

Crystal structure and Hirshfeld surface analysis of 5-(5-phenyl-1,2-oxazol-3-yl)-1,3,4-thiadiazol-2-amine

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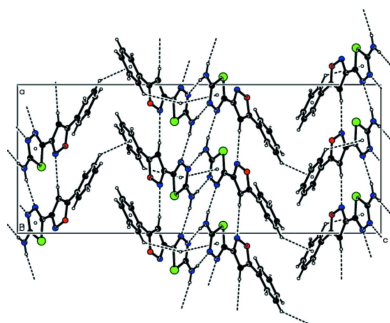
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The title compound, C₁₁H₈N₄OS, crystallizes with two independent molecules in the asymmetric unit. In the crystal, the N—H···N and C—H···N hydrogen bonds connect the molecules, generating double layers parallel to the (001) plane. The layers are joined by C—H··· π interactions to form a three-dimensional supramolecular structure.

1. Chemical context

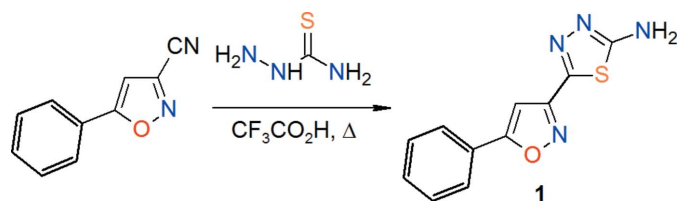
Compounds with the five-membered isoxazole, isothiazole and 1,3,4-thiadiazole heterocycles possess high potential for biological activity and are privileged scaffolds for the development of pharmaceutical agents (Das & Chanda, 2021; Kletskov *et al.*, 2020; Khalilullah *et al.*, 2014; Yadigarov *et al.*, 2009; Safavora *et al.*, 2019; Zubkov *et al.*, 2014). In particular, isoxazoles are able to enhance the action of 'first-line' anti-tumor substances, which makes it possible to reduce their therapeutic doses and thus reduce toxic side effects (Khalilov *et al.*, 2021; Kulchitsky *et al.*, 2012; Naghiyev *et al.*, 2020). The combination of the pharmacophore fragments of isoxazole and thiadiazole in one molecule increases the variability of its binding to the key sites of enzymes regulating the biological action. The presence of an amino group additionally increases the biopotential of the molecule, and the introduction of an aromatic fragment makes it possible to implement binding with a biotarget by π -stacking (Shixaliyev *et al.*, 2014, 2018; Mahmudov *et al.*, 2011, 2013; Gurbanov *et al.*, 2017, 2018*a,b*). To assess the biological potential of a molecule *in silico* and the molecular docking procedure, which is widely used for the development of new pharmaceuticals, information about the structures of promising molecules is needed. All this initiated our research on the synthesis of 5-(5-phenylisoxazol-3-yl)-1,3,4-thiadiazol-2-amine (**1**) and the further determination of the accurate structure of its molecule. The synthesis and structure of the compound has not published before. There are many approaches for building a thiadiazole heterocycle based on the use of carboxylic acids (Bhinge *et al.*, 2015; Nayak *et al.*, 2014), carbonyl chlorides (Sun *et al.*, 2001; Kudelko *et al.*, 2020), aldehydes (Shivakumara *et al.*, 2019; Wang *et al.*, 2019),



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etc. We chose here a method based on the transformation of carbonitriles (as shown in the scheme) as the shortest and most convenient way to achieve this purpose (Sakthivel *et al.*, 2016; *et al.*; Abdelhamid *et al.*, 2011). Its efficacy has recently been demonstrated by one of us (Petkevich *et al.*, 2021). The synthetic procedure involves the interaction of 5-phenylisoxazole-3-carbonitrile with thiosemicarbazide. The starting 5-phenylisoxazole-3-carbonitrile was obtained according to the previously described method (Kulchitsky *et al.*, 2012; Bumagin *et al.*, 2018).



2. Structural commentary

The title compound **1** crystallizes in the orthorhombic space group $Pca2_1$, with two independent molecules (I with S1 and II with S2) in the asymmetric unit (Fig. 1). The oxazole (O1/N2/C3/C4/C5 and O12/N13/C14/C15/C16) and thiadiazole (S1/N3/N4/C1/C2 and S2/N14/N15/C12/C13) rings are essentially planar and inclined to one another by 18.8 (3) and 14.6 (3)° in molecules I and II, respectively. The phenyl rings (C6–C11 and C17–C22) make dihedral angles of 24.6 (3) and 26.8 (3)° with the oxazole rings in molecules I and II, respectively. Fig. 2

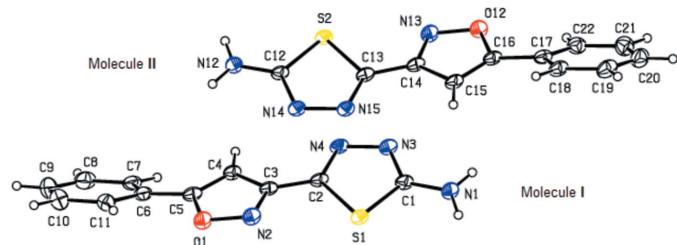


Figure 1
View of the two independent molecules, I and II, in the asymmetric unit of the title compound, with displacement ellipsoids for the non-hydrogen atoms drawn at the 30% probability level.

