that van der Waals interactions and hydrogen bonding play the major roles in the crystal packing (Hathwar *et al.*, 2015).

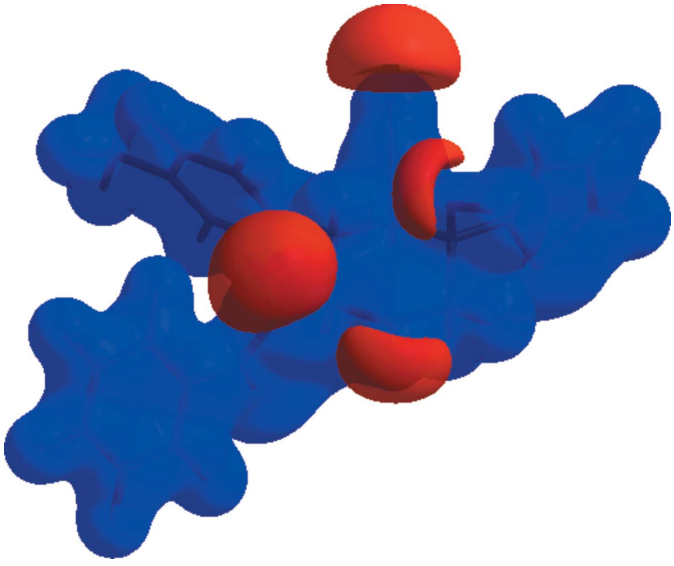


Figure 5
The Hirshfeld surface of the title compound plotted over electrostatic potential energy in the range from −0.0500 to 0.0500 a.u. using the *STO*-3*G* basis set at the Hartree–Fock level of theory. Hydrogen-bond donors and acceptors are shown as blue and red regions around the atoms, corresponding to positive and negative potentials, respectively.

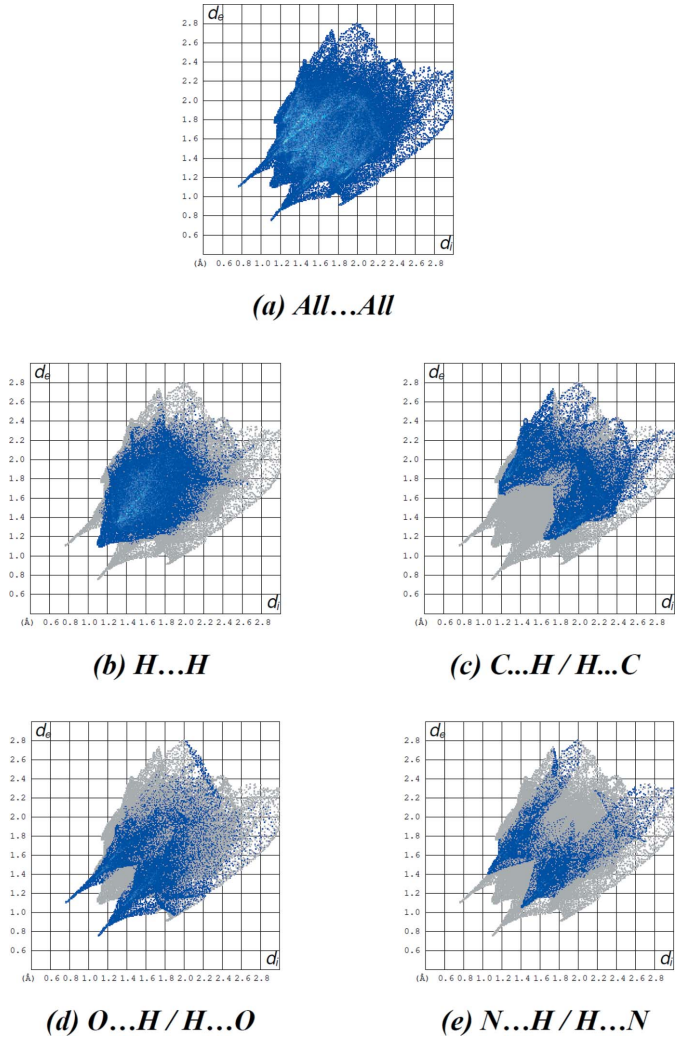


Figure 6
The two-dimensional fingerprint plots of the title compound, showing (*a*) all interactions, and delineated into (*b*) H···H, (*c*) C···H/H···C, (*d*) O···H/H···O and (*e*) N···H/H···N, interactions [d_e and d_i represent the distances from a point on the Hirshfeld surface to the nearest atoms outside (external) and inside (internal) the surface, respectively].