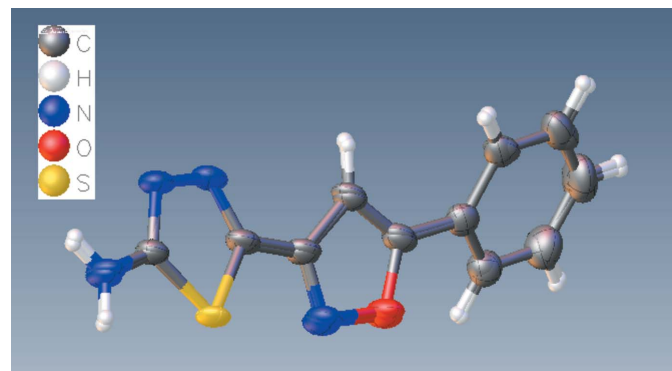


Figure 2
Overlay image of two independent molecules in the asymmetric unit of the title compound.

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

$Cg4$ and $Cg6$ are the centroids of the S2/N14/N15/C12/C13 and C17–C22 rings, respectively

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
N1–H1A \cdots N14 ⁱ	0.88	2.10	2.974 (6)	172
N1–H1B \cdots N4 ⁱⁱ	0.88	2.20	3.071 (5)	169
N12–H12A \cdots N3 ⁱⁱⁱ	0.88	2.06	2.933 (6)	174
N12–H12B \cdots N15 ^{iv}	0.88	2.24	3.108 (5)	170
C4–H4 \cdots N2 ^{iv}	0.95	2.56	3.363 (6)	142
C15–H15 \cdots N13 ⁱⁱ	0.95	2.46	3.323 (6)	151
C8–H8 \cdots Cg6 ^v	0.95	2.98	3.774 (6)	142
C22–H22 \cdots Cg4 ⁱ	0.95	2.95	3.648 (6)	132

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

shows the overlay of molecules I and II in the asymmetric unit, with an r.m.s. deviation of 0.087 Å. The C–N bond distances to the amino N atom of 1.330 (6) and 1.328 (6) Å, respectively, in molecules I and II indicate strong conjugation of the amino groups with the thiadiazole π -systems.

3. Supramolecular features

In the crystal, molecules are linked by N–H \cdots N and C–H \cdots N hydrogen bonds (Table 1, Figs. 3 and 4), forming double layers of cross-linked molecules parallel to the (001) plane.

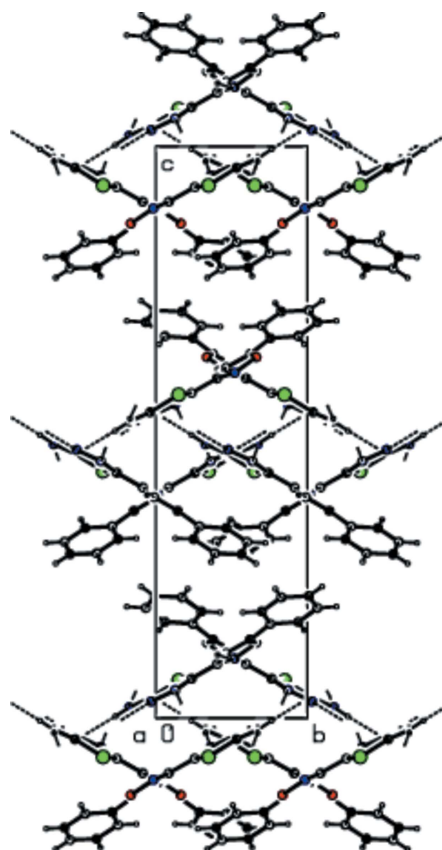


Figure 3
A view of the intermolecular N–H \cdots N and C–H \cdots N interactions in the crystal structure of the title compound projected along the a axis.

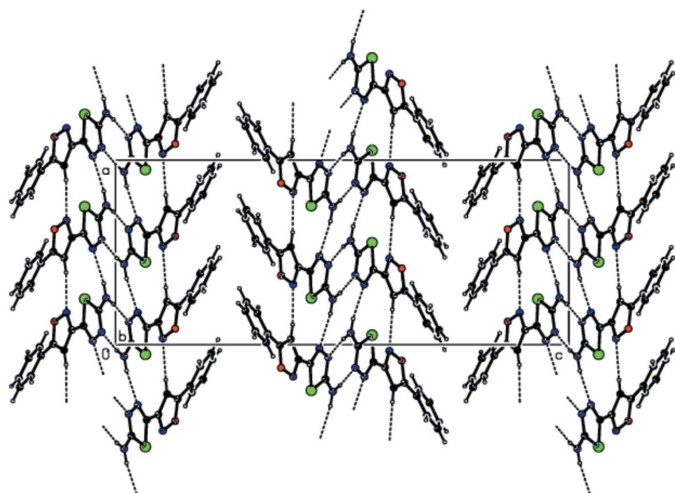


Figure 4
A view of the intermolecular N—H...N and C—H...N interactions in the crystal structure of the title compound projected along the *b* axis.

The molecules within a layer are further linked by π – π stacking interactions between the thiadiazole rings [$Cg1 \cdots Cg4(x, y, z) = 3.636(3) \text{ \AA}$, slippage = 1.283 \AA , where *Cg1* and *Cg4* are the centroids of the rings S1/N3/N4/C1/C2 and S2/N14/N15/C12/C13, respectively]. The layers are linked by van der Waals interactions (Table 2), forming a three-dimensional supramolecular structure (Fig. 5).

4. Hirshfeld surface analysis

Crystal Explorer 17 (Turner *et al.*, 2017) was used to construct Hirshfeld surfaces for both independent molecules in the asymmetric unit of the title compound. The d_{norm} mappings for molecule I were performed in the range of -0.5418 to 1.2328 a.u., and for molecule II in the range of -0.5446 to 1.1988 a.u.

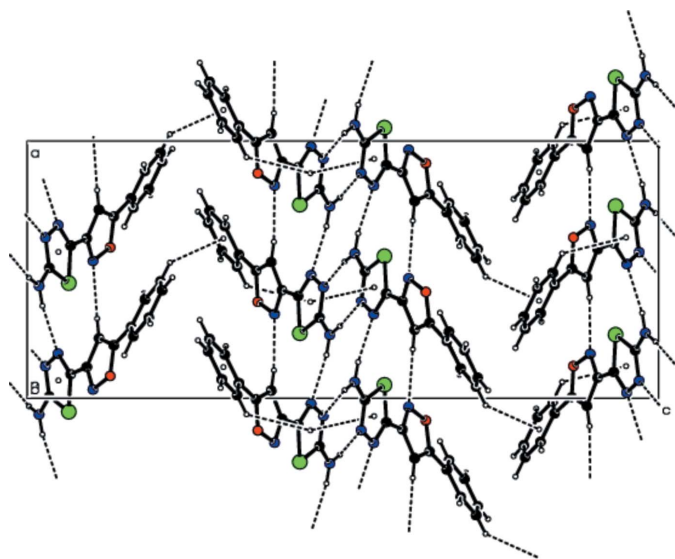


Figure 5
A view of the layer structure formed by intermolecular N—H...N, C—H...N, C—H... π and π – π interactions in the crystal structure of the title compound projected along the *b* axis.

Table 2
Summary of short interatomic contacts (\AA) in the title compound.

Contact	Distance	Symmetry operation
S1...H12B	3.10	$\frac{1}{2} + x, 1 - y, z$
N2...H4	2.56	$\frac{1}{2} + x, 1 - y, z$
N3...H12A	2.06	$x, -1 + y, z$
H1B...S2	3.09	$\frac{1}{2} + x, -y, z$
H1B...N4	2.20	$\frac{1}{2} + x, -y, z$
C2...N14	3.437 (7)	x, y, z
C4...H10	3.05	$x, -1 + y, z$
C7...H20	2.91	$1 - x, -y, \frac{1}{2} + z$
H10...H19	2.49	$1 - x, 1 - y, \frac{1}{2} + z$
H8...C18	2.87	$\frac{1}{2} - x, 1 + y, \frac{1}{2} + z$
H9...H21	2.59	$\frac{1}{2} - x, 2 + y, \frac{1}{2} + z$
N13...H15	2.46	$-\frac{1}{2} + x, -y, z$
H12B...N15	2.24	$-\frac{1}{2} + x, 1 - y, z$
C13...H22	2.91	$x, 1 + y, z$
C19...H22	2.94	$\frac{1}{2} + x, -1 - y, z$

Table 3
Percentage contributions of interatomic contacts to the Hirshfeld surface for the title compound.

Contact	molecule I	molecule II
H...H	26.6	25.3
N...H/H...N	24.1	24.1
C...H/H...C	19.3	21.0
S...C/C...S	6.7	5.5
O...H/H...O	6.0	5.5
S...H/H...S	5.9	6.9
N...C/C...N	4.5	5.3
O...C/C...O	2.5	2.6
C...C	1.3	0.9
O...N/N...O	1.1	1.0
N...N	1.0	0.9
S...N/N...S	0.9	0.8
S...O/O...S	0.1	0.1

On the d_{norm} surfaces, bold red circles show the locations of N—H...N interactions. Smaller red spots are caused by C—H...N interactions (Fig. 6*a,b* for molecule I and Fig. 6*c,d* for molecule II).

Fingerprint plots (Fig. 7) reveal that while H...H (26.6% for molecule I and 25.3% for molecule II) interactions make the largest contributions to the surface contacts (Table 2), N...H/H...N (24.1% for I and 24.1% for II) and C...H/H...C (19.3% for I and 21.0% for II) contacts are also significant. The contributions of other, less noteworthy contacts are listed in Table 3. The environments of molecules I and II are quite similar, as indicated in Table 3.

5. Database survey

The only hit related to the title compound found in a search of the Cambridge Structural Database (CSD, Version 5.42; May 2021; Groom *et al.*, 2016) was 1-[[3-(thiophen-2-yl)-4,5-dihydro-1,2-oxazol-5-yl]methyl]-1*H*-indole-2,3-dione (NAQQOO; Rayni *et al.*, 2017). In the structure of NAQQOO, the indole ring system is almost planar as expected. The dihedral angle between this plane and that of the thiophene ring is 2.01 (2)°. The mean plane of the isoxazole ring is inclined by 19.78 (14) and 20.83 (12)° to the thiophene and indoline mean planes, respectively. In the crystal, the

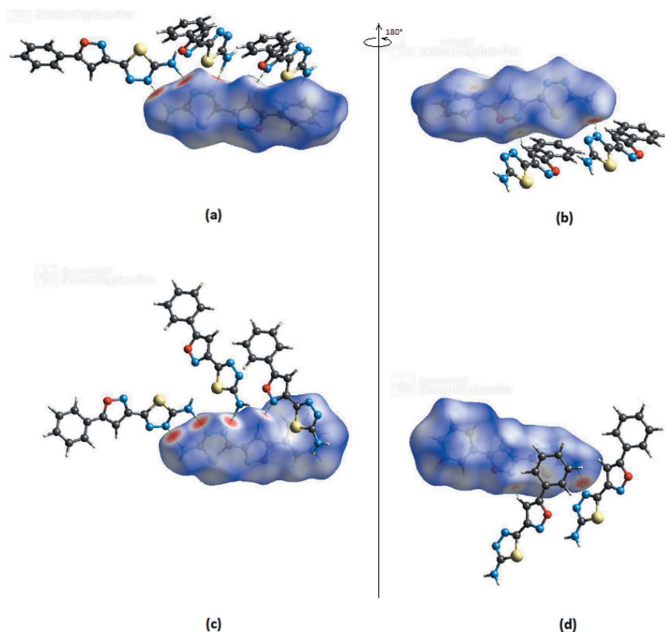


Figure 6
Front (a) and back (b) views of the three-dimensional Hirshfeld surface for molecule I. Front (c) and back (d) views of the three-dimensional Hirshfeld surface for molecule II. Some intermolecular N–H...N and C–H...N interactions are shown as dashed lines.

combination of C–H...O hydrogen bonds forms stepped layers two molecules thick, or slabs, which are oriented parallel to $(\bar{1}03)$. These layers are associated through offset π -stacking interactions, involving inversion-related indole rings in adjacent layers [interplanar distance of 3.479 (1) Å], forming a supramolecular three-dimensional structure.