5. Database survey

A search of the Cambridge Structural database (CSD, version 5.42, update November 2020; Groom *et al.*, 2016) for the 4-hydroxy-5-methyl-2-oxocyclohexane-1-carboxamide moiety revealed seven hits, of which the structures most similar to the that of the title compound are 4-hydroxy-4,*N*,*N*′-trimethyl-2-(3-nitrophenyl)-6-oxo-1,3-cyclohexanedicarbox-amide (HALROB; Ravikumar & Mehdi, 1993), 4-hydroxy-*N*,*N*,*N*′,*N*′,4-pentamethyl-6-oxo-2-phenylcyclohexane-1,3-dicarboxamide (IFUDOD; Gein *et al.*, 2007), 5-hydroxy-5-methyl-3-phenyl-2,4-bis(*N*-methylcarbamoyl)cyclohexanone (IWEVOV; Mohan *et al.*, 2003), 5-hydroxy-5-methyl-3-(*o*-tolyl)-2,4-bis(*N*-methylcarbamoyl)cyclohexanone (IWEVUB; Mohan *et al.*, 2003), 2-(4-chlorophenyl)-4-hydroxy-4-methyl-6-oxo-*N*,*N*′-diphenylcyclohexane-1,3-dicarboxamide *N*,*N*-dimethylformamide solvate (OZUKAX; Tkachenko *et al.*, 2014), 4-hydroxy-4-methyl-2-(4-methylphenyl)-6-oxo-N^1,N^3-diphenylcyclohexane-1,3-dicarboxamide (PEWJUZ; Fatahpour *et al.*, 2018) and 4-hydroxy-4-methyl-2-(3-nitrophenyl)-6-oxocyclohexane-1,3-dicarboxamide ethanol solvate (ZOMDUD; Gein *et al.*, 2019).

ZOMDUD crystallizes in the monoclinic space group $P2_1/c$, with Z = 4, HALROB, IFUDOD and IWEVUB in $P2_1/n$ with Z = 4, PEWJUZ in $I2/c$ with Z = 4, and IWEVOV and OZUKAX in the orthorhombic space group *Pbca* with Z = 8.

In the crystal of HALROB, the amide carbonyl groups are oriented in different directions with respect to the cyclohexanone ring. These orientations of the carboxamide groups facilitate the formation of an intramolecular O—H···O hydrogen bond. The molecules are packed such that chains are formed along the *b*-axis direction. These chains are held together by N—H···O hydrogen bonds.

In the crystal IFUDOD, there are no classical hydrogen bonds. Intermolecular C—H···O contacts and weak C—H···π interactions lead to the formation of a three-dimensional network.

In the crystal of IWEVOV, the molecules pack such that both carbonyl O atoms, participate in hydrogen-bond formation with symmetry-related amide nitrogen atoms, present in the carbamoyl substituents, forming N—H···O hydrogen bonds in a helical arrangement. In the crystal, the phenyl rings are positioned so as to favour edge-to-edge aromatic stacking. When the crystal packing is viewed normal to the *ac* plane, it reveals a 'wire-mesh' type hydrogen-bond network.

In the crystal of IWEVUB, unlike in IWEVOV where both carbonyl O atoms participate in hydrogen bonding, only one of the carbonyl oxygen atoms participates in intermolecular N—H···O hydrogen bonding while the other carbonyl oxygen participates in a weak C—H···O interaction. In addition, one of the amide nitrogen atoms participates in N—H···O hydrogen bonding with the hydroxyl oxygen atom, linking the molecules in a helical arrangement, which is similar to that in the structure of IWEVOV. As observed in the structure of IWEVOV, the packing of the molecules viewed normal to the *ab* plane resembles a 'wiremesh' arrangement of the molecules.

In OZUKAX, molecules are linked by intermolecular N—H···O and C—H···O hydrogen bonds, forming sheets parallel to the *ac* plane. C—H···π interactions are also observed. Intermolecular O—H···O hydrogen bonds consolidate the molecular conformation.

In PEWJUZ, molecules are linked by intermolecular N—H···O and C—H···O hydrogen bonds, forming sheets parallel to the *bc* plane. C—H···π interactions are also observed.

In ZOMDUD, molecules are linked by intermolecular N—H···O and C—H···O hydrogen bonds, forming a three-dimensional network. C—H···π interactions are also observed.

Intermolecular interactions can be weaker or more robust based on the presence or absence of different functional groups and the molecular environment, depending on the crystal system, which all affect the molecular conformation.

6. Synthesis and crystallization

To a dissolved mixture of 2-(thiophene-2-carbonyl)-3-(*p*-tolyl)acrylonitrile (1.32 g; 5.2 mmol) and acetoacetanilide (0.92 g; 5.2 mmol) in methanol (35 mL), 2–3 drops of methyl piperazine were added and the mixture was stirred at room temperature for 5–7 min. The reaction mixture was kept in a closed flask for 24–48 h. Then, 25 mL of methanol was removed from the reaction mixture and it was left overnight. The precipitated needle-like crystals were separated by filtration and recrystallized from ethanol (yield 72%; m.p. 483–484 K).

^{1}H NMR (300 MHz, DMSO-d_6, m.h.): δ 2.23 (*s*, 3H, CH_3); 2.79 (*d*, 2H, CH_2, $^2J_{\text{H-H}}$ = 18.1 Hz); 3.50 (*t*, 1H, C*H*, $^3J_{\text{H-H}}$ = 13.8 Hz); 3.63 (*s*, 1H, O*H*); 4.06 (*d*, 1H, C*H*, $^3J_{\text{H-H}}$ = 10.5 Hz); 4.28 (*dd*, 1H, C*H*, $^3J_{\text{H-H}}$ = 10.5 Hz, $^3J_{\text{H-H}}$ = 11.9 Hz); 6.97–7.48 (*m*, 12H, 9Ar-*H* + 3CH_{thienyl}); 9.94 ppm (*s*, 1H, N*H*). ^{13}C NMR (75 MHz, DMSO-d_6, m.h.): δ 21.14 (CH_3–Ar), 44.26 (*C*H—Ar), 47.40 (*C*H—CN), 54.07 (*C*H$_2$), 62.64 (C*H*—CO), 75.29 (O—$C_{\text{quat.}}$), 119.02 (*C*N), 119.49 (2*C*H$_{\text{arom}}$), 123.87 (*C*H$_{\text{thienyl}}$), 124.45 (*C*H$_{\text{arom}}$), 125.71 (*C*H$_{\text{thienyl}}$), 127.63 (*C*H$_{\text{thienyl}}$), 128.75 (2 *C*H$_{\text{arom}}$), 129.14 (2 *C*H$_{\text{arom}}$),129.54 (2 *C*H$_{\text{arom}}$), 137.06 (C_{arom}), 137.17 (C_{arom}), 139.14 (C_{arom}), 150.57 (C_{thienyl}), 165.85 (O=*C*), 203.12 ppm (O=C_{ket}). As a result of the overlap of peaks in the ^{1}H NMR spectrum, it was not possible to determine precisely all coupling constants.

7. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 2. The H atoms of the OH and NH groups were located from the difference-Fourier synthesis and refined freely. All C-bound H atoms were positioned geometrically and refined using a riding model, with C—H = 0.95–1.00 Å, and with U_{iso}(H) = 1.2 or 1.5U_{eq}(C).

Data with a resolution higher than 0.8 Å have a mean $I/\sigma(I)$ of less than 4, and significant errors in the equivalent intensities (high R_{merge}). The dataset was therefore truncated at

0.8 Å. Furthermore, there is a small cavity in the crystal, which is only partially occupied by a water molecule (only about 4%) and the protons could not be located. It is also highly probable that, in the presence of a fully occupied water molecule, the proton of the OH group would have a different orientation.

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Table 2
Experimental details.

Crystal data	
Chemical formula	$C_{25}H_{22}N_2O_3S{\cdot}0.04H_2O$
M_r	1724.87
Crystal system, space group	Monoclinic, $P2_1/c$
Temperature (K)	100
a, b, c (Å)	12.049 (2), 20.223 (4), 9.1743 (18)
β (°)	100.91 (3)
V (Å^3)	2195.0 (8)
Z	1
Radiation type	Mo $K\alpha$
μ (mm^{-1})	0.18
Crystal size (mm)	0.36 × 0.03 × 0.03
Data collection	
Diffractometer	Bruker D8 QUEST PHOTON-III CCD
Absorption correction	Multi-scan (*SADABS*; Krause *et al.*, 2015)
T_{min}, T_{max}	0.930, 0.990
No. of measured, independent and observed [$I > 2\sigma(I)$] reflections	40890, 4492, 3208
R_{int}	0.086
(sin $\theta/\lambda)_{max}$ (Å^{-1})	0.625
Refinement	
$R[F^2 > 2\sigma(F^2)]$, $wR(F^2)$, S	0.043, 0.099, 1.02
No. of reflections	4492
No. of parameters	297
No. of restraints	7
H-atom treatment	H atoms treated by a mixture of independent and constrained refinement
$\Delta\rho_{max}$, $\Delta\rho_{min}$ (e Å^{-3})	0.24, −0.28

Computer programs: *APEX3* (Bruker, 2018), *SAINT* (Bruker, 2013), *SHELXT2014/5* (Sheldrick, 2015*a*), *SHELXL2018/3* (Sheldrick, 2015*b*), *ORTEP-3 for Windows* (Farrugia, 2012) and *PLATON* (Spek, 2020).