6. Synthesis and crystallization

5-(5-Phenylisoxazol-3-yl)-1,3,4-thiadiazol-2-amine:

Thiosemicarbazide (1.0 g, 11 mmol) was added at r.t to a solution of 5-phenylisoxazole-3-carbonitrile (1.70 g, 10 mmol) in $\text{CF}_3\text{CO}_2\text{H}$ (10 mL), and the resulting mixture was heated under reflux for 6 h. After cooling, the mixture was poured into water (150 mL) and basified with 25% aqueous ammonia to pH \sim 8. The precipitate was filtered off, washed with warm H_2O (3×30 mL) and dried under reduced pressure over P_2O_5 . The obtained solid product was recrystallized from MeOH giving light-yellow cubic crystals, yield 2.37 g (97%), m.p. = 501–503 K. IR (KBr), ν (cm^{-1}): 3413, 3278, 3147, 3125, 2927, 1615, 1592, 1575, 1508, 1450, 1436, 1417, 1323, 1220, 1140, 1068, 947, 931, 817, 763, 686, 661, 629, 575. ^1H NMR (DMSO- d_6 , 500 MHz, 301 K): δ = 7.51–7.58 (*m*, 4H, 3HAr + 1H-isox), 7.80 (*br.s*, 2H, NH_2), 7.92–7.98 (*m*, 2HAr). ^{13}C NMR (DMSO- d_6 , 125 MHz, 301 K): δ = 98.53 (CH-isox), 126.45 (2CHAr), 129.89 (2CHAr), 131.47 (1CHAr), 126.90, 145.57, 157.67, 170.46, 170.76 (5C). Mass-spectrum, m/z (I_{rel} , %): 267 [$M+\text{Na}$] $^+$ (5), 245 [$M+\text{H}$] $^+$ (100). Elemental analysis calculated for $\text{C}_{11}\text{H}_8\text{N}_4\text{OS}$ (%): C 54.09, H 3.30, N 22.94, S 13.12; found (%): C 54.21, H 3.11, N 22.99, S 13.18.

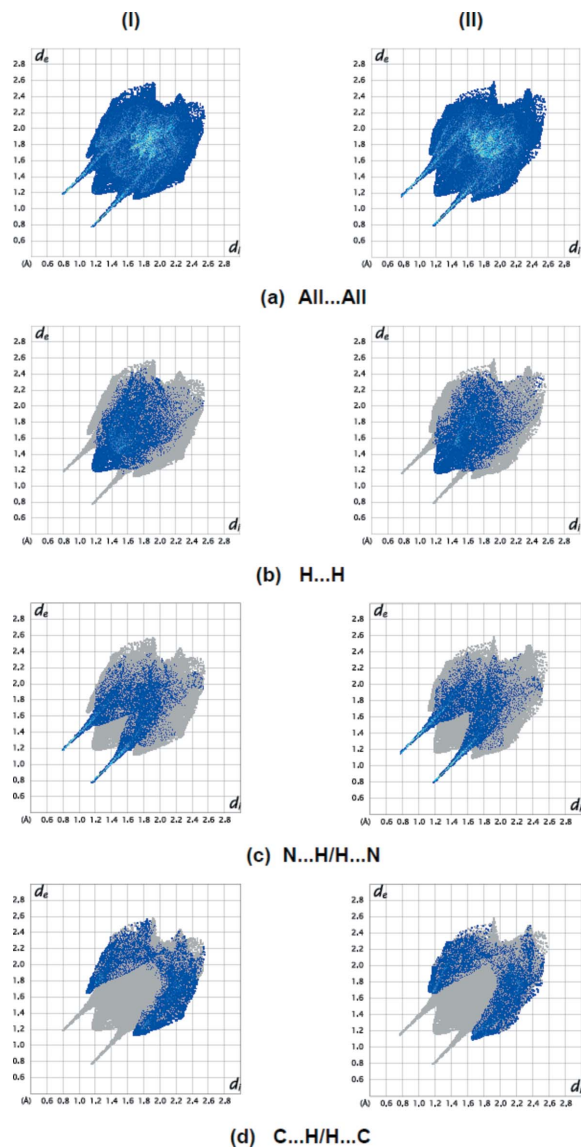


Figure 7
The two-dimensional fingerprint plots for molecules I and II of the title compound showing (a) all interactions, and delineated into (b) H...H, (c) N...H/H...N and (d) C...H/H...C interactions. The d_i and d_e values are the closest internal and external distances (in Å) from given points on the Hirshfeld surface.

7. Refinement

Crystal data, data collection and structure refinement details are summarized in Table 4. All H atoms were positioned geometrically (N–H = 0.88 Å, C–H = 0.95 Å) and refined using a riding model with $U_{\text{iso}}(\text{H}) = 1.2U_{\text{eq}}(\text{N}, \text{C})$.

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The authors' contributions are as follows: Conceptualization, EVN, MA and SM; synthesis, EVN, EKP, SKP and EAA; X-ray analysis, STÇ, VNK and MA; writing (review and editing of the manuscript), EVN, STÇ, MA and SM; funding acquisition, EVN, SKP, EAA and SM; supervision, MA, SKP and SM.

Table 4

Experimental details.