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Crystal structure and Hirshfeld surface analysis of 3-cyano-4-hydroxy-2-(4-methylphenyl)-6-oxo-*N*-phenyl-4-(thiophen-2-yl)cyclohexane-1-carboxamide 0.04-hydrate

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Computing details

Data collection: *APEX3* (Bruker, 2018); cell refinement: *SAINT* (Bruker, 2013); data reduction: *SAINT* (Bruker, 2013); program(s) used to solve structure: *SHELXT2014/5* (Sheldrick, 2015a); program(s) used to refine structure: *SHELXL2018/3* (Sheldrick, 2015b); molecular graphics: *ORTEP-3 for Windows* (Farrugia, 2012); software used to prepare material for publication: *PLATON* (Spek, 2020).

3-Cyano-4-hydroxy-2-(4-methylphenyl)-6-oxo-*N*-phenyl-4-(thiophen-2-yl)cyclohexane-1-carboxamide 0.04-hydrate

Crystal data

$C_{25}H_{22}N_2O_3S\cdot0.04H_2O$
M_r = 1724.87
Monoclinic, $P2_1/c$
a = 12.049 (2) Å
b = 20.223 (4) Å
c = 9.1743 (18) Å
β = 100.91 (3)°
V = 2195.0 (8) Å^3
Z = 1
$F(000)$ = 906
D_x = 1.305 Mg m^{-3}
Mo $K\alpha$ radiation, λ = 0.71073 Å
Cell parameters from 6355 reflections
θ = 2.5–27.2°
μ = 0.18 mm^{-1}
T = 100 K
Needle, colourless
0.36 × 0.03 × 0.03 mm

Data collection

Bruker D8 QUEST PHOTON-III CCD diffractometer
φ and ω scans
Absorption correction: multi-scan (SADABS; Krause *et al.*, 2015)
T_{min} = 0.930, T_{max} = 0.990
40890 measured reflections
4492 independent reflections
3208 reflections with $I > 2\sigma(I)$
R_{int} = 0.086
θ_{max} = 26.4°, θ_{min} = 2.0°
h = −15→15
k = −25→25
l = −11→11

Refinement

Refinement on F^2
Least-squares matrix: full
$R[F^2 > 2\sigma(F^2)]$ = 0.043
$wR(F^2)$ = 0.099
S = 1.02
4492 reflections
297 parameters
7 restraints
Hydrogen site location: mixed
H atoms treated by a mixture of independent and constrained refinement

$w = 1/[\sigma^2(F_o^2) + (0.034P)^2 + 1.3559P]$
where $P = (F_o^2 + 2F_c^2)/3$
$(\Delta/\sigma)_{max} < 0.001$

$\Delta\rho_{max} = 0.24$ e Å^{-3}
$\Delta\rho_{min} = -0.28$ e Å^{-3}

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.

Fractional atomic coordinates and isotropic or equivalent isotropic displacement parameters (Å^2)

	x	*y*	*z*	U_{iso}*/U_{eq}	Occ. (<1)
S1	0.94322 (4)	0.33798 (3)	0.19635 (6)	0.02478 (14)	
O1	0.64646 (13)	0.20448 (7)	0.48755 (16)	0.0284 (4)	
O2	0.44002 (12)	0.28766 (7)	0.52178 (15)	0.0236 (3)	
O3	0.79249 (12)	0.35394 (8)	0.55025 (15)	0.0262 (4)	
H3O	0.8523 (16)	0.3394 (12)	0.595 (3)	0.039*	
O4	0.612 (3)	0.351 (2)	0.700 (4)	0.031 (14)	0.040 (5)
N1	0.36773 (14)	0.23974 (9)	0.29809 (18)	0.0206 (4)	
H1N	0.3849 (18)	0.2305 (11)	0.211 (3)	0.025*	
N2	0.72836 (16)	0.51020 (9)	0.3630 (2)	0.0281 (4)	
C1	0.65290 (17)	0.24998 (10)	0.4037 (2)	0.0209 (4)	
C2	0.55201 (16)	0.29125 (10)	0.3322 (2)	0.0184 (4)	
H2	0.536629	0.282554	0.222891	0.022*	
C3	0.57511 (16)	0.36608 (10)	0.3578 (2)	0.0185 (4)	
H3	0.582369	0.375121	0.466358	0.022*	
C4	0.68857 (16)	0.38432 (9)	0.3124 (2)	0.0180 (4)	
H4	0.680962	0.376165	0.203480	0.022*	
C5	0.78937 (17)	0.34269 (10)	0.3945 (2)	0.0207 (4)	
C6	0.76359 (17)	0.26933 (10)	0.3603 (2)	0.0221 (5)	
H6A	0.759197	0.261182	0.252955	0.026*	
H6B	0.825432	0.241803	0.415728	0.026*	
C7	0.44750 (17)	0.27263 (10)	0.3935 (2)	0.0190 (4)	
C8	0.26345 (17)	0.21588 (10)	0.3278 (2)	0.0198 (4)	
C9	0.22262 (17)	0.15683 (10)	0.2617 (2)	0.0230 (4)	
H9	0.264590	0.133517	0.200325	0.028*	
C10	0.12021 (18)	0.13192 (11)	0.2855 (2)	0.0272 (5)	
H10	0.092562	0.091213	0.241189	0.033*	
C11	0.05831 (18)	0.16603 (12)	0.3732 (2)	0.0284 (5)	
H11	−0.012143	0.149162	0.388622	0.034*	
C12	0.09986 (18)	0.22518 (11)	0.4386 (2)	0.0280 (5)	
H12	0.057482	0.248606	0.499304	0.034*	
C13	0.20247 (17)	0.25057 (11)	0.4167 (2)	0.0235 (5)	
H13	0.230470	0.291052	0.461766	0.028*	
C14	0.47911 (16)	0.40798 (10)	0.2754 (2)	0.0194 (4)	
C15	0.45216 (18)	0.40895 (11)	0.1203 (2)	0.0246 (5)	
H15	0.492962	0.381703	0.064508	0.030*	
C16	0.36664 (18)	0.44924 (11)	0.0475 (2)	0.0269 (5)	