Crystal data	
Chemical formula	C ₁₁ H ₈ N ₄ OS
<i>M_r</i>	244.27
Crystal system, space group	Orthorhombic, <i>Pca</i> 2 ₁
Temperature (K)	100
<i>a</i> , <i>b</i> , <i>c</i> (Å)	11.142 (2), 7.2555 (15), 27.333 (6)
<i>V</i> (Å ³)	2209.6 (8)
<i>Z</i>	8
Radiation type	Mo <i>K</i> α
<i>μ</i> (mm ⁻¹)	0.28
Crystal size (mm)	0.24 × 0.18 × 0.02
Data collection	
Diffractionmeter	Bruker D8 QUEST PHOTON-III CCD
Absorption correction	Multi-scan (<i>SADABS</i> ; Krause <i>et al.</i> , 2015)
<i>T_{min}</i> , <i>T_{max}</i>	0.924, 0.985
No. of measured, independent and observed [<i>I</i> > 2σ(<i>I</i>)] reflections	37296, 6442, 4347
<i>R_{int}</i>	0.110
(sin θ/λ) _{max} (Å ⁻¹)	0.703
Refinement	
<i>R</i> [<i>F</i> ² > 2σ(<i>F</i> ²)], <i>wR</i> (<i>F</i> ²), <i>S</i>	0.053, 0.125, 1.03
No. of reflections	6442
No. of parameters	307
No. of restraints	1
H-atom treatment	H-atom parameters constrained
Δρ _{max} , Δρ _{min} (e Å ⁻³)	0.32, -0.34
Absolute structure	Flack <i>x</i> determined using 1699 quotients [(<i>I</i> ⁺) - (<i>I</i> ⁻)] / [(<i>I</i> ⁺) + (<i>I</i> ⁻)] (Parsons <i>et al.</i> , 2013)
Absolute structure parameter	0.44 (7)

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

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supporting information

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Crystal structure and Hirshfeld surface analysis of 5-(5-phenyl-1,2-oxazol-3-yl)-1,3,4-thiadiazol-2-amine

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Computing details

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

5-(5-Phenyl-1,2-oxazol-3-yl)-1,3,4-thiadiazol-2-amine

Crystal data

$C_{11}H_8N_4OS$

$M_r = 244.27$

Orthorhombic, *Pca*2₁

$a = 11.142$ (2) Å

$b = 7.2555$ (15) Å

$c = 27.333$ (6) Å

$V = 2209.6$ (8) Å³

$Z = 8$

$F(000) = 1008$

$D_x = 1.469$ Mg m⁻³

Mo $K\alpha$ radiation, $\lambda = 0.71073$ Å

Cell parameters from 5781 reflections

$\theta = 2.8$ – 28.1°

$\mu = 0.28$ mm⁻¹

$T = 100$ K

Plate, yellow

$0.24 \times 0.18 \times 0.02$ mm

Data collection

Bruker D8 QUEST PHOTON-III CCD diffractometer

φ and ω scans

Absorption correction: multi-scan (SADABS; Krause *et al.*, 2015)

$T_{\min} = 0.924$, $T_{\max} = 0.985$

37296 measured reflections

6442 independent reflections

4347 reflections with $I > 2\sigma(I)$

$R_{\text{int}} = 0.110$

$\theta_{\max} = 30.0^\circ$, $\theta_{\min} = 2.8^\circ$

$h = -15 \rightarrow 15$

$k = -10 \rightarrow 10$

$l = -38 \rightarrow 38$

Refinement

Refinement on F^2

Least-squares matrix: full

$R[F^2 > 2\sigma(F^2)] = 0.053$

$wR(F^2) = 0.125$

$S = 1.03$

6442 reflections

307 parameters

1 restraint

Primary atom site location: difference Fourier map

Secondary atom site location: difference Fourier map

Hydrogen site location: inferred from neighbouring sites

H-atom parameters constrained

$w = 1/[\sigma^2(F_o^2) + 1.1115P]$

where $P = (F_o^2 + 2F_c^2)/3$

$(\Delta/\sigma)_{\max} < 0.001$

$\Delta\rho_{\max} = 0.32$ e Å⁻³

$\Delta\rho_{\min} = -0.34$ e Å⁻³

Absolute structure: Flack x determined using
 1699 quotients $[(F^+)-(F^-)]/[(F^+)+(F^-)]$ (Parsons et
 al., 2013)
 Absolute structure parameter: 0.44 (7)

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 (\AA^2)

	x	y	z	$U_{\text{iso}}^*/U_{\text{eq}}$
S1	0.55238 (9)	0.15104 (17)	0.56580 (4)	0.0346 (3)
O1	0.4133 (3)	0.6622 (5)	0.63143 (14)	0.0407 (8)
N1	0.5629 (3)	-0.1735 (6)	0.51880 (17)	0.0411 (11)
H1A	0.5313	-0.2668	0.5028	0.049*
H1B	0.6408	-0.1700	0.5241	0.049*
N2	0.4659 (3)	0.5198 (6)	0.60417 (16)	0.0404 (10)
N3	0.3753 (3)	-0.0298 (6)	0.52886 (16)	0.0368 (10)
N4	0.3268 (3)	0.1278 (6)	0.54882 (15)	0.0363 (9)
C1	0.4931 (4)	-0.0378 (7)	0.53495 (18)	0.0337 (11)
C2	0.4066 (3)	0.2358 (7)	0.56877 (18)	0.0324 (10)
C3	0.3784 (4)	0.4041 (7)	0.59427 (18)	0.0325 (10)
C4	0.2667 (4)	0.4653 (7)	0.61365 (18)	0.0339 (10)
H4	0.1905	0.4077	0.6107	0.041*
C5	0.2934 (4)	0.6234 (7)	0.63716 (19)	0.0353 (11)
C6	0.2228 (4)	0.7554 (7)	0.66463 (18)	0.0381 (11)
C7	0.1161 (4)	0.6999 (7)	0.68654 (19)	0.0400 (11)
H7	0.0917	0.5746	0.6847	0.048*
C8	0.0454 (5)	0.8268 (9)	0.7110 (2)	0.0547 (16)
H8	-0.0272	0.7883	0.7261	0.066*
C9	0.0801 (6)	1.0089 (10)	0.7136 (2)	0.0622 (17)
H9	0.0305	1.0958	0.7299	0.075*
C10	0.1865 (6)	1.0655 (9)	0.6926 (2)	0.0586 (16)
H10	0.2103	1.1910	0.6949	0.070*
C11	0.2591 (5)	0.9399 (7)	0.66806 (19)	0.0435 (12)
H11	0.3325	0.9788	0.6538	0.052*
S2	0.25267 (9)	0.34769 (16)	0.43188 (5)	0.0345 (3)
O12	0.3748 (3)	-0.1645 (5)	0.36528 (14)	0.0414 (8)
N12	0.2466 (3)	0.6713 (6)	0.47918 (16)	0.0401 (10)
H12A	0.2801	0.7631	0.4952	0.048*
H12B	0.1686	0.6711	0.4740	0.048*
N13	0.3275 (3)	-0.0167 (6)	0.39175 (17)	0.0406 (10)
N14	0.4322 (3)	0.5220 (6)	0.46910 (15)	0.0354 (9)
N15	0.4782 (3)	0.3622 (5)	0.44954 (15)	0.0336 (9)
C12	0.3137 (4)	0.5330 (7)	0.46289 (18)	0.0325 (11)
C13	0.3977 (3)	0.2571 (7)	0.42917 (19)	0.0324 (10)