H16	0.349713	0.449300	−0.057939	0.032*
C17	0.30501 (17)	0.48957 (11)	0.1251 (2)	0.0256 (5)
C18	0.33140 (18)	0.48823 (11)	0.2794 (2)	0.0257 (5)
H18	0.290300	0.515437	0.334897	0.031*
C19	0.41680 (17)	0.44777 (10)	0.3536 (2)	0.0219 (4)
H19	0.432838	0.447282	0.459033	0.026*
C20	0.2125 (2)	0.53442 (12)	0.0457 (3)	0.0349 (6)
H20A	0.188806	0.519550	−0.057203	0.052*
H20B	0.240883	0.579854	0.046566	0.052*
H20C	0.147738	0.532911	0.096157	0.052*
C21	0.71119 (17)	0.45522 (11)	0.3399 (2)	0.0216 (4)
C22	0.89866 (17)	0.36488 (10)	0.3544 (2)	0.0218 (4)
C23	0.97306 (17)	0.40966 (11)	0.4282 (2)	0.0267 (5)
H23	0.962924	0.430925	0.517123	0.032*
C24	1.06711 (19)	0.42148 (12)	0.3596 (3)	0.0312 (5)
H24	1.127012	0.450845	0.398265	0.037*
C25	1.06228 (18)	0.38632 (11)	0.2328 (2)	0.0280 (5)
H25	1.117772	0.388191	0.171907	0.034*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
S1	0.0239 (3)	0.0333 (3)	0.0184 (3)	−0.0043 (2)	0.0072 (2)	−0.0021 (2)
O1	0.0322 (8)	0.0279 (8)	0.0260 (8)	0.0009 (7)	0.0077 (7)	0.0086 (7)
O2	0.0275 (8)	0.0310 (8)	0.0141 (7)	−0.0036 (6)	0.0085 (6)	−0.0010 (6)
O3	0.0262 (8)	0.0395 (10)	0.0130 (7)	0.0029 (7)	0.0038 (6)	0.0014 (6)
O4	0.024 (18)	0.04 (2)	0.027 (19)	−0.001 (13)	−0.004 (13)	−0.009 (13)
N1	0.0234 (9)	0.0270 (10)	0.0130 (8)	−0.0028 (8)	0.0077 (7)	−0.0021 (7)
N2	0.0329 (10)	0.0281 (11)	0.0235 (10)	−0.0047 (8)	0.0060 (8)	−0.0014 (8)
C1	0.0272 (11)	0.0221 (11)	0.0143 (10)	−0.0014 (9)	0.0062 (8)	−0.0013 (8)
C2	0.0211 (10)	0.0236 (11)	0.0112 (9)	−0.0022 (8)	0.0050 (8)	−0.0014 (8)
C3	0.0218 (10)	0.0210 (10)	0.0138 (9)	−0.0012 (8)	0.0064 (8)	−0.0015 (8)
C4	0.0204 (10)	0.0207 (10)	0.0132 (9)	−0.0023 (8)	0.0038 (8)	−0.0020 (8)
C5	0.0221 (10)	0.0272 (11)	0.0131 (9)	0.0005 (9)	0.0042 (8)	0.0009 (8)
C6	0.0214 (10)	0.0247 (11)	0.0207 (11)	0.0021 (9)	0.0054 (9)	0.0036 (9)
C7	0.0219 (10)	0.0192 (10)	0.0168 (10)	0.0018 (8)	0.0063 (8)	0.0026 (8)
C8	0.0207 (10)	0.0243 (11)	0.0153 (10)	−0.0003 (8)	0.0055 (8)	0.0040 (8)
C9	0.0277 (11)	0.0245 (11)	0.0176 (10)	0.0006 (9)	0.0067 (9)	0.0001 (9)
C10	0.0300 (12)	0.0283 (12)	0.0223 (11)	−0.0057 (10)	0.0029 (9)	0.0025 (9)
C11	0.0231 (11)	0.0386 (13)	0.0245 (11)	−0.0061 (10)	0.0065 (9)	0.0049 (10)
C12	0.0271 (11)	0.0361 (13)	0.0228 (11)	0.0029 (10)	0.0102 (9)	0.0013 (10)
C13	0.0248 (11)	0.0257 (11)	0.0200 (10)	0.0004 (9)	0.0046 (9)	0.0001 (9)
C14	0.0226 (10)	0.0193 (10)	0.0171 (10)	−0.0027 (8)	0.0058 (8)	0.0009 (8)
C15	0.0292 (11)	0.0275 (12)	0.0183 (10)	0.0021 (9)	0.0075 (9)	−0.0029 (9)
C16	0.0300 (12)	0.0318 (12)	0.0183 (10)	0.0044 (10)	0.0033 (9)	0.0014 (9)
C17	0.0232 (11)	0.0261 (11)	0.0277 (12)	0.0004 (9)	0.0056 (9)	0.0028 (9)
C18	0.0267 (11)	0.0255 (12)	0.0274 (11)	0.0024 (9)	0.0118 (9)	−0.0009 (9)
C19	0.0239 (10)	0.0271 (11)	0.0165 (10)	−0.0013 (9)	0.0083 (9)	−0.0028 (9)

C20	0.0335 (13)	0.0390 (14)	0.0327 (13)	0.0106 (11)	0.0075 (11)	0.0064 (11)
C21	0.0215 (10)	0.0295 (12)	0.0146 (10)	−0.0020 (9)	0.0058 (8)	0.0011 (9)
C22	0.0244 (11)	0.0250 (11)	0.0161 (10)	0.0020 (9)	0.0038 (8)	0.0016 (8)
C23	0.0256 (11)	0.0329 (13)	0.0221 (11)	−0.0007 (10)	0.0057 (9)	−0.0048 (9)
C24	0.0266 (11)	0.0360 (13)	0.0310 (12)	−0.0065 (10)	0.0056 (10)	−0.0020 (10)
C25	0.0221 (11)	0.0377 (13)	0.0253 (11)	−0.0059 (10)	0.0076 (9)	0.0011 (10)

Geometric parameters (Å, º)

S1—C25	1.716 (2)	C9—H9	0.9500
S1—C22	1.727 (2)	C10—C11	1.381 (3)
O1—C1	1.211 (2)	C10—H10	0.9500
O2—C7	1.236 (2)	C11—C12	1.389 (3)
O3—C5	1.440 (2)	C11—H11	0.9500
O3—H3O	0.815 (16)	C12—C13	1.388 (3)
N1—C7	1.347 (3)	C12—H12	0.9500
N1—C8	1.420 (3)	C13—H13	0.9500
N1—H1N	0.89 (2)	C14—C19	1.389 (3)
N2—C21	1.143 (3)	C14—C15	1.398 (3)
C1—C6	1.514 (3)	C15—C16	1.382 (3)
C1—C2	1.517 (3)	C15—H15	0.9500
C2—C7	1.520 (3)	C16—C17	1.387 (3)
C2—C3	1.549 (3)	C16—H16	0.9500
C2—H2	1.0000	C17—C18	1.391 (3)
C3—C14	1.515 (3)	C17—C20	1.513 (3)
C3—C4	1.547 (3)	C18—C19	1.388 (3)
C3—H3	1.0000	C18—H18	0.9500
C4—C21	1.472 (3)	C19—H19	0.9500
C4—C5	1.551 (3)	C20—H20A	0.9800
C4—H4	1.0000	C20—H20B	0.9800
C5—C22	1.501 (3)	C20—H20C	0.9800
C5—C6	1.536 (3)	C22—C23	1.361 (3)
C6—H6A	0.9900	C23—C24	1.417 (3)
C6—H6B	0.9900	C23—H23	0.9500
C8—C13	1.387 (3)	C24—C25	1.355 (3)
C8—C9	1.387 (3)	C24—H24	0.9500
C9—C10	1.388 (3)	C25—H25	0.9500
C25—S1—C22	92.19 (11)	C11—C10—H10	119.8
C5—O3—H3O	107.5 (18)	C9—C10—H10	119.8
C7—N1—C8	126.29 (17)	C10—C11—C12	119.5 (2)
C7—N1—H1N	115.6 (14)	C10—C11—H11	120.3
C8—N1—H1N	118.0 (14)	C12—C11—H11	120.3
O1—C1—C6	121.94 (19)	C13—C12—C11	120.9 (2)
O1—C1—C2	123.36 (19)	C13—C12—H12	119.5
C6—C1—C2	114.70 (17)	C11—C12—H12	119.5
C1—C2—C7	110.84 (16)	C8—C13—C12	118.9 (2)
C1—C2—C3	111.44 (16)	C8—C13—H13	120.5

C7—C2—C3	108.88 (16)	C12—C13—H13	120.5
C1—C2—H2	108.5	C19—C14—C15	118.25 (19)
C7—C2—H2	108.5	C19—C14—C3	120.15 (17)
C3—C2—H2	108.5	C15—C14—C3	121.59 (18)
C14—C3—C4	111.24 (16)	C16—C15—C14	120.5 (2)
C14—C3—C2	111.86 (16)	C16—C15—H15	119.7
C4—C3—C2	109.56 (16)	C14—C15—H15	119.7
C14—C3—H3	108.0	C15—C16—C17	121.4 (2)
C4—C3—H3	108.0	C15—C16—H16	119.3
C2—C3—H3	108.0	C17—C16—H16	119.3
C21—C4—C3	109.29 (16)	C16—C17—C18	118.0 (2)
C21—C4—C5	110.05 (16)	C16—C17—C20	121.5 (2)
C3—C4—C5	112.98 (16)	C18—C17—C20	120.5 (2)
C21—C4—H4	108.1	C19—C18—C17	121.1 (2)
C3—C4—H4	108.1	C19—C18—H18	119.5
C5—C4—H4	108.1	C17—C18—H18	119.5
O3—C5—C22	109.67 (16)	C18—C19—C14	120.75 (19)
O3—C5—C6	108.76 (16)	C18—C19—H19	119.6
C22—C5—C6	113.04 (17)	C14—C19—H19	119.6
O3—C5—C4	105.49 (16)	C17—C20—H20A	109.5
C22—C5—C4	111.18 (16)	C17—C20—H20B	109.5
C6—C5—C4	108.40 (16)	H20A—C20—H20B	109.5
C1—C6—C5	110.49 (17)	C17—C20—H20C	109.5
C1—C6—H6A	109.6	H20A—C20—H20C	109.5
C5—C6—H6A	109.6	H20B—C20—H20C	109.5
C1—C6—H6B	109.6	N2—C21—C4	179.1 (2)
C5—C6—H6B	109.6	C23—C22—C5	127.05 (19)
H6A—C6—H6B	108.1	C23—C22—S1	110.32 (16)
O2—C7—N1	124.66 (19)	C5—C22—S1	122.57 (15)
O2—C7—C2	120.42 (18)	C22—C23—C24	113.4 (2)
N1—C7—C2	114.92 (17)	C22—C23—H23	123.3
C13—C8—C9	120.61 (19)	C24—C23—H23	123.3
C13—C8—N1	121.85 (19)	C25—C24—C23	112.6 (2)
C9—C8—N1	117.52 (18)	C25—C24—H24	123.7
C8—C9—C10	119.7 (2)	C23—C24—H24	123.7
C8—C9—H9	120.1	C24—C25—S1	111.40 (17)
C10—C9—H9	120.1	C24—C25—H25	124.3
C11—C10—C9	120.3 (2)	S1—C25—H25	124.3