C14	0.4201 (4)	0.0858 (7)	0.40348 (19)	0.0339 (11)
C15	0.5296 (4)	0.0103 (7)	0.38637 (18)	0.0355 (11)
H15	0.6085	0.0576	0.3907	0.043*
C16	0.4959 (4)	-0.1445 (7)	0.36254 (19)	0.0348 (10)
C17	0.5587 (4)	-0.2878 (7)	0.33530 (18)	0.0354 (11)
C18	0.6693 (4)	-0.2494 (8)	0.31302 (18)	0.0403 (12)
H18	0.7024	-0.1289	0.3145	0.048*
C19	0.7299 (5)	-0.3898 (8)	0.2886 (2)	0.0487 (14)
H19	0.8046	-0.3646	0.2733	0.058*
C20	0.6826 (5)	-0.5652 (9)	0.2866 (2)	0.0519 (14)
H20	0.7252	-0.6607	0.2704	0.062*
C21	0.5732 (5)	-0.6019 (8)	0.3082 (2)	0.0492 (14)
H21	0.5400	-0.7223	0.3063	0.059*
C22	0.5121 (5)	-0.4653 (7)	0.3324 (2)	0.0422 (12)
H22	0.4372	-0.4923	0.3474	0.051*

Atomic displacement parameters (Å²)

	U^{11}	U^{22}	U^{33}	U^{12}	U^{13}	U^{23}
S1	0.0126 (4)	0.0464 (6)	0.0447 (7)	-0.0005 (4)	-0.0026 (4)	-0.0051 (6)
O1	0.0207 (14)	0.047 (2)	0.055 (2)	-0.0023 (14)	0.0010 (14)	-0.0061 (18)
N1	0.0154 (16)	0.047 (3)	0.061 (3)	0.0009 (17)	-0.0043 (17)	-0.011 (2)
N2	0.0187 (18)	0.049 (3)	0.053 (3)	-0.0012 (17)	0.0002 (17)	-0.006 (2)
N3	0.0159 (17)	0.047 (2)	0.048 (3)	-0.0013 (16)	-0.0018 (16)	-0.002 (2)
N4	0.0162 (17)	0.050 (3)	0.043 (2)	0.0009 (17)	-0.0030 (15)	0.0001 (19)
C1	0.0166 (19)	0.047 (3)	0.037 (3)	-0.0025 (18)	0.0005 (18)	0.000 (2)
C2	0.0130 (16)	0.048 (3)	0.036 (3)	0.0006 (17)	-0.0018 (18)	0.003 (2)
C3	0.0170 (19)	0.044 (3)	0.036 (3)	-0.0025 (18)	-0.0032 (17)	0.003 (2)
C4	0.0175 (19)	0.045 (3)	0.039 (3)	-0.0010 (19)	-0.0010 (18)	0.001 (2)
C5	0.0191 (19)	0.050 (3)	0.037 (3)	-0.0005 (18)	-0.0018 (19)	0.006 (2)
C6	0.031 (2)	0.049 (3)	0.034 (3)	0.006 (2)	-0.0073 (19)	0.000 (2)
C7	0.028 (2)	0.059 (3)	0.033 (3)	0.008 (2)	-0.005 (2)	-0.001 (2)
C8	0.038 (3)	0.086 (5)	0.040 (3)	0.012 (3)	0.002 (2)	-0.004 (3)
C9	0.062 (4)	0.071 (4)	0.053 (4)	0.020 (3)	0.003 (3)	-0.021 (3)
C10	0.064 (4)	0.056 (4)	0.056 (4)	0.005 (3)	-0.002 (3)	-0.012 (3)
C11	0.044 (3)	0.048 (3)	0.039 (3)	0.003 (2)	-0.003 (2)	-0.003 (2)
S2	0.0129 (4)	0.0473 (6)	0.0433 (6)	-0.0003 (5)	-0.0025 (4)	-0.0049 (6)
O12	0.0193 (15)	0.049 (2)	0.056 (2)	-0.0022 (14)	-0.0014 (15)	-0.0103 (18)
N12	0.0158 (17)	0.051 (3)	0.053 (3)	0.0013 (17)	-0.0033 (16)	-0.013 (2)
N13	0.0206 (19)	0.048 (3)	0.054 (3)	0.0026 (18)	-0.0004 (18)	-0.007 (2)
N14	0.0158 (17)	0.047 (2)	0.044 (2)	-0.0001 (15)	-0.0025 (15)	-0.0051 (19)
N15	0.0155 (16)	0.044 (2)	0.041 (2)	-0.0003 (15)	-0.0010 (14)	-0.0016 (18)
C12	0.0150 (19)	0.043 (3)	0.039 (3)	-0.0015 (18)	-0.0035 (17)	0.000 (2)
C13	0.0147 (16)	0.044 (3)	0.039 (3)	-0.0014 (17)	-0.0005 (18)	0.005 (2)
C14	0.0138 (18)	0.046 (3)	0.041 (3)	0.0009 (18)	-0.0021 (17)	0.004 (2)
C15	0.0135 (18)	0.051 (3)	0.042 (3)	0.0038 (19)	-0.0004 (18)	0.002 (2)
C16	0.0163 (19)	0.051 (3)	0.037 (2)	0.0032 (19)	-0.0007 (17)	0.005 (2)
C17	0.025 (2)	0.048 (3)	0.033 (3)	0.003 (2)	-0.0036 (19)	0.004 (2)