O1—C1—C2—C7	6.3 (3)	C8—C9—C10—C11	0.7 (3)
C6—C1—C2—C7	−174.55 (16)	C9—C10—C11—C12	−0.6 (3)
O1—C1—C2—C3	127.8 (2)	C10—C11—C12—C13	0.2 (3)
C6—C1—C2—C3	−53.1 (2)	C9—C8—C13—C12	0.1 (3)
C1—C2—C3—C14	174.89 (16)	N1—C8—C13—C12	178.60 (19)
C7—C2—C3—C14	−62.5 (2)	C11—C12—C13—C8	0.0 (3)
C1—C2—C3—C4	51.1 (2)	C4—C3—C14—C19	−120.6 (2)
C7—C2—C3—C4	173.62 (15)	C2—C3—C14—C19	116.5 (2)
C14—C3—C4—C21	57.0 (2)	C4—C3—C14—C15	58.1 (2)

C2—C3—C4—C21	−178.84 (15)	C2—C3—C14—C15	−64.8 (2)
C14—C3—C4—C5	179.86 (16)	C19—C14—C15—C16	0.8 (3)
C2—C3—C4—C5	−55.9 (2)	C3—C14—C15—C16	−177.84 (19)
C21—C4—C5—O3	64.9 (2)	C14—C15—C16—C17	−0.2 (3)
C3—C4—C5—O3	−57.6 (2)	C15—C16—C17—C18	−0.3 (3)
C21—C4—C5—C22	−54.0 (2)	C15—C16—C17—C20	179.1 (2)
C3—C4—C5—C22	−176.43 (16)	C16—C17—C18—C19	0.0 (3)
C21—C4—C5—C6	−178.80 (16)	C20—C17—C18—C19	−179.4 (2)
C3—C4—C5—C6	58.7 (2)	C17—C18—C19—C14	0.7 (3)
O1—C1—C6—C5	−124.8 (2)	C15—C14—C19—C18	−1.1 (3)
C2—C1—C6—C5	56.1 (2)	C3—C14—C19—C18	177.61 (18)
O3—C5—C6—C1	57.7 (2)	O3—C5—C22—C23	−22.9 (3)
C22—C5—C6—C1	179.77 (16)	C6—C5—C22—C23	−144.4 (2)
C4—C5—C6—C1	−56.5 (2)	C4—C5—C22—C23	93.4 (2)
C8—N1—C7—O2	−1.1 (3)	O3—C5—C22—S1	160.44 (14)
C8—N1—C7—C2	178.99 (18)	C6—C5—C22—S1	38.9 (2)
C1—C2—C7—O2	71.2 (2)	C4—C5—C22—S1	−83.3 (2)
C3—C2—C7—O2	−51.7 (2)	C25—S1—C22—C23	0.82 (17)
C1—C2—C7—N1	−108.87 (19)	C25—S1—C22—C5	178.01 (18)
C3—C2—C7—N1	128.20 (18)	C5—C22—C23—C24	−178.2 (2)
C7—N1—C8—C13	36.3 (3)	S1—C22—C23—C24	−1.2 (2)
C7—N1—C8—C9	−145.1 (2)	C22—C23—C24—C25	1.0 (3)
C13—C8—C9—C10	−0.5 (3)	C23—C24—C25—S1	−0.4 (3)
N1—C8—C9—C10	−179.04 (18)	C22—S1—C25—C24	−0.26 (19)

Hydrogen-bond geometry (Å, º)

D—H···*A*	*D*—H	H···*A*	*D*···*A*	*D*—H···*A*
N1—H1*N*···O2^{i}	0.89 (2)	2.00 (2)	2.886 (2)	174 (2)
C2—H2···O2^{i}	1.00	2.44	3.320 (2)	146
C3—H3···O3	1.00	2.54	2.879 (2)	100
C4—H4···O1^{i}	1.00	2.54	3.434 (2)	149
C6—H6*A*···S1	0.99	2.83	3.179 (2)	101
C9—H9···N2^{ii}	0.95	2.57	3.272 (3)	131
C13—H13···O2	0.95	2.48	2.939 (3)	110

Symmetry codes: (i) *x*, −*y*+1/2, *z*−1/2; (ii) −*x*+1, *y*−1/2, −*z*+1/2.