C18	0.021 (2)	0.056 (3)	0.044 (3)	0.005 (2)	-0.0004 (18)	0.004 (2)
C19	0.033 (3)	0.070 (4)	0.042 (3)	0.014 (2)	0.008 (2)	0.009 (3)
C20	0.051 (3)	0.061 (4)	0.044 (3)	0.018 (3)	0.003 (3)	-0.002 (3)
C21	0.052 (4)	0.050 (3)	0.045 (3)	0.002 (3)	0.003 (3)	0.000 (3)
C22	0.035 (3)	0.052 (3)	0.039 (3)	0.001 (2)	-0.001 (2)	0.000 (2)

Geometric parameters (Å, °)

S1—C1	1.739 (5)	S2—C12	1.729 (5)
S1—C2	1.739 (4)	S2—C13	1.746 (4)
O1—C5	1.374 (5)	O12—C16	1.359 (5)
O1—N2	1.402 (5)	O12—N13	1.398 (5)
N1—C1	1.330 (6)	N12—C12	1.328 (6)
N1—H1A	0.8800	N12—H12A	0.8800
N1—H1B	0.8800	N12—H12B	0.8800
N2—C3	1.315 (6)	N13—C14	1.312 (6)
N3—C1	1.324 (5)	N14—C12	1.334 (5)
N3—N4	1.377 (6)	N14—N15	1.376 (5)
N4—C2	1.304 (6)	N15—C13	1.302 (6)
C2—C3	1.441 (7)	C13—C14	1.449 (7)
C3—C4	1.424 (6)	C14—C15	1.417 (6)
C4—C5	1.348 (7)	C15—C16	1.352 (7)
C4—H4	0.9500	C15—H15	0.9500
C5—C6	1.449 (7)	C16—C17	1.458 (7)
C6—C7	1.391 (7)	C17—C22	1.391 (7)
C6—C11	1.402 (7)	C17—C18	1.402 (7)
C7—C8	1.384 (7)	C18—C19	1.393 (7)
C7—H7	0.9500	C18—H18	0.9500
C8—C9	1.378 (9)	C19—C20	1.379 (8)
C8—H8	0.9500	C19—H19	0.9500
C9—C10	1.379 (9)	C20—C21	1.380 (8)
C9—H9	0.9500	C20—H20	0.9500
C10—C11	1.391 (8)	C21—C22	1.373 (7)
C10—H10	0.9500	C21—H21	0.9500
C11—H11	0.9500	C22—H22	0.9500
C1—S1—C2	86.9 (2)	C12—S2—C13	87.1 (2)
C5—O1—N2	108.4 (3)	C16—O12—N13	108.7 (4)
C1—N1—H1A	120.0	C12—N12—H12A	120.0
C1—N1—H1B	120.0	C12—N12—H12B	120.0
H1A—N1—H1B	120.0	H12A—N12—H12B	120.0
C3—N2—O1	105.7 (4)	C14—N13—O12	105.3 (4)
C1—N3—N4	112.0 (4)	C12—N14—N15	111.7 (4)
C2—N4—N3	113.4 (4)	C13—N15—N14	113.8 (4)
N3—C1—N1	124.7 (4)	N12—C12—N14	124.0 (4)
N3—C1—S1	113.8 (4)	N12—C12—S2	122.1 (3)
N1—C1—S1	121.5 (3)	N14—C12—S2	113.9 (4)
N4—C2—C3	124.3 (4)	N15—C13—C14	126.2 (4)

N4—C2—S1	113.9 (4)	N15—C13—S2	113.5 (4)
C3—C2—S1	121.7 (3)	C14—C13—S2	120.2 (3)
N2—C3—C4	111.9 (4)	N13—C14—C15	112.2 (5)
N2—C3—C2	118.6 (4)	N13—C14—C13	117.9 (4)
C4—C3—C2	129.4 (4)	C15—C14—C13	129.8 (4)
C5—C4—C3	104.4 (4)	C16—C15—C14	103.9 (4)
C5—C4—H4	127.8	C16—C15—H15	128.0
C3—C4—H4	127.8	C14—C15—H15	128.0
C4—C5—O1	109.6 (4)	C15—C16—O12	109.8 (4)
C4—C5—C6	133.6 (4)	C15—C16—C17	134.9 (4)
O1—C5—C6	116.8 (4)	O12—C16—C17	115.4 (4)
C7—C6—C11	119.6 (5)	C22—C17—C18	119.2 (5)
C7—C6—C5	119.7 (5)	C22—C17—C16	120.6 (5)
C11—C6—C5	120.6 (5)	C18—C17—C16	120.1 (5)
C8—C7—C6	120.1 (5)	C19—C18—C17	119.2 (5)
C8—C7—H7	119.9	C19—C18—H18	120.4
C6—C7—H7	119.9	C17—C18—H18	120.4
C9—C8—C7	120.2 (6)	C20—C19—C18	120.6 (5)
C9—C8—H8	119.9	C20—C19—H19	119.7
C7—C8—H8	119.9	C18—C19—H19	119.7
C8—C9—C10	120.4 (6)	C19—C20—C21	119.9 (5)
C8—C9—H9	119.8	C19—C20—H20	120.0
C10—C9—H9	119.8	C21—C20—H20	120.0
C9—C10—C11	120.3 (6)	C22—C21—C20	120.4 (6)
C9—C10—H10	119.8	C22—C21—H21	119.8
C11—C10—H10	119.8	C20—C21—H21	119.8
C10—C11—C6	119.4 (5)	C21—C22—C17	120.7 (5)
C10—C11—H11	120.3	C21—C22—H22	119.7
C6—C11—H11	120.3	C17—C22—H22	119.7
C5—O1—N2—C3	0.5 (5)	C16—O12—N13—C14	0.4 (5)
C1—N3—N4—C2	0.8 (6)	C12—N14—N15—C13	0.3 (6)
N4—N3—C1—N1	-179.2 (5)	N15—N14—C12—N12	178.6 (5)
N4—N3—C1—S1	-0.2 (5)	N15—N14—C12—S2	-0.7 (5)
C2—S1—C1—N3	-0.2 (4)	C13—S2—C12—N12	-178.6 (5)
C2—S1—C1—N1	178.7 (5)	C13—S2—C12—N14	0.7 (4)
N3—N4—C2—C3	-176.7 (5)	N14—N15—C13—C14	176.6 (5)
N3—N4—C2—S1	-1.0 (6)	N14—N15—C13—S2	0.3 (6)
C1—S1—C2—N4	0.7 (4)	C12—S2—C13—N15	-0.5 (4)
C1—S1—C2—C3	176.5 (4)	C12—S2—C13—C14	-177.1 (4)
O1—N2—C3—C4	0.7 (6)	O12—N13—C14—C15	-0.9 (6)
O1—N2—C3—C2	-176.3 (4)	O12—N13—C14—C13	176.6 (4)
N4—C2—C3—N2	-166.4 (5)	N15—C13—C14—N13	169.7 (5)
S1—C2—C3—N2	18.2 (7)	S2—C13—C14—N13	-14.2 (7)
N4—C2—C3—C4	17.1 (9)	N15—C13—C14—C15	-13.3 (9)
S1—C2—C3—C4	-158.3 (4)	S2—C13—C14—C15	162.9 (4)
N2—C3—C4—C5	-1.7 (6)	N13—C14—C15—C16	1.1 (6)
C2—C3—C4—C5	174.9 (5)	C13—C14—C15—C16	-176.1 (5)

C3—C4—C5—O1	2.0 (6)	C14—C15—C16—O12	-0.7 (6)
C3—C4—C5—C6	-180.0 (5)	C14—C15—C16—C17	178.6 (6)
N2—O1—C5—C4	-1.7 (6)	N13—O12—C16—C15	0.2 (6)
N2—O1—C5—C6	179.9 (4)	N13—O12—C16—C17	-179.2 (4)
C4—C5—C6—C7	24.7 (9)	C15—C16—C17—C22	152.5 (6)
O1—C5—C6—C7	-157.4 (4)	O12—C16—C17—C22	-28.2 (7)
C4—C5—C6—C11	-153.3 (6)	C15—C16—C17—C18	-25.4 (9)
O1—C5—C6—C11	24.5 (7)	O12—C16—C17—C18	154.0 (5)
C11—C6—C7—C8	0.9 (8)	C22—C17—C18—C19	-0.2 (7)
C5—C6—C7—C8	-177.2 (5)	C16—C17—C18—C19	177.7 (5)
C6—C7—C8—C9	0.3 (8)	C17—C18—C19—C20	-0.4 (8)
C7—C8—C9—C10	-1.2 (10)	C18—C19—C20—C21	1.0 (9)
C8—C9—C10—C11	0.8 (10)	C19—C20—C21—C22	-1.1 (9)
C9—C10—C11—C6	0.4 (9)	C20—C21—C22—C17	0.5 (9)
C7—C6—C11—C10	-1.2 (8)	C18—C17—C22—C21	0.1 (8)
C5—C6—C11—C10	176.8 (5)	C16—C17—C22—C21	-177.8 (5)

Hydrogen-bond geometry (\AA , $^\circ$)

$Cg4$ and $Cg6$ are the centroids of the S2/N14/N15/C12/C13 and C17–C22 rings, respectively

$D-H\cdots A$	$D-H$	$H\cdots A$	$D\cdots A$	$D-H\cdots A$
N1—H1A \cdots N14 ⁱ	0.88	2.10	2.974 (6)	172
N1—H1B \cdots N4 ⁱⁱ	0.88	2.20	3.071 (5)	169
N12—H12A \cdots N3 ⁱⁱⁱ	0.88	2.06	2.933 (6)	174
N12—H12B \cdots N15 ^{iv}	0.88	2.24	3.108 (5)	170
C4—H4 \cdots N2 ^{iv}	0.95	2.56	3.363 (6)	142
C15—H15 \cdots N13 ⁱⁱ	0.95	2.46	3.323 (6)	151
C8—H8 \cdots Cg6 ^v	0.95	2.98	3.774 (6)	142
C22—H22 \cdots Cg4 ⁱ	0.95	2.95	3.648 (6)	132

Symmetry codes: (i) $x, y-1, z$; (ii) $x+1/2, -y, z$; (iii) $x, y+1, z$; (iv) $x-1/2, -y+1, z$; (v) $-x+1/2, y+1, z+1/2$.